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A multidisciplinary analysis of the hydrogeology of the Maricopa superconducting super collider (SSC) site, Maricopa County, Arizona

Brooks, Steven John, M.S.

The University of Arizona, 1988

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A MULTIDISCIPLINARY ANALYSIS OF THE HYDROGEOLOGY OF THE MARICOPA SUPERCONDUCTING SUPER COLLIDER (SSC) SITE, MARICOPA COUNTY, ARIZONA.

by

Steven John Brooks

A Thesis Submitted to the Faculty of the

DEPARTMENT OF HYDROLOGY AND WATER RESOURCES

In Partial Fulfillment of the Requirements
For the Degree of

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WITH A MAJOR IN HYDROLOGY

In the Graduate College

THE UNIVERSITY OF ARIZONA

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S. N. Davis   May 2, 1988

S. N. Davis
Professor of Hydrology   Date

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The scale and complexity of the Arizona SSC effort prohibits me from thanking everyone who assisted me in the technical and political adventure it became and I apologize to those that space does not permit me to mention.

Initial thanks, or maybe blame, goes to Professor Stan Davis for first getting me involved with this project, and for his suggestions for improvements in the final manuscript. Thanks also goes to Professor Ben Sternberg for allowing me the chance to learn a little about geophysics, the best way possible, by going out in the field and doing it. I would also like to thank Richard Wilson of the U.S. Geological Survey and Bob Farrer of the Arizona Department of Water Resources for their help and expediency in fulfilling my numerous data requests over the past three years. A special thanks goes to my many teamates on the technical team, especially John Welty and Dickson Cunningham, for their excellent advice, and more importantly, friendship. A very special thanks goes to the one person, whom without, this thesis and the Arizona SSC project would not be where it is today. The hardest working person I've ever met, Ms. Nita Haddock. And last but not least, I must thank my parents, Bill and Mary Lou Brooks, yes mom and dad I'm finally through with school, I think.

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ABSTRACT

Geology and tunnelling was given by the U.S. Department of Energy (DOE) as the most important criteria in siting the SSC. The impact of ground water on construction and vice-versa is an important part of a sites geologic and tunnelling attributes, and its potential environmental impacts. Because of the site's undeveloped nature, only limited reconnaissance-type investigations of the regions hydrogeology had occurred prior to the siting of the SSC. To overcome this ignorance geological, geotechnical, and geophysical characteristics of the site were used to describe the hydrogeology.

A hydrologically ideal site would lie above any aquifers, have little or no surface water interaction, and yet, have an adequate and reliable supply of good quality water nearby. The Maricopa site possesses all of these characteristics while apparently being absent of subsidence due to ground-water withdrawal.

Chapter 1

INTRODUCTION

In 1983 the State of Arizona began an investigation to locate possible sites in Arizona for the U. S. Department of Energy's (DOE) Superconducting Super Collider (SSC). Briefly, the SSC is a proton-antiproton particle accelerator consisting of five components (1) an injector complex of four cascaded accelerators which include a 500 foot linear accelerator and three circular synchrotron accelerators up to four miles in circumference; (2) a 52.8 mile circumference collider ring with a tunnel diameter of 10 feet; (3) experimental areas containing the collision halls and particle detectors; (4) campus/laboratory areas; and (5) site infrastructure consisting of roads and utilities. Of the criteria outlined for site evaluation by the DOE, the greatest weight was given to geology and tunneling and its impact on construction and operational costs. Surface and subsurface hydrology are important aspects of the geologic criteria.

The initial screening of more than 30 possible sites in Arizona was based largely on geological, hydrological and environmental criteria. The number of sites was reduced to seven when demographics (i.e. access, cultural and educational resources, etc.) were considered. Of these seven sites, two were found to stand out, the Sierrita Site, approximately 35 miles southwest of Tucson, and the Maricopa Site, approximately 35 miles southwest of Phoenix.

The Maricopa Site (Figure 1) was located carefully so as to optimize geographic, topographic, and engineering constraints and requirements. Requirements included maintaining a cover of at least 35 feet over the tunnel, having easily accessible

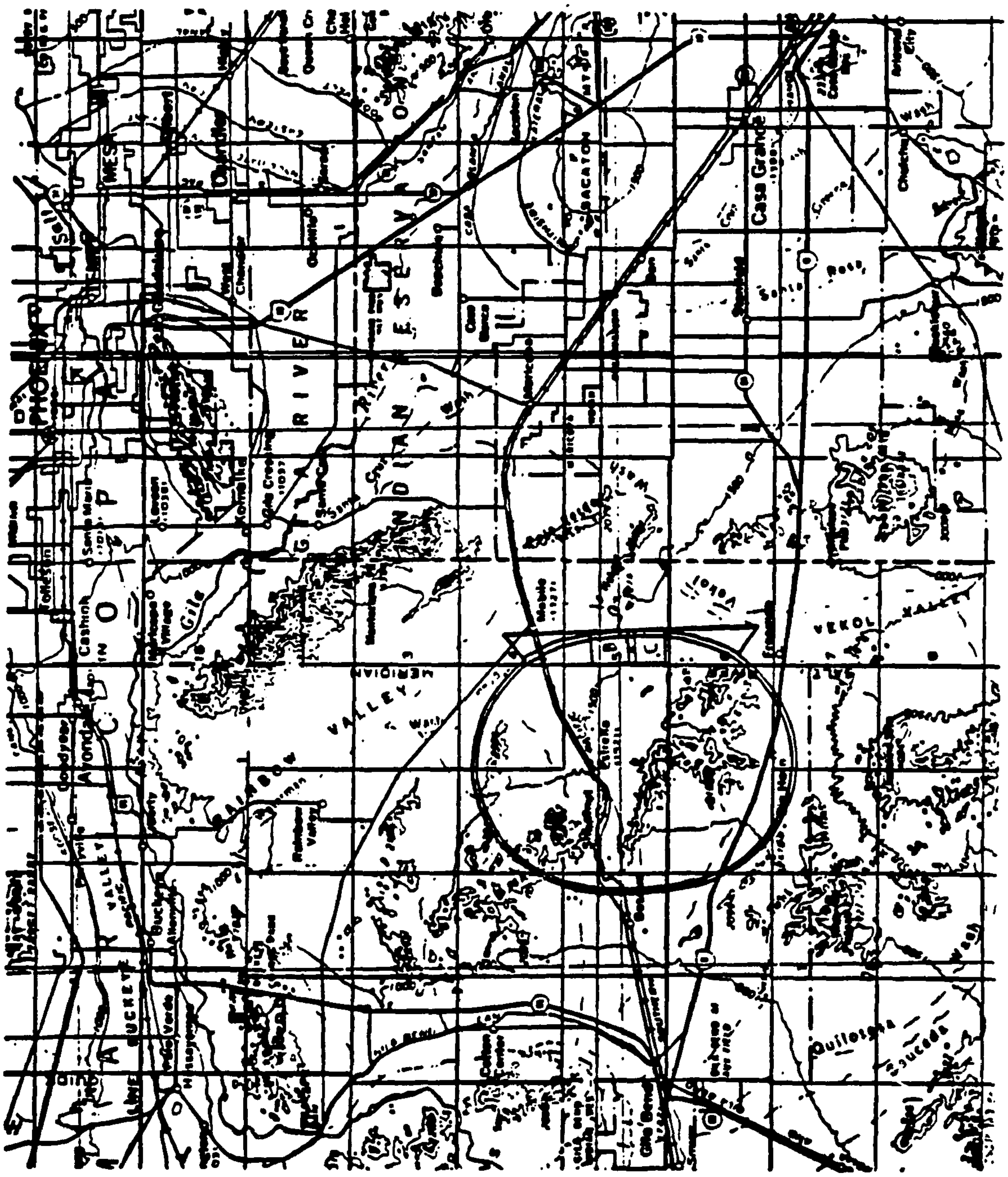


Figure 1. Regional Location Map

service and utility shafts which are spaced every 2.5 miles around the ring, and staying safely below or away from major sources of vibration such as the Southern Pacific Railroad and Interstate Highway 8. Geographical constraints include the Goldwater Bombing Range to the south and potential land surface subsidence due to ground-water withdrawal in northern Waterman Wash basin to the north. A topographical constraint was imposed by the preference to keep the enormous collision halls/particle detectors close to the surface.

The size and logistical requirements of the SSC are met only by a large, relatively uninhabited area with no future plans for large-scale development. These same conditions commonly characterize an area where detailed hydrologic investigations are unnecessary. As a result, the development of a hydrologic database for the SSC was hindered by a lack of previous surface and subsurface investigation. In addition, only limited funds were allocated for SSC hydrologic investigations which in turn has limited the amount of new surface and subsurface information obtainable for this thesis. This lack of information has been offset somewhat by a maximum use of available geological, geophysical, and geotechnical measurements made in connection with other phases of the project.

Purpose and Scope

Thorough and accurate descriptions of both the ground-water hydrology and surface-water hydrology are vital aspects of choosing an ideal site for the SSC. Ground- and surface-water hydrology are important parameters in estimating project construction costs, scheduling, and long-term operational costs. In addition, they are key components in the preparation of the Environmental Impact Statement (EIS) necessary to comply with the National Environmental Policy Act (NEPA). I hope that this thesis can provide a guide for future hydrologic work being planned for Phase II which is the investigation of sites selected by DOE from the original large number of candidates and the EIS to be done on the final preferred site.

A thorough literature review discovered little hydrologic information for the Maricopa SSC site and money for the acquisition of new, site-specific hydrologic data was not available. Primary sources of information used were 1) past geologic studies and recent mapping done in conjunction with the SSC project; 2) drill-hole information gathered during geotechnical investigations; 3) recently obtained geophysical data which includes seismic refraction, electrical resistivity, and a large gravity data base; and 4) remote sensing information from aerial photography and Landsat Multispectral Scanning images. An integration of the information obtained from these disciplines has provided an adequate hydrogeologic description of the Maricopa site without an expensive drilling program.

Information Needed

The Invitation for Site Proposal (ISP) issued in April, 1987 by the U.S. Department of Energy is a diverse yet specific document with regards to information requested. Although separated into eight volumes and arranged in topic-specific categories, hydrologic-related needs are found throughout the ISP. The following list details these needs as outlined in the ISP.

1. Profile of the tunnel, illustrating position of rock/soil contacts, formations, and ground-water conditions with respect to the proposed tunnel and other underground facilities.
2. Identify and describe areas that may be affected by subsidence, such as... areas in which water or other fluids are withdrawn from the ground in

sufficient quantities to cause surface displacements.

3. Detailed characteristics of (a) the overall hydrogeological regime, including ground-water table, perched ground water, and the interaction with surface streams, and (b) precipitation and annual and historical variations in ground-water levels around the site. Permeability results should be representative of each saturated unit anticipated within the proposed construction areas. In bedrock, primary and secondary permeability should be differentiated in order to characterize the rock mass.

4. Water-resources information, including water-quality information for local aquifers and identification of ground-water resources. Identify the applicable water-quality standards. If local ground water resources are to be used for SSC project needs, indicate what effect ground-water depletion will have on surface subsidence in the vicinity of SSC facilities.

5. Identification of locations where underground construction may be impacted as a result of ground-water pressure or inflows, effects of swelling clays, or by chemical constituents of the ground water, including alkalinity and salinity.

6. Delineation of major drainage basins and identification of major surface-water features.

7. Baseline and seasonal variations in quantity of the surface waters.

8. Baseline and seasonal variations in quality of the surface waters identified.

9. Identification on maps of the extent of flood areas and corresponding flood frequency.

10. Itemization of the available sources of water proposed for use as industrial cooling water and their seasonal variations.

11. Estimated cost to the SSC project of industrial cooling water delivered to the campus and service area locations.

12. Description of the physical and chemical properties of the water available for use as industrial cooling water and any treatment that may be required.
13. Description of the sources of water available for use as potable water.
14. Estimates of the present and projected cost of potable water delivered to the campus and experimental areas.

As can be seen, a complete discussion of ground- and surface-water hydrology is expected in addition to the identification, procurement, and cost estimate of an adequate supply of water. This thesis will concentrate on the hydrogeology of the site along with a description of the available sources of water.

Well-Numbering System

The well numbers used in this thesis follow numbering which is based on land subdivision and is the same system as is used by the Arizona Department of Water Resources and the Water Resources Division of the U.S. Geological Survey. The land survey in Arizona starts at the Gila and Salt River meridian and base line respectively, which divide the State into four quadrants (Figure 2). All the well locations mentioned in this thesis are in the southwest quadrant (C) or the south-east quadrant (D) of the state. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The first letter denotes a particular 160-acre tract or 1/4 section the second the 40-acre tract, and the third the 10-acre tract.

Units

The units used in this thesis are those used in the DOE Invitation for Site Proposal. In general, these will be English but occasionally metric (e.g. permeability in

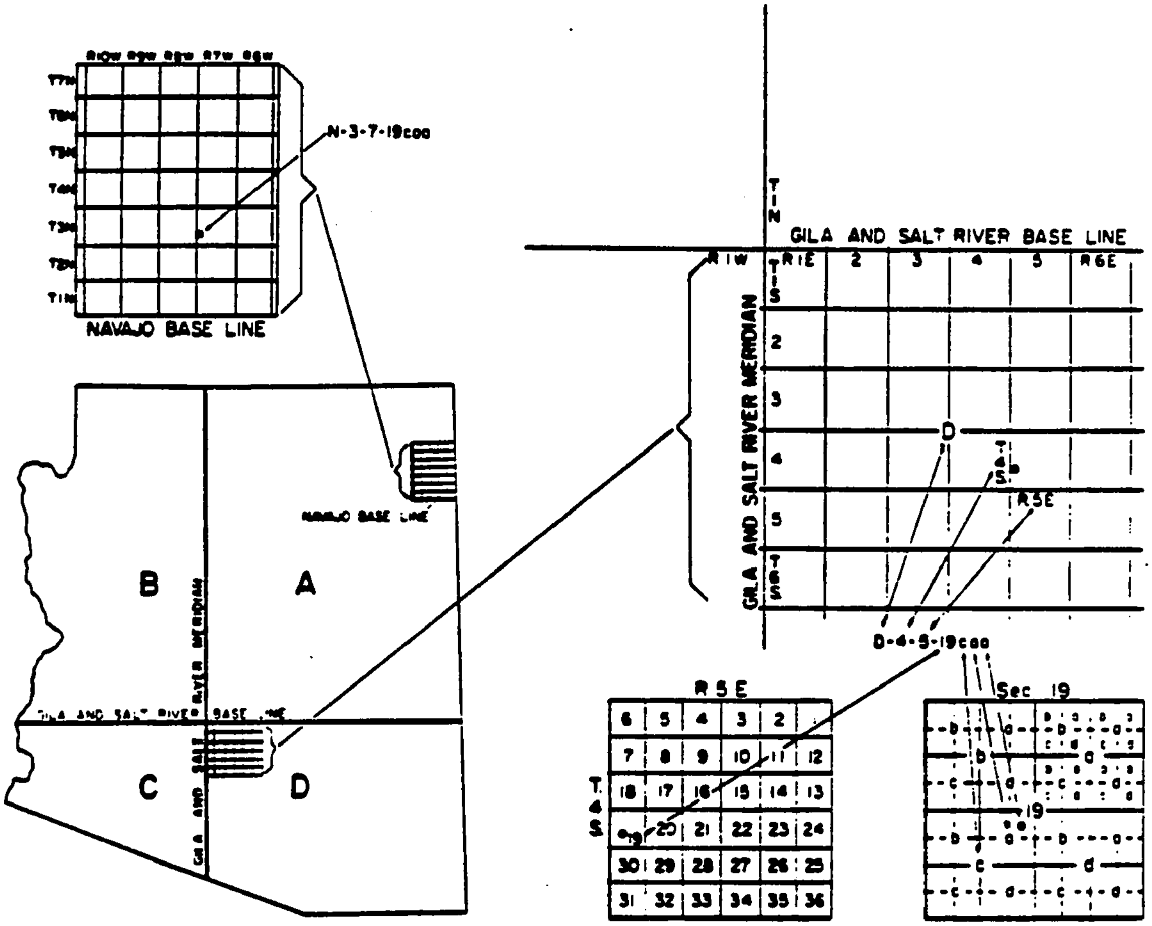


Figure 2. Well and spring location system used in this report

cm/sec) units will be seen.

Description of Study Area

The Maricopa SSC Site is in Maricopa County, 35 miles southwest of Phoenix. The proposed alignment of the accelerator (Plate 1) encircles the southern Maricopa Mountains and passes through the northern Maricopa Mountains. The center of the SSC facility is at 32° 58' 14"N latitude and 112° 23' 53"W longitude. The major axis of the collider trends N4°W. The highest elevations in the Maricopa Mountains are approximately 3,100 feet falling to 1,150 feet in the adjacent valleys. The SSC plane has been positioned with a 0.30 degree tilt to the southwest. It passes close to the surface in the eastern and western sections of the ring path and passes at greater depths beneath the surface in the northern and southern sections of the ring. As preferred by the DOE in the Invitation for Site Proposals (ISP), greatest consideration was given to keeping the injection facilities, labeled as B on Plate 1, and the experimental chambers, labeled as K, as close to the surface as possible. The plane is within 100 feet of ground surface at the east campus area and injector complex, and within 80 feet of ground surface at the west experimental campus.

The study area for this report will include the entire area circumscribed by the ring plus hydrologically important areas outside of the ring (Plate 1). These additional areas include most of Waterman Wash basin and the northern Vekol Valley basin.

The Maricopa Site traverses portions of the Waterman Wash, Vekol Valley, and Bosque hydrogeological basins which are structural depressions surrounded by mountains that are composed of intrusive rocks, mostly granite, with small areas of metamorphic and sedimentary rocks. The basins are underlain by dense, impermeable bedrock. Pediment areas, in which the bedrock is at a shallow depth, extend valleyward for varying distances from the base of the mountains. The central portions of the valleys are underlain by great thicknesses of basin-fill sediments. These sediments are composed of alluvial fan and alluvial plain deposits consisting of lenticular beds of gravel, sand, silt, and clay.

The Waterman Wash area is in a northwest-trending valley about 30 miles long and 10 miles wide which is bounded by the Buckeye Hills on the north, the Haley and Booth Hills and Palo Verde Mountains on the south, the Sierra Estrella on the east, and the Maricopa Mountains on the west. Waterman Wash, with a drainage area of about 400 mi^2, flows northward and leaves the valley between the Buckeye Hills and the Sierra Estrella.

Northern Vekol Valley is a north-trending valley about 12 miles long and 5 to 10 miles wide. It is bounded by the Table Top and Vekol Mountains on the east, the Sand Tank and Maricopa Mountains on the west, and the Booth and Haley Hills on the north. Vekol Wash flows northward exiting through a narrow gap between the Haley Hills and Table Top Mountains.

The Bosque area, an eastern extension of the Gila Bend basin, is about 15 miles long, 2 to 10 miles wide, and is bounded by the Maricopa Mountains on the north and east, the Sand Tank Mountains on the south, and the Gila River on the west (Wilson, 1979). The major drainage is Bender Wash which flows northwest into the Gila River.

Most of the land included in the Maricopa Site is controlled by the Federal Government under the administration of the Bureau of Land Management. Smaller portions are privately or State owned.

Under boundaries set by the Arizona Groundwater Management Act of 1980, the site is in two active management areas (AMA), the Phoenix AMA (Waterman Wash basin) and the Pinal AMA (Vekol Valley basin), and a non-AMA (Gila Bend basin).

Climate

The climate at the Maricopa SSC site is arid and is characterized by hot, dry summers and mild winters. The average annual temperature at an elevation of 1200 feet is 71°F (22°C). Rainfall averages 6.50 inches per year with most of it occurring from July through September due to short but intense convective storms. The potential evaporation rate is estimated to be 90 inches per year (Sellers et al., 1986). These arid conditions reduce the amount of precipitation available for recharge to the ground-water reservoir.

Previous Investigations

The lack of any perennial surface water combined with the great depth to ground water have effectively discouraged any large-scale development from occurring at the Maricopa site. As a result, few hydrologic investigations have been made of the area. In addition, the site is considered metallogenically barren resulting in virtually no mining activity in the area.

Wilson (1979) provided the most thorough summary of ground-water conditions in the Waterman Wash, Vekol Valley, and Bosque areas. The report by Wilson provides much of the deep-basin information for the Waterman Wash basin and the only information for the Bosque basin. Matlock (1983) constructed generalized numerical models for the Waterman Wash, Vekol Valley and Bosque basins utilizing Wilson's work. Hollett and Marie (1986) further expanded the work on Vekol Valley by developing a detailed numerical model to provide management information, and well-field design and operation for the northern Vekol Valley basin. Earlier summaries of ground-water conditions in the Waterman Wash area were provided by White (1963), and Denis (1968). The Bosque and Vekol Valley were essentially uninvestigated prior to Wilson (1979). Additional work, done by private consultants, includes hydrogeologic analyses of the Arizona Hazardous Waste Site (ADWS), about six miles west of Mobile, and a proposed oil refinery one mile southeast of Mobile.

Chapter 2

Method of Investigation

New geologic and hydrologic data were not required by the DOE for the proposal stage. However, the intense inter-state competition for the project dictated site characterization well beyond what was formally required.

In many ways, the Maricopa site is hydrologically simple and easily assessed. As a result and in response to the ISP, many of the hydrologic concerns can be dismissed and needs fulfilled. The arid climate, deep water table, and remote, uninhabited location suggest a hydrologically ideal site for construction of the SSC. However, these same attributes contribute to water-supply problems related to the operational phase.

The lack of site-specific data places an uncertainty on the assumptions of hydrologic simplicity and lack of tunnel construction problems. With a limited budget for site characterization, and most of this being allotted for geotechnical studies, a multidisciplinary approach was used in the present study. This approach combined available hydrologic information with a thorough understanding of the site geology reinforced by a program of surface geophysics. Coordination among the various engineering and geologic interests in locating and designing the geophysics and subsequent drilling programs resulted in an efficient utilization of the money and time available for site characterization.

In describing the hydrogeology of the area a fundamental assumption was that certain aquifer properties and flow system processes are common to many Southwestern basins and that hydrogeological similarities can be assumed in using properties and processes estimated from well-documented basins for basins with sparse data. This was the approach taken by the U.S. Geological Survey (USGS) in their Regional Aquifer-System Analysis (RASA) Program to study the Nation's ground water on a regional scale.

The alluvial geology is paramount in describing Basin and Range aquifer systems. Adequate understanding of the region's tectonic history and the depositional processes which produced the aquifer material allow for a qualitative, and to some extent quantitative, understanding of the aquifer properties. Additionally, the quality of ground water in alluvial basins is closely related to geology, mineralogy, structure, internal and external drainage patterns, and historical development (Anderson, 1985). Therefore, particular attention was paid to interpreting the geologic history and depositional processes which formed the basin in question. This was accomplished using a detailed literature review of Southwestern basin and range geology, drillers logs, and information obtained from the SSC Arizona Project geotechnical exploration programs.

Throughout 1986 and part of 1987, the Arizona SSC Project undertook geophysical exploration and geotechnical drilling programs. Geophysical exploration included seismic refraction, gravity, magnetic, and resistivity surveys along segments of the ring path lacking bedrock outcrops (Bryan et al., 1987; Sternberg and Esher, 1987; Sternberg et al., 1987; Sternberg and Sutter, 1987). The geotechnical drilling program (Plate 2) consisted of three diamond-drill core holes, six augered holes, and two reverse-circulation air-rotary holes (Cummings et al., 1987; Sergent, Hauskins, and Beckwith Inc., 1987). Additionally, standard borehole geophysical logs were run in the rotary holes and four of the auger holes. The noticeable lack of hydrologic-specific field work was due, in part, to my conclusion that the tunnel could be situated wholly above the water table and, therefore, many of the DOE hydrologic concerns were irrelevant.

Surface Geophysics

Surface geophysics is a well known and commonly employed tool in geologic and engineering site characterization. It has also proved to be an indirect and inexpensive means of determining general hydrogeologic conditions. General targets for geophysical investigations are basin structure, basin stratigraphy, and depth to water.

The attractiveness of the Maricopa site was in large part due to its apparent geologic and hydrologic simplicity. However, the sparse geologic information, essential for assessing possible construction methods, and the sparse hydrogeologic information, essential for construction methods and ground-water resource evaluation, attach uncertainty to the apparent simplicity of the site. In order to answer or dispel the geotechnical uncertainties without exceeding the budget, close cooperation was required among the technical committee in designing the geotechnical program.

In designing a program to characterize geotechnically an area as large and previously uninvestigated as the Maricopa site, a program of surface geophysics was the logical first choice. The benefits of first performing a general, large-scale geophysical survey are many-fold. They include: 1) it is relatively fast and inexpensive (compared to drilling); 2) it can be used as a "first look" to guide the location of drilling so that the most relevant information can be obtained; and 3) after drilling is completed, geophysical measurements can be calibrated using information from the drillholes.

The geophysics program included a gravity survey consisting of more than 400 stations, more than 40,000 feet of seismic refraction line, and almost 9,000 feet of direct-current resistivity. Detailed discussions of theory and procedures used in individual geophysical methods can be found in Zohdy et al., (1974) and Telford et al., (1976). The following is a brief discussion of how surface geophysics can aid in hydrologic analyses and how it was used by the Arizona SSC technical group. Further mention of its benefits (and some of its problems) can be found interspersed throughout the sections on geology, hydrogeology, and subsidence potential.

Gravity

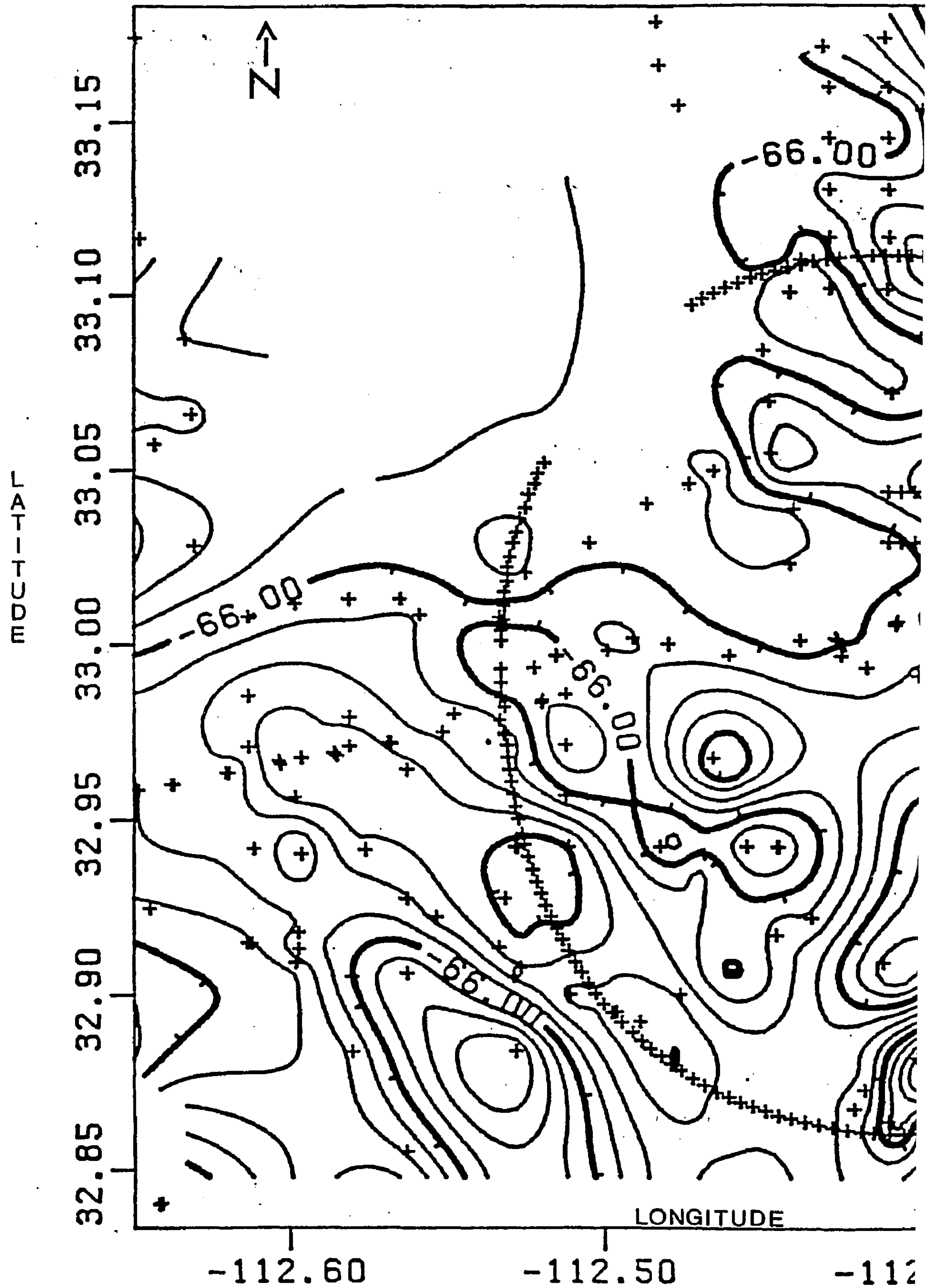
A gravity survey is an excellent, low cost means of providing basic data on configuration of the basement complex. Provided an adequate density contrast between the nonindurated sediments and the underlying bedrock exists, it can assist in determining the general configuration of the bedrock surface and in planning the location and spacing of seismic refraction profiles. The presence of predominantly granitic basement rock with an alluvial cover of varying thickness appears to provide the simplicity and the density contrasts necessary to allow accurate interpretation and description of the basins using the gravity method.

