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16. Abstract (Limit: 200 words)

Ground water and tailings pond monitoring in the Upper Santa Cruz Basin Mines Task Force Special Studies Area was performed to determine the nature and extent of aquifer contamination from copper tailings pond recharge in the basin. A monitoring program for each of three mining areas (Mines A, B, and D) was developed. Analysis of data shows that recharge from Mine A ponds caused increased hardness, sulfate, and total dissolved solids in local ground water. However, pumpage in the area has controlled most of the water's movement. Pond recharge from Mine B led to similar conditions, and the degraded water is moving towards a local public-supply well. Pumpage from Mine D interceptor wells is controlling some, but not all, of the movement of recharge seepage from ponds in that area. Recommendations include the need for enhanced monitoring programs at each current mine site, development of a monitoring program for the Mine C area, development of water budgets for all mines, investigation of tailings pond compaction and sliming, establishment of mine closure plans for containment of recharged pond water, and the need for additional interceptor wells in several locations.

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- Ground water monitoring
- Upper Santa Cruz Basin Mines Task Force

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Interceptor wells
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FOREWORD

This report was prepared by the Pima Association of Governments under U.S. Bureau of Mines Contract No. J0215006. The contract was initiated under the Mining Research Program. It was administered under the technical direction of the Bureau of Mines with Christopher H. Roe acting as Technical Project Officer. Darlene Wilson was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period April 15, 1981 to July 30, 1983. This report was submitted by the authors on July 30, 1983.

This report is a product of the combined efforts of the members, and some former members, of the Upper Santa Cruz Basin Mines Task Force and the Pima Association of Governments Areawide Water-Quality Planning Staff. Major portions of this document were written by Frank G. Postillion and K. D. Schmidt.

During the course of this study, the following Technical Subcommittee members, and former members, reviewed and commented on this project. Their cooperation and assistance is gratefully acknowledged.

Robert Bierman	- Papago Tribal Utility Authority, Papago Tribe of Arizona
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Successive drafts of this report were edited by Gail F. Kushner and Frank Postillion and prepared by Barbara Pollard of the Pima Association of Governments.

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Arizona Department of Health Services
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City of Tucson
Farmers Investment Co.
Indian Health Service
Papago Tribe of Arizona
Pima County
Mine A
Mine B
Mine C
Mine D

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Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

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LIST OF ACRONYMS

ADHS - Arizona Department of Health Services
ADWR - Arizona Department of Water Resources
AMA - Active Managment Area
APHA-AWWA-WPCF - American Public Health Association
American Water Works Association
Water Pollution Control Federation
BIA - Bureau of Indian Affairs
CW - Community Water Well
EC-F - Electrical Conductance, Field
EC-L - Electrical Conductance, Lab
EPA - Environmental Protection Agency
gpm - gallons per minute
GV - Green Valley
I - Interceptor
M - Monitor
NOAA - National Oceanic and Atmospheric Administration
PAG - Pima Association of Governments
RCRA - Resource Conservation and Recovery Act
SAR - Sodium Adsorption Ratio
ST - Santo Tomas
SX - San Xavier
TDS - Total dissolved solids
UPS - United Parcel Service

Chapter 1

INTRODUCTION AND EXECUTIVE SUMMARY

A. Project Objectives

Ground water is the only source of water for domestic, industrial, and agricultural uses in the Tucson Basin. Preliminary studies (Upper Santa Cruz Basin Mines Task Force, 1979; Engineers Testing Laboratory, 1973; Wahler and Associates, 1973; Hail, 1974) have indicated that two or more tailings ponds, operated by copper mining firms south of Tucson, may be leaking degraded water to the ground-water system.

The studies conducted over the past two years by the Upper Santa Cruz Basin Mines Task Force were prompted by questions raised by the baseline study the Task Force released in 1979 (Upper Santa Cruz Basin Mines Task Force, 1979). The primary purpose of the current work program is to answer the following questions asked by the above-mentioned study:

1. Is there a ground-water quality problem or will there be one due to the mining activity south of Tucson?

2. If so, what are the nature and extent of the problem?

3. If not, could there be, and if so, under what conditions?

4. What future actions could best prevent or remedy pollution problems if they exist?

Secondly, and more specifically, the objectives for monitoring each participating mine's tailings ponds were:

1. Mine A - To determine the source of increased sulfates and total dissolved solids (TDS) in the ground water in the vicinity of the Mine A ponds, and to develop, as necessary recommendations for future activities which should be undertaken.

2. Mine B - To monitor changes in water level and water quality in the vicinity of Mine B tailings ponds to determine the hydrologic impacts of the ponds, and to develop recommendations, as necessary for future activities.

3. Mine C - To monitor changes in water level and water quality in the vicinity of tailings ponds nos. 7 and 8 to determine the impacts of the ponds on the ground-water quality, and to develop recommendations, as necessary, for future activities.

4. Mine D - To determine the effectiveness of Mine D interceptor wells as a management practice for mitigating downgradient ground-water degradation, and to develop recommendations concerning the Mine D interceptor and water-quality monitoring system.

All monitoring programs, with the exception of Mine C's, were approved for technical sufficiency by the Mines Task Force Technical Subcommittee. The Mine C proposed program had too many deficiencies (explained in Chapter 2) to prove useful for the Mines Task Force Work Program. The reader is referred to a report to the EPA (PEDCo. Environmental Inc., 1983) for more information on monitoring of Mine C's tailings ponds.

B. Organization of the Study

Chapter 1 is the Introduction and Executive Summary. It summarizes the project's objectives, and all conclusions and recommendations from Chapter 4. Chapter 2, Study Methodology, describes the history behind program development and implementation, and describes individual study area water-quality sampling methodologies. This chapter also describes the interpretive techniques used in approaching the evaluation of the study areas and the analytical aids involved. Chapter 3 gives a general description of the study area's location, physiography, climate, and hydrogeology, including regional water levels. Chapter 4 includes the interpretive aspects of the report, as well as detailed hydrogeologic aspects in Mine D's study area. Appendix A contains the references cited in the text.

C. Summary of Conclusions

Seepage through tailings ponds in all the study areas has recharged the aquifer in each respective localized area. This has resulted in increased sulfates, hardness and total dissolved solids in some wells downgradient of the ponds.

1. Mine A Area

   a. Pumpage in the Mine A and Mine C well fields appears to be controlling most, if not all, of the pond recharge.

   b. Continued pumpage of Mine A and Mine C mine-supply wells will probably minimize the threat to the quality of water pumped from downgradient wells.

2. Mine B Area

   a. Recharged pond water from one Mine B pond appears to be moving towards at least one public-supply well.

   b. Mine-supply wells are located too far from the Mine B ponds to control the movement of recharged pond water.

3. Mine D

   a. Mine D interceptor wells have been effective in altering the direction of ground-water movement in the area east of the southeast corner of the Sierrita ponds.

   b. Two public-supply wells are no longer downgradient of the Sierrita ponds, as they were in 1976-77, and, under the present pumping regime, appear not to be threatened by recharged pond seepage.

   c. Pumpage of the interceptor wells near the Sierrita ponds is not sufficient to control the movement of recharged pond seepage.

   d. Public-supply wells in a nearby community which are downgradient of the Mine D interceptor wells appear to be threatened by recharged pond water.

D. Summary of Recommendations

1. Enhanced monitoring programs are necessary for each mine area. These programs should include additional characterization of pond water and determination of water budgets for pond seepage. Additional organic, inorganic, and radiologic constituents should be sampled in the ponds and wells.

2. More investigation of tailings pond sliming and compaction is necessary to determine if this is an effective management tool for minimizing ground-water recharge from tailings ponds south of Tucson.

3. To produce an accurate assessment of current conditions in the area, all potential sources of ground-water pollution should be investigated. This program should include all ore leaching operations and all storage sites that involve potential radioactive contamination.

4. Mine closure plans should be formulated.

5. Specific Mine Areas

   a. Mine A Area

   Additional monitor wells should be drilled northeast of the ponds, and north of the San Xavier well field, and added to the enhanced monitoring program.

   b. Mine B Area

   (1) Additional monitor wells should be installed, or drill holes sampled, farther east of the ponds.

(2) Information should be obtained concerning the current pilot interceptor wells upgradient of two public-supply wells, and there should be an investigation of the need for additional interceptor wells.

c. Mine D Area

(1) Pumpage from interceptor wells should be increased by about 50 to 100 percent, with more water pumped in the area where sulfate and hardness contents exceed 1,200 mg/l.

(2) Additional interceptor wells are needed northeast of the existing interceptor wells.

(3) Additional monitor wells need placement between the present wells and nearby public-supply wells.

(4) A depth sampling program for delineation of the exact vertical distribution of recharged pond seepage in the aquifer should be implemented.

d. Mine C Area

Because of ground-water degradation at similar sites, a specific monitoring program is warranted at Mine C. This study should include all elements of the enhanced monitoring programs as recommended above, as well as an investigation of the effects of mine closure on ground-water quality.

Chapter 2

STUDY METHODOLOGY

A. Program Development

Studies concerning tailings pond seepage and eventual aquifer recharge in the Tucson Copper Mining District began over 12 years ago, prompted by two law suits over water rights and water quality. Data collected in the early 1970's by the United States Geological Survey showed increased concentrations of sulfate and total dissolved solids in downgradient wells monitored over time, suggesting tailings pond recharge at one mine. Information from the water rights case suggested significant ground-water recharge was occurring through tailings ponds (Thuss, 1978).

Several soils and water-quality studies followed with varied conclusions. A materials investigation of the tailings ponds south of Tucson helped characterize the water quality, soil density, particle sizes, and permeabilities of the ponds (Engineers Testing Laboratory Inc., 1973). The rather high sulfate and total dissolved solids contents in the tailings ponds suggested they were a possible source of the degraded water in wells immediately downgradient of the ponds. Two additional studies (W. A. Wahler and Associates, 1973; Hail, 1974) for the City of Tucson included a drilling exploration program at the four mines' tailings ponds with soil sampling and laboratory analyses of the soils. These studies also included drilling four monitor wells at the base of four different tailings ponds. Water of a degraded nature, exceeding suggested Arizona State sulfate and TDS drinking limits, was found in three of the four wells.

The Upper Santa Cruz Basin Mines Task Force completed its first study in 1979 investigating water levels and water quality in the Sahuarita - Continental - Green Valley area. Conclusions regarding tailings ponds impacts on ground water were somewhat inconclusive since there were few monitor wells to sample near the tailings ponds, and only one round of samples was taken. Thus, the Mines Task Force recommended further investigations of the tailings ponds effects on ground-water quality.

All three current monitoring programs described in this report evolved from the recommendations in the above-mentioned Mines Task Force's Baseline Report (Upper Santa Cruz Basin Mines Task Force, 1979). The overall program received funding from federal, state, and local sources, including inkind services from all the participating Mines Task Force members.

The Mines Task Force was formed in August, 1976, in response to the earlier studies' findings, with membership from the following organizations:

Arizona Department of Health Services (ADHS)
Arizona Attorney General
Arizona Water Commission (now Arizona Department of Water Resources, ADWR)
Arizona State Land Department
Pima Association of Governments (PAG)
Pima County Health Department
Four Copper Mines
- Mine A (withdrew November, 1980)
- Mine B (withdrew September, 1982)
- Mine C (withdrew October, 1982)
- Mine D

Papago Tribe of Arizona
U.S. Indian Health Services
Farmers Investment Co. (FICO)
Tucson Water
U.S. Geological Survey (USGS)

The Task Force consists of an Oversite Committee and a Technical Subcommittee. The Oversite Committee includes attorneys and managers from participating organizations while the Technical Subcommittee consists of consultants, hydrologists and engineers. All products from the Technical Subcommittee must be approved by the Oversite Committee.

Responding to recommendations in the 1979 Baseline Report, the Mines Task Force prepared detailed work programs for each mining company.

Specific tasks for the Mine A area included: describing the local hydrogeology in and near the ponds; describing local water quality; drilling a new monitor well at the base of tailings pond no. 3 and one to the northeast of the tailings ponds; and analyzing and interpreting data for this report.

The detailed work program for Mine B included: describing the local hydrogeology and water quality in and near the ponds; and analyzing and interpreting these data for the purpose of making recommendations.

The Mines Task Force recommended (Upper Santa Cruz Basin Mines Task Force, 1979) that Mine C develop a monitoring program for ponds nos. 7 and 8. Mine C presented a monitoring program to the Task Force, but the Task Force considered the proposal technically unacceptable. As part of an independent program for additional Resource Conservation and Recovery Act studies on mining waste disposal, EPA contracted PEDCo. Environmental, Inc. to conduct an 8-month monitoring program of pond no. 8 (PEDCo. Environmental, Inc., 1983). Data from this study is not yet available. Mine C dropped out of the Mines Task Force in October, 1982.

Mine D established a monitoring well network as part of their detailed work program. Specific tasks included: describing local hydrogeology; describing local water quality in and near the ponds; and analyzing water-quality data to develop conclusions concerning their interceptor well system.

B. Program Implementation

Even though Mine A withdrew from the Upper Santa Cruz Basin Mines Task Force in November, 1980, they still participated in all the duties for which they were responsible (Upper Santa Cruz Mines Task Force, 1980). Their consultants wrote a preliminary draft hydrogeology report for the vicinity of Mine A tailings ponds (Clark, 1981). A final draft was never issued to the Mines Task Force due to various problems related to another monitoring program. Mine A and Pima Association of Governments (PAG) conducted a cooperative monitoring program, and Tucson Water contributed inkind services to redevelop the existing monitor well at the base of tailings ponds no. 1 and 2. Data analysis was performed by PAG and other interested Mines Task Force members.

Mine B withdrew from the Mines Task Force in September, 1982. They completed most of the tasks requested of them by the Task Force. Mine B's consultants wrote a draft hydrogeology report on the Mine B study area. Again, a final draft was not delivered to the Mines Task Force. Water-quality data were collected by Mine B's consultants and PAG (check samples). These data were analyzed by PAG, PAG's consultant, and other interested Mines Task Force members. Mine B was also given a copy of this report for review and comment.

Mine D decided not to release their hydrogeology and water-quality report. Alternatively, PAG contracted with Dr. Kenneth Schmidt, ground-water quality consultant, to write a hydrogeology and data interpretation report using data supplied by PAG, ADWR, and Mine D. Most of the required elements in the work program are included in the PAG Mine D hydrogeology report. This report was analyzed and reviewed by the Mines Task Force Technical Subcommittee, of which Mine D is a member.

C. Sampling Methodology

1. Mine A Area

The Mine A area monitoring program was established in the fall of 1980 when representatives from Mine A and the Mines Task Force decided upon the sampling sites, sampling frequency, and constituents to be sampled (Upper Santa Cruz Mines Task Force, 1980).

Due to monetary constraints, a decision to sample existing monitor wells, production wells, and pits prevailed. However, there were sufficient funds to redevelop the existing monitor well owned by the City of Tucson and sampled in 1978. It is located at the base of tailings ponds nos. 1 and 2 (Figure 5, Chapter 4). Also, another monitor well was drilled later during the sampling program when BIA funds became available. The jointly sponsored BIA - Tucson Water - PAG well was drilled in May 1982, between the base of Mine A's tailings ponds nos. 2 and 3 (Figure 5, Chapter 4). This well was subsequently sampled during two more quarterly sampling runs. Another well sponsored by BIA, Tucson Water, and PAG will be drilled sometime in 1983. The well will be drilled about 3/4 of a mile east of tailings pond no. 3, near D(16, 13) 22 ad (Figure 5). Tailings pond monitoring was not included in this sampling program. Pond water-quality data was collected in 1981 on two occasions when an independent team sampled the ponds (Thurnblad, 1982).

The sampling frequency was also determined, in part, by available funding from the Bureau of Mines, Mine A, the City of Tucson, and the BIA. A quarterly program was affordable and was the maximum frequency that could be established. The Technical Subcommittee felt temporal changes in water quality could be adequately addressed with a quarterly monitoring program.

The constituents sampled were based upon the Mines Task Force approved Detailed Work Program Standardized Sampling, Analysis and Reporting Procedures (Upper Santa Cruz Mines Task Force, 1980). Most of the important parameters were analyzed, although sampling for organics and other trace constituents was beyond the scope of this project.

Field sampling included measurements of electrical conductance, pH, temperature, and well discharge. Static water-level measurements were taken in the fall of 1980-81 and 1981-82 when most of the other well fields were shut down. A field sheet was developed to include such pertinent information as site name, location, date sampled, hours and well volume pumped, discharge, perforation interval, field parameter monitoring over time, and types of samples taken. A field team of one PAG and one Mine A representative collected samples after the pumped well water attained constant electrical conductance, pH, and temperature. All sampling procedures followed the Upper Santa Cruz Mines Task Force Detailed Work Program. Other wells sampled were M-6, M-7, M-8, M-10, M-11, SX-1, SX-2, and SX-3. Additionally, the BIA - Tucson Water - PAG well at D(16, 13) 21 dad (Figure 5, Chapter 4) was sampled. Twelve total sites were sampled.

Samples were shipped via UPS in refrigerated, insulated containers to either BC Laboratories, Inc., California, or the Arizona Department of Health Services Laboratory (ADHS), Phoenix, Arizona. The Arizona Department of Health Services Laboratory served as a check laboratory to insure quality control.

Both BC and ADHS laboratories made chemical determinations according to APHA-AWWA-WPCF Standard Methods and the EPA Manual for Analysis of Water and Wastewater.

BC Labs was chosen as the primary analytical laboratory because the Mines Task Force Technical Subcommittee felt it needed continuity from its Baseline Report. BC Labs was chosen to analyze selected constituents in the well water sampled in the Baseline Report and performed admirably. Over 95 percent of their analytical results fell below a 5 percent cation-anion balance, documenting the validity of major ion analyses. Also, BC Labs is an Arizona State Certified Laboratory.

2. Mine B Area

A similar procedure occurred for the Mine B sampling program. Mine B, PAG, and other Mines Task Force members decided upon sampling sites, frequency, and constituents. The Detailed Work Program describes the sampling sites, participants and laboratory. Three monitor wells at the base of the tailings ponds and two Santo Tomas municipal supply wells downgradient of the ponds were sampled quarterly. Water-level measurements were taken in fall 1980-81 and fall 1981-82. The most recent pond water quality data available is from November 1972 (Engineers Testing Laboratory, 1973).

Mine B's consultants conducted the field sampling, and PAG hydrologists and technicians obtained check samples for quality control. BC Laboratories, Inc. was used as the primary analyzing lab, while ADHS laboratory was used as the check laboratory. Both laboratories made chemical determinations according to APHA-AWWA-WPCF Standard Methods and the EPA Manual for Analysis of Water and Wastewater.

3. Mine D Area

Mine D's monitoring program was also approved by the Mines Task Force in the Detailed Work Program. Thirteen monitor wells were drilled by Mine D prior to interceptor well placement. These wells ringed the southern and eastern edges of Mine D's Sierrita North and South ponds, and three extended out about one mile east beyond the ponds (Figure 24, Chapter 4). The interceptor wells were drilled after preliminary data had been collected from the monitor wells, and were placed immediately south and east of the ponds (Figure 24, Chapter 4). Other monitor sites chosen were the Community Water Company well no. 3 (a municipal well), two wells in the Mine D Esperanza well field east of the Sierrita tailings ponds, and two Green Valley Water Company municipal wells about one mile southeast of the ponds.

The interceptor wells were sampled on a weekly basis by Mine D technicians, and samples were sent immediately to the Mine D laboratory which was several miles northwest of the wells. The monitor wells, pond reclaim water, and Community Water Company no. 3 well were sampled monthly by Mine D technicians and the samples were delivered to their laboratory. Pumping and static water levels were taken monthly, and total pumpage volume and rates were recorded for the interceptor wells. Static water levels were measured monthly in the monitor wells. Two Esperanza wells, the Community Water Company well no. 3, and the Green Valley Water Company well no. 1 were sampled annually by PAG technicians and sent to BC Laboratories of Bakersfield, California. PAG also sampled about 10 percent of Mine D's sampling program as a quality control check and sent the samples to ADHS Laboratory in Phoenix, Arizona.

All wells were pumped at least 24 hours prior to sampling, except for the Mine D monitor wells which were bailed by a mechanical stainless steel bailer. The 3-inch monitor wells would not accommodate a submersible pump. Field electrical conductance, pH, and temperature were collected by PAG technicians for check samples, although Mine D technicians also collected field temperature. Standardized field sheets describing location, name, date sampled, well depth, perforation interval, discharge, field parameters, well volumes, and time pumped were used for the check sampling done by PAG.

Mine D laboratory used standard analytical techniques. BC Labs made chemical determinations according to APHA-AWWA-WPCF Standard Methods and the EPA Manual for Analysis of Water and Wastewater.

D. Interpretive Methodology and Analysis of Data

Although tailings pond water-quality sampling was not included in two of the work programs, the first step in the overall program was to identify all sources and causes of pollution in the wells previously monitored. Tailings pond water was historically monitored in a materials investigation in the early 1970's, which revealed elevated TDS (total dissolved solids), sulfates, calcium, molybdenum, and, in some cases, high cyanides (Engineers Testing Laboratory, 1973). Additionally, the tailings ponds were upgradient of contaminated wells previously sampled in the Baseline Report and earlier investigations. Next, ground-water usage, in terms of location, type of use, and quantity, was identified (Arizona Department of Water Resources, 1983). Then the hydrogeologic framework, both regionally and, most importantly, locally, was defined (Clark, 1981; Hargis and Montgomery, 1982; Schmidt, 1982; 1983).

Next, an evaluation of the infiltration rates of tailings pond water on alluvium and on tailings was made. Previous investigations indicated infiltration rates of 2×10^{-5} to 7×10^{-7} ft/sec on typical tailings material compacted over a range of average field densities (Wahler and Associates, 1973). Wahler concluded seepage was occurring at all of the tailings ponds south of Tucson, but at a low apparent rate. Infiltration on alluvial soils in the area of tailings disposal was more on the order of magnitude of 3×10^{-5} ft/sec (Soderberg, 1983).

Other investigators have researched development of low-permeability soil zones at the bottom of tailings slime zones which may reduce seepage significantly (Kealy, et.al., 1974). Infiltration rates have been reduced significantly from about 3×10^{-5} ft/sec to about 3×10^{-8} ft/sec by use of tailings pre-sliming and compaction at Mine A's tailings pond no. 3 (Soderberg, 1983).

Mobility of different elevated chemical constituents in the pond water was then considered. Sulfate was considered the primary traceable constituent since this anion is very mobile in the vadose zone/aquifer system. Other elevated constituents analyzed in pond water were calcium, sodium, hardness (an expression of the presence of calcium plus magnesium), and total dissolved solids. Previous studies found some selenium, probably as SeO_3^{-2} above pH 6.6, in pond water which exceeded drinking water limits (Engineers Testing Laboratory, 1973). The Sodium Adsorption Ratio, SAR, has been used to show relative concentrations of calcium, but SAR could have problems due to base exchange reactions and the presence of gypsum or anhydrite in the natural soils (Wahler, 1973). Other possible tracers such as isotopes of sulfur, oxygen-18, and deuterium were examined but considered not conservative enough for the Task Force Study. A study was done at Mine A by an independent University of Arizona research team using deuterium and oxygen-18 isotopes as possible tracers for recharge of tailings pond water (Thurnblad, 1982).

Numerous estimates of tailings pond recharge have been made and were highly variable. Wahler and Associates (1973) estimated pond recharge at a maximum of about 1 acre-ft. per year per acre of tailings pond, based upon soils from exploration drill holes. Another study estimated recharge values at slightly lower values than the first study (Hail, 1974). An average value of 50 percent of water pumped by each mine was estimated as pond recharge from summarized data from affidavits of technical experts in the FICO vs. mines suits (Thuss, 1978). These estimates were given in a suit regarding water use and quantity rights.

In the current study, an attempt was made to collect inflow-outflow information for all the tailings ponds. This was deemed most essential for an evaluation of tailings pond recharge, and data were requested of all the mining companies involved with the Mines Task Force, but the requests were not fulfilled. However, PAG staff was able to obtain recharge estimates from the Arizona Department of Water Resources based on data collected from the mines.

Current and historic well water quality was then examined in light of the other evaluations.

Water-quality analytical data interpretation aids included sulfate, TDS, and hardness hydrographs to show water-quality trends over time. Also, water-quality contour maps depicted what the areal extent of a plume might be. Trilinear diagrams were used to classify water types and indicated the kinds of mixing taking place between native ground water and tailings pond seepage. Integrated water-quality depth sampling was beyond the scope of this project, and geochemical sections were not depicted. Also, vadose zone monitoring was beyond the scope of this study.

Chapter 3

GENERAL DESCRIPTION AND HYDROGEOLOGY OF STUDY AREAS

A. Location, Physiography, and Climate

The three study areas lie mostly within the western end of Reach 2 and the northwestern portion of Reach 1 of the Upper Santa Cruz Basin (Figure 1). The Mine A study area lies about 15 miles south of Tucson, Arizona, centered at Interstate 19 and the southern boundary of the San Xavier Indian Reservation (Figure 2). The Mine B study area is about 20 miles south of Tucson, Arizona, and about 2 miles northwest of Green Valley, Arizona (population 10,000). Mine D's study area is approximately 25 miles south of Tucson, Arizona, and 2 miles southwest of Green Valley, Arizona (Figure 2).

In the vicinity of the three study areas, the Upper Santa Cruz Basin is about 15 to 20 miles wide. The basin is a northwest-sloping plain and is in the Basin and Range physiographic province. The basin is bounded on the north and east by the Tortolita, Santa Catalina, Tanque Verde, Rincon, and Santa Rita Mountains. The Tucson and Sierrita Mountains border the basin to the west. The northern and eastern mountains vary from 6,000 to over 9,000 feet altitude, while the western mountains bordering the basin are 3,000 to 6,000 feet high. Topographic elevations in the study areas vary from 2,750 feet in the northeastern portion to 3,500 feet in the western fringes.

Potential evaporation is about 40 to 45 inches May-October (Farnsworth, et. al., 1982), and pan evaporation is as high as 80 inches per year. Temperatures in the study areas are slightly lower (5° F) than the Tucson averages of 67.3° F (mean annual), 86.1° F (July), and 50.0° (January) reported by Laney (1972) due to the slightly higher elevations of the study areas.

Precipitation in the study areas ranges from about 12 inches/year in the northern portion, to nearly 20 inches/year in the southern portion. Rainfall is of two types - high intensity thunderstorms occurring from July through September during which most (93 percent) of the streamflow peaks occur (Condes de la Torre, 1970), and long duration frontal storms from December through March which yield floods of lower peaks yet larger volumes.

