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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

AVAILABILITY OF GROUND WATER ON FEDERAL LAND NEAR THE AK-CHIN INDIAN RESERVATION, ARIZONA—A RECONNAISSANCE STUDY

By Richard P. Wilson

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CONVERSION FACTORS

For readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]

AVAILABILITY OF GROUND WATER ON FEDERAL LAND NEAR THE AK-CHIN INDIAN RESERVATION, ARIZONA—A RECONNAISSANCE STUDY

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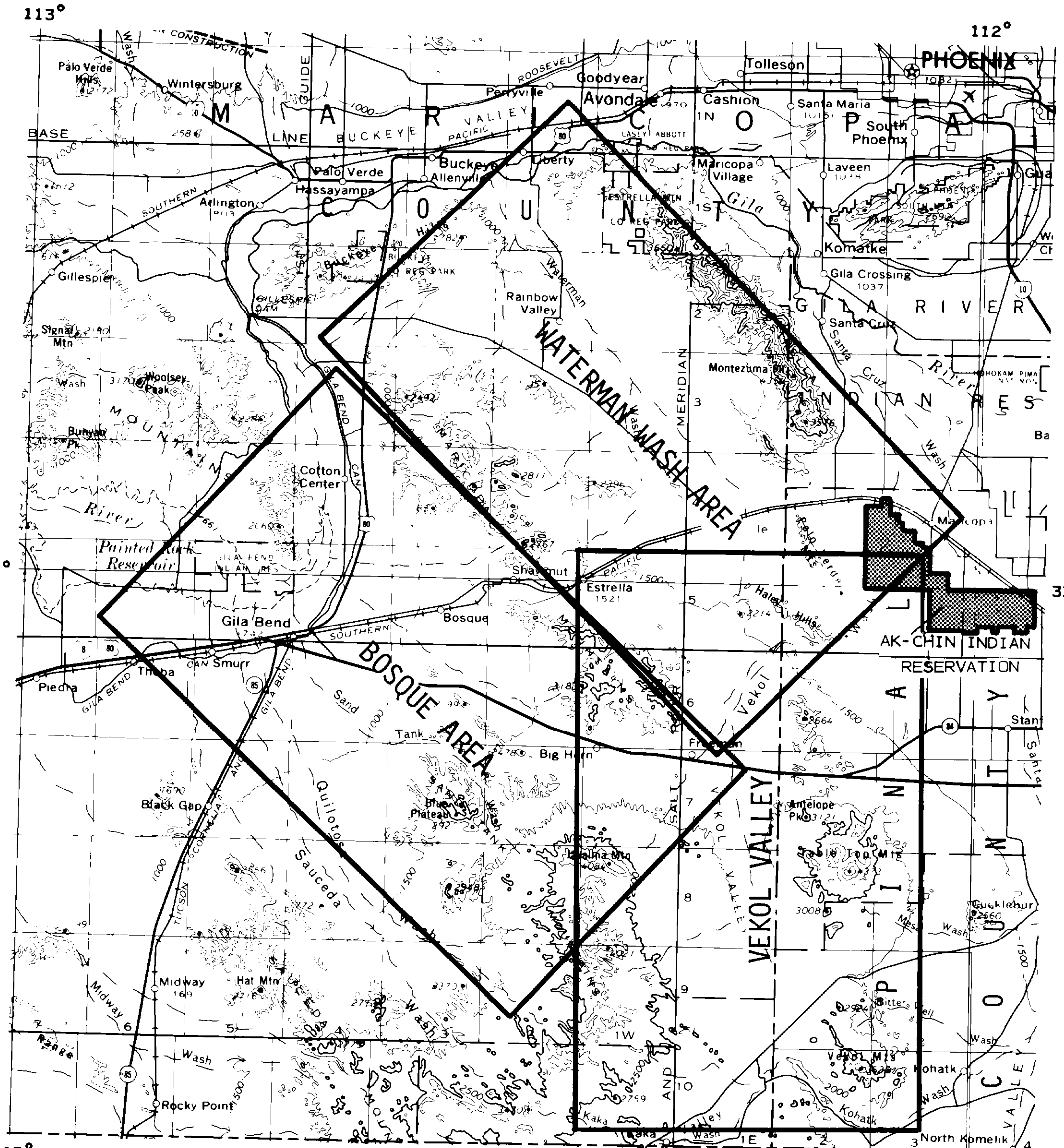
ABSTRACT

Sufficient ground water to provide about 2.1 million acre-feet in a 25-year period is available for delivery to the Ak-Chin Indian Reservation from Federal land in the Vekol Valley, Waterman Wash area, and Bosque area in south-central Arizona. Withdrawal of 85,000 acre-feet per year as required by the Ak-Chin water-supply act—Public Law 95-328—will greatly deplete the amount of water in storage and may cause land subsidence in the areas. Study concurrent with well-field development will enable design changes to minimize pumping costs, water-level declines, movement of poor-quality water into the well fields, and potential land subsidence and associated earth fissures. Surface and bore-hole geophysical testing, aquifer tests, and the development of simulative mathematical models will accomplish these goals and permit quantitative evaluations of the potential deleterious effects resulting from development of the water supply.

INTRODUCTION

The Ak-Chin water-supply act—Public Law 95-328 enacted on July 28, 1978—directs the Secretary of the Interior to undertake hydrologic studies to determine if sufficient ground water is available in Federal land near the Ak-Chin Indian Reservation to deliver 85,000 acre-ft/yr of water for irrigation use in the reservation. The required amount of ground water must be delivered until such time as a permanent surface-water supply is made available—no more than 25 years after passage of the law. Therefore, as much as 2.1 million acre-ft of ground water may be required to satisfy the demand. On December 13, 1978, the U.S. Geological Survey at the request of the U.S. Bureau of Indian Affairs began the study of the ground-water resources in the Federal land near the reservation.

The Ak-Chin Indian Reservation is 32 mi south of Phoenix (fig. 1). The three areas being considered as a source of irrigation water for the reservation—Vekol Valley, the Waterman Wash area, and the Bosque area—are southwest, northwest, and west, respectively, of the reservation. The areas extend from about 20 mi north of the Southern Pacific railroad tracks to 18 mi south of Interstate Highway 8 and are between the reservation and Gila Bend (fig. 1).

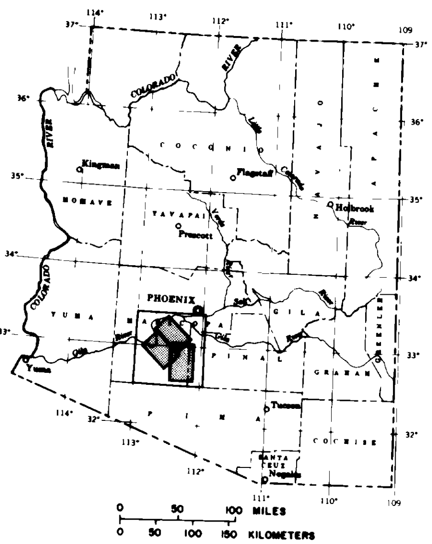


BASE FROM U.S. GEOLOGICAL SURVEY STATE TOPOGRAPHIC MAP, 1:500,000

0 10 20 MILES

0 10 20 KILOMETERS

CONTOUR INTERVAL 500 FEET
NATIONAL GEODETIC VERTICAL
DATUM OF 1929



INDEX MAP SHOWING AREA OF REPORT (SHADED)

Figure 1.--Area of report.