The gravity survey of the Maricopa site consisted of stations at one-quarter mile intervals along the tunnel alignment, grids of closer spacing in areas of greatest interest and randomly located stations at points of known or easily determined elevations in the more remote areas. After standard data reduction a complete Bouguer anomaly map (Figure 3) was produced of the region (Sternberg and Sutter, 1986).

A major objective of the gravity survey was to map an assumed basin-bounding fault on the west side of Waterman Wash valley and to determine the extent of the pediment development northeast of the northern Maricopa Mountains. This assumed fault, herein called the pipeline fault, trends northwest, roughly parallel to the El Paso natural gas line just northeast of the site. It was hoped that shallow depth to bedrock to the west of the fault could eliminate the fear of ground-water decline and subsequent land surface subsidence at the tunnel alignment caused by ground-water withdrawals in the Waterman Wash agricultural areas. The closely spaced Bouguer anomaly contours trending northwest leading to a gravity low near the center of the Waterman Wash basin supported the presence of a fault (Figure 4). However, quantitative modeling is necessary in order to calculate the depth to basement. Preliminary modeling by the University of Arizona, Geophysics Fieldcamp (Bryan et al., 1987) also supports the presence of a fault but show the bedrock elevation west of the fault to be well below the water table. Further discussion on this topic can be found in the section on alluvial geology and the section on subsidence potential.

Seismic Refraction

The most common use of the seismic method in hydrogeology is in the determination of the thickness of sediments which overlie essentially non-water-bearing bedrock. This, and the determination of compressional wave velocity as an indicator of



CØMPLETE BØUGUER GRAVITY FØR MARIC

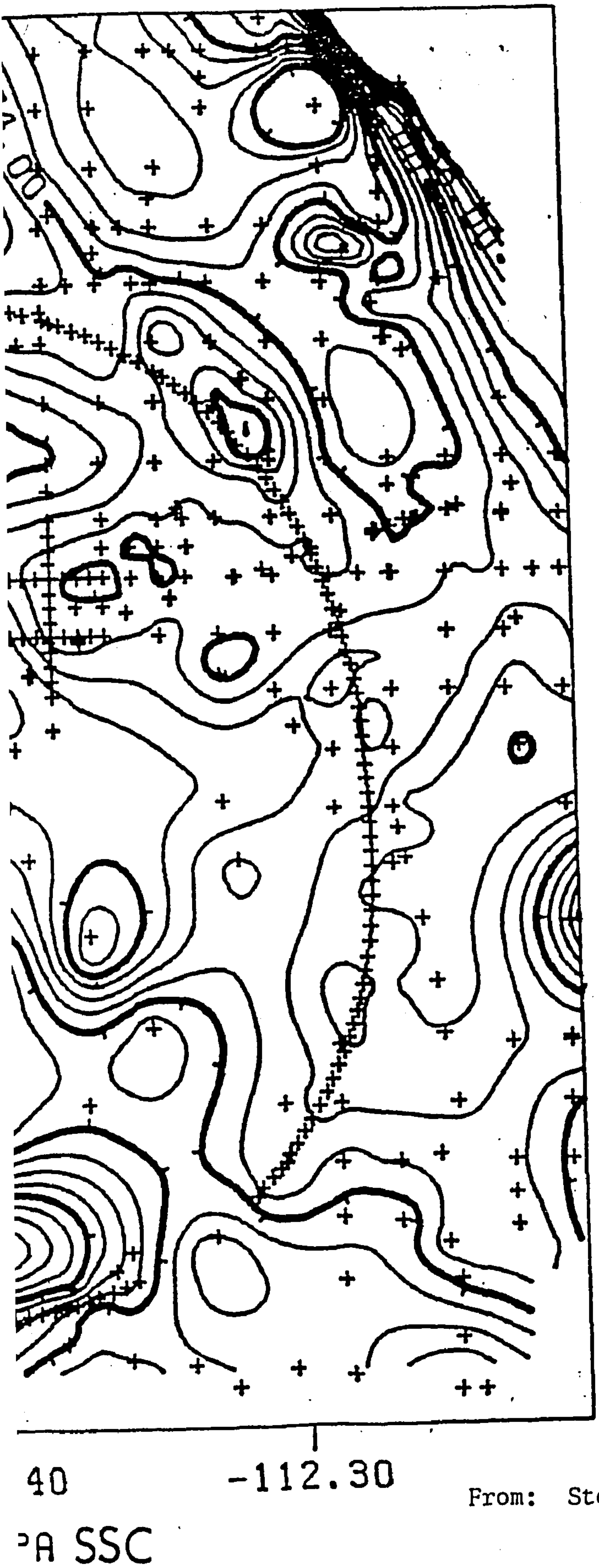


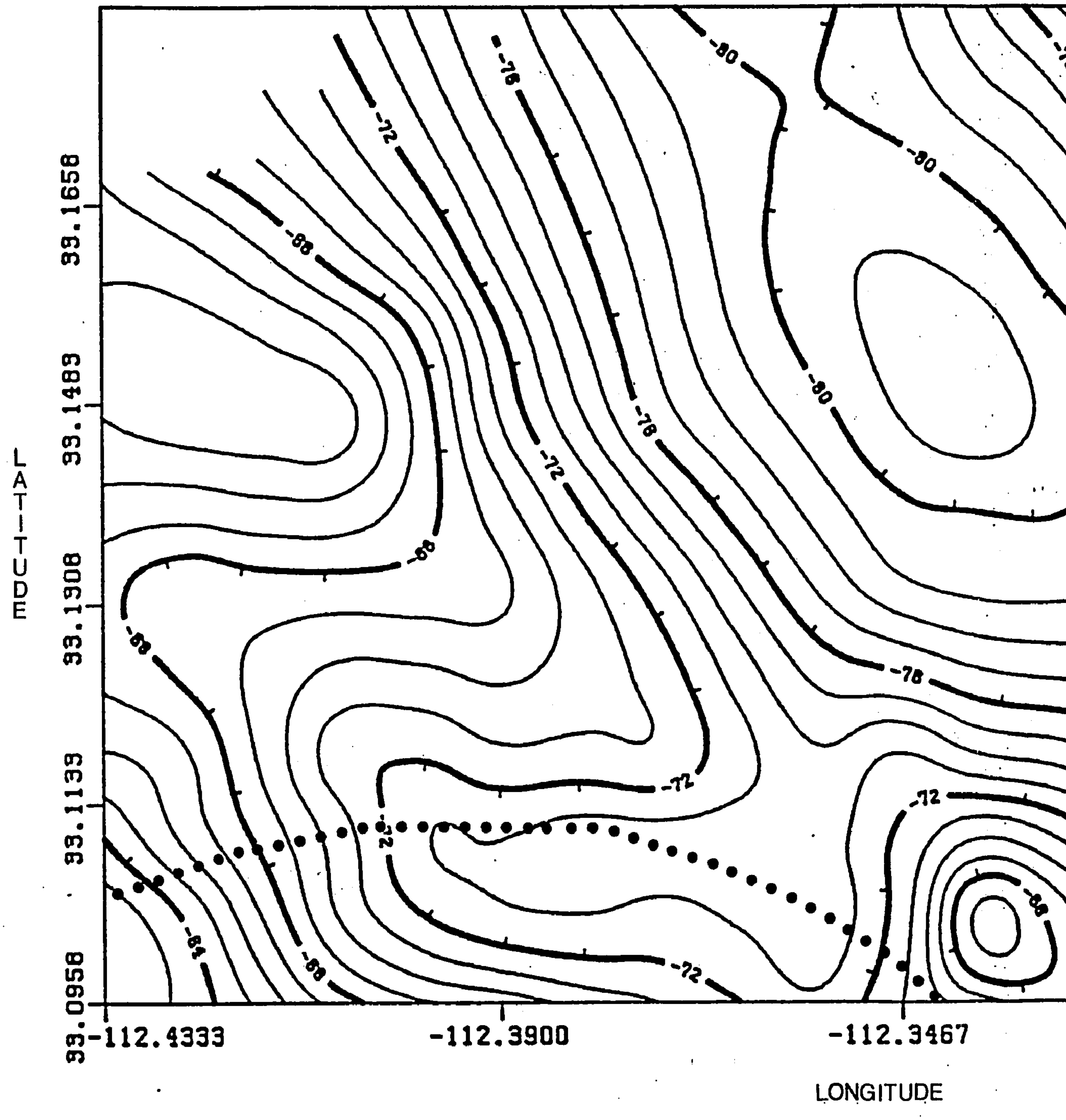
Figure 3

+-gravity station

—— – CONTOUR INTERVAL (2mgals)

From: Sternberg and Sutter, 1987

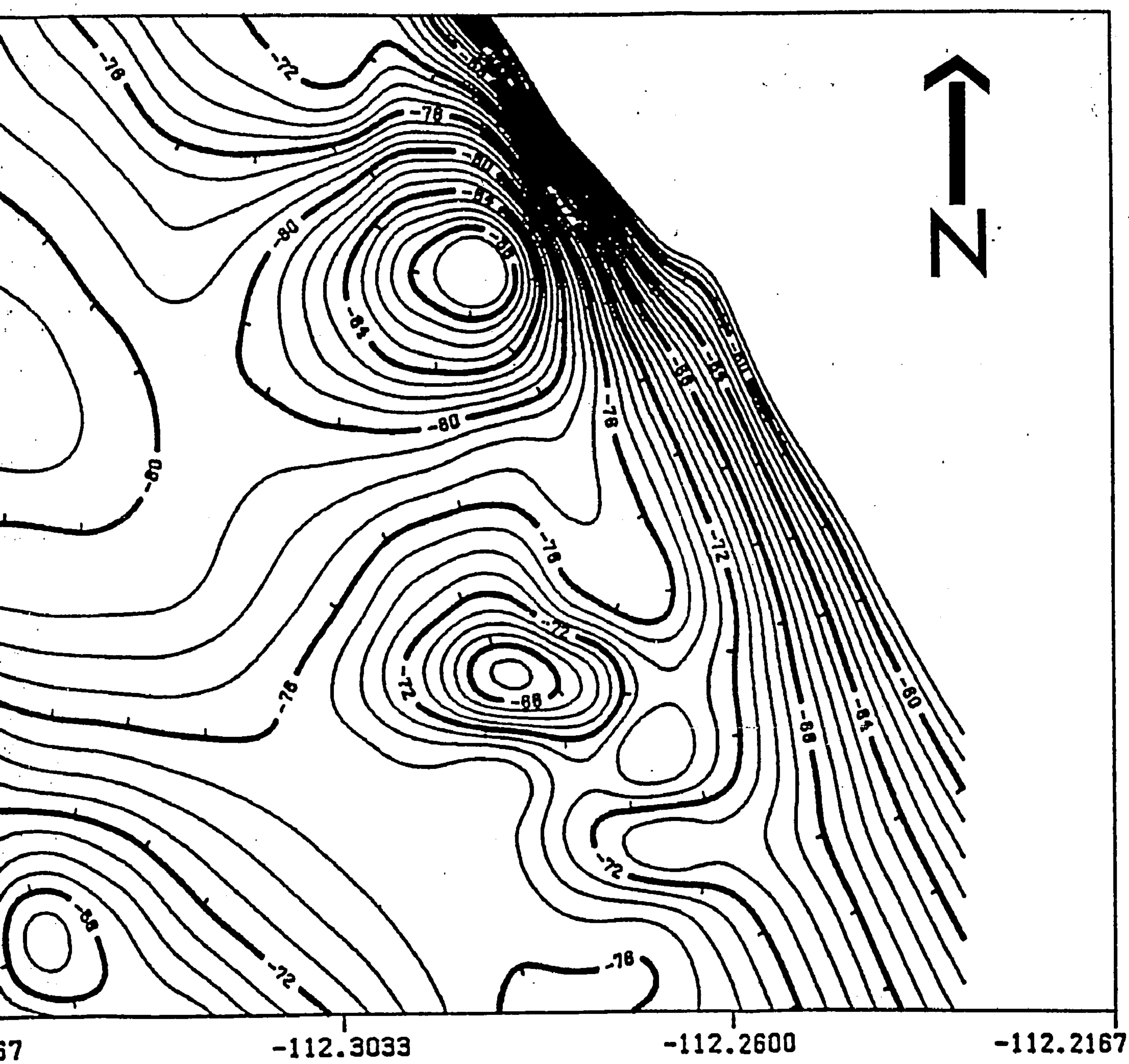
Figure



●●●●● — SSC
——— contours in mgals

complete bouguer anomaly map—

Figure 4



From: Sternberg and Sutter, 1987

map—northeast section

alluvial strength were the main targets of the seismic refraction work done at the Maricopa site.

Although the great bulk of all applied seismic work done today is done by the reflection method, the refraction method is more common in hydrologic work and was better adapted to the needs and the characteristics of the Maricopa site. Good reflection records would be difficult to obtain in the thick alluvial cover present in much of the area. Also, Zohdy (1974) says "In areas where steeply dipping boundaries are encountered, the refraction method is better suited for exploration than the reflection method". Because the Basin and Range-type geology which is found at the Maricopa site abounds in steep boundaries the method was chosen. Another consideration is that no prior knowledge of sediment velocities is required in reconnaissance refraction measurements and the velocity information obtained may help in characterizing the strength of the material investigated.

Many attempts to measure the depth to the water table by seismic refraction, in particular those of Tucci and Pool (1986); and Libby et al. (1970), have been completed in southern Arizona. This was generally unnecessary and not possible at the Maricopa site because of the great depth to water. A typical 1320-foot refraction line with twelve, 120-foot geophone spacings would investigate to depths of about 250 to 300 feet. A one-half mile line, which increased the effective depth to about 600 feet, was run between sections 32 and 33 in C-4-1 (Plate 2). Initial interpretation showed a refractor with a velocity increase of 3,400 ft/sec to 7,500 ft/sec at an apparent depth of 300 feet (Appendix 1). This velocity change agrees closely with what Tucci and Pool (1986) found to occur at the water table in similar materials. However, subsequent drilling found the water table to be at a depth of 385 feet and no readily apparent lithologic difference at 300 feet. The discrepancy of 22 percent is greater than expected, even in reconnaissance geophysics work. Reinterpretation of the data, more carefully considering the low velocity weathered zone at the surface was performed but did not increase the depth to the refractor (Sternberg et al., 1988). Examination of other drillholes with lithologic and borehole geophysical logs showed a similar discrepancy. A USGS exploration hole four miles east of MD-7, and an exploration hole for a proposed oil refinery seven miles to the southeast showed changing geophysical responses and drilling time with no major lithologic change (Wilson, 1979 and Manera, 1982). Re-examination of the geologist log from MD-7 revealed an increase in clay content from 240 to 290 feet, a thin greenish-gray clay lense at 295 feet, and a slightly moist silty sand with moderate to strong lime cementation. The combination of all these factors may have increased the density and compressional strength of the basin-fill such that it's sonic velocity was similar to saturated alluvium.

Electrical Resistivity

Surface electrical techniques have long been used for a wide variety of geotechnical and ground-water exploration problems. These include self potential, induced polarization, and d.c. resistivity. The popularity of these methods has been due in part to their low cost compared to drilling and their ability to obtain information which can be related directly to water quality. The electrical technique most widely used for ground-water exploration is d.c. resistivity owing to the relatively low equipment cost, ease of performing surveys, and the abundance of interpretation methods. Bisdorf (1986) wrote "direct-current resistivity measurements are the most extensively used electrical technique for engineering applications". In hydrogeology, recent trends have been towards detection of water quality changes from waste sites or contaminant leaks and spills. More traditional hydrologic uses have been mapping of the water table and clay layers. The success of electrical methods, as in other geophysics tools, depends largely upon the presence of significant and detectable contrasts of the earth's properties. In resistivity soundings this contrast can be provided through changes in water content and water quality, particularly salinity, and through geology with changing lithology and porosity.

Identification of the water table using d.c. resistivity has met with limited success in Arizona (Tucci and Pool, 1986). At the Maricopa site, d.c. resistivity was used primarily to locate thick clay layers or other fine-grained deposits which could impact construction methods and costs, and to compare the interpreted changes with depth with the seismic refraction results. Hydrologically, these results could be useful for locating perched water and subsidence-prone material.

Conclusions and Limitations of the Surface Geophysics Program

The problem of equivalence in the interpretation of geophysical data is well known. Equivalence refers to the inability to determine certain properties of thin layers when noise is in the data. In alluvial deposits this is an especially acute problem because of the rapid horizontal and vertical facies changes. Large electrical or velocity contrasts and/or thick layering is desired in picking boundaries and these generally are not present in alluvial deposits which increases the demand for geologic data of high quality.

Some useful information and probable cost savings did result from the surface geophysics program. The extensive gravity survey adequately differentiated the deep basins from the pediment areas and provided a basis for planning of the drilling program. Future refinements in modeling of the gravity data should further quantify the thickness of alluvium beneath the collider tunnel and the possibility of ground water being present. Current work shows that although most of the alluvial portions of the Maricopa site are on a pediment, some sections do have alluvial deposits thick enough to be a part of the regional aquifer system and thus contain ground water which, if withdrawn, might cause subsidence.

The seismic refraction work was useful in confirming the basin structure and assumed alluvial depths inferred from the gravity work. Though seismic refraction is commonly used and relatively successful in identification of the water table it was unnecessary, and therefore, not utilized for this purpose at the Maricopa site. The great depth to the water table and the careful placement of the tunnel to avoid ground water, suggest that an interaction with the regional aquifers will not take place if the SSC is constructed. The compressional velocities calculated for the alluvial material do allow an estimate to be made of its degree of consolidation and its strength. This aids in assessing the potential for ground-water withdrawal causing subsidence. The results show the deposits assumed to be below the water table to have minimum seismic velocities in excess of 7,000 ft/sec. This velocity suggests a competent material which will be unlikely to compact and cause subsidence.

The electrical resistivity data were the most complex and, therefore, the most difficult to interpret and utilize. The lithologic and stratigraphic complexity of the alluvial fan and fluvial deposits present, demand more and better subsurface checks, by means of drillhole data, to use electrical methods with confidence.

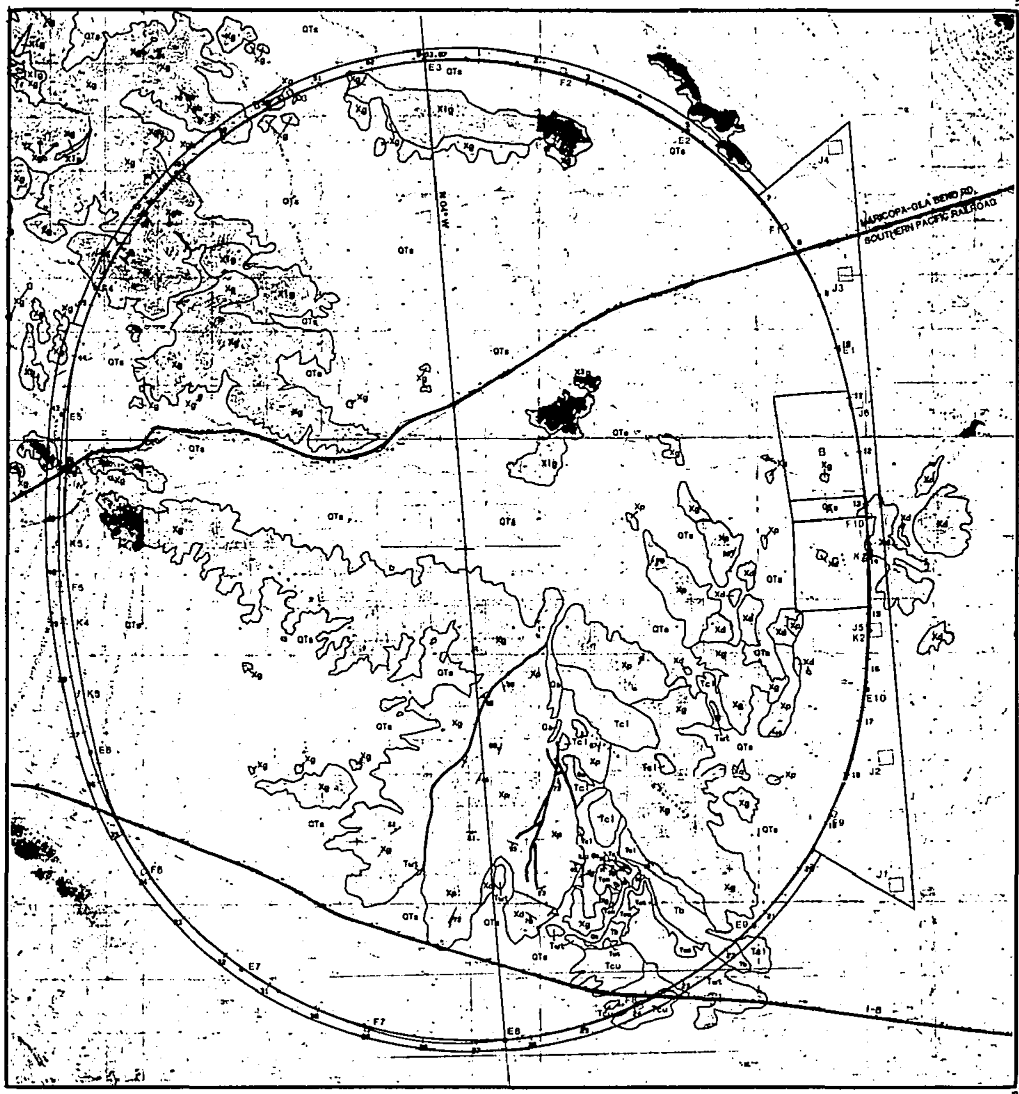
Chapter 3

GEOLOGY AND GROUND-WATER HYDROLOGY

Geologic characteristics and the geologic history of an area are important keys to the understanding of the hydrogeology of the area. Geologic characteristics, such as the structural and depositional history of the basin along with the mineralogy of the basin-fill's source rock, control the physical and chemical properties of the aquifer. The Maricopa site hydrogeology is complex in that it extends through three hydrologic basins each with a complex structural history. However, this geologic complexity has created a relatively simple hydrologic system through its formation of well-defined basins with essentially impermeable lateral boundaries and predominantly water-table conditions. It is felt that an understanding of Basin-and-Range depositional systems along with a potential range of aquifer properties determined from other basins or other parts of the same basin with similar geology and geologic history, should adequately describe the area for the present stage of site characterization.

Bedrock Geology

Few geologic studies of the Maricopa Mountain region have been made. The first reconnaissance geologic map (Figure 5) of the area was completed in 1987 at the request of the Arizona SSC Project (Cunningham et al., 1987). Prior to this the Maricopa Mountains had been discussed only in a cursory fashion as part of regional work of the U. S. Geological Survey (Ross, 1923; Kahle et al., 1978; Hollett and Garrett, 1984; Peterson et al., 1985) and the Arizona Geological Survey (Wilson et al., 1957; Morrison, 1984). The following descriptions and conclusions are drawn from these sources as well as from independent studies carried out by



ROCK UNITS

Qa	SURFICIAL DEPOSITS (QUATERNARY)
QTs	FANGLOMERATE (QUATERNARY AND LATE TERTIARY)
Tcu	UPPER CONGLOMERATE (MIDDLE TERTIARY)
Twt	WELDED TUFF (MIDDLE TERTIARY)
Tcm	MIDDLE CONGLOMERATE (MIDDLE TERTIARY)
Tb	BASALT (MIDDLE TERTIARY)
Tcl	LOWER CONGLOMERATE (MIDDLE TERTIARY)
Xlg	LEUCOCRATIC GRANITE (EARLY PROTEROZOIC)
Xgb	GABBRO (EARLY PROTEROZOIC)
Xg	PORPHYRITIC GRANITE (EARLY PROTEROZOIC)
Xd	DIORITE (EARLY PROTEROZOIC)
Xdg	DIORITE AND GRANITE, UNDIFFERENTIATED (EARLY PROTEROZOIC)
Xp	PINAL SHIST (EARLY PROTEROZOIC)

SYMBOLS

- CONTACT: DASHED WHERE INFERRED OR APPROXIMATELY LOCATED
- FAULT
- STRIKE AND DIP OF BEDDING
- STRIKE AND DIP OF FOLIATION
- STRIKE OF VERTICAL FOLIATION

FIGURE 5
SITE GEOLOGIC MAP
MARICOPA SITE

SCALE 1:62500
1 .5 0 1 2 3 4 MILES
3000 0 3000 6000 9000 12000 15000 18000 FEET
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NORTH

team members of the Arizona SSC project.

The Maricopa Mountains are composed predominantly of Proterozoic plutonic and metamorphic rocks. The oldest rock unit, Proterozoic Pinal Schist, occurs in the southern Maricopa Mountains. The schist has been intruded by Proterozoic granitic rocks, of which most of the range is composed. The plutonic rocks consist of two separate granitic plutons and a dioritic pluton. A sequence of Tertiary sedimentary and volcanic rocks overlies the Proterozoic basement in the southeastern corner of the range. Paleozoic and Mesozoic lithologies are recognized in the Maricopa Mountains.

The Tertiary sequence consists of a gently southwest-dipping stack of sedimentary and volcanic rocks that form an asymmetric southeasterly plunging trough that disappears beneath younger sediments. The lowermost unit consists of a poorly sorted dominantly granite-clast conglomerate that was derived from Proterozoic basement. Field relations suggest that the basal conglomerate is in depositional contact with the basement. Above the lower conglomerate lies a sequence of dense to highly vesicular basalt flows dated at 20.4 Ma (million years) by Shafiquallah et al. (1980). A granite- and schist-clast conglomerate unit that contains smaller clasts than the basal conglomerate is above the basalt. This middle conglomerate unit locally contains a basal sandstone and is intercalated with locally great thicknesses of vesicular basalt. A welded tuff overlays the middle conglomerate along an angular unconformity and is probably unconformably overlain by an upper conglomeratic unit. The thickness of each unit has not been measured, and may vary considerably. The Tertiary section was drilled (MD-1R) to a depth of 1,250 feet without encountering basement. A 500-foot electric sounder detected no

water in this hole, indicating either a very deep bedrock water table, or more likely, an impermeable ground-water divide between the Vekol Valley and Bosque hydrologic basins.

In much of Arizona, the Paleozoic Era was characterized by transgressions of broad epicontinental seas that covered the region and deposited thick sequences of marine sediments. No record of these events is preserved at the surface in the Maricopa SSC region, but it is remotely possible that Paleozoic sedimentary rocks may be buried deeply in the basins beneath alluvial cover (Peirce et al., 1970). Similarly, Mesozoic plutonic, volcanic, and sedimentary rocks, which occur commonly throughout Arizona and represent Jurassic and Laramide orogenic events, are not found on the surface or in the subsurface in the site region, but may occur deeply buried beneath basin-fill (Peirce et al., 1970).

In southern Arizona, crustal extension occurred in the middle Tertiary at both deep and shallow crustal levels. In late Tertiary time, extension formed block faults during the Basin and Range disturbance. This event, which is responsible for the present physiographic character of the area, was characterized by mostly east-west extension occurring along north-south-trending normal faults. Accompanying regional extension was widespread silicic and basaltic volcanism. Basin and Range extension ceased in the Maricopa region in the Late Tertiary probably prior to 5 Ma ago. Since then, the region has undergone very little tectonic activity. The Maricopa Site area is now characterized by eroding mountain fronts, extensive pediment development, and an integrated drainage system, all signs of a tectonically quiescent region.

Alluvial Geology

The alluvial basins traversed by the Maricopa SSC site are typical of many in southern Arizona. For the most part consisting of locally derived clastic sediments and lesser amounts of interbedded volcanics.

Basin-fill units of the Maricopa site are not dated by radiometric methods, but the regional geologic history of southwestern Arizona can probably generally be applied to these materials. Eberly and Stanley (1978) divided southern Arizona Cenozoic sedimentary deposits into an older Unit I and a younger Unit II. They describe the general structural history of southwestern basins:

> "Sedimentation during early Cenozoic time (Unit I) took place in broad interior depressions under predominantly continental conditions. The late Miocene block-faulting episode changed the geography of southwestern Arizona and gave the area a typical basin-and-range structure of mountain-forming horsts separated by valleys underlain by grabens or half-grabens. The prevailing structural grain trends in a northwest direction. Unit II sediments were deposited in these troughs or grabens during late Cenozoic time".

Shafiquallal et al., (1980) described a history where Tertiary sediments and volcanics were probably first tilted, producing widespread angular unconformities. This Tertiary tectonic event has been bracketed between 16.9 and 15.0 Ma in the area of the nearby Palo Verde Nuclear Generating Station (PVNGS, 1975). This tilting appears to have been accomplished by rotation of relatively small crustal blocks along shallow listric normal faults (Shafiquallal et al., 1980). Sediments shed into topographic lows produced during these events are probably found deep in the basins around the Maricopa site and are analogous with the previously mentioned Unit I.

Steep normal faulting of the Basin and Range disturbance followed shallow listric faulting between about 14.0 and 8.0 Ma in most of southwestern Arizona (Shafiquallal et al., 1980). The subsiding fault troughs, or grabens, became centers for the deposition of clastic material eroded from adjacent highlands. The material deposited in these grabens, which correspond to Unit II, are the important water-bearing deposits beneath the Maricopa site.

Eberly and Stanley (1978) described Unit II by treating separately three geographic areas in which the sedimentary strata of this unit have distinct and differing characteristics. Based on drill-hole data, the Maricopa site basins appear to lie in what they call the "central area". The central area is differentiated from the more intensely investigated eastern area, which includes the Tucson, Picacho, and Salt River Valley basins, by its shallower Tertiary troughs, thinner fluviolacustrine deposits and the absence of extensive evaporite deposits (Eberly and Stanley, 1978).

