UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

ADDENDUM TO:

SOURCES OF POWERPLANT COOLING WATER IN THE DESERT AREA OF SOUTHERN CALIFORNIA--RECONNAISSANCE STUDY

By J. H. Koehler and M. J. Mallory

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CALIFORNIA DEPARTMENT OF WATER RESOURCES

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

The inch-pound system of units is used in this report. For readers who prefer metric units, the conversion factors for the terms used are listed below:

Multiply	By	To obtain
acres	0.4047	hm^2 (square hectometers)
acre-ft (acre-feet)	0.001233	hm^3 (cubic hectometers)
acre-ft/yr (acre-feet per year)	0.001233	hm^3/yr (cubic hectometers per year)
ft (feet)	0.3048	m (meters)
ft/mi (feet per mile)	0.1894	m/k (meters per kilometer)
ft^2/d (feet squared per day)	0.0929	m^2/d (meters squared per day)
gal/min (gallons per minute)	0.06309	L/s (liters per second)
(gal/min)/ft (gallons per minute per foot)	0.2070	(L/s)/m (liters per second per meter)
inches	25.4	mm (millimeters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)

Degrees Fahrenheit (°F) is converted to degrees Celsius (°C) by using the formula: °C = (°F-32)/1.8.

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ABSTRACT

A hydrologic reconnaissance study was made in five basins previously classified as suitable for providing sufficient ground water for cooling a 1,000-megawatt electric-power generating plant. The criteria used to evaluate the basins were (1) theoretical aquifer response to pumping, (2) alternative sources of water, and (3) chemical quality of water. The basins were ranked relative to each other for the three criteria and in overall suitability.

On the basis of subjective analysis, the basins were ranked in the following order for overall suitability: (1) Calzona-Vidal Valley, (2) Middle Amargosa Valley, (3) Chuckwalla Valley, (4) Soda Lake Valley, and (5) Caves Canyon Valley.

INTRODUCTION

This report is an addendum to the report "Sources of Powerplant Cooling Water in the Desert Area of Southern California--Reconnaissance Study" (Koehler and Ballog, 1979). The original study, hereinafter referred to as Phase I, was undertaken to determine which of the ground-water basins in the southern California desert area were best suited for providing cooling water for a 1,000-megawatt electric-power generating plant (fig. 1).

Phase I evaluated 142 desert basins, using the following assumed requirements: (1) Storage--a minimum of 1 million acre-ft of recoverable ground water in storage, (2) well yield--a minimum well yield of 500 gal/min, (3) water quality--ground water that is chemically suitable for cooling but unsuitable for most other uses, and (4) basin development--minimum development to avoid conflict with other users.

According to these criteria, each basin was classified in one of the following categories:

1. Suitable (appear to meet all the criteria)--Basins include Middle Amargosa Valley (6-20), Soda Lake Valley (6-33), Caves Canyon Valley (6-38), Chuckwalla Valley (7-5), and Calzona-Vidal Valley (7-41, 7-42). Evaluation of these basins is the subject of this report. (The numbers in parentheses following the basin names are basin numbers assigned by the California Department of Water Resources.)

2. Suitable with qualifications (appear to meet all the established criteria but in some respects available data are inconclusive)--Basins include Coyote Lake Valley (6-37), Harper Valley (6-47), Panamint Valley (6-58), Rice Valley (7-4), Dale Valley (7-9), and Palo Verde Mesa (7-39).

3. Insufficient data (cannot be classified because of insufficient data but are potentially suitable)--Basins include Eureka Valley (6-16), Saline Valley (6-17), Lower Kingston Valley (6-21), Upper Kingston Valley (6-22), Riggs Valley (6-23), Kelso Valley (6-31), Broadwell Valley (6-32), Ward Valley (7-3), West Salton Sea (7-22), Amos Valley (7-34), Ogilby Valley (7-35), Arroyo Seco Valley (7-37), and Chemehuevi Valley (7-43).

4. Unsuitable (did not meet established criteria)--All the remaining basins of those evaluated in Phase I are included in this category.

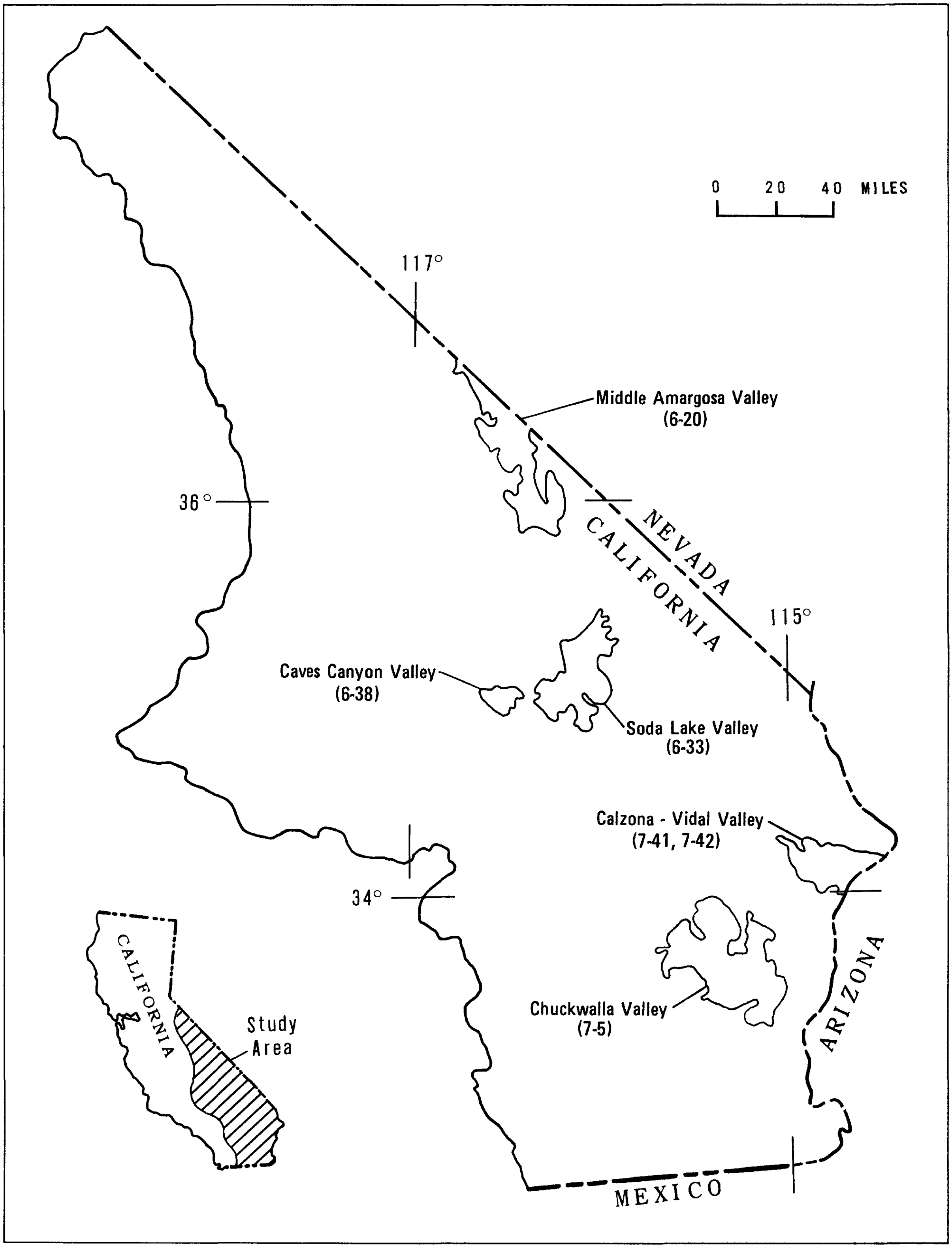


FIGURE 1. – Study area, showing basins classified as suitable for powerplant siting. (Numbers in parentheses are basin numbers assigned by the California Department of Water Resources.)

Purpose and Scope

This study, hereinafter referred to as Phase II, is a more in-depth study of the basins previously classified as suitable. As requested by the California Department of Water Resources, the five basins are examined in more detail so they can be ranked for hydrologic suitability. The criteria used in Phase I are modified and expanded in this study. The work elements, as suggested in Phase I, were slightly modified to fit the time frame and funding allotted for Phase II. Fieldwork consisted of collecting water samples and measuring water levels where necessary. Transmissivity and storage coefficients were estimated to allow prediction of aquifer response to large-scale pumping.

