HYDROGEOLOGIC CONDITIONS IN INDIAN WELLS VALLEY AND VICINITY

Prepared for

California Department of Water Resources

Contract No. DWR B-56783

By

Robert T. Bean

Consulting Geologist

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About the Author

Robert T. Bean has more than 40 years' experience in ground water investigations. He holds a Master's degree in geology from Ohio State University, and has had further graduate work in geology at Stanford. His principal employment has been 18 years with the California Department of Water Resources, 6 years as Coordinator of Ground Water Projects for the United Nations (technical assistance), and 17 years as a consulting geologist, during the last 10 of which he has taught ground water courses at full Professor level at California State University, Los Angeles.

While with the California DWR, Mr. Bean supervised or conducted the geologic aspects of over 40 investigations concerned with ground water, and either wrote or reviewed the appropriate sections of the resulting Bulletins. These included four Bulletins on desert areas and six Bulletins on areas in the Sierra Nevada. In a great many investigations for DWR, the UN, and as a consultant, Mr. Bean has made or supervised measurements and made quantitative estimates of key hydrologic parameters including stream flow, ground water recharge, subsurface water movement, and ground water quality and storage capacity, and has developed numerous hydrologic balances including calculations of overdraft where present. He is the author or co-author of numerous additional technical papers concerned with ground water.

Mr. Bean is past Chairman of the Hydrogeology Division of the Geological Society of America, and past President of the Association of Engineering Geologists. He is a registered geologist (No. 1339) and certified engineering geologist (No. 483) in California.

HYDROGEOLOGIC CONDITIONS IN INDIAN WELLS VALLEY AND VICINITY

INTRODUCTION

Indian Wells Valley lies just east of the Sierra Nevada, in the northern part of the Mojave Desert, California. The valley is a topographic and structural basin, largely surrounded in addition to the Sierra Nevada by the Coso Range on the north, the Argus Range on the east, and El Paso Mountains on the south. The valley floor is underlain by permeable materials containing an ample ground water reservoir.

Ground water conditions in Indian Wells Valley and vicinity have been a matter of disagreement and a certain amount of contention for some time. One group, relying on investigations by the U. S. Geological Survey and other geologists, considers that Indian Wells Valley is essentially a closed basin as far as ground water is concerned. This group considers that almost all the recharge to ground water in the valley occurs by percolation (infiltration) within the valley of surface streams draining the surrounding mountains. Natural discharge is considered to be almost entirely by evapotranspiration in the valley, except for a small amount of ground water that may move eastward through alluvium to Salt Wells Valley. Extraction by pumping is considered by all concerned to be the principal discharge of ground water at the present time.

The second group, relying on information and investigations by geologist Carl Austin of the Naval Weapons Center (NWC) and

other professionals largely on contract with the Eastern Kern County Resource Conservation District (EKCRCD), believe that a regional ground water flow pattern exists that has been ignored by the closed basin group. Those supporting a regional flow system consider that significant amounts of ground water enter the basin at depth directly or indirectly from fracture systems in the Sierra Nevada, perhaps originating as far to the west as the Kern River drainage. Similarly, they believe that ground water may well move at depth to the east and south, beneath the Argus and El Paso Mountains.

An independent review of hydrogeologic conditions and evaluation of the merits of the concepts of the two groups mentioned, along with recommendations for further investigation needed to resolve questions that are still unanswered, has obviously been needed. Accordingly, the California Department of Water Resources (CDWR) and the Kern County Water Agency (KCWA), joined by the Eastern Kern County Resource Conservation District (EKCRCD) and the Indian Wells Valley Water District (IWVWD), have cooperated in authorizing and funding the investigation resulting in the present report.

Objectives and Purpose

According to the contract under which the investigation has been carried out, the study was directed toward achieving the following objectives:

[1]. Determination of the hydrogeologic characteristics and properties of the Indian Wells Valley ground water system, utilizing existing data and information.

[2]. Estimating the uncertainties involved in assigning values to the hydrogeologic parameters of the Indian Wells Valley ground water system.

[3]. Comparing and evaluating alternative theories governing the nature of the Indian Wells Valley ground water system including boundary conditions.

Objective [1] is covered in the four sections of this report following the Introduction, namely Hydrogeologic Framework, Occurrence and Movement of Ground Water, Water Quality, and Hydrologic Balance.

With regard to objective [2], it must be stated that there are considerable uncertainties involved in assigning values to hydrologic or hydrogeologic parameters in any study. Some values can be ascertained with more accuracy than others. Measurement of water levels in wells, for example, is normally done with considerable accuracy, and if the wells are all completed in the same aquifer, and measurements are rejected if a well has recently pumped, the resulting ground water contour map is an essentially accurate picture of water levels.

On the other hand, estimates of certain parameters may be very uncertain. Subsurface movement into or out of a ground water basin can be estimated with reasonable accuracy if hydrogeologic conditions where the subsurface movement occurs are known, including the results of pumping tests giving transmissivity values. However, if hydrogeologic conditions

including transmissivity values are not known, estimates of subsurface movement are very uncertain.

We have attempted to evaluate the accuracy of the values assigned to the various hydrogeologic parameters assigned in this study, as required. However, we believe that any attempt to quantify the accuracy of a parameter by a percentage or other numerical means would be inaccurate in itself and therefore misleading.

With regard to objective [3], a brief comparison of alternative theories regarding the Indian Wells Valley ground water system has been done in this Introduction. Evaluation of these theories is done in the Conclusions by setting forth the findings of our present study, including a statement of further work needed to resolve remaining uncertainties.

There was no attempt to critically analyze the various reports and publications, including U. S. Geological Survey models, in detail. Such would have been been beyond the scope of this investigation. Instead, concepts and information presented in these reports were studied and evaluated, following which they were accepted, modified, or in some cases rejected in accordance with our professional experience and understanding of the hydrogeology of the Indian Wells Valley region.

Previous Investigations

A very large amount of study has been made of hydrogeologic

conditions in Indian Wells Valley and vicinity, and it would not be practicable to review here all documents, publications, and basic data that exist on the area. However, the attempt has been made to secure and utilize all the major documents representing the differing schools of thought, plus existing pertinent basic data, in preparing this report. All the principal sources used are listed in the References.

Acknowledgments

Excellent cooperation has been received from all agencies and individuals contacted with regard to furnishing documents and basic data for this study. So many individuals have helped that it is not feasible to mention them by name, lest one or two be inadvertently left out.

Personnel employed by or associated with the cooperating agencies, the California Department of Water Resources, Kern County Water Agency, Eastern Kern County Resource Conservation District, and Indian Wells Valley Water District have been uniformly helpful. Cooperation and documents furnished by personnel of the Naval Weapons Center and the U. S. Geological Survey have been indispensable.

All cooperation and assistance received is acknowledged with sincere thanks.

In this report, where a personal reference is necessary, the editorial "we" is used instead of the more formal "the writer."

HYDROGEOLOGIC FRAMEWORK

Sedimentary Materials

The unconsolidated sediments of the floor of Indian Wells Valley have been described in detail in a numerous reports, including several by the U.S. Geological Survey. The importance of these materials is obvious, as where they are below the water table they constitute the reservoir materials from which ground water is pumped.