Land Status

Vekol Valley includes 173.4 mi^2, of which 109.8 mi^2 is Federal land administered by the U.S. Bureau of Land Management, 5.6 mi^2 is State land, 23.3 mi^2 is private land, and 34.7 mi^2 in the extreme south end of the valley is Papago Indian Reservation (fig. 2). In 1979 no land is being irrigated in the valley, and most of the land is used for livestock grazing.

The Waterman Wash area includes about 210 mi^2, and the part being considered for the Ak-Chin water supply—the east-central part—includes 64.2 mi^2, of which 54.9 mi^2 is Federal land administered by the U.S. Bureau of Land Management, 8.8 mi^2 is private land, and 0.5 mi^2 is State land (fig. 3). In 1979 no land is being irrigated in the area, but about 17,000 acres is being irrigated a few miles to the west (fig. 8). Irrigation development began about 1951, was substantial by 1960, and has increased slightly since 1960. In 1977 about 72,000 acre-ft of water was withdrawn for irrigation (U.S. Geological Survey, 1978).

The Bosque area includes 82.8 mi^2, of which 65 mi^2 is Federal land administered by the U.S. Bureau of Land Management, 17.3 mi^2 is State land, and 0.5 mi^2 is private land (fig. 4). In 1979 no land is being irrigated in the area, but about 6,000 acres to the north and west along the flood plain of the Gila River is under irrigation (fig. 11). Irrigation development began about 1940, was substantial by 1955, and has increased slightly since 1955. In 1977 about 70,000 acre-ft of water was withdrawn along the west margin of the Bosque area (R. S. Stulik, U.S. Geological Survey, oral commun., 1979). Several stock and domestic wells in the area probably withdrew less than 20 acre-ft/yr.

Scope of the Report

The report describes the extent, thickness, volume, and lithology of the water-bearing deposits in three areas near the Ak-Chin Indian Reservation. Depth to water, well yields, amount of recoverable ground water in storage, chemical quality of the water, and potential effects of the proposed ground-water development are discussed. The report contains recommendations for a program of concurrent study and development that will minimize the adverse effects of additional ground-water withdrawals in the areas.

Methods of Investigation

An inventory of existing hydrologic data from files and published reports of the U.S. Geological Survey, U.S. Bureau of Land Management, Arizona Water Commission, Arizona Department of

EXPLANATION

PRIVATE LAND—Includes military reservation

STATE LAND

FEDERAL LAND ADMINISTERED BY U.S. BUREAU OF LAND MANAGEMENT

INDIAN RESERVATION

APPROXIMATE BOUNDARY OF VALLEY FLOOR

Figure 2.--Land status in and near Vekol Valley.

EXPLANATION

PRIVATE LAND

STATE LAND

FEDERAL LAND ADMINISTERED BY U.S. BUREAU OF LAND MANAGEMENT

INDIAN RESERVATION

APPROXIMATE BOUNDARY OF VALLEY FLOOR

PART OF WATERMAN WASH AREA CONSIDERED FOR AK-CHIN WATER SUPPLY

Figure 3.--Land status in and near the Waterman Wash area.

EXPLANATION

PRIVATE LAND—Includes military reservation

STATE LAND

FEDERAL LAND ADMINISTERED BY U.S. BUREAU OF LAND MANAGEMENT

INDIAN RESERVATION

APPROXIMATE BOUNDARY OF VALLEY FLOOR

BOSQUE AREA

Figure 4.--Land status in and near the Bosque area.

Transportation, Arizona State Land Department, and U.S. Bureau of Reclamation and a literature search for geologic and geophysical data were made. Water levels were measured in a few wells during this study. Gravity-anomaly, thickness of basin fill, and water-level contour maps were made using existing and reconnaissance field data for the three areas. The maps were used to define the extent and saturated thickness of the basin-fill deposits. Seven test holes and two pilot wells were drilled to provide subsurface information, and chemical analyses of the water were made. Aquifer tests were made at the two pilot wells to determine well yields and transmissivity.

Previous Investigations

Geohydrologic studies by Babcock and Kendall (1948), Coates (1952), Wolcott (1952; 1953), Johnson and Cahill (1955), Heindl and Armstrong (1963), White (1963), Stulik and Moosburner (1969), and Denis (1968; 1975) were helpful in evaluating the ground-water resources in the Waterman Wash and Bosque areas. Previous hydrologic studies have not been made in Vekol Valley. The Arizona State Land Department collected water-level and chemical-quality data in the Gila Bend and Bosque areas in 1977 (material in files of Arizona State Land Department, Phoenix), and the U.S. Bureau of Reclamation (1977) drilled a test hole and made gravity-anomaly maps and interpretations of drillers' logs in the Gila Bend area. The U.S. Bureau of Reclamation (1977) prepared a gravity-anomaly map of the Waterman Wash and Bosque areas. Geologic studies by Sell (1968), Wilson and others (1969), Cooley (1968; 1977) Eberly and Stanley (1978), and Dockter and Keith (1978) were beneficial to this investigation.

Acknowledgments

The test-drilling program that provided most of the data used in this study was successfully completed owing to the excellent cooperation of W. J. Carlyle, Chairman, Ak-Chin Indian Community Council; D. A. England, Ak-Chin Indian Community; C. E. Franzoy, Franzoy, Corey and Associates; J. D. Crisp, U.S. Bureau of Land Management; C. P. Corke and T. W. Neumann, U.S. Bureau of Indian Affairs; K. T. Morstain, Morrow Drilling Co.; R. M. McDaniel, McDaniel Well and Machine Co.; and Anthony Bouchard, B. C. and M. Drilling, Inc. The Ak-Chin Indian Community, which was represented by Franzoy, Corey and Associates, contracted for the drilling of the test holes and pilot wells and ran preliminary chemical analyses of the water. J. S. Sumner of the Department of Geosciences, University of Arizona, prepared gravity-anomaly and thickness of basin-fill maps, which were useful in this study.

GEOHYDROLOGY

Vekol Valley and the Waterman Wash and Bosque areas, which are being considered as a source of irrigation water for the Ak-Chin Indian Reservation, are partly filled with unconsolidated to moderately consolidated deposits, herein called the "basin-fill deposits." The basin-fill deposits generally are saturated within a few hundred feet of the land surface, store large amounts of water in their pore spaces, and generally yield from 500 to 2,500 gal/min of water to properly constructed wells. In the report area the deposits, where saturated, typically contain 8 to 20 percent of water by volume, and the specific yield is estimated to be 0.1 or 10 percent of the volume of saturated material. The assumed specific yield is conservatively small and gives larger projected values of water-level decline and smaller estimates of the amount of recoverable water in storage than those which may occur. The water generally is under water-table conditions, although the presence of clay and silt in the deposits indicates that confined conditions may exist in places. The consolidated rocks that underlie the basin fill and form the mountains that surround the areas consist of igneous, metamorphic, and sedimentary rocks. Although the consolidated rocks may yield a few tens of gallons per minute of water where fractured, the rocks will not yield sufficient amounts of water for irrigation in the reservation and were not considered as a potential source of water in this study.

