EVALUATION OF GROUND-WATER RECHARGE ALONG THE GILA RIVER AS A RESULT OF THE FLOOD OF OCTOBER 1983, IN AND NEAR THE GILA RIVER INDIAN RESERVATION, MARICOPA AND PINAL COUNTIES, ARIZONA

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CONVERSION FACTORS

For readers who prefer to use International System (SI) units, conversion factors for the terms in this report are listed below:

Multiply inch-pound units	*By*	*To obtain metric units*
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "*Sea Level Datum of 1929*."

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ABSTRACT

Flow in the Gila River from the flood of October 1983 infiltrated the stream channel and recharged the ground-water system along the Gila River flood plain from Ashurst-Hayden Dam to the confluence with the Salt River. Changes in ground-water levels from January 1983 to March 1984 confirmed the occurrence of recharge to the ground-water system. The average water-level change for 74 wells was +24.2 feet. The magnitude of water-level changes and the distribution of recharge throughout the study area probably were due to general or localized differences in geologic characteristics in the sediments being recharged, quantity of water available, and duration of availability of the water. On the basis of the geologic characteristics, the study area was subdivided into four subareas, starting at Ashurst-Hayden Dam (river mile 0). The water-level rise was greatest in the reach from river mile 15 to river mile 22, where the average water-level change for 10 wells was +59.4 feet.

Estimates of recharge from January 1983 to March 1984 ranged from 449,000 to 640,000 acre-feet. A water-budget method and a water-level change method were used to estimate the recharge to the aquifer. About 46 to 66 percent of the recharge from October 1983 to March 1984 was the result of streamflow infiltration from the Gila River. The estimated quantity of recharge was one to two times greater than the quantity of ground water pumped from the Gila River Indian Reservation during the 10 years preceding the flood.

INTRODUCTION

A cooperative study between the U.S. Geological Survey and the U.S. Bureau of Indian Affairs was begun in 1985 to evaluate the effects of the flood of October 1983 on the ground-water system in and near the Gila River Indian Reservation, Maricopa and Pinal Counties, Arizona. The study was based on hydrologic data collected by the U.S. Geological Survey and the San Carlos Irrigation Project in the area before, during, and after the flood. Water-level measurements and a water budget were used to estimate the volume of recharge.

The flood of October 1983 filled the San Carlos Reservoir, which is upstream from the study area. Infiltration from tributary inflow and releases from the reservoir resulted in significant recharge to the alluvial aquifer in a 71-mile reach of the Gila River from Ashurst-Hayden Dam to the confluence with the Salt River (fig. 1). The study area is a sediment-filled valley surrounded by low mountains in south-central Arizona and includes the Gila River Indian Reservation and adjacent lands east of the reservation to Ashurst-Hayden Dam. An unconfined aquifer underlies the area and receives recharge from periodic infiltration of streamflow.

Water resources within the area consist of surface water diverted from the Gila River and ground water pumped from the extensive aquifer. The periodic recharge to the aquifer has not kept pace with ground-water withdrawal. Pumpage in excess of recharge has resulted in declining water levels since the 1940's. In October 1983, major flooding of the Gila River occurred as a result of large amounts of precipitation over southeastern Arizona and western New Mexico. Total rainfall in the Gila River drainage from September 28 to October 3 ranged from 5.5 in. at Florence to 11.2 in. near Clifton (Garrett and others, 1986). Thousands of acre-feet of streamflow infiltrated the channel and flood plain, resulting in widespread recharge to the aquifer. The recharge was confirmed by a rise in ground-water levels along the Gila River.

Purpose and Scope

The purpose of this study was to evaluate the quantity and distribution of recharge to the ground-water system that was a result of the flood of October 1983. Effects of streamflow loss on ground-water recharge were determined, and the volume of recharge was estimated. Geohydrologic factors that control distribution of recharge were also defined.

Methods

A water-budget method and a water-level change method were used to determine the effect of the flood on the ground-water system and to estimate recharge to the aquifer. The water-budget method used streamflow data, canal diversions, and water use by crops. The water-level change method used water levels measured during January and November 1983, and January, March, and April 1984.

Water-Budget Method

For the water-budget method, the difference between inflow and outflow is the change in storage. Inflow consists of streamflow at Ashurst-Hayden Dam and water delivered to the area through a canal system. Outflow consists of streamflow at the Gila River and Salt River confluence and consumptive use by crops (table 1).