With few wells and only one site-specific aquifer test, little is known of the aquifer properties along the proposed tunnel alignment. Therefore, much of the aquifer information had to be based on extrapolations from wells near the basin's axis combined with inferences on the characteristics of the sediments which make up the aquifer. Although types of sediments and their depositional geometries are difficult to predict in the desert basins of the southwest, a generalized picture and subsequent range of aquifer properties can be made.

HYDROGEOLOGY

Preliminary information suggests that the entire tunnel will be above the regional water table. A cross-section showing the tunnel in relation to the topography, water table, and bedrock-alluvial contact is shown in Figure 6. The arid climate, deep water table, and remote, uninhabited location suggest a hydrologically ideal site for construction of the SSC. However, these same attributes complicate the identification and securing of an adequate water supply for the operational phase. The lack of site-specific data places an uncertainty on the assumptions of hydrologic simplicity and lack of ground water-related construction problems. A multidisciplinary approach was used to test the above-mentioned assumptions. This approach combined available hydrologic information with a thorough understanding of the site geology reinforced by a program of surface geophysics.

A fundamental assumption is that certain aquifer properties and flow system processes are common to many southwestern basins in the United States and that hydrogeological similarities may be assumed, so that properties and processes estimated from well documented basins may be extrapolated to those basins with sparse data. The geology of the alluvium is paramount in describing basin and range aquifer systems. Therefore, particular attention was paid to interpreting the geologic history and depositional processes that formed the basin in question. This was accomplished using a detailed literature review, drillers logs, and information obtained from the Arizona SSC Project geotechnical exploration programs.

Bedrock Hydrogeology

The bedrock present at the Maricopa site does not constitute an important source of ground water. As a result, very little is known about its hydrologic proper-

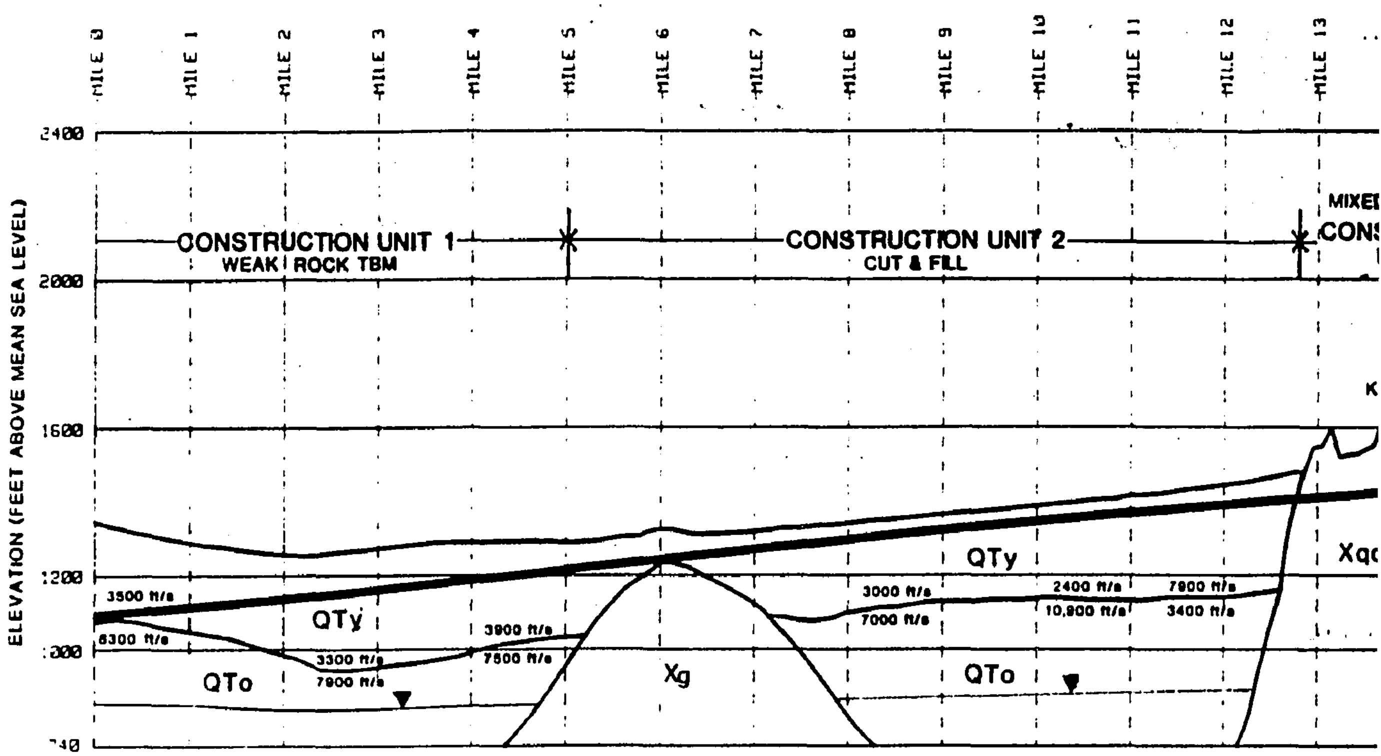
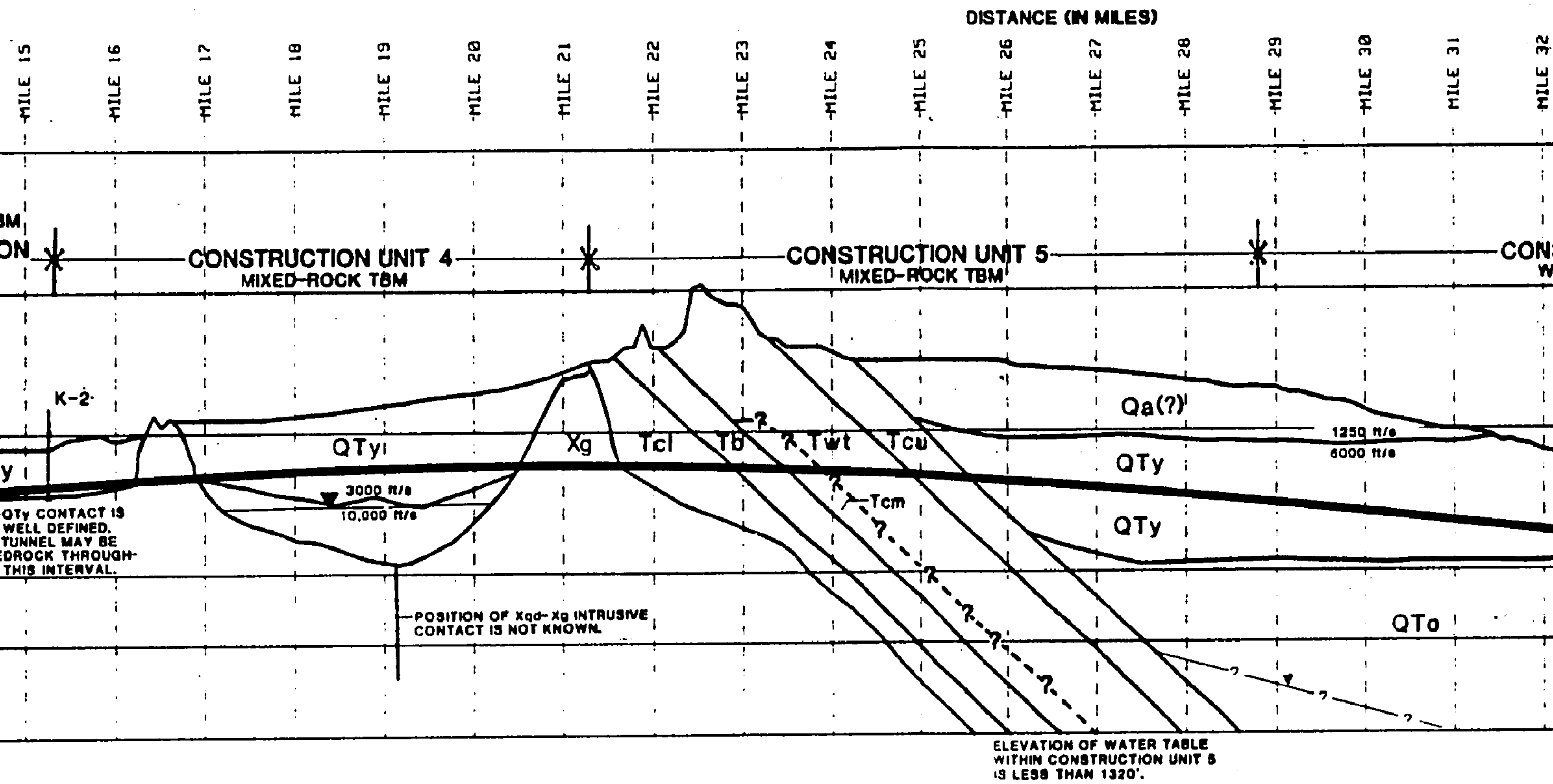


FIGURE 6

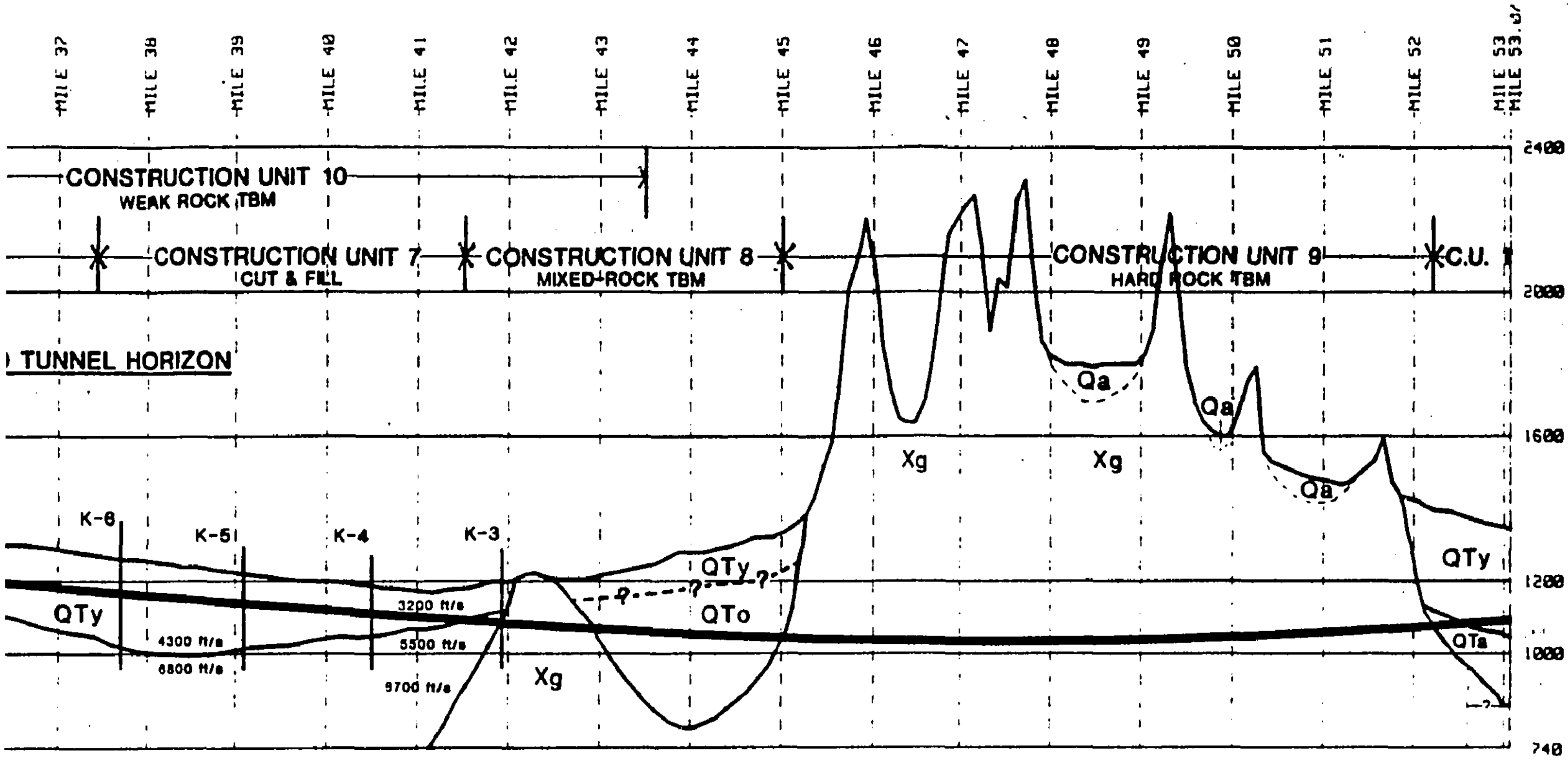
GEOLOGIC PROFILE

MARICOPA SITE

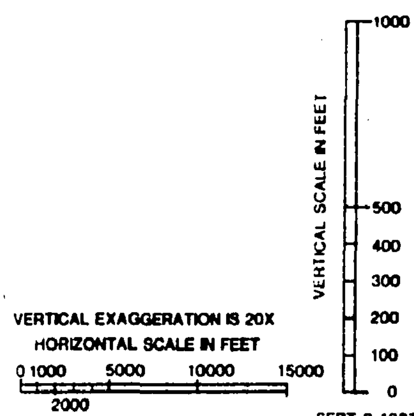
STATE OF ARIZONA SSC PROJECT



Qa	QUATERNARY ALLUVIUM
QTy	QUATERNARY - TERTIARY YOUNGER FANGLOMERATE LOWER SEISMIC VELOCITIES THAN QTo
QTo	QUATERNARY - TERTIARY OLDER FANGLOMERATE
	NOTE: SEISMIC VELOCITY MEASURED IN FEET PER SECOND.
Tcu	TERTIARY, POLYLITHOLOGIC UPPER CONGLOMERATE
Twt	TERTIARY, WELDED ASH-FLOW TUFF
Tcm	TERTIARY, BASEMENT-CLAST MIDDLE CONGLOMERATE
Tb	TERTIARY, BASALT FLOWS
Tcl	TERTIARY, GRANITIC-CLAST LOWER CONGLOME
Xqd	PROTEROZOIC, BOOTH HILLS QUARTZ DIORITE
Xg	PROTEROZOIC, PORPHYRITIC GRANITE



- CONTACT
- INFERRED CONTACT
- WATER TABLE
- INFERRED WATER TABLE



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ties. Where fractured, these rocks may yield small amounts of water. However, the deep water levels in adjacent basins combined with the minimal precipitation and high evaporation rates suggest that large volumes of water are unlikely inthe bedrock.

Alluvial Hydrogeology

The alluvial basins of south-central Arizona constitute a major source of ground water and are relied upon extensively for agricultural, industrial, and public water supplies. In comparison with the nearby and heavily exploited Salt River Valley and Lower Santa Cruz ground-water basins, the basins traversed by the Maricopa SSC site are relatively undeveloped. Each basin is discussed below.

Waterman Wash

Drillhole data show the Waterman Wash basin to be underlain by as much as 1800 feet of basin-fill deposits. The basin-fill has been divided into two distinct units based on the results of two deep exploratory wells and numerous water wells (Wilson, 1979). The upper unit is approximately 800 feet thick where drilled in the center of the basin and thickens to the northwest, away from the Maricopa site. The unit is unconsolidated sandy clay to sand and gravel, and generally contains more gravel in the northwestern part, and more clay and silt in the central part. The lower unit is as thick as 1,000 feet and consists of poorly to moderately consolidated coarse sandy gravel to sand and gravel that contains small amounts of silt and clay (Wilson, 1979). The lower unit is distinguished by its texture, difference in borehole geophysical responses including higher density, lower porosity, increased sonic velocity, generally higher resistivity, and decreased rate of penetration during drilling (Wilson, 1979).

The absence of fines in the lower unit suggests that the area had through-flowing drainage prior to late Miocene block faulting. However, the direction is uncertain as dating of volcanics near the Luke Salt body indicate that the present day Gila River did not become through flowing until 10 Ma to 6 Ma (Eberly and Stanley, 1978). This integrated drainage was apparently closed by a west-northwest trending uplift of the Buckeye Hills. Although no mention of this scenario was found in the literature, it is suggested by well information from White (1963). Well logs show a depth to bedrock in excess of 1,100 feet in C-2-2 5ddc approximately one mile south of the narrow gap in an outlier of the Sierra Estrella and Buckeye Hills where Waterman Wash exits to join the Gila River. Depth to bedrock in the gap is generally less than 200 feet indicating at least a 900 foot difference in elevation of basement rock. Ground-water is currently flowing south through the gap from the buckeye area into the Waterman Wash basin alleviating somewhat the overdraft currently occurring.

The basin aquifer is generally under water-table conditions but confined conditions may exist locally because of silt and clay lenses. The general flow of ground water is from the southeast to the northwest toward a cone of depression that has formed in response to ground-water withdrawal in a large irrigated area centered around C-2-2. The water table slopes towards this cone of depression at about 30 feet per mile in the northwest, decreasing to about 15 feet per mile in the southeast.

Irrigated agriculture began in 1951 but not extensively until 1955. Based on available pumping records and assuming 2000 acre-feet of recharge per year (White, 1963) approximately 1.75 million acre-feet (MAF) of water has been removed from storage since 1951. In 1979 it was estimated that 10.3 MAF of water was in storage to a depth of 1000 feet below the water table (Wilson, 1979). Therefore, approximately 9.7 MAF of water remain in storage. These values are computed assuming a specific yield of .10. White (1963) considered this conservatively low, therefore, estimates of water resources could likewise be considered low.

Examaination of data from deep water wells and USGS exploration holes indicates a gradual shallowing of basin fill of approximately 75 feet per mile moving to the south (White, 1963 and Wilson, 1979). The depths to bedrock and the gradual shallowing of alluvium to the south do not appear to be in accord with gravity data (Oppenheimer and Sumner, 1980; Sternberg and Sutter 1986), and drillhole data (Manera 1982).

Aquifer Properties. An obvious problem in using geologic assumptions to extrapolate aquifer characteristics in southwestern alluvial basins is that the type of sediments and their depositional geometries can be complex and difficult to predict. Many sedimentary deposits found in desert basins are as discontinuous sheets and lenses that are commonly more extensive in a down-dip direction than in the strike direction. This small scale complexity is compounded by the variability of larger scale factors such as the rate of tectonic uplift. Therefore, aquifer properties derived from drillhole lithologies and aquifer tests can often be very localized; however, because the water table is expected to be below all SSC structures and the project water supply will come from an off-site source the site-specific aquifer properties lose some of their importance with regards to information requested by the DOE.

Wells which penetrate the basin-fill aquifer yield between 500 gallons per minute (gpm) to more than 2,500 gpm of water (Wilson, 1979, and ADWR, 1987). The specific capacity is estimated at between 15 to 74 gpm/ft (White, 1963).

The transmissivity of the upper unit ranged between 4,500 square feet per day (ft^2/day) to 13,000 ft^2/day and average about 8,000 ft^2/day (White, 1963). The transmissivity from a test well which penetrates the lower unit in the central portion of the basin was 11,000 ft^2/day (Wilson, 1979). The porosity of the basin-fill aquifer ranges from 8 to 20 percent. The specific yield is given a range of 0.05 to 0.20 with an average of 0.12 (White, 1963).

As previously mentioned, the importance of the Waterman Wash basin aquifer is more for its water resources and not its specific aquifer properties. However, the threat of future land surface subsidence resulting from ground-water withdrawal is considered a potential problem from pumping in the Waterman Wash agricultural areas. Therefore, knowledge of aquifer characteristics is necessary for the basin and crucial for the section of the collider from mile 0 to mile 5. This section of the tunnel lies in a western extension of the Waterman Wash basin with little aquifer information.

Where it traverses Waterman Wash basin, the SSC tunnel is at depths of 50 to about 300 feet below land surface. Therefore, it will be entirely in the upper unit. Test holes MD-7, MA-3, and MA-2, drilled near SSC mile posts 2.0, 5.0, and 8.5 (Plate 3), respectively, show the material at and above tunnel level to be essentially a dense clayey, silty sand with small (<3 ft.) interbeds of clean sand. Undisturbed samples were obtained from MA-3 at depths ranging from 10 to 70 feet using a specialized CME sampling device. Permeability tests conducted on these samples at the University of Arizona, Department of Civil Engineering Soil Mechanics Laboratory indicated permeabilities on the order of 1.5×10^{-4} cm/sec (De Natale and Nowatzki, 1987).

MD-7, a reverse circulation air-rotary hole one mile north of SSC milepost 3 was drilled to a depth of 655 feet. Ground water was found at a depth of 396 feet in a visually described well-graded, subangular, moderately cemented fine to medium sand, which graded into a medium to coarse sand to sand and fine gravel with minor amounts of silt at about 495 feet. The transmissivity of the deeper material is estimated at 10,000 to 15,000 ft^2/day based on aquifer tests performed on wells with similar lithologies elsewhere in the basin. The lithologic log of MD-7 agrees closely with a 1,175 foot well two miles northeast (C-3-1 21dcc) indicating some continuity in the alluvial properties. The 1,175-ft well has a reported maximum pumping yield of 3000 gpm. Seismic refraction and d.c. resistivity geophysical work conducted one mile north of MD-7 showed similar layering but at different depths depending on the interpretation of the data. This discrepancy may be the result of rapid horizontal changes common in alluvial depositional environments or the non-uniqueness of the geophysical interpretation. As described in the section on surface geophysics, either possibility is a problem in using these techniques in alluvial basins and is strong evidence of the necessity for good geologic information to accurately utilize surface geophysical data.

Further west, the aquifer material is expected to remain coarse, because of its closer proximity to the mountain front, but thin gradually as inselbergs and low-lying bedrock knobs identify the area as a pediment. This was confirmed by seismic refraction line DST510SN near SSC milepost 51.0. At a depth of 75 feet, a layer with a seismic velocity 14,400 ft/s with a north-sloping surface was identified (Sternberg and Esher, 1987).

Moving south, the SSC tunnel enters a portion of the Waterman Wash basin called the Mobile Valley. Hydrologic conditions in the valley were investigated by Manera (1982) for a proposed oil refinery south of Mobile. Manera describes the material in a 1500-foot well in D-4-1 28aaa as 210 feet of silty sand underlain by 780 feet of sand and gravel followed by 510 feet of alternating sequences of coarse sand and sand and gravel. This description is similar to that in MD-7, 7.5 miles to the northwest. Interestingly, although the lithologic logs show no major change between 210 to 990 feet, downhole normal resistivity and neutron logs show a major change in alluvial properties at 610 feet (Manera, 1982). A similar discrepancy was also found near MD-7 where seismic refraction indicated a velocity increase of 3100 ft/s at around 600 feet yet drilling showed no apparent lithologic change.

Results of aquifer tests conducted in section 28 by Manera (1982) give a range for transmissivity of 500 to 2,000 ft^2/day with a mean of 800 ft^2/day. Based on data from lithology logs, the low transmissivity appears to be due to the poor sorting of the aquifer material. Maximum well yields in and around Mobile are reported to be about 300 gpm but one well, in D-4-1 sec. 28, was able to discharge 610 gpm (Manera, 1982). On the eastern side of the Palo Verde Mountains, about seven miles east of Mobile, well yields of 2,000 to 3,000 gpm are reported.

The aquifer properties of the basin-fill within the interior of the ring, from SSC milepost 4 to milepost 13, are essentially unknown. The only hydrologic and lithologic information comes from site characterization, currently underway by Water Resources Associates, of the Arizona Hazardous Waste Facility located in C-4-1 sec. 32. Available data include deep rotary holes, extensive grids of direct current resistivity and gravity data. Drill cuttings show a completely different depositional environment than those interpreted from any of the SSC drillholes or from lithologic logs in central and northeast Waterman Wash basin. Throughout the site, the alluvial sediments are predominantly clay, with thin lenses of varying percentages of sand and gravel. The high percentage of clay and almost total lack of coarse material suggest that at one time the area was a separate basin with internal drainage. Gravity data suggesting a north-south trending bedrock high just west of Mobile support this theory. Drilling at the site detected a thin layer of rhyolite(?) near the presumed alluvium/bedrock interface (Jones, pers. commun., 1987). Similar occurrences of rhyolite are reported in lithologic descriptions given of deep wells in northern Waterman Wash basin (White, 1963). The subsurface hydrologic system is interpreted to be an unconfined aquitard and water-level measurements indicate the ground-water system to be in hydraulic connection with the rest of Waterman Wash basin.

Ground Water Levels and Fluctuations. Within the main part of the valley the depth to ground water ranges from about 110 feet in the far northwest to more than 400 feet near Mobile and along the base of the Sierra Estrella. In the western sub-basin, in which the SSC lies, depth to water of 525 feet has been reported at the Arizona Hazardous Waste Facility in C-4-1 sec. 32. Since 1951, water-level declines range from about 15 feet near the town of Mobile (approximately 1.5 miles east of mile point 8.5) to more than 200 feet in the intensely cultivated area in northeastern Waterman Wash basin. Currently, about 65,000 acre-feet per year of ground water is pumped for irrigation. The area is now a part of the Phoenix Active Management Area (AMA) and as such, further ground-water development for the purpose of agriculture is not allowed.

Seasonally, ground-water levels around the entire site remain very consistent because of the absence of pumping and the negligible aquifer recharge. In southern Arizona, large fluctuations are seen only in areas of agricultural irrigation where heavy pumping occurs or beneath major streams after a large flow event. There is no agriculture within the site area and Waterman Wash is dry for approximately 350 days per year. No operating wells are currently within the site area. Outside of the site area approximately 17,000 acres are under cultivation in northwestern Waterman Wash basin. Here, pumping for agricultural irrigation has created a cone of depression of approximately 50 mi^2. Water table declines of more than 150 feet have occurred in an 18 mi^2 area since 1950. A smaller area of agriculture, about 1,800 acres, is three to five miles northeast of the site. Here, water-level declines of approximately 15 feet have occurred since 1953. Although over ninety percent of the ground-water withdrawal in the three basins is for agriculture, the irrigated areas, which are the centers of pumping, all are at least 7 miles from the SSC site. Available water level data indicate little ground-water decline in the site area from pumping in these outside agricultural areas.

Ground Water Potential Except for the north-central part of the basin, the ground-water of the area is not developed extensively. Most of the land is administered by federal or state agencies. Recoverable ground-water resources are large in the central and southern portions of the basin. However, the depth to water in this area ranges from 300 to 500 feet below land surface. Also, if the SSC comes to the Maricopa Site, ground-water withdrawal around the site can be controlled either through legal methods or the purchasing of ground-water rights (Kleinman, 1987).

Vekol Valley Basin

Although the SSC tunnel traverses only 6 to 7 miles in the northwest corner of Vekol Valley it is an important basin because of its potential as a source of water for the project.

The Vekol Valley ground-water basin is hydrologically separated into a northern and a southern part by a bedrock ridge of crystalline rocks. Only the northern valley is being considered for ground-water development. The northern part, in which the SSC lies, is about 90 mi^2 in area.

The northern basin is filled with as much as 3000 feet of basin sediments. These basin sediments can be divided roughly into two geohydrologic units; a relatively unconsolidated gravelly sand underlain by a moderately to well-consolidated silt, sand, and pebble conglomerate (Cuff, 1984). The thickness of these units varies within the basin. A U.S. Geological Survey (USGS) test hole drilled in the late seventies at D-7-1 10cbc penetrated 1,208 feet of gravelly sand followed by 700 feet of silty, gravelly sand.

Aquifer Properties. Hollett and Marie (1987) described four units in the northern Vekol Valley aquifer system. The upper two units are unconsolidated alluviul-fan, stream channel, and flood plain deposits. A discontinuous silty sand bed forms the base of unit 1 and acts as a confining bed to unit 2. Unit 3, present only in the northern two-thirds of the basin, is a moderately to well-consolidated conglomerate. Where it exists unit 3 acts as a confining bed to unit 4. Unit 4 consists of discontinuous lenses of moderately consolidated to unconsolidated silty sand and sand with intercalated lenses of conglomerate. Unit 4 lies on a well-consolidated conglomerate at depths ranging from about 1,300 feet to about 1,600 feet. The hydraulic conductivity of this conglomerate is much lower than that of any of the upper four units and so for the purpose of aquifer system modeling it represented the base of the aquifer system. Ground water in unit 1 is under unconfined conditions, whereas ground water in units 2, 3, and 4 is under confined conditions.

The lateral extent of these four units is controlled by major blocks of faulted igneous and sedimentary rocks. Within the valley, these faults offset the various aquifer units in a stepped configuration creating non-uniform depths of saturated material.

Because of the wide variability in saturated thickness, the ability of the different units to transmit water are discussed in terms of hydraulic conductivity rather than transmissivity. Transmissivity values will only be given for the proposed SSC well field in D-4-1 Sec. 10. The hydraulic conductivity values were calculated from transmissivities determined from multi-observation well aquifer tests conducted by the USGS (Hollett and Marie, 1987). To obtain hydraulic conductivity the transmissivity was divided by the saturated thickness of each unit in the aquifer system. The saturated thicknesses were determined from geologic analyses of drill-hole cores and cuttings and borehole-geophysical logs. The hydraulic conductivity ranged from 35 to 50 ft/day for unit 1, 8 to 16 ft/day for unit 2, 1 to 2 ft/day for unit 3, and 5 to 6 ft/day for unit 4. Estimates of storage coefficient and specific yield were also determined from the aquifer tests (Table 1).

The transmissivities of the four aquifer-units within the proposed SSC well field in D-4-1 Sec. 10 was estimated using saturated thickness contour maps and geologic cross-sections along with the hydraulic conductivity values from Hollett and Marie (1987). The transmissivity of unit 1 is estimated at 10,500 to 15,000 ft^2/day, unit 2 at 1,800 to 3,600 ft^2/day, unit 3 at 300 to 600 ft^2/day, and unit 4 at 1,000 to 1,200 ft^2/day.