The criteria used in ranking the basins in Phase II are: (1) Theoretical aquifer response to pumping, (2) alternative sources of water, and (3) chemical quality of water.

The relative suitability of the basins for providing cooling water was determined from existing data. As more data, such as from drilling of test holes, become available the basins should be reevaluated.

This study deals only with the occurrence and suitability of ground water for powerplant cooling and should not be considered a feasibility study; that is, no consideration was given to the economic, environmental, or legal aspects of withdrawing water. Before a powerplant could be established, the basins would need to be evaluated also for waste disposal, seismic conditions, and land subsidence.

General Description of Basins

Climate in the five basins studied is typical of southern California desert basins. Annual precipitation ranges from 4 to 6 inches with a range in mean daily minimum and maximum temperatures of 32°F to 64°F in January and 72°F to 108°F in July (National Oceanic and Atmospheric Administration, 1974). High temperatures and frequent strong winds cause a high rate of evapotranspiration.

The basins range in size from 100 to 870 mi^2. Surrounding mountains are generally composed of consolidated rocks that, except where fractured, yield little or no water to wells. The basins are composed of unconsolidated alluvial sediments, which consist of boulders, gravel, sand, silt, and clay. The coarser sediments are generally predominant in alluvial fans near the mountains and grade to finer sediments in the central part of the basin. The sediments, where saturated, yield moderate to large quantities of water to wells.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public land. The part of the number preceding the slash, as in 7S/21E-14A1, indicates the township (T. 7 S.); the part following the slash indicates the range (R. 21 E.); the number following the hyphen indicates the section (sec. 14); the letter following the section number indicates the 40-acre subdivision according to the lettered diagram below. The final digit is a serial number for wells in each 40-acre subdivision. A Z before the final digit indicates that the well is plotted from an unverified location description. The absence of the last letter and serial number indicates that the well has not been assigned an official well number.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

CRITERIA USED TO EVALUATE BASINS

Theoretical Aquifer Response to Pumping

Two analytical methods were developed to estimate theoretical aquifer response to pumping. Estimates were based on extraction of 30,000 acre-ft of water annually for a period of 30 years. Values used for transmissivity and storage coefficient were estimated from pumping tests, drillers' logs, or published data.

For the purpose of calculating the effects of pumping, several assumptions were made. It was assumed that only one homogeneous water-table aquifer existed in a relatively symmetrical basin. In fact, the accuracy of the calculated aquifer response to pumping would be affected by vertical and areal variations in aquifer properties, basin geometry, existing distribution of recharge and discharge, and probable nonuniform distribution of pumping. The objective of the present investigation, however, is to evaluate the relative magnitude of aquifer response. The generalized assumptions and analytical models chosen are satisfactory for this purpose.

Calculations were made for two cases: (1) An idealized closed, circular basin with a circular well field in the center, and (2) an idealized infinite strip aquifer with a line of wells along its center. Results of these calculations are given in table 1. The calculations were made on a programmable pocket calculator. The methods for these calculations were developed as follows.

TABLE 1. - Theoretical aquifer response to pumping

[Based on pumpage of 30,000 acre-ft per year over a 30-year period, well spacing 1 mi, except as footnoted]

Basin	Middle Amargosa Valley (6-20)	Calzona-Vidal Valley (7-41,7-42)	Chuckwalla Valley (7-5)	Soda Lake Valley (6-33)	Caves Canyon Valley (6-38)
Transmissivity (ft^2/d)	6,800	31,000	13,000	3,500	4,000
Storage coefficient	0.12	0.20	0.10	0.10	0.15
Assumed saturated thickness (ft)	400	250	300	400	250 (140-350)
Idealized basin radius for closed circular basin model (mi)	14.1	9.9	16.6	13.7	[1]5.6
Idealized basin width for infinite strip aquifer model (mi)	10	7	11	[2]12	[3]5
Closed circular basin model drawdown at center after 30 years of pumping (ft)	127	42	82	211	217
Closed circular basin model drawdown at center after 30 years of pumping, corrected by Jacob method (ft)	158	46	98	([4])	([4])
Closed circular basin model drawdown at basin boundary after 30 years of pumping (ft)	3.00	16.36	5.82	1.23	53.7
Decrease in saturated thickness from closed circular basin model, at center, corrected drawdown (percent)	32	18	33	100	100
Infinite strip aquifer model drawdown at center after 30 years of pumping (ft)	58	51	48	113	211
Infinite strip aquifer model drawdown at center corrected by Jacob method (ft)	64	58	53	137	([4])
Decrease in saturated thickness from infinite strip model corrected drawdown (percent)	16	23	18	34	100

[1]Well spacing, 3,700 ft.
[2]Well spacing, 3,600 ft.
[3]Well spacing, 1,900 ft.
[4]Drawdown below base of aquifer.

Consider a closed circular basin (for convenience), 314 mi^2 in area, with a regular hexagonal array of 37 wells (fig. 2) spaced 1 mi apart located at its center, and each well pumping 500 gal/min for a period of 30 years.

The drawdown effects of the other 36 wells on the center well will be, by the principle of superposition:

$$s_{\text{interference}} = 6s\big|_{r=d} + 6s\big|_{r=2d} + 6s\big|_{r=3d} + 6s\big|_{r=\sqrt{3}d} + 12s\big|_{r=\sqrt{7}d}$$

where

s = drawdown,
r = the radius used in the Theis solution for each term, and
d = the distance between adjacent wells.

If we let d = 1 mi (5,280 ft) for our example and assume a storage coefficient, S = 0.12, and a transmissivity, T = 10,000 (ft^2/d), we can calculate, as follows, the individual components of drawdown using the Theis non-equilibrium equation at the end of the 30-year period:

$$s_{\text{interference}} = 6(3.29) + 6(2.25) + 6(1.66) + 6(2.46) + 12(1.84)$$

$$s_{\text{interference}} = 80.04 \text{ ft.}$$

If we assume a specific capacity of the center well of about 30 (gal/min)/ft, its drawdown from its own pumping will be about 17 ft:

$$s_{\text{well}} = 17.00 \text{ ft.}$$

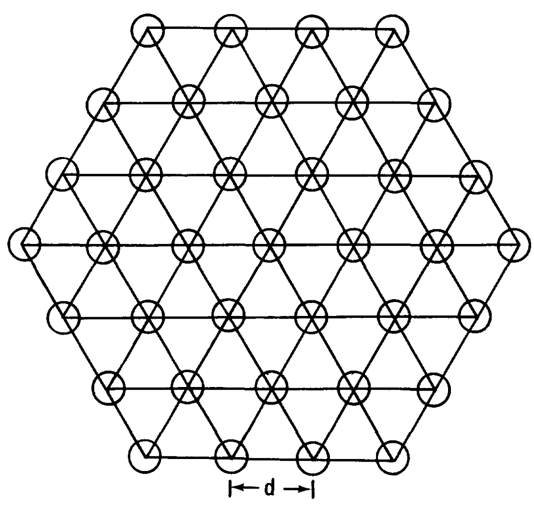


FIGURE 2. – Well field consisting of 37 wells in a regular hexagonal array of spacing d.

Consider now boundary effects. If we approximate the circular basin by a hexagon inscribing it, image theory and symmetry considerations can be invoked to give the effect of the impermeable basin boundary. The strict application of image theory for this geometry results in an infinite hexagonal net of images. For this analysis only the first three rings of the net are considered (fig. 3). By examining the unbalanced gradient at the basin boundary, the effect of this simplification can be quantified. Disregarding rings beyond the third ring results, for our sample problem, in a gradient at the boundary of 5.13×10^{-5} ft/mi. Applying Darcy's law, Q = TIL, around the perimeter of the basin (where Q is discharge, T is transmissivity, I is gradient, and L is the length of the cross section through which flow is taking place), we find that these gradients result in an inflow to the basin of 240 gal/min, or 387 acre-ft/yr. Because this small an amount of recharge is not improbable for even the most arid desert basin of this size, this representation is considered reasonable. At sufficient distance from the boundary, the images of the hexagonal well fields can be treated as point withdrawals equal to the combined pumpages of all 37 wells in the field, namely 18,500 gal/min. The drawdown at the center well, because of the effects of the impermeable boundaries, will be by the principle of superposition:

$$s\big|_{\text{center due to boundary}} = 6s\big|_{r=2R} + 6s\big|_{r=2\sqrt{3}R} + 6s\big|_{r=4R}$$

where R is the radius of the basin.