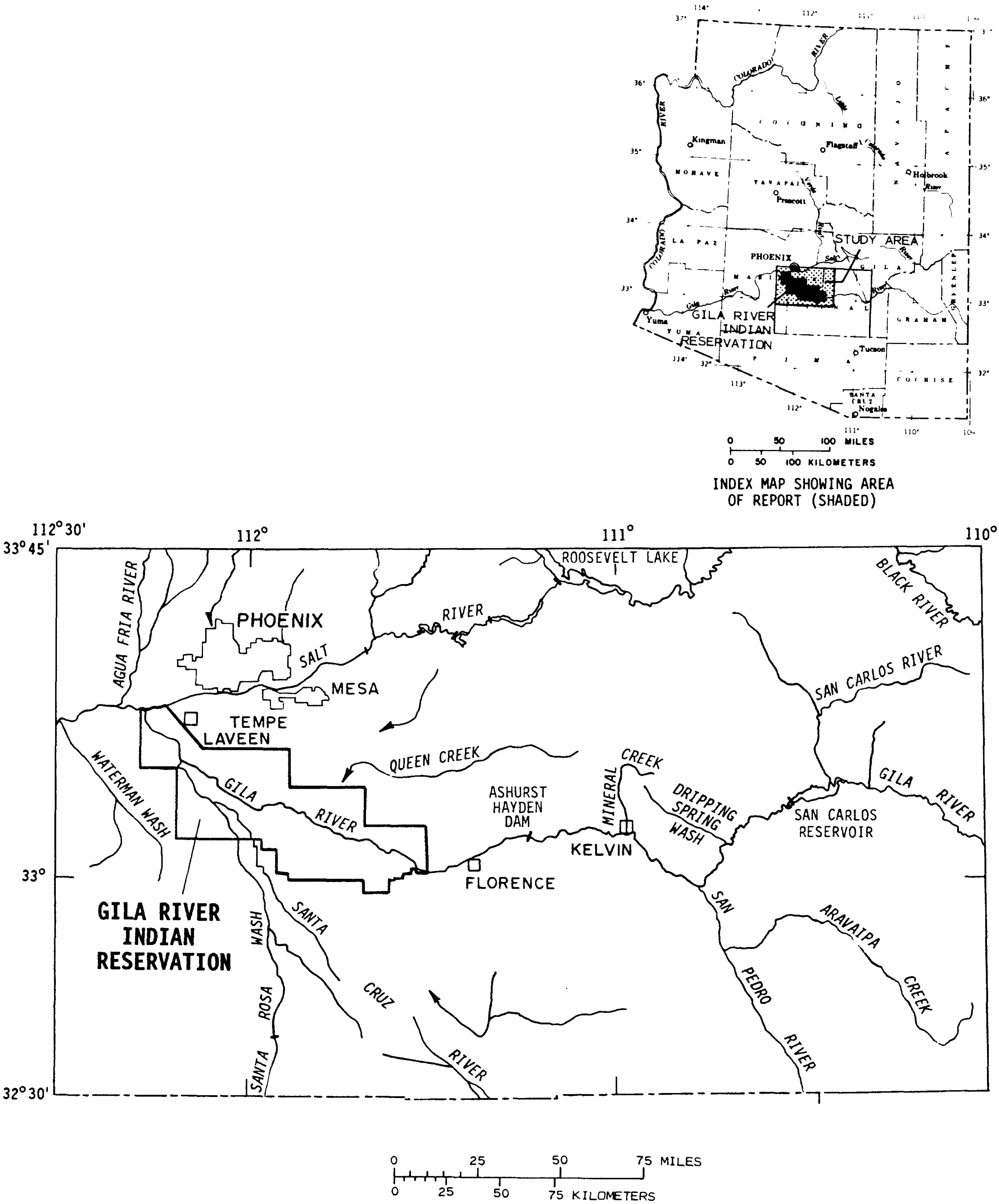


Figure 1.--Location of study area.