Vekol Valley

Vekol Valley is about 30 mi long, 5 to 10 mi wide, and is rimmed by the Table Top and Vekol Mountains on the east and the Sand Tank and Maricopa Mountains on the west (fig. 5). In places the mountains are at an altitude of as much as 2,000 ft above the valley floor. Vekol Wash drains most of the valley; the wash generally is dry and flows only in response to intense rainfall. The valley is relatively flat and slopes gently to the north. The altitude is 2,200 ft above the National Geodetic Vertical Datum of 1929 in the southern part and 1,450 ft in the northern part, where Vekol Wash leaves the valley. The center of the valley is 30 mi from the southeast corner of the Ak-Chin Indian Reservation, and water could be delivered to the reservation by a gravity-flow system. In this report Vekol Valley is divided into a southern part and a northern part, which are separated by a buried ridge of consolidated rocks (fig. 5). The southern part includes part of the Papago Indian Reservation.

The southern part of the valley contains more than 2,000 ft of basin-fill deposits. In this report the deposits are divided in descending order into four units—an upper gravel unit, a silt and clay unit, a lower gravel unit, and a conglomerate unit. A thick sequence

E X P L A N A T I O N

—— 500 —— APPROXIMATE LINE OF EQUAL DEPTH TO WATER—Interval 100 feet

APPROXIMATE SATURATED THICKNESS OF BASIN FILL, IN FEET

- Less than 500
- 500 to 1,500
- More than 1,500
- Insufficient data

CONSOLIDATED ROCKS

o TEST HOLE

Figure 5.--Depth to water and saturated thickness of the basin-fill deposits in Vekol Valley.

of volcanic rocks that overlies the conglomerate in the Sand Tank, Maricopa, and Table Top Mountains on the west and east sides of the valley is not present in the Vekol 1 or Vekol 3 test holes (fig. 5), which may indicate that the upper three units rest on an erosion surface cut into the conglomerate. The upper gravel unit is about 150 ft thick and is an unconsolidated silty gravel made up of all the rock types in the surrounding mountains. The unit is above the water table. The silt and clay unit is unconsolidated light-brown silt and clay and contains small amounts of sand and gravel. The unit is 200 ft thick in Vekol 1 and thickens to 395 ft in Vekol 3. The unit is unsaturated in Vekol 1, but the lower 160 ft is saturated in Vekol 3. The silt and clay unit grades into the lower gravel unit in Vekol 3. The lower gravel unit is unconsolidated to weakly consolidated reddish-gray to red-green sandy gravel composed mainly of silicic volcanic rocks, schist, quartz, and metamorphic rocks. The unit is about 980 ft thick in Vekol 3 and is saturated; the unit is not present in Vekol 1. The conglomerate unit is weakly to moderately consolidated gravel and sand that contains silty and clayey layers. Vekol 1 penetrates 827 ft of the conglomerate unit and 151 ft of the underlying dolomitic limestone. Vekol 3 penetrates only the upper 453 ft of the conglomerate. The unit is saturated in both test holes.

The northern part of the Vekol Valley contains at least 1,908 ft of basin-fill deposits in a roughly circular area near Interstate Highway 8 (fig. 5). The Vekol 4 test hole is 1,995 ft deep and penetrates gravelly sand in the upper 1,208 ft, silty gravelly sand in the next 700 ft, and tuff, silty to clayey sand and gravel, and andesite in the lower 87 ft. The silty gravelly sand is underlain by the volcanic rocks that crop out in the Sand Tank, Maricopa, and Table Top Mountains and that overlie the conglomerate unit penetrated in Vekol 1 and Vekol 3.

Ground-Water Movement

Ground water moves from south to north in the basin-fill deposits in Vekol Valley. The water table in the southern part of the valley slopes gently northward at a hydraulic gradient of less than 1 ft/mi. Ground water probably enters the basin fill near the mountains, moves toward Vekol Wash, and then moves northward across the buried ridge into the northern part of the valley. At the buried ridge, the hydraulic gradient increases to about 90 ft/mi, as a result of the decrease in cross-sectional area of the saturated basin fill (figs. 5 and 6). As the water moves into the northern part of the valley, the hydraulic gradient decreases to about 5 ft/mi. Most of the ground water probably moves into the lower Santa Cruz basin through the narrow gap between the Haley Hills and Table Top Mountains, but some may move into the Waterman Wash area through the narrow gap between the Haley and Booth Hills.

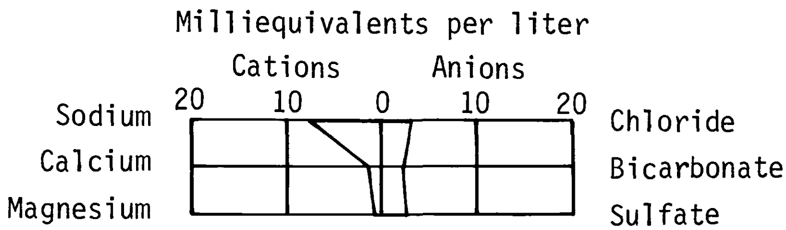
EXPLANATION

—1620— WATER-LEVEL CONTOUR—Shows approximate altitude of the water level, 1979. Contour interval 40 feet. National Geodetic Vertical Datum of 1929

● 349 / 1416 / 525 WELL IN WHICH DEPTH TO WATER WAS MEASURED IN 1979—First number, 349, is depth to water in feet below land surface (R, depth to water reported; M, depth to water measured prior to 1979). Second number, 1416, is altitude of the water level in feet above National Geodetic Vertical Datum of 1929. Third number, 525, is reported depth of well in feet

o 332 / 1613 / 700 / 1313 TEST HOLE—First number, 332, is depth to water in feet below land surface. Second number, 1613, is altitude of water level in feet above National Geodetic Vertical Datum of 1929. Third number, 700, is specific conductance in micromhos per centimeter at 25°C. Fourth number, 1313, is depth of test hole in feet

CHEMICAL-QUALITY PATTERN DIAGRAM—Shows major chemical constituents in milliequivalents per liter. The patterns are in a variety of shapes and sizes, which provides a means of comparing, correlating, and characterizing similar or dissimilar types of water



DS=544 DISSOLVED SOLIDS—Number, 554, is dissolved solids in milligrams per liter

BASIN-FILL DEPOSITS

CONSOLIDATED ROCKS

Figure 6.--Altitude of the water level, specific conductance of water, and depth of selected wells in Vekol Valley.

Depth to Water and Well Yields

The depth to water in the southern part of the valley generally is from about 335 to 500 ft below the land surface but increases to more than 600 ft near the margins (figs. 5 and 6). In the northern part of the valley the depth to water is from about 150 to 400 ft below the land surface but may be more than 500 ft near the margins (figs. 5 and 6). Wells near the margin of the valley may tap the basin fill or the underlying consolidated rocks; subsurface data are not adequate to determine the unit the wells penetrate.

Wells in the Vekol Valley are used for livestock and domestic supplies and yield from a few to a few tens of gallons per minute of water. Subsurface data from the three test holes indicate that yields of 1,000 to 2,000 gal/min probably can be obtained from favorably located and properly constructed wells in the basin fill.