Ground-water Levels and Fluctuations. Measured depth to ground water in the basin sediments ranges from 150 feet, near the subsurface exit east of the Booth Hills, to over 400 feet in the southern part of the basin. Depth to water where the SSC crosses the basin has been approximated at 240 to 350 feet. The tunnel in this area is at depths of 165 to 230 feet and will be above the water table at all locations. The aquifer system in northern Vekol Valley is considered to be in steady-state (Hollett and Marie, 1987). As of 1983 there were about 15 domestic and livestock wells. Withdrawals from these wells is probably less than 50 acre-ft/yr.

Ground-water Recharge. Hollett and Marie (1987) estimated mountain front recharge in the northern Vekol Valley to be about 1200 acre-ft/yr. An unknown amount of recharge also occurs from infiltrated runoff in Vekol Wash and its tributaries.

Ground-water Potential. Ground water is generally in unconfined conditions with small, locally confined conditions possible. Ground-water movement is from the south to north, exiting the valley east of the Booth Hills. Cuff (1984) suggested that properly constructed and developed wells can yield as much as 2500 gallons-per-minute and that specific capacities are as great as 87 gallons-per-minute per foot. Recoverable water in storage is estimated at 375,000 acre-feet from 0 to 450 feet below the water table with an additional 1.6 million acre-feet from 500 to 1500 feet below the water table (Hollett and Marie, 1987). The project demands of 4,000 acre-ft per year should not unduly stress the aquifer or affect other users in the valley.

Table 1

Average storage properties of units 1-4 at wells V-5, NV-7, NV-6, and NV-5*

Unit	Specific yield	Storage coefficient	Specific storage
1	0.12	-----------	----------
2	[1]0.08	2.0×10^{-3} to 8.1×10^{-5}	2.7×10^{-6}
3	-----	4.4×10^{-5} to 4.4×10^{-6}	2.2×10^{-7}
4	-----	2.0×10^{-4} to 6.0×10^{-5}	5.5×10^{-7}

from Hollett and Marie (1987)

* - Located at D-7-1 9add, 9bdd, 10bdd, and 22ccc, respectively.

1

[1]Unit 2 converts to unconfined conditions when water level is drawn down below the top of unit.

Bosque (Gila Bend) Basin.

The Gila Bend basin is a northwest-trending trough that has been filled with as much as 3,000 feet of basin-fill deposits. Although the most developed of the three basins, the SSC is in the eastern, undeveloped portion of the Gila Bend basin. This Gila Bend sub-basin was called the Bosque basin by Wilson (1979). The Bosque basin-fill deposits are divided into an upper, a middle, and a lower unit by Wilson (1979). The upper unit is 700-900 feet thick. It is composed of unconsolidated grayish-brown coarse to fine gravel, sand, silt and clay. The saturated thickness ranges from 100 feet to more than 500 feet. The middle unit is 800 to 1,450 feet thick. It is mainly unconsolidated to poorly consolidated grey-brown fine to very coarse sand and fine to coarse gravel. This unit overlies an erosion surface cut on the lower unit. The thickness of the lower unit is unknown. The unit consists of volcanic rocks interbedded with moderately to weakly cemented conglomerates. A USGS test hole, in C-6-3 2ada (one-half mile west of SSC milepost 38), was drilled to a depth of 1,149 feet. The material penetrated by the well consisted mainly of clayey silty sand (Wilson, 1979).

The land encompassing the Bosque Basin is administered by the Bureau of Land Management (BLM) for the Federal Government. There are no plans to develop any water supplies in the Bosque Basin. Essentially all of the current, and proposed future, ground-water development is along a narrow swath which straddles the Gila River and the areas around the town of Gila Bend. As a result, most of the following discussion will be about this area.

Aquifer Properties. The principal aquifer in the basin is composed of basin-fill deposits and is generally under water-table conditions. Confined conditions may exist locally because of silt and clay lenses. These are generally close to the present-day channel of the Gila River. The general flow of ground water is from the east-southeast to the west-northwest in response to a cone of depression developed along the Gila Bend Canal. Wells which penetrate the upper and middle units yield more than 2,000 gpm of water. The potential specific capacity varies from 3 gpm/ft in the southeast to 60 gpm/ft along the Gila Bend Canal.

Transmissivities near the Gila River range from about 8000 ft^2/day to almost 27,000 ft^2/day (Wilson, 1979). Closer to the SSC site, the USGS well near milepost 38 was pumped at 150 gpm for 2 hours and had a drawdown of 150 feet. Aquifer-test data indicate that the transmissivity of the upper and middle units is about 800 ft^2/day (Wilson, 1979). This is much lower than was expected and may not be representative of the entire region (Wilson, pers. commun., 1986).

Based on drill cuttings and borehole geophysical logs the porosity of the basin-fill aquifer is estimated at 8 to 20 percent. The specific yield has been conservatively estimated at 0.10. These data were used to determine the quantity of recoverable ground water in storage in the aquifer. In 1979 it was estimated that the Bosque sub-basin had 3.6 million acre-feet of recoverable ground water in storage in the upper and middle units (Wilson, 1979).

<u>Ground-water Levels and Fluctuations</u>. There has been minimal ground-water extraction from the Bosque basin. Prior pumping has been restricted to low-volume livestock wells. Ground-water depths below the SSC alignment are estimated to be greater than 500 feet.

The low precipitation and generally low permeability of the surface deposits indicate that aquifer recharge is negligible. Therefore, any fluctuations of ground-water levels are from pumping in the Gila Bend area nine miles to the west. The Gila Bend area has experienced historically only moderate ground-water decline, therefore, the area below the SSC has probably experienced very little ground-water decline.

Aquifer Recharge.

Ground-water recharge to the aquifers occurs primarily through infiltration of runoff along the major streams, and infiltration along the mountain fronts. Interaction with streams is an important aspect of southwestern alluvial hydrogeology. As much as 70 percent of the natural aquifer recharge in the Southwest occurs typically in the permeable stream sediments (Burkham, 1970). But the low precipitation (about 7 in/yr), high evapotranspiration rates, and the great depths to the water table at the Maricopa Site suggest that this interaction is of minimal concern. Typically, streams in the area are dry for more than 95 percent of the year. Therefore, with proper planning, disturbance of the natural recharge environment can be minimized.

Waterman Wash Basin. Very little natural recharge occurs because the low annual precipitation and the great depth to the water table. White (1963) estimated recharge at about 2,000 acre-feet per year, with this being virtually all mountain-front or stream channel recharge.

Northern Vekol Valley Basin. Hollett and Marie (1987) estimate mountain front recharge in the northern Vekol Valley to be about 1200 acre-ft/yr. A smaller amount of recharge also occurs from infiltrated runoff in Vekol Wash and its tributaries. On the basis of infiltration tests in the valley, Hollett and Marie (1987) estimated recharge to the aquifer from Vekol Wash to be 10 percent of the total recharge.

Bosque Basin. Most of the aquifer recharge in the Gila Bend basin can be attributed to percolation of excess irrigation water. Another major, but irregular, source of recharge is from streamflow in the Gila River. Although totally controlled by upstream diversions, occasionally during "wet" years the Gila River and its major tributary the Salt River can flow from a few days to weeks, providing a large source of recharge.

Perched Water

Perched water is known to exist in numerous areas in southern Arizona, but it is most common in heavily irrigated areas where a constant source of recharge is available. There is no agriculture within the Maricopa Site boundaries. Although the presence of clays at the site suggest a possibility for perched water, the available information shows no indication of it. Eight alluvial drill-holes ranging in depth from 70 to 655 feet were spaced around the site perimeter. No saturated or even near-saturated zones were detected other than the regional unconfined water table. This conclusion was confirmed with borehole geophysics. Analysis of aerial photographs and Landsat images of the site show no abnormally vegetated areas that would indicate near-surface perching of water. These findings, along with low precipitation, high evapotranspiration, and the generally impermeable nature of the surface soils indicate that perched water should be rare at the Maricopa Site.

Project Water Requirements - Quantity and Quality

Ground water is the largest and most reliable water resource in Arizona; it is also the most misunderstood. Investigations show large reserves of ground water in storage in the three ground-water basins near the Maricopa site. A report by the Arizona Water Commission (1975) estimated reserves to a depth of 1200 feet at two of the neighboring basins as follows:

- **Waterman Wash - 9 million acre-feet**
- **Gila Bend basin - 60 million acre-feet**

Reports by the U.S. Geological Survey (Wilson, 1979; Hollett and Marie, 1987) estimate reserves to a depth of 1500 feet in additional basins:

- **Bosque sub-basin - 3.6 million acre-feet**
- **N. Vekol Valley - 2.0 million acre-feet**

SSC Water Requirements

Water supply is an important, and sometimes deciding factor, in the planning of any large development in southern Arizona. The SSC Siting Parameters Document lists identification and procurement of an adequate water source as one of the qualifying criteria for a site to even be considered. The potential political and legal ramifications of securing approximately 4,000 acre-feet of water per year required careful investigation and correspondence with the State Department of Water Resources.

Although adequate ground-water reserves to meet the SSC demand were found in all three basins traversed by the project, the northern Vekol Valley basin was chosen based on lower development, pumping, and conveyance costs, the excellent quality of the water, and the large percentage of the valley already controlled

by the federal government. Central Arizona Project water was identified as an alternative source of water but was classified as a secondary or back-up supply because of its susceptibility for interruption.

Northern Vekol Valley has been studied intensely by the USGS. Wilson (1979) was the first to report on the water resources of the Vekol Valley. Upon decision by the Department of Interior that northern Vekol Valley was the optimal choice to supply water guaranteed to the Ak-Chin Indians, the USGS elaborated on Wilson's work and constructed a detailed ground-water flow computer model (Hollett and Marie, 1987). The basin was targeted to supply 30,000 acre-feet per year over a 25 year period to the Ak-Chins, who subsequently turned it down for money and a CAP allocation. This volume is 26,000 acre-feet per year, or 7.5 times more, than that needed by the SSC Project. In the course of their study, the USGS installed, developed, and tested 18 wells with depths ranging from 200 to 3,014 feet. The production wells which could be used for the SSC Project are located in sections 9 and 10 of D-7-1.

The water demands of the project can be separated into two phases.

<u>Construction</u>

dust control

compaction

cement

and

<u>Operation</u>

industrial

-cooling water systems

-conventional equipment

-technical equipment

-fire protection

domestic

irrigation (landscaping)

The volumetric requirements for the construction period are variable at this time. The necessary amounts depend on construction methods and scheduling and are unknown at this time. The volumetric requirements for the operations period can be broken down as follows:

Industrial - 2200 gpm (3500 ac-ft/yr)

Domestic - 250 gpm (400 ac-ft/yr)

Domestic water requirements for the site are based on a population estimate of 3,000 people. Based on a mixed-type usage, a mean per capita consumption of 120 gallons per day per capita was used in the estimates.

Irrigation demands are unknown at this time. However, grey-water from the domestic uses could be used for much of the campus area irrigation needs. A water requirement for fire protection was estimated at 1000 gpm for a duration of four hours. This results in a combined peak demand of 3450 gpm.

Because of the large areal extent of the project and the low water demand at some of the facilities it may be more economical to have separate sources for the east and west sides. Approximately 1300 gpm or 53 percent of the total demand is needed at the campus and injector facilities (east side of the site). Approximately 280 gpm or 11 percent of the total demand is needed at the western experimental facilities. The remaining 870 gpm or 35 percent is needed at cryogenic facilities at the various service areas spaced along the collider ring. Ideally, each refrigeration plant would have its own well and package treatment plant. However, this arrangement is not seen to be sensible nor feasible at the Maricopa Site. Inquiries to the SSC Central Design Group indicated that water lines may be run inside of the tunnel, removing the need to find separate sources of water for the western facilities and the service areas. The Vekol Valley ground water and the CAP are the only sources currently being considered.

Quality Requirements.

The SSC Siting Parameters Document assumes that available water is of neither exceptionally high quality nor low quality and can be treated in a conventional treatment facility.

Potable Water. The quality of potable water must comply with the National Interim Primary Drinking Water Regulations and the state's drinking water quality standards. Most of the potable demand will be at the main campus located on the east side of the site.

Cooling Water. Four different types of cooling water systems are required for removal of heat from the technical equipment.

- Cooling Tower Water
- Industrial Cooling Water
- Low Conductivity Water

- Chilled Water

Cooling tower water is needed for technical equipment at scattered locations around the ring periphery. The major demands are at the injector complex, collision halls and refrigeration/power supply buildings.

Industrial cooling water will be needed throughout the SSC area. It will be softened and treated to the specifications of boiler feedwater to avoid scale formation. In general, the poorer the quality (i.e. high TDS) the more water needed for equivalent heat transfer capability.

Low conductivity water will be supplied from two generating/make-up plants. One plant will be in the injector area near the linear accelerator and the other at the high energy booster radio frequency buildings. Each will produce 100 gpm of ultra-pure, low-conductivity water.

Local Water Quality.

The background quality of local ground water is considered an important part in the siting of the SSC and for the accompanying EIS. However, this importance stems mainly from the assumption that the SSC will affect the local ground water either by tunneling through it or utilizing it as a source of water. The Maricopa site has avoided both of these interactions and so local ground-water quality is of negligible importance. A brief summary of the water quality in the Waterman Wash and Bosque basins will be given along with some data from near-site wells.

Because the site area is rural and undeveloped, water-quality data are scarce. Available data show ground-water quality as good to fair in the Waterman Wash and Bosque basins. Water of lower quality usually means the presence of higher amounts of dissolved solids, usually sodium and chloride. Available ground-water quality generally meets the State of Arizona Water Quality Standards. Occasional violations of the drinking water standards are usually in the form of excessive nitrates or fluorides. Water quality data from the northern, eastern, and western portions of the SSC site are listed in Tables 2, 3, and 6, respectively.

Of more importance is the quality of northern Vekol Valley basin ground water. Chemical testing done by the U.S.G.S. of ground water from wells in D-7-1 Sec. 10 indicated the water to be of excellent quality. A representative example is shown in Table 4. A field check of domestic water users located a few miles down-gradient of the proposed SSC well field showed no treatment was necessary for human consumption. Recent sampling, done by the SSC project, of these wells can be seen in Table 5. With no large-scale agriculture or ranching in the area, nor any industrial activity occurring currently or expected to occur in the future ground-water quality in the area should remain high.

Table 2. Water Quality Data from the Waterman Wash basin

Sample Location: D-4-1 28bbb (Mobile School Well)
Sample Date: Jan. 7, 1987

Primary Drinking Water Measurements

Constituent	(mg/L)
Arsenic	<.015
Barium	<.010
Cadmium	.007
Chromium	<.02
Fluoride	.55
Lead	<.12
Mercury	<.001
Nitrate (NO3-N)	6.3
Selenium	<.01
Silver	<.01

Secondary Drinking Water Measurements

Constituent	(mg/L)
Calcium	22.4
Chloride	87.9
Copper	<.02
Iron	.033
Manganese	<.01
Magnesium	10.1
Sodium	143
Zinc	.077
Sulfate	100
Hardness	97.5
TDS	464
pH	7.86

from: Water Resources Associates (1987)

Table 3. Water Quality Data from Waterman Wash basin

Sample Location: C-3-1 34acc (1.5 miles north of SSC Tunnel)
Sample Date: July, 29, 1985

Constituent	Units	
Boron	ug/L	210
Calcium	mg/L	33
Chloride	mg/L	160
Chromium	ug/L	16
Fluoride	mg/L	.9
Iron	ug/L	5
Magnesium	mg/L	7.5
Manganese	ug/l	3
Nitrogen (NO3+N)	mg/L	8.9
Potassium	mg/L	4.3
Silica	mg/L	17
Sodium	mg/L	170
Sulfate	mg/L	86
Sp. Conductance	us/cm	895
Temperature	deg C	28.5
pH	-	8.0
Hardness as (CaCO3)	mg/l	103

from: ADWR Data files

Table 4. Water Quality Data from Northern Vekol Valley

Sample Date: Sept. 2, 1982
Sample Location: D-7-1 Sec. 10

Constituent	Units	
Boron, dissolved	ug/L	280
Iron, dissolved	ug/L	17
Manganese, dissolved	ug/L	1
Silica, dissolved	mg/L	32
Water temp	deg C	31.5
Sp. Conductance (lab)	us/cm	557
Sodium Absorption Ratio	-	6.4
pH (field)	-	7.1
pH (lab)	-	8.4

Cations	(mg/L)	(meq/L)	Anions	(mg/L)	(meq/L)
Potassium	3.1	0.079	Chloride	29	0.818
Calcium	12	0.599	Fluoride	1.0	0.053
Magnesium	5.6	0.461	Sulfate	31	0.645
Sodium	97	4.218	Alk Tot Lab. CaCO	187	3.735
			Nitr (NO3 + N)	5.4	0.385

from: USGS Data files

Table 5. Water Quality Data from Northern Vekol Valley

Sample Date: Feb. 19, 1988

	Sample Location	
	D-6-1 Sec 15 (Hett)	D-6-1 Sec 27 (Kirian)
Calcium	22. mg/L	22. mg/L
Chloride	16.	28
Magnesium	7.1	7.7
Sodium	99	105
Sulfate	24	31
Dissolved Silica	36	32
Potassium	4.0	4.0
Bicarbonate	264	244
pH (field)*	8.7	8.5
Spec. Conductance	410 us/cm	390 us/cm

* Samples were obtained from water tanks.

Table 6. Water Quality Data from the Bosque basin

Sample Location: C-6-3 02adc2 (approximately 1.5 miles west of SSC milepost 38)
Sample Date: May 21, 1979

Constituent	Units	
Arsenic, Dissolved	ug/L	5
Boron, Dissolved	ug/L	230
Hardness, total	mg/L	30
Iron, Dissolved	ug/L	10
Manganese, Dissolved	ug/L	30
Silica, Dissolved	mg/L	22
Water Temp	deg C	37.0
Sp. Conductance (lab)	us/cm	981
Sodium Absorp Ratio	--	15
pH field	--	8.2
pH lab	--	7.4

Cations	(mg/L)	(meq/L)	Anions	(mg/l)	(meq/L)
Calcium Diss	11	0.549	Bicarbonate	85	1.393
Magnesium Diss	0.7	0.058	Carbonate	0	0.000
Potassium Diss	2.2	0.056	Chloride Diss	170	4.796
Sodium Diss	190	8.265	Fluoride Diss	0.3	0.016
			Sulfate Diss	120	2.498
			NO2+NO3 as N Diss	7.1	0.507
	Total	8.928		Total	9.210

Percent Difference = -1.56

from: USGS Data Files

Chapter 4

Subsidence

An important concern in siting the SSC in Arizona is the avoidance of subsiding ground, or more specifically differentially subsiding ground. Because particle beam stability is required for successful collider experimentation the structural stability of the underlying material is vital. Much of the Maricopa SSC site traverses basin-fill alluvium, a material whose potential for subsidence is well-documented throughout the state (Strange, 1982).

Land surface subsidence can result from many causes including hydrocompaction, cavities formed from dissolution of minerals, and the dewatering of unconsolidated sediments. In southern Arizona most subsidence is caused by the dewatering of fine-grained sediments. Available data indicate that the water table is below the foundation elevations of all SSC facilities, thus the site is free of potential settlement due to excavation dewatering. There are currently no operating wells within the site circumference, and most of the land surrounding the site, and virtually all the land within the site interior is federally owned and controlled by the BLM, so water-table decline from on-site pumping is not a concern. Off site, two areas of heavy pumping are noticeable from Arizona Department of Water Resources (ADWR) maps. These are the Gila Bend and northern Waterman Wash agricultural areas. Though both these areas are 7 to 10 miles away from the proposed tunnel location, uncertainty lies in what the future rate and magnitude of water-table drawdown below the site will be from pumping in these areas.

Land surface subsidence has commonly been associated with ground-water withdrawal in the alluvial basins of the Southwest. It has been observed in the adjacent, but hydrologically separate, Salt River Valley and Lower Santa Cruz basins. This subsidence is usually a general lowering of the land surface, occasionally with differential subsidence near pediments that can form earth fissures. Where subsidence has occurred in Arizona, relationships have been found between water-level decline and subsidence. As a rule of thumb, water-table declines of 100 feet are thought to be sufficient to initiate noticeable subsidence. However, subsidence has been measured in areas with only 50 feet of ground-water decline and undetected in areas with more than 150 feet of ground-water decline. The controlling factor is the characteristics of the material to be dewatered. These include (1) the thickness of the alluvium; (2) the percentage of fine sediments; (3) the degree of cementation or competency of the material; and (4) the extent of compaction which has taken place during the long-term geologic history of a given unit.

The tunnel at the Maricopa Site has been located in an area with no measured or suspected subsidence from ground-water withdrawal. A National Geodetic Survey level line follows the Southern Pacific Railroad through Mobile and across the northern third of the site. Comparison of the elevations from 1949, 1967, and observed elevations in 1980 reveals no subsidence at the site or northeasterly along the railroad in Mobile Valley (Winikka, pers. commun., 1987). Other methods used to check for subsidence included the analysis of aerial photos for earth fissures, and field checking for extruding well heads or casing. No physical signs of subsidence were detected.

The Vekol and Bosque basins have experienced minimal pumping and virtually no ground-water decline. The only portion of the site that appears to have a potential for large ground-water decline is the area from mile 0 to mile 5. The presence of the small northwest trending hills and outcrops to the north and east of this area was initially thought to be an indication of relatively shallow bedrock. It was thought that the tunnel was on or above a well-developed pediment, isolated from the regional water table in the Waterman Wash basin. This assumption was supported by drillhole data from central Waterman Wash basin in conjunction with a complete Bouguer anomaly map of the area (Figure 3). A USGS test hole drilled at D-3-1 31ccc reportedly hit granitic basement at 1170 feet (Wilson pers. commun., 1987). Assuming this to be correct, the gravity contours suggest a much shallower depth to bedrock west of the proposed pipeline fault (see pg. 16). Subsequent work by the SSC project, including drilling, seismic refraction and d.c. resistivity failed to locate any evidence of shallow bedrock. A drillhole (MD-7) located at C-3-1 33ccc was drilled to a depth of 655 feet without encountering bedrock. A one-half mile seismic refraction line run one mile north of MD-7 reached a depth of about 700 feet with no apparent velocities high enough to be interpreted as bedrock. Although the hope of being located on a shallow pediment and thus protected from the regional aquifer water-table decline no longer exists, the gravity data still suggest a large increase in depth to bedrock in the central part of the basin. This suggests, in turn, that the presumed basement at 1170 feet found in the USGS hole is in error. A report by Oppenheimer and Sumner (1980) agrees with this, indicating depths to bedrock for the Waterman Wash basin in excess of 8000 feet. Although based on a regional and therefore somewhat approximate analysis, the results are based on valid assumptions and the discrepancy is too great to be ignored. Further gravity field work and computer modeling to better resolve this discrepancy is being considered.

Although data are lacking because of the absence of wells in the mile 0 to mile 5 section, the area probably has not experienced any significant water-table decline. At the village of Mobile, 1.5 miles east of SSC milepost 8.5, the ground water has been drawn down only 15 feet since 1950. The interior of this portion of the ring, except for one square mile occupied by the proposed Arizona Hazardous Waste Facility, is administered by the Bureau of Land Management, as a result, the only past ground-water withdrawal has been from low-capacity livestock wells. Currently no producing wells exist inside the site circumference.

Theoretically, any overdraft of ground water in unconsolidated materials will result in some subsidence, but it is generally undetectable. Two ways to prevent land subsidence due to ground-water withdrawal are: 1) dewatering only non-compactible deposits, or 2) having ground-water declines less than some threshold value. This threshold value as defined by Holzer (1981) is when the vertical effective stress exceeds the preconsolidation stress. It is not feasible to obtain the geotechnical properties necessary to determine the preconsolidation stress over so large an area, so the approach has been to determine the maximum previous water-table decline, calculate the possible future decline and see if the total exceeds a conservatively chosen drawdown of 50 feet at the ring location.

In order to evaluate the potential for subsidence based strictly on prediction of future ground-water withdrawal numerous drawdown calculations were performed for the northeastern section under various pumping scenarios. The following sections address two questions related to potential subsidence at the Maricopa SSC Site. These are, 1) given that, over a 40 year period, pumping must be controlled around the site, what cumulative pumping rates can be tolerated, for the life of the project, without exceeding a conservative threshold water-table decline of 50 feet at the ring location; and 2) assuming current pumping practices in the Waterman Wash agriculture area continue and that they cannot be controlled until the "safe yield"[2] concept takes effect in 2025, how much water-table decline will occur in the area of mile 0 to mile 5. In answering these two questions for the mile 0 to mile 5 section two assumptions were made. The pumping rate assumed will continue for the life of the projection, and all assumptions inherent in using the Theis solution apply.

Assumption one is judged reasonable because, at worst, pumping will continue at the same rate, but in reality pumping should decrease in the future due to the decline of agriculture. Additionally, if these agricultural lands are converted to urban use a savings of 45 to 60 percent in water use could be realized. Irrigated agriculture currently consumes more than 90 percent of the water used in the Waterman Wash basin. Agreement with the Theis assumptions is considered adequate except for the concept that the aquifer is of infinite areal extent. Impermeable boundaries in the form of bedrock or clay deposits are a possibility. However, occurrences of these boundaries are not thought to be close enough to greatly change the calculated values.

Because drawdown will be taken to be much less than the total aquifer thickness, we can use the Theis (1935) solution to calculate drawdown (s):

2

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[2]Safe-yield means that annual ground-water withdrawals do not exceed ground-water recharge. Thus, no general lowering of the water table occurs.

$$s = \frac{Q\,W(u)}{4\pi T}$$

$$\text{where } u = \frac{r^2 S}{4 T t}$$

T = transmissivity
S = storage coefficient (specific yield in unconfined aquifers)
r = radius of cone of drawdown
t = time in days

solving for the pumping rate, Q,

$$Q = \frac{s\,4\,\pi T}{W(u)}$$

SAMPLE CALCULATION:

Consider r = 1 mile or 5280 feet

Case 1: assume $T = 600\ ft^2/day$ $S = .05$

Basic Equation:

$$s = \frac{Q\,W(u)}{4\,\pi T}$$

$$u = \frac{r^2 S}{4 T t}$$

$$u = \frac{(5280\ ft)^2(.05)}{4\,(600\ ft^2/day)(14600\ days)}$$

$$u = .039$$

$$W(u) = 2.70$$

$$Q = \frac{s\,4\pi T}{W(u)} \quad \text{then}$$

$$Q = \frac{50\ ft\,(4)\,(3.14)\,(600\ ft^2/day)}{2.70}$$

$$Q = 139{,}600\ ft^3/day \text{ or } 725\ gpm$$

Maximum Allowable Pumping

In this first analysis, the problem is what cumulative pumping rate, over a 40 year period, could be allowed at various distances from the tunnel without exceeding 50 feet of drawdown below the tunnel.

The transmissivities used were determined based on aquifer tests described in reports by the U.S. Geological Survey (Wilson, 1979) and the Arizona State Land Department (White, 1963). Transmissivity, T, values ranging from 4,500 to 13,000 ft^2/day with an average value of 8000 ft^2/day were determined for the upper unit (the unit which would be dewatered) in the Waterman Wash Basin by the USGS. Towards the basin margins the values are generally seen to decrease as evidenced by 700 ft^2/day value found near the town of Mobile and the 800 ft^2/day value determined by Manera (1982) just south of Mobile. However, a hole drilled at D-3-1 33ccc, which is only 1 mile north of SSC milepost 2 encountered saturated material composed of a moderately sorted coarse sand and gravel with minor amounts of fines. Although no aquifer testing was done grain size analysis of the material suggested a hydraulic conductivity (K) value of 25 to 65 ft/day. Assuming a 400 foot saturated zone (based on gravity modeling) this gives T values in the range of 10,000 to 26,000 ft^2/day. The K value can be expected to decrease with depth effectively lowering the T value to better match those found elsewhere in the basin. To cover the range of possible values, a worst case of T= 600 ft^2/day, a reasonable case of T= 8,000 ft^2/day, and a best case of 20,000 ft^2/day will be used in the calculations. Specific yields, S, have been estimated by the USGS and private consultants working in the area to be 0.10. This value is generally considered low. In these calculations values of 0.05, 0.10, and 0.25 are used. The results using the worst, reasonable, and best case scenarios can be seen in Table 7.

Table 7

Allowable Pumping Rates
(in gpm)

	1/2 mile[1]	1 mile[1]	2 miles[1]	5 miles[1]
Worst Case Scenario[2]	483	725	1379	8742
Reasonable Case Scenario[3]	4400	5738	8159	17,883
Best Case Scenario[4]	11,007	14,346	20,656	44,104

1 - distance from centroid of pumping to the SSC
2 - worst case is $T = 600$ ft^2/day and $s = 0.05$
3 - reasonable case is $T = 8000$ ft^2/day and $s = 0.10$
4 - best case is $T = 20{,}000$ ft^2/day and $s = 0.25$

Currently there are only five large production wells in operation within seven miles of the northeast section of the ring and these are all from 1.5 miles to 3 miles away from the ring. Their total 1986 pumping rate amounted to 2450 gpm (ADWR, 1987). Even under a worst case scenario these wells are a marginal concern at worst. Combining the indications that aquifer properties do not match those of the worst case scenario and the continuing decline in agriculture, and therefore pumping, subsidence due to ground-water decline is not considered a threat.

Water Level Drawdowns Due to Existing Wells

The second part of this study concerns the potential water-level declines due to existing wells within seven miles of the mile 0 to mile 5 section. See Figure 7 for location of the wells. The analyses will use both a well's maximum possible pumping rate as given by the ADWR, and its most recent (1986) pumping rate for a 40 year period. As previously mentioned only 5 producing (>35 gpm) wells are within seven miles of the northeast section (mile 0 to mile 5) of the ring. The existing well data are summarized in Table 8.