Table 1.--*Water budget for the Gila River from Ashurst-Hayden Dam to the confluence with the Salt River, January 1983 to March 1984*

Inflow, in acre-feet		
Surface water at Ashurst-Hayden Dam............	543,000	
Surface-water diversions in canal system.......	110,000	
Subtotal...............................		653,000
Outflow, in acre-feet		
Surface water at Gila River and Salt River confluence	147,000	
Consumptive use by crops	57,000	
Subtotal...............................		204,000
Inflow minus outflow.....................		449,000

Estimates of streamflow in the study area were based on data collected at four streamflow-gaging stations in and near the study area. Gaging stations in the study area are Florence-Casa Grande Canal near Florence (09475500), Gila River near Laveen (09479500), and Santa Cruz River near Laveen (09489000) (pl. 1). Also included is the gaging station, Gila River at Kelvin (09474000), 19 mi upstream from Ashurst-Hayden Dam (fig. 1). Streamflow into the study area in the Gila River below Ashurst-Hayden Dam was estimated on the basis of measured volume of flow at the gaging station, Gila River at Kelvin, minus diversions into the Florence-Casa Grande Canal at Ashurst-Hayden Dam. A part of the surface water diverted into the Florence-Casa Grande Canal is delivered to the Gila River Indian Reservation and surrounding area through a network of canals. Streamflow out of the study area at the Salt River confluence is the difference between the flow gaged at the Gila River near Laveen and the estimated streamflow losses between Laveen and the Salt River confluence. Crop-type and irrigated-acreage data, supplied by the U.S. Bureau of Indian Affairs, San Carlos Irrigation Project, were used to estimate consumptive use by crops. Information on water use by crops is described in Erie and others (1968).

Streamflow losses from Ashurst-Hayden Dam to Laveen were computed by subtracting the flow at the gaging station, Gila River near Laveen, from the estimated flow into the study area (table 2). Streamflow losses from Laveen to the confluence with the Salt River and intermediate losses between Ashurst-Hayden Dam and Laveen were estimated on the basis of streamflow loss per given length of channel from Ashurst-Hayden Dam to Laveen. Several large ungaged tributaries between Kelvin and Laveen may have contributed flow; however, flow was not measured and was assumed to be small compared to the total volume of flow.

The assumption was made that losses through infiltration between Kelvin and Ashurst-Hayden Dam were negligible because nearly impermeable crystalline rocks underlie the river at shallow depths. Evapotranspiration

Table 2.--*Streamflow and streamflow losses in the Gila River, January 1983 through March 1984*

Site	1983				January through March 1984	October 1983 through March 1984
	January to September	October	November	December		
Streamflow, in acre-feet						
Gila River at Kelvin...........	334,000	269,000	45,000	102,000	174,000	590,000
Florence-Casa Grande Canal near Florence....	245,000	1,000	9,000	24,000	102,000	136,000
Gila River near Laveen...........	6,000	164,000	11,000	12,000	15,000	202,000
Santa Cruz River near Laveen......	25,000	111,000	0	249	40	111,000
Streamflow losses, in acre-feet						
Ashurst-Hayden Dam to Gila River near Laveen (60 miles).......	83,000	104,000	25,000	66,000	57,000	252,000
Ashurst-Hayden Dam to east boundary of the Gila River Indian Reservation (17 miles)[1]......	24,000	29,000	7,000	19,000	16,000	71,000
Ashurst-Hayden Dam to Sacaton Dam near Olberg (30 miles)[1]......	42,000	52,000	12,000	33,000	28,000	126,000
Laveen to Salt River confluence (11 miles)[1] ...	15,000	19,000	5,000	12,000	10,000	46,000

[1]Estimated.

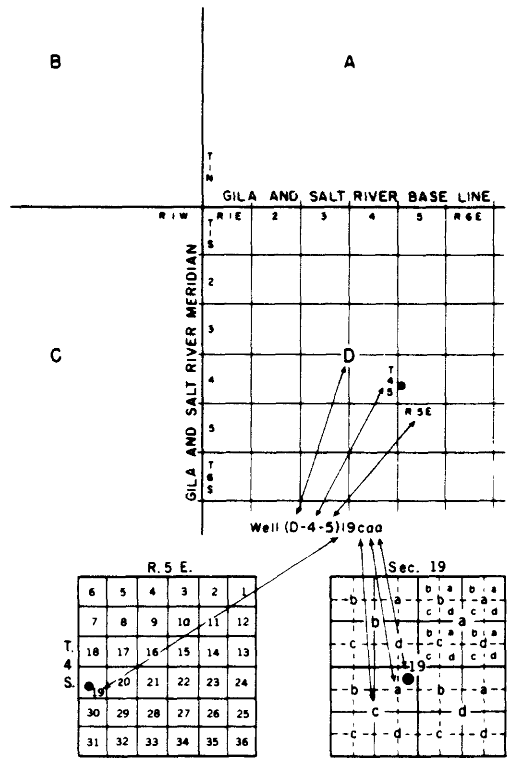
during and after the flood was considered insignificant because flow occurred during the fall and winter months when evapotranspiration potential was low.