Alluvial fans at the base of the mountains, particularly the Sierra Nevada, are of extreme importance, as they constitute the principal recharge areas for the ground water reservoir. The alluvial fan deposits consist mostly of sand and gravel that transmit water readily downward to the water table from the stream beds crosssing them.

Most of the central portion of the floor of Indian Wells Valley is underlain by moderately to well-sorted sand, silt, clay and gravel. Wells penetrate and draw water from these deposits, which range in geologic age from Recent to Pleistocene. Partly consolidated continental sediments of Tertiary age underlie the alluvium at depths ranging up to nearly 2,000 feet, according to Dutcher and Moyle (1973). This depth occurs in the heavily pumped area northwest of Ridgecrest; beneath much of the valley the overlying alluvium is much thinner. Permeability of the underlying Tertiary deposits is generally much less than that of the alluvium.

The alluvium in general becomes progressively more fine grained and clayey toward the eastern part of the valley. The lowest areas in the valley are occupied by playas. Deposits underlying the playas are high in clay, have low permeability, and generally contain water of poor quality. The limited areas of sand dunes are not significant hydrologically, as the sand is mostly above the water table.

Consolidated Rocks

The consolidated rocks that surround most of Indian Wells Valley are of particular interest with regard to the presence or absence of a regional flow system. Water can be transmitted through completely consolidated rocks such as granite, gneiss, indurated siltstone, and shale only through fractures, including both joints and faults. Limestone and marble are a special case -- fractures such as joints can be greatly enlarged by solution into channels that can transmit large volumes of water. Volcanics also, particularly basalts, can contain extensive interconnected openings. Younger basalts may be especially permeable through lava tunnels, flow contacts, and sets of cooling fractures.

The Sierra Nevada, as shown on the Trona sheet of the Geologic Map of California by the State Division of Mines and Geology (1962) is composed almost entirely of granitic rocks, with very limited lenses of basic intrusives and metasediments. Maps prepared for a fault/fracture study by Ward Austin (June,

1987) using computerized orthophotos show a dense and intricate pattern of faulting in the Sierra Nevada, as well as in the other mountain ranges surrounding Indian Wells Valley and on the valley floor itself. Carl Austin (June 10, 1988) believes that the faulting in the Sierra Nevada brings ground water to Indian Wells Valley at depth from west of the crest of the range. He indicates that the ground water moves through interconnected fault and fracture conduits. Faulting is discussed further in a later section of this report.

The Argus Range east of Indian Wells Valley is also almost entirely composed of granitic rocks, according to the Trona sheet (CDMG, 1962). A few patches of Quaternary volcanics are mapped, but these are much too shallow to be a factor in a regional flow system. On the other hand, no less than ten springs and a drainage named "Water Canyon" are shown in the Argus Range. Nearly all the springs and the canyon are on the east flank of the range.

In El Paso Mountains to the south, some limestones have been mapped by Dibblee (1952) in the Garlock Series of Permian age. However, his cross sections show the dip of almost all rocks to be toward Indian Wells Valley, not a favorable attitude for ground water movement away from the vallley. Furthermore, the occurrence of limestone appears to be rather patchy. Other rocks in the range include mostly granitics and consolidated sedimentary rocks, through any of which groundwater movement

would have to be through fractures. Dibblee's cross sections do show a few volcanic rocks. The Black Mountain Basalt is very thin, and well above the level of ground water in Indian Wells Valley. However, a few basalt and andesite flows and intrusions are shown at greater depth, and thus indicate the possibility of conduits for ground water.

Structure

All investigators agree that a great many faults occur in the Indian Wells Valley region. However, the nature of some of the faulting, and its effect on the occurrence and movement of ground water, are matters of considerable disagreement.

Indian Wells valley itself is a great block bordered by faults on all sides. The valley floor is crossed by a number of faults according to the various geologists who conducted studies for the U. S.Geological Survey. Dutcher and Moyle (1973) state that northwest-trending faults are most common in the central and western part of the valley, but short northeast-trending faults occur in the southeast. These authors indicate that some of the faults are barriers to ground water movement in varying degrees, and tend to divide the valley into separate ground water subunits. One of these faults about 3 miles south of Inyokern, labeled "Ground-Water Barrier" on Plate 1 of the present report, separates wells that have had a difference of over 50 feet in ground water levels.

However, the most recent USGS report, a draft by Berenbrock (undated), states that none of the faults were considered as barriers in constructing and validating the ground water model.

In contrast, W. Austin's maps (June, 1987) show a complex pattern of faulting in Indian Wells Valley. He not only shows northwest-trending and northeast-trending faults, but maps a large number of curved patterns, some of which make a complete circle. He states (May 27, 1987) "In most of the area where good photo detail is available, the fault/fractures show up well at least every 100 feet on 1:24,000 scale photos." He recognizes the barrier effect of faults on ground water movement.

There is great disagreement on the type of faulting that has formed the mountain ranges, particularly the Sierra Nevada. The frontal fault zone of the Sierra Nevada west of Indian Wells valley has been considered by many geologists to be a zone of normal faulting. However, the Austins, Erskine, OBrien and others believe that the range has been thrust eastward and contains one or more thrust sheets. The eastern part of the Sierra Nevada, just west of Indian Wells Valley, is thus considered to be underlain by sedimentary materials. If this is true, the sediments underlying the Sierra could collect ground water, which could move at depth into the valley. The concept of recharge from the Sierra Nevada will be discussed more fully later in this report.

Austin and Whelan's maps (Aug. 1987) show a number of

major fault/fracture zones trending both northwest and northeast, and extending from the Sierra Nevada across Indian Wells Valley into the Argus Range. Arrows on these maps indicate "water flow directions," which are westerly from the Sierra and generally southerly from the Coso Range into Indian Wells Valley. A very prominent zone called the "Little Lake-Wilson Canyon fault/fracture" crosses the Sierras in a southeasterly direction, enters Indian Wells Valley near the mouth of Little Lake Canyon, and crosses into Coso Basin and into the Argus Range.