If we let R = 10 mi or 52,800 ft:

$$\begin{aligned} s\big|_{\text{center due to boundary}} &= 6s\big|_{r=20\text{ mi}} + 6s\big|_{r=34.6\text{ mi}} + 6s\big|_{r=40\text{ mi}} \\ &= 6(0.35) + 6(0.00029) + 6(1.2 \times 10^{-6}) \\ &= 2.08 + 0.0018 + 7.3 \times 10^{-6} \\ &= 2.08 \text{ (to the nearest hundredth).} \end{aligned}$$

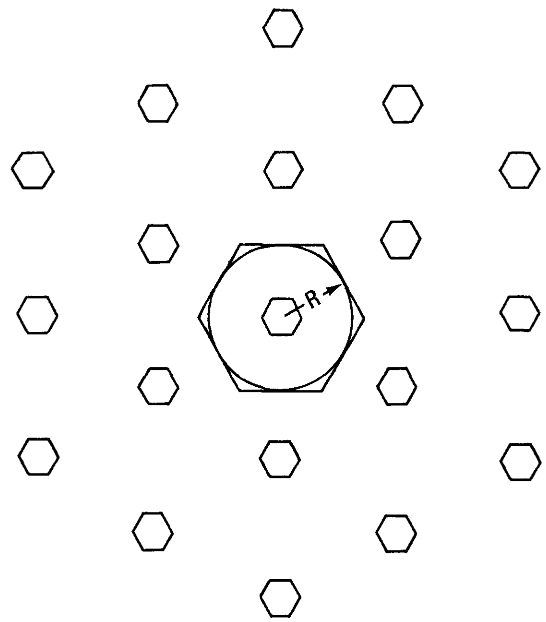


FIGURE 3. – A basin of radius R as approximated by a hexagon showing locations of real and image well fields.

We can now tally the total drawdown at the center of the well field:

$$s_{total} = s_{well} + s_{interference} + s_{boundary\ effect}$$
$$= 17.00 + 80.04 + 2.08$$
$$s_{total} = 99.12,$$ or approximately 100 ft drawdown at the center of the well field.

The drawdown at the basin boundary can be computed by superposition, treating both the real and the image pumping centers as point sinks. Examining the geometry of our idealized representation of the basin, it can be shown that the drawdown at any point on the basin boundary will be:

$$s|_{boundary} = 2s|_{r=R} + 2s|_{r=\sqrt{3}R} + 4s|_{r=\sqrt{7}R} + 2s|_{r=3R} + 4s|_{r=\sqrt{13}R} + 2s|_{r=\sqrt{19}R} + 2s|_{r=\sqrt{21}R} + s|_{r=5R}.$$

Letting R = 10 mi, we have:

$$s|_{boundary} = 2(9.41) + 2(0.94) + 4(0.02) + 2(0.0004) + 4(0.0001) + 2(0.0^{*}) + 2(0.0^{*}) + (0.0^{*})$$
$$= 20.75 \text{ ft (to the nearest hundredth).}$$

(Calculating the quantities marked with asterisks results in values of the u parameter for the Theis equation that are too large, and corresponding values of w(u), the well function of u, that are too small, to be accurately computed with available tables or computer programs. They are, however, less than 1×10^{-6} ft and therefore considered to be zero.)

Thus, if a well field, constructed as described here, were located at the center of this idealized basin, drawdowns in the vicinity of the well field could be expected to be on the order of 100 ft after 30 years. At the edges of the basin, drawdowns of about 21 ft could be expected. Throughout the rest of the basin, drawdowns would range between these values.

Secondly, consider an infinite strip aquifer, bounded on both sides by impermeable barriers, with a line of 37 wells spaced 1 mi apart and each pumping 500 gal/min along its axis (fig. 4).

The total drawdown, s_{total}, at the center well will consist of the drawdown resulting from its own pumping, s_{well}, plus the drawdown from interference effects from the other 36 wells, $s_{interference}$, plus an additional drawdown owing to boundary effects, $s_{boundary\ effects}$,

$$s_{total} = s_{well} + s_{interference} + s_{boundary\ effects}.$$

The drawdown at the center well resulting from its own pumping will be 500 gal/min divided by the well's specific capacity.

$$s_{well} = \frac{500}{S.C.}$$

The drawdown at the center well from interference effects of the other 36 wells will equal, by the principles of superposition and symmetry:

$$s_{interference} = 2\sum_{n=1}^{18} s\Big|_{r=nd}$$

where s is drawdown, d is well spacing, and r is the radius to be used in the Theis equation. Each of the s terms in the summation is evaluated using the Theis non-equilibrium equation at the appropriate radius, r. For the example pictured in figure 4, d is equal to 1 mi.

The drawdown at the center well owing to the effects of the impermeable boundaries can be approximated by a network of image wells. For a complete solution, this network should extend to infinity. However, for this project, the image network on each side was carried to only twice the aquifer width. An examination of the effects of ignoring images beyond this distance indicates that the effects are minor for any case studied in the project.

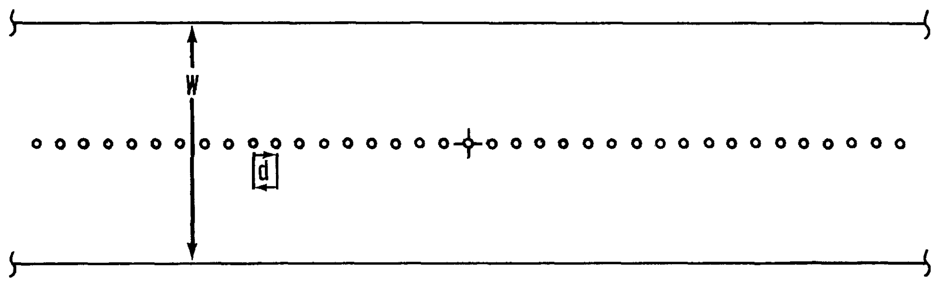


FIGURE 4.-- Idealization of an infinite strip aquifer of width W and well spacing d.

The effects of this limited image network can be quantified as:

$$s_{\text{boundary effects}} = 2s\Big|_{r=w} + 4\sum_{n=1}^{18} s\Big|_{r=\sqrt{w^2 + (nd)^2}}$$

$$+ 2s\Big|_{r=2w} + 4\sum_{n=1}^{18} s\Big|_{r=\sqrt{(2w)^2 + (nd)^2}}$$

where w is the width of the aquifer. Individual terms are evaluated by using the Theis equation as before.

For this study, theoretical drawdowns, calculated as previously described by using the Theis non-equilibrium equation, must be corrected for the decrease in saturated thickness.

Jacob (1963) presented a method for correcting observed drawdowns in a water-table aquifer to account for the decrease in saturated thickness in order to allow their use in the Theis method of aquifer analysis. We, therefore, want to reverse the procedure described by Jacob in order to correct the previously calculated theoretical drawdowns to drawdowns that include the effects of decreasing saturated thickness.

According to Jacob:

$$s_{obs} - s^2_{obs}/2m = s'$$

where s_{obs} is the observed drawdown which includes the effects of decreasing saturated thickness, m is the original saturated thickness of the aquifer, and s' is the corrected drawdown, which corresponds to the value calculated using the Theis equation.

Rearranging terms, the above quadratic equation can be expressed as:

$$s_{obs} = -m\ [\sqrt{1 - 2s'/m} - 1].$$

Observed drawdowns calculated in this manner include the effects of the decrease of saturated thickness which occurs as the water-table aquifer is pumped.

Alternative Sources of Water

In Phase I of this study the amount of ground water in storage in each of the basins was estimated to determine if an adequate supply of water is available. Estimated ground water in storage was 18 million acre-ft in Middle Amargosa Valley, 4 million acre-ft in Soda Lake Valley, 2 million acre-ft in Caves Canyon Valley, 15 million acre-ft in Chuckwalla Valley, and 3.5 million acre-ft in Calzona-Vidal Valley (Koehler and Ballog, 1979, p. 10). Several uncertainties exist as to the feasibility of utilizing all the water stored in any individual basin, primarily because the hydrologic regimen is insufficiently defined at this time. Therefore, the availability both of surface water for recharging each basin and of ground water in adjacent basins was considered a factor in evaluating the basins relative to each other. It may become necessary to establish a well field in adjacent basins and pipe water to the powerplant.

In many places underflow would be induced into the basin by lowering the water level to such an extent that the gradient toward the well field would extend into the adjacent basin. To determine the amount of underflow and induced underflow that would go into a basin, test wells would have to be drilled and a computer model made of the basin. A model, however, is beyond the scope of this study, and, therefore, only gross estimates were made of the relative value of the alternative sources of water.