For part of the flood period, flow at Gila River at Kelvin was estimated because equipment malfunctioned during the high-flow period. Flow at Kelvin during and after the peak was computed on the basis of high-water marks and a discharge measurement made after the flood. For several days, streamflow was estimated by flood-routing methods (H.W. Hjalmarson, hydrologist, U.S. Geological Survey, written commun., 1984) for Gila River near Laveen and Santa Cruz River near Laveen. Accuracy of the streamflow data for Gila River near Kelvin for the 1984 water year was rated good except for October 1 to 5, which was poor; for Gila River near Laveen, the data were rated fair. Data are rated good if 95 percent of the daily discharges are within 10 percent of the true discharge. Data rated fair are considered within 15 percent of the true discharge; and data rated poor have less than fair accuracy.

Water-Level Change Method

The water-level change method was used to determine change in storage in the ground-water system. Ground-water levels measured during January (Thomsen and Baldys, 1985) and November 1983 and January, March, and April 1984 were used to determine changes in water levels (table 3). Measurements made during January 1983 were used to represent the preflood water-level conditions and in this report will be considered the base water level. In November 1983, 102 wells were measured in and near the Gila River flood plain (pl. 1). These wells are numbered in accordance with the well-numbering system used in Arizona described in figure 2. Additional water-level measurements were made in most wells in January, March, and April 1984 (table 3). Water-level changes were determined by comparing measurements before and after flooding (table 4). Recorders were installed on two wells in December 1983 to monitor water-level changes near the Gila River (pl. 1).

To estimate change in storage in the ground-water system, the study area was divided into four subareas (pl. 1). The subareas were divided on the basis of geologic factors and selected grain-size characteristics in the upper alluvium (pl. 2). Subarea 1 includes the area from river mile 0 at Ashurst-Hayden Dam downstream to river mile 15 and has a sand and gravel content that ranges from 60 to about 80 percent. Subarea 2, which extends from river mile 15 to 22, is bounded on the north by crystalline rocks and has a sand and gravel content of less than 20 percent to the south. Subarea 3, which extends from river mile 22 to river mile 40, has a sand and gravel content that ranges from 40 to 60 percent. Subarea 4, which extends from river mile 40 to the confluence of the Salt River, is the largest and most laterally extensive subarea and has a sand and gravel content that ranges from 40 to 80 percent. Average ground-water level changes and change in storage were computed for each subarea. The change in storage is the product of the area of the subarea, average water-level change, and average specific yield of 15 percent (Babcock, 1970). The change in storage for the study area is the sum of change in storage for each subarea (table 5).



The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants. These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (D-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 S., R. 5 E. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Figure 2.--Well-numbering system in Arizona.

Table 3.--*Depth to water in selected wells*

[Dashes indicate no data]