B. General Hydrogeology of Study Areas

Davidson (1973) and Laney (1972) have written definitive works on the geohydrology and water quality in the Tucson Basin which apply to the Mines Study Areas in a general fashion. The mountain ranges near the study areas, Sierrita and Santa Rita, are composed mainly of low to moderately permeable sedimentary, metamorphic, and intrusive igneous rock. Sedimentary rocks of low water-yielding capacity crop

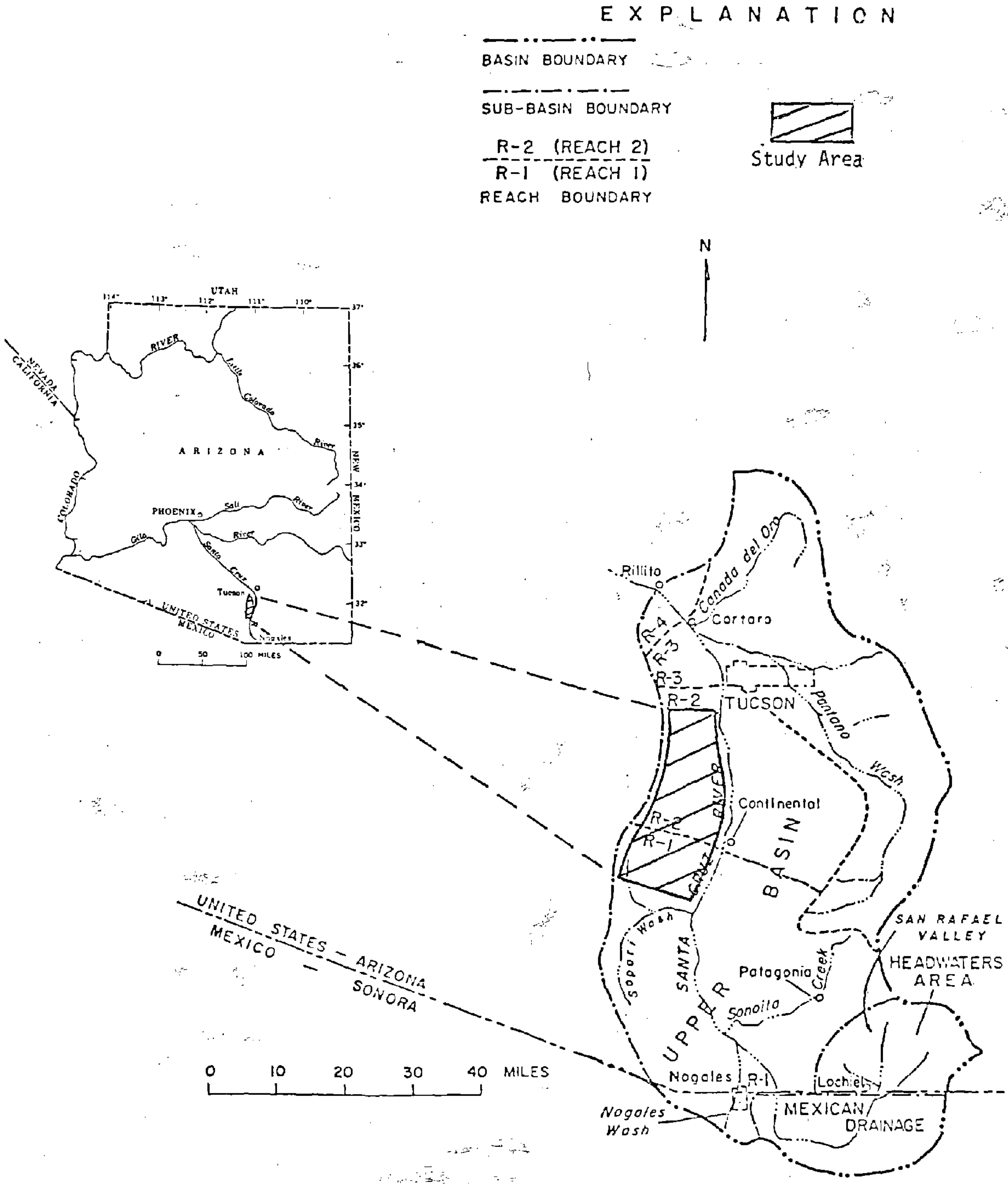


Figure 1. - Mines Special Study Area

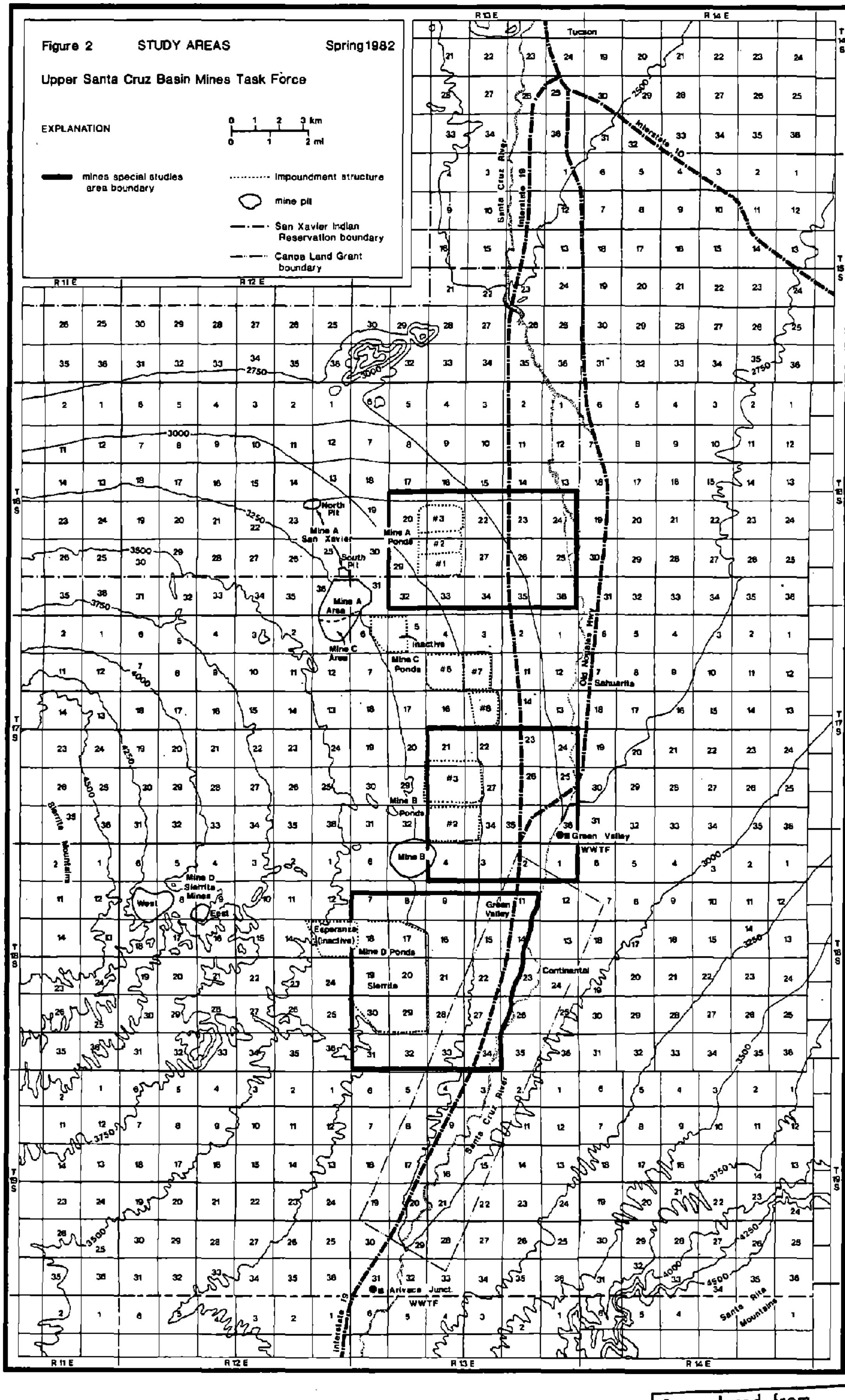


Figure 2 STUDY AREAS Spring 1982
Upper Santa Cruz Basin Mines Task Force
EXPLANATION
0 1 2 3 km
0 1 2 mi
mines special studies area boundary
impoundment structure
mine pit
San Xavier Indian Reservation boundary
Canoa Land Grant boundary
R 11 E
R 12 E
R 13 E
R 14 E
T 14 S
T 15 S
T 16 S
T 17 S
T 18 S
T 19 S
Tucson
Interstate 10
Interstate 19
Santa Cruz River
Old Nogales Hwy
North Pit
South Pit
Mine A San Xavier
Mine A Ponds
Mine A Area
Mine C Area
Mine C Ponds
inactive
Sahuarita
Mine B
Mine B Ponds
Green Valley
WWTF
Mine D Sierrita Mines
West
East
Esperanza (inactive)
Mine D Ponds
Sierrita
Continental
Sierrita Mountains
Arivaca Junct.
Santa Rita Mountains

out in large areas of the Sierrita and Santa Rita Mountains. Most of the sedimentary rocks have low porosity and permeability, but some units have moderate to high porosity and permeability.

Davidson (1973) divided the sedimentary basin deposits into four distinct units based upon color, rock fragment content, degree of cementation, and spatial position. Determination of units is more difficult with increasing depth, and graphic plots of percentages of sand and coarser material aided in unit identification (Davidson, 1973). The basal unit, the Pantano Formation (Finnell, 1970), is a reddish-brown silty sandstone to gravel, weakly to strongly cemented by calcium carbonate. The Pantano Formation thickness varies from 10,500 feet in the Sierrita mountain area (Helmet Fanglomerate correlative) to an estimated 100 to 1,000 feet in the central part of the basin (Davidson, 1973). The Pantano Formation is unconformably overlain by the Tinaja Beds which consist of gravel and sand in the basin margins and grade-to-clayey silt and mudstone near the central part of the basin. The Fort Lowell Formation unconformably overlays the Tinaja Formation and grades from gravel on the basin edges to silt in the basin center. Relatively thin, surficial deposits overlie the Fort Lowell Formation consisting of boulders, pebbles, gravel, and coarse sand. These formations are described in more detail for each of the individual study areas. Permeabilities, porosities, transmissivities, available storage coefficients, specific capacities, water levels, and flow characteristics will also be presented for each individual study area.

To provide information for regional ground-water movement, water levels were obtained by all the cooperating Task Force members from December 1981 to February 1982. A ground-water elevation map (Figure 3, in pocket) was developed showing water levels from the Pima County - Santa Cruz County border going north to the southern boundary of the City of Tucson. The general direction of ground-water movement along the Santa Cruz River is northerly, but is interrupted by a localized cone of depression within and near the Mine A and Mine C well fields at D(16, 13) 25, 26, 35 and 36. Another closed depression occurs in the area of Mine B, possibly the result of pit dewatering (Upper Santa Cruz Basin Mines Task Force, 1979). General direction of ground-water movement along the basin margins is from west to east from the Sierrita Mountains and north-westerly from the Santa Rita Mountains. There is also a recharge lobe east of the Santa Cruz River just outside the southeast corner of the Papago Indian Reservation boundary. This is probably due to subsurface deposits associated with former channels of the Santa Cruz River, which were the most favorable pathways for movement of water recharged from the river.

C. Mine A Hydrogeology

The draft Mine A hydrogeology report was reviewed by the Mines Task Force Technical Subcommittee (Clark, 1981). However, Task Force comments were never addressed because a final report was not submitted by Mine A. A cross section (Figure 4) is provided and is an adaptation from Davidson (1973), cross section H-H'. This cross section shows the top of the Pantano Formation (Helmet Fanglomerate correlative) to be about 250 feet below land surface (not 350 feet as suggested in Mine A's hydrogeology report) near well M-5. But detailed geologic logs of wells M-5, M-6, and M-7 available at PAG reveal a gradation of sedimentary units from 25 feet of surficial deposits, to 125 feet of Fort Lowell deposits, to about 200 feet of Tinaja type material, thus leaving the top of the Helmet Fanglomerate at 350 feet below land surface. Ground-water velocity can be calculated from a hydraulic gradient of 100 feet per mile, an average permeability of about 100 gallons/day/ft^2, and an average porosity of 0.40. This would yield a ground-water velocity of about 0.64 foot/day or 233 feet/year.

Transmissivities are somewhat variable in the Mine A study area. Estimates from specific capacity and aquifer test data suggest values from 4,000 gallons/day/foot at the City of Tucson monitor well next to the pond, to 100,000 gpd/ft in the vicinity of wells M-10 and M-11, to 30,000-40,000 gpd/ft near wells SX-1, SX-2, and SX-3 (Figure 5, Chapter 4) (Clark, 1981).

Depth to water varies from about 300 feet near the tailings ponds to about 360 feet near the M wells, to about 225 feet near the SX wells.

Specific capacities vary from 2.4 gpm/ft at the City of Tucson well next to the ponds, to 11.5 gpm/ft of drawdown at Well M-8, to 49.0 gpm/ft at well M-11 (Clark, 1981).

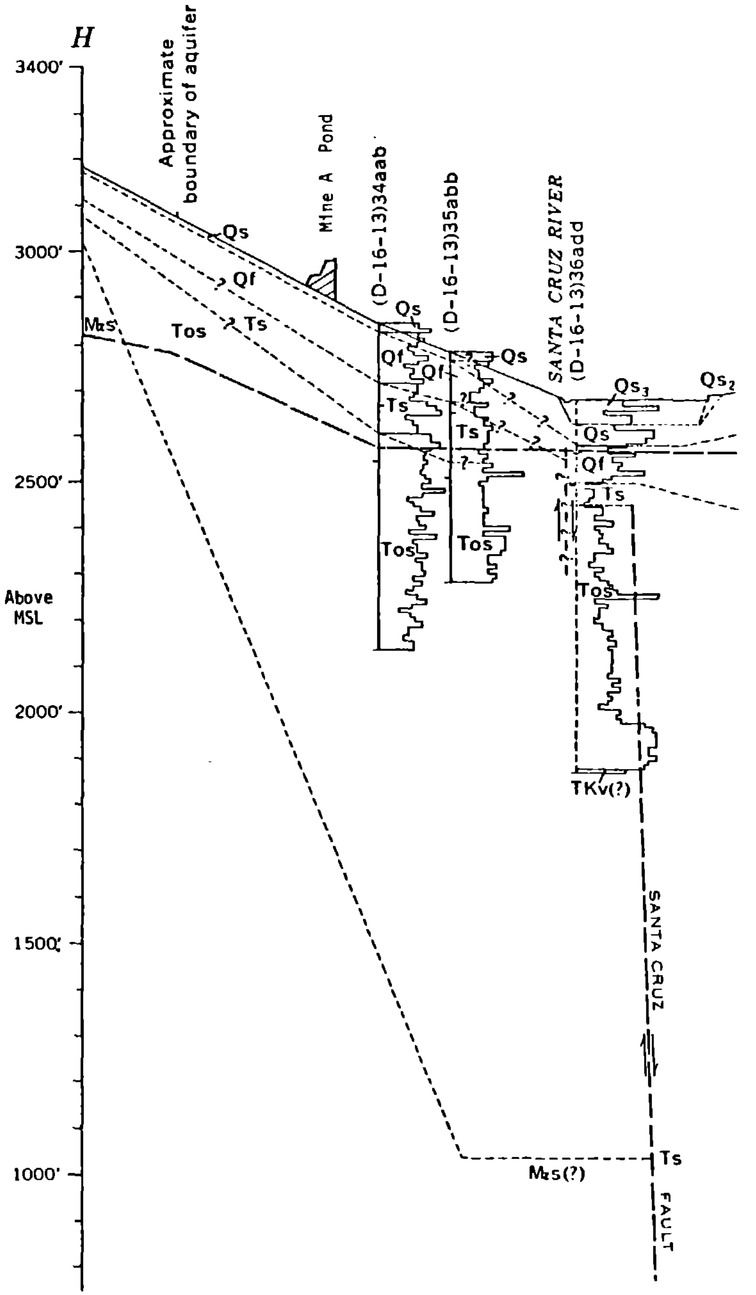
Additional hydrogeologic information for the Mine A area is provided in Chapter 4.

D. Mine B Hydrogeology

Mine B's draft hydrogeology report was reviewed by the Task Force Technical Subcommittee, however, Task Force comments were never addressed because a final report was not submitted by Mine B.

All available well construction data for monitor wells were collected from the Arizona Department of Water Resources drillers logs and from Mine B, and are presented in Table 1. Ground-water velocity between the Mine B ponds and the Santo Tomas wells was calculated from an aquifer thickness of 500 feet estimated from cross-section information, and an estimated permeability of about 140 gallons/day/ft^2. Using an estimated 0.35 porosity value and 66/foot/mile hydraulic gradient, ground-water velocity in the Mine B area near the ponds is about 0.67 foot/day or about 245 feet/year.

Figure 4. - CROSS SECTION OF MINE A STUDY AREA



Adapted From Davidson (1973)

EXPLANATION

Q_{s_3}	Stream and floodplain alluvial deposits	Q_f	Fort Lowell Formation
Q_{s_2}	Youngest terrace deposits	Ts	Tinaga beds
Q_{s_1}	Intermediate terrace deposits	Tos	Pantano Formation
Q_s	Alluvial deposits	Tkv	Welded tuff, breccia, flows, tuff and interbedded sedimentary rocks
		MzS	Bedrock

Fault

Long dashed where approximately located; short dashed where inferred; queried where probable; arrows show relative movement

Contact

Dashed where inferred. Queried where probable; where straight, it represents correlation between wells. Where curved, it represents analysis of structure based on additional wells not shown on sections

(D-13-13)19cdd

Well and number

Dashed where projected to sections

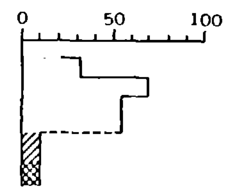
Measured or approximated in 1940

Measured or approximated in 1966

Predicted 1985 level from analog model, assuming current annual rates of inflow to and outflow from aquifer

Water levels in wells projected to section shown separately

Water levels in wells



Grain size

Percentage of material courser than silt (0.061 mm in diameter), averaged per 10-foot interval of drill hole; dashed where estimated from drillers' or lithologic logs; diagonal pattern indicates gypsiferous or anhydritic clayey silt or mudstone; cross-hatched pattern indicates anhydritic clayey silt or mudstone

TABLE 1. - WELL CONSTRUCTION FOR MINE B WATER QUALITY SAMPLING SITES

WELL NAME	LOCATION	CASING DIAMETER (inches)	DEPTH (feet)	TOTAL CASED DEPTH (feet)	PERFORATED ZONE (feet)	DEPTH TO WATER (feet)	DATE MEASURED	DISCHARGE (gpm)
Santo Tomas No. 5	(D-17-13)26bcc	10-3/4	807	805	265-405; ?	376.0	12-2-80	280
Santo Tomas No. 6	(D-17-13)26cad	12-3/4	838	838	NA	331.0	1-12-82	300
P-1758	(D-17-13)27abb	6	650	650	339-639	427.7	1-15-81	15
P-1759	(D-17-13)27dbb	6	650	650	349-649	429.0	1-15-81	15
P-1225	(D-17-13)34bad	8/6	0-500; 480-650	650	415-480; 500-630	442.2	1-12-82	12

NA - Not available.

Aquifer transmissivity in the vicinity of Mine B ponds is about 70,000 gallons/day/ft and the storage coefficient is on the order of 0.10 based on a long-term aquifer test conducted on well RT-1 located immediately northeast and east of tailings dams #2 and #3 (Hargis and Montgomery, 1982) (Figure 14, Chapter 4). Transmissivity increases to about 150,000 gpd/ft nearer to the Santa Cruz River about 1.5 miles east of the ponds. The storage coefficient also increases to about 0.3 (Hargis and Montgomery, 1982).

Additional hydrogeologic information on Mine B is provided in Chapter 4.

E. Mine D Hydrogeology

Mine D hydrogeology is described in Chapter 4, pages 62-78 of this report.

F. Regional Water Quality

Regional ground-water quality is described in detail in a separate report (Upper Santa Cruz Basin Mines Task Force, 1983c). In general, elevated sulfate, TDS, and chloride plumes are centered downgradient from the tailings ponds, indicating evidence of seepage and aquifer recharge from the ponds. Total dissolved solids regionally are highest near Mine D's Sierrita pond where locally 2000 mg/l is exceeded. Near the Mine A and Mine B ponds, total dissolved solids contents in wells exceed 1000 mg/l. Near Mine C's ponds, total dissolved solids in ground water exceed 900 mg/l (PEDCo., 1983; Luhdorff, 1974). Except near the mines tailings ponds, total dissolved solids are usually less than 300 mg/l in ground water beneath both sides of the flood plain. North of Green Valley, total dissolved solids in wells commonly exceed 500 mg/l but are generally under 800 mg/l beneath the flood plain of the Santa Cruz River.

Sulfate shows a similar pattern where the highest contents in wells appear near the Mine D ponds (1400 mg/l), Mine B and Mine A ponds (500 mg/l), and Mine C's ponds (400 mg/l). Generally, sulfate contents in wells are less than 100 mg/l beneath both sides of the flood plain except near mines' tailings ponds. Sulfate contents in ground water beneath the Santa Cruz River flood plain are usually less than 200 mg/l.

Chapter 4

DATA INTERPRETATION, CONCLUSIONS AND RECOMMENDATIONS - EFFECTS OF RECHARGE FROM TAILINGS PONDS FOR COPPER MILLING WASTES IN THE TUCSON COPPER MINING DISTRICT

A. Introduction

There are four major areas with active tailings ponds for copper milling on the eastern flank of the Sierrita Mountains, south of Tucson. From north to south, these are the Mine A, Mine C, Mine B, and Mine D ponds. Three of these areas are being evaluated as part of the Upper Santa Cruz Basin Mines Task Force Special Studies Program.

The purpose of this chapter is to interpret the water-quality information gathered for this report in reference to the hydrogeologic framework of the study areas. A more detailed description of ground-water and hydrogeologic conditions is provided for the vicinity of the Mine D tailings pond due to the lack of a basic hydrogeology report for reference purposes.

B. Tailings Pond and Pit Water

1. Tailings Pond Water

Slurry disposed to the tailings pond is about 50 percent water and 50 percent fine crushed rock. Some free water in most ponds is recirculated to the mill for reuse. Remaining water in the pond is consumed by evaporation, retained in the tailings, or percolated to the ground water.

The results of detailed water budget studies to determine pond recharge were not available for this report. However, information in the files of the Arizona Department of Water Resources indicates that the volume equivalent to about 25 to 30 percent of mine pumpage, on the average, is returned to the ground water from the tailings ponds in the Sahuarita-Continental area. These estimates are based on reports published by the Arizona Bureau of Geology and Mineral Technology (formerly, Arizona Bureau of Mines), and were developed during the calibration of a digital ground-water model of the Upper Santa Cruz Basin (Travers, 1983). In the case of each mine, recharge was estimated initially at 29 percent of the yearly pumpage for the period 1970 through 1979. This amount was adjusted in each mine area until a reasonable fit between measured water levels and model-generated water levels was obtained. In actuality, recharge has probably been greater from ponds such as at Mine D, where free water has been allowed to contact permeable alluvium. Lower recharge rates probably occur from ponds such as at Mine A where free water generally stands on the tailings.

Potential ground-water pollutants can be added to water used in the milling process by two major processes:

1. Addition of flotation agents.
2. Reaction of water with minerals during crushing and milling.

A series of two articles (Mining Engineering, March and April, 1982) described the flotation process. Flotation is a method of concentrating finely ground ores, and flotation agents include collectors, frothers, and modifiers. A collector is a reagent that produces a hydrophobic film on the mineral particle. Xanthates are the most common collectors for sulfide minerals which are processed at the mills. The frother creates a froth capable of carrying mineral-laden bubbles until they can be removed from the flotation machine. Pine oil is a commonly used frother. Modifiers are conditioning agents which may act as depressants, activators, pH regulators, or dispersants. Lime is a common pH regulator, and various forms of cyanide are additional modifiers that are commonly used in the flotation process for copper ore milling.

High sulfate contents can be picked up from ore minerals, both from soluble sulfate minerals and from oxidation of sulfide minerals. The chemical composition of tailings pond water from each of the three study areas is described in more detail in the following sections of this report. Pond water at Mine A and Mine D has high contents of calcium and sulfate, and is probably saturated with respect to gypsum. Pond water at Mine B is generally of the calcium-sodium sulfate type, with lower sulfate contents than present in pond water at the other two study areas. Several trace inorganic chemical constituents such as molybdenum and cyanide would be expected to be present at the high pH normally encountered. The trace organic chemical composition of pond water is not available for the mines in the Sahuarita-Continental area.

2. Pit Water

Ground water commonly found in hardrock of the mine open pits is similar in chemical composition, for the major inorganic constituents, to tailings pond water. Water of this composition appears to be limited, in the hardrock, to mineralized zones. The high sulfate contents are apparently derived from dissolution of sulfate minerals and oxidation of sulfide minerals. The question has arisen whether water in the pits and from the mineralized zone could contribute to the plumes identified beneath the mines' tailings ponds.

Near each pit, a substantial cone of depression has been developed due to pit dewatering. The direction of ground-water movement is thus toward, as opposed to away from, the pit. In addition, ground water moving in the hardrock is believed to comprise only a small part of the ground water moving in the alluvium. That is, most of the ground water moving in the alluvium has originated from streamflow seepage or other sources. Near the mine tailings ponds, most of the recharge to local ground water is from tailings pond percolation. There is no indication that water from the pits or mineralized zone in the hardrock has grossly impacted the composition of water in the nearby alluvium.

C. Mine A Study Area

1. Hydrogeologic Conditions

Figure 5 shows the location of the Mine A tailings ponds, mine supply wells, monitor wells, and drill holes near the ponds. Eight wells are presently used to supply water for milling. Well M-5 was previously a mine supply well that is now unused due to declining water production. Mine C has a number of wells south and east of the Mine A Mission wells; however, a number of these are also presently unused. In general, water-quality data are not available for the drill holes, but water-level measurements are available.

Ground-water conditions in the Mine A study area were discussed by Clark (1981). Since that draft report was prepared, an additional monitor well has been drilled near the southeastern edge of tailings pond no. 3. Clark (1981) indicated that the top of the Helmet Fanglomerate (considered to be equivalent to the Pantano Formation in this report) was slightly less than 300 feet deep near the tailings ponds. Sediments of the Tinaja Beds and Fort Lowell Formation overlie the Helmet Fanglomerate near the tailings ponds. Volcanic rock was encountered at a depth of about 330 feet by the new BIA monitor well, D(16, 13) 21 dad. Depth to water beneath the east edge of the ponds apparently ranges from about 200 feet beneath the north end to about 300 feet beneath the south end. Depth to water generally increases to the south and east toward the Mine A and Mine C well fields.

Figure 6 shows water-level elevation contours for the period November 1981-February 1982. Water-level elevations exceeded 2,600 feet above mean sea level beneath most of the tailings ponds, and were less than 2,450 feet in most of the Mine A wells. The slope of the water table between the ponds and the Mine A Mission well field is about 100 feet per mile. The predominant direction of ground-water flow at this time was to the east beneath pond no. 1, and to the southeast beneath pond no. 2 and pond no. 3. Recharge from the ponds would thus tend to move toward the Mine A well field.

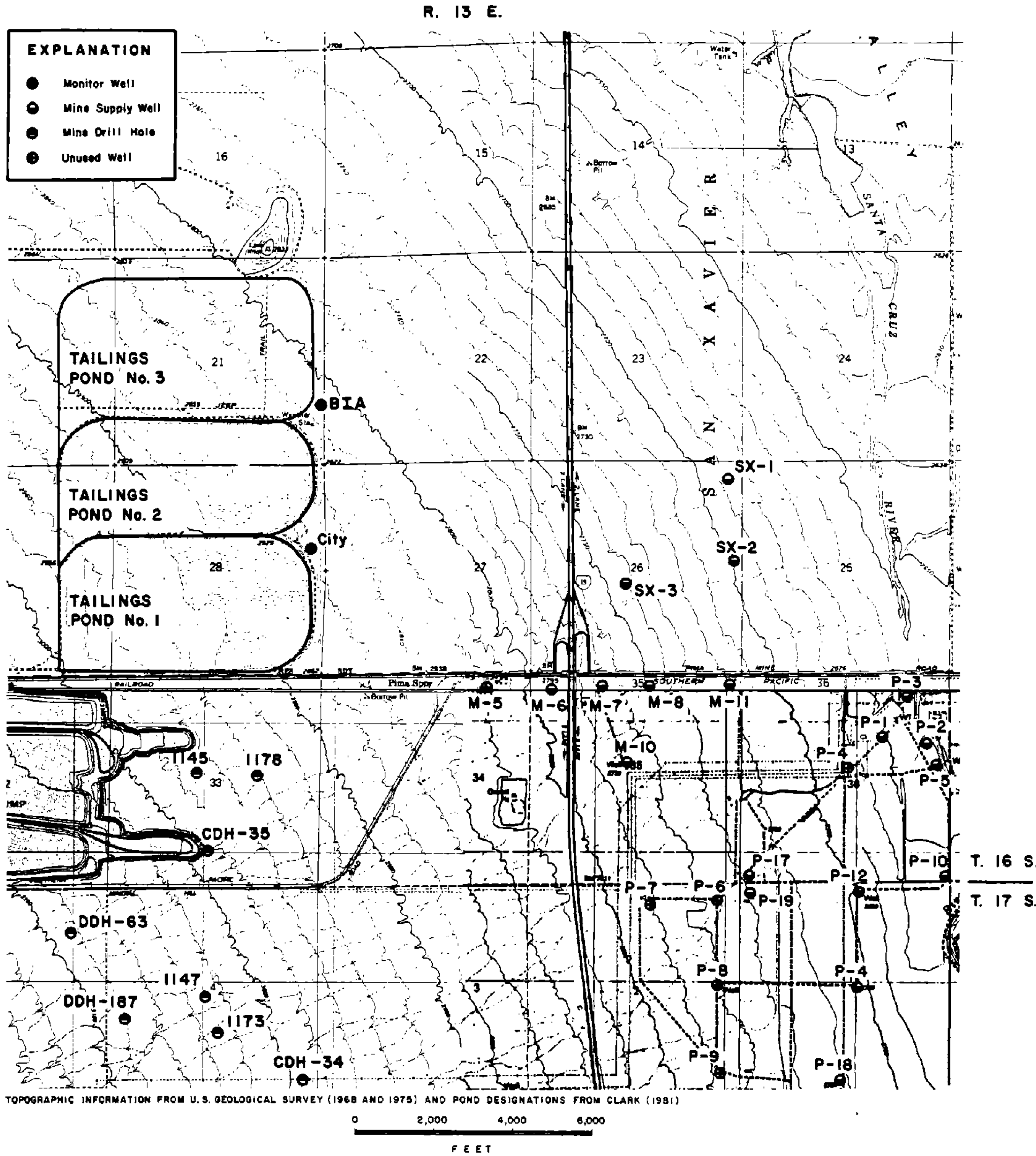


FIGURE 5. - LOCATION OF WELLS AND DRILL HOLES IN THE VICINITY OF THE MINE A PONDS

Pima Association of Governments & K.D. Schmidt, 1983

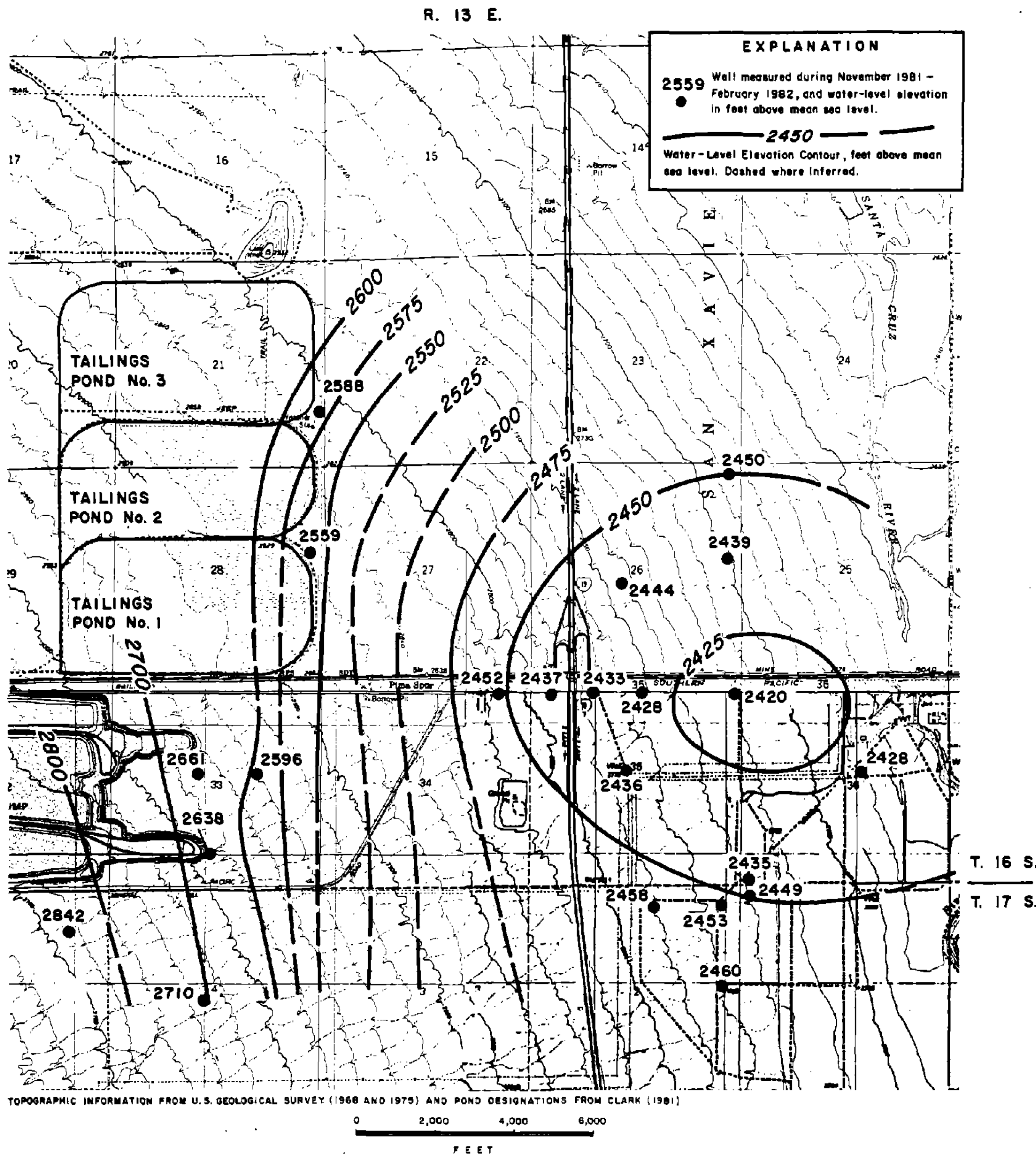


FIGURE 6.-WATER-LEVEL ELEVATIONS IN THE VICINITY OF THE MINE A PONDS (1981 - 1982)

Pima Association of Governments & K. D. Schmidt, 1983

2. Well Use

Wells in the vicinity are used primarily for copper milling. There are numerous irrigation wells and several domestic wells east and south of the Mine A well field. The nearest City of Tucson public-supply wells are located about 4 miles northeast of the edge of pond no. 3. Based on the water-level elevation contour map (Figure 6), these wells do not appear to be downgradient of the Mine A ponds. However, if mine pumpage ceased at some point in the future, the public-supply wells could be downgradient of the ponds, due to a change in the direction of ground-water movement.

