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REVIEW OF THE GEOHYDROLOGY
OF THE
INDIAN WELLS VALLEY REGION
KERN, INYO, AND SAN BERNARDINO COUNTIES
CALIFORNIA

Prepared for
Eastern Kern County Resource Conservation District

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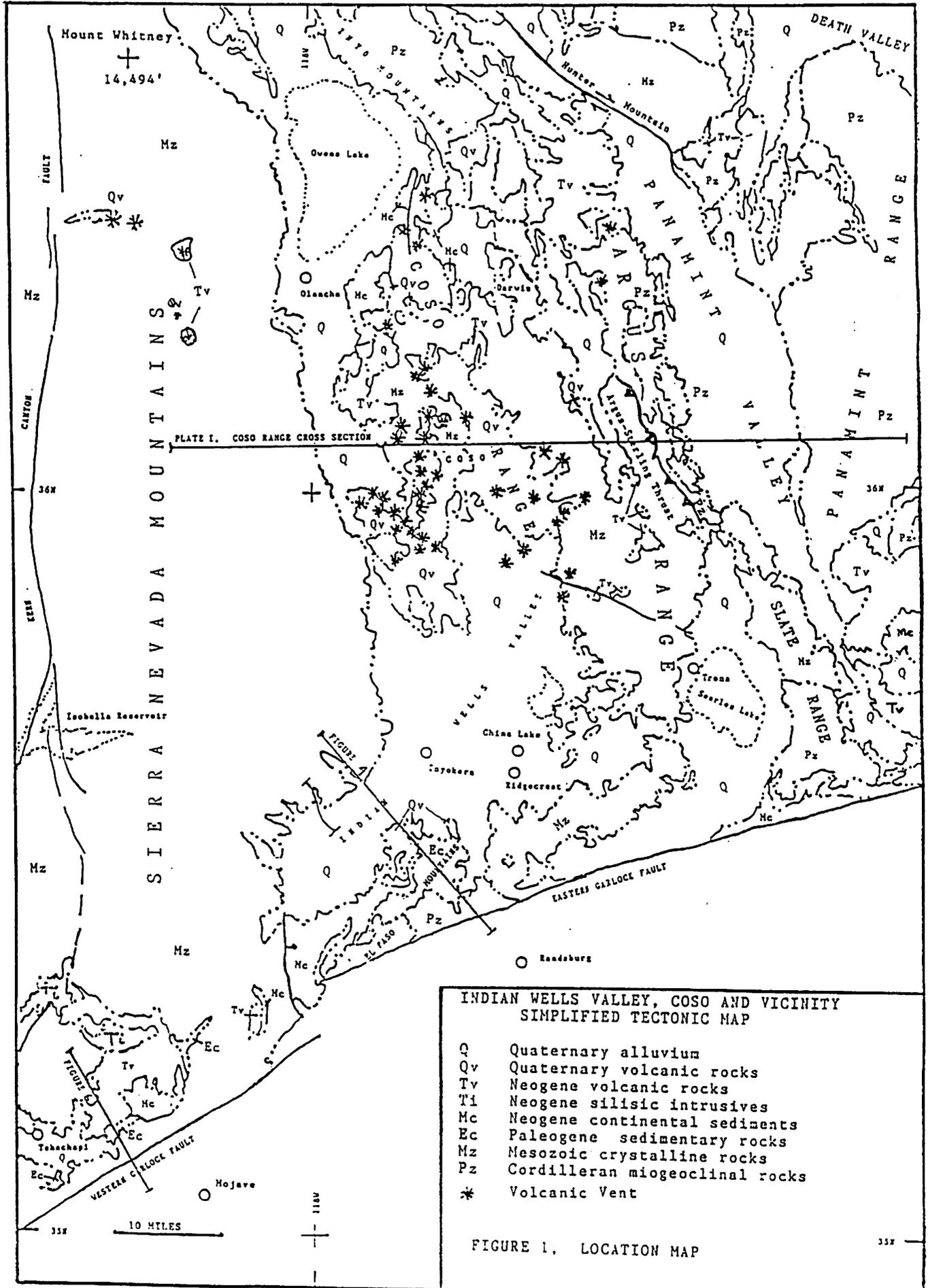
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REVIEW OF THE GEOHYDROLOGY OF THE INDIAN WELLS VALLEY REGION.

INTRODUCTION

This report is a review of the geohydrology of the Indian Wells Valley region, Kern, Inyo and San Bernardino Counties, California. The location of Indian Wells Valley is shown on Figure 1, which is a simplified tectonic map of the Valley and surrounding region. This review was initiated December, 1988, by the Eastern Kern County Resource Conservation District in order to integrate the new data and interpretations generated by the Conservation District and others into water resource planning for the region. The report includes a review of data and work submitted to the Conservation District by Douglas P. O'Brien, PhD, 1987, of COMAP, Inc.; Mark P. Muir and J.H. Birman, 1986, of Geothermal Surveys, Inc.; Prof. J.A. Whelan and R. Baskin, 1987, of the University of Utah; W.H. Austin Jr., 1987, 1988, of Icon Resources, Ltd.; and Robert T. Bean, 1989, Consulting Geologist. Reports from the above listed investigators were provided by the Eastern Kern County Resource Conservation District. In addition, many formal and open-file reports of the U.S. Geological Survey and the China Lake Naval Weapons Center were reviewed and are listed in the bibliography. This investigation has also benefited from data provided by the California Energy Company, Inc. from their work in developing the Coso Geothermal Field. The cooperation of the Indian Wells Valley Water District



INDIAN WELLS VALLEY, COSO AND VICINITY
SIMPLIFIED TECTONIC MAP

- Q Quaternary alluvium
- Qv Quaternary volcanic rocks
- Tv Neogene volcanic rocks
- Ti Neogene silicic intrusives
- Mc Neogene continental sediments
- Ec Paleogene sedimentary rocks
- Mz Mesozoic crystalline rocks
- Pz Cordilleran miogeoclinal rocks
- * Volcanic Vent

FIGURE 1. LOCATION MAP

and especially Joe Mont-Eton is gratefully acknowledged. This investigator would also like to thank the many people in the valley who offered data and guidance during the course of the study, in particular and at the risk of forgetting important sources, I should mention especially useful help from E.G. Cozzens, Larry Mead, Mike Stoner and Carl Austin.

Indian Wells Valley is a ground-water basin in the rain shadow of the Sierra Nevada Mountains. A significant portion of the available ground-water in the basin comes from surface and subsurface flow from Sierra Nevada catchment areas. There is continuing debate as to the amount and quality of the ground-water recharge from the Sierran source and as to the pathways followed by the ground-water into the Valley. It is the purpose of this investigation to review the ground-water data for the Indian Wells Valley region, the new geological data and the new geophysical data developed by the Eastern Kern County Resource Conservation District. The report will also address the issue of ground-water availability in the valley. Since the Sierra Nevada Mountains in outcrop consist of igneous and metamorphic rocks, ground-water storage and flow must be controlled primarily by structure; that is fractures and joints. Thus, an understanding of the structural evolution of the region is important to the understanding of ground-water supply. A tectonic model is, therefore, developed based upon new geological, geophysical and geochemical data generated in part by the geothermal development at Coso by

California Energy Company, Inc. and in part the Eastern Kern County Resource Conservation District as a necessary adjunct to the rational management of the District's water resources.

In the Coso geothermal development just to the north of Indian Wells valley deuterium (D) and oxygen (¹⁸O) isotope data suggest a High Sierran source for a portion of the geothermal waters (Fournier and Thompson, 1982). Recharge to the geothermal system from Owens Lake can be ruled out because evaporation has made Owens Lake water isotopically much heavier than Sierran waters (Friedman and others, 1982). Since both the Sierran recharge area and the Coso Range, host of the geothermal system, consist of crystalline basement rocks that have negligible matrix permeability, hydrologic permeability is clearly controlled by fracture systems. These fracture systems must allow deep circulation of the Sierran groundwater to bypass the Rose Valley-Owens Lake ground-water system, collect heat, and resurface in the Coso geothermal system. Currently the fractured basement rock at the Coso is producing fluids at the rate of about 40,000 acre-feet per year. About 35,000 acre-feet per year is injected back into the reservoir. The very high permeability of fractured crystalline basement demonstrated by many of the geothermal wells at Coso is among the best local indications of the potential permeability of the crystalline bedrock of the Sierra Nevada.

Benjamin E. Lofgren, Consulting Hydrogeologist, conducted a

detailed investigation of the northwestern part of the Valley where agricultural water usage has been particularly heavy since the early 1980's. Fairly detailed ground-water data were available for this area from the time of start-up of heavy irrigation and, thus, the area provides a good model for detailed investigations within the Valley. Lofgren's report, attached as Appendix A, points out the problems associated with a well sampling program that only makes measurements once or twice a year at random times in a region of seasonal drawdowns. In his conclusion Lofgren states, among other things: "Although adjusted long-term hydrographs plotted from USGS data indicate a deepening and expanding long-term drawdown cone developing around the cluster of 12 large irrigation wells, we saw no data in the area studied (the northwest well field) that either proves or disproves regional overdraft."

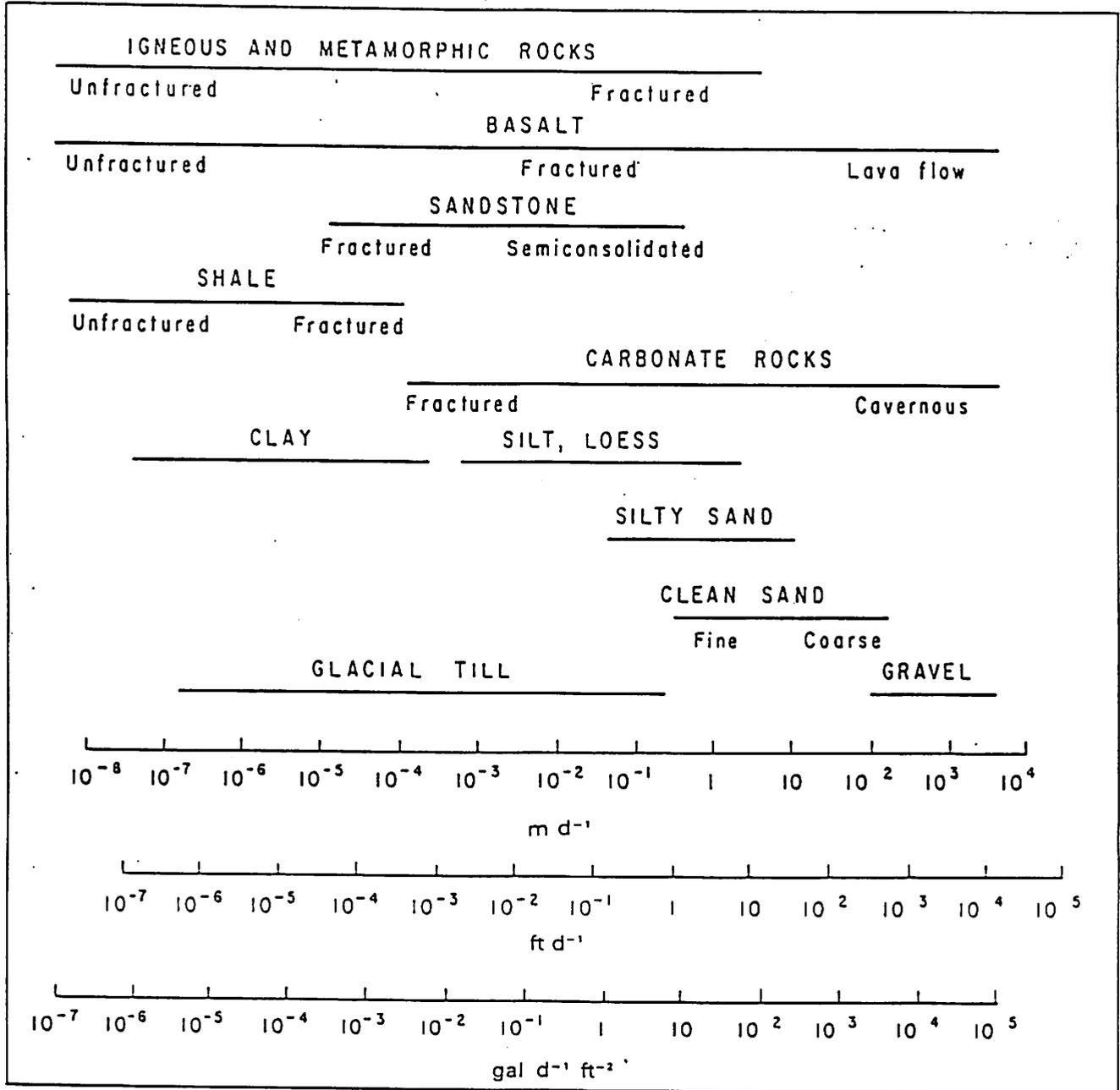
REVIEW OF SOME TERMS AND CONCEPTS FROM GROUND-WATER HYDROLOGY.