Table 8

Well Designation	Max. Yield (gpm)	Withdrawal in 1986 (acre-feet)	Distance from Tunnel (miles)	Distance from summation point, (X) (miles)
21DCC1	3000	730	~3	~3.25
28CDD	2100	521	~2	~2.25
28DDD	3700	834	~2	~2.25
34ACC	2600	755	~1.75	~1.75
34DCD	3450	1100	~1.5	~1.4

X - distance from well to point X on Figure 6. Point X was determined to be the point along the tunnel alignment where the sum of all the wells drawdown would be greatest.

Summary of results:

For each well, drawdowns in feet were calculated using the Theis (1935) solution. Drawdowns were calculated, at the summation point X, using a specific yield of 0.10 and transmissivities of 600 ft^2/day and 8000 ft^2/day. Results can be seen in Table 9.

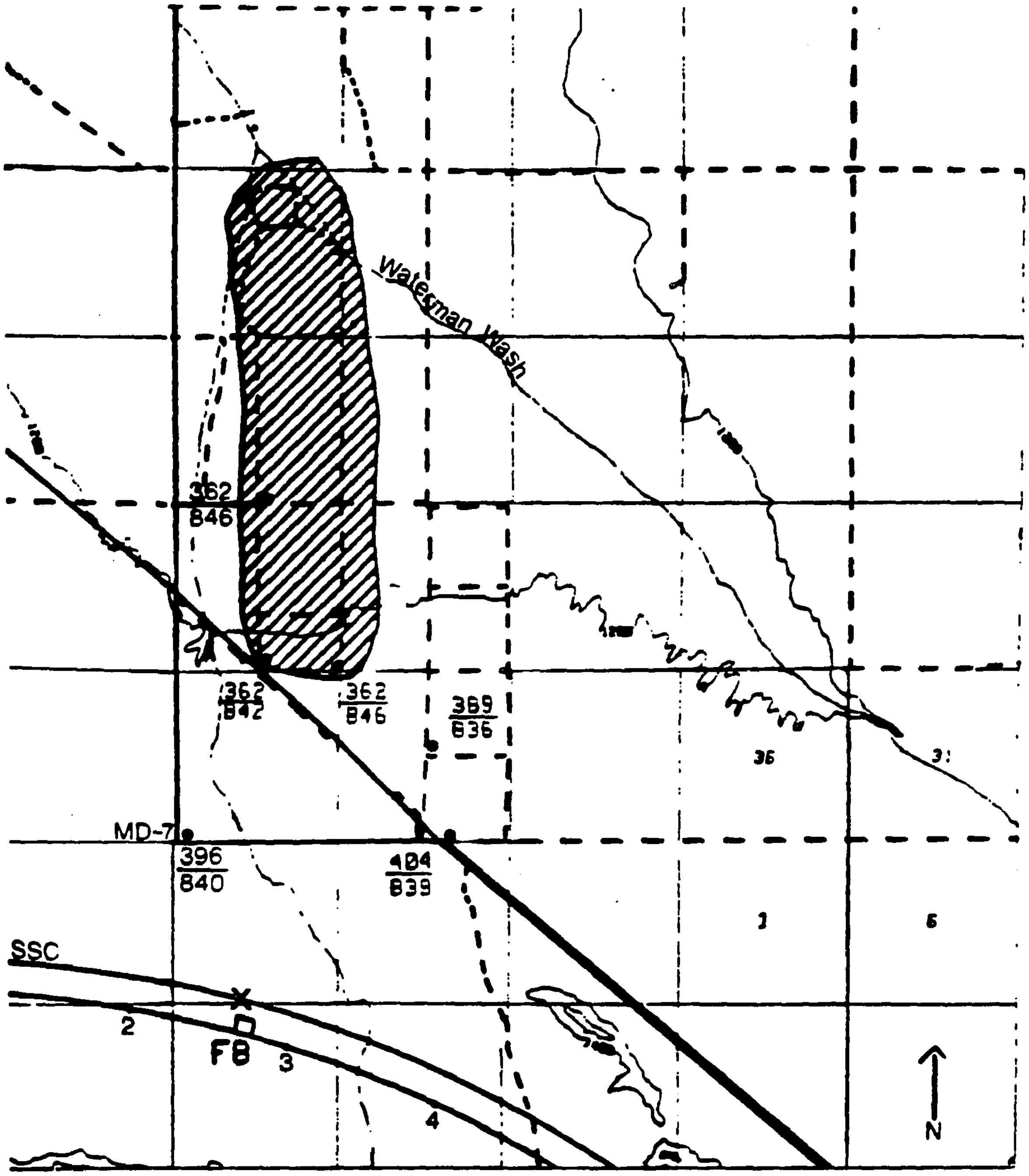


FIGURE 7

1 mile

Wells Used in Subsidence Study

X- estimated point of maximum decline

Table 9

	Drawdowns assuming max. pumping rates[1] (feet)		Drawdowns assuming 1986 actual pumping rates[1] (feet)	
Well	W	R	W	R
21 DCC1	22	13	3	2
28 CDD	37	12	6	2
28 DDD	66	21	9	3
34 ACC	70	17	13	3
34 DCD	128	25	25	5
Total	323	88	56	15

Explanation:
W - worst case scenario, T = 600 ft^2/day, S = 0.10
R - reasonable case scenario, T = 8000 ft^2/day, S = 0.10
[1] - pumping rates continuous for 40 years

As the results in Table 9 show, using the current pumping rates, which are expected to decrease in the future, even assuming the worst case aquifer parameters the maximum drawdown would be only 56 feet. These results combined with the generally coarse, granular nature of the aquifer indicate that subsidence should pose no future hazard to the region.

The worst case aquifer parameters along with the theoretical maximum pumping rates, do show a potential problem. Future geotechnical and hydrological work will be necessary to better identify the regional aquifer properties. If conditions warrant, the State has indicated that it would consider purchasing the land and retiring the water rights.

Conclusion

The Maricopa SSC Site is apparently devoid of any ground water-related construction problems. Available data suggest that the entire tunnel and its associated facilities will be above the regional water table and that the possibility for perched water of any consequence is remote.

Little site-specific data exists on the aquifer properties at the site. However, based on data from other areas in the basins and data from similar type basins elsewhere, a range of values can be given with a fairly high degree of confidence. The basin aquifers are generally under water-table conditions but confined conditions may exist locally because of silt and clay lenses. Aquifer transmissivities can range from approximately 800 ft^2/day to 15,000 ft^2/day depending upon location and depth in the basin. Although more compacted and better cemented, the deeper deposits are generally coarser-grained with very little fine material present. Thus, transmissivity values tend to be higher on average. The specific yield ranges from 8 percent to over 20 percent.

Although the vertical and lateral heterogeneities in alluvial deposits make estimation of aquifer properties difficult, the absence of any interaction between site facilities and the water table, and the fact that no on-site pumping is currently occurring or is expected to occur in the future, suggest that knowledge of site-specific detailed aquifer properties are unnecessary for the construction phase of the project.

A relatively undeveloped yet well-studied reservoir of good quality ground water lies southeast of the site in the largely federally controlled northern Vekol Valley.

Estimated recoverable reserves, to a depth of 450 feet below the water table, of 375,000 acre-feet of ground water more than satisfy the relatively minor project needs of 4,000 acre-feet per year.

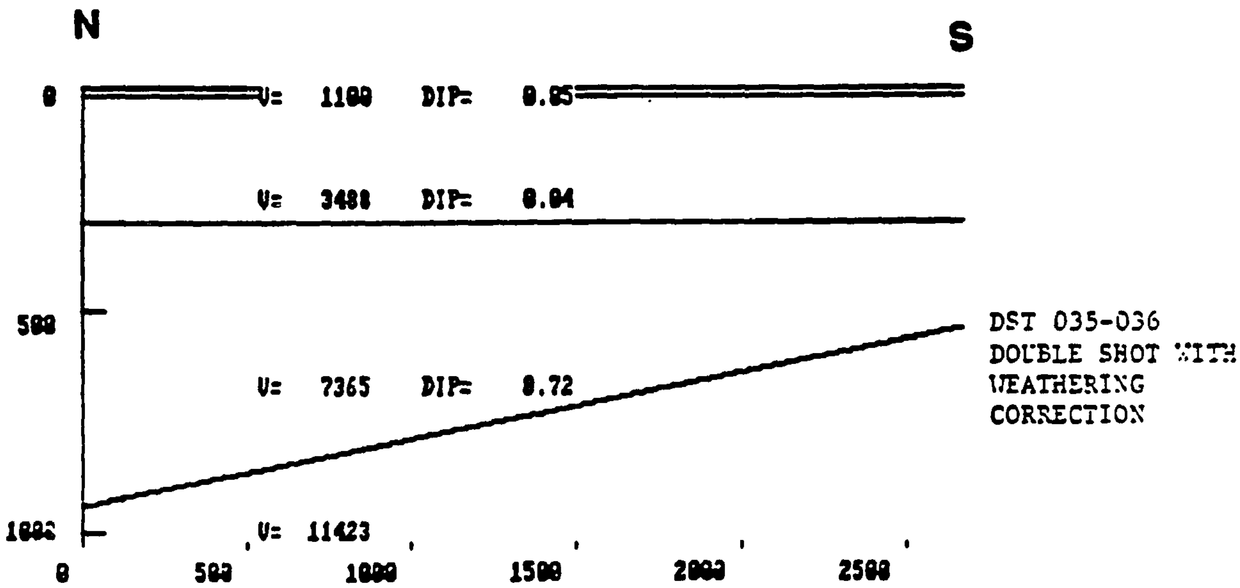
Current and projected future ground-water withdrawals and the physical nature of the aquifer based on a limited amount of information, suggests that subsidence should not be a problem for the Maricopa site. However, if the SSC should be built at the Maricopa site, growth well beyond that of non-SSC projections could occur. The location, magnitude, and water-needs of such growth will be important in assessing the regions hydrogeological future.

Recommendations

Although hydrologically the site is apparently ideal for construction of the SSC project, the paucity of data suggests that more detailed information is needed. A few well-placed drillholes along with additional seismic refraction work to better define the basin shapes and determine the depth to basement will greatly improve the confidence in the assumed conditions. In addition, the computer modeling of the northern Vekol Valley done by Hollett and Marie (1987) should be redone using the proposed SSC well locations and pumping requirements. Informed sources have all concluded that no technical or legal problems appear to be present in using northern Vekol Valley as a source of water but further work using the USGS developed model could greatly strengthen these conclusions. Further refinement is needed in estimating basin-wide water-table decline from SSC pumping and the natural recharge into northern Vekol Valley. Additional water quality sampling should be done in the Vekol Valley to provide a more reliable baseline to compare future water quality data with as the aquifer is dewatered. Depth-specific sampling could be done to estimate what future water quality might be.

As water supply is often a determining factor in growth and development in southern Arizona, better understanding of the regions water resources and the future of its water resources are needed to assess potential impacts on the SSC, particularly those related to ground subsidence due to ground-water withdrawal. Possible growth scenarios along with their respective water requirements should be incorporated into a ground-water/surface-water conjunctive-use management model to determine where and what growth will be compatible with the SSC.

Appendix A



INPUT DATA

	FORWARD PROFILE				REVERSE PROFILE				
Seg	Slope	Va	LEFT Ta(mS)	RIGHT Ta(ms)	Slope	Vb	RIGHT Tb(mS)	LEFT Tb(ms)	RECIPROCITY %
1	0.00091	1100	0.000	2439	0.00091	1100	-0.000	2439	0
2	0.00029	3497	35.569	813	0.00029	3479	34.182	811	0
3	0.00014	7406	178.234	553	0.00014	7325	178.514	554	0
4	0.00007	14250	322.256	510	0.00010	9713	230.042	508	0

CALCULATED MODEL

LAYER	VELOCITY	DIP	Ha	Hb	Da	Db
1	1100	0.00	20.6	19.8	0.0	0.0
2	3488	0.05	279.6	283.0	20.6	19.8
3	7365	0.04	645.5	240.8	300.2	302.8
4	11423	0.72			945.6	543.6

Va = apparent velocity forward profile
Vb = apparent velocity reverse profile
Ta = intercept forward profile
Tb = intercept reverse profile
Slope = slope of line segment (1/V)

Velocity = velocity in units of distance / second
Dip = dip of top of layer in degrees
Ha = thickness of layer under forward shot point
Hb = thickness of layer under reverse shot point
Da = depth to top of layer under forward shot point
Db = depth to top of layer under reverse shot point

From: Sternberg
et al., 1988

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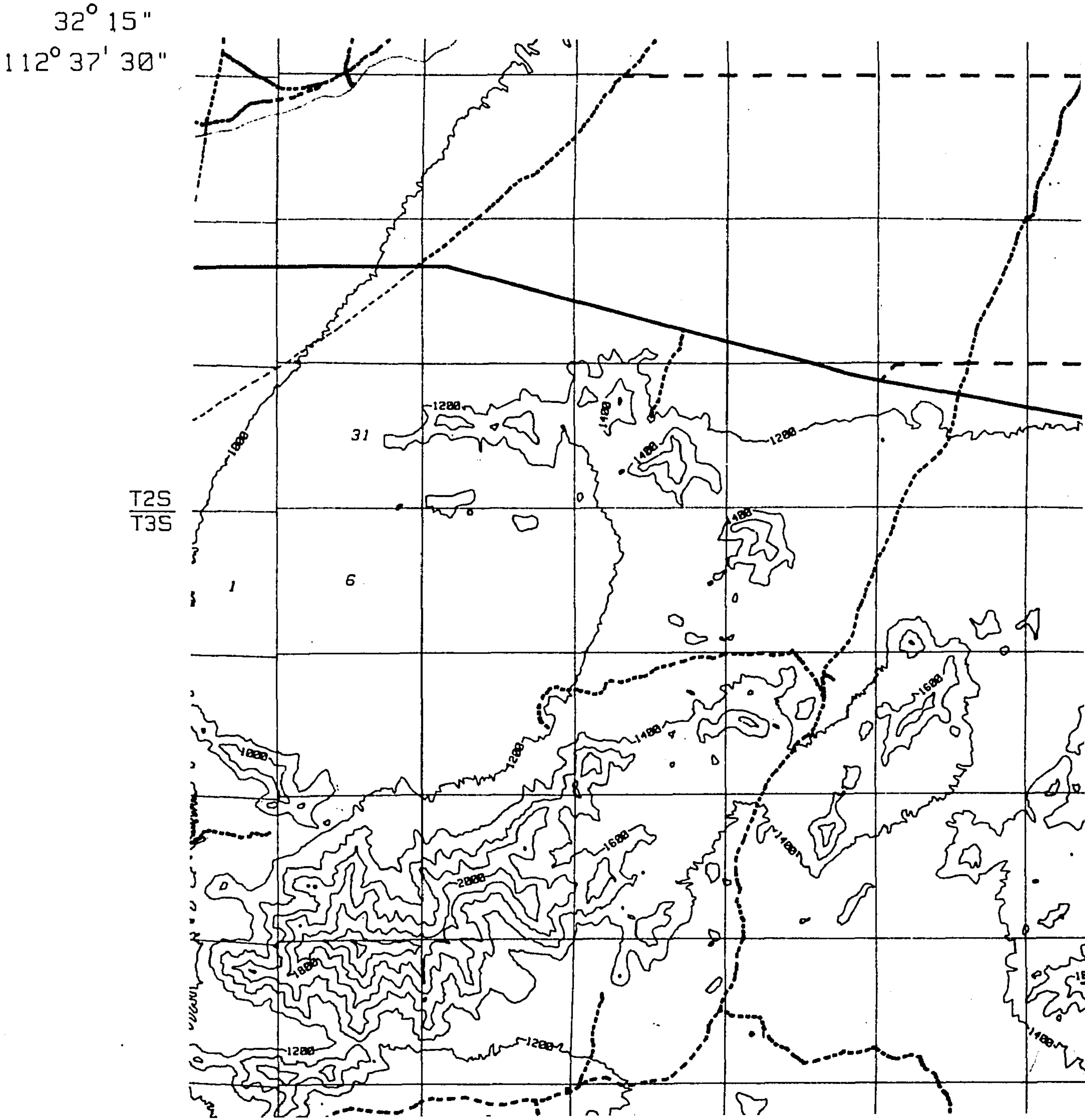

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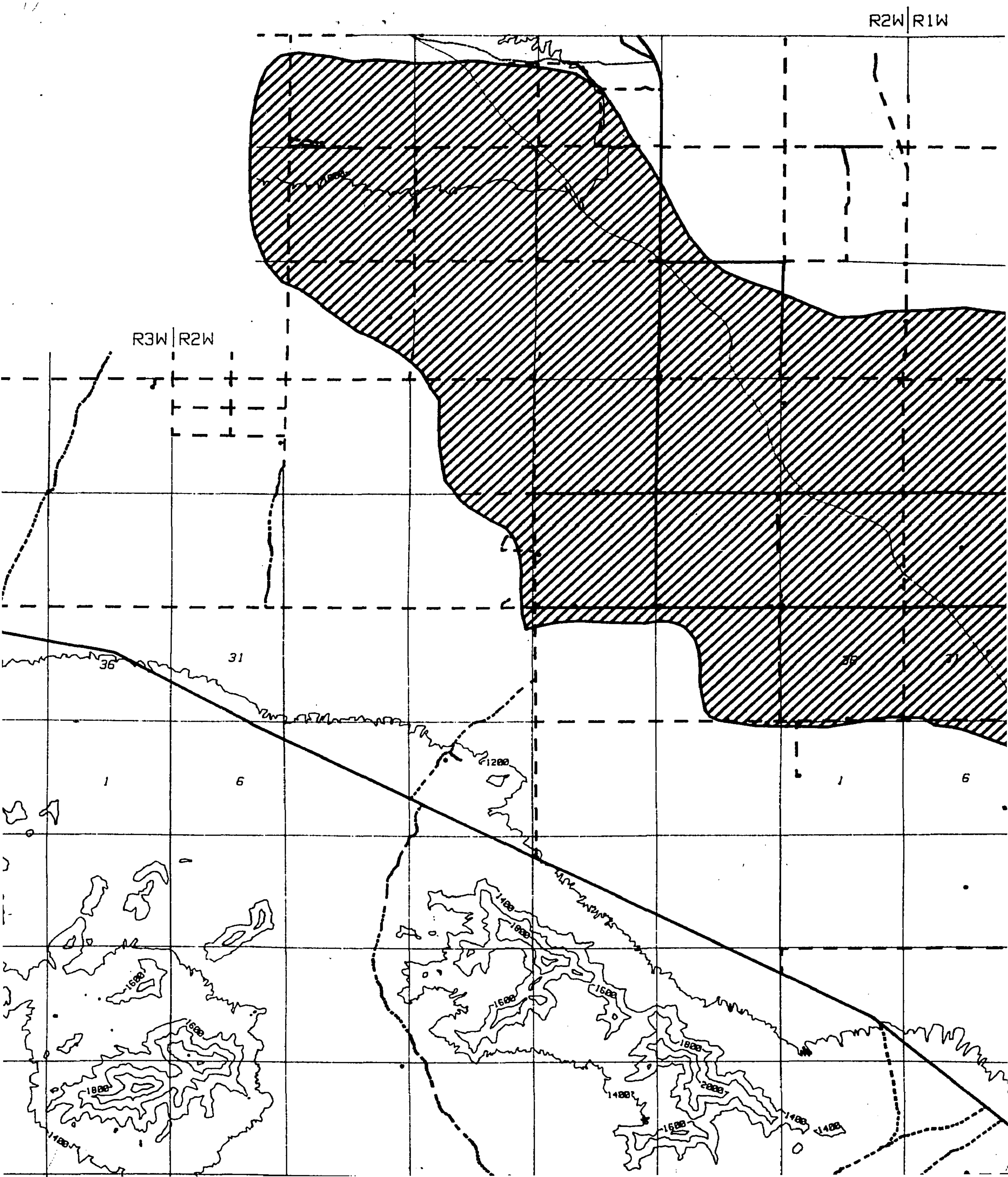
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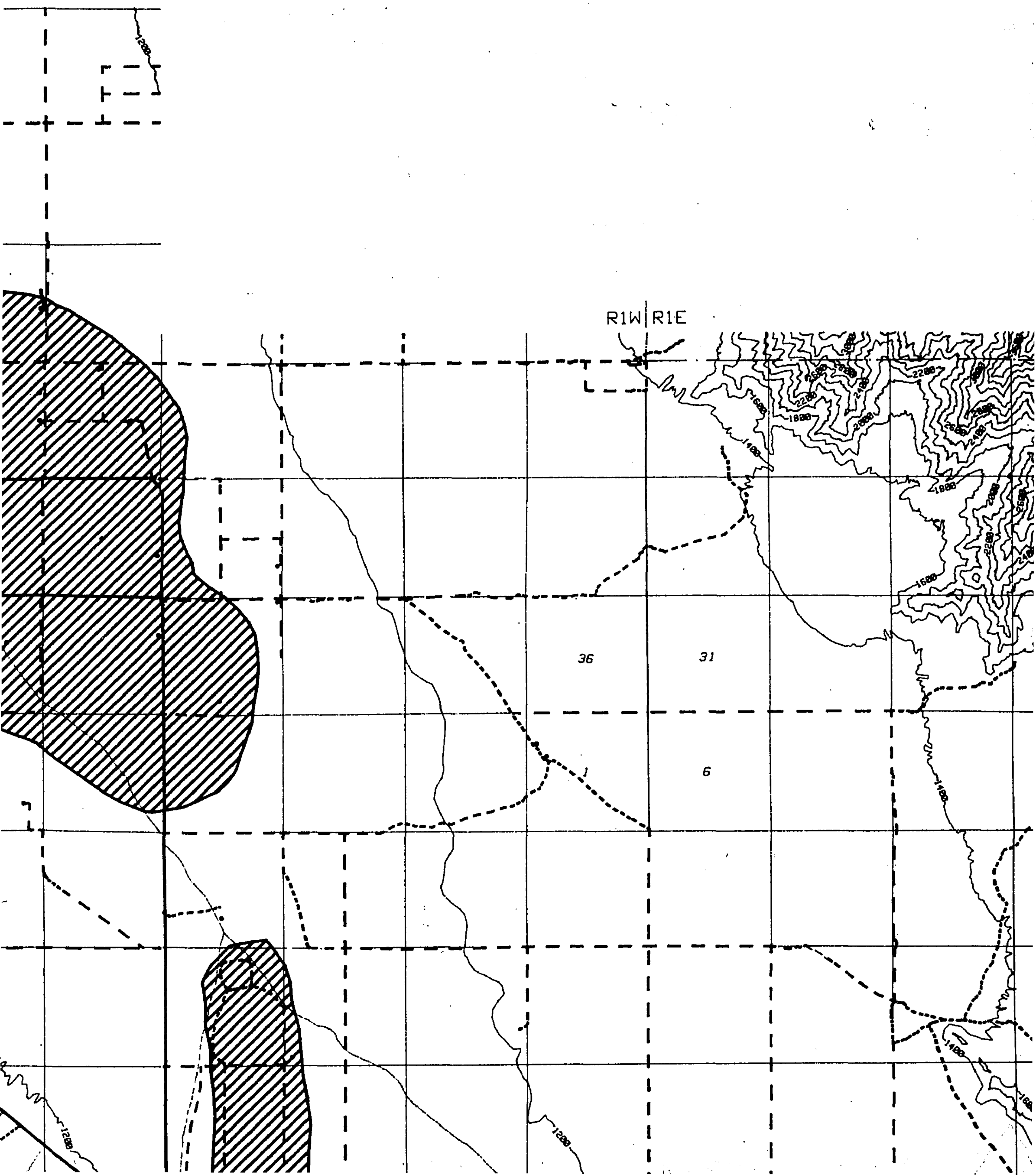
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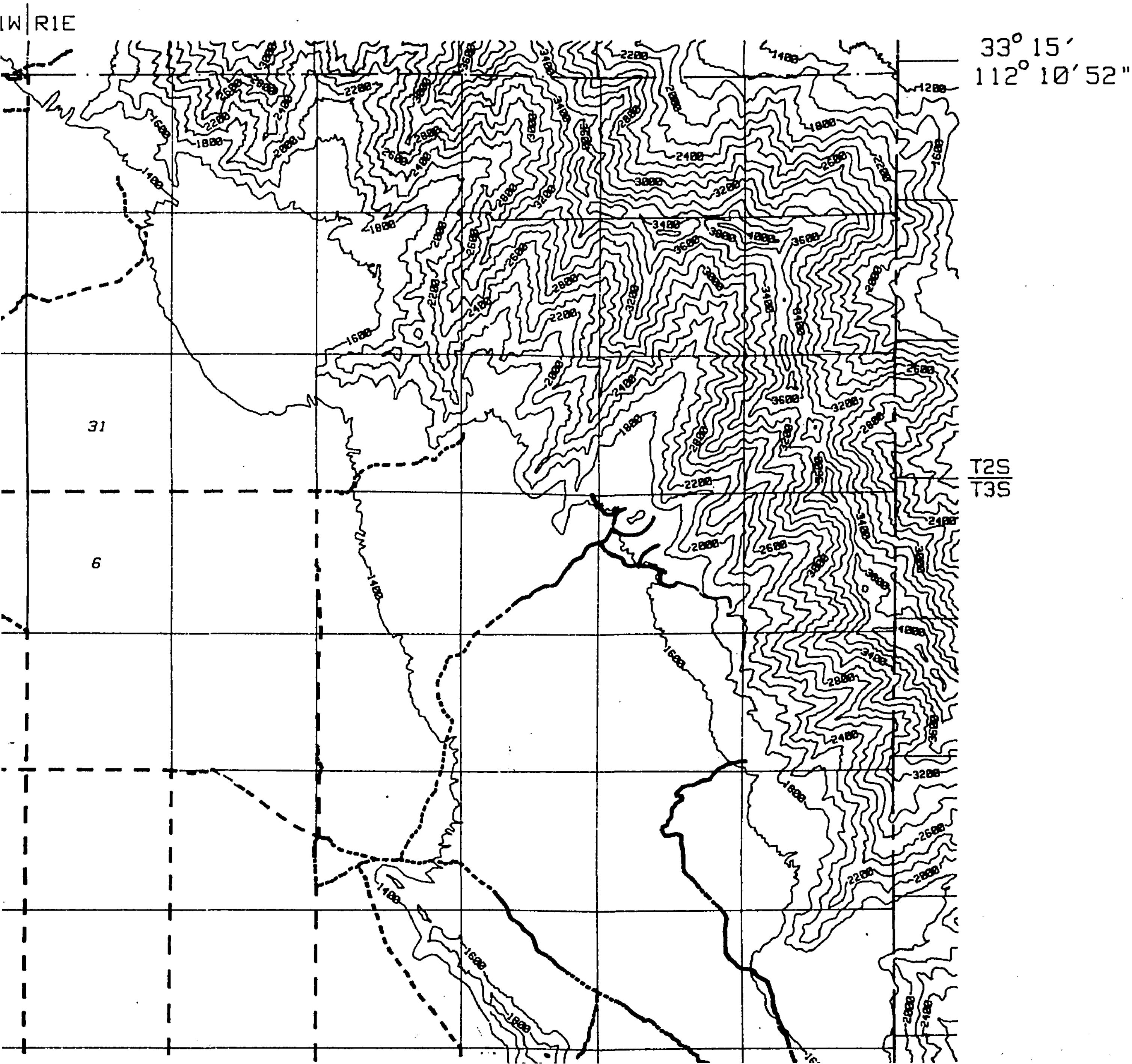