The potential specific capacity of properly constructed wells in the northern part of the Vekol Valley is inferred to be more than 15 (gal/min)/ft based on the lithology of the basin-fill deposits, which is similar to that of the basin fill in the Waterman Wash area. The specific capacity of a well is the rate of discharge of water from the well divided by the drawdown of water level in the well (Lohman and others, 1972, p. 11). The relation between discharge and drawdown is affected by the characteristics of the water-bearing material, well construction and development, and well screen or perforations of the casing. If well losses are significant, the ratio between discharge and drawdown will decrease with increasing discharge. In the northern part of the valley the potential drawdown would be 67 ft at a discharge of 1,000 gal/min. Data are not available to estimate the potential specific capacity or drawdown for the southern part of the valley.

Estimated Amount of Recoverable Ground Water in Storage

The amount of recoverable ground water in storage can be estimated by multiplying the volume of saturated basin fill by the specific yield. The approximate thickness of saturated basin fill in Vekol Valley is shown in figure 5. The conservative estimate of 0.1 was assumed for specific yield of the basin fill (see section entitled "Geohydrology"). If the average specific-yield value differs greatly from the assumed value of 0.1, the estimated amount of recoverable ground water will differ accordingly. For example, if the average specific yield of the basin fill is 0.2, the total amount of recoverable ground water is 15.4 million acre-ft instead of the 7.7 million acre-ft obtained using the average value of 0.1. (See table 1.)

Table 1.--Amount of recoverable ground water in storage in the basin-fill deposits in Vekol Valley

Location	Depth below water table (feet)	Volume of saturated basin fill (millions of acre-feet)	Amount of recoverable ground water in storage (millions of acre-feet)
Southern part of valley	0-500	20	2.0
	500-1,500	26	2.6
Total amount in storage in southern part of valley			4.6
Northern part of valley	0-500	15	1.5
	500-1,500	16	1.6
Total amount in storage in northern part of valley			3.1
Southern and northern parts of valley	0-500	35	3.5
	500-1,500	42	4.2
Total amount in storage in Vekol Valley			7.7

Water-Level Declines

In the northern part of the valley near Interstate Highway 8 the water level probably declined less than 10 ft during 1953-79. For 1953-61, water levels declined less than 15 ft in the northeast corner in response to declines of more than 150 ft 5 mi east in the lower Santa Cruz area; for 1961-79, declines probably were less than 30 ft. In the southern part of the valley water-level declines probably are insignificant; the two stock wells in the southern part of the area yield only a few acre-ft/yr of water.

Chemical Quality

The dissolved solids range from 375 to 544 mg/L (milligrams per liter) in the water from one well and two test holes in Vekol Valley. The main ions in solution are sodium, chloride, bicarbonate, and sulfate (fig. 6).

The suitability of water for irrigation depends on the ratio of sodium to calcium and magnesium, the amount of dissolved solids in the water, soil type, and the type of crop to be grown. In Vekol Valley the main factors harmful to plant growth are the ratio of sodium to calcium and magnesium and the amount of dissolved solids. The possible dangers from excessive concentrations of sodium in irrigation water include the breakdown of soil structure and the nutritional disturbance of crops. A useful parameter in evaluating the sodium hazard in irrigation water is the sodium-adsorption ratio formulated by the U.S. Salinity Laboratory Staff (1954). The salinity hazard can be critical to plant growth. The common test for salinity hazard in irrigation water is to measure the specific conductance. Specific conductance is a measure of the ability of the ions in solution to conduct an electrical current and is an indication of the amount of dissolved solids in water (fig. 6). For irrigation water, 2,250 micromhos per centimeter at 25°C is the approximate upper limit of specific conductance if there is adequate leaching in the root zone.

The sodium hazard is medium to high and the salinity hazard is high for water from one well and two test holes in the valley (fig. 7). However, water having similar sodium and salinity hazards is used successfully in nearby areas.

Waterman Wash Area

The Waterman Wash area is about 30 mi long and 10 mi wide. The area is rimmed by the Buckeye Hills on the north, the Haley and

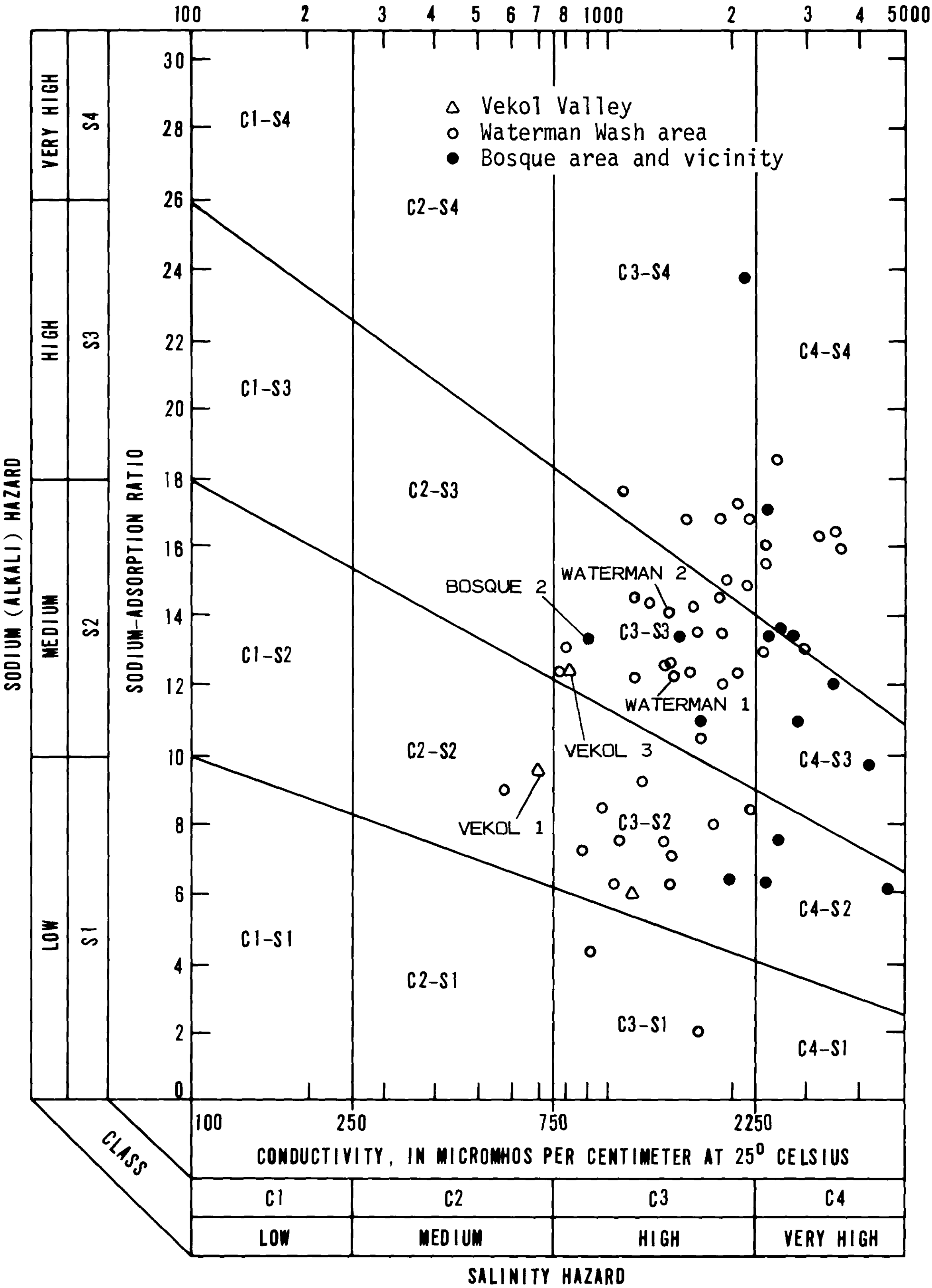


Figure 7.--Sodium and salinity hazard of water. Diagram adapted from U.S. Salinity Laboratory Staff (1954).