It is assumed that an important part of the public for whom this report is prepared does not have a significant background in hydrology. Therefore, a brief discussion of some of the terminology and concepts critical for understanding this report are presented here. A more general and complete review of the basics of ground-water hydrology intended for the non-professional reader may be found in the very inexpensive (\$4.00) United States Geological Survey Water-Supply Paper #2220 (Heath, 1983). This may be purchased from: Distribution Branch

Text Products Section
U.S. Geological Survey
604 South Pickett Street
Alexandria, Virginia 22304

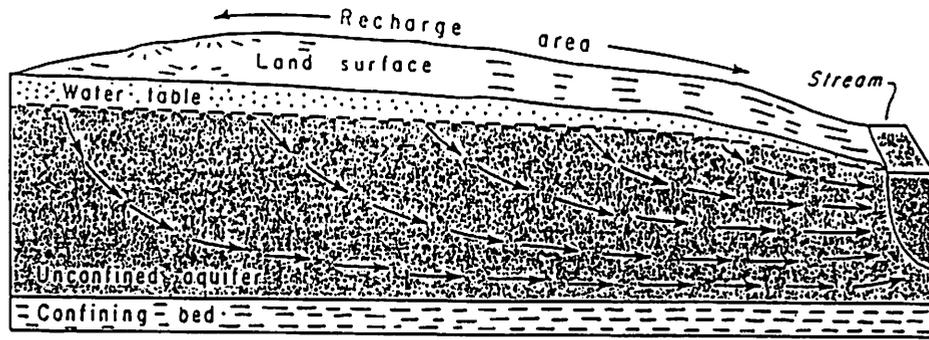
An aquifer is a water bearing layer of rock that will yield ground-water in usable quantities to a well or spring. A sedimentary rock filled valley such as Indian Wells Valley is likely to have a number of more or less continuous layered aquifers stacked in vertical succession separated by layers of rock that are less permeable to ground-water. The hydraulic conductivity of a rock is a measure of the ability of the rock to transmit ground-water. Ground-water moves through rocks either through fractures in the rock or through pore spaces around the grains of mineral matter that make up the rock. When the fractures or pore spaces of a rock are open wide, the rock can transmit water easily; the hydraulic conductivity is high and the rock is said to be very permeable. The sandstones in Indian Wells Valley sedimentary rocks are generally very permeable because the pore spaces around the grains of sand are relatively large. These sandstone aquifers are separated by clay lenses and layers that are rather impermeable. Figure 2 shows the range of the hydraulic conductivity of selected rocks. For the Indian Wells Valley region it is important to note in this figure that the hydraulic conductivity of fractured crystalline basement rocks (igneous and metamorphic rocks in the figure) can be as high or higher than sandstones. The porosity of

Figure 2, Hydraulic Conductivity of Selected Rocks

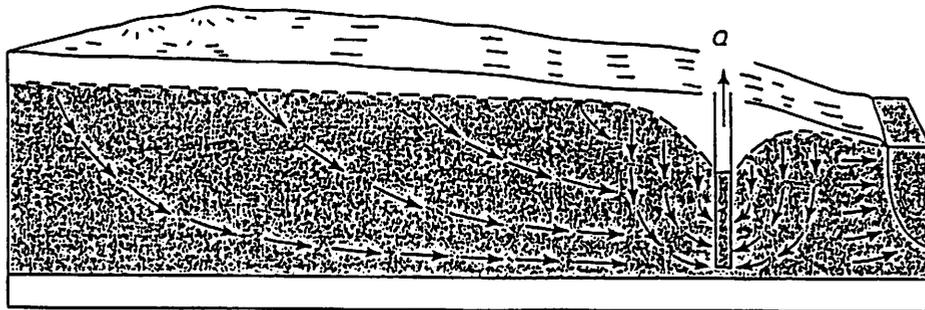


a rock is a measure of the percent by volume of open spaces in a rock and, therefore, the amount of water the rock can contain. The porosity may be due to the pore spaces around mineral grains or to openings within fractures.

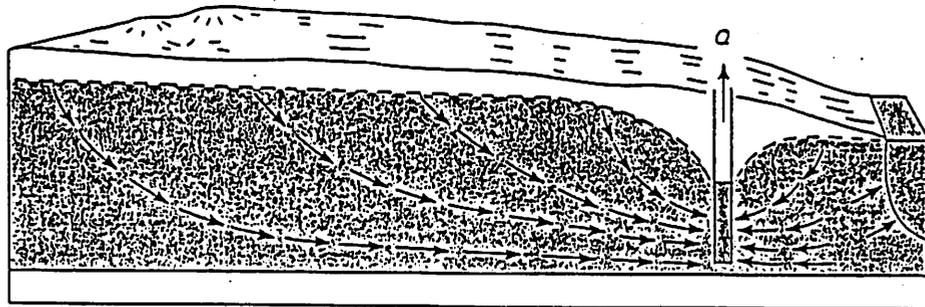
Ground-water like surface water flows down gradients, Figure 3-1. One indication of the direction of ground-water flow is the elevation of the top of the ground water table; the ground-water will flow through permeable volumes in the rock towards the lowest elevation on the top of the ground-water table. The larger the difference in elevation of the top of the ground-water table between two wells, the head difference, the more water will flow in the permeable pathways of the rock from the higher elevation (head) to the lower elevation (head). When a well is pumped, Figure 3-2, a cone of depression is produced that lowers the head in the well so that more water flows toward the well. The more rapidly the well is pumped the deeper the cone of depression becomes so that the head difference is increased, thus, water moves with increased velocity toward the well bore. The cone of depression of the pumped water table normally increases in size until enough water is flowing towards the pumped wells to meet the pumped demand. The cone then stabilizes. This stabilization may take many years or if withdrawal exceeds recharge, may never happen. The cone of depression is measured by measuring the drawdown of the surface of the water in the pumped well and other surrounding wells. Drawdown of the water surface in a well is the



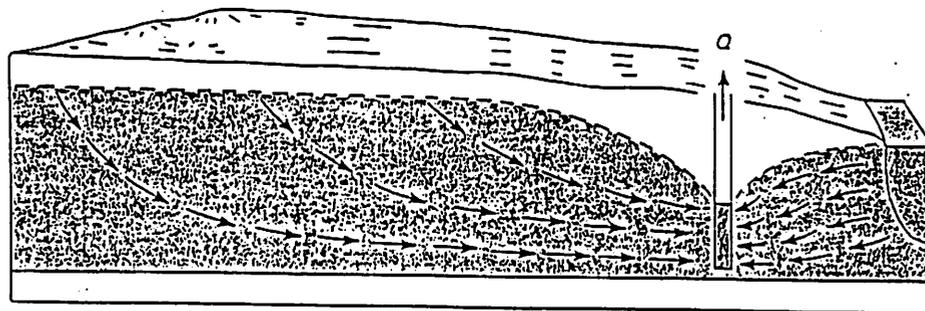
Discharge (D) = Recharge (R) (1)



Withdrawal (Q) = Reduction in storage (ΔS) (2)



Withdrawal (Q) = Reduction in storage (ΔS) + Reduction in discharge (ΔD) (3)



Withdrawal (Q) = Reduction in discharge (ΔD) + Increase in recharge (ΔR) (4)

Figure 3, (From Heath, 1983)

normal result of pumping a well. It is not an indication of or a measure of ground-water overdraft.

Naturally occurring waters are chemically analyzed for their content of dissolved salts to determine their quality, by which we mean their suitability for a particular use (Hem, 1970). Water from shallow depths in the China Lake Playa contains large quantities of dissolved sodium chloride, common table salt. This water is, therefore, unfit for human consumption. The China Lake Playa ground-water is of very poor quality. Smith, 1957, describes a drill core taken from this playa that shows saline minerals to a depth of 225 feet, but the hole bottomed at 700 feet without indicating more salt. In fact, fresh water ostracod shells were common in the sediments, which appear to have been deposited in a fresh water lake. Whelan and Baskin, 1987, analyzed a well in the northeast corner of section 1, T26S, R40E, MDBM, just south of the playa, that had 5000 ppm dissolved salts in the water at 15 feet, but only 250 ppm dissolved salts at 190 feet. In some areas within the valley ground-water quality apparently improves with depth.

TECTONIC SETTING OF INDIAN WELLS VALLEY.

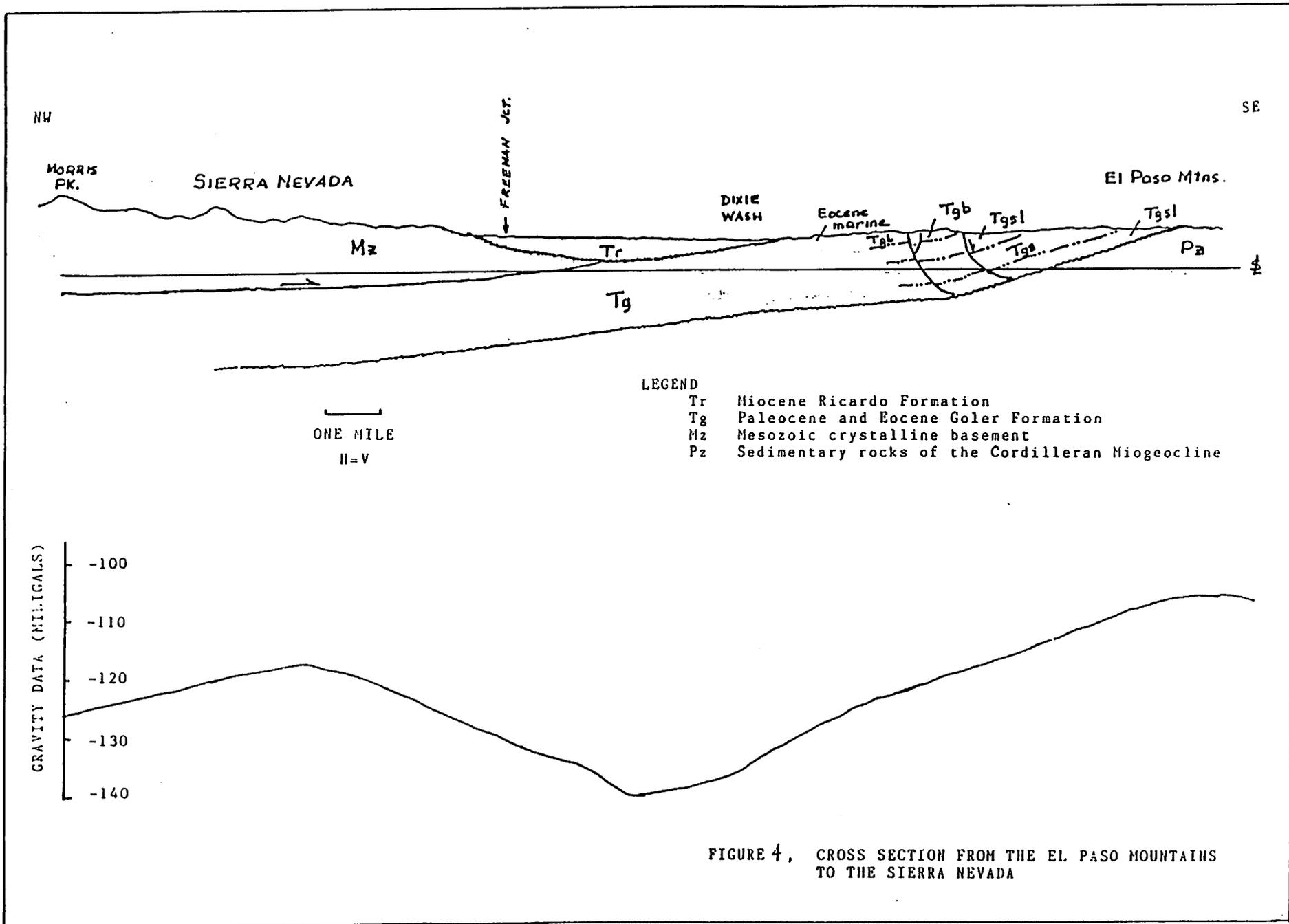
Indian Wells Valley lies on the boundary between the Sierra Nevada and the Basin Range physiographic provinces. A detailed review of the many attempts by geologists and geophysicists to interpret this important tectonic boundary is beyond the scope of the paper. The

most comprehensive of recent published attempts at regional tectonic synthesis across this boundary are the DNAG continent/ocean transects C-2 (Saleeby, 1984) and C-3 (Gibson, and others, 1985). The reader is referred to these transects as a review of current wisdom on the problem. The DNAG transects are monumental compilations of extremely diverse data whose interpretation is held together largely by geography and conventional wisdom, not by any particular unifying sets of geologic or tectonic concepts. The fundamental assumptions of this present synthesis are that all the data - geological, geophysical, geochemical, topographical and hydrological - are derived from the same rocks in the same geometrical configuration and that constraints on interpretations demanded by one data set must constrain the interpretations of all other data sets to be acceptable.

The tectonic synthesis is based upon the construction of three cross sections in and around Indian Wells Valley. The location of these cross sections is shown on Figure 1. The first cross section extends in a northwesterly direction from the northern end of the El Paso Mountains across Indian Wells Valley through Freeman Junction into the Sierra Nevada. This cross section is designed to make use of outcrop data on the Paleocene-Eocene Goler formation from the El Paso Mountains (Cox and Diggles, 1986) and is parallel to an available industry generated reflection seismic line that runs from State highway 14 at Armistead up Cow Heaven Canyon into the Sierra (O'Brien, and others, 1989). The second cross section

is an east-west cross section located just north of the Coso geothermal reservoir. This cross section is released through the courtesy of the California Energy Company, Inc. It extends from the hypothesized Sierran groundwater recharge area in the west to the Panamint Range on the west side of Death Valley in the east. The cross section is constructed along latitude 36°04'N to take advantage of NURE aeromagnetic data flown along that latitude in the Death Valley AMS (1:250,000) Quadrangle. The cross section passes over the northern portion of Coso Volcanic Field (Duffield and Bacon, 1981) just to the north of the presently producing geothermal field. The third cross section trends NNW across outcrops of the Eocene Witnet Formation in the Tehachapi Quadrangle (Dibblee and Louke, 1970). This final cross section is included as an example of the complexity of late Tertiary brittle deformation of the Sierra Nevada crystalline "basement."

Figure 4 is the cross section drawn from the El Paso Mountains through Freeman Junction into the Sierra Nevada, north of Walker Pass. The geologic control for the south east end of the section comes from Cox and Diggles, 1986; Cox, 1987; and from Dibblee, 1952, 1967. The Goler Formation, Tg, is a Paleocene to Eocene, dominantly conglomeratic alluvial sandstone that has a relatively thin marine claystone (Cox, 1987) member near the top. Continuous sections as much as 8500 feet thick have been measured and the top is not exposed. The Goler Formation was deposited on an unconformity of high relief developed upon Triassic and Jurassic



igneous rocks and a thick, somewhat cryptic section of Paleozoic metasedimentary and metavolcanic rocks that has tentatively been correlated with the eugeoclinal facies Paleozoic and early Mesozoic rocks of the Great Basin to the north (Smith and Ketner, 1970). Figure 4 also shows the gravity data (O'Brien, 1987) along the line of this section. Figure 5 is the gravity map presented at the same scale as the tectonic map on Figure 1. The excellent conformity of the gravity anomaly shape with the outcrop dip of the Goler Formation in cross section and the outcrop pattern in map view, strongly suggests that the eastern boundary of the Indian Wells Valley basin as defined by the gravity data is controlled by the Goler Formation subcrop. This means that under the relatively thin cover of the Pleistocene to Recent alluvium and lake beds of Indian Wells Valley an east-west cross section through Ridgecrest and Inyokern should look very much like Figure 4. The abundant conglomerates of the Goler Formation should make good aquifers where they project into the subsurface of Indian Wells Valley. The limestones of the Paleozoic basement rocks may also make good aquifers where cavernous solution permeability has developed along fractures.