OBrien (undated) utilized gravity and magnetic data in concluding that the Sierra Nevada has been thrust from the west. His Profile C-C', showing gravity data with interpretation, is reproduced as Figure 1 of the present report. The profile extends east-west from SE of Pinyon Peak across Indian Wells Valley to the southern Argus Range and is modified to show the location of certain key geographic features. The interpretation of the various units in this profile is given by OBrien in the following table:

Unit	Interpretation	Density Contrast (g/cc)
A	Overthrusted unit	.35
B	Sediments	-.45
C	Intrusive?	.375
D	Thrust Sheet	.20
E	S. flank of Argus Mountain Thrust Sheet	.30

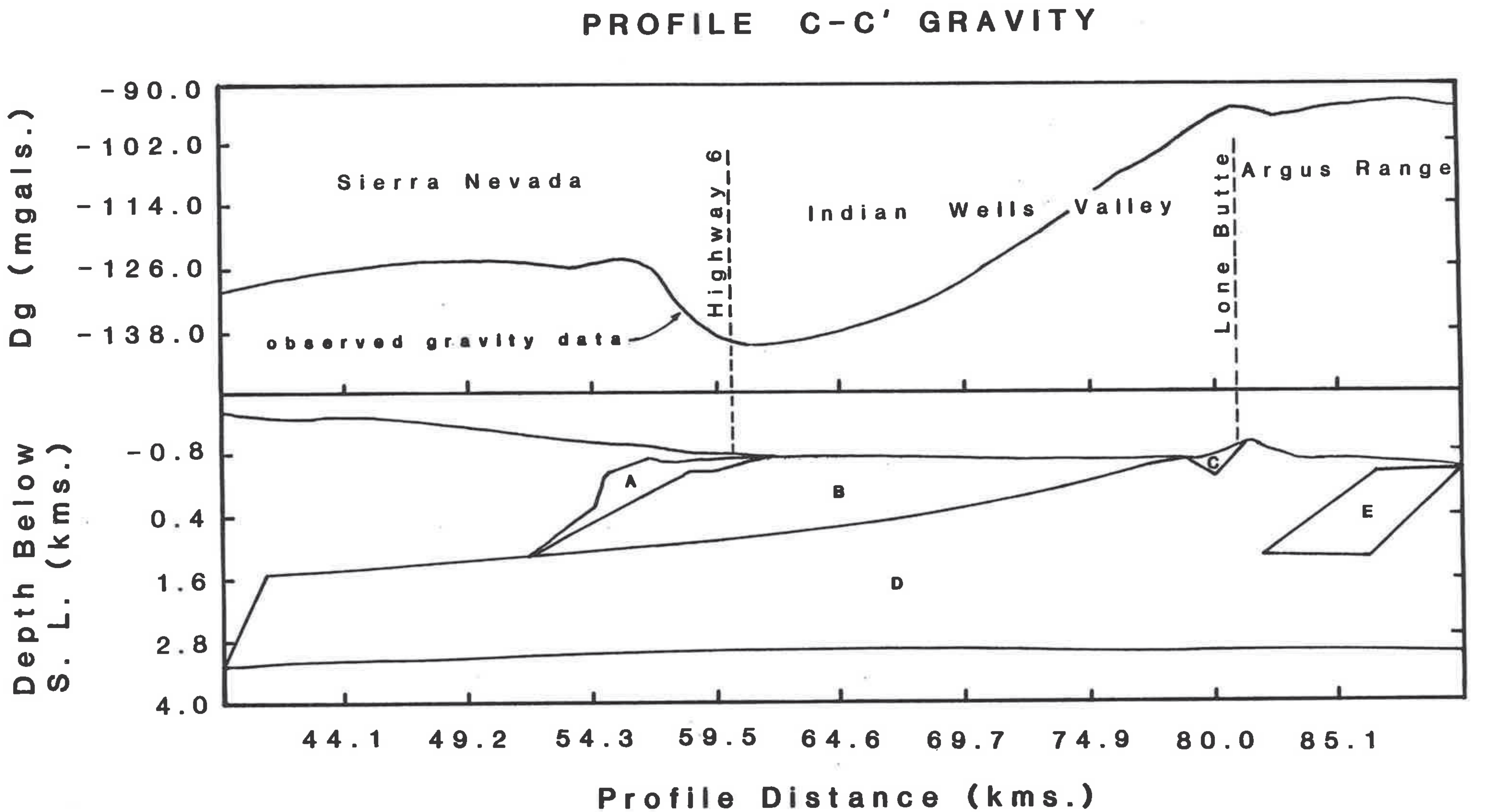

Figure 1

Modified from OBrien, Fig. 3

EAST-WEST PROFILE ACROSS INDIAN WELLS VALLEY REGION

OBrien (p. 23) details his interpretation as follows:

"Sediments are interpreted to lie beneath the Sierras at least 7 kilometers west from the Front. Sedimentary thicknesses exceed 1.40 kilometers [4,600 ft.] near location 62.0 in Figure 3. The sediments are deposited upon a pre-Tertiary basement unit (body D) . . . This unit is intruded by two denser units (bodies C and E) . . . Body C forms part of the western flank of Lone Butte, while body E forms part of the southern pediment of the Argus Range."

The sedimentary thickness indicated by OBrien is in conformance with the depth of test wells (4,000 to 5,000 feet or more) proposed by Ward Austin (1987) and recommended later in the present report.

Allan Katzenstein (oral communication) agrees with OBrien that the geophysical data indicate the Sierra Nevada is a thrust sheet. M. C. Erskine (undated) has prepared a cross section through Rose Valley and the Coso Range showing complex thrusting from the west.

However, the nature of the faulting at the Sierran front remains a matter of some difference of opinion. If indeed the fault is a thrust, and the thrust sheet is underlain by sufficiently permeable sediments, large amounts of ground water could move through these sediments into Indian Wells Valley. This possibility will be considered subsequently in this report.

OCCURRENCE AND MOVEMENT OF GROUND WATER

The principal known occurrence of ground water in Indian Wells Valley is in the alluvial sediments of the valley floor. The largest amount of recharge takes place by percolation of the intermittent streams from the Sierra Nevada after they reach the valley floor. Under natural conditions before development by man, this ground water from the west moved eastward. Its rate of movement was checked where fault barriers were encountered. However, eventually this water reached the area of the playas in the eastern part of the valley, where the water moved upward towrd the surface and returned to the atmosphere by evapotranspiration.

If the concept of a regional ground-water flow pattern is correct, there may be additional ground water entering Indian Wells Valley at depth through or below the granitic thrust sheet of the Sierra Nevada. However, the presence, quality, and availability of such deep ground water is yet to be demonstrated, and until this is done, we can only describe the occurrence and movement of the known ground water body.

Under present conditions, a large part of the natural ground water discharge has been diverted to pumping wells. As a result, a regional cone of depression has formed, centered according to Berenbrock (Pl. 1) about three miles northwest of the center of Ridgecrest.

In the eastern part of the valley, beds of clay and silt confine the principal ground-water body. The approximate western and southern limit of the confining beds is shown on Plate 1. A second shallow water body occurs overlying these confining clays. Under natural conditions, ground water in the confined aquifer had higher head, and seeped upward into the shallow aquifer, to be finally discharged by evapotranspiration. At present, according to Berenbrock, the head of the shallow aquifer is higher than that of the deep aquifer in some areas, which means that the shallow water of poor quality is seeping downward into the pumping aquifer in those areas. Furthermore, the hydraulic gradient in the eastern valley is now toward the center of the cone of depression northwest of Ridgecrest, as noted above, and poor quality water is moving in that direction.

The amount of water contributed to Rose Valley by streams from the Sierra Nevada and then in part moving into Indian Wells Valley is a matter of considerable controversy. This will be dealt with quantitatively in a subsequent section of this report.