3. Amounts of Pumpage and Pond Recharge

Information on pumpage and recharge for the Mine A study area is on file at the Arizona Department of Water Resources in Phoenix. Pumping from the Mine A Mission Wells first began in 1959, and annual pumpage was about 4,800 acre-feet by 1965. In 1969, the annual pumpage increased to about 6,400 acre-feet and has ranged from about 4,700 to 6,700 acre-feet since that time. Pumping from the Mine A San Xavier wells began in 1977, and annual pumpage has ranged from 500 to 1,300 acre-feet per year. Total pumpage from these mine-supply wells was about 6,200 acre-feet in 1979. It is estimated that about 1,600 acre-feet of water was recharged from the Mine A tailings ponds in 1979. Thus, pumpage from the Mine A well field appears to be almost four times greater than the amount of water recharged from the ponds. There has probably been a total of about 30,000 acre-feet of recharge from the Mine A ponds since 1959.

4. Quality of Tailings Pond Water

Water from the Mine A tailings ponds has not been sampled as part of the Mines Special Studies Program. However, limited data are available, such as that from Engineers Testing Laboratory, Inc. (1973) and Thurnblad (1982). Table 2 shows the chemical composition of water collected near the decant tower at tailings pond no. 1, and from the recycling pond which was receiving water from tailings pond no. 2. Mine A pond water is of the calcium-sulfate type. Calcium contents have generally ranged from about 500 to 700 mg/l, and have probably averaged about 600 mg/l. Hardness is virtually all due to calcium content, as magnesium contents are low. Hardness contents as calcium carbonate have averaged about 1,600 mg/l. Sulfate contents have usually ranged from about 1,500 to 2,400 mg/l, and have probably averaged about 1,800 mg/l. Total dissolved solids contents have ranged from about 2,600 to 3,500 mg/l, and have probably averaged about 3,000 mg/l. Contents of molybdenum were at noticeable levels (2-16 mg/l). Valid cyanide analyses were not available for this report.

TABLE 2. - CHEMICAL COMPOSITION OF WATER
FROM MINE A TAILINGS PONDS

Constituent (mg/l)	Pond No. 1	Pond No. 2		
Calcium	530	552	615	760
Magnesium	<1	5	2	1
Sodium	190	163	166	240
Potassium	49	70	-	72
Carbonate	35	0	0	0
Bicarbonate	0	39	41	18
Chloride	43	26	38	32
Sulfate	1,600	1,558	1,745	2,400
Nitrate	2	2	<1	2
Flouride	2.0	3.7	0.6	2.3
Iron	<0.08			0.05
Manganese	<0.04	-	-	0.08
Arsenic	<0.005	-	-	<0.01
Chromium	<0.04	-	-	<0.01
Selenium	0.013	-		<0.01
Molybdenum	1.9	5.5	16	2.0
Lead	-	-	-	<0.01
Copper	-	-	-	0.01
Zinc	-	-	-	0.14
Cadmium	-	-	-	<0.01
Boron	-	0.4	-	0.13
Vanadium	-	-	-	<0.1
Electrical Conductivity (micromhos at 25°C)	2,993	-	-	3,351
Total Dissolved Solids	3,500	-	2,629	3,333
Total Organic Carbon	7.8	-	-	6.7
Field pH	-	-	-	5.5
Lab pH	10.1	6.7	5.0	6.5
Date	5/4/81	2/17/71	10/18/71	8/20/81
Lab	U of A	ETL	ETL	BC Labs

1971 analyses from Engineers Testing Laboratory, Inc. (1973) and 1981 analyses from Thurnblad (1982).

5. Ground-Water Quality

Contour maps have been prepared for sulfate, hardness, and total dissolved solids content in water from wells in the vicinity of the Mine A tailings ponds that were sampled in Fall 1982 (Figures 7, 8, and 9). Chemical analyses for this time period were unavailable for water from Mine C wells. Contents of all of these constituents decrease to the southeast from the Mine A tailings ponds. Contents of sulfate and hardness are almost identical, which is expected if pond recharge is the major factor influencing ground-water quality. Water in the tailings ponds is virtually a calcium-sulfate type and the equivalent weights of sulfate and hardness are almost identical (48 and 50, respectively).

Sulfate contents ranged from about 600 to 800 mg/l in water from the two monitor wells near the ponds in Fall 1982. The BIA monitor well is perforated from 200 to 336 feet in depth, opposite most of the saturated alluvium at that location. The City of Tucson monitor well is perforated from 200 to 440 feet in depth. Sulfate contents were less than 100 mg/l in the eastern part of the Mine A well field. This indicates that water in the monitor wells is a mixture of pond recharge and native ground water. The sulfate contents indicate that only about one-third of the water at the monitor wells is derived from recharge of tailings pond water. The two monitor wells appear to be directly downgradient of the ponds. The relatively low sulfate contents suggest that pond recharge probably has not affected the entire saturated thickness of the aquifer beneath the Mine A ponds. Instead, the pond recharge is probably mostly present in the shallower ground water. Hardness as calcium carbonate contents were about 900 mg/l in water from the two monitor wells in Fall 1982, and were less than 100 mg/l in the eastern part of the Mine A well field. Total dissolved solids contents in water from the two monitor wells ranged from about 1,300 to 1,700 mg/l in Fall 1982, and were less than 300 mg/l in the east part of the Mine A well field.

Water-quality hydrographs were prepared for water from four wells that appear to have been influenced by tailings pond recharge. Figures 10, 11, and 12 show changes in sulfate, hardness, and total dissolved solids contents for these wells between 1960 and 1982. There have been sharp increases in sulfate, hardness, and total dissolved solids contents in water from all of these wells. Water from Mission well no. 5 was apparently influenced beginning in the early 1970's. Mission wells no. 6 and no. 7 and San Xavier well no. 3 were influenced at progressively later times. These wells are all at progressively greater distances from the tailings ponds. Sulfate contents in water from M-6 and M-7 now exceed the recommended level for drinking water of 250 mg/l. However. sulfate contents in water from these wells are slightly higher than that

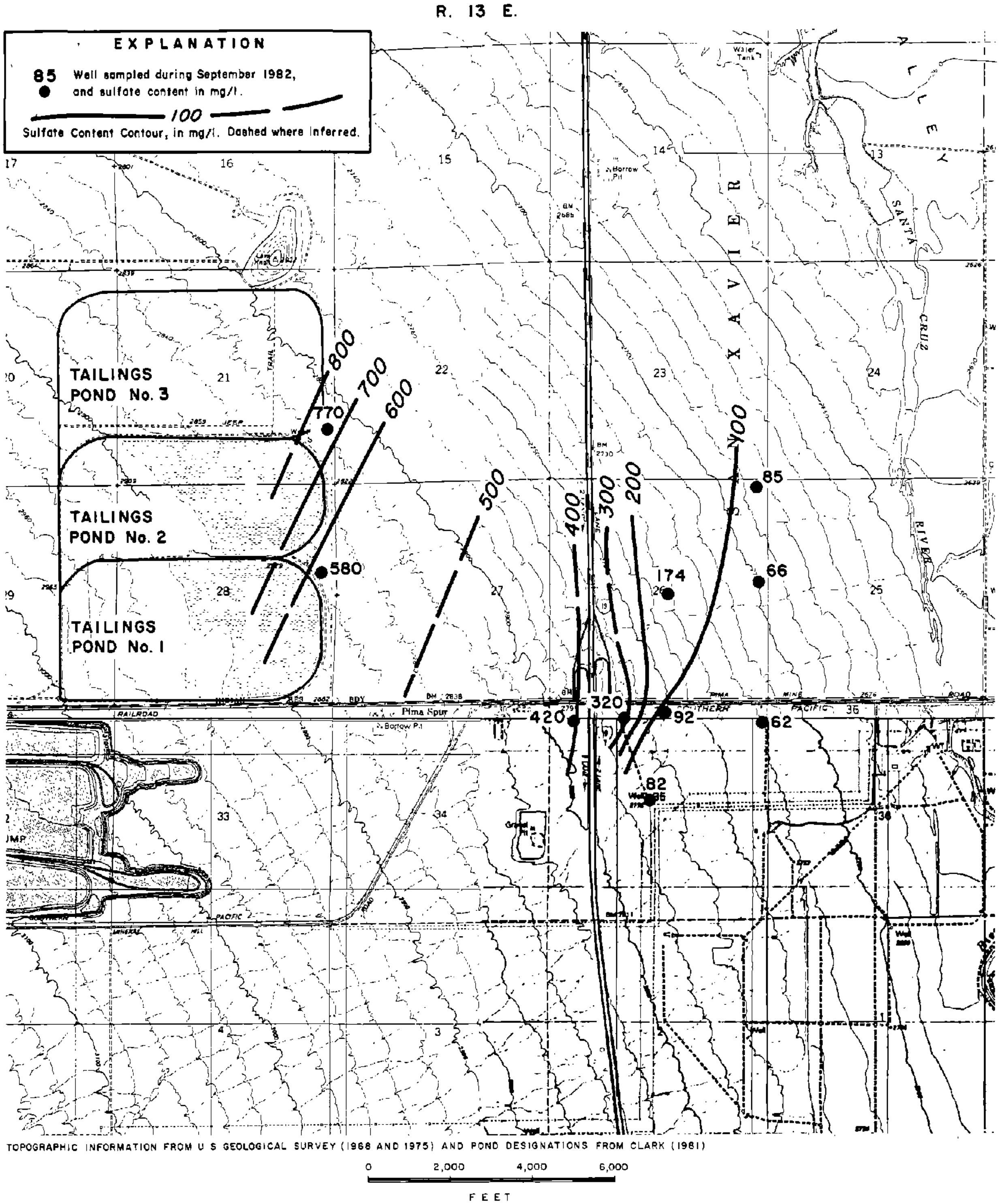


FIGURE 7. – SULFATE CONTENT IN WATER FROM WELLS IN THE VICINITY OF THE MINE A PONDS (FALL 1982)

Pima Association of Governments & K. D. Schmidt, 1983

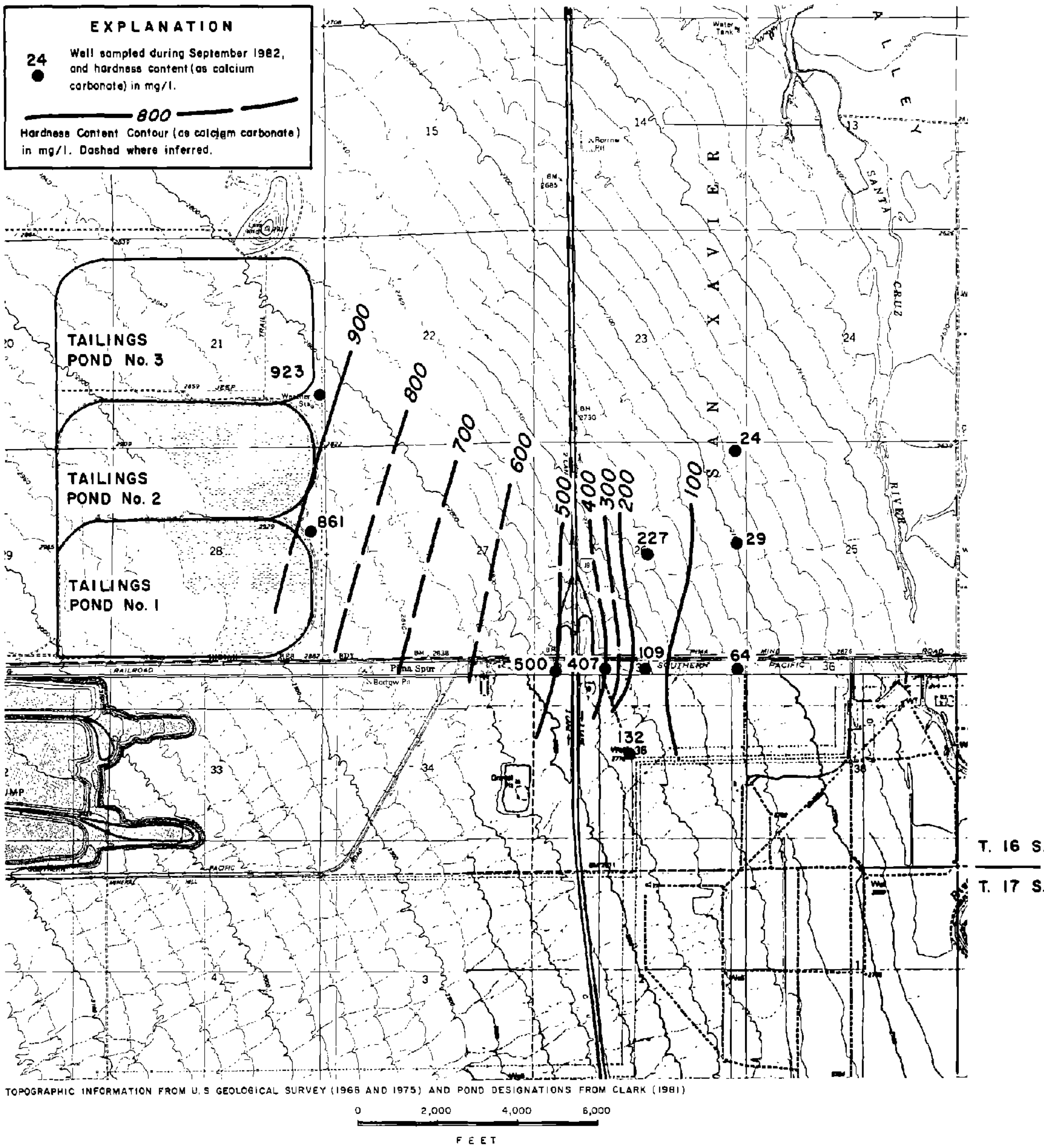


FIGURE 8.-HARDNESS CONTENT IN WATER FROM WELLS IN THE VICINITY OF THE MINE A PONDS (FALL 1982)

Pima Association of Governments & K. D. Schmidt, 1983

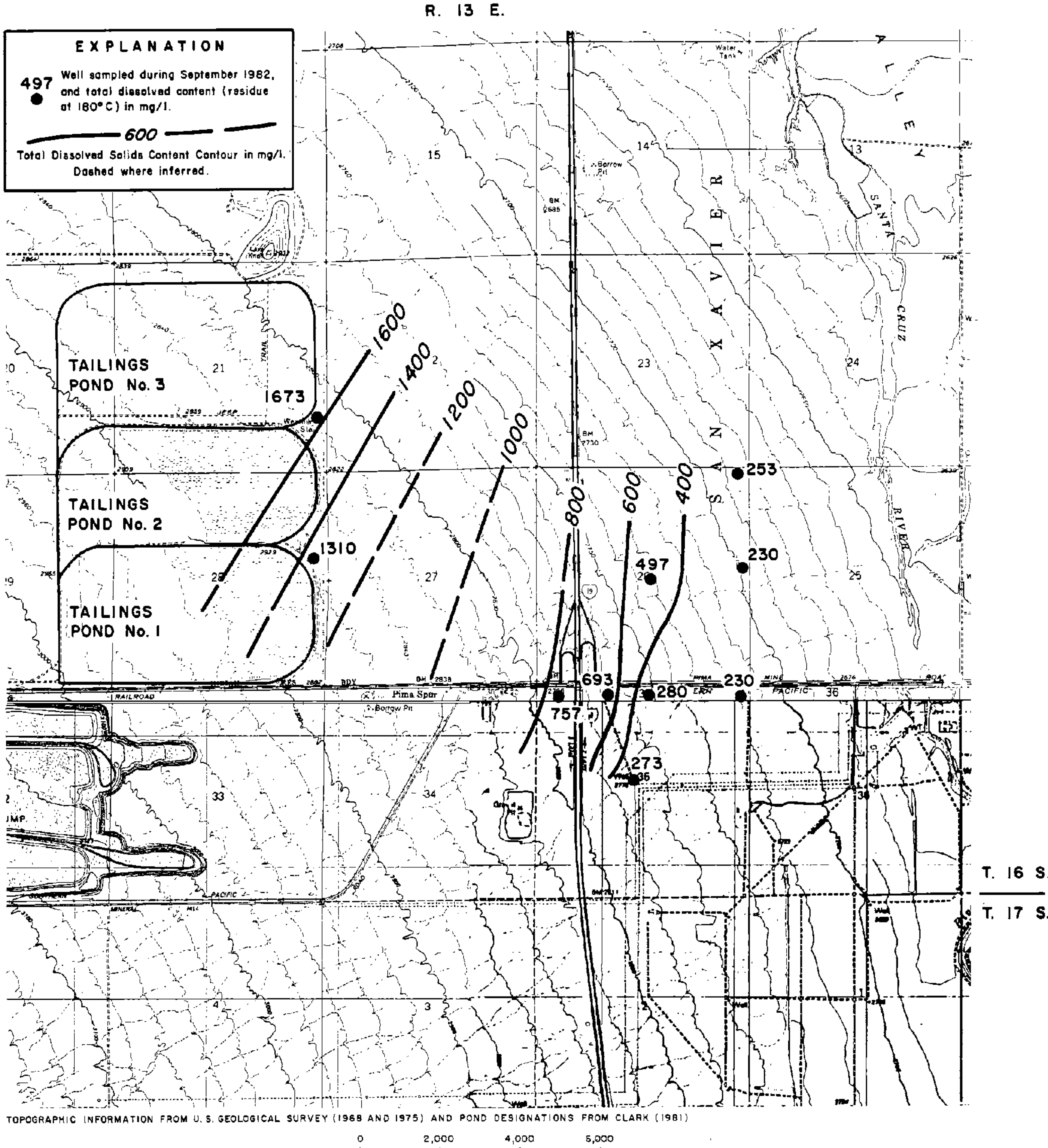


FIGURE 9. – TOTAL DISSOLVED SOLIDS CONTENT IN WATER FROM WELLS IN THE VICINITY OF THE MINE A PONDS (FALL 1982)

Pima Association of Governments & K. D. Schmidt, 1983

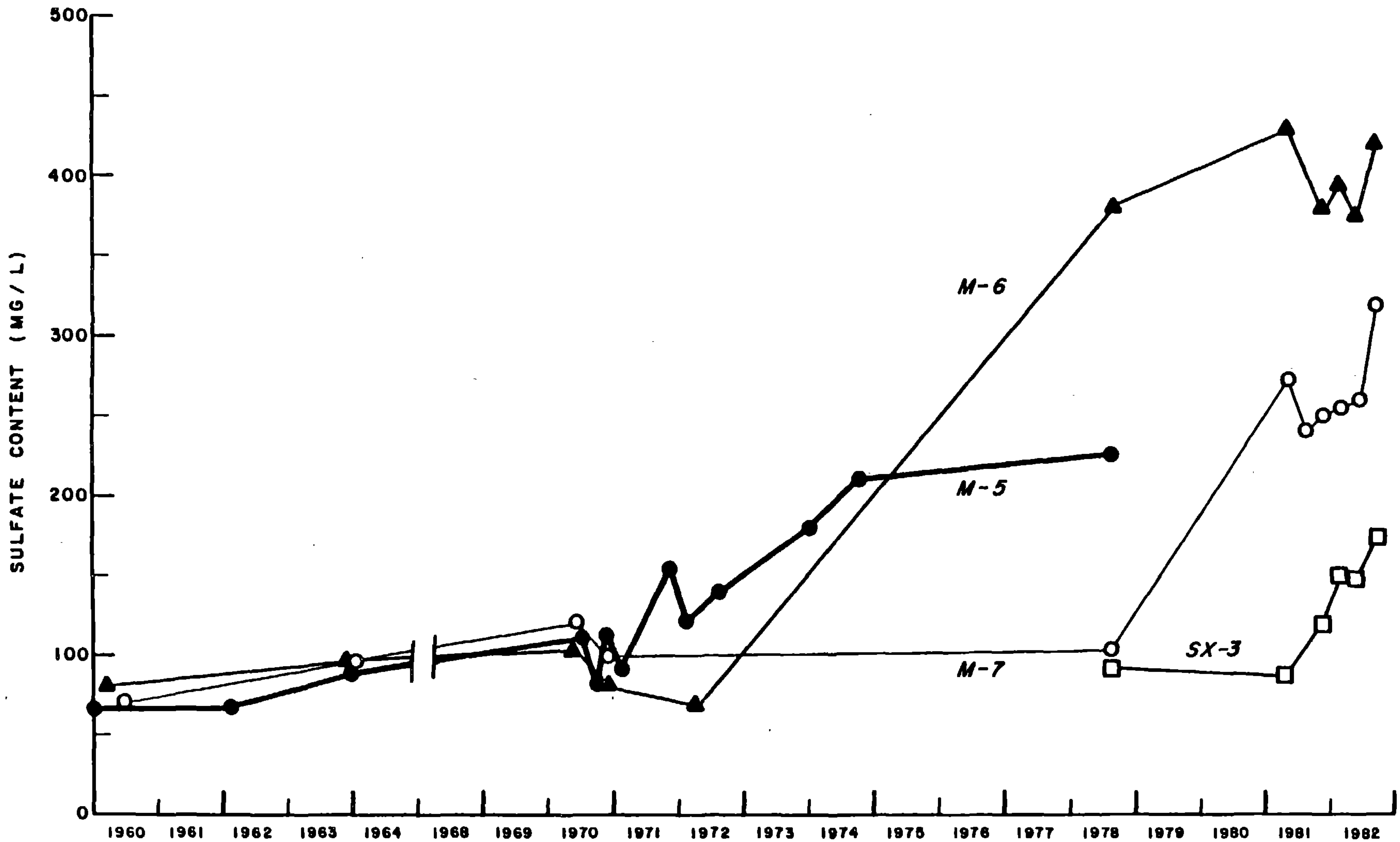


FIGURE 10. - SULFATE CONTENTS FOR WELLS NEAR MINE A PONDS

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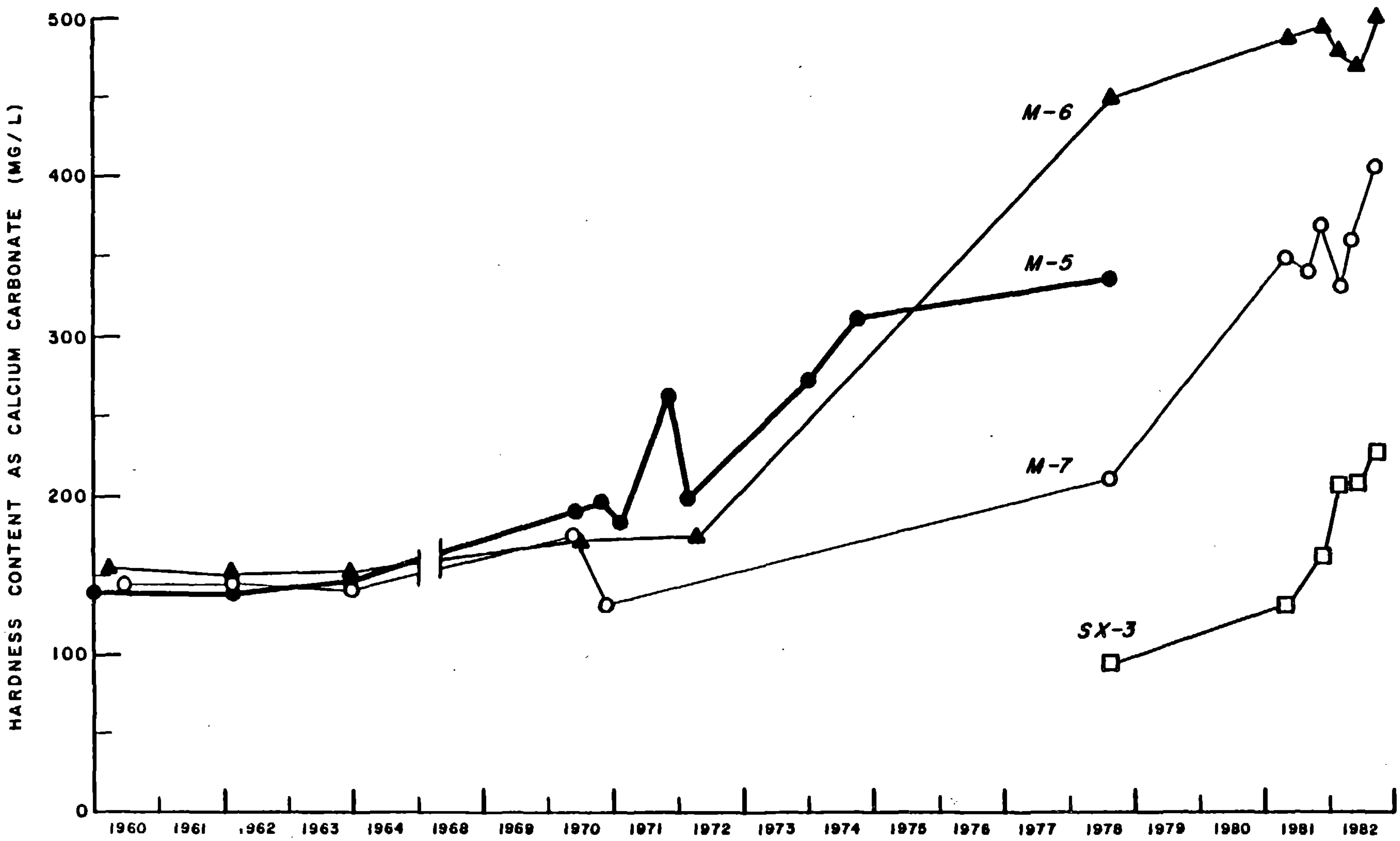


FIGURE 11.- HARDNESS CONTENTS FOR WELLS NEAR MINE A PONDS

Pima Association of Governments & K. D. Schmidt, 1983

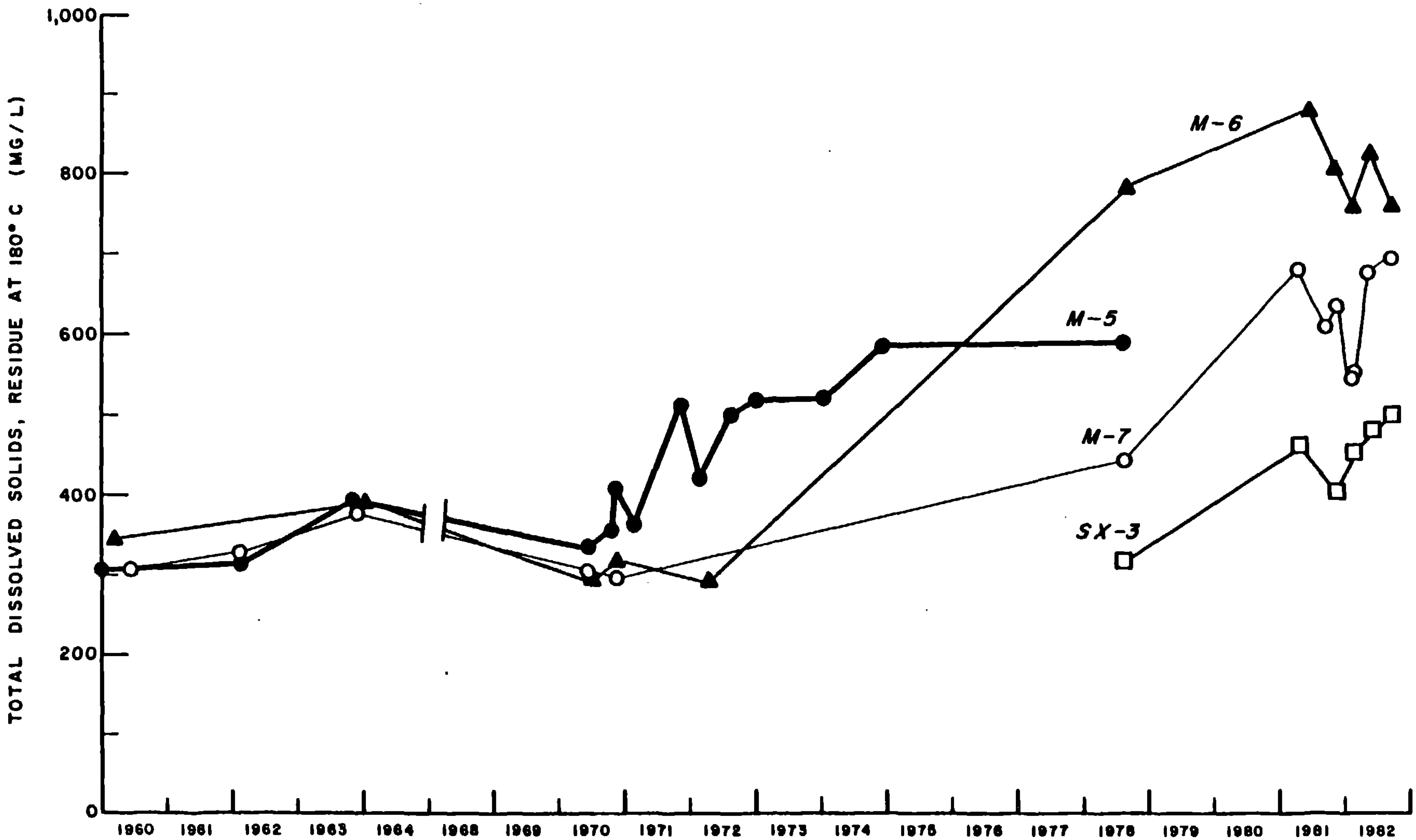


FIGURE 12. - TOTAL DISSOLVED SOLIDS CONTENTS FOR WELLS NEAR MINE A PONDS

Pima Association of Governments & K. D. Schmidt, 1983

present in some irrigation wells to the east that have not been influenced by tailings pond recharge. More extensive regional water-quality information is included in the report, "Region Wide Ground Water Quality in the Upper Santa Cruz Basin Mines Task Force Study Area," prepared by the Upper Santa Cruz Basin Mines Task Force and Pima Association of Governments (1983).

Water-quality hydrographs for the two monitor wells were prepared, but are not shown. This is because the sampling frequency for the City monitor well has not been adequate to determine long-term trends in chemical quality. Because the BIA monitor well is relatively new, records are not available for an adequate time to determine trends. Water-quality hydrographs for wells apparently unaffected by tailings pond recharge (M-8, M-10, M-11, SX-1, and SX-2) show no significant long-term changes in sulfate, hardness, or total dissolved solids contents.

The trilinear diagram constitutes a useful tool in water-analysis interpretation. Applications of the diagram pointed out by Piper (1944) include testing groups of water analyses to determine whether a particular water may be a simple mixture of others for which analyses are available or whether it is affected by solution or precipitation of a single salt. It can easily be shown that the analysis of any mixture of water A and B will plot on the straight line AB in the plotting field (where points A and B are for the analysis of the two components) if the ions do not react chemically as a result of mixing.