The interpretation of the central and western portions of the cross sections of Figure 4 are based upon the gravity and magnetic interpretations of O'Brien, 1987; an industry reflection seismic line taken in Cow Heaven Canyon, interpreted by O'Brien and others, 1989; and work done by myself at the Coso Geothermal Development

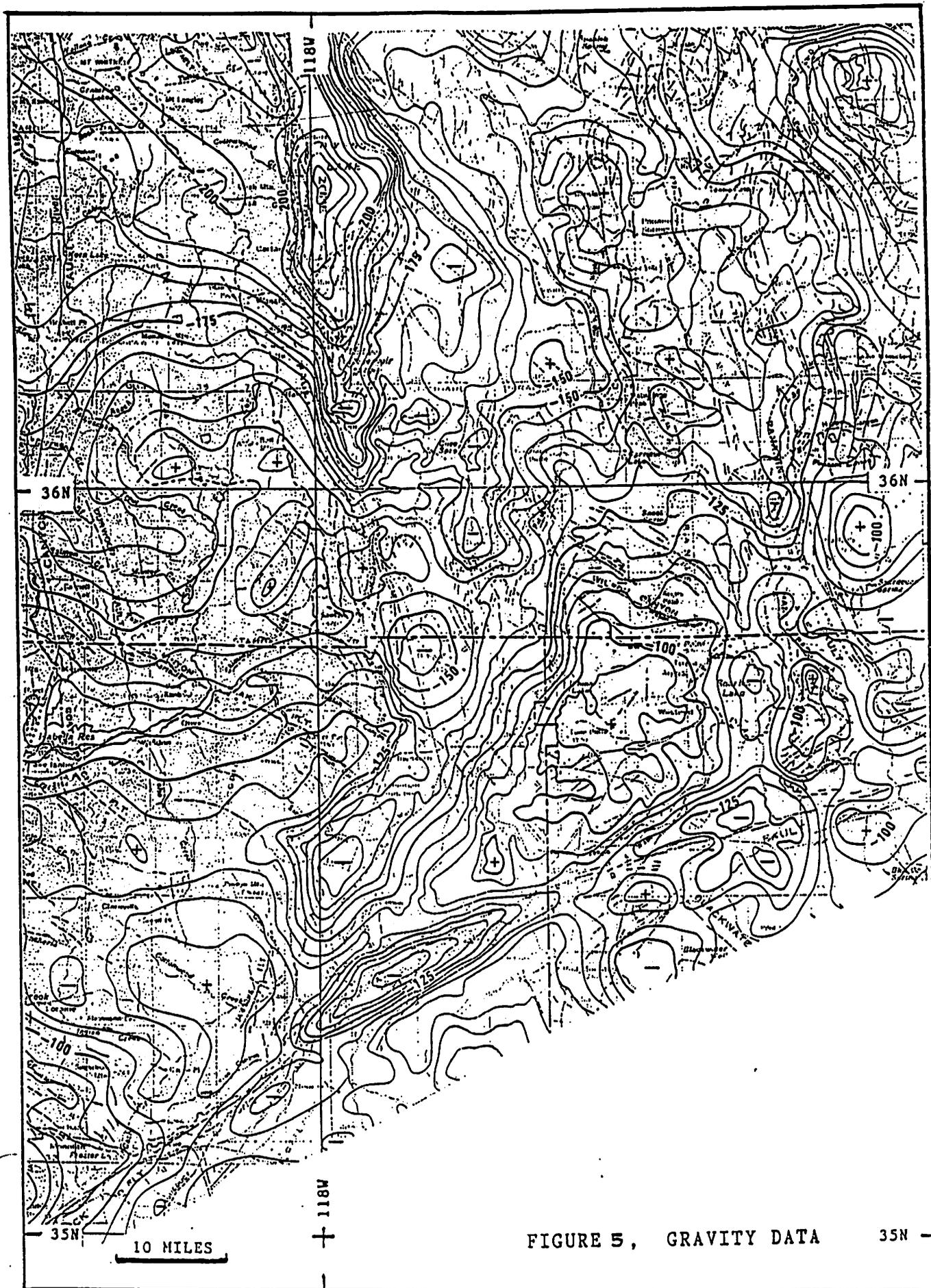
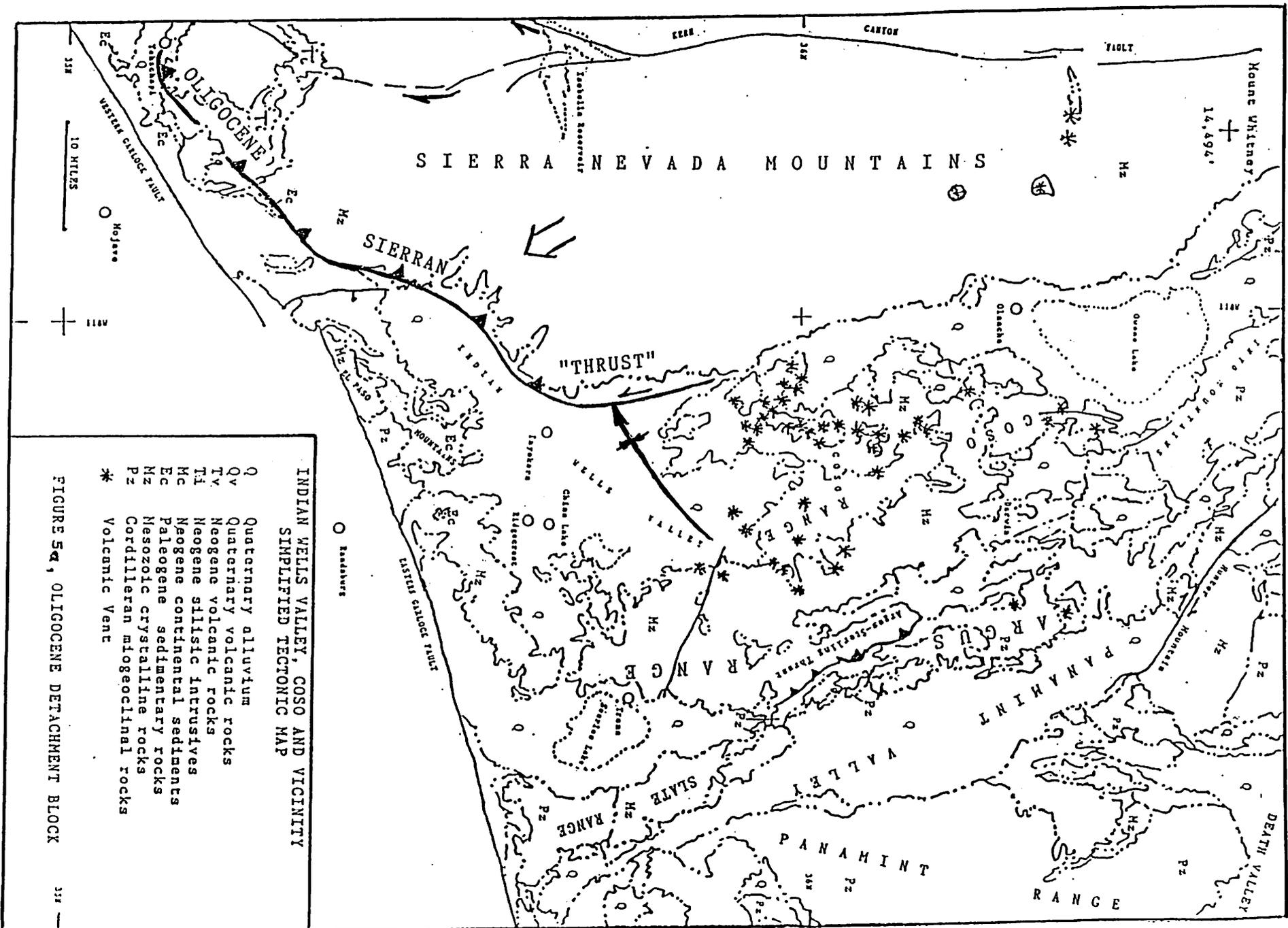


FIGURE 5, GRAVITY DATA

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INDIAN WELLS VALLEY, COSO AND VICINITY
SIMPLIFIED TECTONIC MAP

- Q Quaternary alluvium
- Qv Quaternary volcanic rocks
- Tv Neogene volcanic rocks
- Tt Neogene siltsic intrusives
- Mc Neogene continental sediments
- Ec Paleogene sedimentary rocks
- Mz Mesozoic crystalline rocks
- Pz Cordilleran miogeoclinal rocks
- * Volcanic Vent
- O Badlands

FIGURE 5a, OLIGOCENE DETACHMENT BLOCK

for California Energy Company, Inc. (Erskine, 1989). The interpretation shows Mesozoic Sierran crystalline basement rocks thrust on top of early Tertiary sedimentary rocks of the Goler Formation. The concept that the Sierra Nevada crystalline rocks have been thrust into their present high topographic position is not new. Eldridge Moores and his coworkers at the University of California at Davis have developed an overthrust model for the northern Sierra Nevada based upon careful geologic mapping (Moores and Day, 1984; Day and others, 1985). Barnes and others, 1981, have used geochemical data from carbonate springs in the high Sierra just west of Indian Wells Valley to infer that rocks in the basement beneath the Sierra consist of currently metamorphosing sediments of Paleozoic and Mesozoic age. Carl Wentworth of the U.S. Geological Survey has a 20 kilometer long reflection seismic line from Sierran basement terrain just east of Merced that shows a thick package of seismic reflectors beneath the batholith (Wentworth, 1987, personal communication). Regional relations and the timing of Cordilleran orogenic events have led me to suggest that the relationships shown on Figure 4 developed during the Eocene when the Sierran basement upper plate slumped as a giant landslide into the depocenter of the Goler basin (Erskine, 1989). Thus, the upper plate of the thrust is interpreted as a tectonic denudation slice off of the higher Sierran thrust culmination to the north. As suggested by this proposed tectonic history, the Sierra Nevada to the west of Indian Wells Valley is in fact strongly faulted and the density of the rock interpreted from

gravity modeling (O'Brien, 1987) indicates a porosity of seven to ten percent due to fractures. This interpretation of high porosity is further supported by seismic velocities as determined from industry data as low as 8000 feet per second in crystalline basement rocks (O'Brien, 1989), which normally have seismic velocities more than 16,000 feet per second.

Figure 6 is a N22E trending cross section through the east end of the Tehachapi Valley. Mapping by Dibblee and Louke, 1970, indicated an Eocene continental sedimentary formation, the Witnet Formation, which is probably a correlative of the Goler Formation (Dibblee, 1967). The Witnet Formation was deposited with strong angular unconformity on Sierran crystalline basement and is overlain with strong angular unconformity by Miocene volcanoclastics, the Kinnick Formation. This strong resemblance to the field relations of the Goler Formation in the El Paso Mountains to the east suggested the reinterpretation shown in Figure 6. Geologic reconnaissance in the Sierra Nevada between Figure 6 and Figure 4 supports this interpretation and suggests that the Mesozoic crystalline basement shown as structurally resting on the Witnet Formation on the north end of the cross section may be part of the same tectonic denudation block indicated as resting on the Goler Formation on the north end of Figure 4. It also suggests that the wedge of basement underlying the Witnet on Figure 4 may be a detached part of the El Paso Mountains basement.

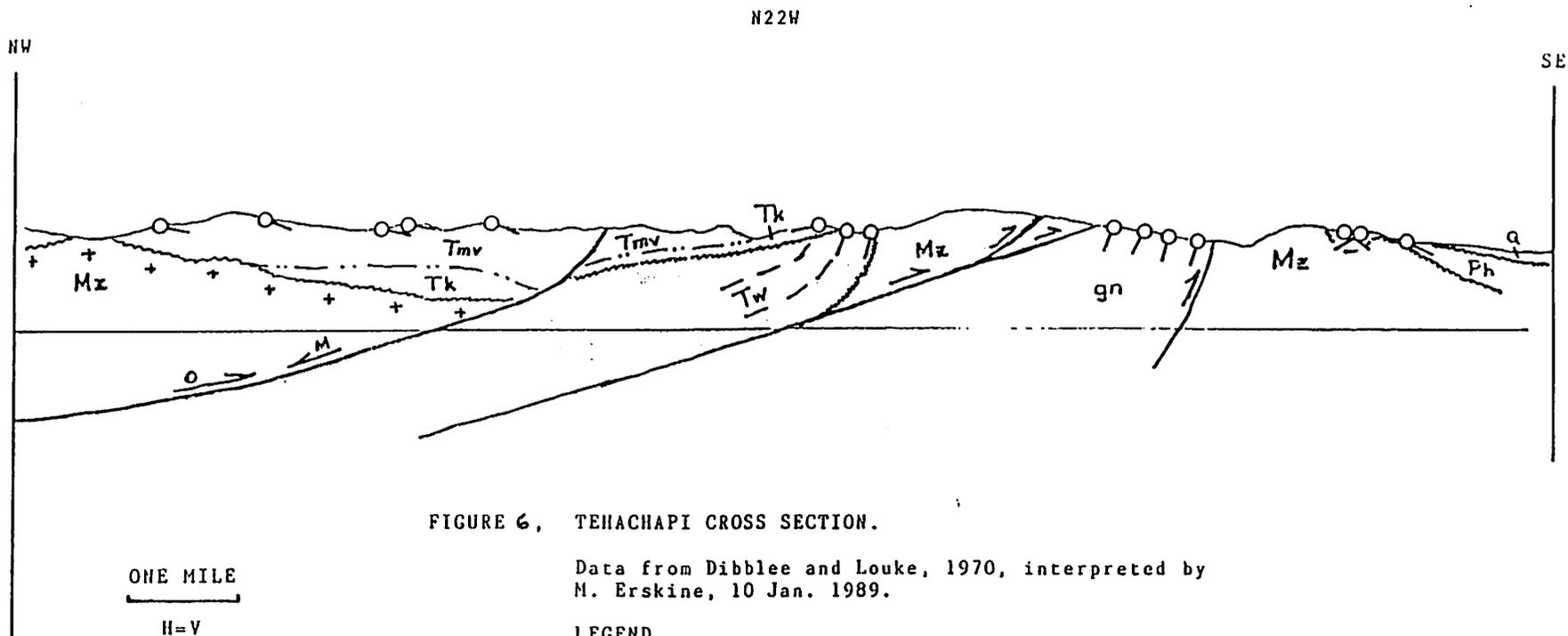


FIGURE 6, TEHACHAPI CROSS SECTION.

Data from Dibblee and Louke, 1970, interpreted by M. Erskine, 10 Jan. 1989.

LEGEND

- Q Quaternary alluvium
- Ph Pliocene Horntoad Formation
- Tmv Miocene andesitic volcanics interbedded with the Kinnick Formation
- Tk Miocene Kinnick Formation, volcanoclastics
- Tw Eocene Witnet Formation, continental clastics
- Mz Mesozoic crystalline basement
- gn gneiss (Rand Schist?)