Well number	Depth to water, in feet				
	1983		1984		
	Base[1]	November[2]	January[2]	March[3]	April[3]
(D-1-1)3add	73.10	15.10	19.40	16.60	------
(D-1-1)13ddd1	62.10	62.57	60.90	59.89	59.70
(D-1-2)7cba	43.40	50.70	55.20	------	------
(D-1-2)19aaa	44.10	40.20	38.30	------	------
(D-1-2)20add	62.50	60.80	57.00	------	54.90
(D-1-2)31aca	34.30	31.60	31.70	31.00	------
(D-2-2)15cbb	36.50	34.30	32.60	31.10	33.60
(D-2-2)29adb	38.60	36.70	36.30	34.30	34.00
(D-2-3)1bda	116.60	114.50	110.00	101.90	101.60
(D-2-3)1dac1	102.60	99.80	103.90	97.10	------
(D-2-3)9abc2	105.30	------	106.80	105.70	------
(D-2-3)11bab	102.40	99.50	103.60	------	101.40
(D-2-3)21cdc	82.10	79.00	77.20	82.10	------
(D-2-3)22ddd	85.10	82.40	79.70	75.50	0.00
(D-2-3)25add	94.90	90.50	88.70	------	90.60
(D-2-3)25baa	94.10	90.30	88.40	87.10	------
(D-2-4)25ddd	104.70	105.60	99.90	------	------
(D-3-2)23acd	100.40	89.30	88.50	87.90	87.60
(D-3-2)23add	90.00	88.70	85.20	84.70	84.20
(D-3-2)25aaa	79.90	78.10	76.00	75.00	74.90
(D-3-4)1aaa	106.50	110.60	98.90	0.00	0.00
(D-3-4)24cda	120.90	113.00	101.90	100.30	103.20
(D-3-4)25bda	127.80	118.70	109.30	105.30	113.20
(D-3-4)32dab	111.30	103.10	------	------	------
(D-3-4)33adc	139.40	132.80	127.80	120.90	122.10
(D-3-4)34cbb	104.90	70.50	------	------	------
(D-3-4)35dcb	136.50	133.70	125.30	130.80	131.30
(D-3-5)4bbc	100.70	102.00	99.60	100.10	103.20
(D-3-5)13add1	149.60	163.90	------	------	------
(D-3-5)14ddd	132.10	117.70	107.90	113.10	114.00
(D-3-5)25cda	112.20	97.90	86.70	90.70	92.20
(D-3-5)29bcb	100.40	74.70	61.60	------	------
(D-3-5)30ccc	98.90	94.00	84.80	78.10	81.30
(D-3-5)30dad	108.30	101.40	81.30	80.10	81.30
(D-3-5)33aaa	100.60	78.70	63.10	70.60	74.90
(D-3-5)33cdd	84.60	79.50	72.20	67.30	65.00
(D-3-6)17bdd	195.60	183.30	190.70	------	------
(D-3-6)29add	150.20	155.80	136.00	131.50	133.00
(D-3-6)31aba	114.10	110.80	93.60	------	------
(D-4-3)1aac	181.10	171.10	161.60	164.80	164.60

See footnotes at end of table.

Table 3.--*Depth to water in selected wells*--Continued

Well number	Depth to water, in feet				
	1983		1984		
	Base[1]	November[2]	January[2]	March[3]	April[3]
(D-4-3)2cbb	128.60	112.60	106.30	98.50	96.10
(D-4-3)9cdd PZ1	156.80	144.30	154.60	154.00	153.80
(D-4-3)9cdd PZ2	186.70	173.60	169.90	180.90	190.40
(D-4-3)12ddd	233.80	228.20	209.80	------	227.20
(D-4-3)12ddd	233.80	228.20	209.80	------	227.20
(D-4-4)1aaa	155.90	127.50	121.70	118.46	124.60
(D-4-3)12ddd	233.80	228.20	209.80	------	227.20
(D-4-4)1aaa	155.90	127.50	121.70	118.46	124.60
(D-4-4)1ccc1	137.60	143.40	------	------	------
(D-4-4)1ccc2	173.10	164.90	156.80	155.40	161.10
(D-4-4)3ddd	191.00	177.60	168.90	168.60	169.90
(D-4-4)7cdd	240.10	233.30	------	------	------
(D-4-4)16cdd	275.30	264.10	------	------	------
(D-4-4)16ddd	277.50	272.10	251.40	------	------
(D-4-5)2bcb	94.00	86.60	75.80	77.20	76.60
(D-4-5)6baa	127.50	122.00	115.90	109.90	113.80
(D-4-5)10ccd	119.00	122.80	120.20	119.10	123.40
(D-4-5)11bba	92.20	89.90	82.80	82.40	------
(D-4-5)12bbd	96.00	90.50	82.50	82.00	------
(D-4-5)14dbb	139.70	142.40	141.80	140.00	146.10
(D-4-6)4aaa	135.80	129.60	123.10	117.10	------
(D-4-6)4cad	106.10	98.90	85.20	84.40	------
(D-4-6)4ddd	104.40	93.50	81.80	82.30	87.30
(D-4-6)7add	92.60	96.90	------	------	------
(D-4-6)8ddd	91.50	93.70	82.30	83.80	78.70
(D-4-6)12dad	102.30	84.50	58.80	50.20	51.90
(D-4-6)21bbb	133.20	138.80	135.70	134.00	131.80
(D-4-6)23baa	92.90	83.50	73.40	66.60	------
(D-4-6)24bbb	95.90	83.10	71.00	64.60	------
(D-4-7)19bbc	100.10	87.20	73.10	64.50	------
(D-4-7)19ccc	105.50	99.90	89.80	80.70	77.30
(D-4-7)28add	150.80	143.30	131.90	117.40	------
(D-4-7)30daa	111.30	107.40	100.00	90.50	85.40
(D-4-7)34aaa	177.00	161.90	148.00	137.40	134.00
(D-4-7)34bad	175.20	159.60	147.50	137.70	------
(D-4-7)35dad	151.20	149.50	141.10	130.20	124.80
(D-4-7)36dcc	133.00	131.40	133.10	------	------
(D-4-8)31dda	212.80	196.70	------	------	------
(D-4-8)32add	225.10	------	------	176.60	------
(D-4-8)33ddb	236.40	218.00	208.00	189.90	180.50
(D-4-8)35daa	162.10	155.50	143.90	135.20	------