In evaluating sources of ground-water pollution, the anion field has proved to be extremely useful. This is because cation exchange commonly occurs as wastewaters percolate to the water table. This sometimes complicates the use of the cation field to determine sources of pollution, when comparing the composition of a waste with that of an affected well. However, there seems to be little anion exchange in many situations. Thus dissolution of minerals and precipitation of salts become about the only major chemical changes to be considered in evaluating the anion field. In addition, both chloride and sulfate appear to act as conservative constituents in many hydrogeologic situations.

A trilinear diagram (Figure 13) was prepared for pond water and water from wells in the Mine A area. The results confirm the conclusions previously drawn. The plot indicates that recharged tailings pond water picks up magnesium and chloride during passage through the vadose zone and aquifer. All of the wells affected by pond recharge produce water of the sulfate type, as opposed to the bicarbonate type present in water from wells that are unaffected.

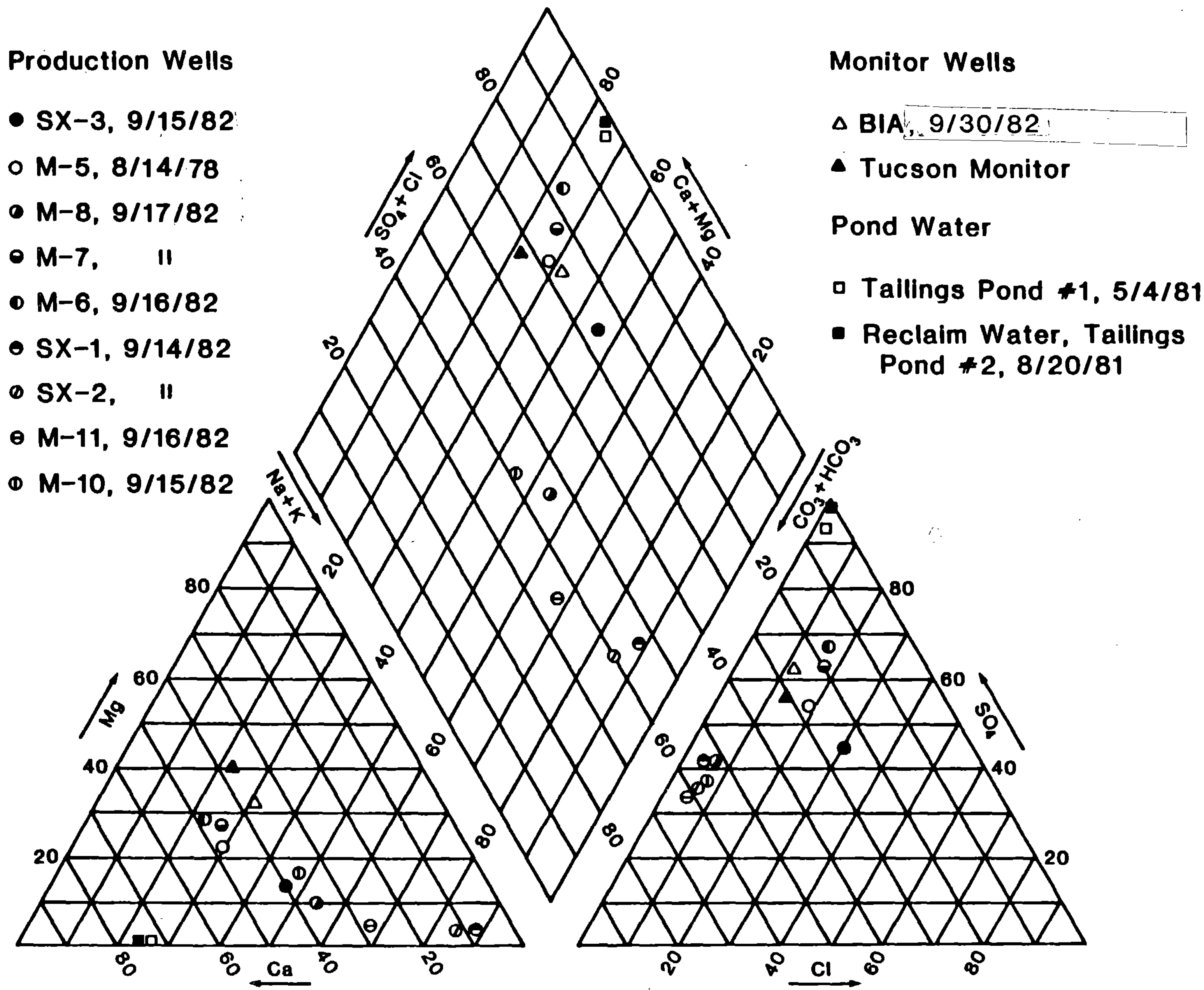


FIGURE 13. — TRILINEAR DIAGRAM OF MINE A WELL AND POND WATER QUALITY

Pima Association of Governments & K.D. Schmidt, 1982

6. Conclusions and Recommendations

Recharge of water from the Mine A tailings ponds has caused increases in sulfate and hardness contents in water from wells in the western part of the Mine A well field. Presently available information indicates that pumpage in the Mine A and Mine C well fields is controlling a substantial portion and probably all of this recharge. As long as Mine A mine-supply wells continue to be pumped, it appears that there is little threat to the quality of water pumped from other wells. A new monitor well is being installed by the BIA that will provide more information on the direction of ground-water flow and ground-water quality downgradient from the ponds. However, in order to provide additional protection for City of Tucson public-supply wells northeast of the ponds (such as SC-5, SC-12, and SC-13), several additional monitor wells should be installed in sections 14 and 23 of T16S/R13E, north of the San Xavier wells.

D. Mine B Study Area

1. Hydrogeologic Conditions

Ground-water conditions in the Mine B study area were discussed in a draft report (Hargis and Montgomery, 1982). They indicated that hydrologic bedrock has been encountered east of the tailings ponds at a depth of about 800 feet. Most of the saturated alluvium beneath the tailings ponds is part of the Tinaja Beds, as the Fort Lowell Formation appears to be above the water level as of 1981.

Figure 14 shows the location of drill holes, public-supply wells, mine-supply wells, domestic wells, irrigation wells, and unused wells near and east of the Mine B tailings ponds. Two public-supply wells are present near a small community east, and within 1 mile of pond no. 3. In addition, one more public-supply well (Old New Pueblo) is located about 1 mile east of pond no. 3. A domestic well is also present at the Air Force facility east of pond no. 2. Numerous irrigation wells and some domestic wells and mine supply wells are located farther to the east along the flood plain of the Santa Cruz River. Depth to water beneath the east edge of the ponds was about 430 feet in 1981 (Hargis and Montgomery, 1982, Table 1). Water levels in Drill Hole P-1225 declined almost 80 feet between 1970 and 1981, or at a rate averaging about 7 feet per year.

Figure 15 shows water-level elevation contours for the period December 1980-February 1981. Water-level elevations exceeded 2,550 feet above mean sea level beneath the tailing ponds, and were less than 2,525 feet northeast of pond no. 3. The direction of ground-water movement beneath the east edge of pond no. 2 is to the northeast toward Santo Tomas well no. 6. The direction of ground-

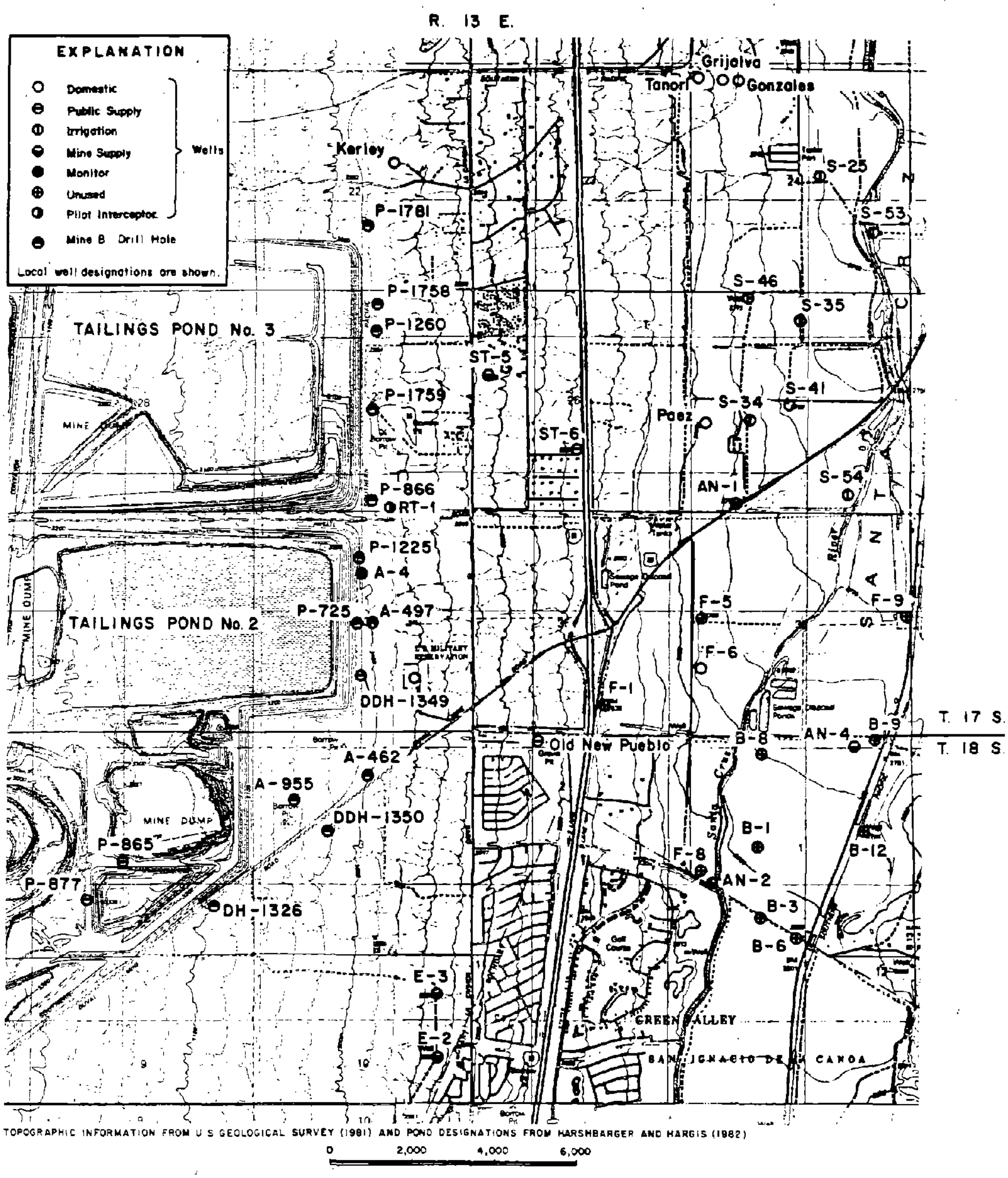


FIGURE 14. - LOCATION OF WELLS AND DRILL HOLES IN THE VICINITY OF THE MINE B PONDS

Pima Association of Governments & K.D.Schmidt, 1983

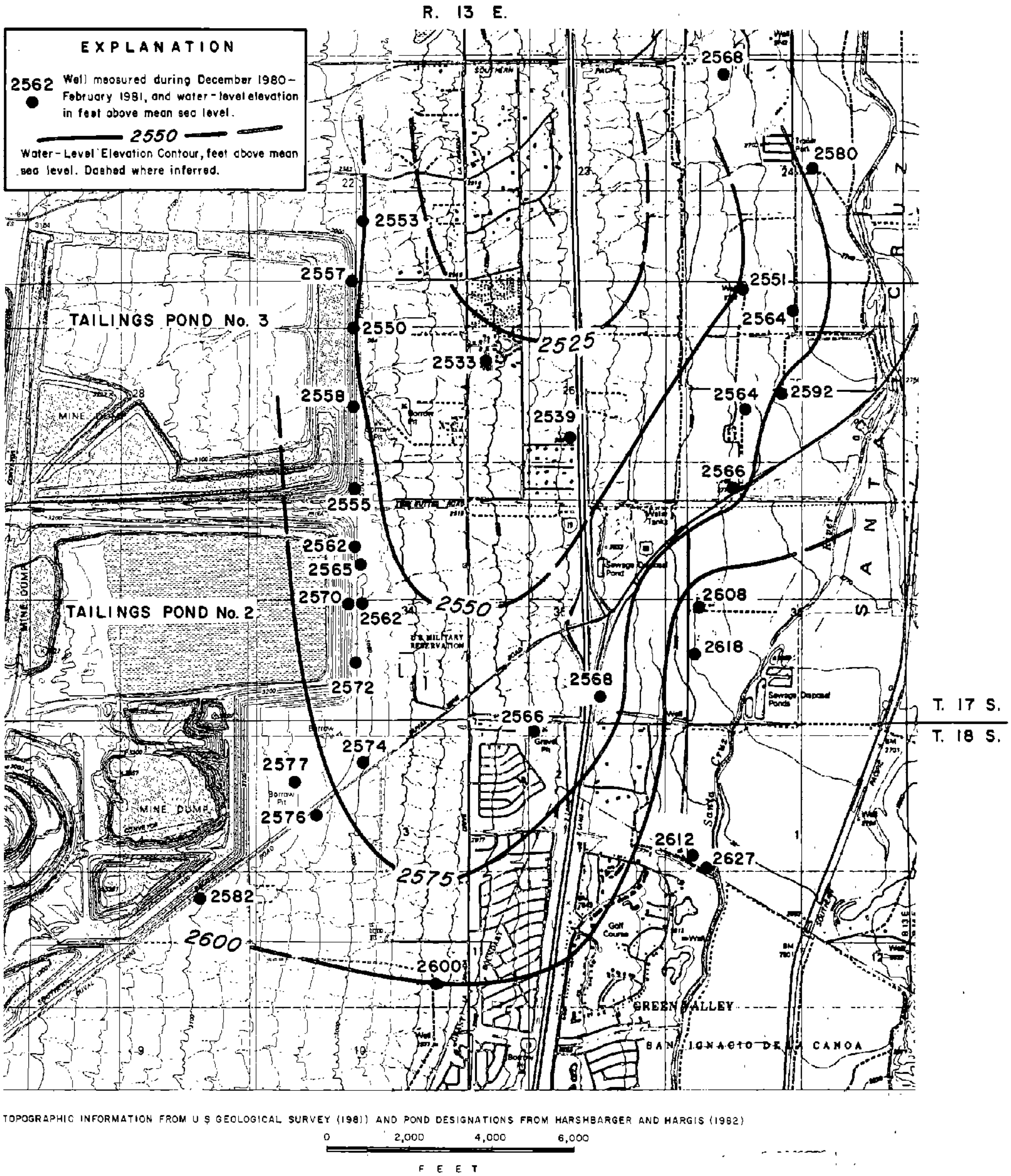


FIGURE 15.— WATER-LEVEL ELEVATIONS IN THE VICINITY OF THE MINE B PONDS (1980-81)

Pima Association of Governments & K. D. Schmidt, 1983

water movement beneath pond no. 3 appears to be easterly toward the community of Santo Tomas. The slope of the water table averages about 60 feet per mile in the vicinity of the Mine B tailings ponds. Recharge from the ponds would thus tend to move northeast toward Santo Tomas, and thence northerly.

2. Amounts of Pumpage and Pond Recharge

Information on pumpage and recharge from tailings ponds is on file with the Arizona Department of Water Resources in Phoenix. Pumpage from the Mine B mine-supply wells commenced in 1966. Annual pumpage from three wells was about 8,900 acre-feet in 1970. Annual pumpage from the mine-supply wells ranged from about 5,500 to 11,900 acre-feet during 1970-80. The average annual pumpage during this period was about 8,800 acre-feet. Recharge from the Mine B tailings ponds is estimated to have been about 3,200 acre-feet in 1979. Since 1976, some ground water pumped near the Twin Buttes pit has apparently also been largely disposed to the tailings ponds, but this is not included in the previous values. In 1979 and 1980, the volume of this ground water was slightly greater than the pumpage from the mine-supply wells.

Pumpage from the Mine B mine-supply wells is derived from relatively deep alluvial deposits beneath the flood plain of the Santa Cruz River. Only one of these wells (no. 3) is downgradient of the ponds. However, this well is presently far beyond the influence of recharge from the Mine B ponds. Thus, the mine-supply wells at Mine B cannot be expected to control the movement of recharge from the tailings ponds, as is occurring at Mine A. Total recharge from the tailings ponds (exclusive of water from the pit vicinity) since 1969 has probably been in the range of about 45,000 to 60,000 acre-feet (Travers, 1983).

3. Quality of Tailings Pond Water

Water from the Mine B tailings pond has not been sampled as part of the Mines Special Studies Program. However, limited data are available (Engineers Testing Laboratory, Inc., 1973). Table 3 contains chemical analyses of water collected from Mine B pond no. 2 in the early 1970's. The water was generally of the calcium-sodium sulfate type, with total dissolved solids contents ranging from about 900 to 1,100 mg/l. Sulfate contents ranged from about 500 to 700 mg/l, and hardness as calcium carbonate ranged from about 350 to 400 mg/l. Sulfate and total dissolved solids contents of water in the Mine B pond thus were only about one-third of those for water in the Mine A ponds.

TABLE 3. - CHEMICAL QUALITY OF WATER
IN MINE B POND NO. 2

Constituent (mg/l)	6/14/71	7/26/71	9/10/71
Calcium	153	130	137
Magnesium	<1	9	4
Sodium	118	193	191
Carbonate	<1	<1	<1
Bicarbonate	26	54	49
Sulfate	513	677	615
Chloride	54	22	42
Nitrate	1	1	1
Flouride	3.0	1.4	0.7
Molybdenum	6.3	5.8	4.6
pH	6.15	6.75	8.20
Total Dissolved Solids	883	1,094	1,044
Total Hardness ($CaCO_3$)	385	365	356

Analyses from Engineers Testing Laboratories, Inc. (1973).
Analyses by ETL of Phoenix.

4. Ground-Water Quality

Maps have been prepared for sulfate, hardness, and total dissolved solids contents in water from wells in the vicinity of the Mine B ponds that were sampled during Summer 1982 (Figures 16, 17, and 18). Because of a paucity of data points, particularly where high contents are present, contours were not prepared. In general, contents of these constituents were lowest to the west of the Santa Cruz River flood plain, except at Drill Hole P-1225 which is adjacent to the northeast edge of pond no. 2. Sulfate and total dissolved solids contents in water from P-1225 were almost identical, in Summer 1982, to average levels in the pond water. Drill Hole P-1225 was 650 feet deep, and perforated from 415 to 630 feet in depth (Hargis and Montgomery, 1982). Sulfate contents in water from two drill holes immediately east of pond no. 3 were less than 40 mg/l in Summer 1982. Based on these maps alone, no other wells appear to have been impacted by recharge from the Mine B ponds. More extensive regional water-quality information is included in the report, "Region Wide Ground Water Quality in the Upper Santa Cruz Basin Mines Task Force Study Area," prepared by the Task Force and Pima Association of Governments (1983).

Water-quality hydrographs were prepared for the three drill holes immediately east and downgradient of the Mine B ponds (Figures 19, 20, and 21). Contents of these constituents in water from Drill Hole P-1225 were relatively constant from 1970 to 1979, but increased substantially thereafter. Within a period of several years, sulfate contents in water from P-1225 increased from less than 50 to more than 500 mg/l. There were also substantial increases in hardness and total dissolved solids contents. Water from P-1758 has had rather constant sulfate, hardness, and total dissolved solids contents since sampling commenced in 1978. There were significant increases in constituent levels in water from P-1759 in about 1979. However, levels had rapidly declined by 1981, virtually back to background levels. The decreases may be partly due to the disposal of large volumes of ground water pumped from near the Twin Buttes pit after 1978.

Water-quality hydrographs were prepared for sulfate and hardness content in water from Santo Tomas wells nos. 5 and 6 (Figure 22). Sulfate and hardness contents in water from well no. 6 fluctuated and slightly decreased from 1971 through 1982. On the other hand, contents of these two constituents in water from well no. 5 apparently remained fairly constant between 1970 and 1979. However, there were significant increases in sulfate and hardness contents during 1980-82 in water from this well. Hardness content in water from Santo Tomas well no. 5 had increased to more than 170 mg/l in 1982, compared to less than 80 mg/l in 1970. These results suggest that water from Santo Tomas well no. 5 is also beginning to be affected by recharge from the Mine B tailings ponds.

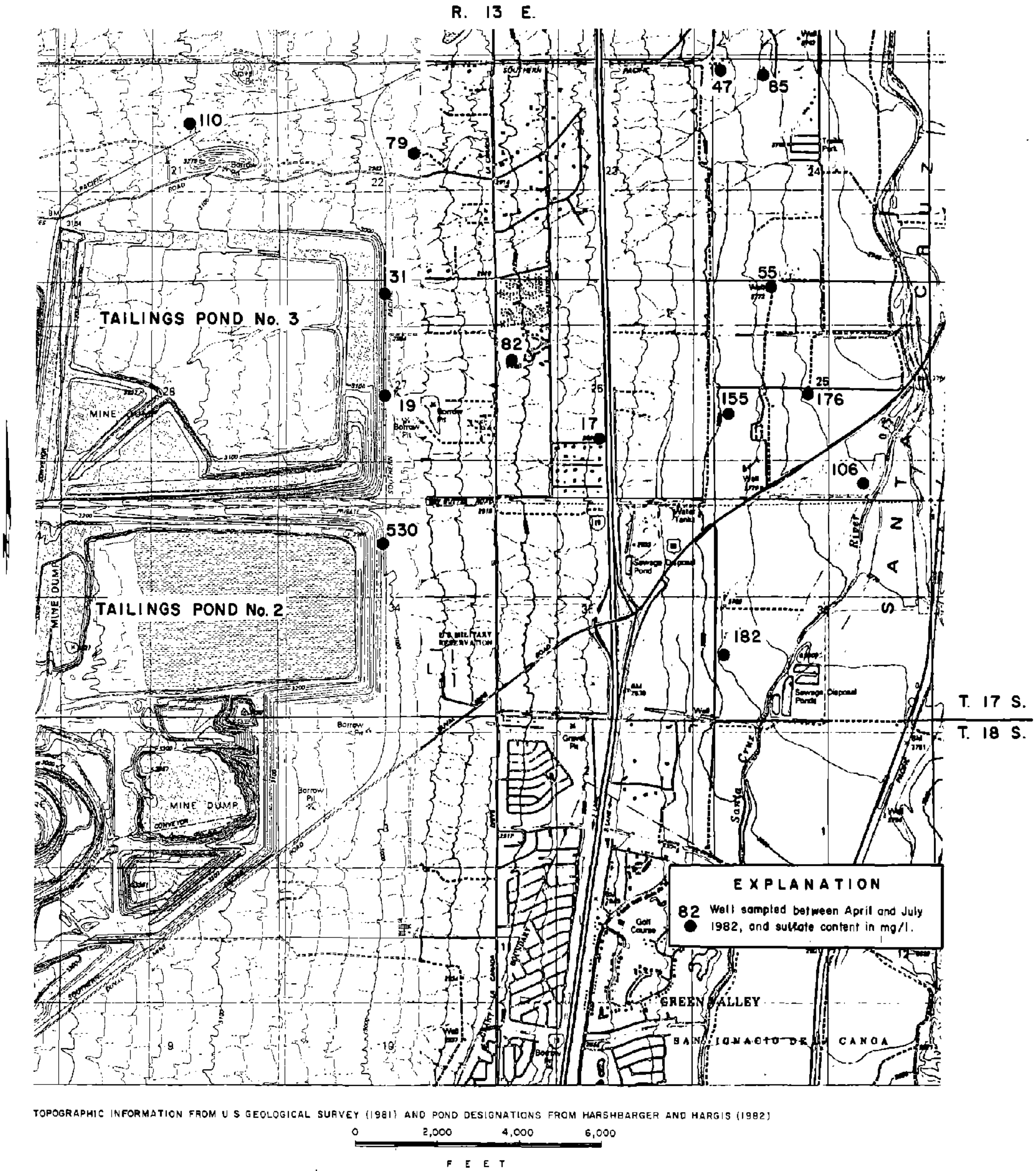
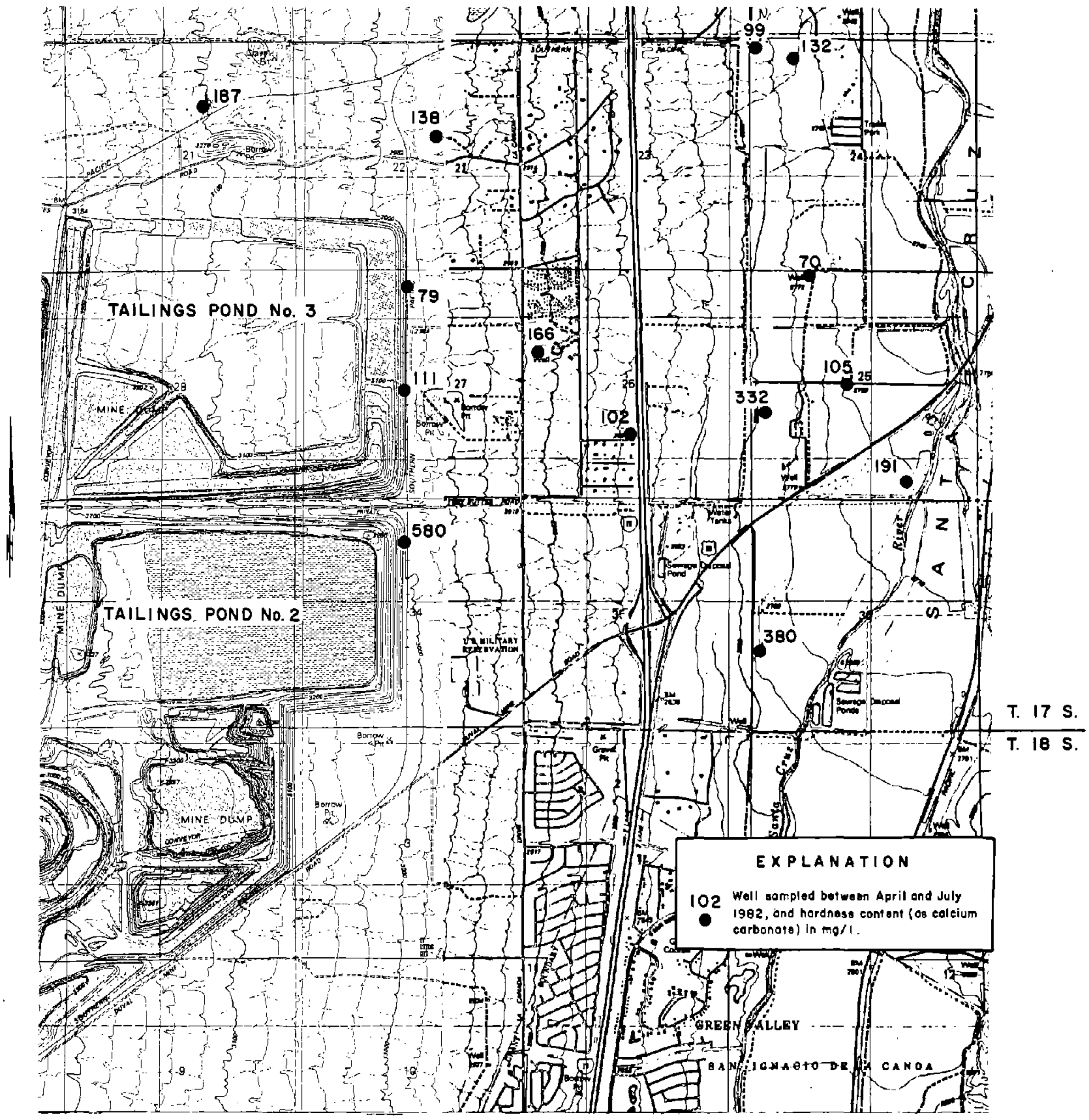


FIGURE 16. – SULFATE CONTENT IN WATER FROM WELLS IN THE VICINITY OF THE MINE B PONDS (SUMMER 1982)

Pima Association of Governments & K. D. Schmidt, 1983



TOPOGRAPHIC INFORMATION FROM U S GEOLOGICAL SURVEY (1981) AND POND DESIGNATIONS FROM HARSHBARGER AND HARGIS (1982)

0 2,000 4,000 6,000 FEET

FIGURE 17. – HARDNESS CONTENT IN WATER FROM WELLS IN THE VICINITY OF THE MINE B PONDS (SUMMER 1982)

Pima Association of Governments & K. D. Schmidt, 1983

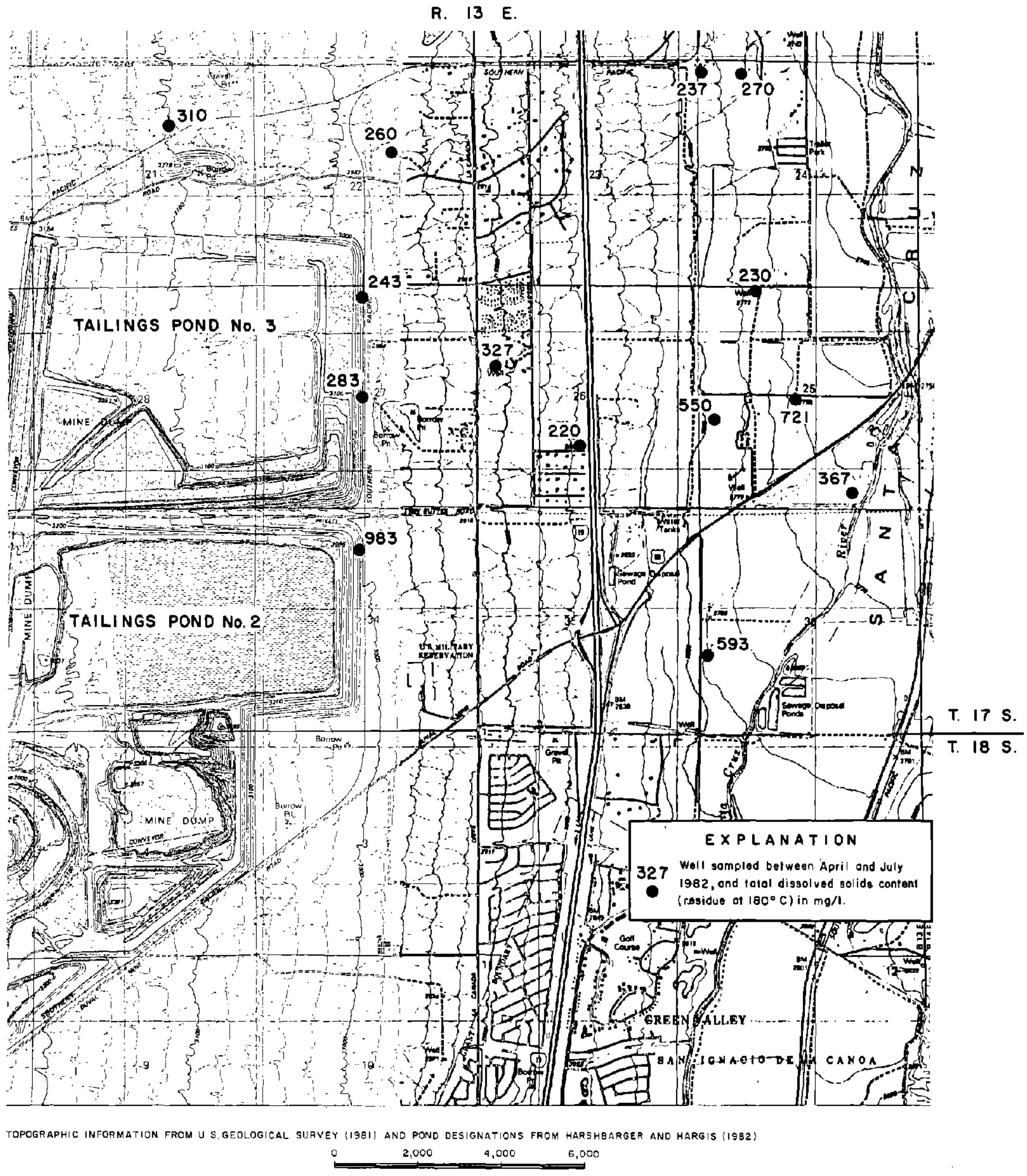


FIGURE 18. – TOTAL DISSOLVED SOLIDS CONTENT IN WATER FROM WELLS IN THE VICINITY OF THE MINE B PONDS (SUMMER 1982)