Plate 1 is a regional east-west cross section through the Coso geothermal field supported by detailed gravity and magnetic interpretation; refraction seismic interpretation; and regional stratigraphic and structural data and models. Interpretation of regional refraction seismic data by Prodehl, 1979, has suggested the existence of a low velocity zone of regional extent under the Basin Range province and under the eastern Sierra. In the Indian Wells Valley - Coso area this low velocity zone is about 50,000 feet thick and the top is about 18,000 feet below sea level (Prodehl, 1979, figure 45). Prodehl's figure 45 is reproduced here on Plate 1. Interpretation of gravity data across the Sierra Nevada along Prodehl's section indicates that the low velocity zone corresponds to an anomalously low rock density zone as well (O'Brien, 1987). In addition, the thrust-ramp like feature that truncates the low velocity zone to the west on Prodehl's figure 45 corresponds to a gravity high as might be expected at the top of a thrust ramp. This is a thrust ramp upon which basement material is thrust over less dense supercrustal rocks. This suggestion that the southern Sierra Nevada is thrust into place and represents the ramp-run anticline of a simple thrust structure and the consequence of this tectonic configuration is herein explored on the cross section of Plate 1. The lack of readily mappable tectono-stratigraphic packages in the southern Sierra makes recognition of thrust related structures from surface mapping much more difficult in the southern Sierra than in the northern Sierra (Moore and Day, 1984). On Plate 1, Prodehl's low velocity zone is interpreted by

me as sedimentary rocks of the Cordilleran miogeocline. The reasons for this interpretation include:

1. The regional thickness of the Cordilleran miogeoclinal package is 45,000 to 55,000 feet between the Spring Mountains, Nevada, on the east and the Sierran front on the west (Stewart, 1970; Troxel, 1974; Stewart and Poole, 1974) which is the approximate thickness of the seismic low velocity zone.

2. The lack of exposed depositional thinning of the miogeoclinal package in this region.

3. The stratigraphic and structural relief represented by the contrast in stratigraphy and structural vergence between the east vergent uppermost Paleozoic limestone package mapped on the west side of Panamint Valley (Moore, 1976) and the west vergent anticline of Eocambrian to Cambrian clastics and carbonates mapped on the east side of Panamint Valley (Albee and others, 1981).

4. The interpretation by Barnes and others, 1981, that the geochemical and stable isotopic composition of CO₂ spring waters in the central and southern Sierra Nevada requires that the batholith be underlain by currently metamorphosing Paleozoic and Mesozoic marine sediments.

Given the depositional thickness of the miogeoclinal package I suggest that it was deposited on Precambrian oceanic crust and that the high velocity layer at the base of the low velocity zone is that Precambrian oceanic crust.

The cross section goes through the Argus Range south of Bendire

Canyon and north of Shepherd Canyon. Moore (1976) measured a stratigraphic section in essentially unmetamorphosed, highly fossiliferous, miogeoclinal, upper Paleozoic, sedimentary rocks south of Bendire Canyon. This section is measured within a mile of the cross section of Plate 1. He notes that alteration to hornfels adjacent to igneous contacts destroys fossils and sedimentary structures. The section is measured in an eastward vergent anticline that exposes Mississippian Tin Mountain Limestone in its core. This is overlain progressively by Mississippian Perdito Formation, Mississippian and Pennsylvanian Lee Flat Limestone, Pennsylvanian and Permian Keeler Canyon Formation, and Permian Owens Valley Formation. This sedimentary package is about 4500 feet thick. These essentially unmetamorphosed sedimentary rocks are tectonically overlain by Sierran type Jurassic quartz monzonite and intruded by sill-like bodies of Jurassic alkalic granitic rocks. To the north the sill-like bodies may be interpreted to intrude a thrust fault which separates the above described sedimentary package from a lower plate package which contains sedimentary rocks as old as the Silurian and Devonian Hidden Valley Dolomite. Moore (1976) interprets the sill-like alkalic granitic rocks as syntectonic.

Along the line of the section there appears to be about 4500 stratigraphic feet of Pennsylvanian and Permian rocks exposed between the tectonically overlying Sierran quartz monzonite and the underlying sill-like alkalic granitic intrusive in a package that

is structurally about 4500 feet thick. Topographic analysis of the outcrop pattern of the overlying fault suggests a dip of about 16 degrees S66W in the eastern most exposures but flattening to the west. Moore calls this fault the Argus/Sterling thrust fault. Dunne, and others (1978) show that this thrust fault is part of a regionally mappable thrust system that may be traced from the Slate Range in the south to the central Inyo Range to the north. This is a distance of over 100 miles (160 kilometers).

The Sierran granitic rocks to the west have numerous roof pendants of metasedimentary and metavolcanic rocks. These metamorphic rocks are difficult to correlate with the miogeoclinal rocks to the east even though the ages in many cases overlap because the sedimentary facies imply a vastly different environment of deposition. In addition, the western sections contain Mesozoic volcanic rocks that are not well represented to the east of the thrust trace. The differences in facies and degree of metamorphism suggest very different tectonic histories for the two packages. This means that the thrusting has brought together originally widely separated tectonic packages.

The most important aspect of Plate 1 for this review of the hydrogeology of the Indian Wells Valley region is the hypothesized ground-water plumbing system indicated on the west end of the section. Current data supports the view that the source of fluids for the geothermal production at Coso is precipitation falling on

the Kern Plateau of the high Sierra. This precipitation is gathered by the drainage of the South Fork of the Kern River and enters the ground-water system through the complex of large meadows that the South Fork meanders through: Templeton, Strawberry, Monache, and Kennedy. This complex of large meadows is a truly anomalous feature of the southern Sierra. In this interpretation the meadows represent the head wall basins of large listric normal faults. These listric faults curve into the gently dipping Mesozoic thrust faults and represent a passive accommodation to the local high topographic relief and Basin-Range extension.

Independent evidence for the existence of some such structural plumbing system is the existence of four rhyolite volcanic centers on the Kern Plateau spatially associated with the complex of meadows (Bacon and Duffield, 1981). These rhyolites are coeval with the Coso rhyolite dome field. Bacon and Duffield, 1981, use petrological and chemical data to relate them to the same source. The youngest of the rhyolites has a K-Ar age of 0.185 ± 0.15 (du Bray and Moore, 1985). This young rhyolite, located at Long Canyon, shows the effects of glaciation.

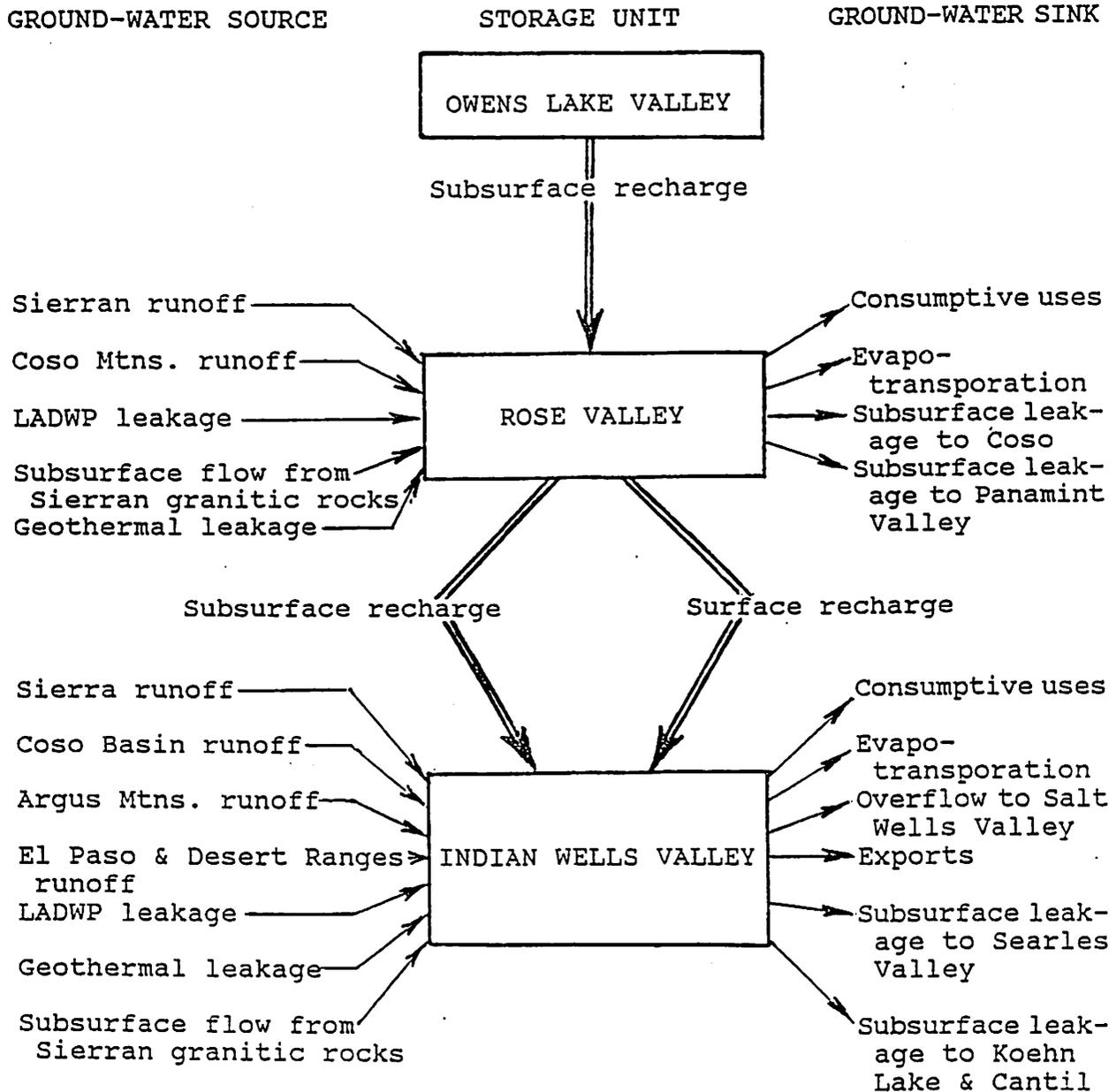
Fournier and Thompson, 1982, have used deuterium and oxygen stable isotope ratios to suggest that the thermal water produced at Coso is derived from Sierran precipitation. These waters must have circulated very deep within the crust to have reached economic geothermal temperatures.

It should also be noted on the cross section, Plate 1, that the geothermal reservoir is located beneath the Coso Rhyolite Dome Field entirely within crystalline basement rocks. A number of the production wells in the geothermal field produce over 1,500,000 pounds per hour (5000 ac-ft per year) of geothermal fluids. These fluids are produced from fractures in the crystalline basement.

GROUND-WATER AVAILABILITY IN INDIAN WELLS VALLEY.

The potential sources and sinks for the ground-water of Indian Wells Valley have been summarized by C. Austin, 1988. Figure 7, which lists those potential sources is slightly modified from Austin's memo. As pointed out by a number of investigators (Bean, 1989; and C. Austin, 1988, among others) the major disagreement is in estimating the amount of water coming into the Valley from each possible source and the amount of water leaving the Valley through each possible sink. The estimates of the amount of water withdrawn from the Valley through pumpage, 23,800 ac-ft per year in 1985 (per Bean, 1989, who modified Berenbrock, 1987), is reasonably well controlled by hard data. Amounts of water associated with all of the other sources and sinks shown on Figure 7 must be estimated from generally inadequate data (Thompson, 1929; C. Austin, 1988; and Bean, 1989) and experienced investigators have made widely different estimates of all of the quantities involved. The most important of the estimates for understanding the availability of water for Indian Wells Valley are those associated with recharge

FIGURE 7, ELEMENTS OF THE INDIAN WELLS VALLEY REGIONAL GROUND-WATER FLOW SYSTEM.



from the Sierra Nevada Mountains and the Rose Valley/Owens Valley system. Unfortunately, these are the estimates that vary most widely among experienced investigators and for which there is the least hard data. Estimates of recharge from Sierran granitic rocks in recent years have varied from effectively zero (St.-Amand, 1984) through 2,500 ac-ft per year (Bean, 1989) to, by analogy with Milford, Utah, perhaps as much as 16,000 ac-ft per year (C. Austin, 1988). Yet another estimate based upon present data would be a waste of everyone's time and money. Figure 8 is a topographic profile that extends from potential recharge areas in the Sierra Nevada across Indian Wells Valley through the China Lake playa to Searles Valley. At an estimated fracture porosity of 7 percent for Sierran crystalline rocks, estimated from gravity data (O'Brien, 1987), the amount of ground-water potentially stored above Indian Wells Valley is truly impressive. Present data is, however, inadequate to estimate the amount of water that is actually available for use in Indian Wells Valley from this source.

The present distribution of pumping wells in Indian Wells Valley has created a large cone of depression in the immediate Ridgecrest area (Bean, 1989; Berenbrock, 1987) and ground-water levels continue to fall in many parts of the valley. However, the ground-water level at the China Lake playa, the major natural hydrographic low in the valley, has suffered only minor changes with time and is currently at approximately the same elevation as it was in 1921 (Bean, 1989) and 1953 (Dutcher and Moyle, 1973). This stability has

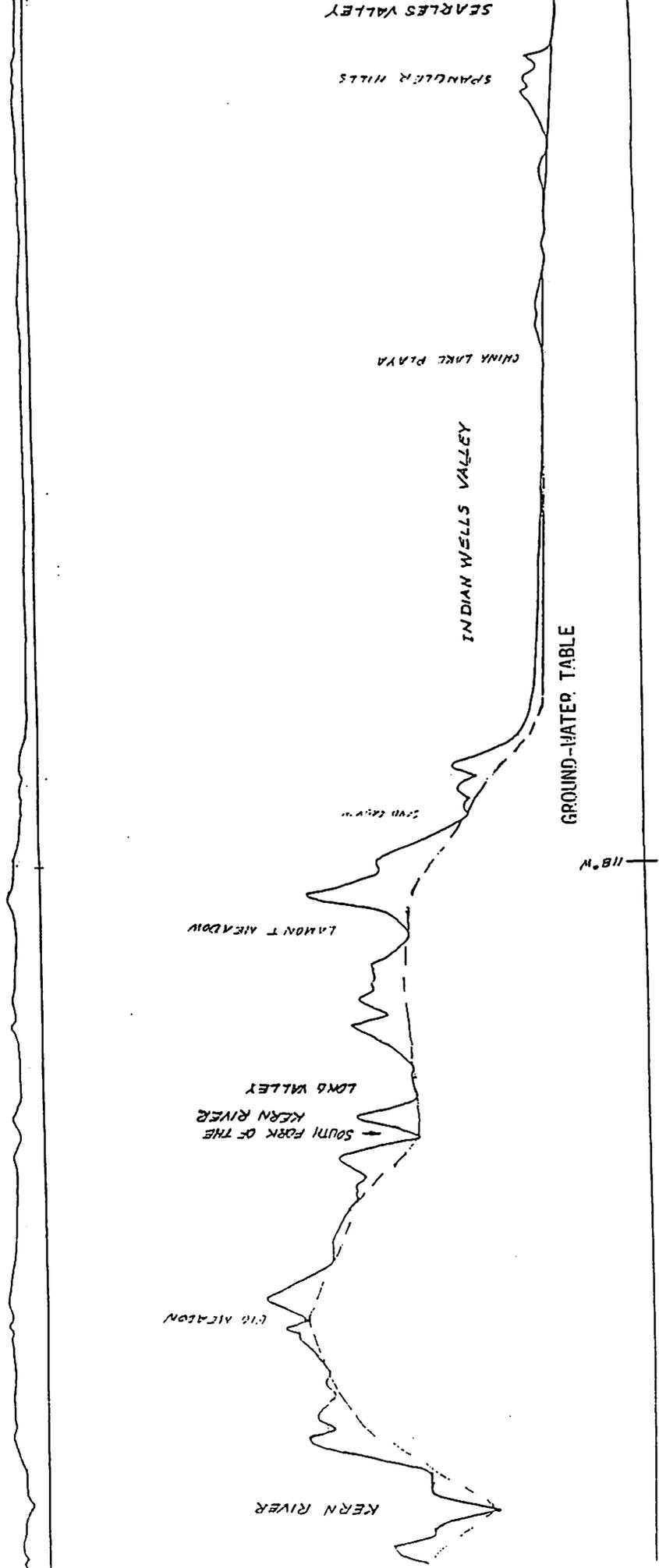
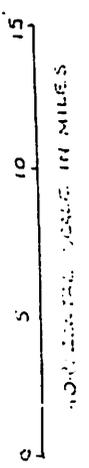