Chemical Quality of Water

Only those basins that contain ground water that is unsuitable for most agricultural and domestic uses were considered potential powerplant sites in Phase I of this study. Accordingly, mimimum concentrations were established for dissolved solids, fluoride, arsenic, boron, and percent sodium (Koehler and Ballog, 1979, p. 5-8).

The water-quality criteria for Phase II of the study were selected on the basis of problem-causing chemical characteristics; that is, those chemical characteristics that could cause corrosion or scale formation within the cooling system. The chemical characteristics considered are hardness, dissolved solids, and silica. Maximum concentrations were not assigned to these chemical parameters. Basins that have water with the lowest concentrations of undesirable characteristics were ranked best with regard to water quality.

The data sites shown in figures 5 through 9 were selected to best depict the general quality of the water in an area and do not always represent the extremes in concentrations. The basins were ranked by roughly estimating the concentrations of constituents that would be most probable for a composite water sample of the entire basin. These estimates are, in many cases, based on few chemical data and should be reevaluated as more data become available.

BASIN EVALUATION

Calzona-Vidal Valley (7-41, 7-42)

Theoretical aquifer response to pumping.--The average transmissivity determined from test pumping wells 1S/24E-10F1 and 16B1 (fig. 5) was 31,000 ft^2/d (Metzger and others, 1973). This value probably represents only the transmissivity of the river-channel deposits within a few miles of the Colorado River. Pumping tests of two wells near Vidal Junction and two wells near Vidal indicate an average yield for these four wells of about 40 gal/min (Giessner, 1963b). Although no data are available on the transmissivity at these well sites, it is considered to be small. The average coefficient of storage at 14 sites on the Arizona side of the Colorado River (Metzger and others, 1973) was determined to be 0.39. This value represents the upper 15 ft of river sediments. The storage coefficient for the deeper more compact sediments would probably be much less. For the purpose of calculating water-level declines, a coefficient of storage of 0.20 was used.

To provide sufficient quantities of cooling water, the well field would probably have to be located near the Colorado River. The water-level decline (table 1) at the center of an idealized circular basin, after 30 years of pumping, would be 46 ft, and a decline of 16 ft would occur at a distance of 10 mi from the center of pumping. By using an infinite strip aquifer model, the decline at the center of the well field was estimated to be about 51 ft. The decrease in well yield would be approximately equal to the decrease in saturated thickness, or about 18 percent in the center of an idealized circular aquifer and 23 percent in the center of an idealized infinite strip aquifer.

The previous estimates of water-level declines do not take into consideration recharge from the Colorado River or the low transmissivity of the sediments outside the river-channel deposits. Therefore, the water-level decline estimates may be severely in error. Additional data and a computer model would be required to obtain more accurate predictions.

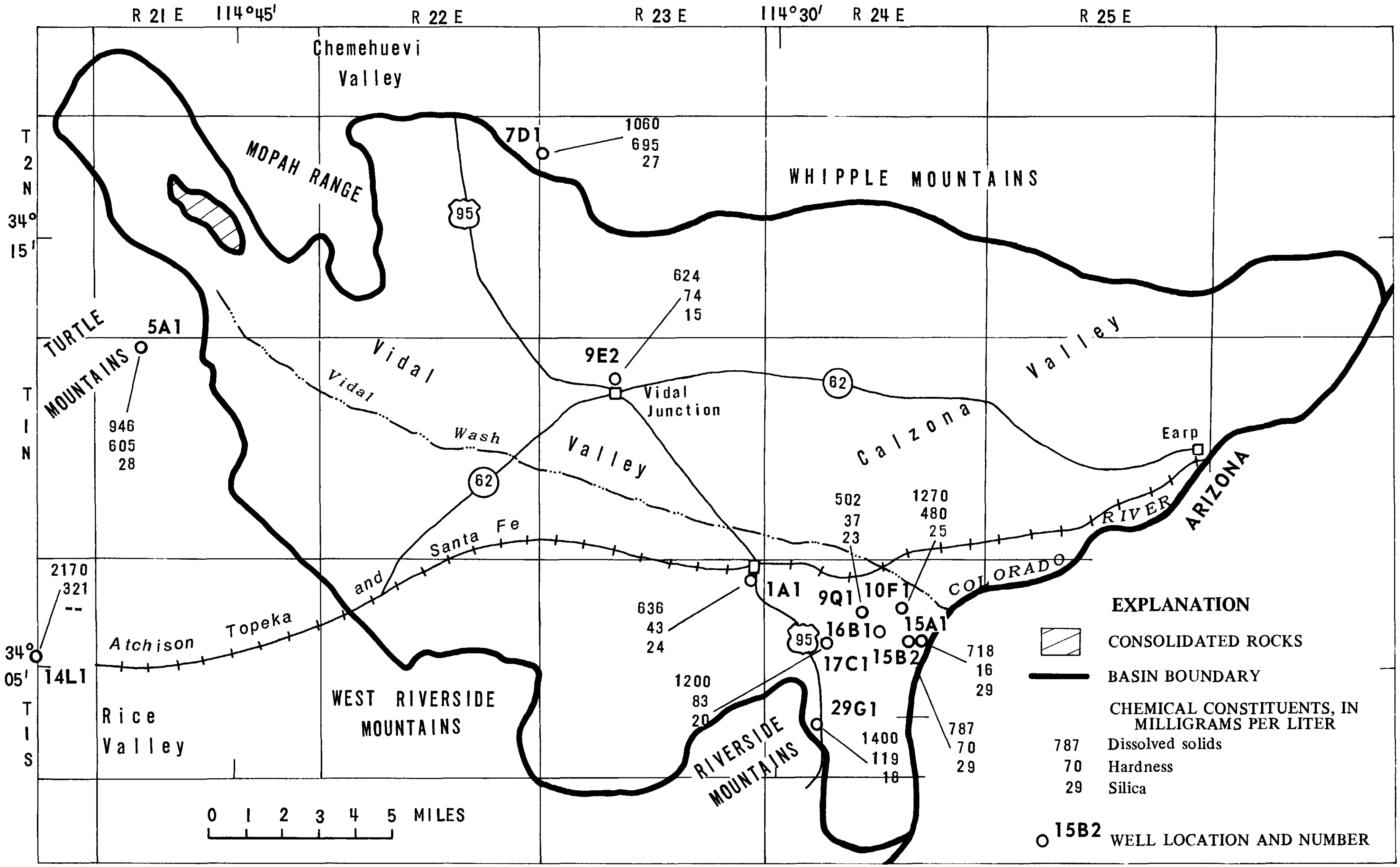
Alternative sources of water.--The Colorado River recharges the northeastern part of the basin; ground water moves out of the basin toward the southeast. Large ground-water withdrawals near the river would probably curtail underflow out of the basin and increase percolation of Colorado River water into the basin. The hydrologic regimen on the Arizona side of the Colorado River could be affected by the well field.

Under present hydrologic conditions, underflow enters the basin from Rice Valley. Data are insufficient to determine if underflow is entering the basin from Chemehuevi Valley. It is doubtful that pumping near the Colorado River would affect the amount of underflow from Rice Valley. If the well field were located in the central or western part of the basin, it might induce more underflow from Rice Valley and possibly induce underflow from Chemehuevi Valley. Both the Rice Valley basin (7-4) and Chemehuevi Valley basin (7-43) could be pumped as supplemental sources of water.

Chemical quality of water.--Figure 5 shows the hardness and concentrations of dissolved solids and silica in water from selected wells in the basin. Water-quality data are sparse except in the southeastern part of the basin. As previously discussed, the transmissivity in the central and western parts of the basin is probably low. Therefore, a well field to provide cooling water would probably have to be located near the Colorado River. The wells in T. 1 S., R. 24 E., probably best represent the water quality in the vicinity of the Colorado River and, therefore, were used exclusively to estimate water quality.

Average dissolved-solids concentration is 980 mg/L (milligrams per liter). Hardness ranges from 16 mg/L in well 1S/24E-15A1 to 480 mg/L in well 1S/24E-10F1 and averages 134 mg/L. The range in silica concentrations is much smaller, from 18 mg/L in well 1S/24E-29G1 to 29 mg/L in wells 1S/24E-15A1 and 15B2 with an average of 24 mg/L.

To compare water quality among selected basins, water-quality characteristics in the Calzona-Vidal Valley basin are estimated to range between 500 and 1,500 mg/L in dissolved solids, between 100 and 200 mg/L in hardness, and between 20 and 30 mg/L in silica.