Pima Association of Governments & K. D. Schmidt, 1983

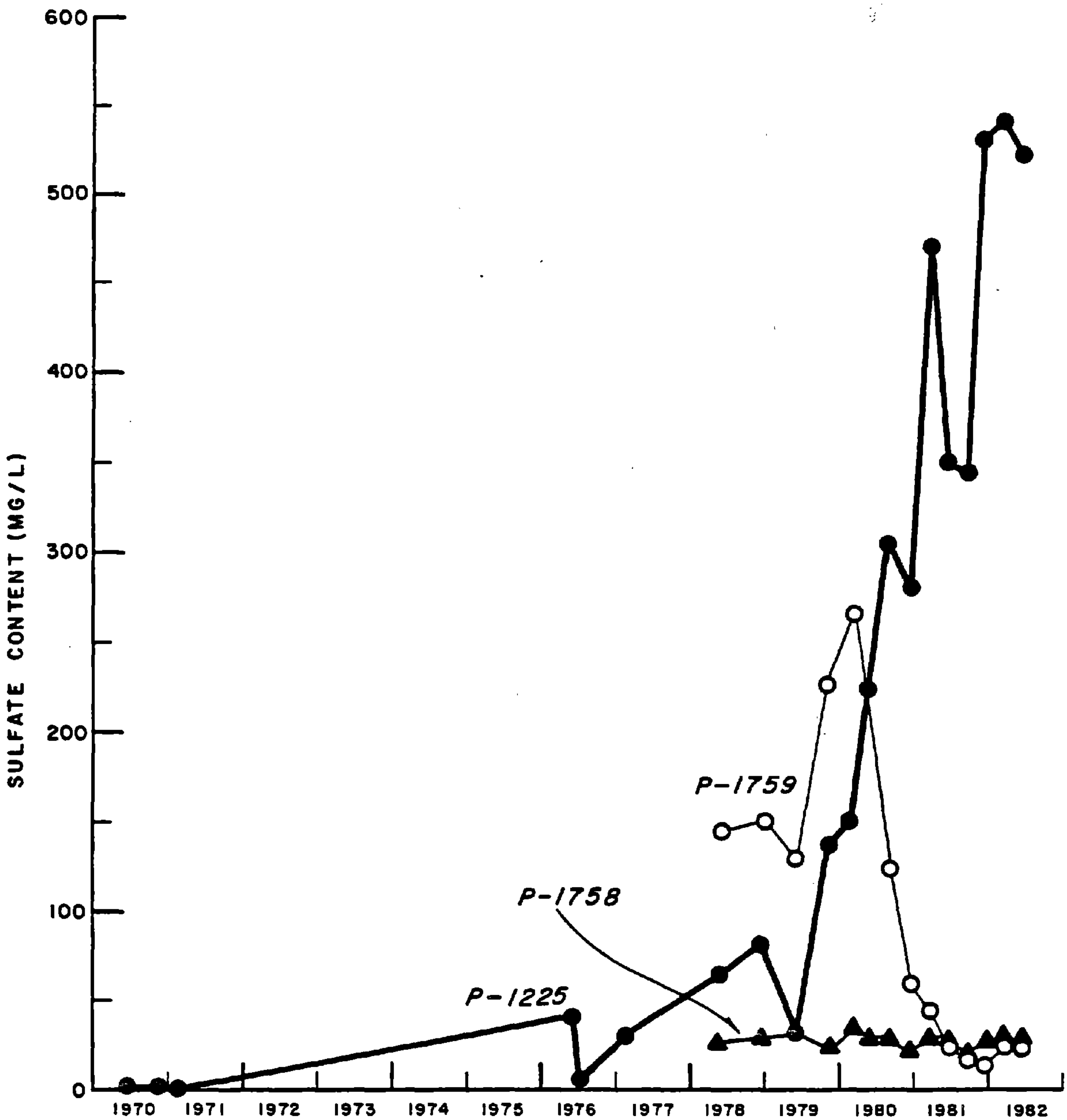


FIGURE 19. - SULFATE CONTENTS

FOR DRILL HOLES NEAR MINE B PONDS

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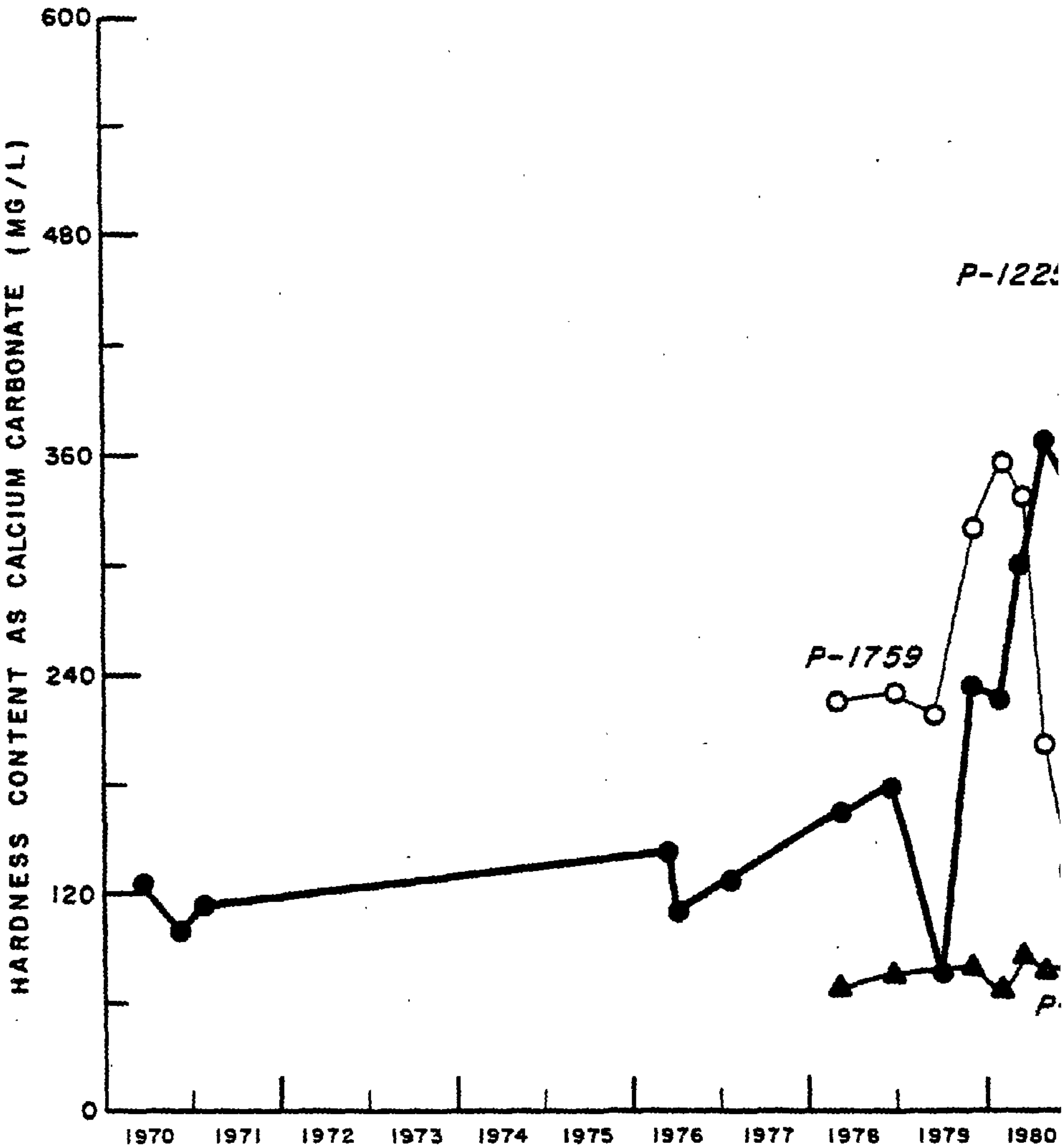

FIGURE 20. - HARDNESS CONTENTS FOR DRILL HOLES NEAR MINE B PONDS

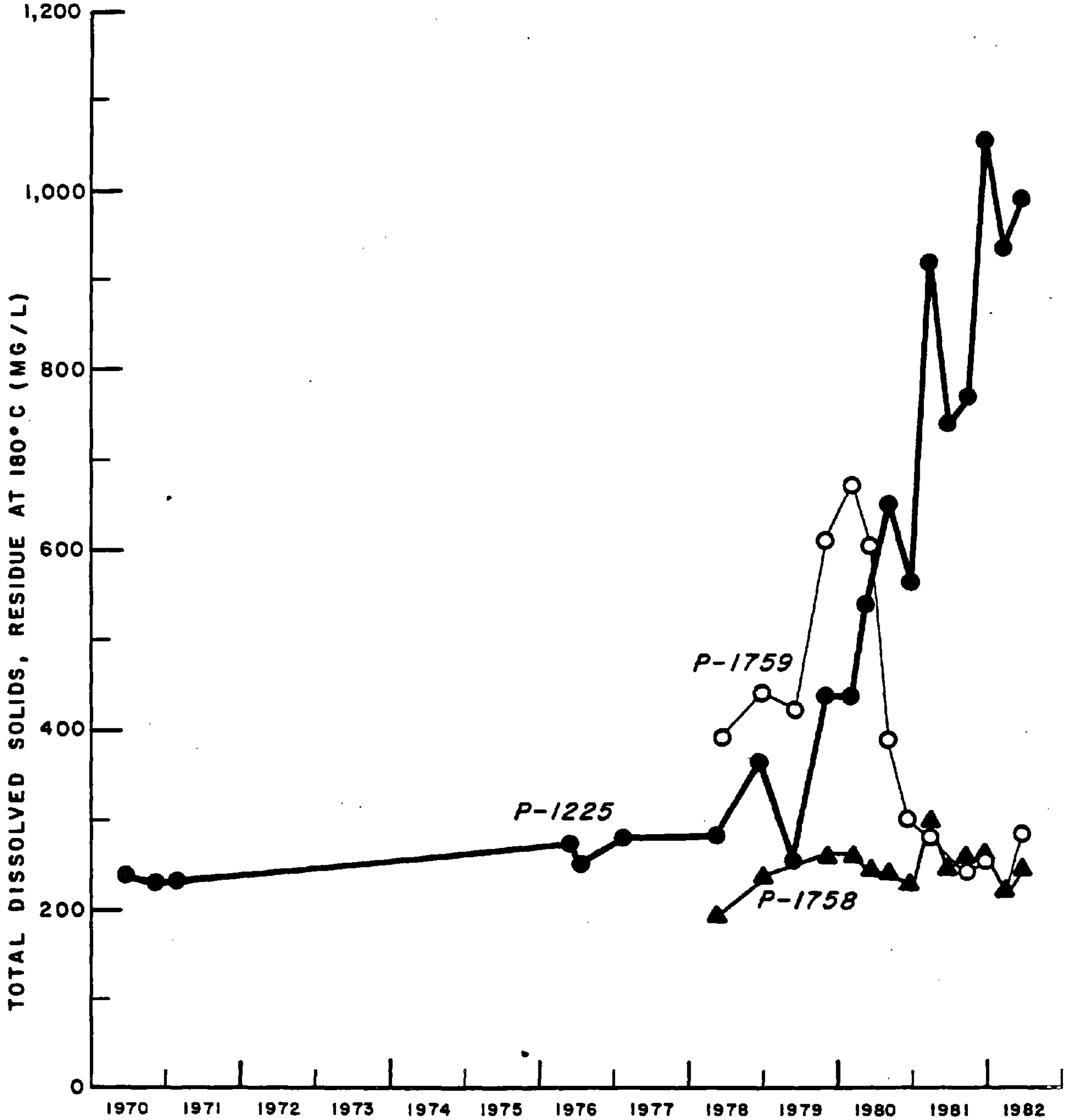

FIGURE 21. - TOTAL DISSOLVED SOLIDS CONTENTS FOR DRILL HOLES NEAR MINE B PONDS

Pima Association of Governments & K.D. Schmidt, 1983

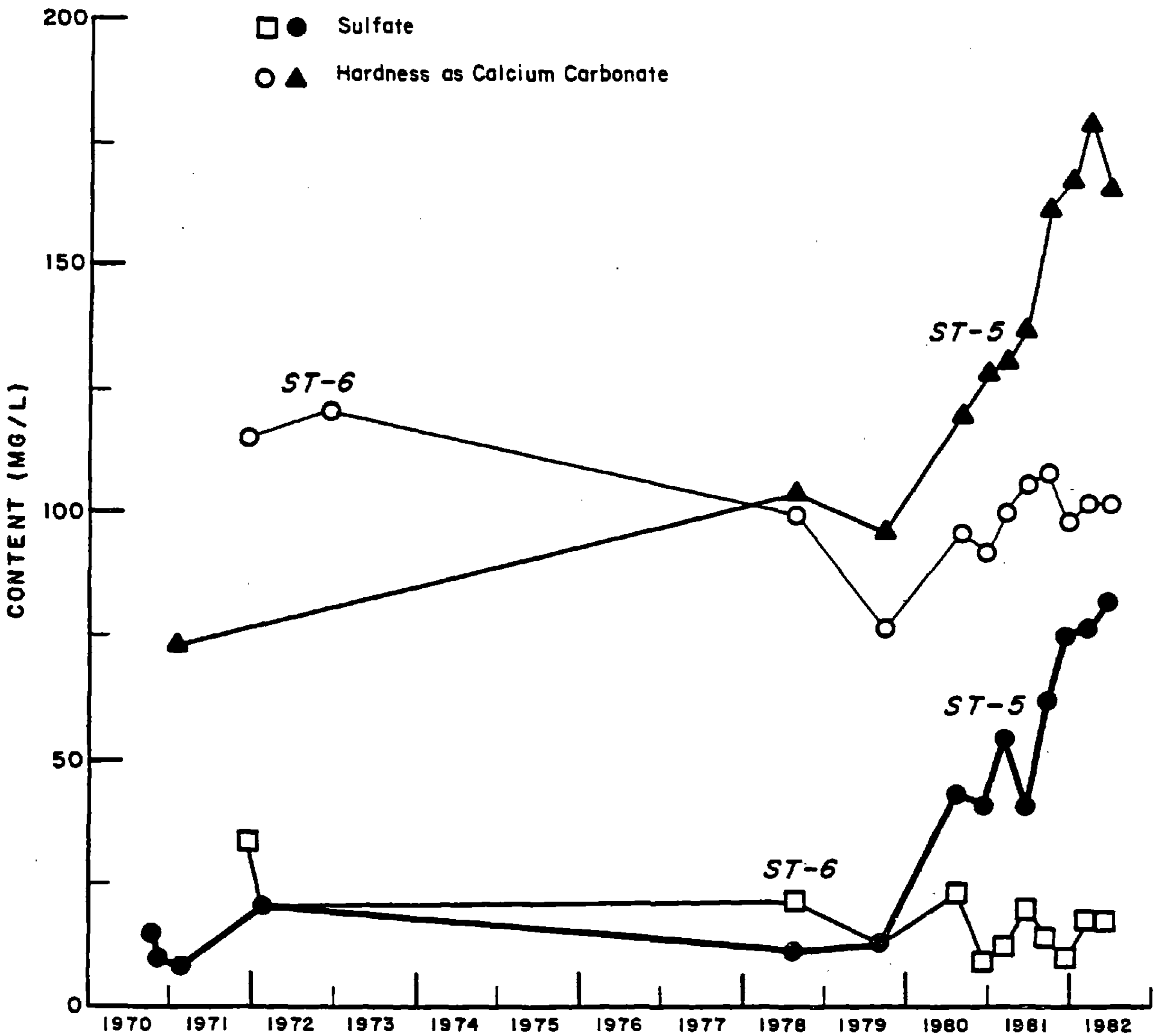

FIGURE 22. - SULFATE AND HARDNESS CONTENTS FOR SANTO TOMAS WELLS

A trilinear diagram (Figure 23) was prepared for pond water, water from two Santo Tomas wells, and water from the three drill holes east of the tailings ponds that have been regularly sampled. Water from the P-1225 plot is almost identical to pond water in the anion field, confirming that water in this drill hole is derived almost entirely from pond recharge. Results of a sample collected from P-1759 in March 1980, when sulfate contents were high, indicated, from the anion plot, that this drill hole was also influenced by tailings pond recharge at that time.

A pilot interceptor reclamation well (RT-1) was installed east of the ponds and pump tested. This well is in T17S, R13E, 27dcc and is 18 inches in diameter, 975 feet deep, and perforated from 415 to 975 feet. Planned withdrawals from this well are 3,500 acre-feet/year (Arizona Department of Water Resources, 1983). However, no results of water-quality sampling have been provided for the Mines Special Studies Program.

5. Conclusions and Recommendations

Recharge of water from Mine B tailings pond no. 2 has caused increases in hardness and sulfate contents in water from Drill Hole P-1225. Sulfate content in water from P-1225 exceeded 500 mg/l, more than double the recommended level for drinking water, in Summer 1982. It appears that pond recharge has also affected water from a downgradient public-supply well (Santo Tomas no. 5). Mine-supply wells are located too distant from the Mine B ponds to control the movement of recharged pond water.

Further efforts should be made to define the plume of degraded ground water downgradient of the Mine B ponds. Monitor wells should be installed, or drill holes sampled, farther east of the ponds than the three drill holes now presently sampled to accomplish this. In addition, interceptor well pumpage may be advisable in the area upgradient of the two public-supply wells. Also, the trace organic chemical composition of water from P-1225 should be determined, specifically with reference to flotation agents used in the milling process. Additionally, pond sampling for inorganic and organic constituents should be initiated and/or data obtained.

E. Mine D Study Area

1. Hydrogeologic Conditions

Subsurface Geology

Mine D provided geologic and gamma-neutron logs for numerous wells in the vicinity of the Sierrita pond. In addition, a map of the hydrologic bedrock topography was also provided. A series of monitor wells and interceptor wells have been installed along the eastern and southern boundaries of the Sierrita tailings pond. In

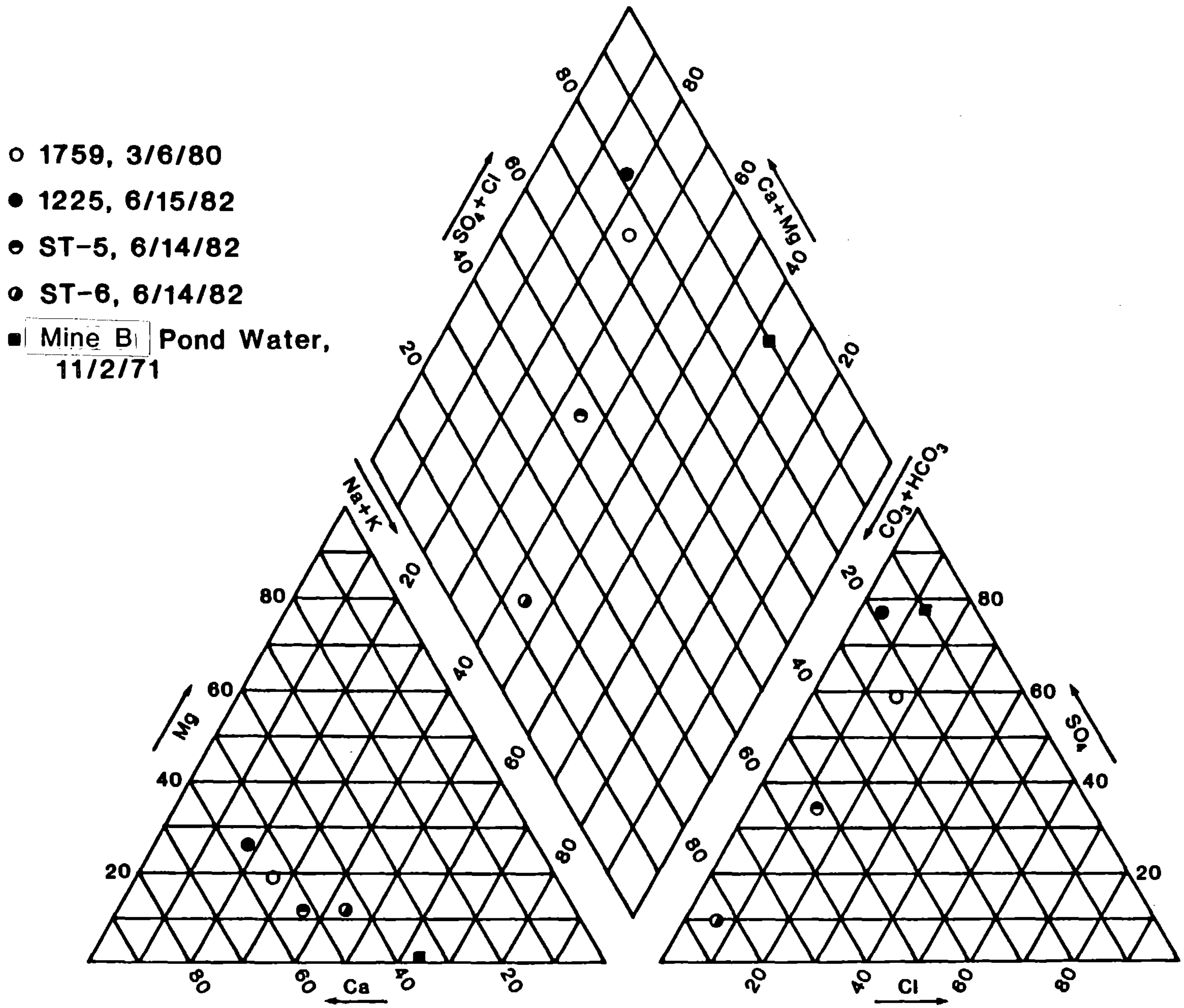

FIGURE 23. —TRILINEAR DIAGRAM OF MINE B WELL AND POND WATER QUALITY

Pima Association of Governments & K.D. Schmidt, 1982

addition, three monitor wells were installed about 1 mile east of the northeast part of the pond. There are now seven interceptor wells and thirteen monitor wells in the network (Figure 24). Information from these wells, plus drill holes and other nearby wells, was used to prepare the bedrock topography map.

Hydrologic bedrock in the vicinity has been described as limestone or volcanics. The top of this unit slopes to the east beneath the north part of the Sierrita pond and to the southeast beneath the south part. The slope is generally about 300 feet per mile beneath the central and western parts of the pond. However, near the eastern edge of the pond, the slope steepens significantly, and in some cases exceeds 2,000 feet per mile. The top of the hydrologic bedrock is about 500 feet deep beneath the northeast corner of the pond and slightly more than 1,000 feet deep beneath the southeast corner. The bedrock topography map indicates the presence of two troughs suggestive of stream erosion of the bedrock surface. One is present near the south edge of the pond and one is present beneath the northern part of the pond.

Figure 24 shows the location of two subsurface geologic cross sections prepared as part of this study. Cross Section A-A' extends from north to south along the east edge of the pond. Cross Section B-B' extends from near the central part of the east edge of the pond easterly to Green Valley.

Figure 25 shows subsurface geologic conditions along Section A-A'. The characteristics of the various subsurface geologic units were discussed in more detail by Schmidt (1982) in a report on the Nitrate Study Area, which lies to the east of the Mine D study area. The top of the hydrologic bedrock slopes to the south along this section. In addition, rocks of the Pantano Formation, or equivalent, apparently overlie the bedrock, and thicken to the south. The Pantano Formation appears to be less than 100 feet thick near the northeast corner of the tailings pond, and may be correlated with the caliche conglomerate at the Twin Buttes pit (Hargis and Montgomery, 1982). Near the southeast corner of the Sierrita pond, this unit appears to be about 200 to 300 feet thick. Deposits of the Tinaja Beds overlie the Pantano Formation and are difficult to distinguish in this area from deposits of the overlying Fort Lowell Formation. In Spring 1982, the water level was near the base of the Tinaja Beds beneath the northeast corner of the pond. However, about 350 feet of this unit appeared to be saturated near the southeast corner of the pond. The Fort Lowell Formation appeared to be above the water level along this section in 1982, except near the south end.

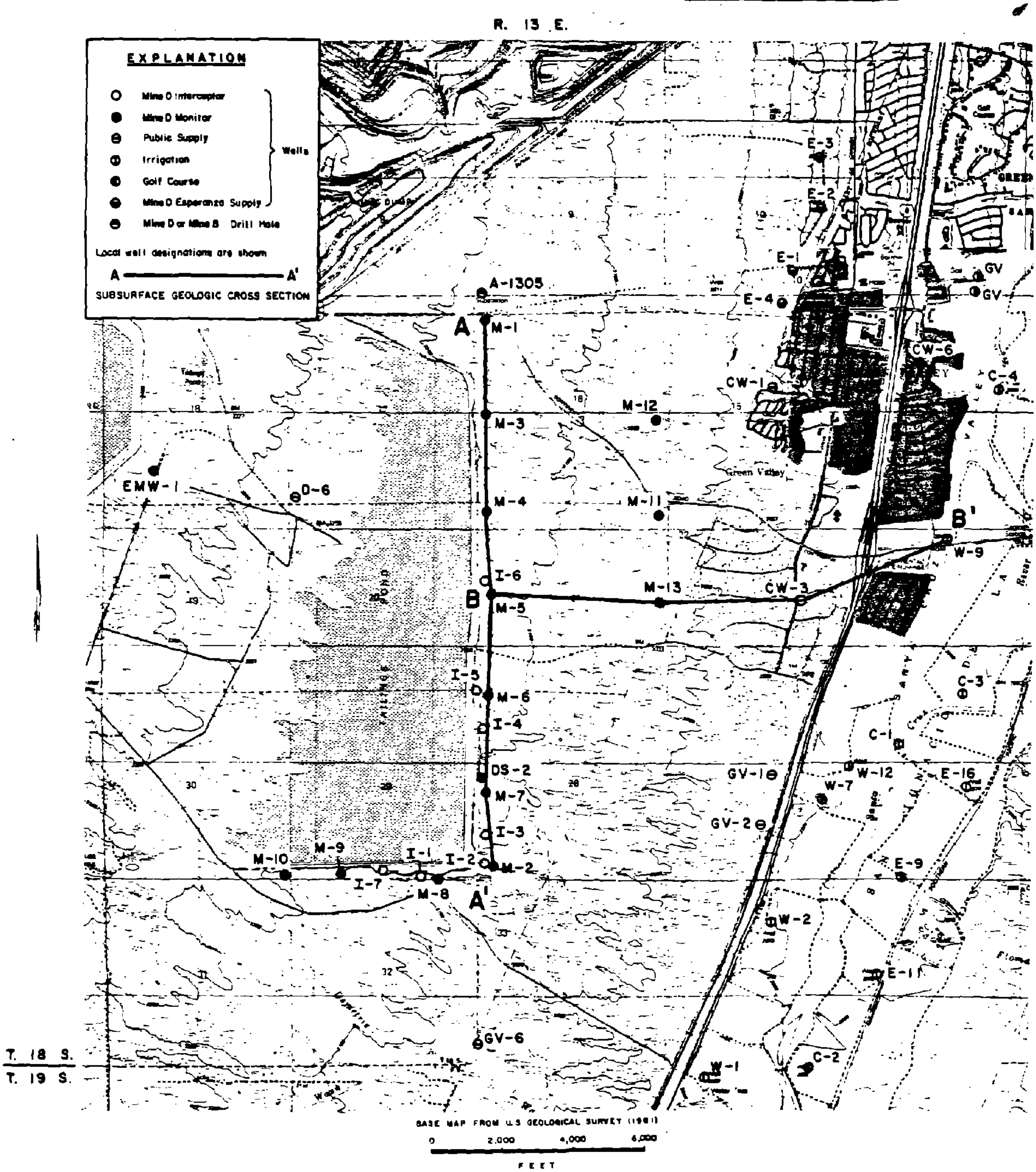

FIGURE 24. - LOCATION OF WELLS, DRILL HOLES AND SUBSURFACE GEOLOGIC CROSS SECTIONS IN THE VICINITY OF THE MINE D SIERRITA POND

Pima Association of Governments & K.D. Schmidt, 1983

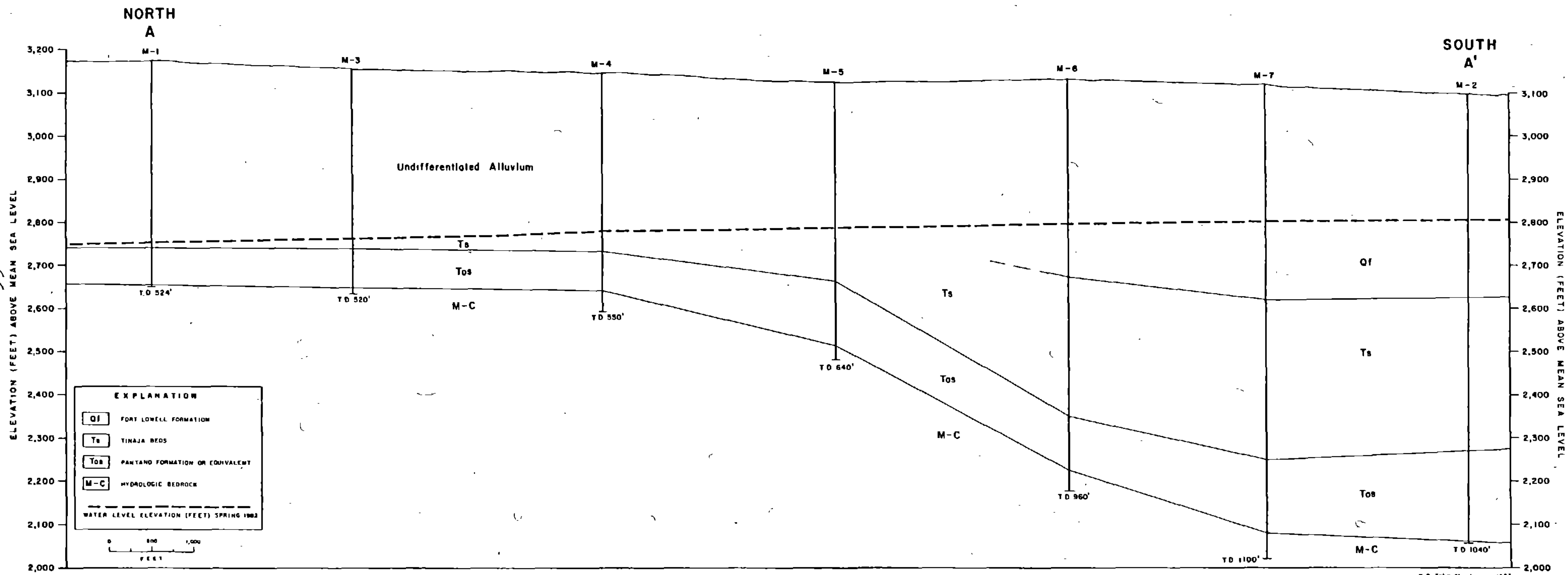

FIGURE 25.- SUBSURFACE GEOLOGIC CROSS SECTION A-A'

Figure 26 shows subsurface geologic conditions along Section B-B', which is oriented from west to east. The top of the hydrologic bedrock slopes steeply to the east along this section. The top of the hydrologic bedrock is about 600 feet below land surface near the pond, but more than 1,400 feet deep only 1 mile to the east at M-13. None of the wells along the flood plain of the Santa Cruz River south of Continental are known to have penetrated the hydrologic bedrock. However, based on deep wells farther to the north, the top of this unit is believed to be almost 2,000 feet deep near FICO well W-9. The Pantano Formation is between 100 and 200 feet thick near the east edge of the pond, and probably more than 700 feet thick near the Santa Cruz River. Slightly more than 100 feet of the Tinaja Beds were saturated near the pond along this section in Spring 1982. Near the Santa Cruz River, the water level was just above the top of the Fort Lowell Formation in Spring 1982.