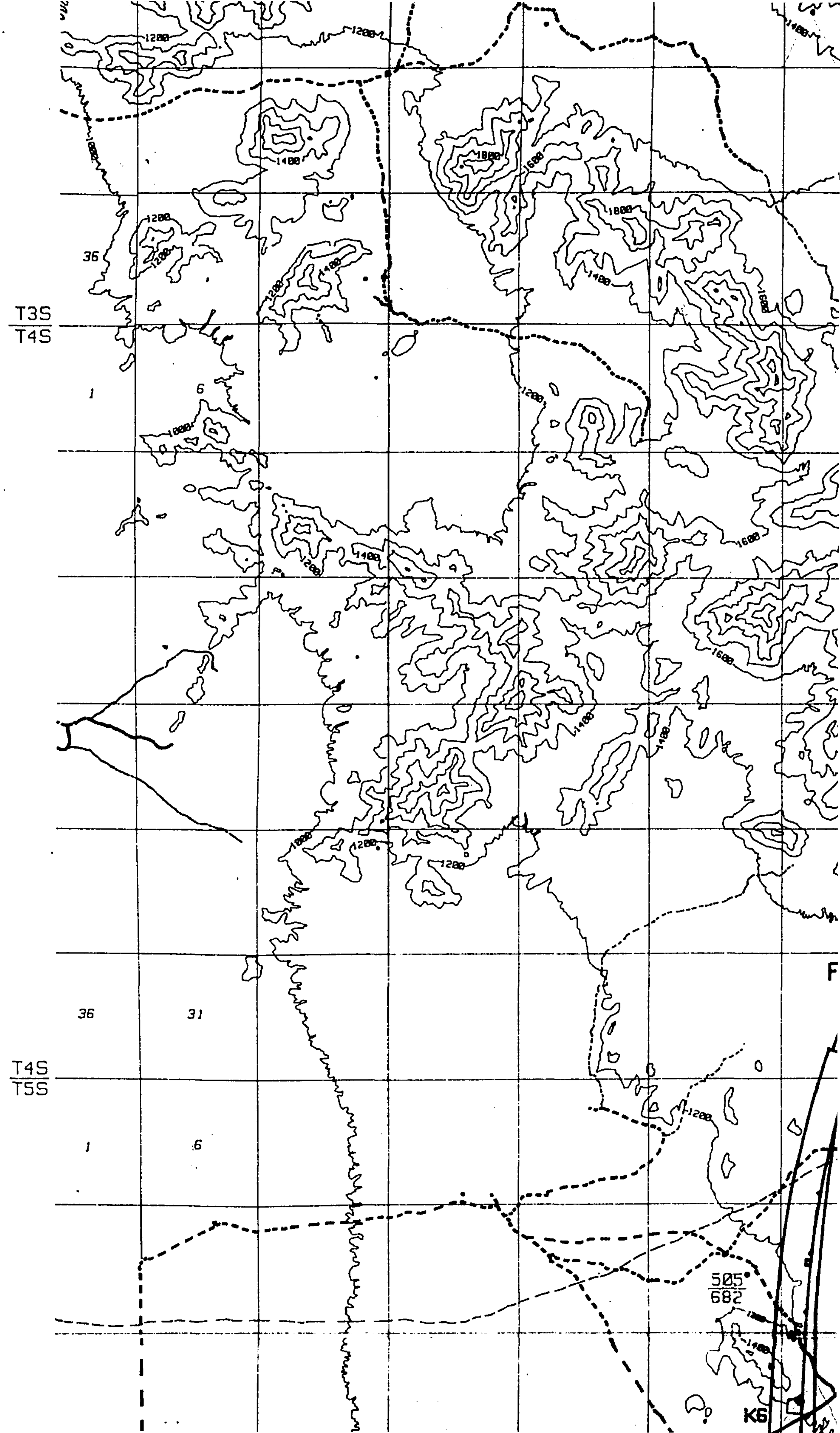
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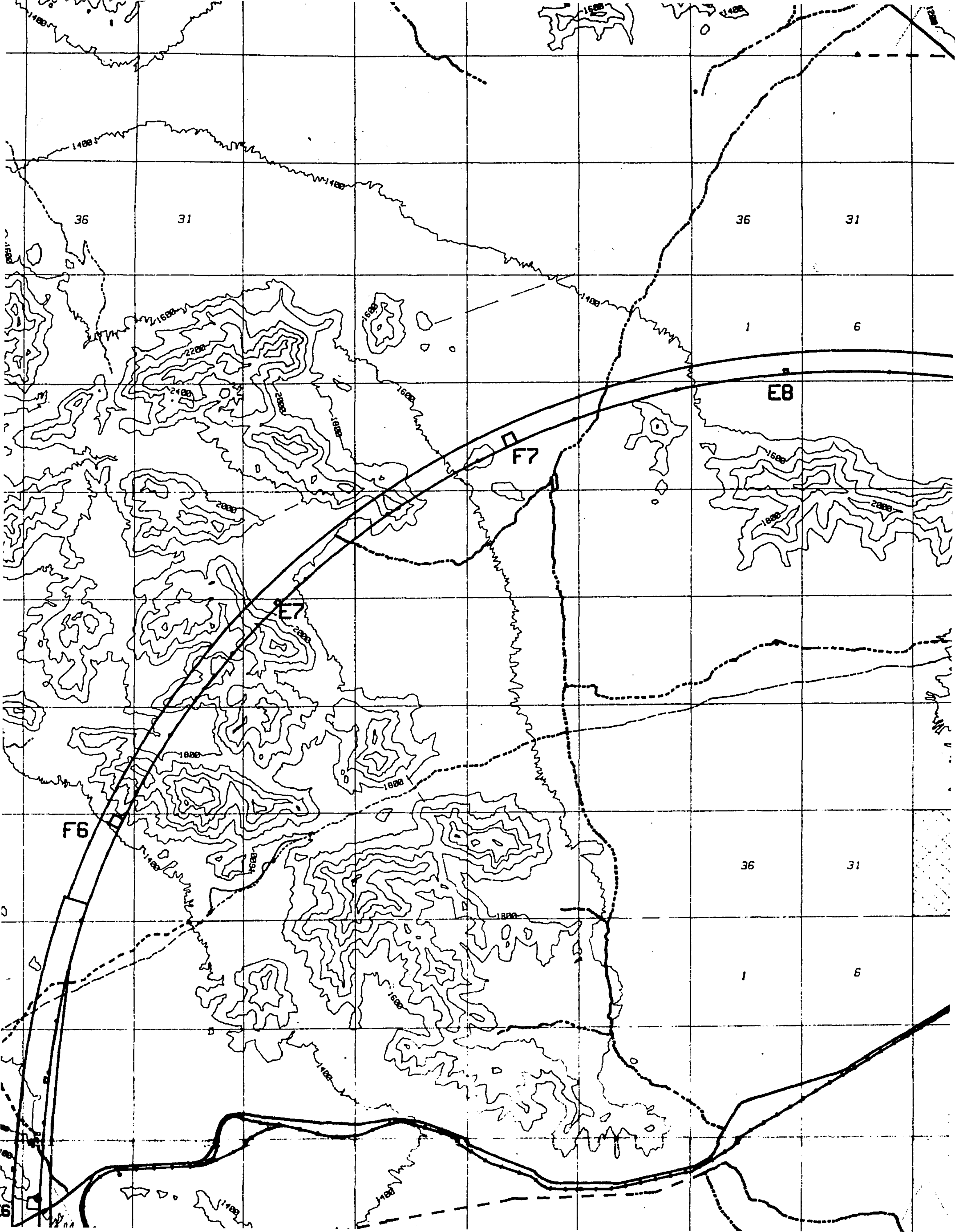

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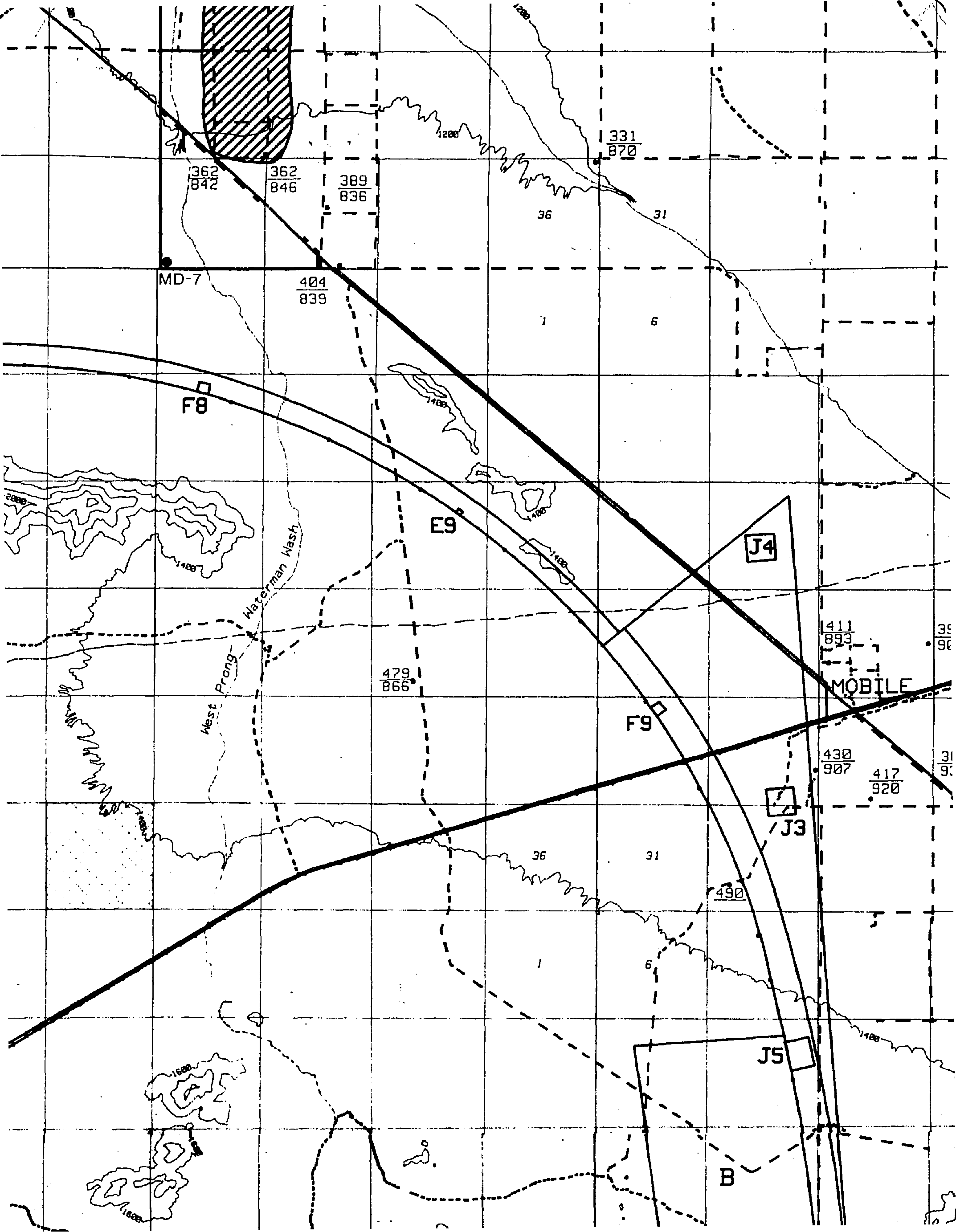
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E9
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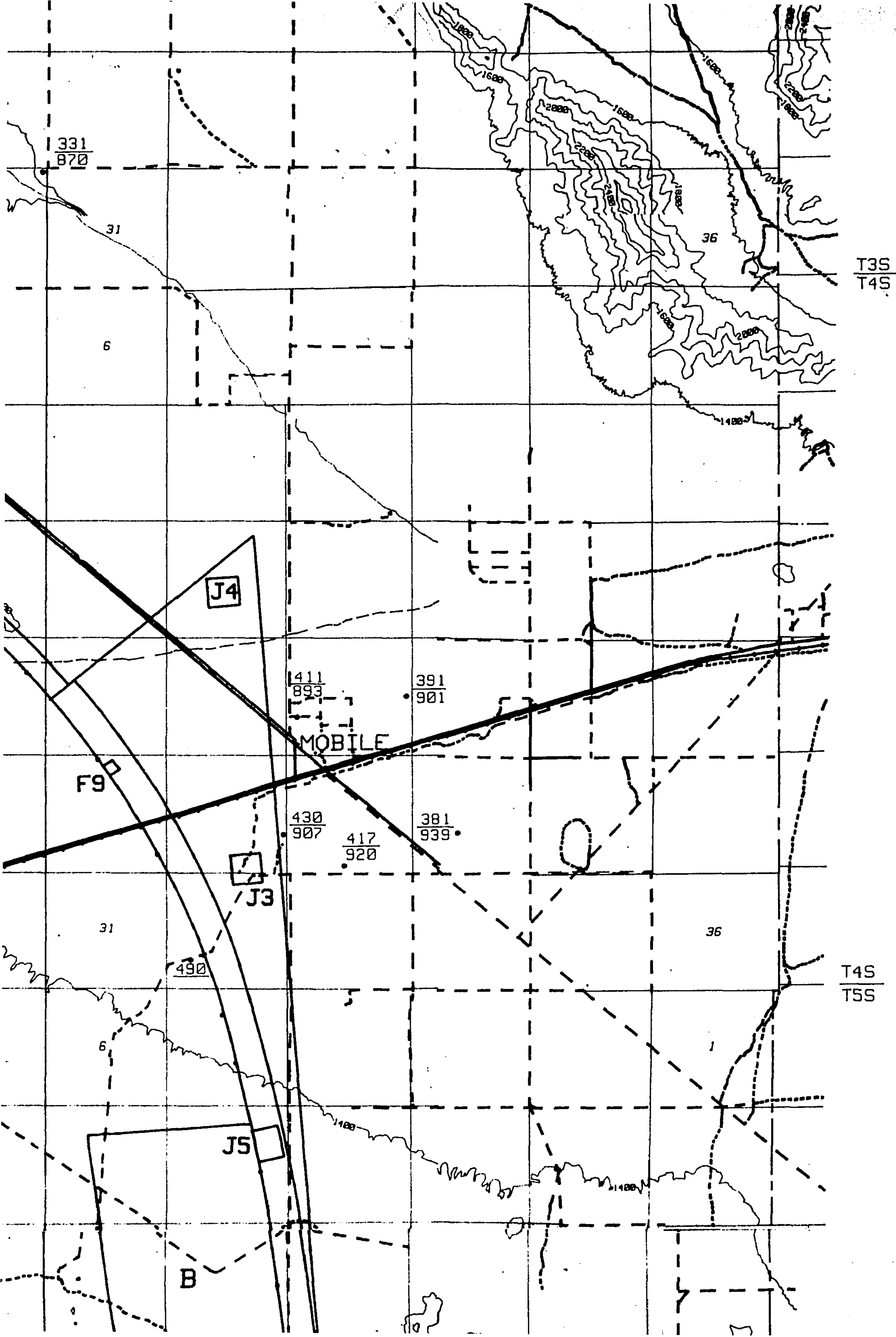

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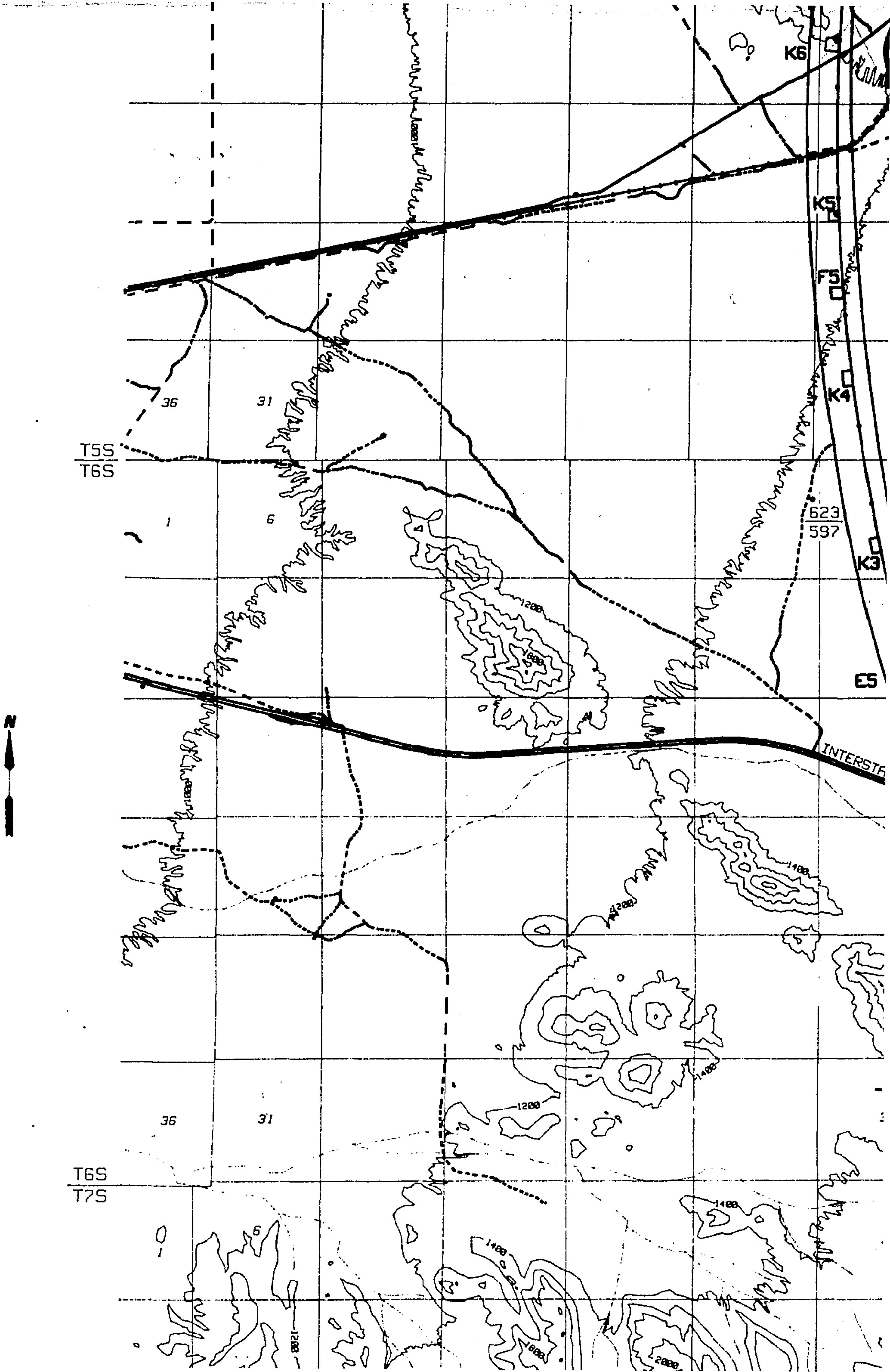
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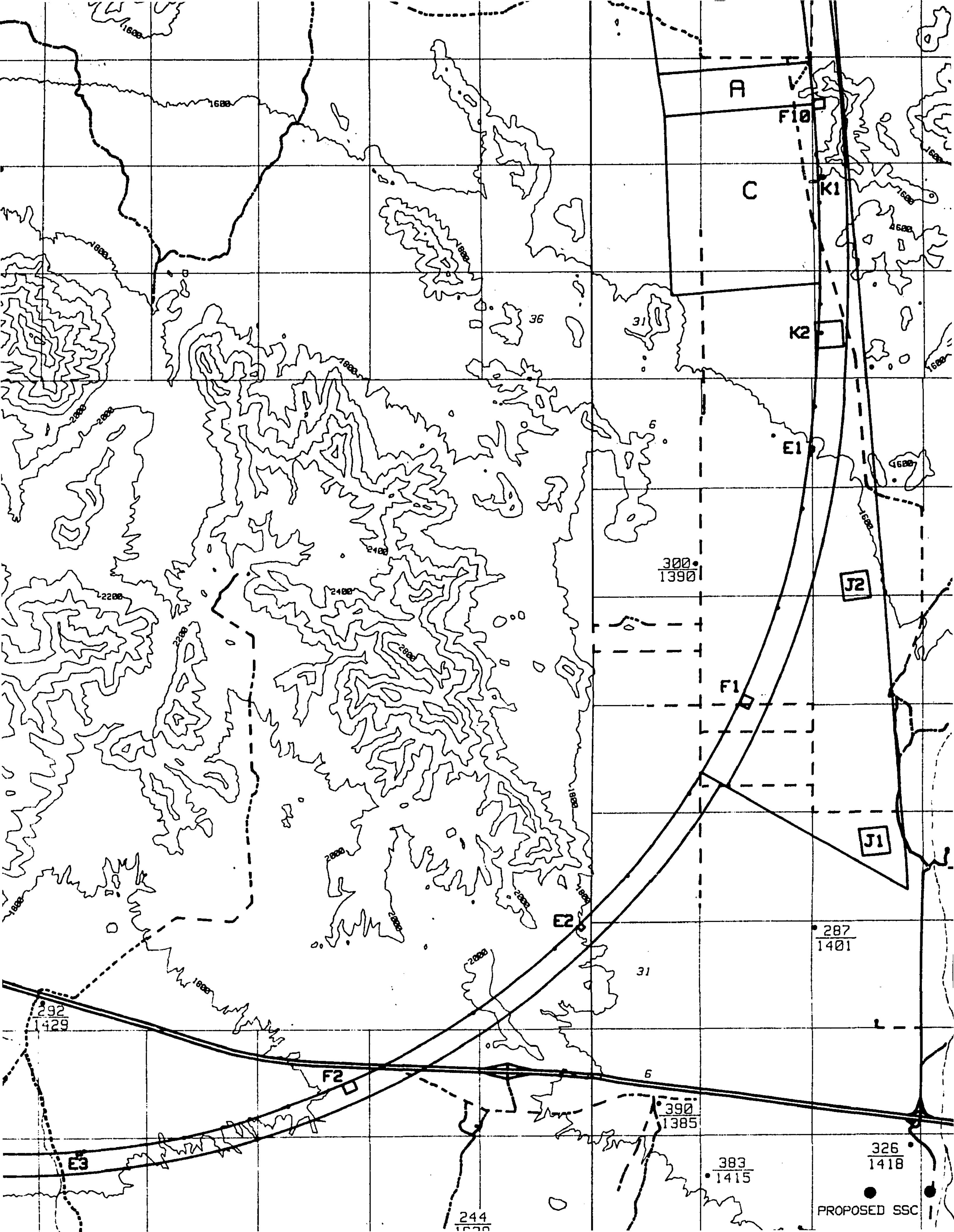

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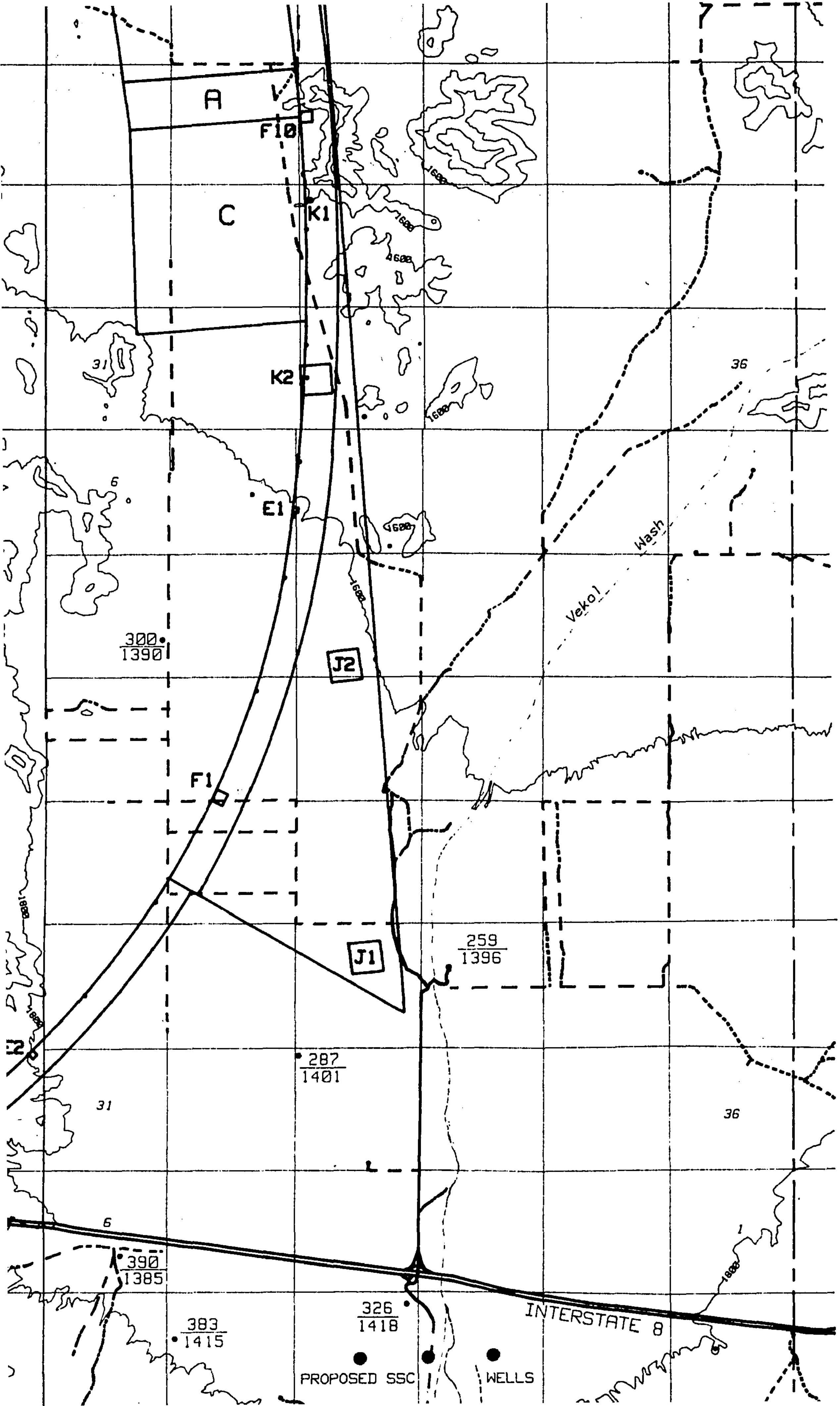
PROPOSED SSC



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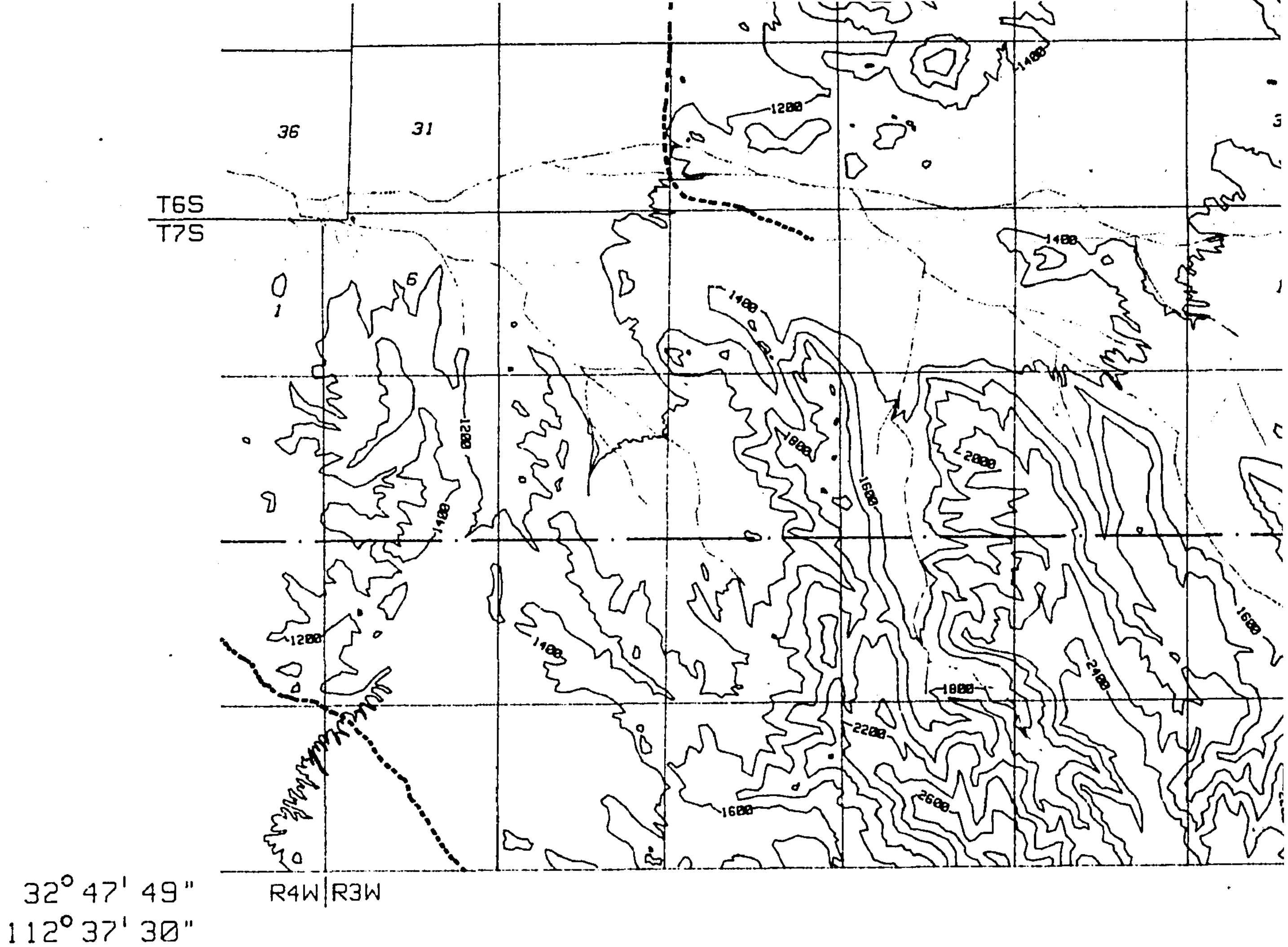
INTERSTATE 8
PROPOSED SSC
WELLS