Basin boundary approximated from California Department of Water Resources (1975)

FIGURE 5.--Ground-water basin, Calzona-Vidal Valley (7-41, 7-42).

Middle Amargosa Valley (6-20)

Theoretical aquifer response to pumping.--Transmissivity was estimated to be 6,800 ft^2/d, based on pumping tests. The storage coefficient was estimated to be 0.12, based on previous estimates of specific yield.

The water-level decline (table 1) at the center of an idealized circular basin, after 30 years of pumping, would be 158 ft and a decline of 3 ft would occur at a distance of 14 mi from the center of pumping. Using an infinite strip aquifer model, the decline at the center of the well field would be 58 ft. The decrease in well yield would be approximately equal to the decrease in saturated thickness or about 32 percent in the center of an idealized circular aquifer and 16 percent in the center of an idealized infinite strip aquifer.

The part of the basin north of Eagle Mountain (fig. 6) would probably be the most suitable for a well field. Lowering the water level in this area would allow for the utilization of the surface and ground water that now moves past Eagle Mountain. The effects of large-scale pumping on the springs and flowing wells in and adjacent to the basin would have to be determined before a powerplant could be established in the basin.

Alternative sources of water.--Most of the recharge to the area comes from underflow from the northern part of the basin in Nevada. The ground water that is not consumptively used moves south out of the basin into Valjean Valley. Large-scale pumping and resulting water-level declines would probably induce more underflow to enter the basin and decrease underflow out of the basin.

A well field in the northern part of the basin would be a considerable distance from Chicago Valley; therefore, it is doubtful that the water in storage in Chicago Valley could be effectively utilized except by direct pumping. Two basins, Pahrump (6-28) and Greenwater Valley (6-84), are close enough to be considered as supplemental sources of water.

Chemical quality of water.--Figure 6 shows the hardness and concentrations of dissolved solids and silica in water from selected wells in the basin. The average dissolved-solids concentration is about 1,600 mg/L for seven wells in the California part of the basin north of Eagle Mountain. The water in storage beneath Alkali Flat is not represented in this average and is probably higher in dissolved solids. This water would increase the dissolved-solids concentration somewhat. The average hardness and concentration of silica are 170 and 58 mg/L, respectively; these averages are probably representative of the area. Sustained pumping for powerplant cooling would probably cause considerable underflow to enter the California part of the basin from Nevada. Therefore, the quality of water in the Nevada part of the basin was also evaluated. Water from 16 wells in the Nevada part of the basin averaged 517 mg/L for dissolved solids, 142 mg/L for hardness, and 51 mg/L for silica. These averages are considered representative of the underflow that would move into the California side of the basin. The quality of water south of Eagle Mountain can reasonably be disregarded because this part of the basin would probably not contribute much water to the total pumpage.

To compare water quality among selected basins, water-quality characteristics for the Middle Amargosa Valley basin are estimated to range between 1,000 and 2,000 mg/L in dissolved solids, between 100 and 200 mg/L in hardness, and between 40 and 60 mg/L in silica.

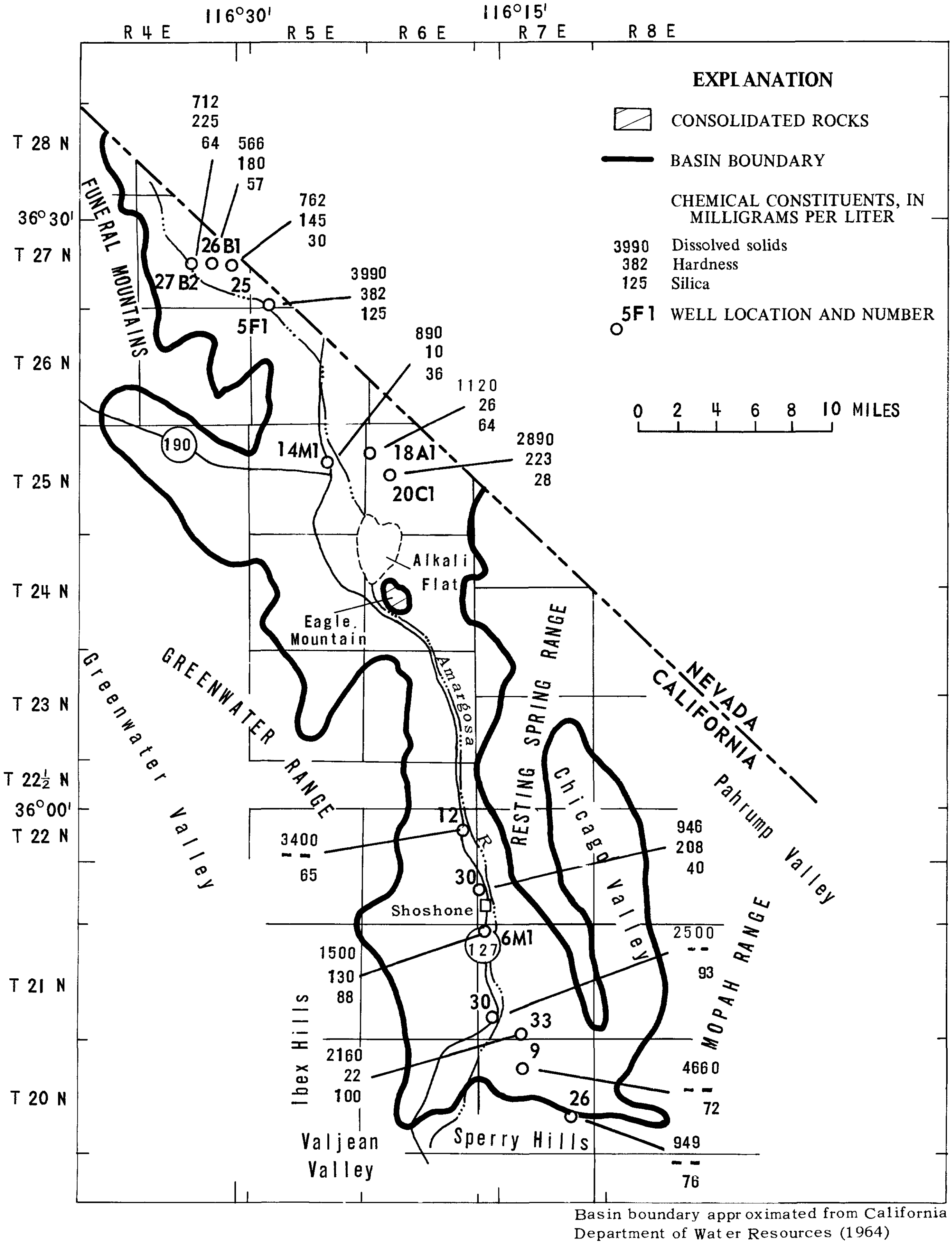


FIGURE 6.--Ground-water basin, Middle Amargosa Valley (6-20).

Chuckwalla Valley (7-5)

Theoretical aquifer response to pumping.--In the vicinity of Desert Center, the average specific capacity of 15 wells is about 55 (gal/min)/ft of drawdown, which indicates a transmissivity of about 15,000 ft^2/d. Transmissivity is probably less near the periphery of the basin and in the vicinity of Palen and Ford dry lakes (fig. 7). For the purpose of calculating water-level declines, a transmissivity of 13,000 ft^2/d and a coefficient of storage of 0.10 were used. The water-level decline (table 1) at the center of an idealized circular basin, after 30 years of pumping, would be 98 ft. A decline of 6 ft would occur at a distance of 17 mi from the center of pumping.

Calculated by using an infinite strip aquifer model, the decline at the center of the well field would be 53 ft. The decrease in well yield would be approximately equal to the decrease in saturated thickness; that is, 33 percent in the center of an idealized circular aquifer and 18 percent in the center of an idealized infinite strip aquifer.

Alternative sources of water.--There are no perennial surface-water sources in the basin from which recharge to the basin could be derived. Most of the ground-water recharge enters the basin as underflow from Pinto Valley on the northwest and from Cadiz Valley on the north. An estimated 400 acre-ft/yr of underflow moves eastward out of the basin (Metzger and others, 1973) into Palo Verde Mesa. As water levels decline owing to large-scale pumping, underflow from Pinto and Cadiz Valleys will probably increase. Some underflow may enter the basin from Orocopia Valley. If water-level declines are sufficient, they could cause a reversal of ground-water gradient in the eastern part of the basin which would induce underflow to enter the basin from Palo Verde Mesa.