FIGURE 8, N72W TRENDING TOPOGRAPHIC PROFILE THROUGH THE SIERRA NEVADA AND INDIAN WELLS VALLEY. INTERPRETED GROUND-WATER TABLE INDICATED.



been attributed to evapo-transpiration from the playa surface by a number of investigators and various quantities of evapo-transpiration have been used to balance or unbalance hydrologic models. It seems equally likely that this level represents the basin spill level for flow into the Searles Valley ground-water basin. What ever the cause of this stability it is an indication that the major ground-water flow in Indian Wells Valley is still towards the China Lake playa sink. While the cone of depression northwest of Ridgecrest has probably diminished that flow, it does not appear to have diverted it. Theoretical considerations suggest that the poor quality ground-water associated with the near surface in the China Lake playa ought to be flowing towards the northwest Ridgecrest cone of depression, but supporting hard evidence for such movement is lacking in the recent water quality data (Whelan and Baskin, 1987). This also suggests that the regional flow to the playa sink may be large, significantly larger than the flow into the cone of depression, so that it over powers flow to the cone of depression.

It should be noted here that ground-water flows into the center of the Searles Lake playa with a head that raises the ground-water elevation at the lake center to 30 feet above the elevation at the lakeshore (Hardt and others, 1972, in Friedman and others, 1982).

Because of the importance of the estimates of Sierran and Rose Valley ground-water underflow to the management of the water

resources of Indian Wells Valley and the amount of the discrepancy relative to recharge from these sources, W. Austin, 1987, proposed and Bean, 1989, agreed that deep test/production wells should be designed and drilled to measure subsurface flow from the Sierran granitic rocks and sub-basalt flow through pre-basalt Owens River channels from Rose Valley. The actual drill hole locations suggested by W. Austin were designed to control the interpretation of three proposed reflection seismic lines (W. Austin, 1987a). More recent discussions with W. Austin (oral communications, June 1989) have resulted in agreement on locations for drill holes that would directly test structural density anomalies that resulted from his photo-structural studies (W. Austin, 1986). These newly agreed upon test well locations are listed in Table I. These locations are all in alluvium at the surface. However, the two northern locations, numbers 3 and 4, should intersect basalt flows at shallow depths. Number 4 is designed to test flow from Rose Valley through or under the basalt at a fracture intersection (W. Austin,

TABLE I, Proposed deep wells to test for underflow from Rose Valley and Austin, 1986, photo-structure density anomalies.

#1	NW1/4, sec. 16, T27S, R38E, MDBM, Kern County, Ca.
#2	SE1/4, sec. 3, T26S, R38E, MDBM, Kern County, Ca.
#3	NW1/4, sec. 4, T24S, R38E, MDBM, Inyo County, Ca.
#4	NE1/4, sec. 5, T25S, R39E, MDBM, Kern County, Ca.

1986. Deep test wells, 4000 to 6000 feet, at each of these sites should provide significant information on the availability of and quality of ground-water from these potential major sources, as well as providing good new production from reasonably dispersed sources. There is a reasonable expectation of artesian pressures from the depths suggested.

Chemical analysis of ground-water from Indian Wells Valley indicates that the water flows from several distinct sources (Whelan and Baskin, 1987). Wells from the Indian Wells Canyon area produce a low salinity sodium sulfate water that flows in a northeastward spreading plume to about 5 miles north of Inyokern. Water in the northwestern and central part of the valley is generally low salinity sodium bicarbonate water. Much of the water encountered along the eastern rim of the valley is of sodium chloride type and high salinities are common. There are local problems with both arsenic (Warner, 1975) and boron (Whelan and Baskin, 1987) through out the Valley and all wells should be tested before use. Both Warner, 1975, and Whelan and Baskin, 1987, conclude that there has been very little change in water quality with time and that the poorer quality water from the sewage treatment plant seems to be moving towards the China Lake playa rather than towards the cone of depression northwest of Ridgecrest. Whelan and Baskin, 1987, note that "water quality may degrade, improve or remain constant with depth. In most cases water has changed too little with time to be identifiable."

RECOMMENDATIONS.

Lofgren, Appendix A, has noted some of the problems associated with the historic ground-water sampling in the Valley. I suggested in an earlier letter, Erskine, Appendix B, further problems encountered with the Indian Wells Valley ground-water data and suggested a sampling pattern and procedure to help recover the valuable historic data and to improve data quality in the future. Long term, systematic sampling of ground-water levels and quality in selected wells is the best guide to ground-water management. A brief standard list of data to be collected and maintained is taken from Heath, 1983, Basic ground-water hydrology and is reproduced here as Figure 9. I suggested in my letter, Appendix B, that this data be collected by a reliable local engineering contractor.

Historical well data should be collected and systematically filed as per Figure 9. The data should be reviewed in detail annually by a competent consulting hydrologist such as Ben Lofgren so that changes and potential problems can be noted and addressed before they become serious. In addition, it would be useful to continue to collect geological, geochemical and geophysical data relating to ground-water availability. Deuterium, tritium and oxygen isotope data for selected wells would help address source and flow direction problems. Completion of photo-structural work on the Mountain Springs Canyon 15' Quadrangle would help understand flow

WELL RECORDS AND FILES

The collection and preservation of records on the construction, operation, maintenance, and abandonment of supply wells are an essential but largely neglected activity. This responsibility rests largely on the well owner or operator. The consequence of this neglect is that it is not possible to identify and to economically correct problems of declining yield or deterioration in water quality, and the design of new wells cannot incorporate past operational experience.

A file should be established on each supply well at the time when plans for its construction are initiated. From the initial planning to the final abandonment of the well, the following records should be generated and carefully preserved in this file:

1. **Initial design**, including drawings or written specifications on diameter, proposed total depth, position of screens or open hole, method of construction, and materials to be used in construction. (See "Water-Well Design.")
2. **Construction record**, including the method of construction and the driller's log and a geophysical log of the materials penetrated during construction, the diameter of casings and screens, the slot size and metallic composition of screens, the depths of casing and screens, the total depth of the well, and the weight of the casing. (See "Well-Construction Methods" and "Well Logs.") Records and logs should also be retained for all test wells, including those that were not successful because of small yields.
3. **Well-acceptance test**, including a copy of the water-level measurements made before, during, and after the drawdown (pumping) test, a record of the pumping rate or rates, copies of any graphs of the data, and a copy of the hydrologist's report on the interpretation of the test results. (See "Well-Acceptance Tests and Well Efficiency.")
4. **Pump and installation data**, including the type of pump, the horsepower of the motor, the depth to the pump intake, a copy of the pump manufacturer's performance and efficiency data, and data on the length of the air line or a description of facilities provided for water-level measurements, including a description of the measuring point. (See "Measurements of Water Levels and Pumping Rates.")
5. **Operating record**, including data on the type of meter used to measure the flow rate, weekly readings of the flow-meter dial, weekly measurements of the static and pumping water levels, and periodic analyses of water quality. (See "Supply-Well Problems—Decline in Yield.")
6. **Record of well maintenance**, including the dates and the activities instituted to increase the yield or to improve the water quality and data showing the results achieved. (See "Supply-Well Problems—Decline in Yield" and "Supply-Well Problems—Changes in Water Quality.")
7. **Record of well abandonment**, including the date that use of the well was discontinued and a description of the methods and materials used to seal or plug the well.

The type of forms used for the records described above is not of critical importance. It is more important that the records be collected, regardless of the type of form that is used. It is important, however, that the date and the watch time be noted with each measurement of pumping rate and depth to water and on each water sample collected for water-quality analyses.

FIGURE 9, Well records, from Heath, 1983, p. 80.

directions for the saline waters of the northeastern part of the Valley. Access to industry reflection seismic data and interpretations would be helpful in defining the volume of water in storage. Periodic reviews and synthesis of this data is also very useful.

A deep test well program should be designed and carried through by a competent hydrogeologist to test the hypothesized sources in the Sierra Nevada and Rose Valley. The sites suggested in Table I have not been investigated for access, but alternates should clearly test the proposed hypothesis.

Greater dispersal of well field development is clearly desirable. The Indian Wells Valley Water District's new southwest well field is a major step towards relief for the cone of depression northwest of Ridgecrest. Purchase of Larry Mead's wells in the northwest should also bring relief to the major historic drawdown areas. However, further dispersal would be very useful and the test well program recommended above should be very helpful.

I see no data at this time that either proves or disproves Valley wide overdraft and with the development of the southwest and northwest well fields there should be less concern with local overdraft in the Ridgecrest area. The volume of ground-water storage in the Valley is very large compared with net local consumptive use (Bean, 1989). This means that there is time, even

given a worst case scenario, to build a careful model of regional ground-water flow and consumptive usage to guide future development.

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APPENDIX A

REPORT ON THE EFFECTS OF AGRICULTURAL PUMPING NORTH OF
INYOKERN, INDIAN WELLS VALLEY, CALIFORNIA.

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May 8, 1989

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HYDROGEOLOGY, GROUND-WATER ENGINEERING

EFFECTS OF AGRICULTURAL PUMPING NORTH OF INYOKERN

INDIAN WELLS VALLEY, CALIFORNIA

May 8, 1989

INTRODUCTION

This report presents the results of an independent study of the long-term effects of ground-water pumping in the area north of Inyokern, Indian Wells Valley, based on available published and unpublished data. Within this area, a dozen large irrigation wells situated along Brown Road have greatly increased the rate of ground-water pumping, especially during the past 15 years.

During this same period, the pumping of scattered domestic and small-farm wells throughout the area and also Naval Weapons Center wells in Inyokern have increased dramatically. Today there is serious concern whether the combined rate of agricultural, domestic, and Naval pumping exceeds the long-term water supply of the area.

DATA USED IN THIS STUDY

The data used in this study include:

- a) Water level measurements in accessible observation wells by the U.S. Geological Survey (USGS), dating back to 1921.
- b) An 8-year record of monthly water-levels measurements by M.C. Cozzens in his domestic well, situated in the vicinity of four of the heavily pumped irrigation wells.
- c) 1988 hydraulic-test data of Southern California Edison Co. (SCE) for 11 of the 12 large irrigation wells, and
- d) Various pumpage records, location sketch maps, and notes of ranchers who have operated the large irrigation wells.

PROBLEMS IN USE OF USGS WATER-LEVEL DATA

Two basic problems are inherent in the USGS water-level data collected over the years and the use made of these data in numerous ground-water studies to date. These problems are:

- 1) Random dates of field measurements. In general, the USGS record for each selected observation well consists of one or two "depth-to-water" measurement per year, and these made on random dates during the year. Prior to the pumping of large irrigation wells in the area, the hydrographs plotted from the random dates approximated long-term water-level trends for the area. Since the mid-1970's, however, it has been virtually impossible in many of the hydrographs plotted from these random data to distinguish the seasonal drawdown effects of large wells from long-term trends.

2) Assumed elevation of measuring points. When a well is selected as an observation well in the water-level monitoring program, the elevation of a fixed measuring point is assigned. Usually the elevation assigned is estimated from the contours of the latest USGS topographic map of the area. When first assigned it is realized this assigned elevation, and thereby the water-surface elevations calculated from this elevation are only rough approximations. After a few years, however, these elevations are accepted as precise.

Measuring-point elevations derived from topographic map contours north of Inyokern are probably accurate to within +/-20 to 30 feet. This uncertainty poses no problems when considering the short- or long-term changes in depth-to-water in a given well. These inaccuracies are unacceptable, however, when water-level contours are drawn through calculated water-surface elevations for scattered observation wells, and these contours then used to, a) determine the direction of ground-water flow in a basin with a relatively flat watertable, or b) calculate changes in ground-water storage by comparing watertable contours for different periods.

THIS STUDY

The principal contributions of this study are:

1) Suggesting a method of estimating the magnitude of the seasonal drawdown effects of nearby irrigation wells on the hydrographs plotted from the random USGS water-level data.

2) From the modified hydrographs of wells with sufficient record, approximating the long-term water-level trend indicated by that record, and

3) Assessing the impact of agricultural pumping on ground-water levels in the area, based on the limited long-term data available.

This independent assessment was initiated at the request of M.C. Erskine, Jr. on behalf of water users of the area.

WATER-LEVEL AND PUMPAGE DATA USED

Larry Mead provided the following background information related to the use of ground-water for irrigation in his area :

1) Two or three wells were operating on the Neal property before Mead came to the area in 1974. These irrigated possibly 40-50 acres.

2) Mead drilled well #5 and began irrigating about 165 acres in 1974. He added other wells in the follows sequence:

1976....#3.....130 acres

1978....#4

1979....#s 1.2.6.7. and 8

3) All Mead wells were pumped continuously through the irrigation season, from the time drilled through 1985. Generally, the wells were not turned off from early March through mid-November each year. During 1986-88, however, wells 5,6,7, and 8 were pumped for much shorter periods. The annual pumpage for the Mead and Neal irrigation wells, as calculated from power company records, are tabulated below:

YEAR	ANNUAL GWH	GWH/AC. FT.	AC. FT./YEAR		WELL #7			
<u>WELL #5</u>					<u>WELL #7</u>			
1981	694878	443	1574		1981	228000	418	548
1982	665180	421	1580		1982	483156	411	1176
1983	621620	429	1449		1983	445716	414	1077
1984	620048	441	1408		1984	493000	457	1079
1985	633184	421	1504		1985	469600	463	1010
1986					1986	422830	465	909
1987	70310	445	158		1987	435800	428	1018
1988	427440	455	940		1988	270876	550	493
<u>WELL #8</u>					<u>WELL #9</u>			
1981	598764	394	1520		1981	519720	490	1061
1982	588736	372	1583		1982	584720	419	1419
1983	547598	380	1441		1983	533840	432	1226
1984	556700	396	1406		1984	585360	436	1343
1985	596300	408	1462		1985	571120	423	1350
1986	529040	408	1297		1986	553680	423	1309
1987	61880	407	152		1987	382000	447	810
1988	410880	410	1003		1988	145080	523	277

6) The USGS has used Mead well #5 as an observation well from about 1974 to the present. Reportedly this is the only Mead well the Survey has measured.