The amounts of runoff from the Argus Range into Coso Basin and Indian Wells Valley, and the contribution from El Paso Mountains are also matters of disagreement. The playa in Coso Basin, Airport Lake, has a smooth hard surface in contrast to the irregular surface typical of playas where the water table is at or near the surface and evaporation is occurring. The water table has always been at considerable depth beneath this playa

(Thompson, 1929), and apparently there is little gradient on the water table at the present time (St.-Amand, 1986). The disposition and movement of recharge from streams of the Argus Range into Coso Basin is thus a matter of some uncertainty.

As noted in the previous section, the Austin-Whelan maps (1987) show "flow directions" by large thick arrows in the region surrounding Indian Wells Valley and the valley itself. Flow is shown coming into the valley from the Sierra Nevada in a number of places, and from Rose Valley and the Coso Range. On the east and south sides of the valley, flow is shown by specific arrows both coming into and leaving the valley, from and into the Argus and El Paso ranges. Qualification of these flow directions is stated as follows: "With the exception of shallow water flow directions from Dr. J. H. Birman shown by arrows in the SW corner of the Inyokern 15' quadrangle [south and southwest of Freeman Junction] the water flow directions are speculative but are based in part on work by Fournier and Thompson, USGS Open File Report 80-454 and Spane, NWC TP 6025, 1978."

Storage Capacity

The storage capacity of the groundwater reservoir was calculated by Dutcher and Moyle (1973, plate 4), who divided the valley into three areas for their calculations. The western limit of the total area evaluated runs roughly along Highway 14, and the eastern limit is the western edge of confining clays, shown on Plate 1 of the present report. The northern limit of

the area is east of the mouth of Fivemile Canyon, and the southern extension is near Terese.

Storage capacity was calculated using specific yields varying from 10 percent to 20 percent, although their text seems to indicate that average specific yields were actually somewhat lower. Storage capacity was calculated to be about 2,200,000 acre-feet for a saturated thickness of 200 feet below the water table of 1921.

Plate 1 of the present report shows the amount of lowering of the water table from 1921 to 1985 in the principal aquifer of Indian Wells Valley, west amd south of the edge of the shallow aquifer. Data for this plate came from various sources, particularly Dutcher and Moyle, Moyle (1963), and recent water level data from the USGS. A rough calculation was made of the depletion of ground water in storage since 1921 caused by this water level lowering, and the depletion amounts to about 150,000 acre-feet. This figure is only approximate, but it indicates that between 5 and 8 percent of the ground water in storage in the principal area of pumpage was exhausted between 1921 and 1985.

Quantitative discussion of ground water recharge, movement, and discharge, with consideration of the various concepts held, will be given in the subsequent section entitled "Hydrologic Balance."

WATER QUALITY

The most complete recent study of ground-water quality in Indian Wells Valley and vicinity has been done by Whelan and Baskin (1987). Their draft report contains 71 pages of text and approximately 140 more pages of charts and diagrams giving analyses, Stiff diagrams, comparisons of quality according to location and depth, etc. The text describes the principal water quality types of each 36-section township. In addition, Whelan furnished the water quality information on the W. Austin-Whelan maps (1987) previously referred to.

Reports by personnel of the USGS also have covered ground water quality in the valley. These include Kunkel and Chase (1969), Dutcher and Moyle (1973), and Warner (1975), The recemt draft report on the ground-water model by Berenbrock does not cover water quality, but according to the author (oral communication), he has a report in preparation that will do so. Presumably that report will model water quality.

All workers agree that a great many different types of ground water quality occur in Indian Wells Valley and vicinity. Whelan and Baskin describe 8 major types out of a total of 55 that occur in the area. These major types are as follows:

1) alpine waters, characteristically calcium-sodium-magnesium--bicarbonate. These are characteristic of the Sierra Nevada.

2) sodium--chloride waters, characteristic of China Lake, parts of southeastern Ridgecrest, and the Coso Geothermal

Area.

3) sodium--carbonate waters, principally occurring in the southwestern part of Indian Wells Valley.

4) sodium--bicarbonate waters, shown on his draft map as a very extensive horseshoe-shaped area with top along the Kern-Inyo county line, the western limb going through Inyokern and about 8 miles southwest, and the eastern limb to the vicinity of the main gate, NWC.

5) sodium--bicarbonate-chloride waters, east of the horseshoe, "representing mixing of easterly moving ground-waters with ground waters of China Laka Playa."

6) sulfate waters from geothermal areas, mineralized areas, and sewage pond seepage.

7) calcium -(sodium-magnesium)-- bicarbonate-chloride-(sulfate) waters, occurring in a long strip from Rose Valley through Little Lake and Indian Wells Valley to where Brown Road turns west. "These waters probably represent a mixture of Alpine and Coso Geothermal Waters."

8) "waters of the well fields. Usually sodium-calcium, but sometimes calcium-sodium-bicarbonate-chloride waters. These waters could represent Alpine Waters concentrated by evapotranspiration mixed with sodium chloride geothermal leakage."

Whelan and Baskin call attention to the effects of geothermal activity on ground water in Indian Wells Valley. They state that the resulting water can vary from very high quality to very poor quality. The best water is simply condensate from geothermal steam. Poor quality geothermal water can be high in chloride and in many cases a number of other constituents, including boron and arsenic.

Whelan and Baskin describe, and the W. Austin-Whelan (1987) maps show, that leakage from the Coso Geothermal Field moves southward into Indian Wells Valley. The maps also show

other evidences of geothermal activity. A "center of possible major thermal plume with geothermal fluid upwelling" is shown in sec. 23, T25S, R39E, between 7 and 8 miles NNE of Inyokern. A similar center is mapped about 4 miles farther to the NNW, just north of the Kern-Inyo county line. Six other centers of "important possible thermal plume[s]" are shown in various other locations in Indian Wells Valley and vicinity, exclusive of the Coso Geothermal Field. One of the centers is shown 2 miles west of the center of Ridgecrest.

We do not find in any of the reports at hand a description of the criteria used to locate the possible thermal plume centers. Our best estimate is that they are located at or near the centers of the circular areas shown by the W. Austin fault maps (1987). C. Austin (oral communication) also describes thermal plume centers, but gives somewhat different locations His criteria are evidently based mainly on ground water quality, such as the presence of arsenic.

Whelan and Baskin state that there is often variation in water quality with depth in a well, but that variation is not consistent. In some cases quality becomes poorer with increasing depth, and in other cases quality improves with depth.

Reports of USGS personnel and the Whelan-Baskin report agree that mixing of ground waters of different quality takes place as the ground water moves generally eastward in the valley. The greater salinity of waters in the east brings an increase in

total dissolved solids, and the chloride concentration increases as well. Base exchange takes place, and calcium and magnesium are exchanged as the water picks up sodium and potassium.

Water quality concerns in Indian Wells Valley at this time include the fact that poorer quality water underlying China Lake Playa and vicinity in the principal aquifer is now moving down the hydraulic gradient towards Ridgecrest and the well fields to the northwest. In addition, the infiltration of sewage has increased the head in the shallow aquifer, tending to move that water downward into the principal aquifer. At this time the lateral gradient in the shallow aquifer appears to be to the northeast.