Basins that are near enough to be pumped as supplemental sources of water are Pinto Valley basin (7-6), Cadiz Valley basin (7-7), Orocopia Valley basin (7-31), Arroyo Seco Valley basin (7-37), and Palo Verde Mesa (7-39).

Chemical quality of water.--Figure 7 shows the hardness and concentrations of dissolved solids and silica in water from selected wells in the basin. Dissolved solids are lowest near Desert Center and generally increase toward the central and eastern parts of the basin. The average concentration of dissolved solids is 2,100 mg/L for the wells shown in figure 7. The composite dissolved-solids concentration may be slightly higher than this average because the water quality in the central part of the drainage is not proportionally represented. Hardness ranges from extremely hard (1,200 mg/L) in well 8S/20E-10N1 to very soft (3 mg/L) in well 4S/16E-29R1 and averages 274 mg/L. The average silica concentration is 20 mg/L, which is considered representative of the basin.

To compare water quality among selected basins, water-quality characteristics for Chuckwalla Valley basin are estimated to range between 2,000 and 3,000 mg/L in dissolved solids, between 200 and 300 mg/L in hardness, and between 15 and 25 mg/L in silica.

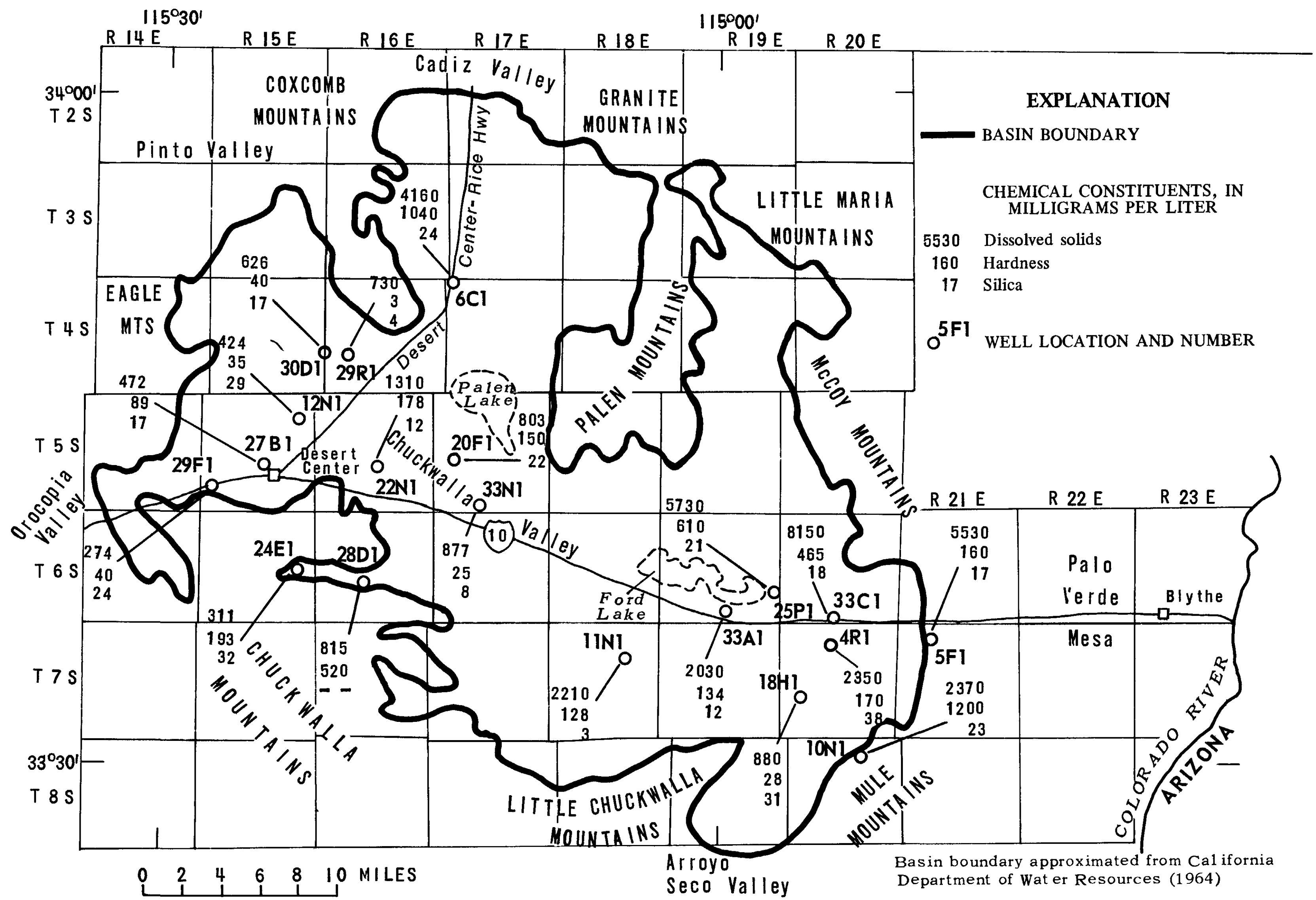


FIGURE 7.-- Ground-water basin, Chuckwalla Valley (7-5).

Soda Lake Valley (6-33)

Theoretical aquifer response to pumping.--The transmissivity of the basin was estimated to be 3,500 ft^2/d, based on a specific capacity of 13 (gal/min)/ft of drawdown in well 11N/8E-7Q3 (fig. 8). The coefficient of storage was assumed to be 0.10, based on the previously estimated specific yield (Koehler and Ballog, 1979).

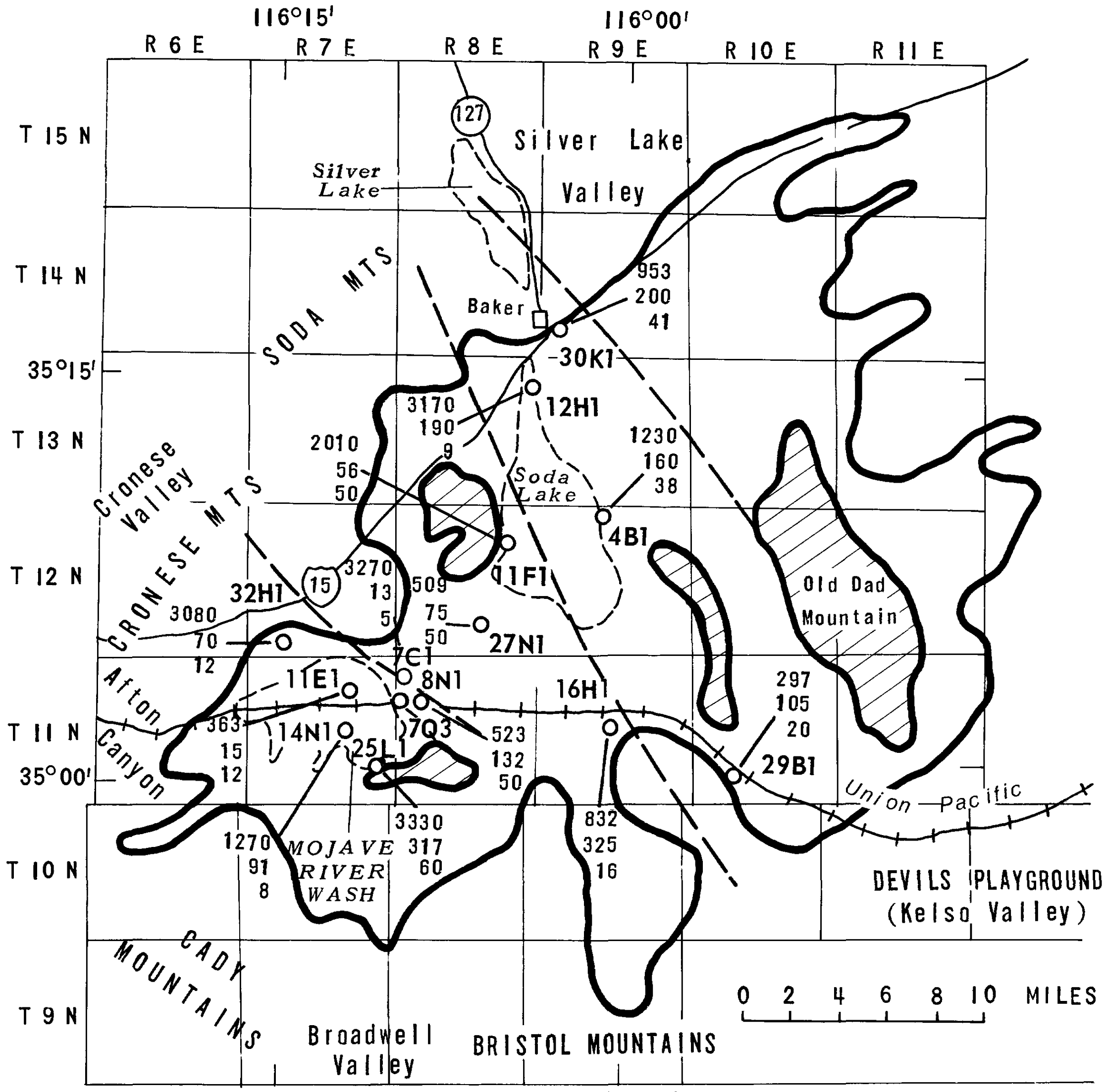
The water-level decline (table 1) at the center of an idealized circular basin, after 30 years of pumping, would be below the base of the aquifer (400 ft). The water-level decline 14 mi from the center of pumping would be 1 ft. Calculated by using an infinite strip aquifer model, the decline at the center of the well field would be 137 ft. The decrease in well yield would be approximately equal to the decrease in saturated thickness, or 100 percent in the center of an idealized circular aquifer and 34 percent in the center of an idealized infinite strip aquifer. These estimates indicate that the circular well field would probably not be feasible in this basin if the hydrologic parameters are correct.