Booth Hills and Palo Verde Mountains on the south, the Sierra Estrella on the east, and the Maricopa Mountains on the west (fig. 8). In places the mountains are at an altitude of more than 4,000 ft. The altitude of the valley floor ranges from 1,000 ft in the northwestern part where the Waterman Wash leaves the area to 1,400 ft in the southeastern part. Waterman Wash drains most of the area; the wash generally is dry and flows only in response to intense rainfall. Only the east-central part of the area is being considered for development of the Ak-Chin water supply (fig. 8). The area being considered for development is 27 mi from the southeast corner of the reservation. Water would have to be pumped over a low divide before it could flow by gravity to the reservation.

The central part of the Waterman Wash area is underlain by by more than 2,000 ft of basin-fill deposits; most of the area contains between 1,000 and 2,000 ft of basin fill. In this report the deposits are divided into an upper unit and a lower unit. The upper unit is about 800 ft thick in the south-central part of the area and as much as 1,000 ft thick in the northwestern part. The unit is unconsolidated sandy clay to sand and gravel and generally contains a higher percentage of gravel in the northwestern part of the area and a higher percentage of clay and silt in the central part. Wells in the northwestern part of the area bottom in the upper unit or penetrate only the uppermost part of the lower unit. In the central part of the area 400 ft of the upper unit is saturated; the saturated thickness increases to 700 ft in the northwestern part. The lower unit is as much as 1,000 ft thick and consists of poorly to moderately consolidated dark-gray coarse sandy gravel to sand and gravel that contains small amounts of silt and clay. The Waterman 2 test hole penetrates 938 ft of the lower unit, which consists of 730 ft of gravelly sand and 208 ft of hard sandy gravel at the base. Waterman 1 penetrates 402 ft of sandy gravel in the lower unit. The lower unit is saturated and overlies the consolidated rocks. The lower unit can be distinguished from the upper unit in geophysical logs by its more uniform and often higher resistivity, higher density, lower porosity, and higher sonic velocity. The drilling-time logs show a marked decrease in the rate of penetration in the lower unit.

Ground-Water Movement

In the Waterman Wash area ground water moves from southeast to northwest toward the cone of depression that has formed in response to ground-water withdrawal (fig. 8). Ground water enters the basin fill mainly near the mountains. The hydraulic gradient ranges from about 10 ft/mi northwest of Mobile to about 30 ft/mi in the northwestern part of T. 3 S., R. 1 W. (fig. 8).

EXPLANATION

800 — WATER-LEVEL CONTOUR—Shows approximate altitude of the water level, 1979. Contour interval 50 feet. National Geodetic Vertical Datum of 1929

WELL

TEST HOLE

APPROXIMATE BOUNDARY OF AREA IN WHICH POTENTIAL WELL YIELD IS MORE THAN 500 GALLONS PER MINUTE FROM PROPERLY CONSTRUCTED WELLS—Queried where uncertain

BASIN-FILL DEPOSITS

CONSOLIDATED ROCKS

IRRIGATED AREA AS OF 1974—Land under cultivation or that prepared for cultivation was considered irrigated. From Denis (1975)

BOUNDARY OF AREA CONSIDERED FOR DEVELOPMENT OF THE AK-CHIN WATER SUPPLY

Figure 8.--Altitude of the water level, potential well yield, and irrigated area in the Waterman Wash area.

Depth to Water and Well Yields

The depth to water ranges from less than 300 ft in the northwestern part of the valley to more than 400 ft southwest of Mobile. In the east-central part of the area the depth to water ranges from about 335 ft in Waterman 1 to more than 400 ft near the foot of the Sierra Estrella (fig. 9).

In the northwestern part of the area wells that penetrate the basin-fill deposits yield from 1,000 to 2,500 gal/min of water. The pilot well 150 ft south of Waterman 2 was pumped at 2,000 gal/min for five days and had a drawdown of 120 ft. Although the lower 355 ft of the upper unit of basin fill is saturated, it was cased off because the material is too fine grained to yield water readily. The well is open in 725 ft of the 938-ft-thick lower unit. Aquifer-test data for the well indicate that the transmissivity of the lower unit is about 11,000 ft^2/d. Transmissivity is the rate at which water of the prevailing temperature is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman and others, 1972, p. 13). Based on the aquifer-test data, properly constructed wells near Waterman 2 could yield as much as 2,500 gal/min of water.

In the part of the area considered for the Ak-Chin water supply the potential specific capacity of wells will range from 15 to 74 (gal/min)/ft, which would produce drawdowns of about 14 to 67 ft at a discharge of 1,000 gal/min or 27 to 133 ft at a discharge of 2,000 gal/min. The specific capacity of the pilot well near Waterman 2 was 17 (gal/min)/ft after 5 days of pumping at 2,000 gal/min.

Estimated Amount of Recoverable Ground Water in Storage

The approximate saturated thickness of the basin-fill deposits in the Waterman Wash area is shown in figure 9. The amount of recoverable ground water in storage—assuming a specific yield of 0.1—is shown in table 2.

Water-Level Declines

The withdrawal of ground water in the Waterman Wash area has resulted in a general decline in water levels. Water-level declines ranged from 8 to 172 ft for 1952-75; the maximum decline was in the northwestern part of T. 2 S., R. 2 W., and the minimum decline was in T. 4 S., R. 1 E. (Denis, 1975). A comparison of water-level data for the east-central part of the area indicates that declines range from about 10 ft in sec. 9, T. 4 S., R. 1 E., to 100 ft in sec. 25, T. 2 S.,

E X P L A N A T I O N

—— 400 —— APPROXIMATE LINE OF EQUAL DEPTH TO WATER—Interval 100 feet

APPROXIMATE SATURATED THICKNESS OF BASIN FILL, IN FEET

Less than 500

500 to 1,000

1,000 to 1,500

More than 1,500

Insufficient data

CONSOLIDATED ROCKS

o TEST HOLE

•••••••••••••••• BOUNDARY OF AREA CONSIDERED FOR DEVELOPMENT OF THE AK-CHIN WATER SUPPLY

Figure 9.--Depth to water and saturated thickness of the basin-fill deposits in the Waterman Wash area.