HYDROLOGIC BALANCE

Some of the most serious differences of opinion on ground water in Indian Wells Valley have to do with supply of water to the valley, use and disposal of that water, and the amount of water available on a perennial basis. In this chapter, the various items of recharge to and discharge from the ground water body of Indian Wells Valley will be examined quantitatively. All available information on each item has been reviewed in preparing the chapter, although all possibe sources cannot be specifically mentioned in connection with each item. In order to prepare a specific hydrologic balance, the validity of each quantitative item will be evaluated, and a decision made as to the most accurate figure describing actual conditions. In addition, the degree of uncertainty in that figure will be indicated.

The hydrologic balance is prepared on the ground water body only. The only components of water on the surface included are the components that go to or come from ground water. As an example, precipitation on the valley floor is not considered an item of supply, as all investigators agree that rainfall within the valley itself is insufficient to reach the water table. Runoff from precipitation in the Sierra Nevada, on the contrary, is a major item of supply after it reaches the valley floor, as essentially all of it recharges ground water.

Conditions in 1985 have been utilized as the base

period. Pumpage for water use for that year for the various uses in the valley is given by Berenbrock (undated), and it has not been within the scope of this study to obtain all the equivalent information for subsequent years. Natural hydrologic quantities such as subsurface inflow, however, are utilized here as they occur in an average year, rather than during the base year only.

A complete listing of external items of supply to and outgo from the Indian Wells Valley ground water body appears in Fig. 1 of C. Austin (June, 1988). This listing will be used as a basis for the hydrologic balance of the present report. However, Austin's paper, with one exception, contains no quantitative data on the individual items of supply and outgo listed. We therefore must use information and data from other sources, modified by our evaluation of that information from our experience and observations in Indian Wells Valley, in obtaining quantitative figures for each item.

Austin does estimate "approximately 4000 acre feet per year" as recharge to Indian Wells and Rose Valleys by leakage from the Owens Valley aqueduct. This estimate is somewhat higher than the figure we will indicate, after obtaining information from the Los Angeles Department of Water and Power. Austin (p. 20) also estimates the total of "locally accessible recharge to average at least 30,000 acre feet per year." This figure will be compared later in this chapter with the sum of the individual

componnents of recharge estimated in the present investigation.

Supply

Recharge from Streams from the Sierra Nevada.-- This item is listed by Austin as "Sierran Runoff from inside topographic basin." The streams draining the Sierra Nevada into Indian Wells Valley are intermittent, but during the winter and spring seasons and during occasional flash floods, large amounts of water enter the valley and recharge the ground water basin. Early estimates of the amount of recharge were made by Lee (1913) and Thompson (1929). Lee, according to Thompson (p. 152), estimated the amount "of run-off from the mountains in Indian Wells Valley alone as about 27,000 acre-feet a year." This figure apparently includes all runoff from mountains surrounding Indian Wells Valley, including the Argus Range and El Paso Mountains. Thompson apparently accepted Lee's figure, but added to it runoff to the Coso Basin estimated at 12,000 acre-feet. However, it must be noted that Thompson (p. 152) states "These estimates are based on inadequate data . . ." (underlining added).

More recent estimates of runoff and recharge from the Sierra Nevada alone, as well as from the other ranges surrounding the valley, have been made by personnel of the USGS. The first direct estimates of runoff from the Sierra Nevada alone were made by Bloyd and Robson (1971). Their original estimates were based on the area of individual drainages lying above 4,500 feet. This was found to be necessary because "no stream-gaging stations

or precipitation gages are in the drainage area above the valley floor" (p. 12). The estimates of runoff from individual drainages were used as input to a mathematical model of the ground water body in the valley. Bloyd and Robson estimated the total recharge from Sierran streams at 6,235 acre-feet annually.

In verifying their model, these authors found that adjustments of the runoff assigned to individual drainages had to be made in order to make ground water levels as determined by the model be in agreement with levels in 1920-21, which were assumed to approximate a steady state condition. They also state that they evidently assigned too little of the total recharge to streams from the Sierra Nevada, and too much to the Argus and El Paso Ranges. However, they did not change their Sierran total, not including Rose Valley, of 6,235 acre-feet.

Austin (June, 1988) is very critical of Bloyd and Robson because the adjustments result in greatly varying amounts of runoff per area over 5,000 ft. for the different drainages.

Berenbrock's recent draft meets part of Austin's criticism, as it uses the unmodified runoff figures according to area of the individual canyons as input to a new mathematical model. Berenbrock states (p. 48) "This distribution was not modified during model calibration as done by Bloyd and Robson . . ." However, the total runoff from the Sierras was not changed (except reduction by one acre-foot), although Bloyd and Robson had stated that it was too low.

In our opinion, this figure of 6,235 acre-feet of recharge to Indian Wells Valley from the Sierra Nevadan streams is in all probability much more nearly correct than the earlier estimates of Lee and Thompson, which did not separate out the Sierran streams as such. We have examined data on precipitation and runoff in Bulletin 3, "The California Water Plan," of the California Department of Water Resources, and in a number of issues of Bulletin 120, "Water Conditions in California," also by CDWR, and these lend support to the reasonableness of a runoff figure in this range. We therefore propose a figure of 6,300 acre-feet as the amount of recharge from streams from the Sierra Nevada. However, until complete long-term stream gaging records are available for the runoff entering the valley, this figure must remain uncertain.

Coso Basin "Runoff".-- The runoff from streams entering Coso basin was not separated out by Lee (1913) from the total of 27,000 acre-feet he estimated entered Indian Wells Valley. However, Thompson (1929) estimated the annual runoff into Coso basin, which includes Coso Wash and Petroglyph and Renegade Canyons, to be 10,000 acre-feet. Both Bloyd and Robson (1971) and Berenbrock (undated) considered this early estimate much too high. Their estimates, although varying from each other, average about 2,130 acre-feet.

C. Austin (1988, p. 18-19) also states that he believes "that Thompson over estimated the recharge from Coso Basin . . ."

We agree with all concerned that the Thompson figure is too high, and suggest that a runoff and recharge figure of about 2,000 acre-feet for the Coso Basin area is much more realistic. However, because of the absence of stream gaging records, this figure is also uncertain.

Argus Mts. "Runoff".-- Runoff and recharge from the Argus Mountains was included by both Lee and Thompson in their total for Indian Wells Valley. The average figure by Bloyd-Robson and Berenbrock for these canyons, which include Mt. Springs, Wilson, Deadman, and Burro Canyons, is just over 1,000 acre-feet. We consider that this is a reasonable figure for annual recharge from these canyons in our present state of knowledge.

El Paso and Desert Ranges "Runoff".-- Again, runoff from these mountains was included by Lee and Thompson in the total for Indian Wells Valley. Both Bloyd-Robson and Berenbrock estimate the annual runoff here to be about 400 acre-feet. Although this figure, along with that for the Argus Mts., may be somewhat on the high side, we consider it a reasonable figure for recharge from the southern mountains. Clearly, the runoff estimates from all ranges surrounding Indian Wells Valley remain uncertain until and if long-term gaging station records become available.

LADWP Leakage.-- The aqueduct from Owens Valley to Los Angeles extends in conduit and tunnel along the lower slopes of the Sierra Nevada west of Indian Wells Valley. Leakage occurs from the aqueduct, and the amount entering the ground water body

of the valley is an item of supply.