Alternative sources of water.--In addition to the water in storage, additional water would be available from surface flow and underflow entering the basin at Afton Canyon. Underflow enters the basin from the Devils Playground area and possibly from Cronese Valley. Underflow, and on rare occasions surface flow, leaves the basin at Baker. Pumping in the basin would probably induce more underflow into the basin from the Devils Playground area and from Cronese Valley. The ground-water gradient at Baker could be reversed, causing underflow to enter the basin from Silver Lake Valley. During floods some of the surface runoff that enters the basin at Afton Canyon occasionally flows to Soda Lake and is lost by evaporation. As the water level is lowered by pumping, more floodflow will percolate into the ground before reaching Soda Lake.

Basins that are near enough to be pumped as supplemental sources of water are Kelso Valley basin (6-31) (Devils Playground area); Broadwell Valley (6-32); Silver Lake Valley basin (6-34); Cronese Valley basin (6-35); and Caves Canyon Valley basin (6-38), which is at the west end of Afton Canyon.

Chemical quality of water.--Figure 8 shows hardness and concentrations of dissolved solids and silica in water from selected wells in the basin. The water quality varies considerably, even in wells only short distances apart, perhaps because of vertical stratification of water of different quality. The average dissolved-solids concentration is 1,600 mg/L for the wells shown in figure 8. The wells are fairly well distributed throughout the basin, so the average should represent the composite water. Hardness ranges from very soft to very hard, with an average hardness of 135 mg/L. The average silica concentration is 29 mg/L.

To compare water quality among selected basins, water-quality characteristics in Soda Lake Valley basin are estimated to range between 1,000 and 2,000 mg/L in dissolved solids, between 100 and 200 mg/L in hardness, and between 25 and 40 mg/L in silica.



Basin boundary approximated from California Department of Water Resources (1964)
Geology from W.R. Moyle, Jr. (1967)

EXPLANATION

CONSOLIDATED ROCKS

FAULT – Approximately located

BASIN BOUNDARY

CHEMICAL CONSTITUENTS, IN MILLIGRAMS PER LITER

832 Dissolved solids
325 Hardness
16 Silica

16H1
O WELL LOCATION AND NUMBER

FIGURE 8.--Ground-water basin, Soda Lake Valley (6-33).

Caves Canyon Valley (6-38)

Theoretical aquifer response to pumping.--Hardt (1971) shows a transmissivity of as much as 6,700 ft^2/d and a storage coefficient of 0.02 along the Mojave River channel. Both transmissivity and storage coefficient probably increase away from the river channel. Therefore, a transmissivity of 4,000 ft^2/d and a storage coefficient of 0.15 were used to estimate aquifer response to pumping. The water-level decline (table 1) at the center of an idealized circular basin, after 30 years of pumping, would be more than 250 ft. A decline of 54 ft would occur at a distance of 5.6 mi from the center of pumping. Calculated by using an infinite strip aquifer model, the decline at the center of the well field would be 211 ft. The decrease in well yield would be approximately equal to the decrease in saturated thickness, or nearly 100 percent in both well-field configurations. These figures, however, do not include the effects of capture of surface-water and ground-water underflow.

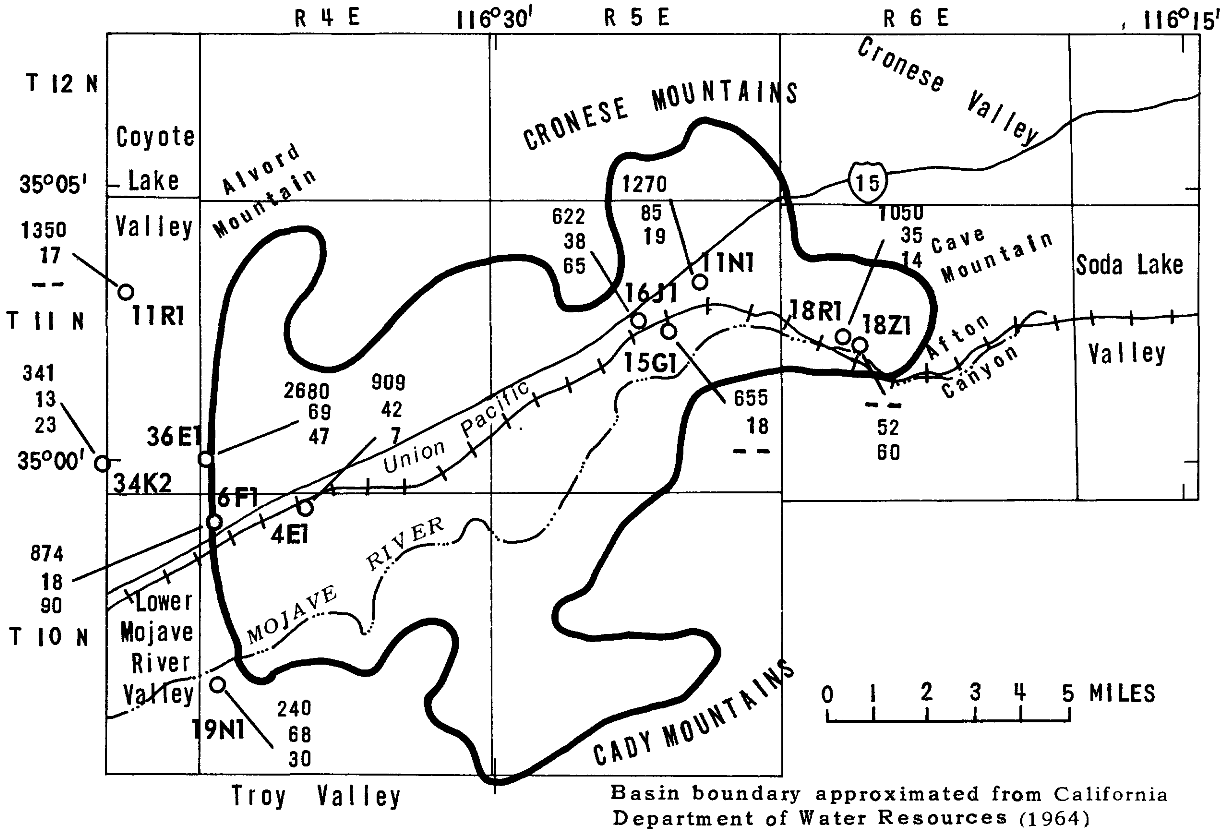
Alternative sources of water.--An average of about 12,000 acre-ft of surface water enters the basin annually in the Mojave River. Much of this water percolates into the basin and the rest leaves the basin through Afton Canyon (fig. 9). Underflow rises to the surface before entering Afton Canyon and flows through the canyon as surface water. As water levels decline, more of the surface flow would percolate into the aquifer and less would leave the basin at Afton Canyon. During severe flooding periods much of the water would still leave the basin because the transit time would not be sufficient to allow the water to percolate into the aquifer. Underflow into the basin is estimated to be 1,000 acre-ft annually. As water levels decline, the gradient will increase, inducing more underflow to enter the basin.