Figure 1 shows the location of the eight Mead irrigation wells, the four Neal irrigation wells and the scattered observation wells discussed in this report. These well locations are not precise, being plotted from rough sketch maps and "quarter-quarter-section" descriptions. On this map, the locations of the irrigation wells are indicated by a double circle; the Mead wells designated M1 through M8, and the Neal wells designated N1 through N4. The observation wells are shown by a solid dot.

Tabulated below are selected parameters of particular interest in this study for 11 of the 12 large irrigation wells, as determined by 1988 hydraulic tests (pumping tests) by SCE.

Well no.	Date of test	Standing depth-to-water (feet)	Pumping depth-to-water (feet)	Capacity (gpm)	Drawdown (feet)	Specific capacity (gpm/ft)	Pumped in 24-hrs. (ac. ft.)	Overall efficiency (%)
Mead 1	12/5/88	225.8	242.0	1533	16.2	94.6	6.776	64.9
2	12/5/88	252.4	263.1	1547	10.7	144.6	6.838	67.8
3	12/5/88	187.6	220.8	1211	33.2	36.5	5.353	62.3
4	12/5/88	166.2	178.2	1388	12.0	115.7	6.135	62.7
5	12/6/88	137.2	157.1	1524	19.9	76.6	6.736	67.9
6	12/5/88	127.2	150.9	1521	23.6	64.4	6.723	64.7
7	12/6/88	115.8	130.0	1206	14.2	84.9	5.331	61.6
8	12/6/88	142.9	159.7	1195	16.8	70.5	5.238	62.3
Neal 1	05/18/88	101.7	186.7	916	85.0	11.0	4.048	59.8
2	05/18/88	84.2	204.2	460	119.0	3.9	2.026	52.5
3	05/18/88	87.3	176.0	1404	98.7	15.8	6.206	58.1

Figure 2 shows the 8-year hydrograph of E.G. Cozzens' domestic well, located in the SW-1/4, Sec. 24. Water-levels in this well record the combined drawdown effect of four of Mead irrigation wells, no's 5, 6, 7, and 8. As far as known, the Cozzens well is the only frequently measured observation well near enough any of the large irrigation wells that seasonal drawdown effects of the nearby pumping can be determined with any degree of precision. Cozzens not only collected the data of Figure 2, but also plotted the data points shown.

During the 4-year period of 1982-85 (Figure 2), both the seasonal low water-levels and the seasonal high water levels in Cozzens' well declined about 1.3 ft./yr. Also, during this period the amplitude of the seasonal cycle, from non-pumping high water-levels to pumping low water levels, averaged about 8.5 ft./yr. It is obvious that the trends before 1982 and especially after 1985, were significantly different, suggesting less pumping than during the 1982-85 period.

As shown in Figure 2, water levels in the Cozzens well are constantly either declining due to nearby pumping or recovering after the nearby wells are turned off. Apparently there is no time during the year when consistent water-level measurements of a non-pumped observation well this close to the heavily pumped irrigation wells would record static levels.

Figures 3a and 3b show the hydrographs of twelve selected USGS observation wells, both east and west of Brown Road, plotted from USGS data. These hydrographs suggest that water levels throughout the study area remained relatively constant until about 1950, then most started a gradual decline apparently in response to the pumping of increasing numbers of small wells in the area. Since the early 1950's, however, most of the hydrographs take on new characteristics in apparent response to: 1) the direct drawdown effect of nearby seasonal pumping, and 2) the long-term water-level decline due to increased regional pumping.

THEORY

When a water well is pumped, water is removed from the aquifer and a three dimensional cone of drawdown develops around the pumping well. The magnitude of the drawdown is greatest in the pumping well, somewhat less outside the well casing, and typically decreases exponentially as the radial distance from the well increases. On semi-logarithmic paper, this exponential "drawdown versus distance" relationship plots as a straight line. The dimensions of the cone of drawdown depend on the rate and duration of pumping, the transmissivity of the aquifer system, and the degree of confinement of the ground-water reservoir.

Figure 4 is a semi-logarithmic plot of decreasing drawdown with increasing distance from a test well, is based on actual data for a test well in an arid valley of Nevada. In many ways the aquifer characteristics of the Nevada basin are much like those of Indian Wells Valley. For purposes of this study, we are assuming that the general relationships of Figure 4 apply to the aquifers supplying the agricultural pumpage north of Inyckern.

As shown in Figure 4, the pumping effects diminish rapidly with distance away from the pumping well. Drawdowns at a distance of 100 ft. are theoretically about 46-percent of those at the well; at 1,000 ft. about 19-percent, at 2,000 ft. about 10-percent, and usually are negligible a mile from the pumped well (percent scale added). Even though actual drawdowns north of Inyckern may differ from the valley in Nevada, the percent relationships of Figure 4 probably are quite reasonable for this study area.

As soon as pumping of a water-supply well stops, the cone of drawdown around the well starts to flatten. If sufficient recovery time elapses, a new "static" water level is established at the pumped well and throughout the cone of drawdown. If a new cycle of pumping begins before full recovery occurs, static conditions may not be reached before a new wave of drawdown begins.

From the above it is apparent that three types of drawdown frequently occur in the pumping cone that surrounds a large seasonally-pumped water well. These are :

1) The drawdown in the pumped well, as measured below a pre-pumping static water level. This includes the entrance losses of water moving through the gravel pack and perforations into the well. These entrance losses are usually quite small for properly constructed irrigation wells.

2) Seasonal drawdown outside the pumping well, as measured in a nearby observation well below a prepumping static water level. This drawdown is greatest near the pumped well and diminishes exponentially with increased distance from the pumped well, as shown in Figure 4. The drawdown cone around a pumping well continues to deepen and enlarge until sufficient recharge is intercepted to balance the pumpage.

3) A long-term water-level decline, resulting from the cumulative effect of years of pumping during which seasonal pumping declines exceed seasonal post-pumping recoveries. This represents a period deepening of the cone of drawdown and steepening of the hydraulic gradients toward the pumped well.

DATA ANALYSIS

ANALYSIS OF THE COZZENS HYDROGRAPH

Both the seasonal drawdown of nearby pumping and the long-term declines due to the cumulative effect of regional ground-water pumpage that exceeds ground-water replenishment are recognized in the 1982-85 record of the Cozzens domestic well (Figure 2). As noted above, the seasonal drawdown due to nearby pumping during this 4-year period averages about 8.0 ft each year, and the long-term decline averages about 1.3 ft./yr. During 1986-88, however, when annual pumpage from the three Mead wells was reduced to about half that of the 1982-85 rate, the seasonal drawdown in the Cozzens well also was roughly half the 1982-85 rate and the long-term trendlines indicate a significant water-level recovery.

Using distances scaled from Figure 1, pumping drawdowns derived from the second table of page 3, and percentage values from Figure 4, the following drawdown effects expected at the Cozzens well due to the pumping of the four Mead wells are calculated:

Mead Well No.	Distance (feet)	Pumping drawdown (feet)	At this distance (percent)	Cozzens drawdown (feet)
M8	2000	16.8	10	1.7
M6	2500	23.6	9	2.1
M7	2800	14.2	9	1.3
M5	4500	19.9	3	0.6
Total.....				5.7

Figure 2 suggests that the seasonal drawdown in the Cozzens well during the 1982-85 full-pumping period decreased from about 8.5 to 7.7 ft/yr., and averaging roughly 8.0 ft. each year. Of this, about 1.3 represents drawdowns to new low levels and the long-term effects of regional pumping. Thus, about 6.7 ft. of seasonal drawdown relates directly to the seasonal pumping of the Mead irrigation wells. The 15-percent difference from the above calculated drawdown may relate to: a) The seasonal pumping effects of wells other than the Mead wells, including the Cozzens

well itself. b) The comparing of drawdown effects after 8 months of pumping with short-term data used in Figure 4, and c) Aquifer parameters in Indian Wells Valley that differ somewhat from the parameters of Figure 4. The reasonably close agreement of the calculated drawdowns with observed drawdowns, however, provides a basis for estimating the seasonal drawdown effects of the large irrigation wells north of Inyokern on the measured water levels in the various USGS observation wells in the area.

ANALYSIS OF USGS HYDROGRAPHS

Using the technique outlined for the Cozzens hydrograph and the "drawdown-distance" relationship of Figure 4, the magnitude of the maximum seasonal drawdown effect that might be expected by the pumping of the large Mead and Neal irrigation wells in each of the hydrographs of Figures 3A and 3B, plotted from the "random" USGS data, have been calculated and tabulated below.

Observation Well	Calculated Drawdown (feet)	Comments
24/38-33J1	0	15 ft. decline in 16 yrs.
24/39-33N1	0	7 ft. decline in 30 yrs.
25/38-11K1	2.3	Steepening trend at end
13D1	0	Record stops before M4
13L1	6.6	Shows Mead recovery
23G1	0	Does not fit hydrograph.
24F1	5.7	30% more drawdown observed.
25L1	3.5	Shows Neal pumping of 1960's
35B1	0	Shows Neal pumping of 1960's
26/39-07N1	0	Erratic. Nearby pumping?
08K1	0	Inyokern pumping
19Q1	0	Inyokern pumping

As shown, only four of the observation wells with long-term hydrographs are near enough to the irrigation wells for water levels to register seasonal drawdown effects. All wells are affected by the apparently increasing regional pumpage, however, of which agricultural pumping probably dominates.

There is little water-level data available to define the lateral extent of the long-term cone of drawdown that has developed around the 12 large irrigation wells during the past dozen or more years, particularly to the west of the pumping wells. Rough calculation of the volume of water that might have been removed by the irrigation wells from such a cone, using hasty guesstimates of the dimensions and characteristics of such a cone and assumed pumpage data, suggests that actual pumpage far exceeds the volume of dewatering. What this means in terms of overdraft or recharge is unknown.

As suggested by the hydrographs of wells 26/39-8K1 and 26/39-19Q1 (Figures 3A and 3B), the cumulative effect of increased pumping in the Inyokern area, probably beyond the influence of the Mead and Neal agricultural wells, apparently dates back to the 1940's. Long-term drawdowns in this area probably exceed those of the Mead-Neal area to the north.

SPECIFIC CAPACITIES

If the discharge of a pumping well is divided by the drawdown, the specific capacity of the well is obtained. This not only is a measure of the productivity of the well, but also is a rough measure of the transmissivity of the aquifer system. The specific capacity actually varies with the pumping rate, type of well completion, type of aquifer system and time of pumping, but generally is a reasonable measure of the water-transmitting capability of the aquifer system, especially if the relationship between specific capacity and transmissivity can be calculated from actual pump-test data.

Figure 6 shows the empirical relationship between specific capacity and transmissivity for the previously discussed basin in Nevada (see Figure 4), based on field data for 7 test wells in that basin. As shown, the least-square regression line through the data points suggests a close linear relation between these two parameters. Thus, values of either specific capacity or transmissivity can be estimated if the other parameter is known or assumed in the similar hydrogeologic setting.

Using the general concepts of Figure 6 and specific capacity values from the second table of page 3, a distinct difference in transmissivity is noted between the Mead wells and the Neal wells. In general, the specific capacity values of the Mead wells in 1988 were roughly ten times as large as those of the Neal wells. Whether this marked contrast is due to lateral or vertical changes in hydrogeologic characteristics of the subsurface formations or is caused by differences in well construction or maintenance is beyond the scope of this study. The reason for this sharp contrast should be of prime concern to operators of the Neal wells and other wells with relatively low specific capacity in the area.

CONCLUSIONS

1. For observation wells within a mile of large pumping wells north of Inyokern, there probably is no time of year when the seasonal drawdown effects of these wells are not affecting ground-water levels. These effects are at a minimum just before these large wells are turned on, usually in late January and February each year.

2. The maximum seasonal effect of this pumping on water level around the pumped well can be estimated from an empirical "drawdown-distance" relationship, such as Figure 4. Hydrograph plotted from random water-level data can be modified, thereby showing the long-term water-level trend. The effects of two or more nearby pumping wells are additive at the observation well.

3). It is noted that when the rate of pumping of four Mead well was reduced in 1986-88, a trend of long-term water-level recovery was immediately initiated. The lateral extent of this trend reversal is not known.

4). In general, both the seasonal and long-term effects of pumping of the 12 large agricultural wells north of Inyokern are roughly defined in this brief study. Additional definition and clarification may be obtained by carefully reviewing the following types of data not used in this study:

- a. Static water level, drawdown, pumpage, and specific yield

records for all wells tested by SCE or others, since their tests began in the area.

b. Pumping history and total pumpage for the 4 Neal wells. Also, identify other large production wells that may have operated, and possible drawdown effects on nearby observation wells

c. Characteristics of the aquifer system--type of confinement, vertical and lateral interferences, pumpage vs. depth relationships.

d. Estimates of total pumpage--- agricultural, small farm, domestic, and Navy.

5). By establishing precise elevations for the measuring point of key USGS observation wells, accomplished by running second-order levels from a reference datum, meaningful water-surface elevation can be calculated from existing data. From these, water-level contours and change contour can be drawn, and ground-water flow directions and gradients calculated.

6). Although adjusted long-term hydrographs plotted from USGS data indicate a deepening and expanding long-term drawdown cone developing around the cluster of 12 large irrigation wells, we saw no data in the area studied that either proves or disproves regional overdraft.

7). This investigation did not address the evidences of valley-wide recharge, discharge or possible overdraft.