A computer print-out of losses from the aqueduct in the reach between Haiwee Reservoir and Fairmont Reservoir, along with a map of the route, as been kindly furnished by Mel Blevins of the Los Angeles Department of Water and Power. Average annual loss from line #1 is calculated since 1934, and for line #2 since 1969. The average annual loss for the combined lines is 5,405 acre-feet. Approximately one-fourth of the length of this reach is west of Indian Wells Vàlley, which would indicate a possible loss of about 1,350 acre-feet above the valley.

Howwever, Blevins states (personal communication) that most of the loss occurs where the aqueduct crosses sand and similar sediments. Seepage from the aqueduct in those reaches causes hydrocompaction of the sediments, resulting in cracking of the concreté and most of the leakage. Since the aqueduct west of Indian Wells Valley is in granitic rocks rather than sediments, we believe that the 1,350 acre-foot figure should be reduced to at least 1,000 acre-feet. Furthermore, some of the leakage will be lost to evapotranspiration before it ever reaches the valley. We suggest that a figure of 900 acre-feet per year is an ample approximation of the amount of recharge to Indian Wells Valley from aqueduct leakage.

Geothermal Leakage.-- Leakage of geothermal fluids from underneath Indian Wells Valley directly into the ground water body is reported by C. Austin, Whelan, and others, but no

quantitative estimates are available. C. Austin was asked directly for a quantitative estimate, but declined to give one. It is certainly true that any estimate must be quite uncertain. We believe that geothermal leakage directly into the ground water is no greater than 100 acre-feet annually.

Sierran Recharge from Outside the Topographic Basin.-- Significant groundwater flows from sources west of the crest of the Sierras into Indian Wells Valley have long been proposed by proponents of the concept of a regional flow system. Flow from the South Fork of the Kern River has been suggested, and as noted above, the Austin-Whelan maps show a prominent fracture system extending southeasterly into Indian Wells Valley. Analogy to the source for geothermal waters for the Coso area is pointed out (C. Austin and Moore, 1987), as at least some of these waters are believed to move from the Sierra Nevada beneath Rose Valley into the Coso Geothermal Field (see also Spane, 1978).

The rocks of the Sierra Nevada are certainly fractured, in common with all granitic rocks, and such fractures can store and transmit ground water. To date, however, no significant supply to ground water in Indian Wells Valley from a source or sources west of the Sierran crest has been demonstrated.

To estimate the contribution to ground water in the valley from rocks of the Sierra Nevada, we suggest a modification of a calculation based on subsurface inflow to San Gabriel Valley in

southern California from the San Gabriel Mountains to the north. This calculation was made by the California Department of Water Resources (1966), and has been used as an item of inflow to the San Gabriel Valley in hydrologic balances for quite a number of years. The geologic conditions are similar -- in fact, the San Gabriel Mountains are a thrust block, similar to the Sierra Nevada as modeled by the Austins and their co-workers. Rocks of the San Gabriels are mostly granitic and metamorphic, but the fracturing of the San Gabriels is generally considered to be greater than that of the Sierrra Nevada.

CDWR estimated the subsurface inflow from the San Gabriel Mountains into San Gabriel Valley along approximiately a 16-mile front at 5,000 acre-feet per year. This is 312.5 ac-ft per mile. If all other conditions were the same, inflow over a 30-mile front into Indian Wells Valley would then be 9,375 acre-feet.

However, precipitation in the Sierra Nevada above Indian Wells Valley is less than one-third that of the frontal portion of the San Gabriels. Furthermore, we have done hydrogeologic work in both the San Gabriel Mountains and the Sierra Nevada, and the former are definitely more highly fractured than the latter. We suggest, therefore, that a more realistic figure for annual groundwater movement from the granitic rocks of the Sierra to Indian Wells Valley, although still uncertain, would be about 2,500 acre-feet.

If it could be demonstrated that larger amounts of ground

water are moving from the Sierra Nevada into Indian Wells Valley, all of us interested in a satisfactory water supply for the future of the valley would be greatly pleased. In the Recommendations section, we will make a suggestion with regard to proving, if it exists, the presence of a more ample supply.

Surface and Subsurface Recharge from Rose Valley.-- C. Austin (June, 1988) and Rockwell International (1980) describe inflow to and outflow from the Rose Valley basin. A complete analysis of that basin is beyond the scope of this report. However, Austin believes that much more water must move from Rose Valley into Indian Wells Valley than previous investigators have shown. On the other hand, as indicated by Spane (1978), perhaps a very large amount of water moves from Rose Valley into the Coso Geothermal Field instead.

Surface flow from Rose Valley into Indian Wells Valley below Little Lake is apparently very rare. Only one reference with quantitative data was found, Rockwell International, 1980. Quoting from a USGS Open-file report, they give figures for runoff into Little Lake for four years in the 1960's. If the figures given for discharge are considered to have lasted for a full day in each case, and the flow continued past Little Lake through the gap into Indian Wells Valley, neither of which was probably true, the average flow would have been 1.5 acre-feet per year. Thus we can consider surface inflow from Rose Valley to be negligible.

Subsurface inflow through Little Lake gap to Indian Wells Valley was estimated by Bloyd and Robson at 43 acre-feet/yr, and by Berenbrock at 46 acre-feet/yr. A careful calculation was made by Rockwell (p. 2-113 ff) using a range in transmissivity as shown by Dutcher and Moyle, the existing hydraulic gradient as shown by water levels in wells, and a constraining width in the gap of about 1500 feet.

We utilized this information using an average of the Dutcher-Moyle transmissivities of 18,000 gal/day/ft and obtained a flow through the gap of about 400 acre-feet per year. We consider this a reasonable figure for subsurface inflow from Rose Valley to Indian Wells Valley.

Recharge from Human Activity.-- In addition to the items of inflow shown on C. Austin's Figure 1 and estimated above, activities of man also add input to ground water. Recharge from wastewater treatment plants in 1985 is shown by Berenbrock (Table 2) as follows:

Ridgecrest Regional Wastewater Treatment Facility	969 ac-ft
Inyokern Community Services District plant	32 ac-ft

In addition to the above figures by Berenbrock, recharge to the ground water body occurs by percolation from septic tanks or cesspools at residences not connected to the two sewage systems, and perhaps a small amount as well from domestic landscape

watering. Furthermore, some leakage of fresh water occurs from the lines of the Indian Wells Valley Water District. After discussion of these conditions with both the Water District and the Ridgecrest City Engineer's office, we would suggest about 500 acre-feet as the annual return to ground water from these sources, making the total recharge to ground water from human activity about 1,500 acre-feet in 1985.

Total Recharge.-- The total estimated recharge to ground water in Indian Wells Valley in 1985 is the sum of the items of external and internal supply, and is summarized as follows:

Recharge from Sierran streams	6,300 ac-ft
Coso Basin runoff	2,000 " "
Argus Mts. runoff	1,000 " "
El Paso Range runoff	400 " "
LADWP leakage	900 " "
Geothermal leakage	100 " "
Recharge from Sierran granitics	2,500 " "
Recharge from Rose Valley	400 " "
Recharge from human activity	1,500 " "
Total	15,100 ac-ft

It must be noted that the recharge total above is about half of the amount of recharge estimated by Carl Austin in his memorandum of June, 1988. There is no assignment of values to

the various items of recharge in the Austin memorandum (with one exception), and no summation to reach his estimated total of "at least 30,000 acre feet per year."