Basins that are near enough to be pumped as supplemental sources of water are Soda Lake Valley basin (6-33), Cronese Valley basin (6-35), Coyote Lake Valley basin (6-37), Troy Valley basin (6-39), and Lower Mojave River Valley basin (6-40).

Chemical quality of water.--Figure 9 shows the hardness and concentrations of dissolved solids and silica in water from selected wells in the basin. Wells 10N/4E-19N1, 11N/3E-11R1, and 34K2 are outside the basin boundary but are considered to represent the underflow into the basin from the west.

The average dissolved-solids concentration from wells shown in figure 9 is 1,000 mg/L. The ground water along the Mojave River is not represented adequately because of the lack of data. Well 10N/4E-19N1 has a dissolved-solids concentration of 240 mg/L and is probably representative of the water in the vicinity of the Mojave River. Taking this into account, the composite ground water would probably have an average dissolved-solids concentration of less than 1,000 mg/L. The water throughout the basin is generally soft, having an average hardness of 41 mg/L. The silica concentration ranges from 7 to 90 mg/L, with an average of 39 mg/L.

To compare water quality among selected basins, water-quality characteristics in Caves Canyon Valley basin are estimated to range between 500 and 1,500 mg/L in dissolved solids, between 30 and 60 mg/L in hardness, and between 35 and 45 mg/L in silica.



BASIN BOUNDARY

CHEMICAL CONSTITUENTS, IN MILLIGRAMS PER LITER

240	Dissolved solids
68	Hardness
30	Silica

19N1 WELL LOCATION AND NUMBER

FIGURE 9.--Ground-water basin, Caves Canyon Valley (6-38).

SUMMARY AND CONCLUSIONS

The five basins that were rated as suitable in Phase I of this study were investigated in more detail so that they could be ranked in order of their potential as a source of water for powerplant cooling.

The basins were evaluated with respect to theoretical aquifer response to pumping, alternative sources of water, and chemical quality of water. The basins are ranked with respect to each of these criteria in tables 2, 3 and 4. Table 5 is the overall ranking of each basin.

Table 2 shows the ranking of the basins with respect to aquifer response to pumping. It must be emphasized that the projected water-level declines are based on gross estimates of transmissivity and storage coefficients and, therefore, could be in considerable error. The order of ranking in table 2 was determined from water-level declines. Soda Lake Valley was ranked fourth because the water-level decline, in the case of an idealized circular aquifer, would be greater than the assumed saturated thickness. The theoretical water-level decline in Caves Canyon Valley is greater than the saturated thickness for both the idealized circular and infinite strip aquifers.

TABLE 2. - Ranking of basins based on theoretical aquifer response to pumping

Ranking	Basin	Water-level decline, in feet, after 30 years of pumping: Center of idealized circular aquifer	Water-level decline, in feet, after 30 years of pumping: Center of idealized infinite strip aquifer
1	Calzona-Vidal Valley (7-41, 7-42)	46	58
2	Chuckwalla Valley (7-5)	98	53
3	Middle Amargosa Valley (6-20)	158	64
4	Soda Lake Valley (6-33)	([1])	137
5	Caves Canyon Valley (6-38)	([1])	([1])

[1]Drawdown greater than assumed saturated thickness.

Table 3 shows the ranking of the basins with respect to alternative sources of water. Alternative sources include surface water, potential for underflow into the basin, and proximity of other basins where a supplementary well field could be established.

Calzona-Vidal Valley was ranked first mainly because of the large potential for recharge from percolation of Colorado River water. The legal and environmental ramifications of inducing recharge from the Colorado River would have to be considered before a powerplant could be established in the basin.

Middle Amargosa Valley was ranked second, mainly because of the large potential for inducing increased underflow from the Nevada side of the basin. Again, the legal and environmental factors of inducing recharge from Nevada would have to be considered before a powerplant could be established in the basin.

Caves Canyon Valley was ranked third because more underflow could be induced to enter this basin than to enter the two remaining basins. Occasional floodflow in the Mojave River would help recharge the basin.

Soda Lake and Chuckwalla Valleys were ranked fourth and fifth, respectively, because underflow into the basins is sparse. Some recharge may occur in Soda Lake Valley from infrequent floodflow in the Mojave River.

TABLE 3. - Ranking of basins based on alternative sources of water

Ranking	Basin	Remarks
1	Calzona-Vidal Valley (7-41, 7-42)	Sustained pumping would cause increased recharge from percolation of Colorado River water and probably would cause underflow to move into the basin from the Arizona side.
2	Middle Amargosa Valley (6-20)	As water levels decline, underflow would move into the basin from the Nevada side.
3	Caves Canyon Valley (6-38)	Underflow entering the basin from the Lower Mojave River Valley would increase as water levels decline and the gradient becomes steeper.
4	Soda Lake Valley (6-33)	The basin may receive some underflow from Silver Lake Valley as water levels decline and the ground-water gradient is reversed.
5	Chuckwalla Valley (7-5)	Some underflow enters the basin from the north and northwest. Underflow may enter from the east if ground-water gradient is reversed.

Table 4 shows the ranking of the basins with respect to the chemical quality of water. Within each basin the quality of water varies from area to area, and it may vary with depth. The range in quality of water shown in table 4 is based on sparse data and should be reassessed as more data become available.

Ranking the basins with respect to water quality was done largely on the basis of dissolved solids and hardness. Those basins with the lowest concentrations of dissolved solids were generally also lowest in hardness. Silica concentrations varied independently of the dissolved solids and hardness (table 4).

Table 5 shows the overall ranking of the basins with respect to all three criteria. The ranking is mostly subjective and could legitimately be changed depending on the emphasis placed on the individual criteria. For the purpose of this report the emphasis was placed on theoretical aquifer response to pumping.

Calzona-Vidal Valley was ranked first with respect to aquifer response to pumping and alternative sources of water and second with respect to chemical quality; therefore the basin was ranked first overall.

TABLE 4. - Ranking of basins based on chemical quality of water

Ranking	Basin	Probable range of chemical concentrations, in milligrams per liter, for a composite ground-water sample		
		Dissolved solids	Hardness	Silica
1	Caves Canyon Valley (6-38)	500-1,500	30-60	35-45
2	Calzona-Vidal Valley (7-41, 7-42)	500-1,500	100-200	20-30
3	Middle Amargosa Valley (6-20)	1,000-2,000	100-200	40-60
4	Soda Lake Valley (6-33)	1,000-2,000	100-200	25-40
5	Chuckwalla Valley (7-5)	2,000-3,000	200-300	15-25

Middle Amargosa Valley was ranked relatively high in each of the three categories and therefore was ranked second overall. It was ranked third with respect to aquifer response to pumping, but underflow from the Nevada side of the basin probably would reduce water-level declines.

Chuckwalla Valley was ranked second with respect to aquifer response to pumping and last in the other two categories. The basin is large (870 mi^2) and has about 15 million acre-ft of ground water in storage. Therefore, an alternative source of water may not be needed.

Soda Lake Valley ranks fourth in all the categories and therefore was ranked fourth overall.

Caves Canyon Valley was ranked fifth because of unfavorable aquifer response to pumping. Underflow from the Lower Mojave River valley would probably not be sufficient to limit water-level declines substantially. The fact that this basin was ranked first with regard to water quality is outweighed by the lack of sufficient quantities of water.

TABLE 5. - Overall ranking of basins

Overall ranking	Basin	Ranking with regard to:		
		Aquifer response to pumping	Alternative sources of water	Chemical quality
1	Calzona-Vidal Valley (7-41, 7-42)	1	1	2
2	Middle Amargosa Valley (6-20)	3	2	3
3	Chuckwalla Valley (7-5)	2	5	5
4	Soda Lake Valley (6-33)	4	4	4
5	Caves Canyon Valley (6-38)	5	3	1

RECOMMENDED FURTHER STUDY

Phase I of this study recommended that further study be done before the final selection of a powerplant site. It suggested that Phase II include measuring water levels, collecting additional water samples for chemical analysis, estimating aquifer response to pumping, conducting a reconnaissance gravity study, and selecting test-well sites. Because of a lack of time and money, the reconnaissance gravity study and selecting test-well sites were omitted from Phase II. These work elements could be done prior to the final phase of hydrologic investigation.

Before additional hydrologic studies are made, it may be desirable to assess all the basins classified suitable, suitable with qualifications, and insufficient data with respect to factors other than hydrology, such as accessibility, site cost, and environment. The final phase of study might consist of a detailed geophysical study and the drilling of test wells in the basins that have the highest potential, hydrologically and otherwise.

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