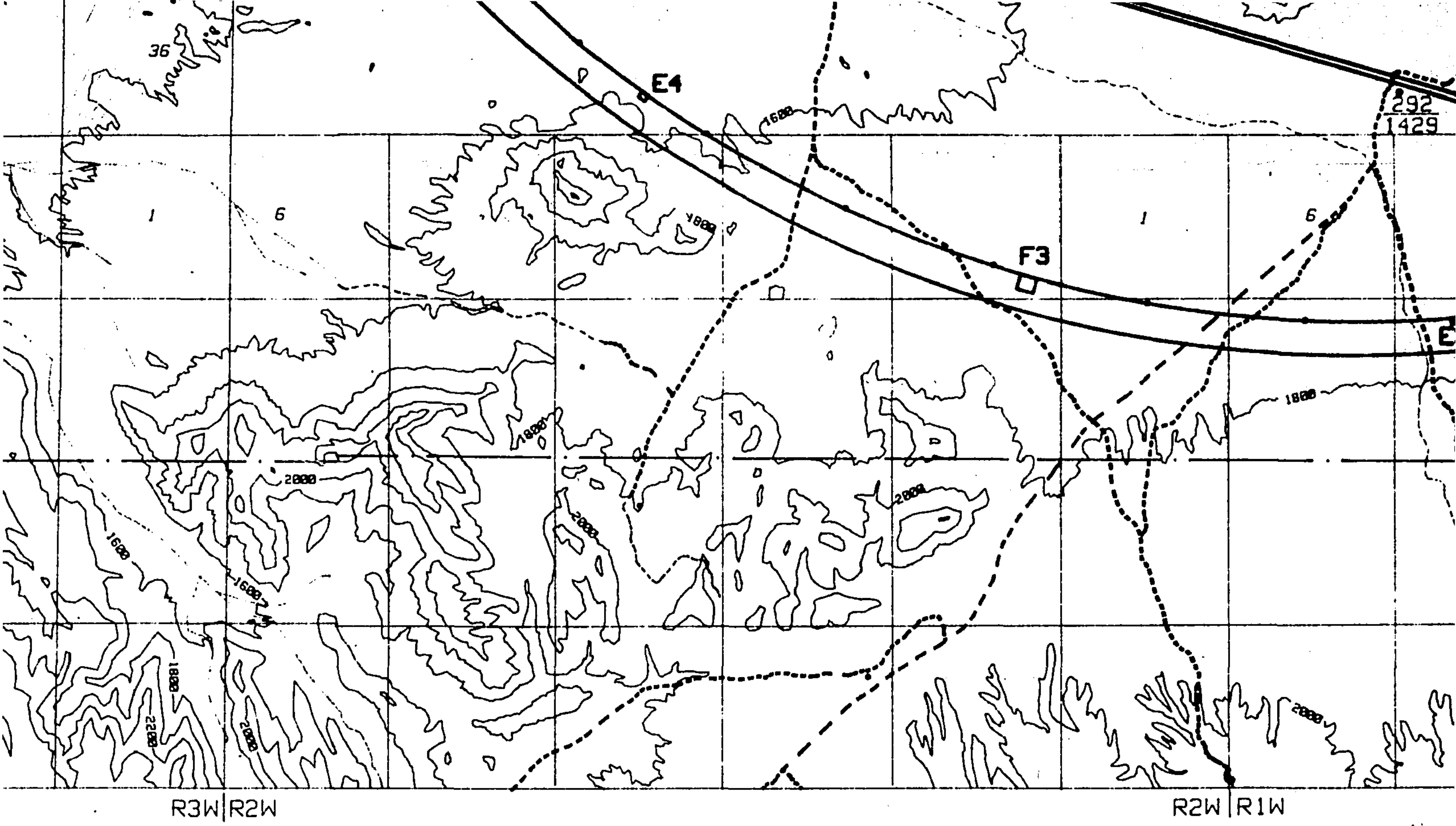


WELL-LOCATION MA

PLATE 1

DIGITIZED IN CONFORMITY WITH STATE PLANE COORDINATE SYSTEM

DRACHMAN INSTITUTE - UNIVERSITY OF ARIZONA



MAP

244
1638

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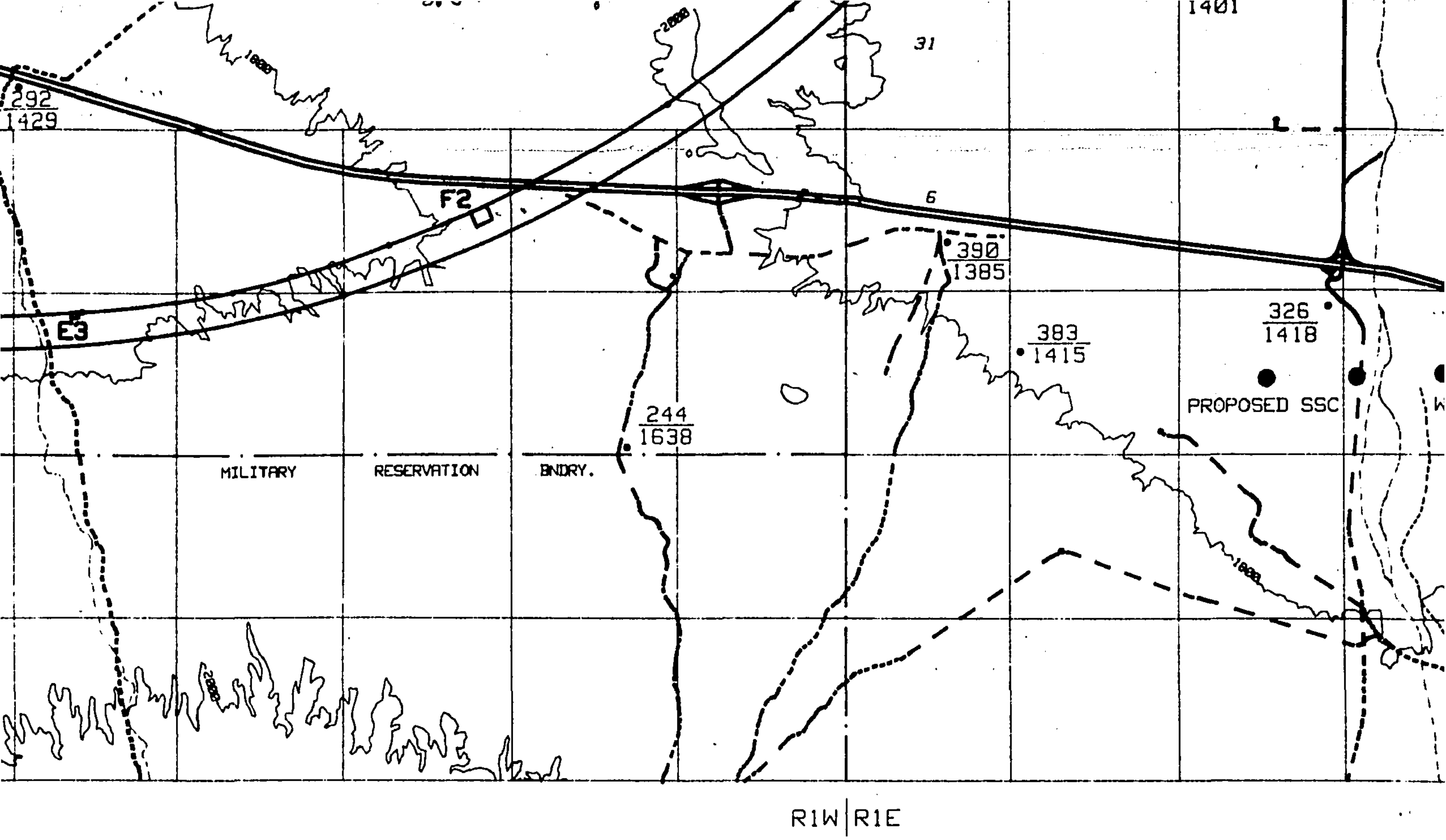
SCALE IN FEET

CONTOUR INTERVAL 200 FEET

COORDINATE SYSTEM

Y OF ARIZONA

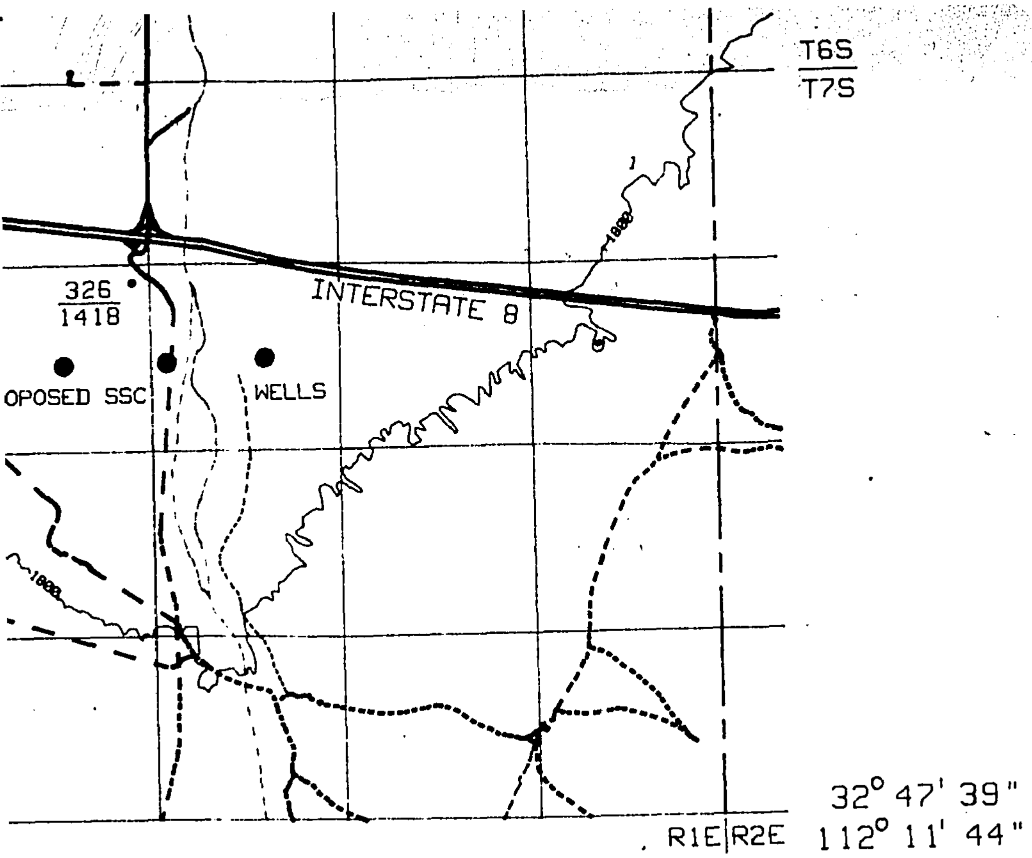


PROPOSED SSC WELLS

244 / 1638 — DEPTH TO WATER / ELEVATION OF WATER TABLE — WELL

ARIZONA HAZARDOUS WAS

APPROXIMATE BOUNDARY
IRRIGATED AREA



S

WASTE SITE

ARY OF

Steven Brooks
M.S., Department of Hydrology
University of Arizona
May 1988

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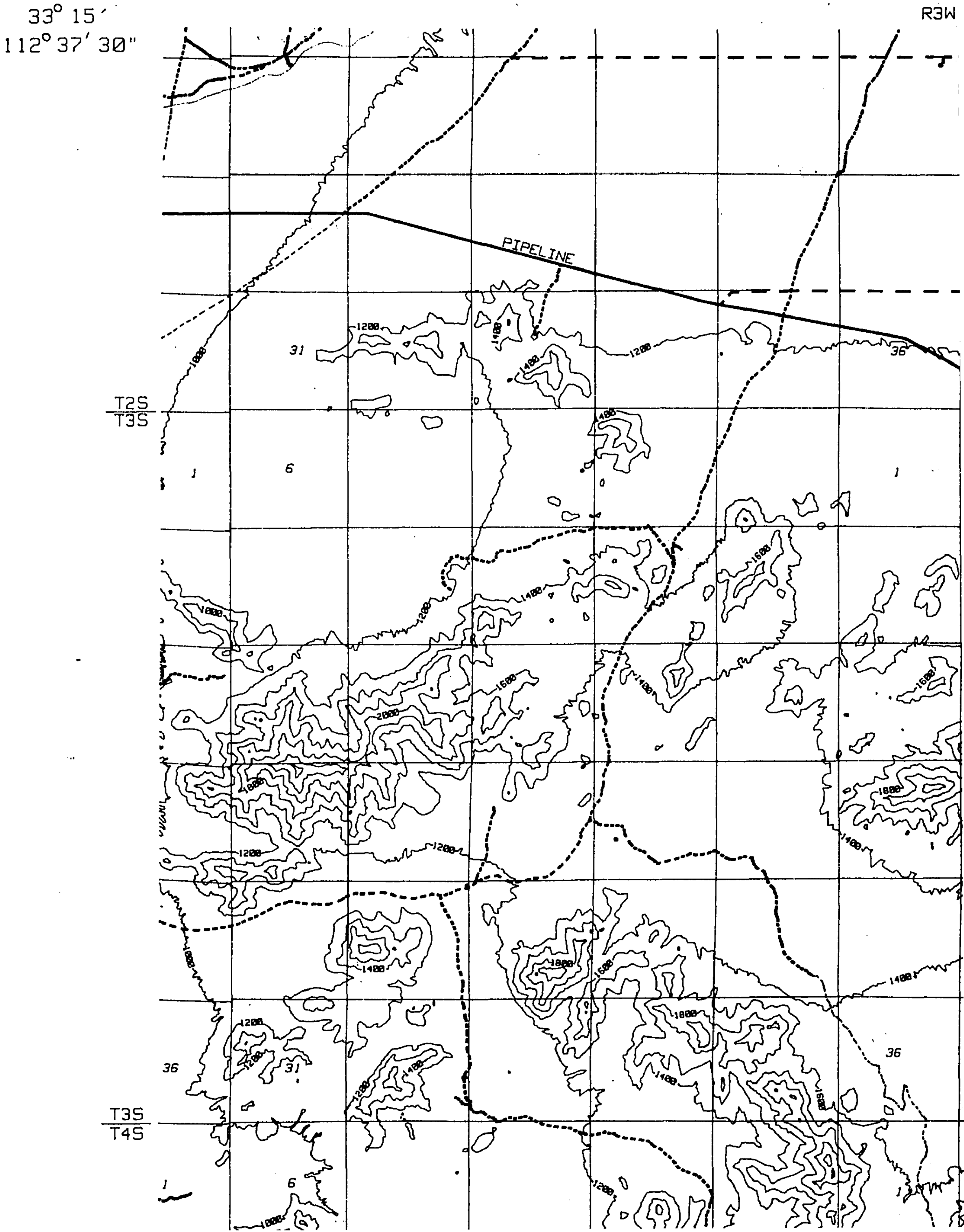
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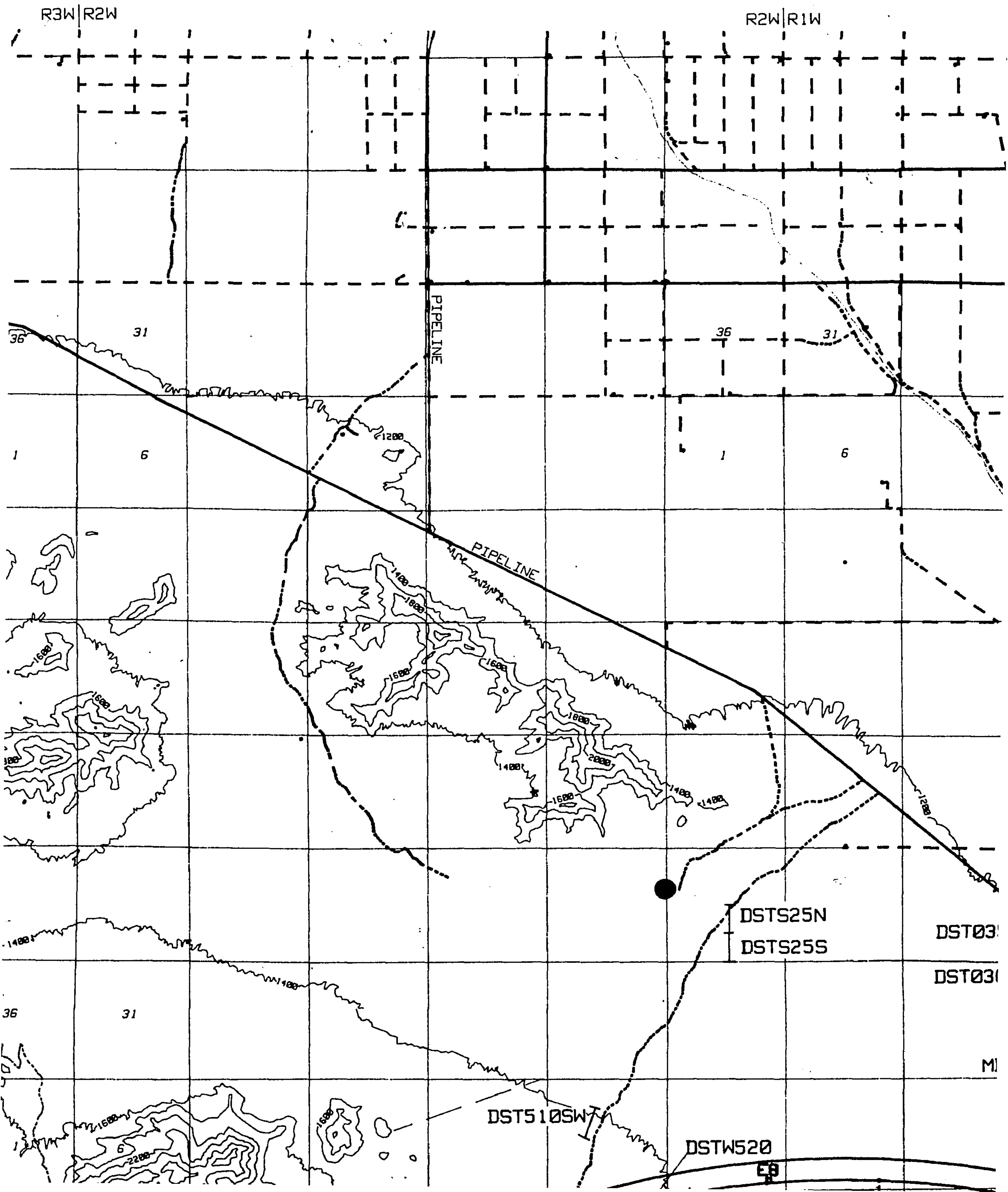

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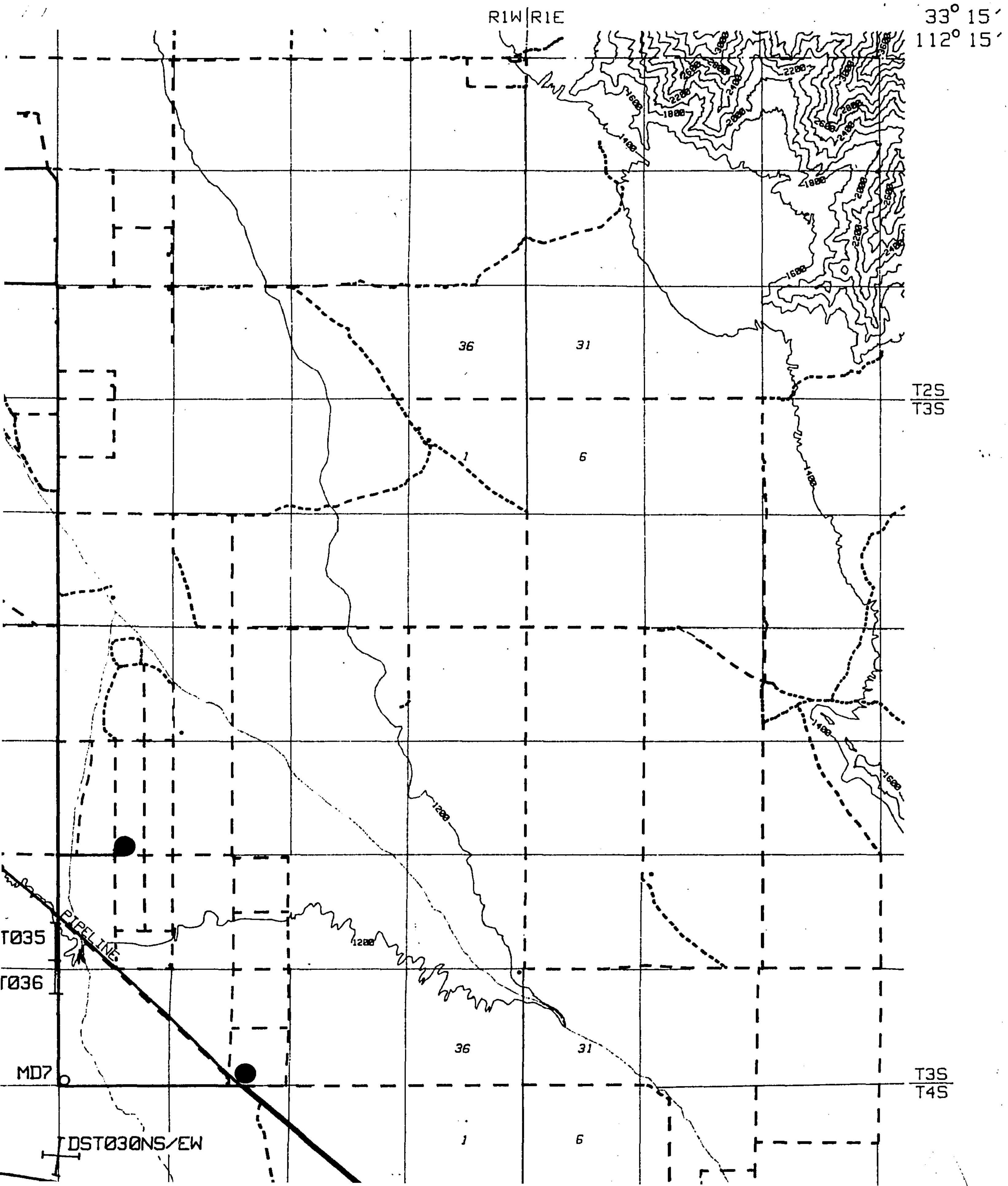

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R1E
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112° 15′
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T3S
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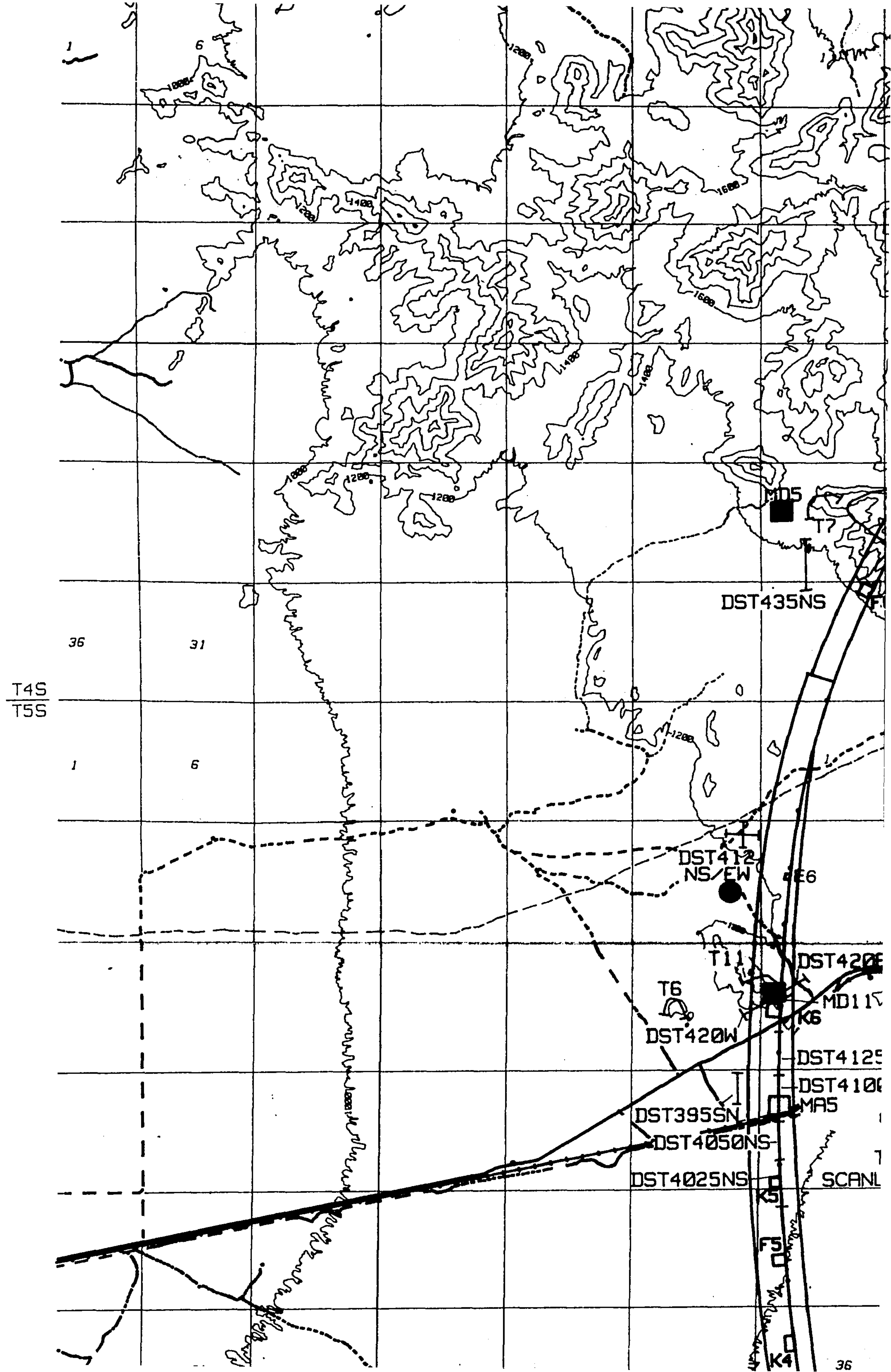
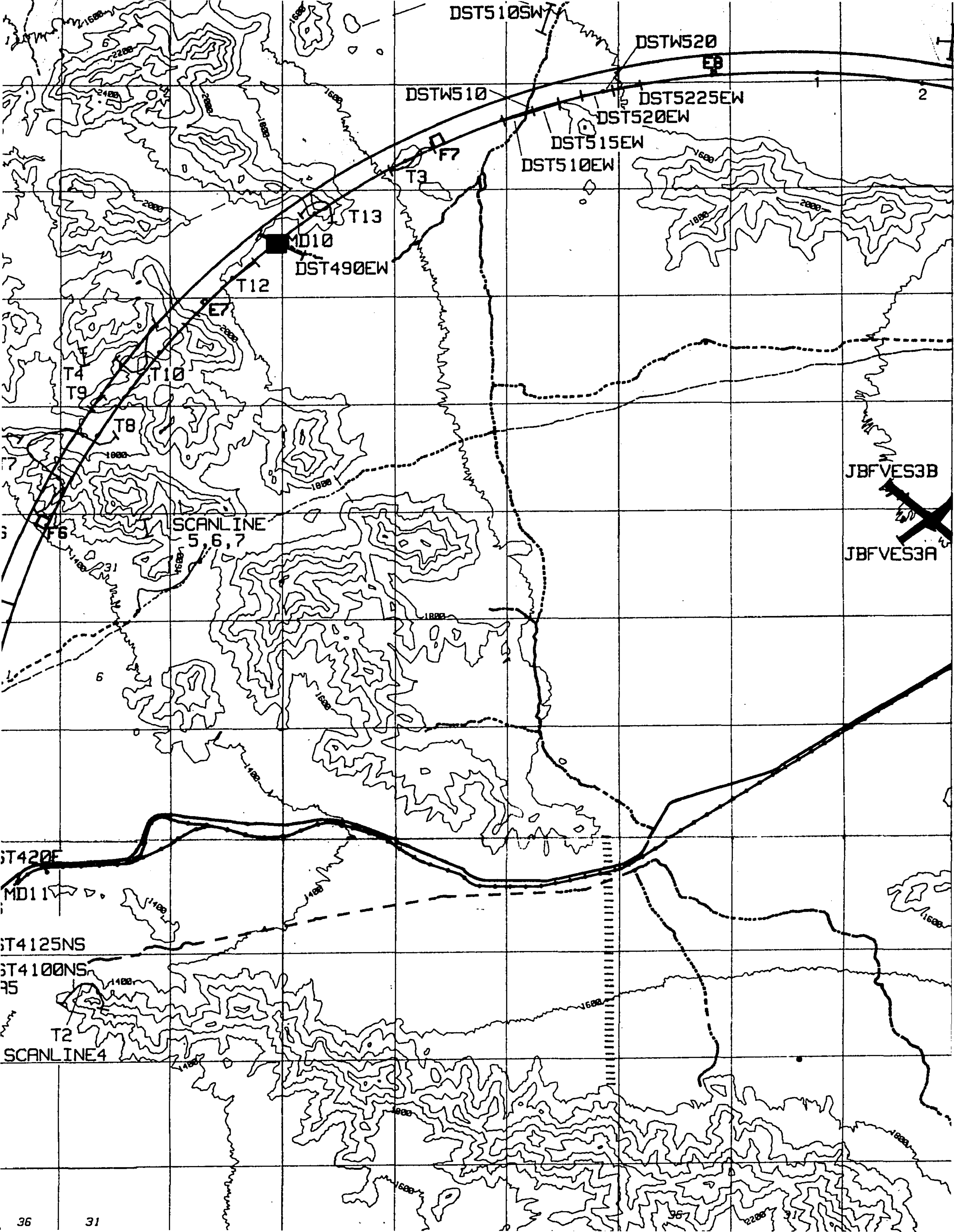
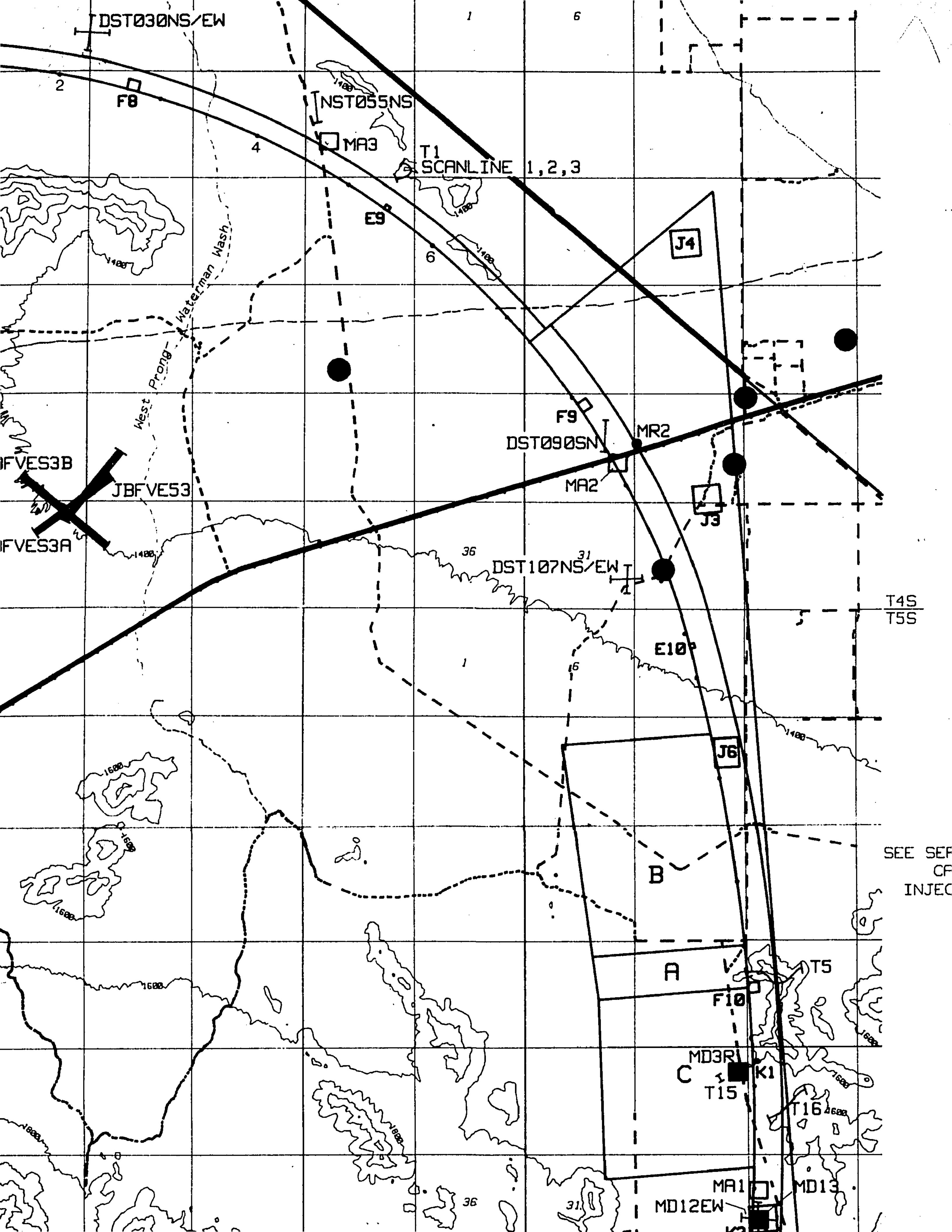
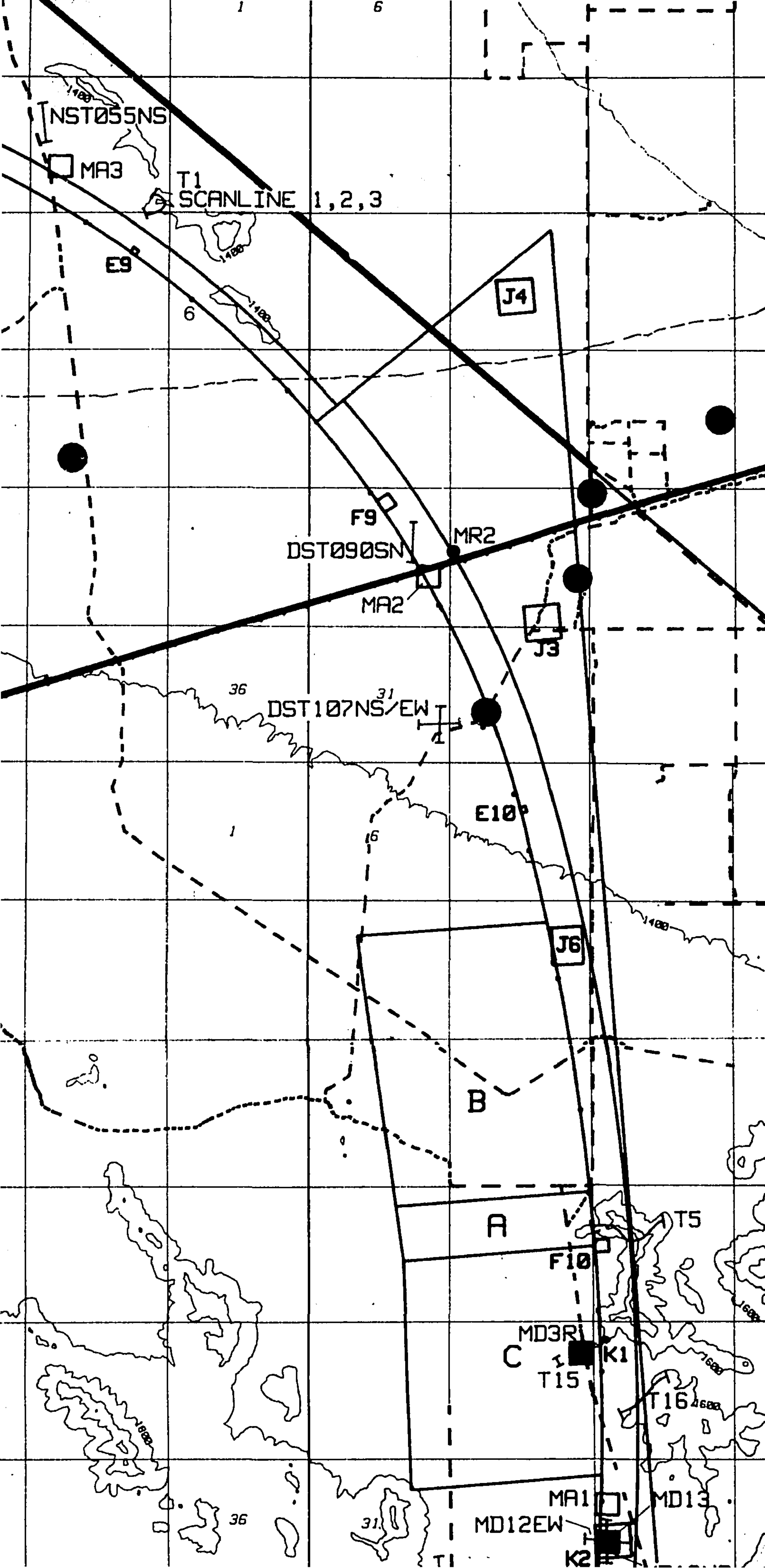