Discharge of Ground Water

Items of outgo or discharge from ground water in Indian Wells Valley are estimated here, like the items of recharge, according to the outline shown by C. Austin (June, 1988) Fig. 1.

Consumptive Uses.-- The principal consumptive use by man is by pumpage. Net agricultural pumpage (gross pumpage minus return) is given by Berenbrock in Table 1. Those values are modified according to information received from Larry Neal (oral communication), and the resulting figures are as follows:

Crop	Acreage		Pumpage (ac-ft)
alfalfa	1,686		8,430
grain	250		625
fruit	50		105
pistacios	23		40
		Total	9,200

Non-agricultural pumpage in 1985 can be obtained from Figure 6 of Berenbrock, entitled "Ground-Water Net Pumpage, in Acre-Feet," as follows:

		Pumpage (ac-ft)
Municipal and domestic supplies		7,500
Industrial		2,900
Military		4,200
Adding net agricultural pumpage		9,200
Gives	Total pumpage	23,800 ac-ft

St.-Amand (1986, Table 6) shows a much larger pumpage of 29,500 acre-feet for 1984 than Berenbrock gives for 1985. A good share of the difference is evidently because St.-Amand gives gross pumpage, whereas Berenbrock's is net: in other words, gross pumpage less return to ground water. St.-Amand states that his value was based on estimates by Decker and Lee.

Rather than try to reduce St.-Amand's gross pumpage by estimating return water, we believe it is desirable to accept a figure of 23,800 acre-feet as the approximate total pumpage for 1985. Pumpage figures are generally more certain than estimates of unmeasured hydrologic quantities.

Evaporation on Playa.-- All authorities agree that the principal natural discharge of ground water from Indian Wells Valley was orignally by evaporation and transpiration at and in the vicinity of the playas, principally China Lake playa. The amount of discharge, however, has been a matter of considerable disagreement. Lee (1913) estimated evapotranspiration as 31,600 acre-feet annually.

A great deal of research has been done on evapotranspiration since Lee's work, particularly by Young, Blaney, and Criddle (example -- Blaney and Criddle, 1949). On the basis of this work, and the decline in the water table due to pumping, Kunkel and Chase estimated the evapotranspiration in 1953 to be about 8,000 acre-feet. The research done by these workers as reported in their report and by Dutcher and Moyle is impressive. Since

1953 there has been a decline in head in the main ground water body, but discharge of wastewater has increased the amount of shallow water. Evapotranspiration in 1985 is estimated by Berenbrock (Table 9) at 6,600 acre-feet. He does not explain the reason for his reduction of the Kunkel-Chase figure 8,000 ac-ft, but perhaps considers that the over-all fall in ground water levels is responsible. We suggest that an intermediate figure of 7,000 acre-feet is a reasonable estimate of evapotranspiration from ground water in Indian Wells Valley in 1985. This figure, partly based on research on evapotranspiration, should be reasonably accurate.

Exports.-- Ground water that is exported from the valley is included in the total net pumpage in a preceding section.

Overflow to Salt Wells.-- This is listed as an item of discharge on C. Austin's Fig. 1. However, examination of topographic conditions indicate that, although there might be a small amount of surface outflow at times of heavy precipitation, it is very doubtful if there would be any movement of ground water to the surface and out by this route.

None of the previous workers have considered this to be an item of discharge, and we agree that if any occurs, it is insignificant.

Subsurface Leakage to Searles Valley.-- The matter of ground water movement through mountain ranges is a fascinating one, and one that must be dealt with in consideration of a regional flow pattern. Regional ground water flow in Nevada is described by Mifflin (1968), "Delineation of GrounWater Flow Systems in Nevada," but no such report is in existence for California. A principal reason for this is the existence of numerous thick limestone sequences in some ranges in Nevada. Solution channels in limestone form excellent conduits for inter-basin movement of ground water. Most ranges in California do not contain known thick limestone sections.

Nevertheless, our work in the California desert areas for the Department of Water Resources (CDWR 1954 and 1964) has demonstrated that inter-basin movement through mountain ranges does occur in California. One key as to whether or not such movement is taking place is the nature of the playa bed in a basin. An irregular, fluffy bed showing evidence of much evaporation occurs in basins where little or no ground water leaks out of the basin. China Lake has a bed of this kind. A playa bed that is hard and smooth is well above the water table, and movement from that basin does occur.

The playa now called Airport Lake in Coso Basin is reported by Thompson to have a bed of the latter kind. Furthermore, he states (p. 150) "the water table lies at a considerable depth below the surface." This is confirmed by St.-Amand (1986).

Thus ground water movement quite certainly occurs from Coso Basin. Whether this movement takes place into Indian Wells Valley proper, or by leakage through the Argus Range into Searles Valley, or partly in each direction, cannot be stated with any degree of certainty at this time.

Dutcher and Moyle do not consider ground water movement through the Argus Range, but state that movement does take place down Salt Wells Valley. They estimate discharge by underflow out of Indian Wells Valley as "less than 50 acre-feet per year." (p. 25).

Our estimate of subsurface leakage to Searles Valley would have to be little more than a guess at this stage. Including the 50 acre-feet of Dutcher and Moyle, we would suggest that this subsurface leakage might amount to 200 acre-feet annually.

Subsurface Leakage to Koehn Lake and Cantil.-- In our description of El Paso Mountains, we noted that some limestone and some volcanics are known to be present in the range. However, the known limestone is at some distance from Indian Wells Valley and dips toward that valley. Furthermore, the known volcanics are mostly at a higher elevation than would be available for ground water movement.

We doubt if there is any significant leakage through El Paso Mountains from Indian Wells Valley.

Total Discharge.-- The discharge from ground water in Indian Wells Valley is thus estimated as follows:

Consumptive use	23,800 ac-ft
Evapotranspiration	7,000 " "
Leakage to Searles Valley	200 " "
	31,000 ac-ft

Results

The basic hydrologic balance is:

recharge - discharge = change in storage

Substituting the estimates for ground water of Indian Wells Valley in 1985:

15,100 ac-ft - 31,000 ac-ft = -15,900 ac-ft

Thus approximately 15,900 acre-feet of ground water was taken out of storage in 1985, and will be taken out each year if conditions of recharge and discharge remain the same. This figure is the estimated overdraft on the basin.

Interpretation

There is no question that the Indian Wells Valley ground water basin is in serious overdraft, whether the figure of nearly 16,000 acre-feet estimated here is accepted, or St.-Amand's even more serious figure of 26,500 acre-feet (Table 6). However, many ground water basins in California are in overdraft, including the San Joaquin Valley and some of the basins in southern California.