See footnotes at end of table.

Table 3.--*Depth to water in selected wells*--Continued

Well number	Depth to water, in feet				
	1983		1984		
	Base[1]	November[2]	January[2]	March[3]	April[3]
(D-4-9)28cca	209.40	206.60	195.60	------	------
(D-4-9)28dac	203.90	199.30	192.10	190.90	------
(D-4-9)30ccd	187.50	184.70	------	------	------
(D-4-9)32baa	187.70	182.90	175.50	177.70	167.90
(D-4-10)10dad	16.00	9.50	8.70	------	------
(D-4-10)12aab	74.30	68.20	64.60	64.60	62.20
(D-4-10)16acc	112.80	75.20	66.70	70.10	69.30
(D-4-10)18dcd PZ1	224.70	225.90	225.70	------	------
(D-4-10)18dcd PZ2	224.30	224.80	224.50	------	------
(D-4-10)21acd	145.30	------	104.50	101.20	103.50
(D-4-10)28baa	167.50	159.40	142.20	------	------
(D-4-10)29ddc	212.70	211.80	207.10	203.60	203.20
(D-4-10)30bdd	152.00	140.00	126.90	122.20	135.20
(D-4-10)31daa	220.40	217.70	213.90	------	------
(D-4-11)6dcc	49.90	37.80	35.40	39.40	38.60
(D-5-8)2aaa	153.60	142.80	130.10	100.90	99.30
(D-5-8)4ccb	225.40	206.60	185.50	172.30	------
(D-5-8)5bba	213.80	197.90	168.50	150.30	------
(D-5-8)7baa	217.60	208.00	174.30	160.10	------
(D-5-8)9aad	158.00	101.70	74.30	82.30	77.40
(D-5-8)9dac	201.30	------	------	------	187.50
(D-5-8)10add	129.20	74.60	60.00	69.90	90.20
(D-5-8)10bad	239.60	160.40	143.90	129.80	------
(D-5-8)11cdc	129.00	106.20	92.80	------	------
(D-5-8)17bbb2	145.30	------	126.10	------	------
(D-5-9)2abd	203.90	202.60	195.10	190.30	198.40
(D-5-9)5ccd	139.90	147.80	------	------	------
(D-5-9)6aac	148.40	------	------	72.00	------
(D-5-9)9aba	188.40	189.00	175.90	------	------
(D-5-9)9dad	217.30	218.10	207.80	------	------

[1]Base water-level measurement, made during January 1983.
[2]Runoff and controlled releases occurred during October 1983 to January 1984.
[3]No flow in the study area after February 1984.

A data base, which contained 20 variables for each well, was used for analysis of water-level changes and for correlation purposes. The data base included well name and number; construction data, where available; depth to water; date of water-level measurement; changes in

Table 4.--Changes in water levels in selected wells, January 1983 to April 1984

[Dashes indicate no data]