Interceptor and Monitor Wells

The Mine D interceptor and monitor wells generally extend to the top of the hydrologic bedrock. Table 4 includes construction data for the 13 monitor wells. All are equipped with 3-inch-diameter casing and are generally perforated opposite all of the saturated alluvium. The first nine of these wells were drilled between November 1975 and July 1976, and the last four were drilled in February 1977. Table 5 contains construction data for the seven interceptor wells. The first four interceptor wells were installed during May-July 1978, and were located near the southeast part of the Sierrita tailings pond. Three of these wells are equipped with 14-inch-diameter casing and were drilled by the reverse rotary method and gravel-packed. The fourth was drilled by the cable-tool method and equipped with 16-inch-diameter casing to a depth of 700 feet and smaller-diameter casing below. These wells are generally perforated opposite all of the saturated alluvium. In addition, many had perforations above the water level as of Spring 1982.

Interceptor Well Pumpage

Pumpage of the first four interceptor wells (I-1 through I-4) commenced in April 1979. Pumpage of well I-5 commenced in October 1980, and pumpage of wells I-6 and I-7 began in March 1981. Figure 27 shows monthly pumpage for each of the interceptor wells, based on records supplied by Mine D. Total monthly pumpage has usually ranged from about 380 to 540 acre-feet per month. The annual pumpage from the interceptor wells was between 5,000 and 6,000 acre-feet during 1980-81. However, in 1982, the pumpage through September had decreased to the equivalent of an annual total of about 3,800 acre-feet per year. Approximately 18,000 acre-feet of water had been pumped from the interceptor wells by the end of September 1982.

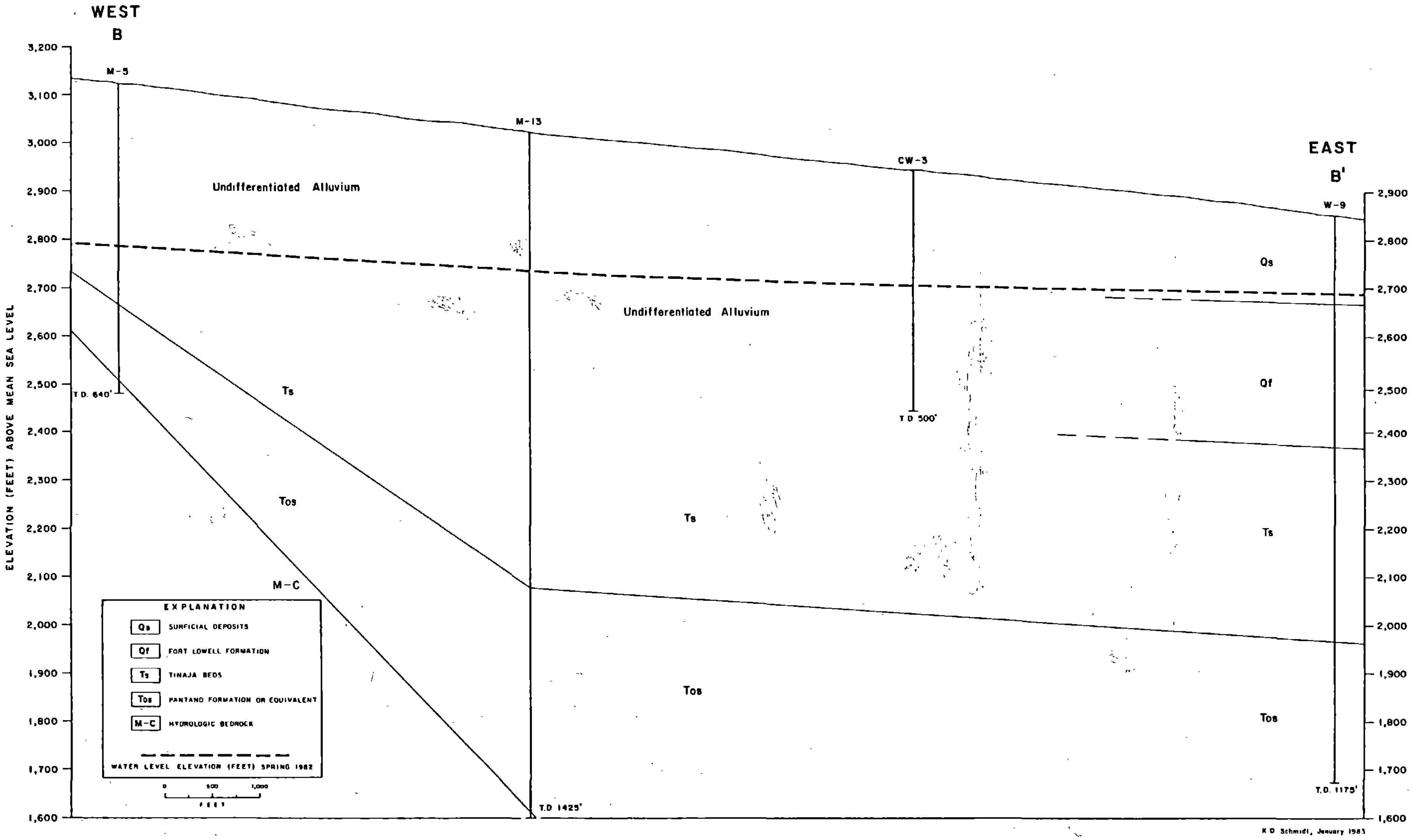

FIGURE 26. - SUBSURFACE GEOLOGIC CROSS SECTION B-B'

TABLE 4. - CONSTRUCTION DATA FOR MINE D MONITOR WELLS

Local No.	State No.	Date Drilled	Total Depth (feet)	Casing Diameter (inches)	Cased Depth (feet)	Perforated Interval (feet)
M-1	(D-18-13) 16bbb	11/75	520	3	480	420-480
M-2	28ccc	11/75	1,038	3	1,038	520-1,038
M-3	16bcc	2/76	520	3	500	400-500
M-4	21bbb	3/76	550	3	520	420-520
M-5	21bcc	3/76	640	3	640	340-640
M-6	28bbb	3/76	960	3	960	320-960
M-7	28cbb	4/76	1,100	3	1,100	300-1,100
M-8	29ddc	6/76	1,065	3	1,060	300-1,060
M-9	29cdc	7/76	1,400	3	1,365	350-1,365
M-10	30ddd	2/77	600	3		
M-11	21aab	2/77	820	3	820	300-820
M-12	16daa	2/77	800	3	800	280-800
M-13	21add	2/77	1,425	3	1,420	420-1,420

Data from drillers logs on file with Arizona Department of Water Resources, Phoenix.

TABLE 5. - CONSTRUCTION DATA FOR MINE D INTERCEPTOR WELLS

Local No.	State No.	Date Drilled	Total Depth (feet)	Casing Diameter (inches)	Cased Depth (feet)	Perforated Interval (feet)
I-1	(D-18-13) 29dcd	7/78	855	14	843	234-843
I-2	28ccc	5/78	1,035	16 12 10 8	700 930 1,011 1,035	40-1,035
I-3	28cbc	7/78	1,047	14	1,041	232-1,041
I-4	28bcb	7/78	946	14	946	334-946
I-5	21ccc	6/79	956	14	956	301-956
I-6	21bcc	6/79	489	14	489	297-489
I-7	29cdd	9/79	1,050	14	1,045	321-1,045

Data from drillers logs on file with Arizona Department of Water Resources, Phoenix.

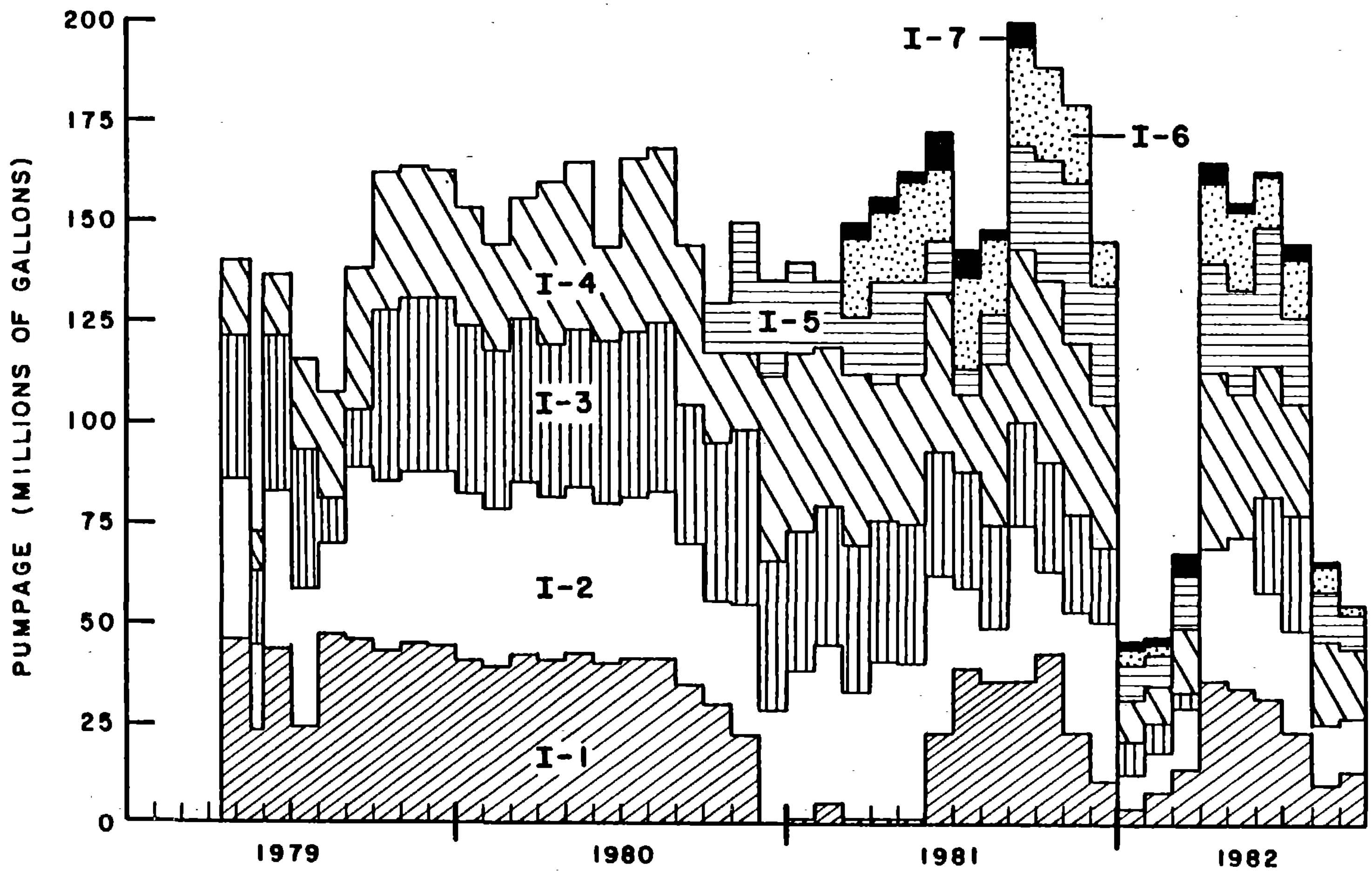

FIGURE 27. - PUMPAGE FROM MINE D INTERCEPTOR WELLS

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Water Levels

Figure 28 shows water-level elevation contours for December 1976-January 1977 in the vicinity of the Mine D Sierrita pond. This map thus shows conditions prior to commencement of pumpage from the interceptor wells. The direction of ground-water flow was generally to the northeast toward the community of Green Valley and the Mine D Esperanza well field. Water-level elevations were about 2,850 feet above mean sea level in the vicinity of the first four interceptor wells. Water-level elevations were less than 2,650 feet in the vicinity of the Esperanza well field. Beneath the south part of the pond, the hydraulic gradient exceeded 150 feet per mile. Beneath the northern part of the pond, the hydraulic gradient exceeded 200 feet per mile. Based on the 1976-77 water-level elevation contour map, several FICO irrigation wells, at least two public-supply wells at Green Valley, and the Esperanza well field appeared to be downgradient of the Sierrita tailings pond.

Depth to water in April 1979, before pumpage of the interceptor wells began, ranged from about 270 feet at M-2 and M-13 to about 420 feet at M-1. Thus, depth to water at that time along the east edge of the pond increased to the north. Depth to water also increased to the north at the three monitor wells about 1 mile east of the east edge of the pond.

Figure 29 shows water-level elevation contours for December 1981-February 1982 in the vicinity of the Sierrita pond. Better control was available for this time period than for 1976-77 because the three newest monitor wells were also measured. Pumpage of the interceptor wells has influenced some of the contours, notably those east of the south part of the pond. The direction of ground-water flow was still to the northeast; however, the hydraulic gradient had been considerably decreased. The gradient beneath the south part of the pond appeared to be less than 25 feet per mile for December 1981-February 1982. However, there was no indication of a cone of depression near the interceptor wells. Water-level elevations were about 2,800 feet above mean sea level in the vicinity of the first four interceptor wells. Water-level elevations in the Esperanza well field were generally less than 2,625 feet at this time.

Water-level hydrographs were prepared for some of the monitor wells for the period April 1979-September 1982 (Figures 30, 31, and 32). These are based on records supplied by Mine D. Hydrographs for three monitor wells in the vicinity of the first four interceptor wells are shown in Figure 30. Water levels in all of these wells have shown a noticeable response to pumpage of nearby interceptor wells. Water levels in well M-8 are highly influenced by

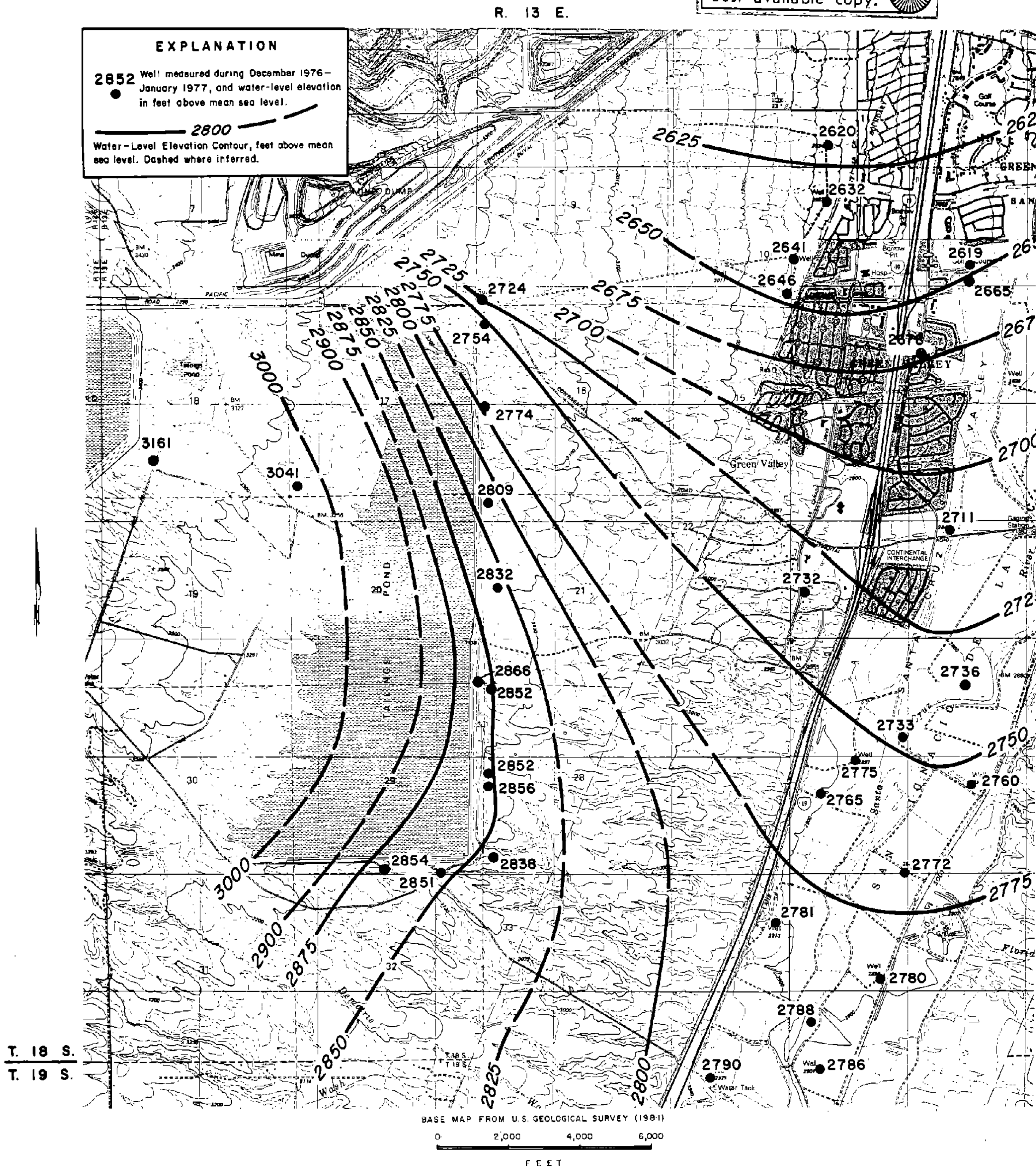

FIGURE 28. - WATER-LEVEL ELEVATIONS IN THE VICINITY OF THE MINE D SIERRITA POND (1976 — 1977)

Pima Association of Governments & K. D. Schmidt, 1983

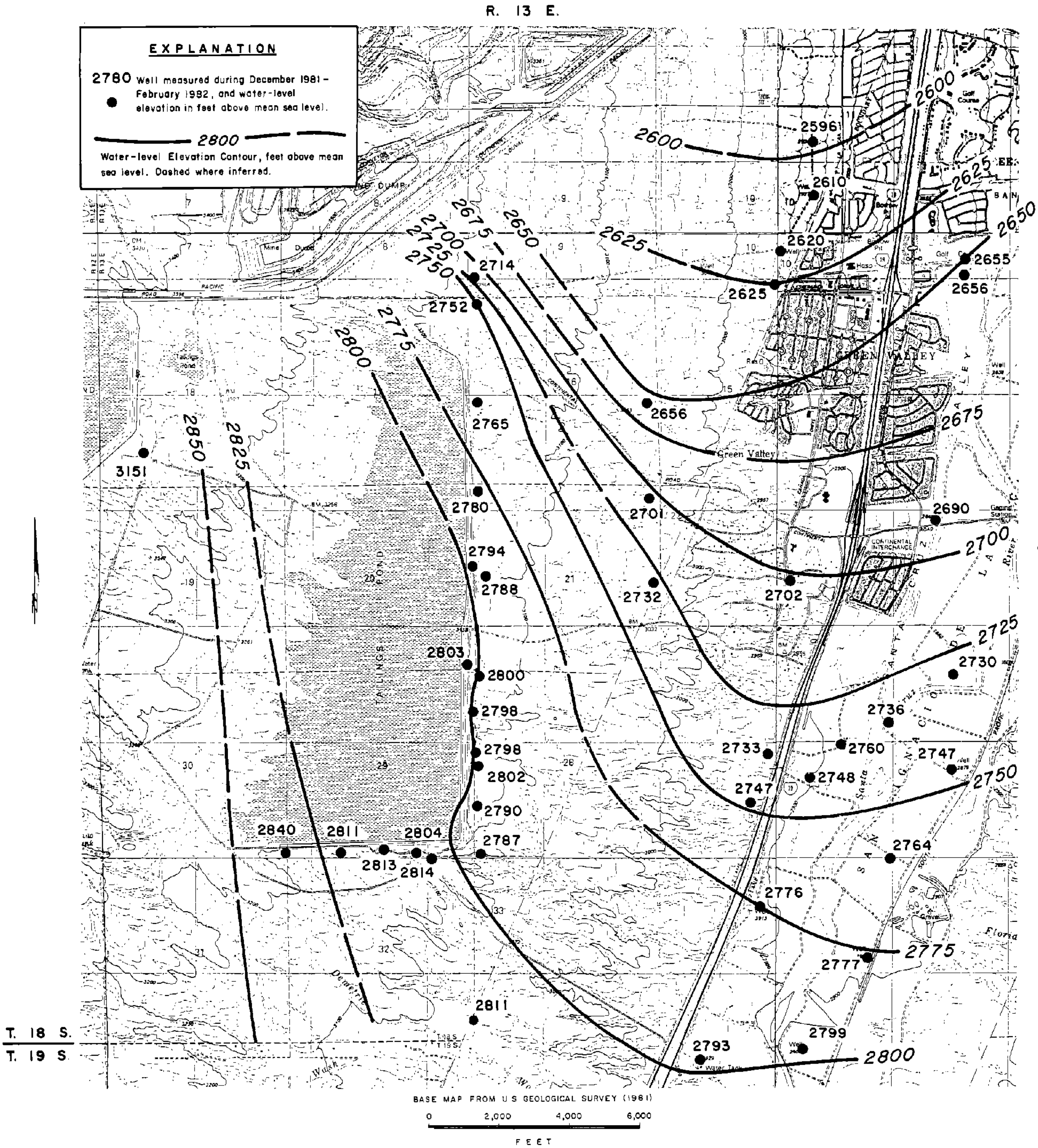

FIGURE 29. - WATER-LEVEL ELEVATIONS IN THE VICINITY OF THE MINE D SIERRITA POND (1981 - 82)

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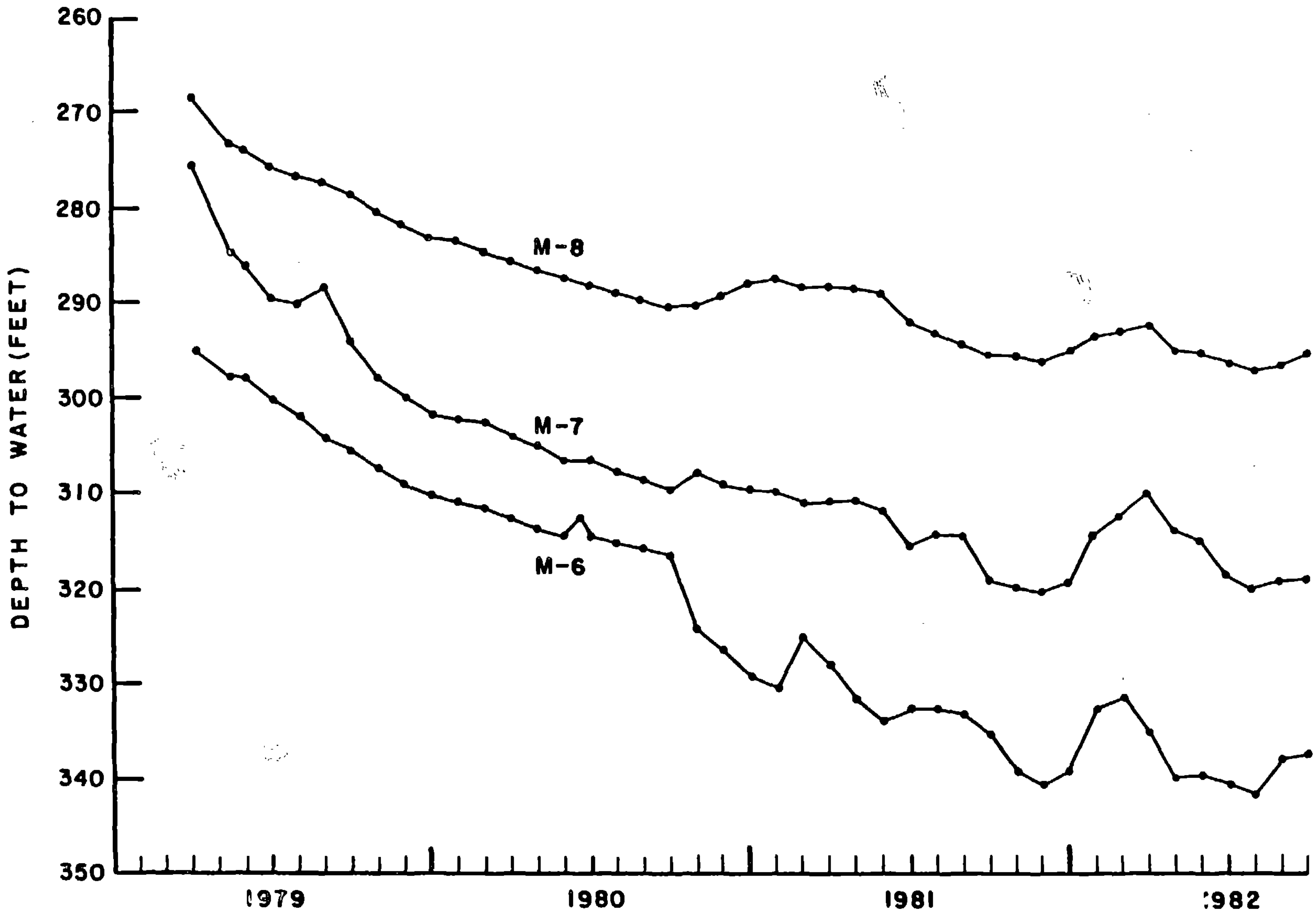