Table 2.--Amount of recoverable ground water in storage in the basin-fill deposits in the Waterman Wash area

Location	Depth below water table (feet)	Volume of saturated basin fill (millions of acre-feet)	Amount of recoverable ground water in storage (millions of acre-feet)
East-central part of area being considered for development of the Ak-Chin water supply	0-500	13	1.3
	500-1,500	16	1.6
Total amount in storage in the east-central part of area			2.9
Waterman Wash area	0-500	54	5.4
	500-1,500	49	4.9
Total amount in storage in the Waterman Wash area			10.3

R. 1 W. (White, 1963; Denis, 1975). The water-level decline is about 30 ft at Waterman 1 and about 70 ft at Waterman 2. The water-level declines in the east-central part of the area are the result of ground-water withdrawals in the northwestern part of the area.

Chemical Quality

In the Waterman Wash area the ground water generally is of acceptable chemical quality for irrigation use. The main ions in solution are sodium and chloride with smaller concentrations of sulfate, bicarbonate, and calcium. The sodium and salinity hazard is high to very high in most of the water (fig. 7). The dissolved solids and specific conductance of the water are largest in the northern part of the area and lowest in the south-central part (fig. 10). The water has been used for irrigation for more than 30 years and apparently has not caused soil alkalinity or salinity problems; however, irrigators apply soil amendments and have developed special management practices to prevent the accumulation of salts in the soil (Denis, 1968).

In the east-central part of the area water samples from Waterman 1 and 2 indicate that specific conductance ranges from 1,400 to 1,500 micromhos per centimeter at 25°C. The sodium hazard is very high, and the salinity hazard is medium (fig. 7). The water is of slightly better quality than that being used for irrigation in the northwestern part of the area (fig. 10).

Bosque Area

The Bosque area is about 15 mi long, 2 to 10 mi wide, and is rimmed by the Maricopa Mountains on the northeast and the Sand Tank Mountains on the south (fig. 11). The mountains rise abruptly to altitudes of more than 1,000 ft above the valley floor. The altitude of the valley floor ranges from 740 ft along the Gila Bend Canal to 1,440 ft above the National Geodetic Vertical Datum of 1929 along the southeast boundary. The valley is drained by the many small washes that are tributary to the Gila River; the washes generally are dry and flow only in response to intense rainfall. The Bosque area is 41 mi west of the southeast corner of the reservation, and water would have to be pumped over a divide about 500 ft above the center of the area and across the southern part of the Waterman Wash area before it could flow by gravity to the reservation.

The Bosque area is a northwest-trending trough that has been filled with as much as 3,000 ft of basin-fill deposits. The basin-fill deposits were laid down in lenses and discontinuous sheets and in this report are divided into an upper unit, a middle unit, and a lower

E X P L A N A T I O N

——550—— WATER-LEVEL CONTOUR—Shows approximate altitude of the water level, 1979. Contour interval 50 feet. National Geodetic Vertical Datum of 1929

● WELL

○ TEST HOLE

BASIN FILL

CONSOLIDATED ROCKS

IRRIGATED AREA AS OF 1973—Land under cultivation or that prepared for cultivation was considered irrigated. From National Aeronautics and Space Administration Skylab S190B color infrared photograph, September 6, 1973

•••••••••••••••• BOUNDARY OF BOSQUE AREA

Figure 11.--Altitude of the water level and irrigated area in and near the Bosque area.

unit. All the units are saturated, but only the upper and middle units are considered as a source of water for development of the Ak-Chin supply. The composite thickness of the upper and middle units ranges from 1,600 ft in the southwestern part of the area to more than 2,200 ft about 1 mi southeast of the Bosque 2 test hole.

The upper unit is from 700 to 900 ft thick and is composed of unconsolidated grayish-brown coarse to fine gravel and sand, silt, and clay. Reddish silty layers are common and increase to the southwest. The log of a U.S. Bureau of Reclamation test hole (fig. 11) shows that 65 percent of the upper unit is composed of reddish-brown silty and clayey layers. In the Bosque 2 test hole 100 ft of the upper unit is saturated, and in the Bureau test hole, which is 8 mi west of Bosque 2, 550 ft of the upper unit is saturated. The contact between the middle and upper units was selected using the geophysical logs from the Bureau and Bosque 1 and Bosque 2 test holes. The middle unit has a higher and more uniform resistance and sonic velocity than the upper unit. The middle unit is 800 ft thick in the southwest corner of the area and thickens to more than 1,450 ft to the east and southeast. The middle unit is composed mainly of unconsolidated to poorly consolidated gray-brown fine to very coarse sand and fine to coarse gravel. The unit contains a few reddish-brown silty and clayey layers. The unit is mainly gravelly sand in the U.S. Bureau of Reclamation test hole, sand and gravel in Bosque 1, and silty and clayey gravelly sand and some crumbly tuffaceous sandstone in Bosque 2. The middle unit overlies an erosion surface cut on the lower unit.

The thickness of the lower unit is unknown; the Bureau and Bosque 1 and 2 test holes penetrate less than 200 ft of the unit. The unit consists of volcanic rocks interbedded with and underlain by moderately to weakly cemented conglomerate. The volcanic rocks consist of layers of welded tuff, tuff, interbedded tuffaceous sandstone, and dark andesitic flows that typically contain many small red grains of crystalline material. The conglomerate consists mainly of gravel and sand and has some cobbles, boulders, silt, and clay. Heindl and Armstrong (1963, p. 14) estimate the thickness of the conglomerate to be 1,500 ft near Gila Bend.

Ground-Water Movement

In the Bosque area ground water moves from southeast to northwest toward the cone of depression that has formed in response to ground-water withdrawal along the Gila Bend Canal (fig. 11). The hydraulic gradient in the central part of the area is about 13 ft/mi (fig. 11).

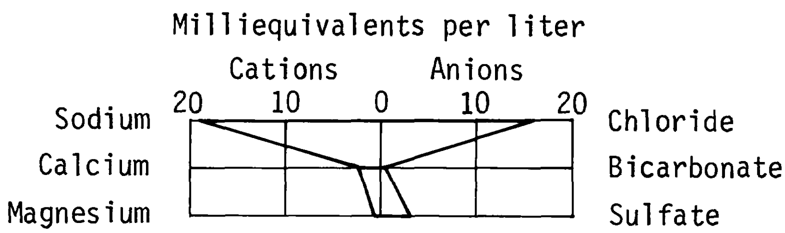
EXPLANATION

SPECIFIC CONDUCTANCE, IN MICROMHOS PER CENTIMETER AT 25°C		DISSOLVED SOLIDS (CALCULATED), IN MILLIGRAMS PER LITER
Less than 1,000		Less than 600
1,000 to 2,000		600 to 1,200
2,000 to 3,500		1,200 to 2,100
Insufficient data		Insufficient data

● WELL

○ TEST HOLE

CHEMICAL-QUALITY PATTERN DIAGRAM—Shows major chemical constituents in milliequivalents per liter. The patterns are in a variety of shapes and sizes, which provides a means of comparing, correlating, and characterizing similar or dissimilar types of water



DS=1050 DISSOLVED SOLIDS—Number, 1050, is dissolved solids in milligrams per liter

CONSOLIDATED ROCKS

•••••••••••••••• BOUNDARY OF AREA CONSIDERED FOR DEVELOPMENT OF THE AK-CHIN WATER SUPPLY

Figure 10.--Chemical quality of the ground water in the basin-fill deposits in the Waterman Wash area.