Well number	Change in water level, in feet, from base[1] November 1983	January 1984	March 1984	April 1984	Change in water level, in feet, between consecutive measurements November 1983 to January 1984	January to March 1984	March to April 1984	November 1983 to April 1984
(D-1-1)3add	58.00	53.70	56.50	------	-4.30	2.80	------	------
(D-1-1)13ddd1	-0.47	1.20	2.21	2.40	1.67	1.01	0.19	2.87
(D-1-2)7cba	-7.30	-11.80	------	------	-4.50	------	------	------
(D-1-2)19aaa	3.90	5.80	------	------	1.90	------	------	------
(D-1-2)20add	1.70	5.50	------	7.60	3.80	------	------	5.90
(D-1-2)31aca	2.70	2.60	3.30	------	-0.10	0.70	------	------
(D-2-2)15cbb	2.20	3.90	5.40	2.90	1.70	1.50	-2.50	0.70
(D-2-2)29adb	1.90	2.30	4.30	4.60	0.40	2.00	0.30	2.70
(D-2-3)1bda	2.10	6.60	14.70	15.00	4.50	8.10	0.30	12.90
(D-2-3)1dac1	2.80	-1.30	5.50	------	-4.10	6.80	------	------
(D-2-3)9abc2	------	-1.50	-0.40	------	------	1.10	------	------
(D-2-3)11bab	2.90	-1.20	------	1.00	-4.10	------	------	-1.90
(D-2-3)21cdc	3.10	4.90	0.00	------	1.80	-4.90	------	------
(D-2-3)22ddd	2.70	5.40	9.60	------	2.70	4.20	------	------
(D-2-3)25add	4.40	6.20	------	4.30	1.80	------	------	-0.10
(D-2-3)25baa	3.80	5.70	7.00	------	1.90	1.30	------	------
(D-2-4)25ddd	-0.90	4.80	------	------	5.70	------	------	------
(D-3-2)23acd	11.10	11.90	12.50	12.80	0.80	0.60	0.30	1.70
(D-3-2)23add	1.30	4.80	5.30	5.80	3.50	0.50	0.50	4.50
(D-3-2)25aaa	1.80	3.90	4.90	5.00	2.10	1.00	0.10	3.20
(D-3-4)1aaa	-4.10	7.60	------	------	11.70	------	------	------
(D-3-4)24cda	7.90	19.00	20.60	17.70	11.10	1.60	-2.90	9.80
(D-3-4)25bda	9.10	18.50	22.50	14.60	9.40	4.00	-7.90	5.50
(D-3-4)32dab	8.20	------	------	------	------	------	------	------
(D-3-4)33adc	6.60	11.60	18.50	17.30	5.00	6.90	-1.20	10.70
(D-3-4)34cbb	34.40	------	------	------	------	------	------	------
(D-3-4)35dcb	2.80	11.20	5.70	5.20	8.40	-5.50	-0.50	2.40
(D-3-5)4bbc	-1.30	1.10	0.60	-2.50	2.40	-0.50	-3.10	-1.20
(D-3-5)13add1	-14.30	------	------	------	------	------	------	------
(D-3-5)14ddd	14.40	24.20	19.00	18.10	9.80	-5.20	-0.90	3.70
(D-3-5)25cda	14.30	25.50	21.50	20.00	11.20	-4.00	-1.50	5.70
(D-3-5)29bcb	25.70	38.80	------	------	13.10	------	------	------
(D-3-5)30ccc	4.90	14.10	20.80	17.60	9.20	6.70	-3.20	12.70
(D-3-5)30dad	6.90	27.00	28.20	27.00	20.10	1.20	-1.20	20.10
(D-3-5)33aaa	21.90	37.50	30.00	25.70	15.60	-7.50	-4.30	3.80
(D-3-5)33cdd	5.10	12.40	17.30	19.60	7.30	4.90	2.30	14.50
(D-3-6)17bdd	12.30	4.90	------	------	-7.40	------	------	------
(D-3-6)29add	-5.60	14.20	18.70	17.20	19.80	4.50	-1.50	22.80
(D-3-6)31aba	3.30	20.50	------	------	17.20	------	------	------
(D-4-3)1acc	10.00	19.50	16.30	16.50	9.50	-3.20	0.20	6.50
(D-4-3)2cbb	16.00	22.30	30.10	32.50	6.30	7.80	2.40	16.50
(D-4-3)9cdd PZ1	12.50	2.20	2.80	3.00	-10.30	0.60	0.20	-9.50
(D-4-3)9cdd PZ2	13.10	16.80	5.80	-3.70	3.70	-11.00	-9.50	-16.80
(D-4-3)12ddd	5.60	24.00	------	6.60	18.40	------	------	1.00
(D-4-4)1aaa	28.40	34.20	37.44	31.30	5.80	3.24	-6.14	2.90
(D-4-4)1ccc1	-5.80	------	------	------	------	------	------	------
(D-4-4)1ccc2	8.20	16.30	17.70	12.00	8.10	1.40	-5.70	3.80
(D-4-4)3ddd	13.40	22.10	22.40	21.10	8.70	0.30	-1.30	7.70
(D-4-4)7cdd	6.80	------	------	------	------	------	------	------
(D-4-4)16cdd	11.20	------	------	------	------	------	------	------
(D-4-4)16ddd	5.40	26.10	------	------	20.70	------	------	------
(D-4-5)2bcb	7.40	18.20	16.80	17.40	10.80	-1.40	0.60	10.00
(D-4-5)6baa	5.50	11.60	17.60	13.70	6.10	6.00	-3.90	8.20
(D-4-5)10ccd	-3.80	-1.20	-0.10	-4.40	2.60	1.10	-4.30	-0.60