FIGURE 30. - WATER-LEVEL HYDROGRAPHS FOR MONITOR WELLS ADJACENT TO SOUTH PART OF MINE D SIERRITA POND

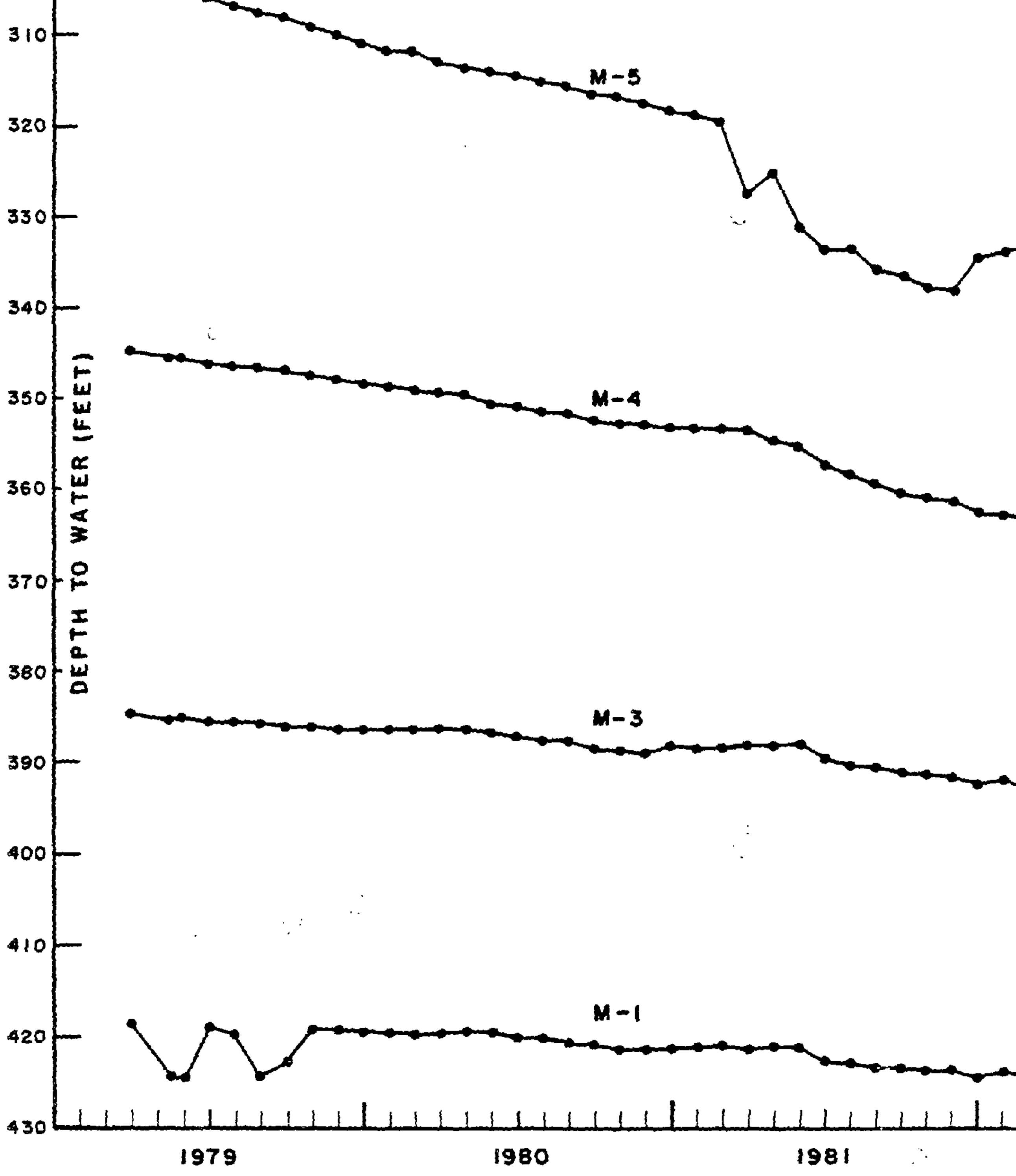

FIGURE 31.- WATER-LEVEL HYDROGRAPHS FOR MONITOR WELLS ADJACENT TO NORTH PART OF MINE D SIERRITA

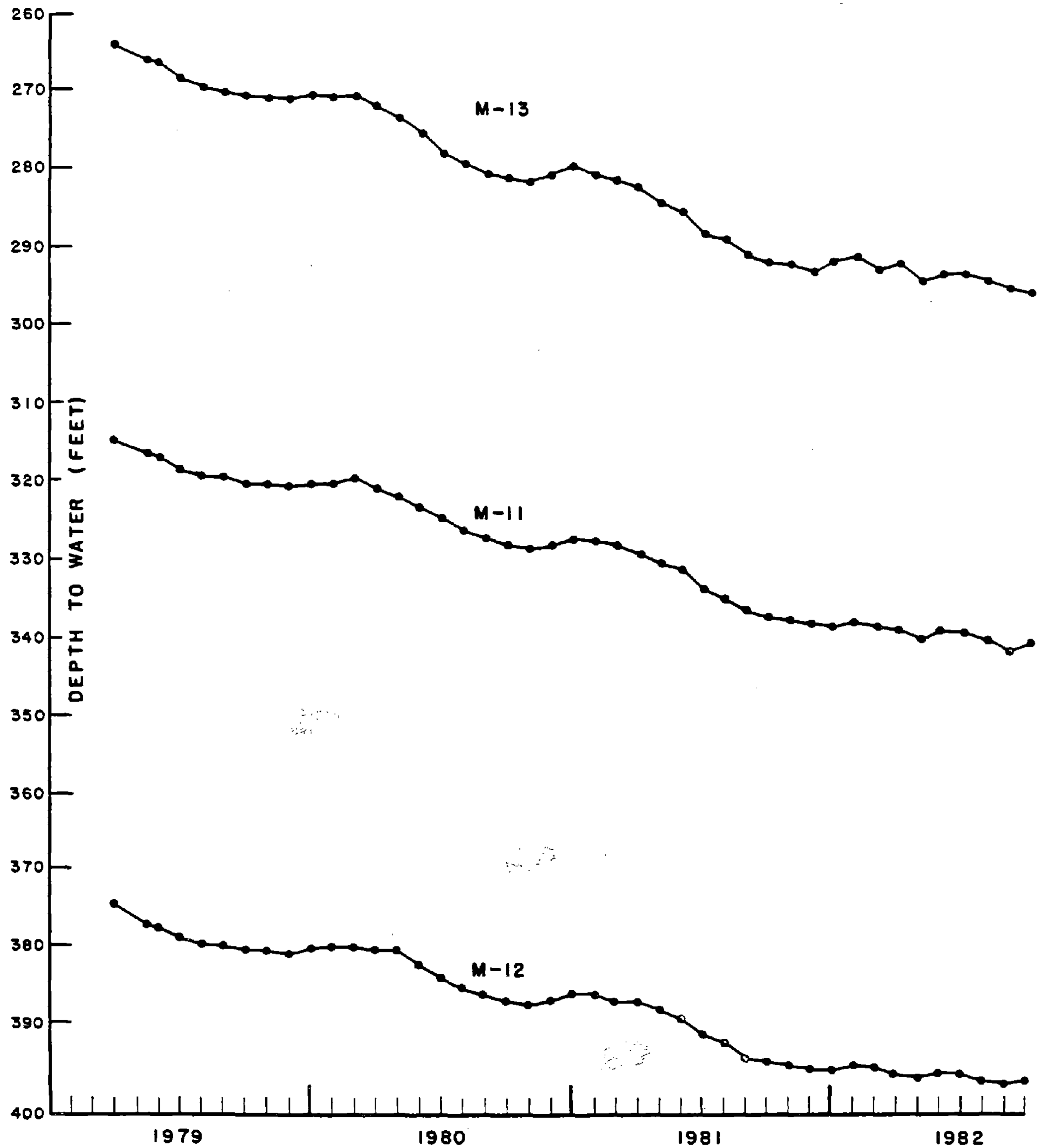

FIGURE 32. - WATER-LEVEL HYDROGRAPHS FOR MONITOR WELLS ABOUT ONE MILE EAST OF MINE D SIERRITA POND

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pumpage of well I-1, and water levels in well M-6 are highly influenced by pumpage of I-5. Short-term drawdown and recovery patterns are related to increases and decreases in pumpage of water from specific interceptor wells. Total pumpage from all interceptor wells was, temporarily, substantially reduced in early 1982, and water levels in these three monitor wells recovered noticeably at that time. Water-level declines in these wells ranged from about 25 to 40 feet between April 1979 and September 1982.

Figure 31 shows water-level hydrographs for monitor wells along the east edge of the Sierrita pond, north of most of the interceptor wells. Well M-5 is in close proximity to well I-6, and water levels in M-5 drew down noticeably when pumpage of I-6 began in early 1981. Water levels in the remaining three monitor wells farther north have shown little response to pumpage of the interceptor wells. Water levels in the two northernmost wells (M-1 and M-3) fell less than 5 feet between April 1979 and September 1982.

Figure 32 shows water-level hydrographs for the three monitor wells about 1 mile east of the east edge of the Sierrita pond. Water levels in these wells appear to fall during the summer and to rise or stay relatively constant in the winter. Water levels in these wells appear to be affected by pumpage of nearby public-supply wells and irrigation wells to the east and southeast. Water-levels in the three monitor wells declined from about 25 to 35 feet between April 1979 and September 1982.

Aquifer Characteristics

In Summer 1978, 24-hour pump tests were conducted on the first four interceptor wells. Pumping rates ranged from 800 gpm at well I-4 to about 1,500 gpm at well I-2. Specific capacities ranged from 10 to 16 gpm per foot. Transmissivities ranged from about 16,000 to 27,000 gpd per foot, in good agreement with the specific capacity data. Transmissivity is, thus, relatively uniform along the eastern edge of the ponds south of well I-5. Information on aquifer characteristics at wells I-5 and I-6 was not available for this report. However, transmissivity is expected to decrease substantially to the north, due to the thinning of the aquifer in that direction. Storage coefficients for these short-term tests are indicative of a semiconfined aquifer. Longer-term pump tests would likely provide results indicative of the specific yield of the alluvial materials.

2. Well Use

There are two public-supply wells (CW-1 and CW-3) at Green Valley that are about 1-1/2 miles east of the east edge of the Sierrita pond. Both of these wells appear to have been downgradient of the pond, both in 1976-77 and 1981-82, based on Figures 28 and 29. There are two other public-supply wells (GV-1 and GV-2) about 1-1/2 miles east of the southeast corner of the Sierrita pond. Based on Figure 29, these two wells did not appear to be downgradient of the tailings pond as of 1981-82. Two other public-supply wells in the vicinity (GV-6 and CW-6) do not appear to have been downgradient of the Sierrita pond as of 1981-82. The Esperanza well field was downgradient of the southern part of the pond as of 1981-82. Most of the FICO wells along the flood plain of the Santa Cruz do not appear to have been downgradient of the pond as of 1981-82.

3. Pond Recharge

Data on file with the Arizona Department of Water Resources indicate that recharge from the Sierrita pond was about 6,900 acre-feet in 1979. This was about 30 percent of the pumpage from the Esperanza and Sierrita mine-supply wells. This amount should probably be considered a minimum value because there has been substantial ponding of free water on alluvium at the Sierrita pond. Pumpage from the Esperanza wells has decreased in recent years and was only about 1,700 acre-feet in 1979. The Sierrita wells are located to the south and do not exert a control on the movement of tailings pond recharge in the ground water. Recharge from the tailings pond appears to have been at least 50 percent greater than the average pumpage from the interceptor wells during 1979-81. It is possible that recharge of tailings pond water was almost double the volume of pumpage from the interceptor wells during 1979-81. Between 1970 and 1982, there has probably been at least 90,000 acre-feet, and possibly more than 130,000 acre-feet, of recharge from the Sierrita tailings pond. About 18,000 acre-feet have been removed by pumpage of the interceptor wells.

4. Chemical Quality of Pond Water

Table 6 contains the results of several chemical analyses of water reclaimed from the Sierrita pond. Mine D has provided numerous analyses of pond water for April 1979 through October 1982. The water is of high pH and of the calcium sulfate type, similar in composition of the major inorganic chemical constituents to Mine A pond water. Calcium and sulfate contents suggest that the water is saturated with respect to gypsum. Trace elements analyzed are at low levels and are not expected to be present at significant levels in water at such a high pH. Contents of cyanide, molybdenum, and selenium, which might be expected to be present in such water, have not been reported.

TABLE 6. - CHEMICAL QUALITY OF WATER
FROM MINE D SIERRITA POND

Constituent (mg/l)	12/17/79	12/2/80	11/23/81
Calcium	631	608	601
Magnesium	<1	5	7
Sodium	177	264	267
Potassium	36	29	50
Bicarbonate	24	35	27
Sulfate	1,806	1,842	1,948
Chloride	158	102	83
Silica	24	-	28
Copper	<0.1	<0.1	-
Iron	<0.1	<0.1	-
Lead	<0.1	<0.1	-
pH	9.2	9.4	9.3
Electrical Conductivity (micromhos/cm @ 25°C)	3,240	4,440	2,450
Total Dissolved Solids	2,856	2,885	3,011

Data from Duval Corporation for reclaimed water from pond. Analyses by Duval Corporation chemical laboratory.

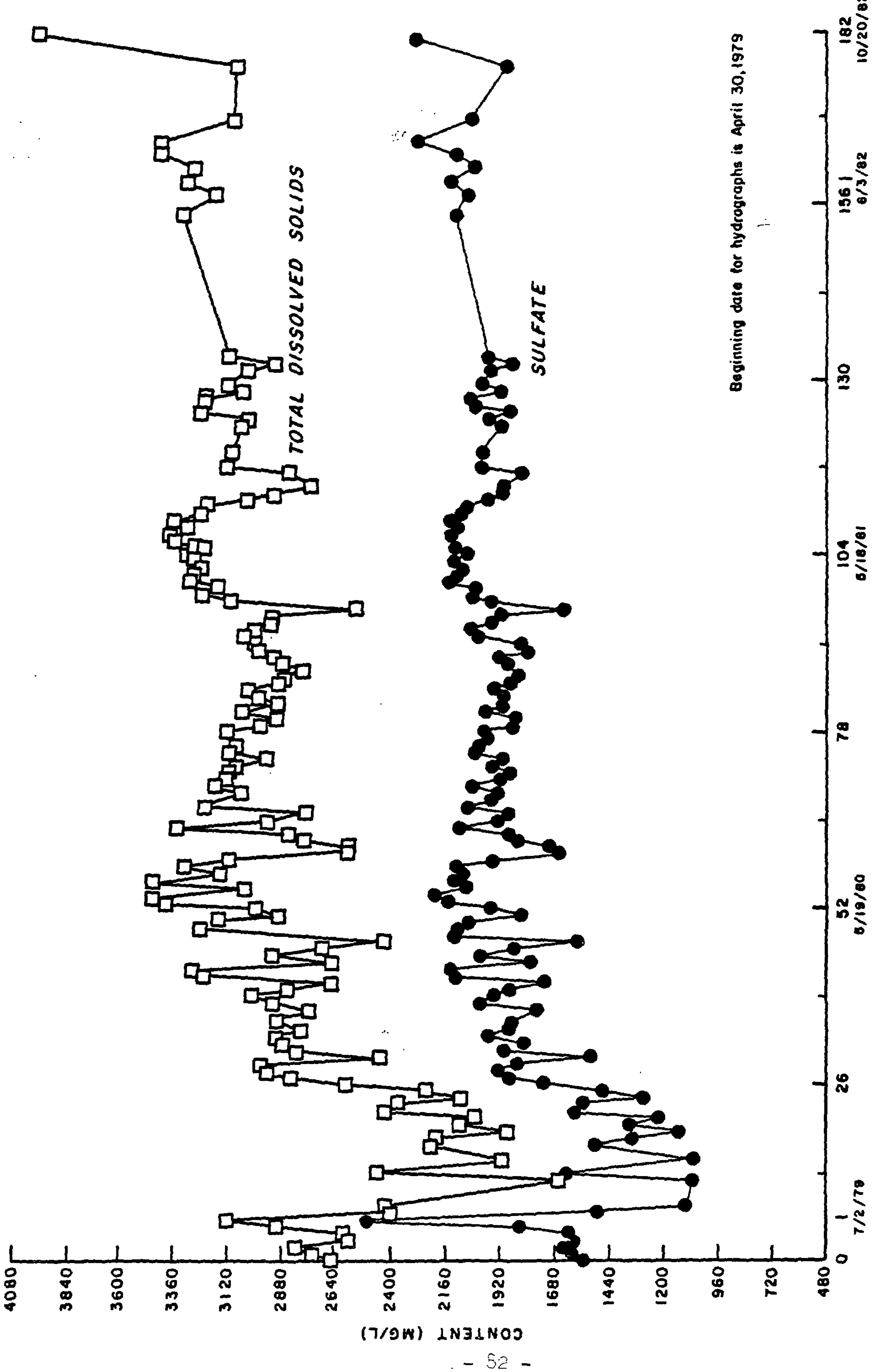
Figure 33 shows changes in sulfate and total dissolved solids contents in Sierrita pond water from April 1979 through October 1982. Both sulfate and total dissolved solids contents increased during the first year of pumping of the interceptor wells. Increasing contents of these constituents in the pond water during 1979 and early 1980 are likely due to the contribution of interceptor well pumpage to makeup water for the mill. The average sulfate content was about 2,000 mg/1, and the average total dissolved solids content was about 3,000 mg/1 in the pond water during 1980-82.

5. Ground-Water Quality

Contour maps were prepared for sulfate, hardness, and total dissolved solids contents in well water in the vicinity of the Sierrita pond, based on sampling in Fall 1982 (Figures 34, 35, and 36). Sulfate contents exceeded 1,200 mg/1 along the east edge of the pond, except for the extreme northern part. A plume of high sulfate content is apparent, extending easterly and northeasterly from the tailings pond. This plume extends to M-11 and M-13, about 1 mile east of the east edge of the pond, but has apparently not reached any other wells farther downgradient. However, water from public-supply well CW-1 has apparently not been routinely sampled, and this well appears to be directly downgradient of the plume. The plume also had not reached public-supply well CW-3, based on analyses for late 1982. Background contents of sulfate in the area appear to be less than 200 mg/1, based on contents in water from the Esperanza well field and from public-supply wells along Interstate 19, east of the plume. Pumpage of the interceptor wells appears to have distorted the shape of the plume near the southeast corner of the pond.

Figure 35 shows contours for hardness in well water in the vicinity of the Sierrita pond. The distribution of hardness (primarily due to calcium content) was similar to that for sulfate. Hardness content as calcium carbonate exceeded 1,200 mg/1 in about the same area as where the sulfate content exceeded the same level. This is further confirmation that recharge of tailings pond water, high in calcium and sulfate, has caused the plume. Background levels in the area for hardness as calcium carbonate appeared to be less than 200 mg/1.

Figure 36 shows contours for total dissolved solids content in well water in the vicinity of the pond. Total dissolved solids contents had a similar distribution to that for sulfate and hardness. Total dissolved solids contents exceeded 2,000 mg/1 along most of the east edge of the pond, except for the northern part. Background levels for total dissolved solids in the vicinity appear to be less than 500 mg/1. More extensive regional water-quality data is included in "Region Wide Ground Water Quality in the Upper Santa Cruz Basin Mines Task Force Study Area," prepared by the Upper Santa Cruz Basin Mines Task Force and the Pima Association of Governments (1983).


TOTAL DISSOLVED SOLIDS
SULFATE
Beginning date for hydrographs is April 30, 1979
CONTENT (MG/L)
TIME (WEEKS)
0
1
7/2/79
26
52
6/19/80
78
104
6/18/81
130
156
6/3/82
182
10/20/82
480
720
960
1200
1440
1680
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2160
2400
2640
2880
3120
3360
3600
3840
4080

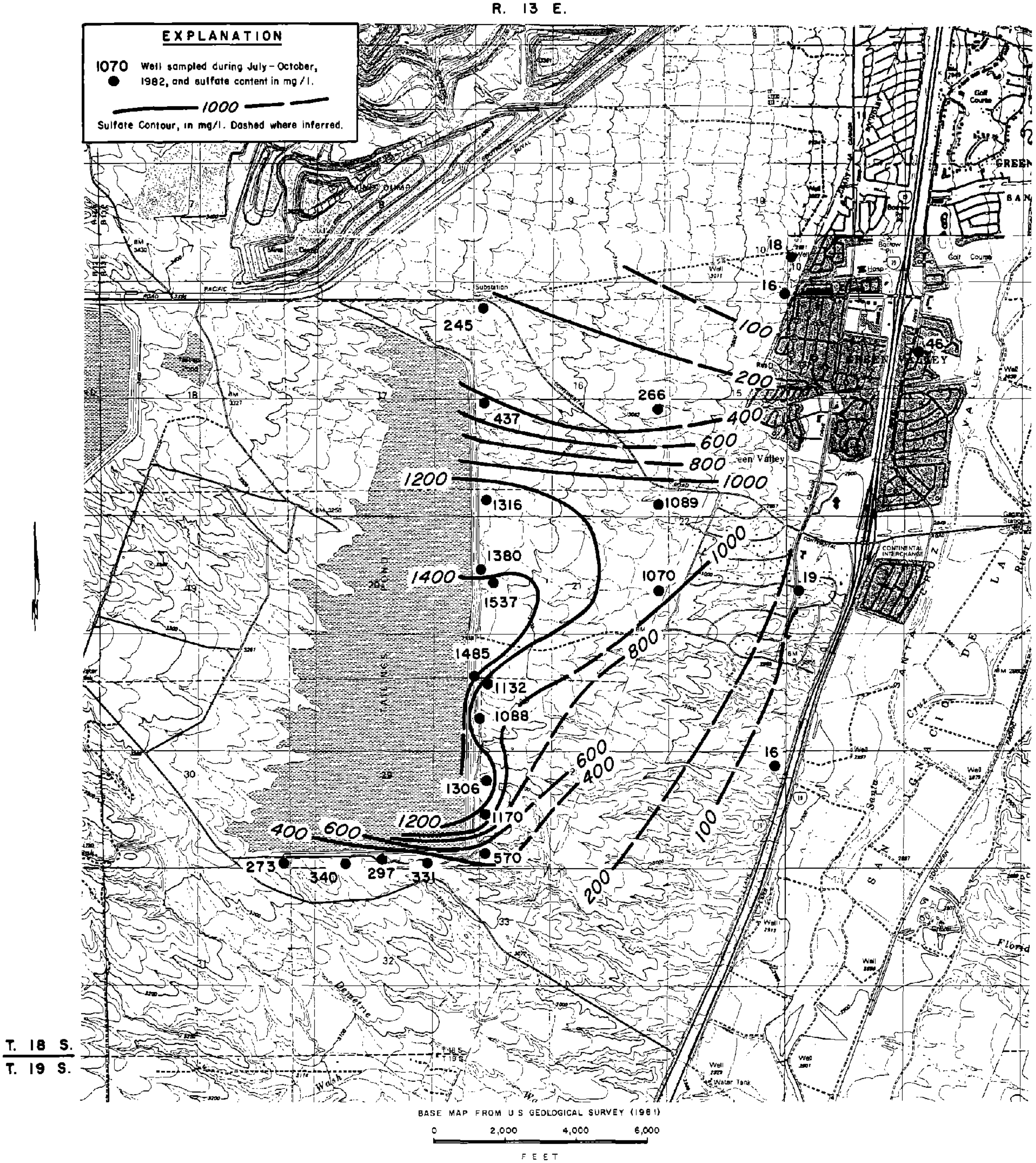

FIGURE 34. - SULFATE CONTENT IN WATER FROM WELLS IN THE VICINITY OF THE MINED SIERRITA POND (FALL 1982)

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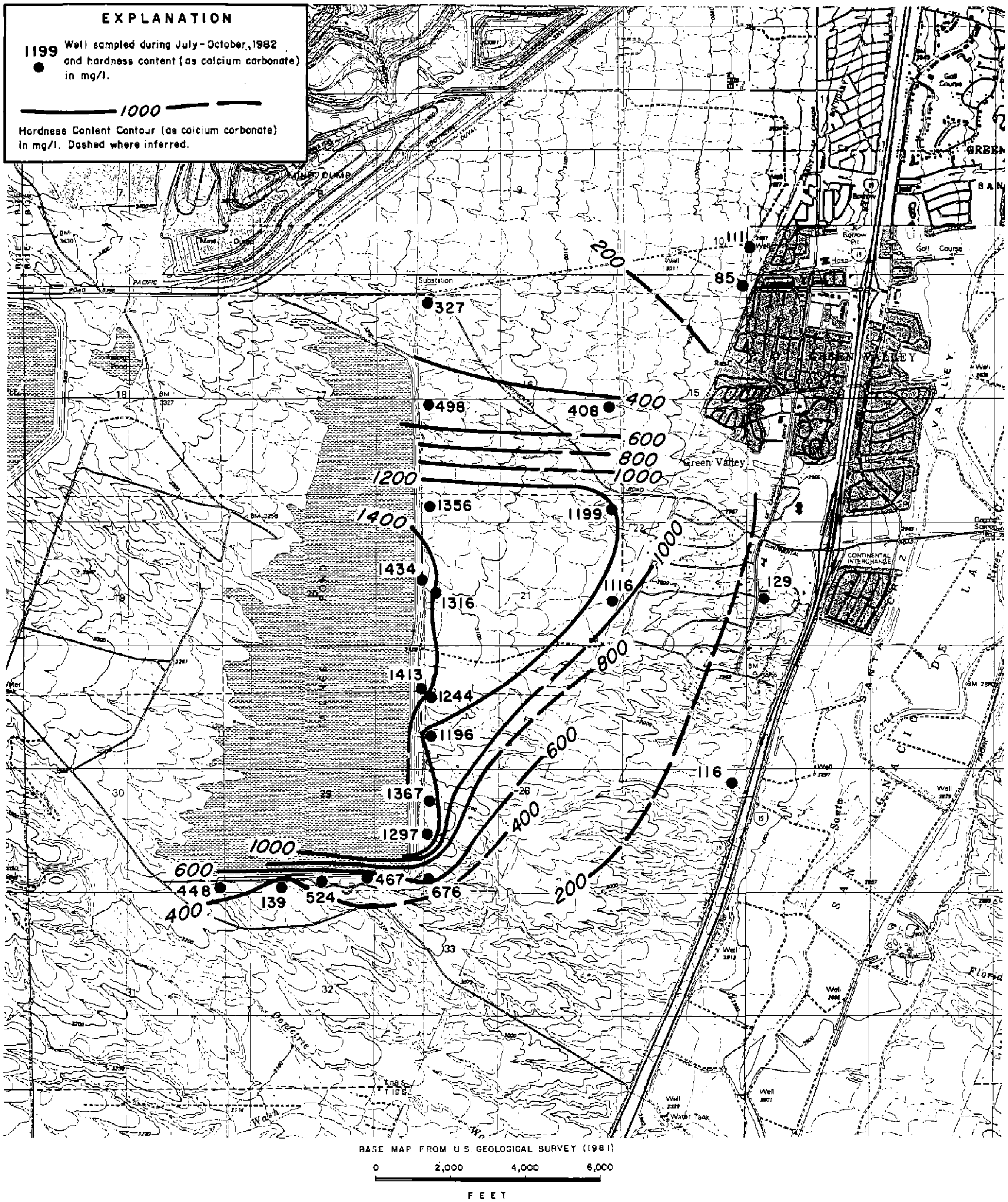
R. 13 E.



T. 18 S.

T. 19 S.

FIGURE 35. - HARDNESS CONTENT IN WATER FROM WELLS IN THE VICINITY OF THE MINE D SIERRITA POND (FALL 1982)

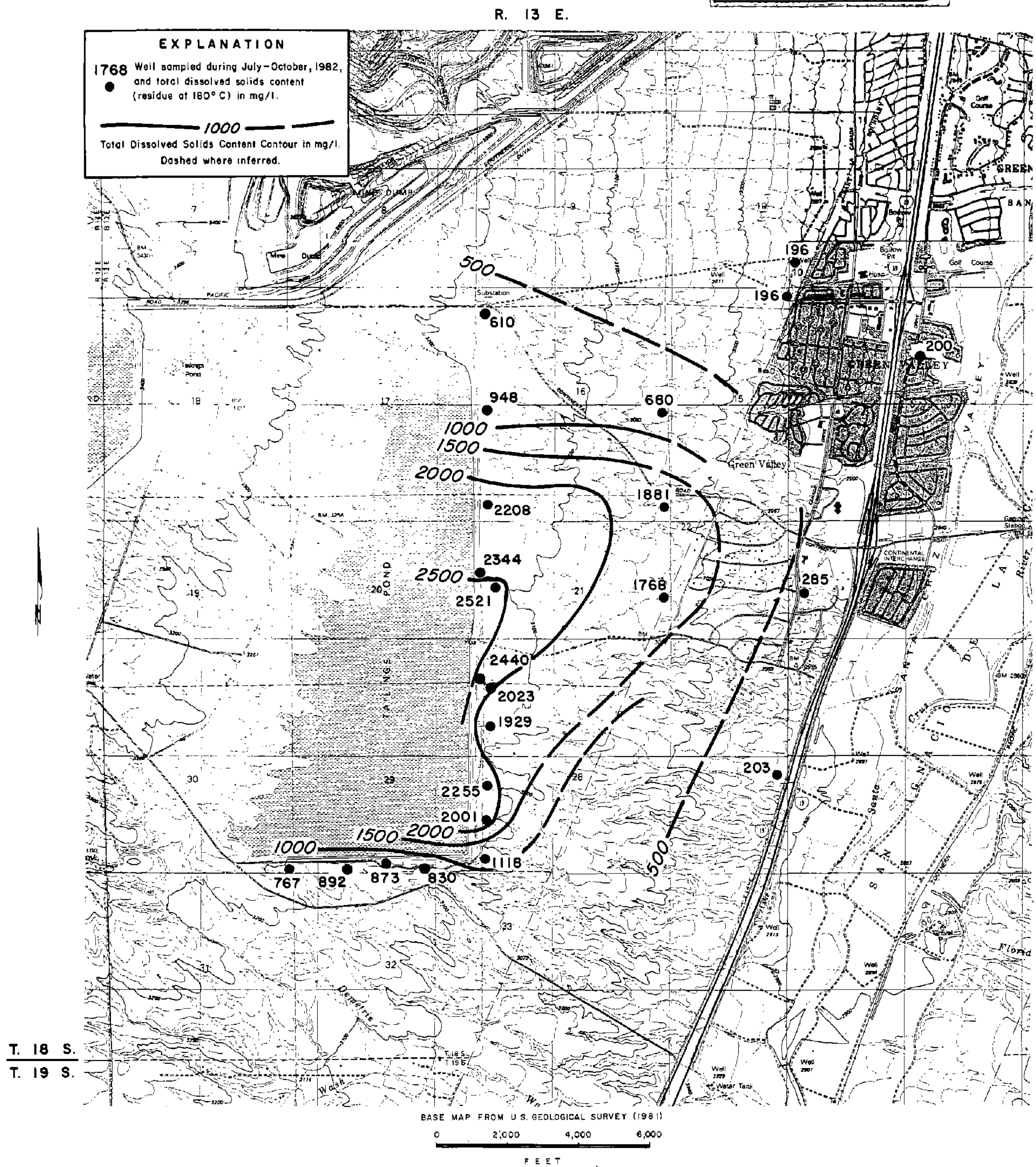


FIGURE 36. - TOTAL DISSOLVED SOLIDS CONTENT IN WATER FROM WELLS IN THE VICINITY OF THE MINE D SIERRITA POND (FALL 1982)

Pima Association of Governments & K. D. Schmidt, 1983

Water-quality hydrographs were prepared for numerous interceptor and monitor wells. Mine D provided chemical analyses for April 1979-October 1982. Figures 37 and 38 show sulfate and total dissolved solids contents in water from two of the interceptor wells. Contents for I-2, which is located near the southeast corner of the pond, have decreased with time (Figure 37). Sulfate content declined from about 1,200 to less than 600 mg/l after 3-1/2 years of pumping. The sulfate content of 600 mg/l indicates that only about one-third of the water pumped from this well in late 1982 was recharged tailings pond water. Thus, the interceptor wells along the south edge of the pond (I-1, I-2, and I-7) are probably substantially affected by inflow of good quality water from the southwest.

Figure 38 indicates that contents of sulfate and total dissolved solids in water from well I-4, which is located about 4,000 feet north of well I-2, have remained relatively constant. Contents declined during the first 6 months of pumping, but then slowly rose to approximately constant levels. The average sulfate content in water from well I-4 has been about 1,200 mg/l. It is estimated that water from this well pumps a mixture of about three-fourths recharged tailings pond water and one-fourth other ground water. Of the seven interceptor wells, only I-4, I-5, and I-6 are in the part of the plume with highest sulfate contents.

Figures 39 and 40 show sulfate and total dissolved solids contents in water from two monitor wells, north of the first four interceptor wells. Contents in water from well M-3, which is near the northeastern part of the pond, remained relatively constant between April 1979 and October 1982 (Figure 39). However, there has been a slight increase in sulfate and total dissolved solids contents during this period. Well M-3 is about 4,500 feet north of well I-6, which is the northernmost of the interceptor wells. Contents of sulfate and total dissolved solids in water from well M-3 indicate no response to pumpage of the interceptor wells, which is consistent with conclusions based on water-level measurements (Figure 31). Well M-6 is located between wells I-4 and I-5, and appears to be in the area of the highest sulfate content.

Both sulfate and total dissolved solids contents in water from well M-6 remained relatively constant between April 1979 and October 1982. Sulfate contents have averaged about 1,500 mg/l, and water from well M-6 is probably almost all derived from tailings pond recharge.