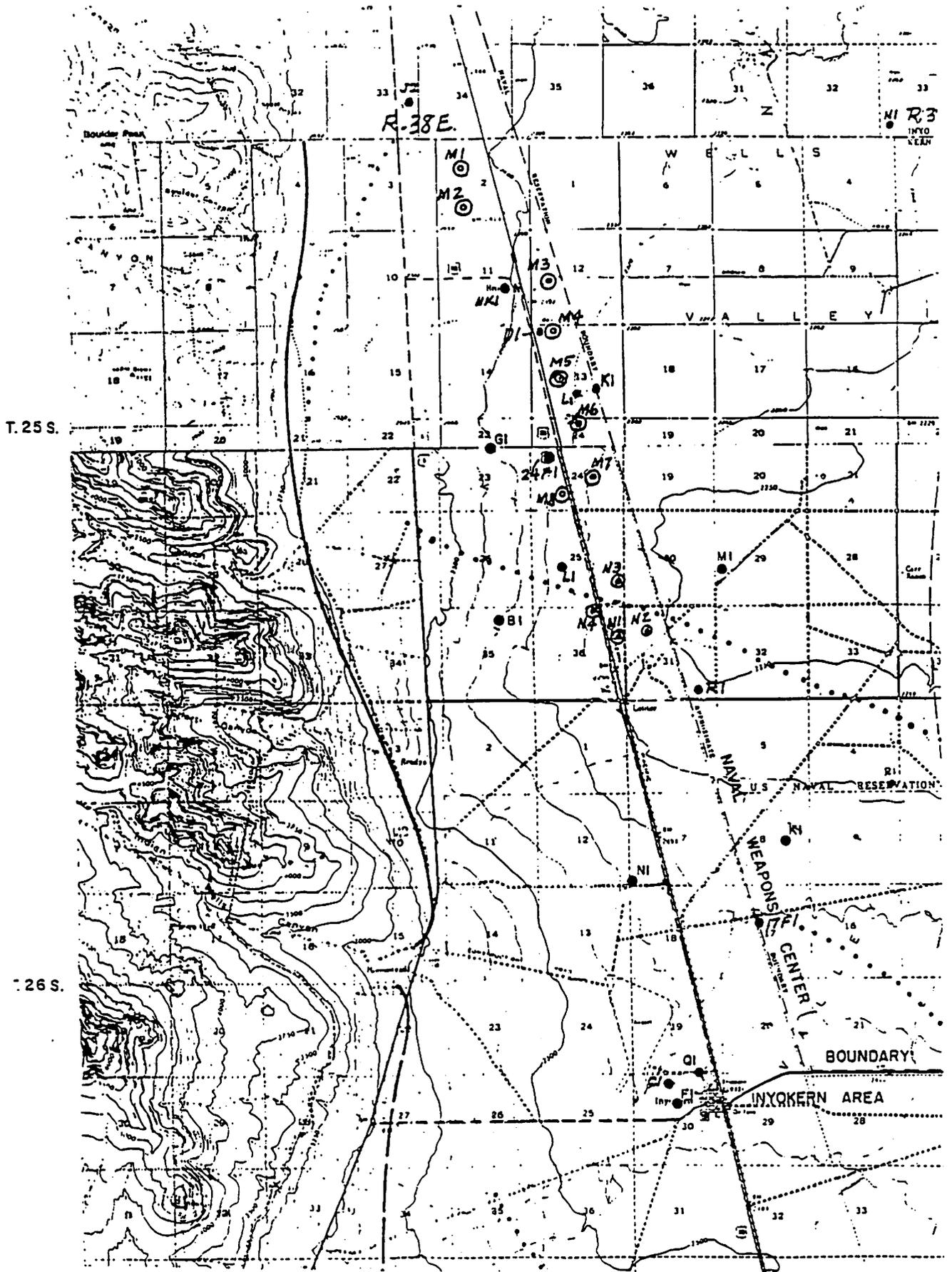
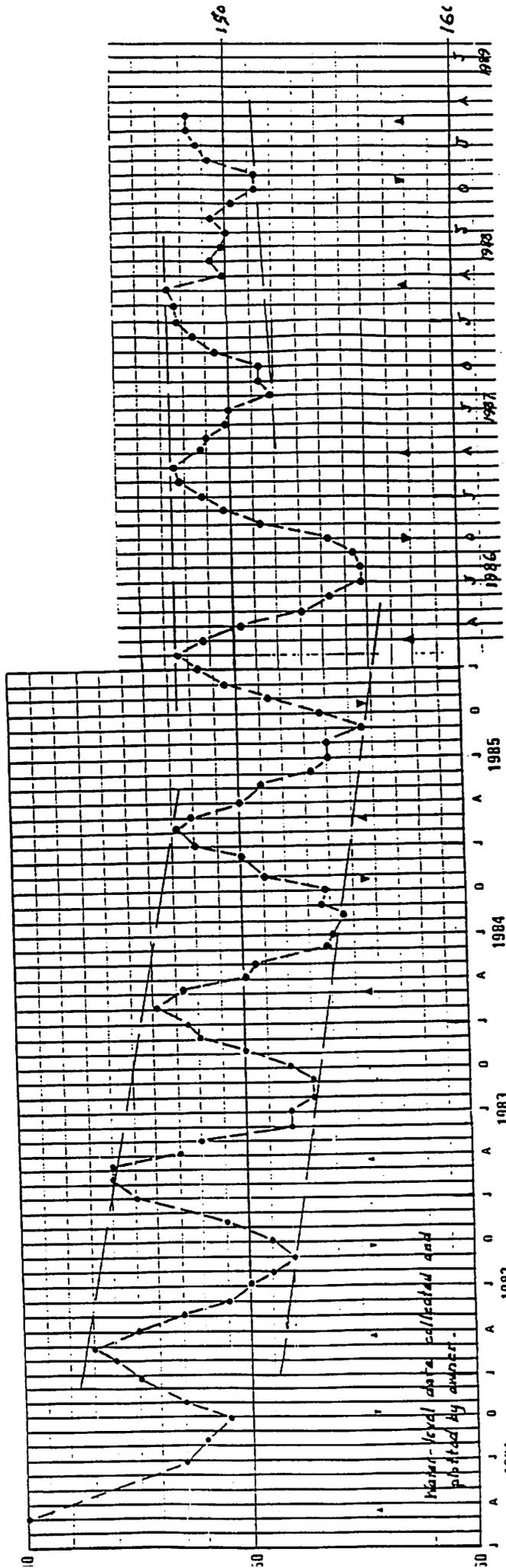