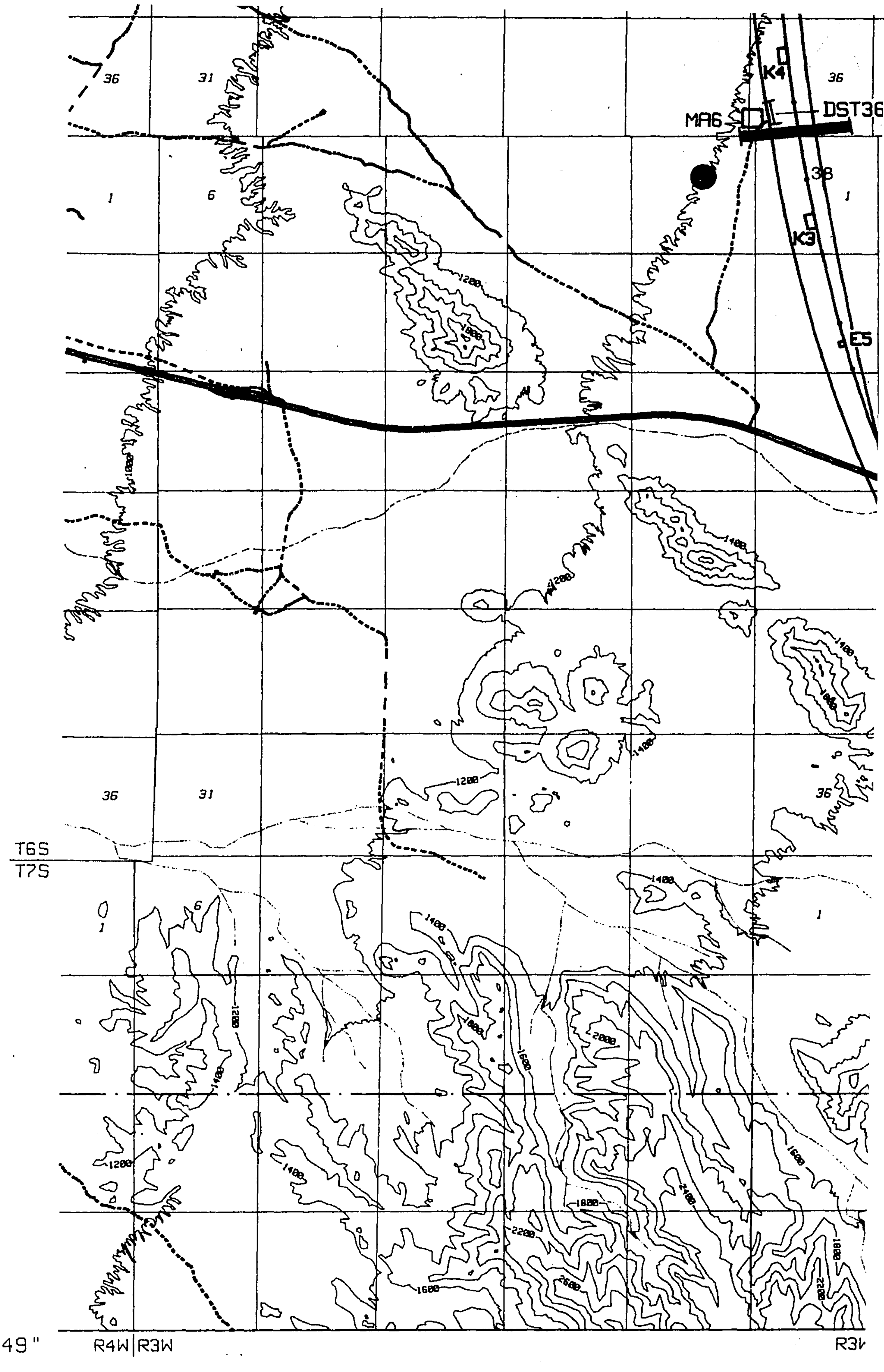
1
6
36
31
T4S
T5S
1
6
MD5
T7
DST435NS
DST412
NS/EW
E6
T11
DST420E
T6
MD11
K6
DST420W
DST4125
DST4100
MA5
DST395SN
DST4050NS
DST4025NS
SCANL
K5
F5
K4
36


DST510SW
DSTW520
E8
1
2
DSTW510
DST5225EW
DST520EW
DST515EW
DST510EW
F7
T3
T13
MD10
DST490EW
T12
E7
T4
T10
T9
T8
T7
F6
SCANLINE
5,6,7
JBFVES3B
JBFVES3A
ST420E
MD11
ST4125NS
ST4100NS
T2
SCANLINE4
2400
2200
2000
1800
1600
1400
36
31
6

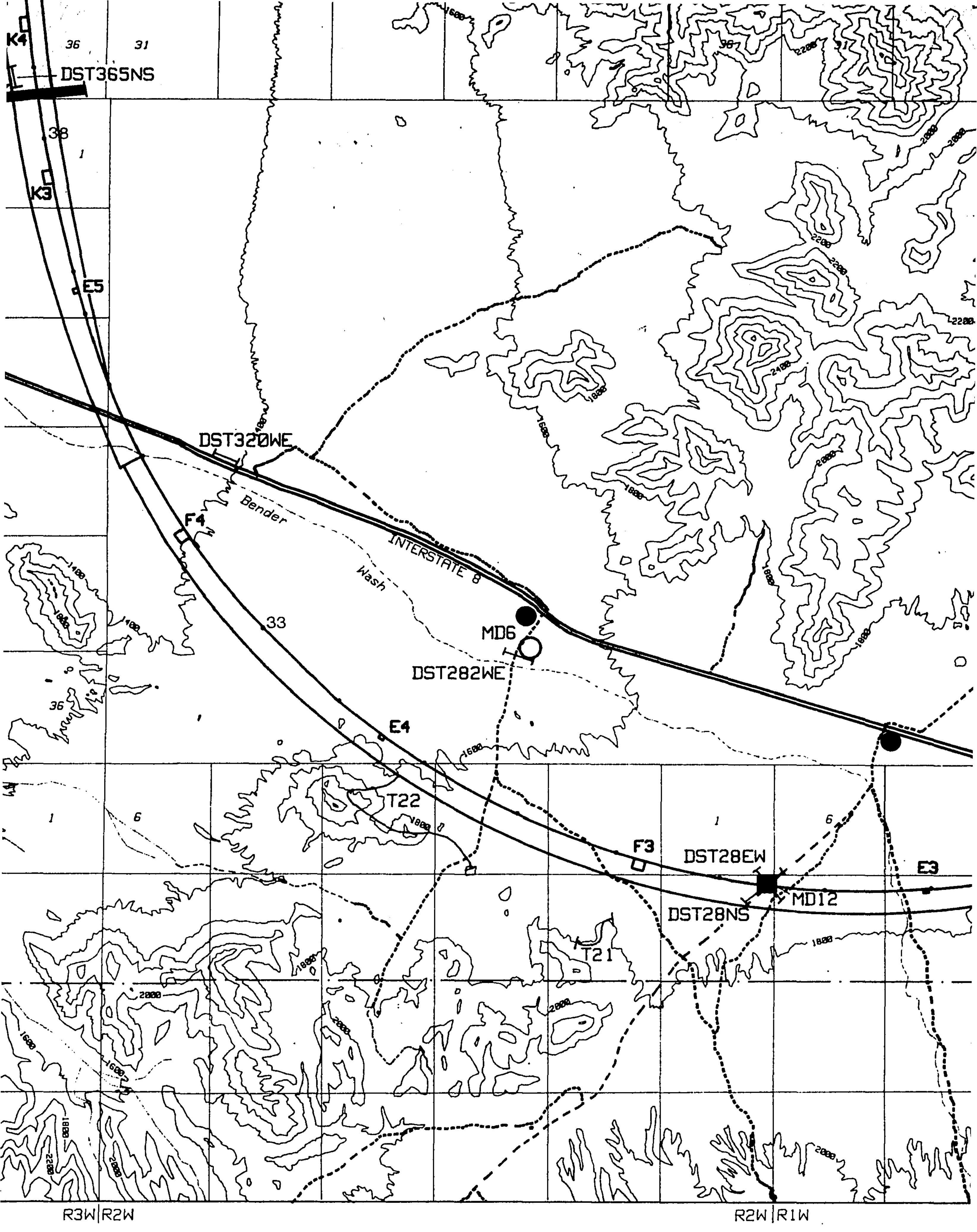

DST030NS/EW
NST055NS
MA3
T1
SCANLINE 1,2,3
E9
J4
West Prong - Waterman Wash
F8
F9
DST090SN
MR2
MA2
JBFVES53
FVES3B
FVES3A
J3
DST107NS/EW
E10
T4S
T5S
J6
B
A
T5
F10
MD3R
K1
C
T15
T16
MA1
MD13
MD12EW
SEE SE
C
INJEC

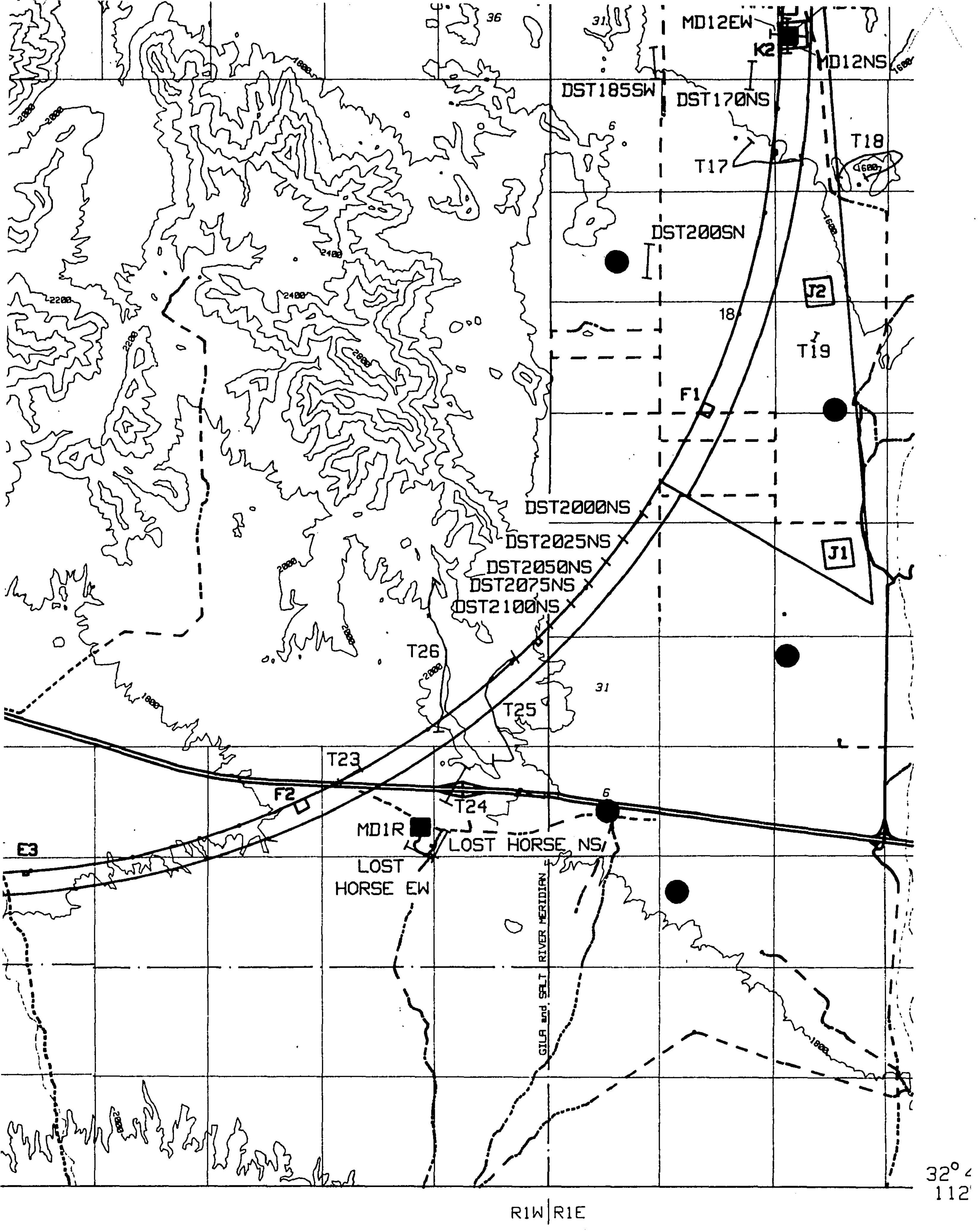


SEE SEPARATE MAP OF
CAMPUS AND
INJECTOR COMPLEX



36
31
36
K4
MA6
DST36
38
1
6
1
K3
1200
1000
E5
1000
1400
1200
1400
1600
1400
1200
36
31
36
T6S
T7S
1400
6
1
1400
1
1200
1800
2000
1600
1400
1200
1400
1600
2400
1800
2200
1800
2600
2200
1600
32° 47' 49"
R4W
R3W
R3W


K4
36
31
DST365NS
38
1
K3
E5
DST320WE
Bender
Wash
INTERSTATE 8
F4
33
MD6
DST282WE
E4
36
T22
1
6
F3
DST28EW
E3
MD12
DST28NS
T21
1
6
36
31
R3W|R2W
R2W|R1W


MD12EW
K2
MD12NS
DST185SW
DST170NS
T17
T18
DST200SN
J2
18
T19
F1
DST2000NS
DST2025NS
J1
DST2050NS
DST2075NS
DST2100NS
T26
31
T25
T23
F2
T24
6
MD1R
LOST HORSE NS
LOST
HORSE EW
E3
GILA and SALT RIVER MERIDIAN
36
2400
2200
2000
1800
1600
R1W|R1E

32° 47' 49"
112° 37' 30"

R4W | R3W

R3W

WATER WELLS

ARIZONA SSC
ROTARY DRILL

ARIZONA SSC
DIAMOND DRIL

ARIZONA SSC
AUGER DRILL

GEOTECHNICAL D

PLATE 2

R3W|R2W R2W|R1W

LS RES

SC PROJECT
ILL HOLES GRA

SC PROJECT
RILL HOLES AR
GE

SC PROJECT
LL HOLES SE
PR

DATA LOCATIONS -

CONTOUR INTERVAL 200 FEET

DRACHMAN I

R1W | R1E

RESISTIVITY SURVEYS

GRAVITY/MAGNETIC SURVEY

ARIZONA SSC PROJECT
GEOTECH TRAVERSES (T)

SEISMIC REFRACTION
PROFILES

N

UPDATED

0 5000 10000

SCALE IN FEET

CHMAN INSTITUTE – UNIVERSITY OF ARIZONA

DIGITIZED IN CONFORMITY WITH STATE PLANE COORDINATE SYS

ITY SURVEYS

MAGNETIC SURVEY

SSC PROJECT

TRAVERSES (T)

REFRACTION

N

TED

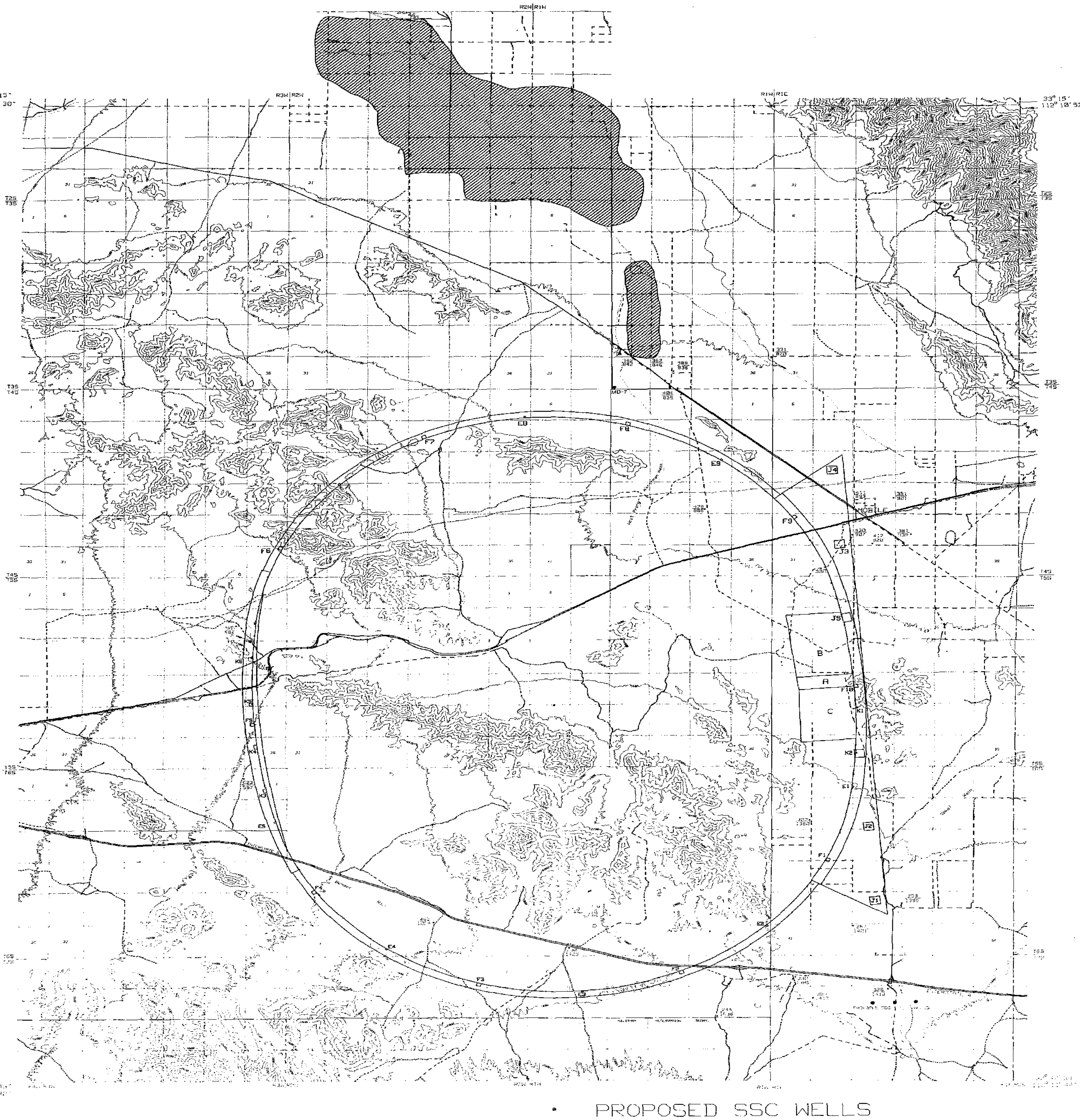
0 5000 10000

SCALE IN FEET

ARIZONA

DIGITIZED IN CONFORMITY WITH STATE PLANE COORDINATE SYSTEM

Steven Brooks
M.S., Department of Hydrology
University of Arizona
May 1988



WELL-LOCATION MAP

• PROPOSED SSC WELLS

WELL

ARIZONA HAZARDOUS WASTE SITE

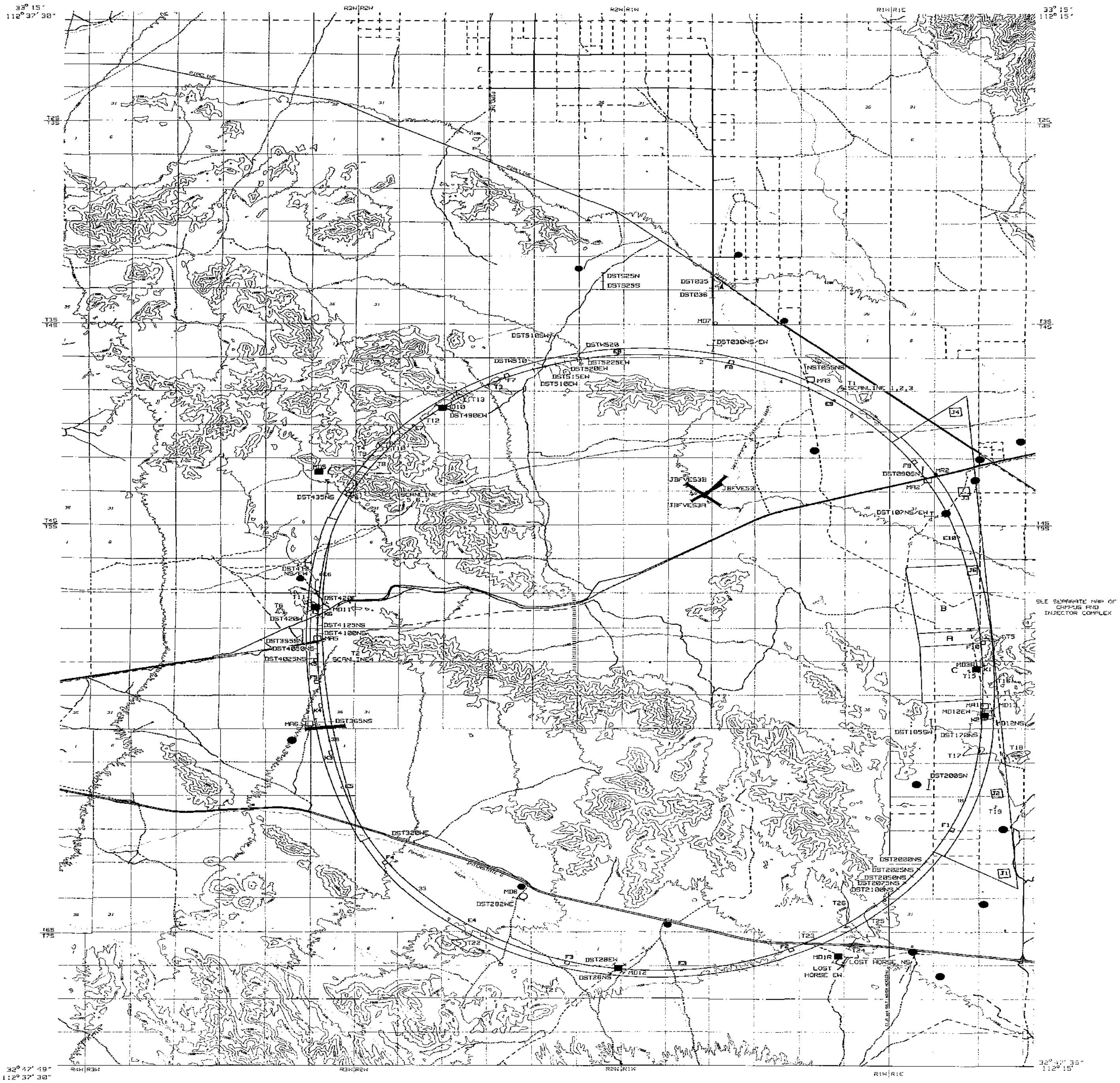
APPROXIMATE BOUNDARY OF
IRRIGATED AREA

PLATE 1

0 5000 10000
SCALE IN FEET

CONTOUR INTERVAL 200 FEET

Steven Brooks
M.S., Department of
University of Arizo
May 1988



WATER WELLS

ARIZONA SSC PROJECT ROTARY DRILL HOLES

ARIZONA SSC PROJECT DIAMOND DRILL HOLES

ARIZONA SSC PROJECT AUGER DRILL HOLES

RESISTIVITY SURVEYS

GRAVITY/MAGNETIC SURVEY

ARIZONA SSC PROJECT GEOTECH TRAVERSES (T)

SEISMIC REFRACTION PROFILES

GEOTECHNICAL DATA LOCATIONS - UPDATED

0 5000 10000
SCALE IN FEET

PLATE 2

CONTOUR INTERVAL 200 FEET

[illegible] INSTITUTE UNIVERSITY OF ARIZONA

DIGITIZED IN CONFORMITY WITH STATE PLANE COORDINATE SYSTEM

Steven Brooks
M.S., Department of Hydrology
University of Arizona
May 1988