The overdraft in these basis is recognized, and management techniques are employed to mitigate the problem in various ways. Recommendation of management techniques is beyond the scope of this paper. However, it is essential that problems be faced and dealt with. Some of the problems facing Indian Wells Valley are the following:

1. Continuation of the present pumping pattern, which has resulted in a regional cone of depression northwest of Ridgecrest, will cause poorer quality water from the east to move toward and eventually impact the pumping wells.

2. Similar conditions can be expected to develop elsewhere in the valley. Because areas of poor ground water quality are not pumped, the water in such areas moves down the hydraulic gradient into nearby areas of good water that are being pumped.

3. Pumping lifts will increase as water levels drop, with consequent increases in power costs.

4. The ground water in storage in the valley will be slowly mined. We believe that Dutcher and Moyle's estimate of 2,200,000 acre-feet available within 200 feet of the 1921 water table is a little high, but even an amount nearly that large is slowly depleted by a continued annual overdraft.

5. The depletion of ground water in storage since 1921, where water levels are available for that year, is shown graphically in Plate 1. The drop in levels in the principal aquifer over most of the basin is less than 20 feet. However,

water levels have fallen more than 50 feet in an extensive area in the present regional cone of depression northwest of Ridgecrest, and the average static water levels of wells 26S/40E-30K1, -30K2, and -30K3 indicate a drop of over 85 feet by 1985 from the levels at that location in 1921.

6. Water level measurements since 1985 indicate that levels are continuing to drop on the average at about the same rate.

CONCLUSIONS

1. There is general agreement on most aspects of the hydrogeologic framework of Indian Wells Valley among people concerned with ground water in the valley.

2. The nature of the mountains surrounding the valley, and whether or not there is significant ground water flow into and/or out of the valley through or beneath the mountains, is a matter of definite disagreement.

3. A major item of disagreement is the nature of the Sierra Nevada fault zone bordering Indian Wells Valley. However, whether or not this is a thrust fault has bearing on the ground water problem only with regard to whether or not significant volumes of ground water enter Indian Wells Valley from the Sierras through the fault zone and/or associated structures.

4. Recent hydrologic balances on the ground water body of the valley all indicate a condition of overdraft. The estimate of this report is that the annual overdraft under 1985 conditions was about 15,900 acre-feet.

5. The above estimate is not an exact figure, because of considerable uncertainty with regard to many of its components. However, continually falling ground water levels indicate that significant overdraft is occurring.

6. Continued overdraft with falling water levels has caused reduction of the amount of ground water in storage. Plate 1 shows that the drop in levels from 1921 to 1985 has been more

than 2Ø feet over much of the valley, and has reached a maximum of between 8Ø and 9Ø feet in a regional cone of depression northwest of Ridgecrest.

7. An appropriate redistribution of the pumping pattern could partially relieve the continuing fall of water levels where it is most severe.

8. Eight major ground water quality types occur in Indian Wells Valley. Wells in a number of areas yield water of good quality for domestic and/or irrigation use.

9. Unfortunately, the ground water gradient presently indicates that higher salinity water on the east is moving toward the regional pumping depression northwest of Ridgecrest.

1Ø. It seems quite clear that those who challenge the experienced evluations that Indian Wells Valley is in overdraft, should demonstrate additional ground water supply.

11. Neither evidence of large amounts of faulting, nor indirect geophysical evidence from gravity, magnetic, and seismic surveys, are evidence of additional useable ground water supply.

12. Test holes that can be converted to water wells are the only satisfactory method of finding and developing ground water.

13. If ground water is entering Indian Wells Valley from the Sierra Nevada in sufficient amount to alleviate the present evident overdraft, its occurrence at depth would be sufficiently widespread that it could be readily tapped by wells.

14. Fortunately, Ward Austin, a proponent of the theory that

large flows of ground water enter Indian Wells Valley at depth, has proposed (1987, p. 3) "6 potential deep well locations . . . of which the first two, adjacent to the Sierra Nevada front, will probably be excellent producing water wells." He suggests that these wells should be "4000 to 5000 ft. or deeper". His proposed locations for these wells appear on Plate 1 of the present report.

15. It is certainly hoped that ground water of good quality, under sufficient head to be within an ecomomic pumping limit, and in an aquifer of sufficient transmissivity to furnish an adequate supply, would be found by such test wells. If such water is not found, it would be quite evident that there are no large volumes of water entering Indian Wells Valley from the Sierra Nevada at depth.

RECOMMENDATIONS

The following recommendations are proposed as the most desirable steps to be taken to solve the ground water problems of Indian Wells Valley. Economics of the proposals is not addressed, nor is there any statement as to which agency or agencies should undertake the various proposals.

1. One or more deep test holes that can be converted to water wells if an aquifer is encountered should be drilled. Six possible locations, all located according to descriptions by Ward Austin (1987), are shown on Plate 1. The two locations nearest to the Sierras are recommended by Austin as probably "excellent producing water wells" (see Conclusion 14).

2. Carl Austin (June, 1988, p. 18), without recommending specific locations, describes "great potential aquifers." He then suggests "Let us try to identify them, and if they are there exploit them."

3. We concur that test holes near the Sierras are the best method of finding whether or not "great potential aquifers" fed by ground water from the mountains exist. Locations 1 and 2 suggested by Ward Austin should be entirely satisfactory to test this theory.

4. Specifications for drilling these test holes should provide for a total depth of 4,000 to as much as 6,000 feet (see W. Austin, p. 9, and Fig. 1, this report, after OBrien). If drilled by the straight rotary method, an electric log should be

run after reaching total depth. The log should include a "long normal" curve, thus readily evaluating water quality throughout the hole(s).

5. A local hydrogeologist should direct the drilling, log the lithology of the hole(s), and indicate when total optimum depth has been reached. Recommendations of W. Austin and C. Austin should be given major consideration with regard to the hole depth, as well as the original location of the hole(s).

6. Specifications should provide for conversion of test hole(s) to water well(s). Perforation of the casing should be done on recommendation of the geologist after study of the litho log and electric log. The water well should then be developed, presumably by test pumping.

7. Specifications should provide for access for measurement of depth to water when desired.

8. A pumping or aquifer test should be run on the test well(s), with the hydrogeologist in charge of each test and its interpretation. The tests need only be of limited length. Since no observation well would probably be available in the same aquifer, transmissivity obtained by the pumping test should be checked by a recovery test, using measurements after shutoff.

9. Test wells may be drilled and completed at locations other than near the Sierra Nevada, but such would be at a lower priority. A test south of Rose Valley is possible. Ground water entering Indian Wells Valley from the Coso Geothermal Field would

very possibly be of poor quality, so a test in that area is of doubtful utility.

10. The location of wells to detect possible ground water movment out of Indian Wells Valley through either the Argus or El Paso Ranges would be so uncertain as to make such holes quite impractical.

11. An organization is needed to evaluate and implement water management techniques for Indian Wells Valley.

12. Before undertaking this study, we challenged those concerned with the ground water of the valley to evaluate the resulting report on the basis of the facts, conclusions, and recommendations presented, even though each and all persons would probably have to give up some preconceived ideas. We trust the people of Indian Wells Valley will accept and act on that challenge.

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