Depth to Water and Well Yields

In the Bosque area the depth to water ranges from 200 ft along the western margin to more than 700 ft at the southeast end of the area (fig. 12). Along the Gila Bend Canal 1 mi west of the Bosque area, wells that tap from 585 to 1,282 ft of the saturated basin fill yield more than 2,000 gal/min of water (fig. 12); therefore, yields of as much as 2,000 gal/min probably can be obtained from wells that penetrate the upper and middle units of the basin fill in the western part of the area. In the central part of the area Bosque 1 penetrates 1,347 ft of saturated upper and middle basin fill. The geophysical and lithologic logs for Bosque 1 indicate a potential yield of more than 2,000 gal/min.

Well yields decrease to the southeast, and the pilot well 150 ft from Bosque 2 penetrates 1,149 ft of saturated upper and middle basin fill. The material penetrated by the well consists mainly of clayey silty sand, of which 1,052 ft is open to the well. The well was pumped at 300 gal/min for 2 hours and had a drawdown of 150 ft. Aquifer-test data for the well indicate that the transmissivity of the upper and middle units is about 800 ft^2/d. Yields of properly constructed wells near Bosque 2 probably will be about 500 gal/min.

In the Bosque area the potential specific capacity of wells will range from 3 (gal/min)/ft near Bosque 2 to 60 (gal/min)/ft along the west margin, which would produce drawdowns of 33 ft at a discharge of 2,000 gal/min in wells along the west margin to 167 ft at a discharge of 500 gal/min near Bosque 2.

Estimated Amount of Recoverable Ground Water in Storage

The approximate saturated thickness of the upper and middle units of the basin-fill deposits in and near the Bosque area is shown in figure 12. The amount of recoverable ground water in storage—assuming a specific yield of 0.1—is shown in table 3.

Water-Level Declines

Water-level declines along the west side of the Bosque area are the result of ground-water withdrawals in adjacent areas along the Gila Bend Canal and west and northwest of the canal. During 1953-77, water levels declined 80 to 100 ft near the canal. During 1953-79, the water level declined 84 ft in a stock well in sec. 7, T. 5 S., R. 3 W., 3 mi east of the canal. During 1966-75, the water level declined 24 ft in a stock well in sec. 29, T. 5 S., R. 3 W.

E X P L A N A T I O N

——600—— APPROXIMATE LINE OF EQUAL DEPTH TO WATER—Interval 100 feet

APPROXIMATE SATURATED THICKNESS OF THE UPPER AND MIDDLE UNITS OF BASIN FILL, IN FEET

Less than 500

500 to 1,000

1,000 to 1,500

More than 1,500

Insufficient data

CONSOLIDATED ROCKS

TEST HOLE

BOUNDARY OF BOSQUE AREA

Figure 12.--Depth to water and saturated thickness of the upper and middle units of the basin-fill deposits in and near the Bosque area.

Table 3.--Amount of recoverable ground water in storage in the upper and middle units of the basin-fill deposits in the Bosque area

Depth below water table (feet)	Volume of saturated upper and middle basin fill (millions of acre-feet)	Amount of recoverable ground water in storage (millions of acre-feet)
0-500	18	1.8
500-1,500	18	1.8
Total amount in storage in the upper and middle units		3.6

Chemical Quality

In the area along the Gila Bend Canal adjacent to the Bosque area chemical analyses of the ground water from wells indicate that the water is of very poor quality for irrigation. Specific-conductance values range from 1,500 to 3,000 micromhos per centimeter at 25°C and average about 2,460 (fig. 13). The main ions in solution are sodium, chloride, bicarbonate, sulfate, and calcium. The salinity hazard is high to very high, and the sodium hazard is medium to very high (fig. 7); however, the water has been used for irrigation for more than 30 years and apparently has not caused soil alkalinity or salinity problems.

Analyses of water from Bosque 1 and 2 and from several stock wells in the area indicate that the chemical quality improves toward the east and southeast (fig. 13). The main ions in solution are sodium, chloride, bicarbonate, and sulfate. Water from Bosque 2 has a very high sodium hazard and a medium salinity hazard. The water is acceptable for irrigation if soil amendments and special management practices are used to prevent accumulation of salts in the soil.

POTENTIAL EFFECTS OF PROPOSED GROUND-WATER DEVELOPMENT

The potential effects of withdrawing 85,000 acre-ft/yr of ground water in the three areas being considered for the Ak-Chin supply are (1) ground water in storage will be depleted, and large water-level declines will result; (2) land subsidence and earth fissures could occur owing to the dewatering of the basin fill; and (3) the withdrawals and the resultant change in hydraulic gradients could cause a marked change in the chemical quality of the ground water. In this report it is assumed that the annual pumpage of 85,000 acre-ft would be withdrawn from a single area rather than a combination of areas. This assumption gives an approximation of the most unfavorable situation that could develop in each basin.

Water Levels

The prediction of water-level declines that will result from pumping 85,000 acre-ft/yr for 25 years is of necessity a crude approximation. The withdrawal of large amounts of water in a small area, such as the east-central part of the Waterman Wash area, will create a deep cone of depression near pumping wells. Some time after pumping ceases—perhaps in tens of years—the cone of depression will flatten as water moves into the area from adjacent areas, and the water-level decline eventually will become fairly uniform throughout the area. The prediction of water-level declines from the time pumping starts to the time the cone flattens can be made using a simulative mathematical

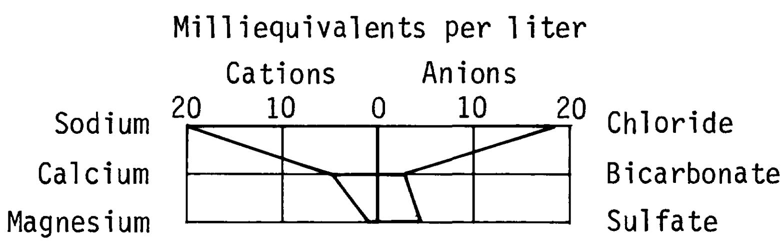
E X P L A N A T I O N

SPECIFIC CONDUCTANCE, IN MICROMHOS PER CENTIMETER AT 25°C	DISSOLVED SOLIDS (CALCULATED), IN MILLIGRAMS PER LITER
Less than 1,000	Less than 600
1,000 to 2,000	600 to 1,200
2,000 to 3,000	1,200 to 2,100
Insufficient data	Insufficient data

WELL

TEST HOLE

CHEMICAL-QUALITY PATTERN DIAGRAM—Shows major chemical constituents in milliequivalents per liter. The patterns are in a variety of shapes and sizes, which provides a means of comparing, correlating, and characterizing similar or dissimilar types of water



DS=1570 DISSOLVED SOLIDS—Number, 1570, is dissolved solids in milligrams per liter

CONSOLIDATED ROCKS

BOUNDARY OF BOSQUE AREA

Figure 13.--Chemical quality of the ground water in the basin-fill deposits in and near the Bosque area.

model. The model should be constructed prior to the development of the well field and should be revised and calibrated on a continuing basis as new data become available. For the purpose of this report, however, the water-level decline is projected to the time when the cone of depression flattens. It should be recognized that the water-level decline during the pumping period will be much greater near the well field than that given in this report. The conservative specific yield of 0.1 used in this report directly affects the predicted amount of long-term decline; if the specific yield is greater than 0.1, the water-level decline will be proportionately less.