FIGURE 1.- LOCATION OF 12 IRRIGATION WELLS AND SELECTED USGS OBSERVATION WELLS



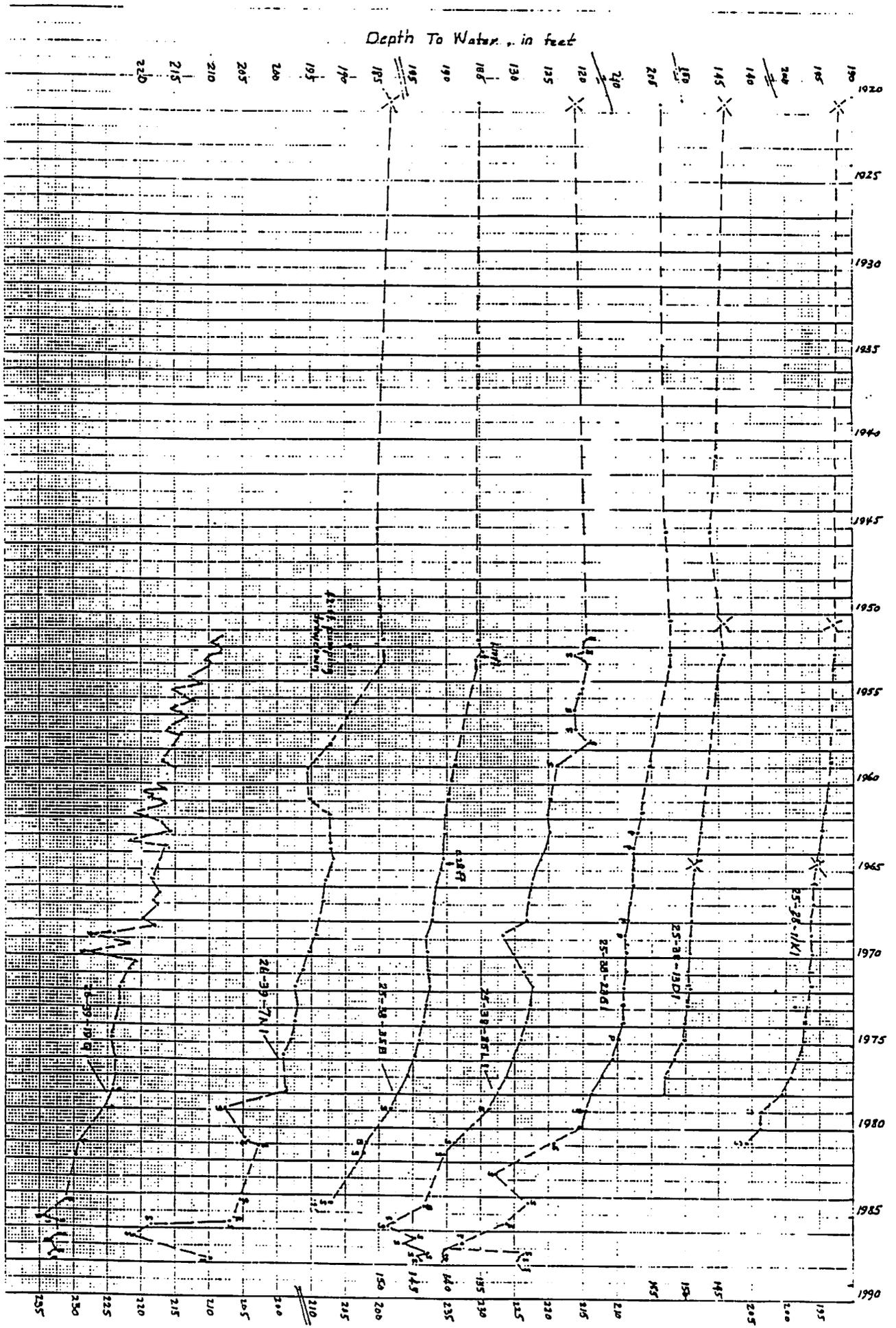


E. O. COZZENS
 7255 BROWN ROAD
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WATER TABLE LEVEL vs TIME

FIGURE 2.- HYDROGRAPH OF STATIC WATER LEVELS IN THE COZZENS DOMESTIC WELL, 25/38-24F1

FIGURE 3A. - HYDROGRAPH OF 7 USGS OBSERVATION WELLS



Depth to water, in feet

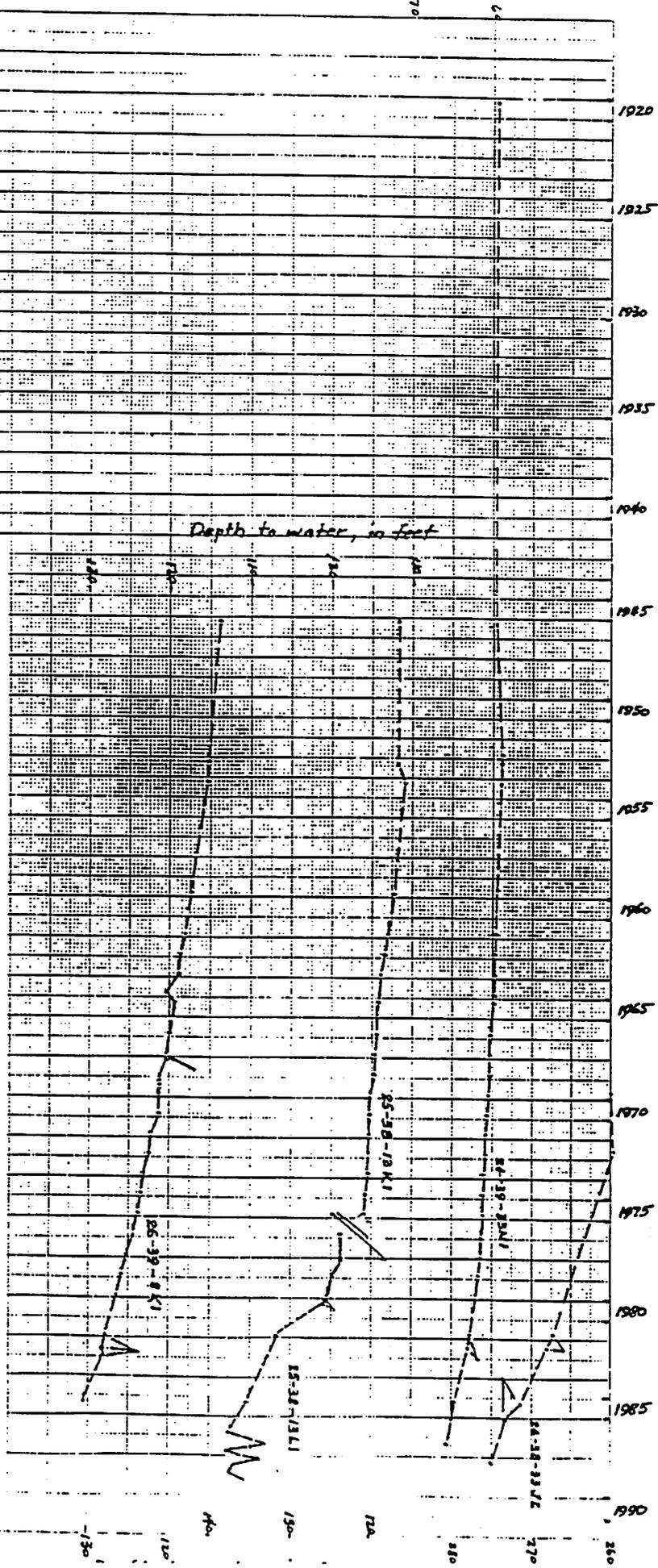


FIGURE 3B. - HYDROGRAPH OF 5 USGS OBSERVATION WELLS

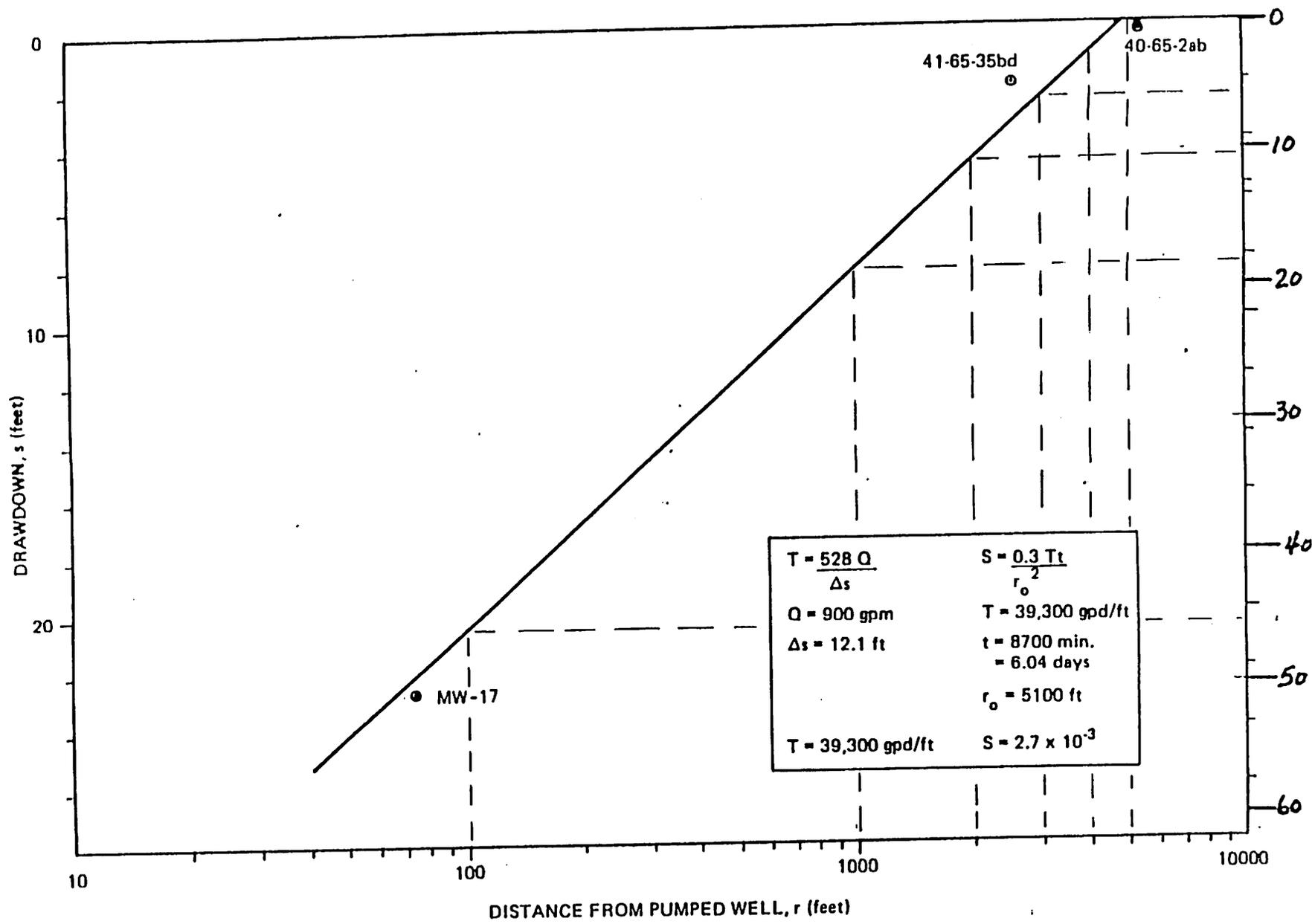


FIGURE 4.- REDUCED DRAWDOWN WITH DISTANCE FROM A PUMPED WELL

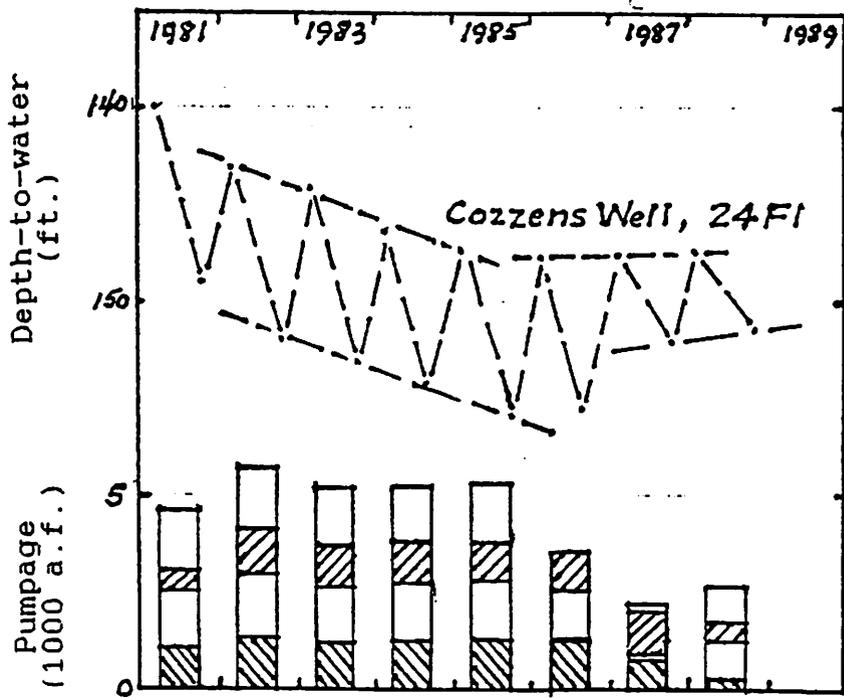


Figure 5.- Drawdown in Cozzens well, 24F1 and pumping rate of four nearby wells
M8....bottom bar (right hash)
M6....blank
M7....left hash
M5....top (blank)

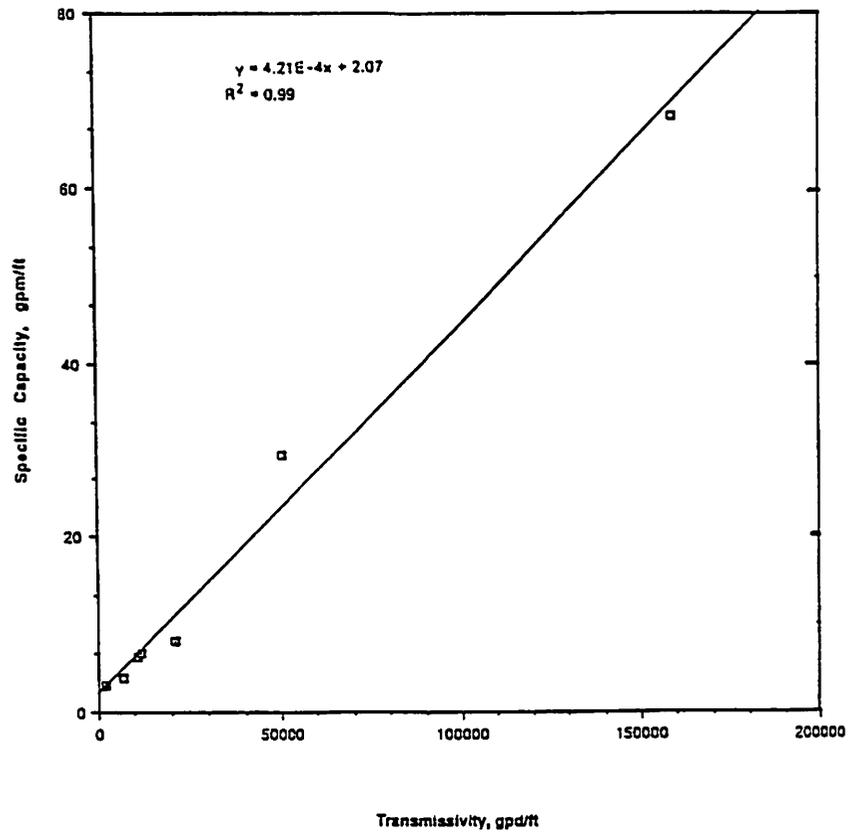


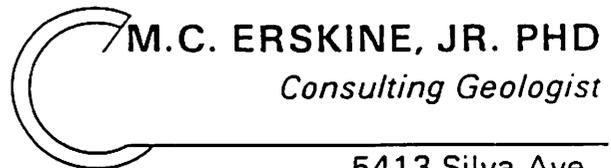
FIGURE 6.- CORRELATION OF SPECIFIC CAPACITIES OF 7 TEST WELLS AND
AQUIFER TRANSMISSIVITIES, NORTHEASTERN NEVADA

APPENDIX B

Letter stating preliminary results and recommendations from
the review of the geohydrology of Indian Wells Valley.

Prepared by M. C. Erskine, PhD, Consulting Geologist

May 17, 1989



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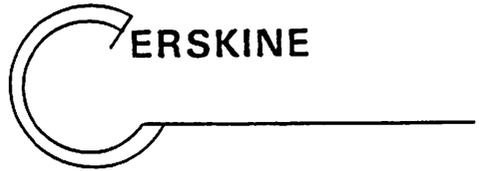
Mr. LeRoy Marquardt
Eastern Kern County Resource Conservation District
P.O. Box 1000
Inyokern, California 93527

Dear LeRoy;

Preliminary results from the study of the groundwater resources of Indian Wells Valley have suggested that the existing groundwater data base is inadequate for determining the amount of groundwater available for sustained yield within the Valley. Two basic problems are inherent in the USGS water-level data collected over the years and in the use made of these data. First, the data for each observation well have been collected, in general, only one or two times per year and at random seasons. In an area strongly affected by seasonal agricultural drawdowns, it is virtually impossible to separate seasonal drawdown effects from long-term trends from this data.

Second, when a well is selected as an observation well in a water-level monitoring program, the elevation of a reference measuring point at the wellhead is assigned. Usually the reference elevation assigned to the wellhead is estimated from the contours of the latest USGS topographic map of the area. When first assigned, it is realized that this elevation and the water-level elevation calculated from it are only rough approximations. After a few years, however, these elevations tend to be accepted as precise. Measuring-point elevations derived from topographic maps in this manner tend to a precision of about one-half the contour interval, +/- 25 feet in the case of the Inyokern 15' Quadrangle. Indian Wells Valley, however, has a special problem in this regard. The contours on the Inyokern 15' Quadrangle miss-tie with the contours on the Little Lake 15' Quadrangle by as much as 30 feet, indicating potential problems with the elevation of the groundwater table of as much as 65 feet. The groundwater gradient contoured by Dutcher and Moyle (USGS Water-Supply Paper #2007) in 1965 across the entire Valley is only 65 feet.

Given the above problems with the groundwater data set, I have, as suggested by you, prepared a recommendation for a water well sampling program. The attached map shows the approximate location by township, range and section of wells that should be included in a systematic monthly sampling program. The locations were selected to give systematic aerial coverage of the Valley. In general, they are the deepest good-quality water well in their general area.



However, each major groundwater type is represented. I have three basic recommendations for the sampling program:

1. Each well selected for monitoring should have a resurveyed reference elevation clearly marked at the wellhead. Precision barometric leveling (± 1.0 ft.) should be adequate for this.

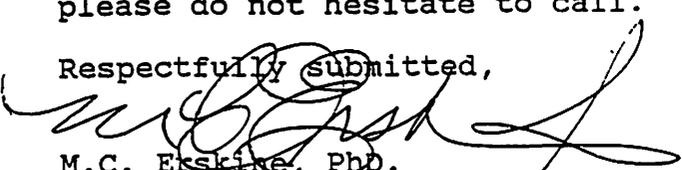
2. Each well selected should have a water-level measurement recorded once each month. The measurement of depth to water from the reference elevation should be made with a non-polluting device capable of a precision of ± 0.1 feet. In addition, the use status of the well should be recorded.

3. Once each year each well should be sampled for temperature, pH and water quality.

The above outlined program should be carried out by a reliable local engineering contractor. Such a program will provide a data base for assessing whether Indian Wells Valley groundwater basin is in fact in overdraft or not and for designing a test well program for optimum groundwater management.

If you should have any questions about the above outlined program please do not hesitate to call.

Respectfully submitted,

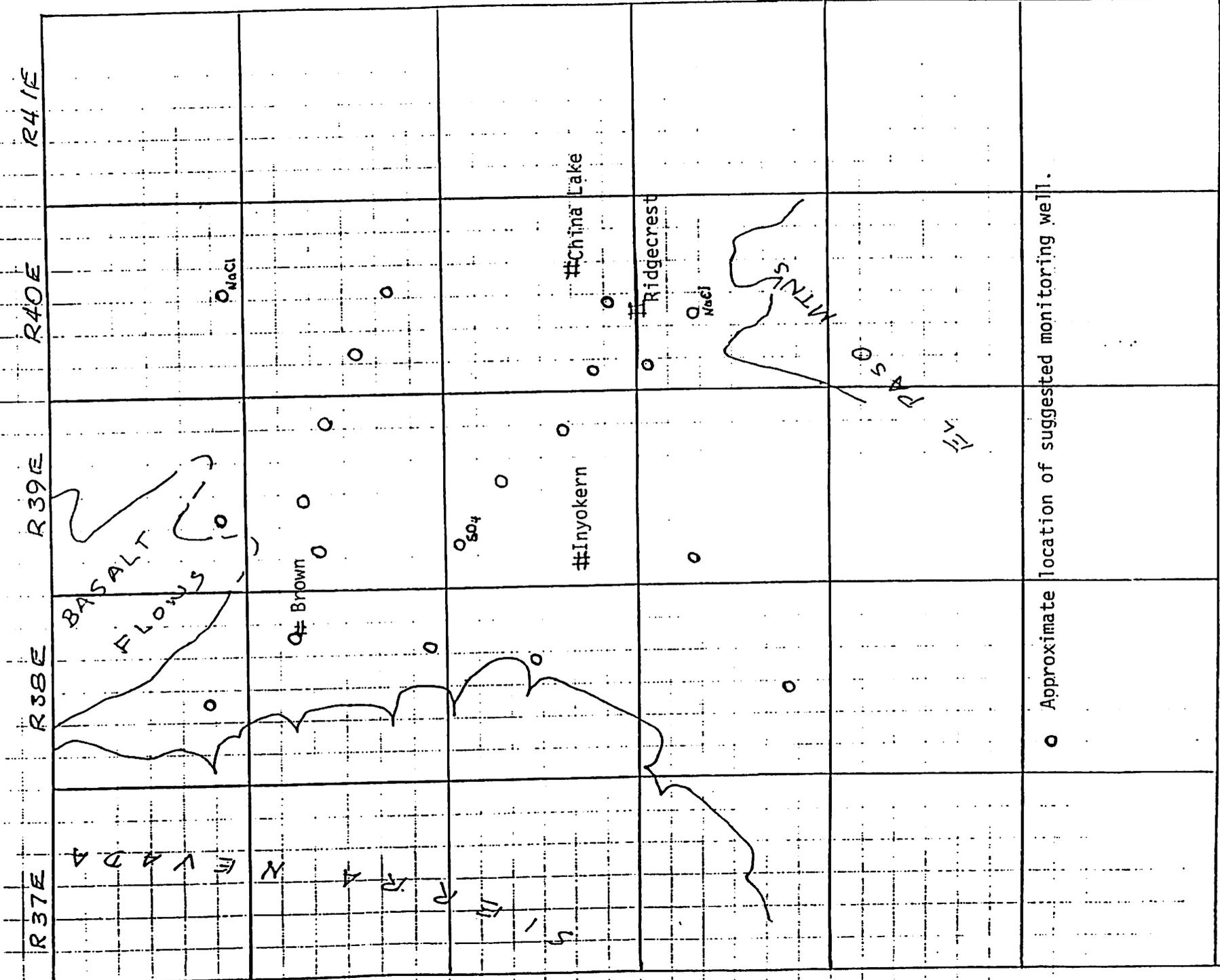


M.C. Erskine, PhD.

Registered Geologist, California #1944

Enclosure.

SUGGESTED MONITORING WELLS



○ Approximate location of suggested monitoring well.

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