Figures 41 and 42 show sulfate and total dissolved solids contents in water from two of the monitor wells about 1 mile east of the east edge of the pond. Both of these wells are located within the plume. Sulfate and total dissolved solids contents in water from well M-11 have remained relatively constant (Figure 41). Sulfate contents

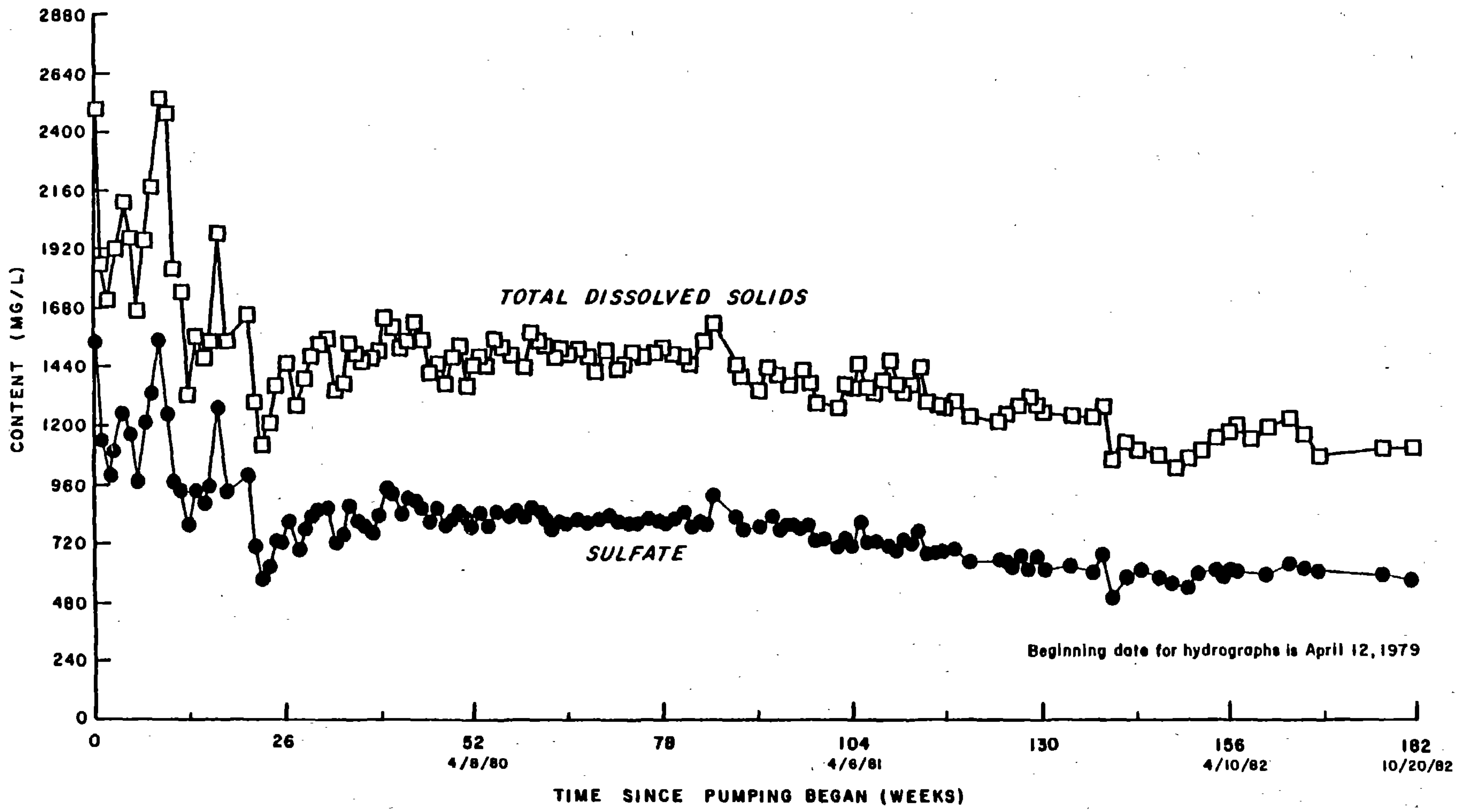


FIGURE 37. - SULFATE AND TOTAL DISSOLVED SOLIDS CONTENTS FOR MINE D INTERCEPTOR WELL No. 2

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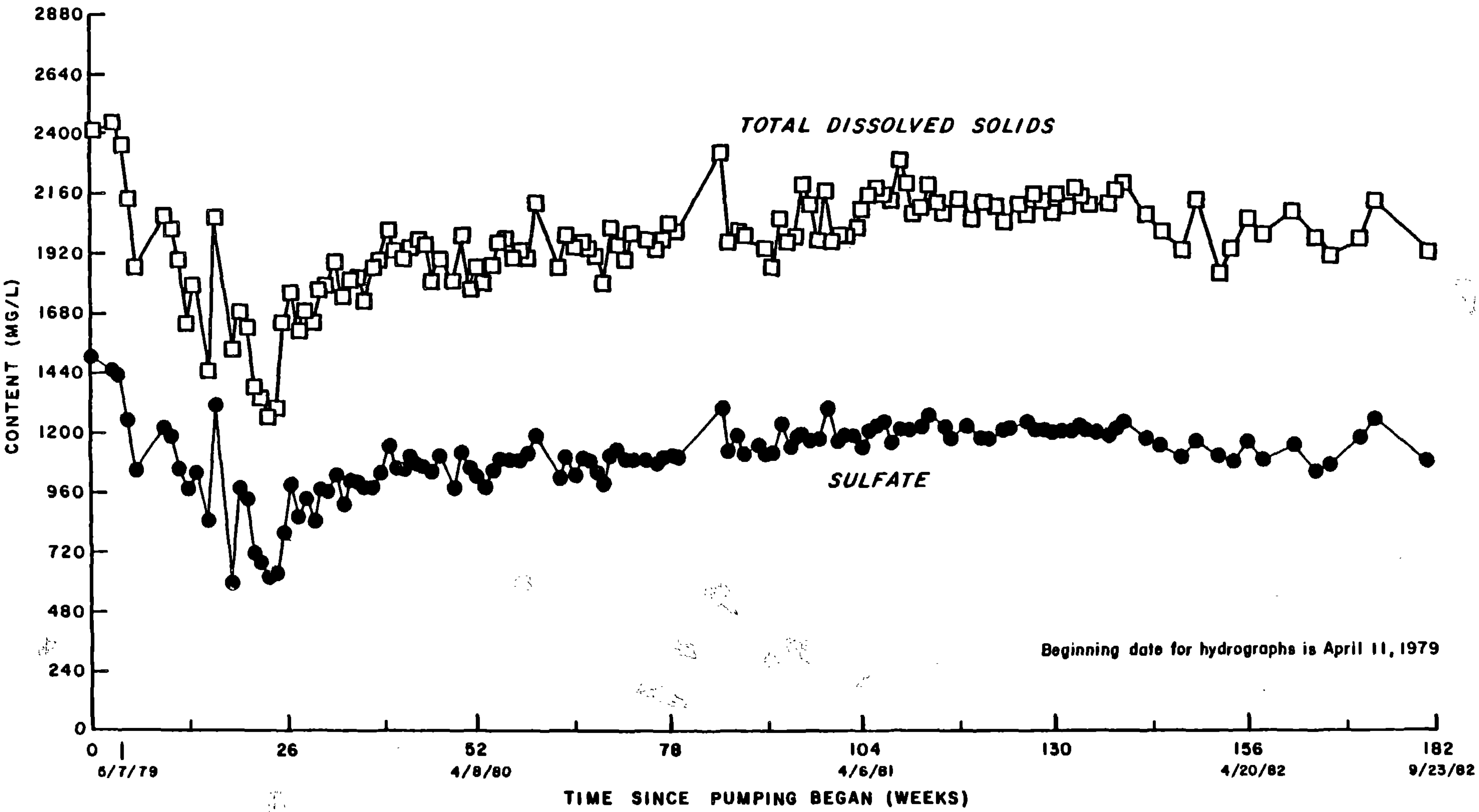

FIGURE 38.- SULFATE AND TOTAL DISSOLVED SOLIDS CONTENTS FOR MINE D INTERCEPTOR WELL No. 4

Pima Association of Governments & K D Schmidt 1983

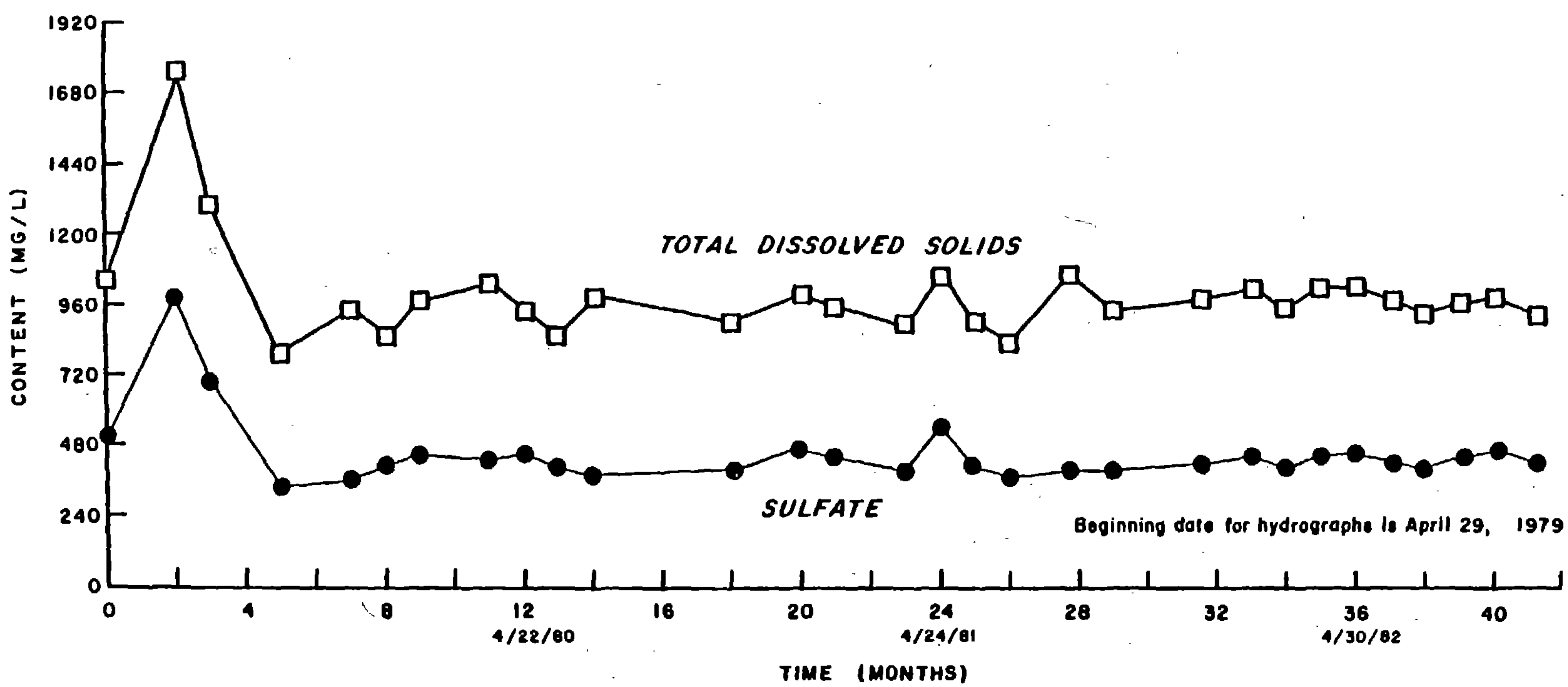

FIGURE 39. - SULFATE AND TOTAL DISSOLVED SOLIDS CONTENTS FOR MINE D MONITOR WELL No. 3

Pima Association of Governments & K.D. Schmidt, 1983

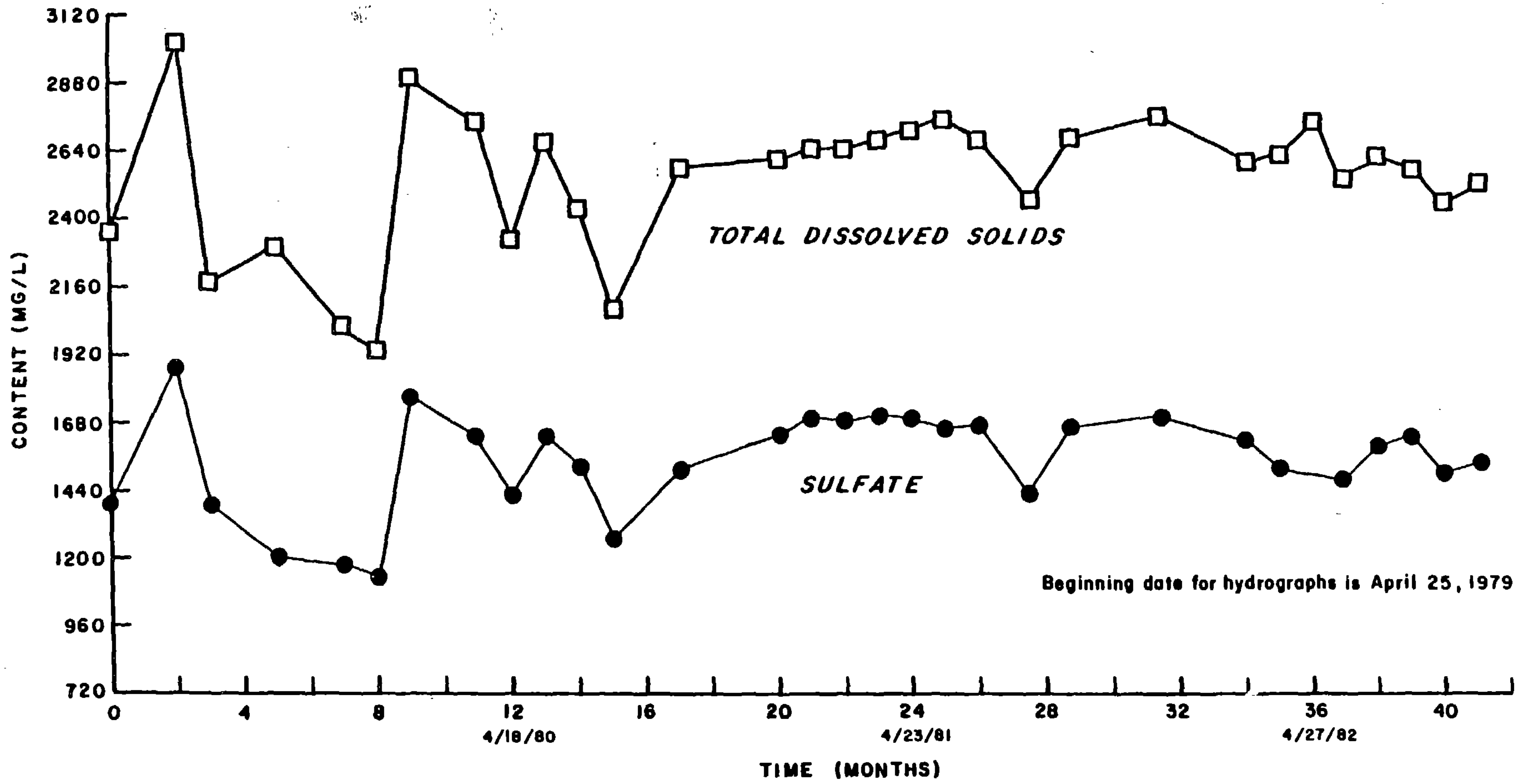

FIGURE 40. - SULFATE AND TOTAL DISSOLVED SOLIDS CONTENTS FOR MINE D MONITOR WELL No. 5

Pima Association of Governments & K. D. Schmidt, 1983

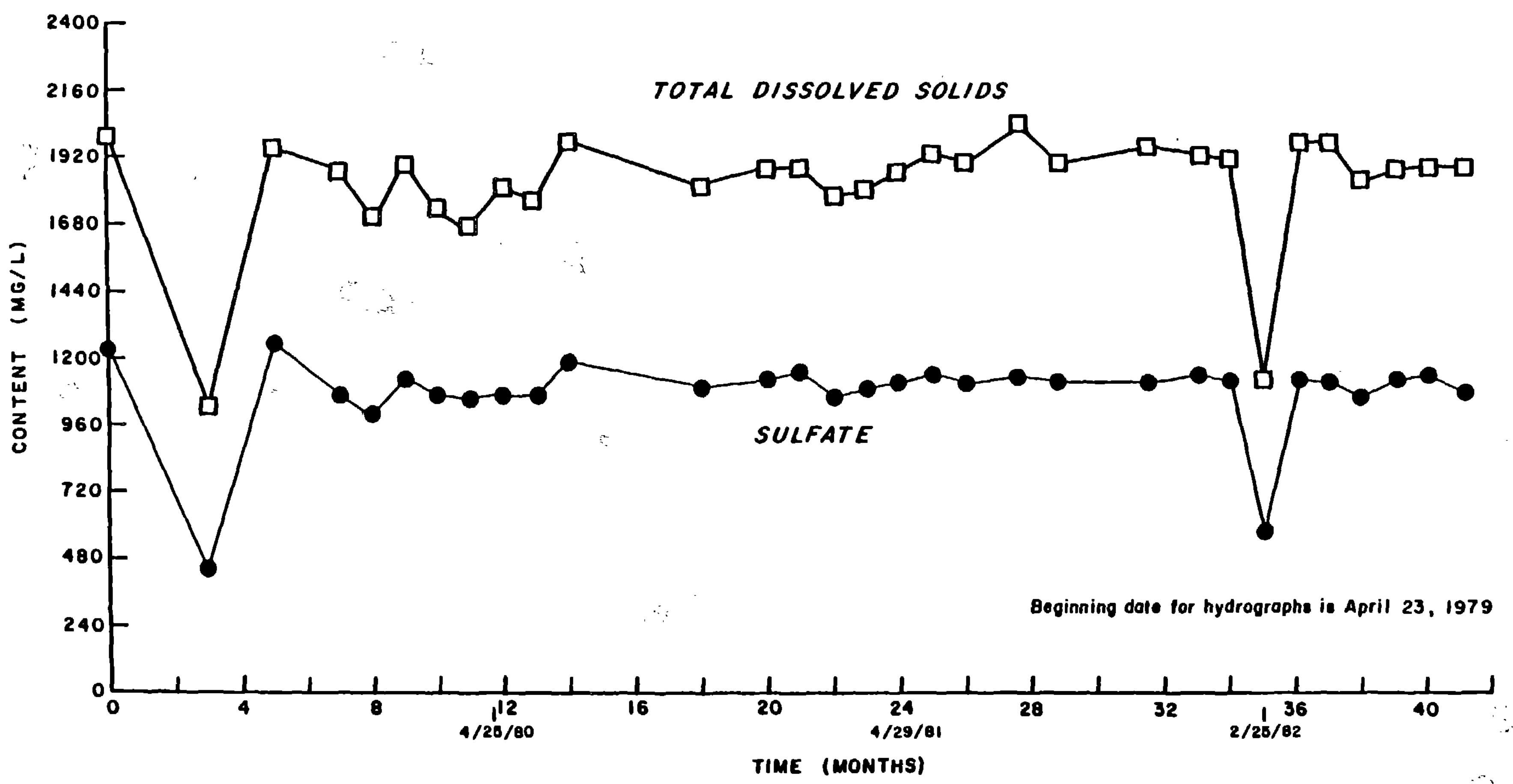

FIGURE 41. - SULFATE AND TOTAL DISSOLVED SOLIDS CONTENTS FOR MINE D MONITOR WELL No. 11

Pima Association of Governments & K.D. Schmidt, 1983

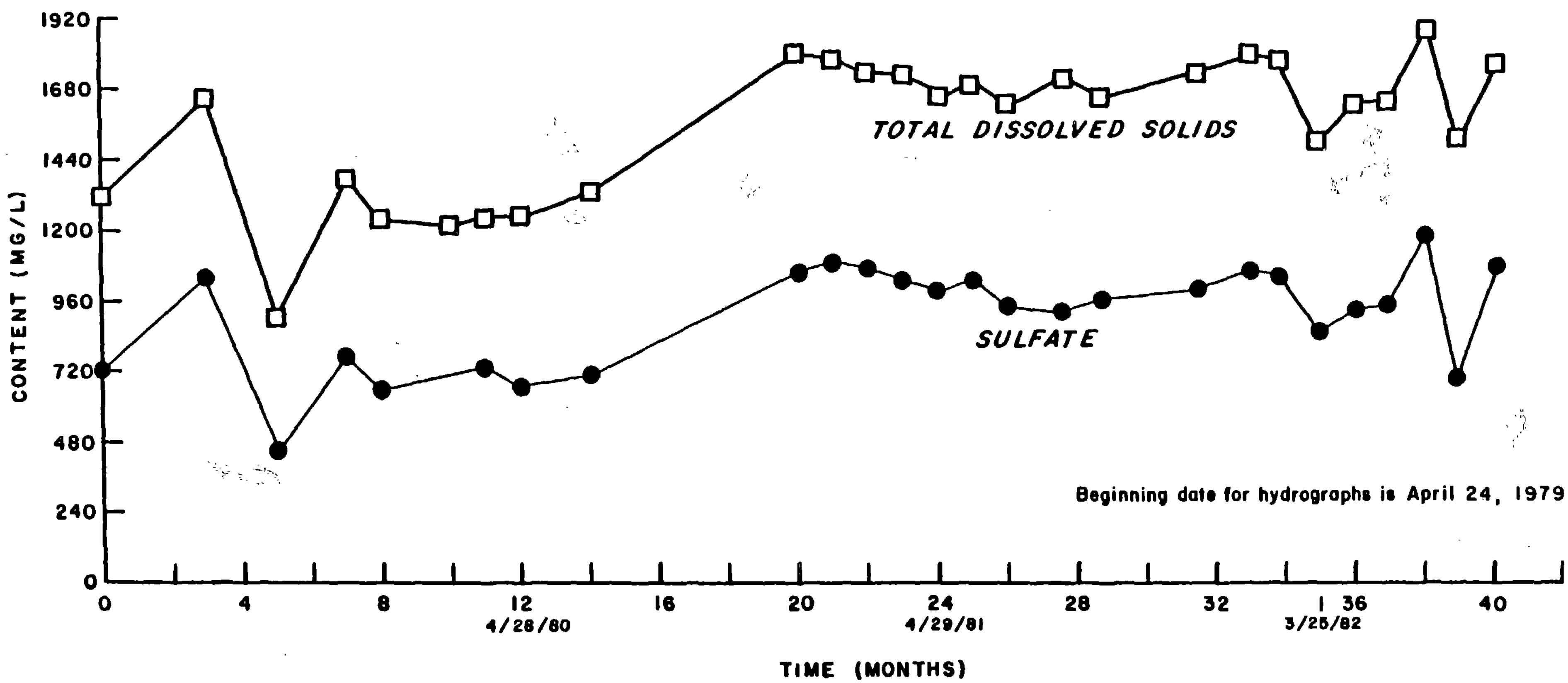

FIGURE 42. - SULFATE AND TOTAL DISSOLVED SOLIDS CONTENTS FOR MINE D MONITOR WELL No. 13

Pima Association of Governments & K.D. Schmidt, 1983

have averaged about 1,100 mg/l. It is estimated that about two-thirds of the water present at this well is derived from tailings pond recharge. Well M-13 is about one-half mile south of well M-11. Both sulfate and total dissolved solids contents of water from this well rose during the first 20 months of interceptor well pumpage (Figure 42). Since that time (about the end of 1980), contents of both constituents have remained relatively constant. Sulfate contents in water from well M-13 averaged about 1,000 mg/l during 1981-82. Slightly less than two-thirds of the water from well M-13 is derived from tailings pond recharge.

A trilinear diagram (Figure 43) was prepared for pond water and wells in the vicinity. Of the interceptor wells, water from wells I-3, I-4, I-5, and I-6 plot closest to pond water in the anion field, indicating that water from these wells contains a high percentage of recharged tailings pond water. Water from wells I-1 and I-7 plots the least similarly to pond water of the interceptor wells, indicating the influence of other ground water near the south edge of the pond. Water from wells M-4, M-11, and M-13 plots close to pond water in the anion field, also indicating that water from these wells contains a high percentage of recharged pond water. Water from wells M-1, M-3, and M-12, which are all to the north, also shows the influence of other ground water. The results of the trilinear diagram thus confirm previously drawn conclusions.

6. Conclusions and Recommendations

Pumping of the interceptor wells since April 1979 has removed a large volume of degraded ground water near the Sierrita pond. The interceptor wells have been effective in altering the direction of ground-water movement in the area east of the southeast corner of the pond. Based on water-level elevation contours for 1981-82, two public-supply wells east of the ponds (GV-1 and GV-2) are no longer downgradient of the ponds, as they may have been in 1976-77.

The interceptor wells have had little noticeable impact on the part of the plume near two other public-supply wells (CW-1 and CW-3). Also, contents of hardness and sulfate near most of the east edge of the pond are remaining relatively constant. The volume of pond recharge is believed to be about 50 to 100 percent more than the volume of interceptor well pumpage at present. Also, pumpage of wells along the south edge of the pond has been relatively less effective than other interceptor wells because induced ground-water underflow is mixing with recharged tailings pond water in that vicinity.

It appears that pumpage from interceptor wells should be increased by about 50 to 100 percent. In addition, more water should be pumped in the area where sulfate and hardness contents exceed 1,200 mg/l. Wells I-4, I-5, and I-6 are in this area, but additional wells are probably needed between about one-quarter and one-half mile to the northeast of these wells.

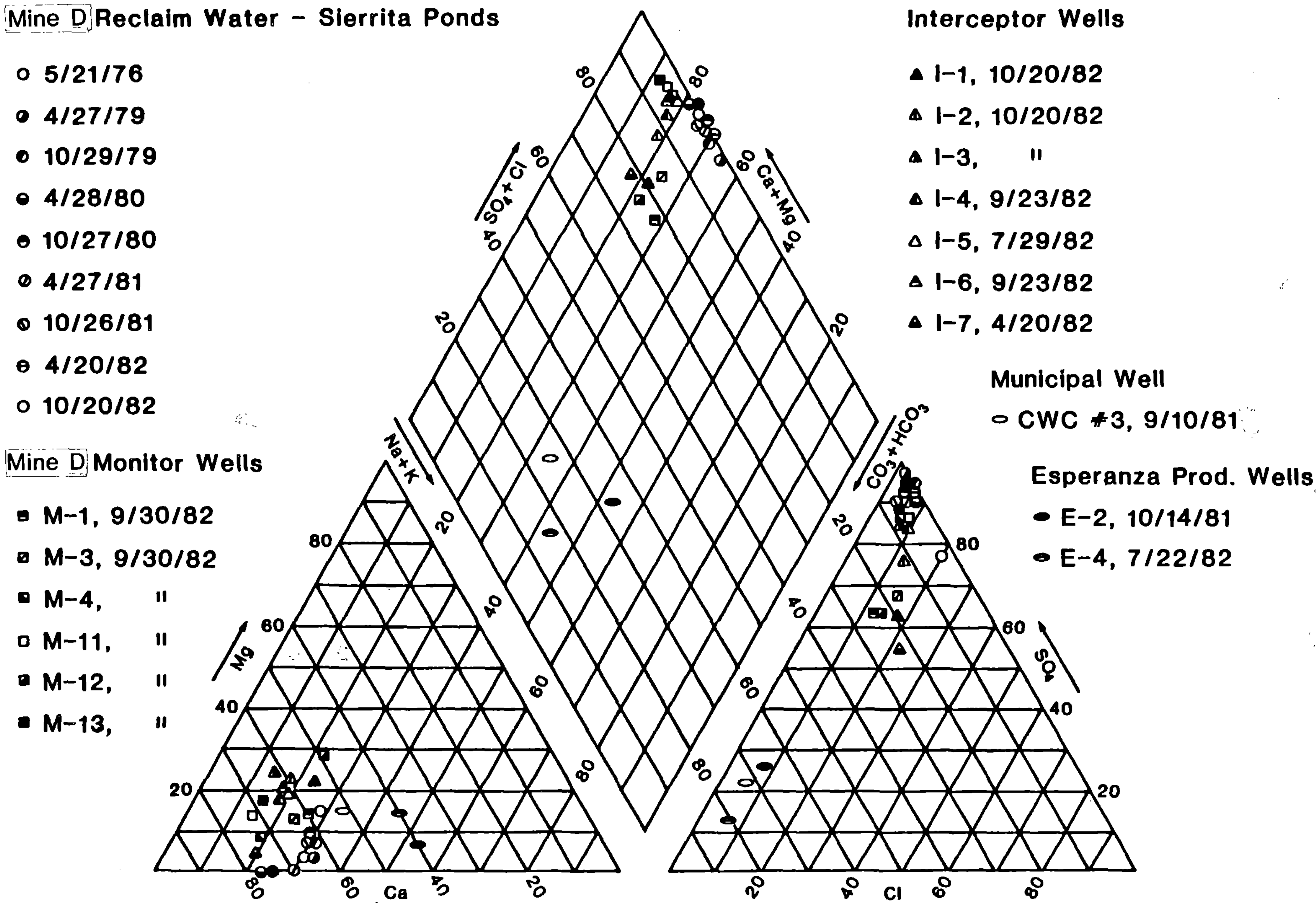

FIGURE 43. — TRILINEAR DIAGRAM OF MINE D WELL AND POND WATER QUALITY

Pima Association of Goverments & K.D. Schmidt, 1982

Monitoring to provide protection for Green Valley public-supply wells appears to be inadequate. At least one monitor well should be installed between well M-11 and public-supply well CW-1, and the monitor well should tap a depth interval similar to CW-1. At least one monitor well should be installed between well M-13 and public-supply well CW-3, and the monitor well should tap a depth interval similar to CW-3. Both public-supply wells and the two monitor wells should be sampled on a monthly basis, at least for indicator constituents (electrical conductivity, sulfate, and hardness). In addition, other constituents that are believed to be present at significant levels in tailings pond water should be determined in water from wells within the plume. These include cyanide, molybdenum, and trace organics. In addition, selenium should be routinely monitored.

Presently, the vertical distribution of calcium and sulfate in the aquifer is poorly known downgradient of the pond. It is unlikely that the plume is present in the entire saturated thickness of the aquifer, particularly near wells M-11 and M-13. Before new deep monitor or interceptor wells are drilled and perforated over large depth intervals, a careful depth sampling program for water quality should be undertaken. This would allow delineation of the exact vertical distribution of recharged pond water in the aquifer. Potential vertical transfer of pollutants along the annular spaces of future wells could then be minimized through the use of adequate annular seals.

If exact amounts of pond recharge are unknown, efforts should be intensified to make this determination. This would appear to be necessary in order to fully evaluate the effectiveness of the interceptor well system.

F. Summary of Conclusions

1. Recharge from tailings ponds at Mine A, Mine B, and Mine D has locally degraded the quality of downgradient ground water. High contents of sulfate and hardness are indicative of this recharge.

2. Migration of recharged water from the Mine A tailings ponds appears to be limited at present by pumpage of the Mine A mine-supply wells.

3. Recharged water from the Mine B pond no. 2 appears to be moving toward at least one public-supply well. Pumpage of an interceptor well or wells may be desirable.

4. Pumpage of the interceptor wells near the Mine D Sierrita pond is not adequately controlling the movement of recharged pond water. At least two downgradient public-supply wells appear to be threatened. A substantial increase in the volume of pumpage from interceptor wells appears to be necessary.

5. Enhanced monitoring programs appear to be necessary at each of the three study areas. These include additional characterization of the pond water and determination of water budgets for pond recharge. Also, contents of cyanide, molybdenum, selenium, and selected trace-organic chemical constituents should be determined in water from wells affected by tailings pond recharge.

APPENDIX A

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