If 85,000 acre-ft/yr of water were withdrawn uniformly throughout Vekol Valley, 12 ft/yr of decline would occur, and the cumulative decline in 25 years would be 300 ft. About 15 stock and domestic wells in the valley may require deepening. Withdrawals of 85,000 acre-ft/yr in the part of the Waterman Wash area being considered for development of the Ak-Chin water supply eventually would cause water-level declines of 8 ft/yr in the entire area. Because the water would be withdrawn only in the east-central part of the area, the rate of decline would be much larger near the well field, and it probably would take several years for the decline to spread over the entire area. The cumulative decline for 25 years would be 200 ft in addition to the decline being caused by the present pumpage of about 72,000 acre-ft/yr—a total cumulative decline of about 400 ft. The water-level decline would increase the pumping lift in about 50 irrigation wells and probably would require deepening about 8 stock and domestic wells. In the Bosque area the annual rate of decline would be 24 ft, and the cumulative decline in 25 years would be 600 ft in addition to the decline being caused by the present pumpage of about 70,000 acre-ft/yr in the adjacent areas along and west of the Gila Bend Canal. The decline would increase the pumping lift in about 40 irrigation wells and probably would require deepening about 5 stock and domestic wells.

Land Subsidence

Compaction of the water-bearing deposits and land subsidence may become a serious problem in the areas of large water-level declines. The weight of the deposits is partly borne by the ground water, and large ground-water declines may cause the deposits to settle. The inception of subsidence is dependent on the composition, degree of compaction, and cementation of the deposits being dewatered. Subsidence poses a threat to structures, especially in areas where differential amounts of subsidence produce earth fissures. Accurate projections cannot be made of when, how much, or if subsidence will occur because accurate methods are not available for predicting the amount of water-level decline required to start subsidence. According to R. L. Laney (oral commun., 1979), south-central Arizona basins similar to those in this study typically have from 2 to 5 ft of subsidence per 100 ft of water-level decline, and in this report the potential subsidence is estimated using these ratios.

In Vekol Valley 300 ft of water-level decline could cause from 0 to 15 ft of subsidence. In the Waterman Wash area 200 ft of water-level decline could cause from 0 to 10 ft of subsidence; in effect, the decline would double that expected from the continuation of the present pumpage. In the Bosque area 600 ft of water-level decline could cause from 0 to 30 ft of subsidence; however, the actual subsidence may be greater because of the existing nearby pumpage.

Chemical Quality

The withdrawal of 85,000 acre-ft/yr of ground water from Vekol Valley would cause major changes in the direction of ground-water movement, which would cause changes in the present distribution of dissolved solids in the water. In the east-central part of the Waterman Wash area the withdrawal of 85,000 acre-ft/yr of water would cause a reversal in the direction of ground-water movement from the northwest to the southeast and east. The specific conductance and dissolved solids in the ground water in the entire Waterman Wash area are largest in the northern part and decrease to the west, south, and southeast (fig. 10). The water that contains the large concentrations of dissolved solids could move into the east-central part of the area, which is being considered for development of the Ak-Chin water supply. The increase in dissolved solids would make the water less desirable for irrigation. As the water moves southeast, the dissolved-solids concentrations also could increase in the water in existing wells. In the Bosque area the withdrawal of 85,000 acre-ft/yr of water would cause a reversal in the direction of ground-water movement from the northwest to the southeast. The specific conductance and dissolved solids in the ground water are largest in the northwest and along the west margin and decrease to the east and southeast (fig. 13). Within a few years, the water that contains the large concentrations of dissolved solids could move into the central part of the area.

CONCLUSIONS AND RECOMMENDATIONS

Sufficient ground water to provide 85,000 acre-ft/yr or about 2.1 million acre-ft in a 25-year period is available for delivery to the Ak-Chin Indian Reservation from Federal land in the Vekol Valley, the Waterman Wash area, and the Bosque area. Many factors will influence the decision as to which area or combination of areas could or should be developed. The following tabulation gives a comparison of the factors in the areas. In the Waterman Wash area the effects of the ground-water withdrawal in the 64-mi^2 east-central part are distributed over the entire 210-mi^2 area.

Item	Vekol Valley	Waterman Wash area	Bosque area
Recoverable water in storage in millions of acre-feet:			
0 to 500 feet below the water table . . .	3.5	5.4	1.8
500 to 1,500 feet below the water table	4.2	4.9	1.8
Total	7.7	10.3	3.6
Probable well yield in gallons per minute . .	1,000 to 2,000	2,000 to 2,500	500 southeast 2,000 west
Probable drawdown in feet in a well pumping 1,000 gallons per minute	(?) south 67 north	27 to 133	16 to 334
Distance in miles from center of area to point of delivery . . .	30	27	41
Lift in feet above land surface from center of area to point of delivery . . .	0	50	500
Average annual water-level decline in feet	12	8	24
Existing irrigation wells that could be adversely affected . . .	0	50	40
Existing domestic and stock wells that could be adversely affected	15	8	5
Potential subsidence in feet	0 to 15	0 to 10	0 to 30
Salinity hazard in irrigation water	High	High to very high	High to very high
Sodium hazard in irrigation water	Medium to high	High to very high	Medium to very high

The following steps are recommended to minimize the cost and adverse effects of development of the Ak-Chin water supply.

1. The approximation of the extent and thickness of the basin-fill deposits should be refined using surface geophysical methods, such as resistivity, seismic-reflection, and seismic-refraction surveys.

2. Mathematical models should be constructed to simulate the water-level declines in the basin-fill deposits and the subsidence in each area. The models should be constructed prior to development and should be modified as new data become available. Using the models as predictive tools, the data-collection program and design of the well fields should be modified during development to derive optimum solutions to such problems as areal distribution of water-level declines, land subsidence, and pumping costs. The models also can be used to evaluate the extent of the deleterious effects caused by the Ak-Chin pumpage and to separate these effects from those caused by existing pumpage.

3. Drill cuttings and core samples should be collected and lithologic and geophysical logs should be made for each well drilled during development to determine the water-bearing characteristics of the basin fill.

4. Short-term aquifer tests (24- to 48-hour duration) should be made in most of the wells, and long-term aquifer tests (10- to 20-day duration) should be made in about 10 percent of the wells to determine the water-yielding characteristics of the basin fill.

5. A network of bench marks should be installed, and first-order levels should be run periodically to determine the amount of land subsidence near existing wells and near the new development for the Ak-Chin water supply. High-resolution aerial photographs should be taken at intervals to document the formation of earth fissures.

6. About six small-diameter test holes should be drilled in each area and extensiometers should be installed to record aquifer compaction and land subsidence.

7. An observation-well network should be established in and near existing wells and the proposed well fields to

monitor water-level declines caused by existing pumpage and those caused by the new development for the Ak-Chin water supply. Meters should be installed on all production wells to monitor the rate and duration of pumping.

8. Water samples from existing and new wells should be analyzed periodically to monitor any change in chemical quality with time. Water samples from different depths in selected wells should be analyzed to detect whether or not the chemical quality is uniform with depth. Changes in chemical quality with depth should be measured using packers and specific-conductivity, temperature, and ion probes. If there is a large variation in water quality, a solute-transport model should be developed to estimate the potential effect of the existing and new pumpage on the quality of the water.

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