See footnote at end of table.

Table 4.--Changes in water levels in selected wells, January 1983 to April 1984--Continued

Well number	Change in water level, in feet, from base[1]				Change in water level, in feet, between consecutive measurements			
	November 1983	January 1984	March 1984	April 1984	November 1983 to January 1984	January to March 1984	March to April 1984	November 1983 to April 1984
(D-4-5)11bba	2.30	9.40	9.80	------	7.10	0.40	------	------
(D-4-5)12BBD	5.50	13.50	14.00	------	8.00	0.50	------	------
(D-4-5)14DBB	-2.70	-2.10	-0.30	-6.40	0.60	1.80	-6.10	-3.70
(D-4-6)4aaa	6.20	12.70	18.70	------	6.50	6.00	------	------
(D-4-6)4cad	7.20	20.90	21.70	------	13.70	0.80	------	------
(D-4-6)4ddd	10.90	22.60	22.10	17.10	11.70	-0.50	-5.00	6.20
(D-4-6)7add	-4.30	------	------	------	------	------	------	------
(D-4-6)8ddd	-2.20	9.20	7.70	12.80	11.40	-1.50	5.10	15.00
(D-4-6)12dad	17.80	43.50	52.10	50.40	25.70	8.60	-1.70	32.60
(D-4-6)21bbb	-5.60	-2.50	-0.80	1.40	3.10	1.70	2.20	7.00
(D-4-6)23baa	9.40	19.50	26.30	------	10.10	6.80	------	------
(D-4-6)24bbb	12.80	24.90	31.30	------	12.10	6.40	------	------
(D-4-7)19bbc	12.90	27.00	35.60	------	14.10	8.60	------	------
(D-4-7)19ccc	5.60	15.70	24.80	28.20	10.10	9.10	3.40	22.60
(D-4-7)28add	7.50	18.90	33.40	------	11.40	14.50	------	------
(D-4-7)30daa	3.90	11.30	20.80	25.90	7.40	9.50	5.10	22.00
(D-4-7)34aaa	15.10	29.00	39.60	43.00	13.90	10.60	3.40	27.90
(D-4-7)34bad	15.60	27.70	37.50	------	12.10	9.80	------	------
(D-4-7)35dad	1.70	10.10	21.00	26.40	8.40	10.90	5.40	24.70
(D-4-7)36dcc	1.60	-0.10	------	------	-1.70	------	------	------
(D-4-8)31dda	16.10	------	------	------	------	------	------	------
(D-4-8)32add	------	------	48.50	------	------	------	------	------
(D-4-8)33ddb	18.40	28.40	46.50	55.90	10.00	18.10	9.40	37.50
(D-4-8)35daa	6.60	18.20	26.90	------	11.60	8.70	------	------
(D-4-9)28cca	2.80	13.80	------	------	11.00	------	------	------
(D-4-9)28dac	4.60	11.80	13.00	------	7.20	1.20	------	------
(D-4-9)30ccd	2.80	------	------	------	------	------	------	------
(D-4-9)32baa	4.80	12.20	10.00	19.80	7.40	-2.20	9.80	15.00
(D-4-10)10dad	6.50	7.30	------	------	0.80	------	------	------
(D-4-10)12aab	6.10	9.70	9.70	12.10	3.60	0.00	2.40	6.00
(D-4-10)16acc	37.60	46.10	42.70	43.50	8.50	-3.40	0.80	5.90
(D-4-10)18dcd PZ1	-1.20	-1.00	------	------	0.20	------	------	------
(D-4-10)18dcd PZ2	-0.50	-0.20	------	------	0.30	------	------	------
(D-4-10)21acd	------	40.80	44.10	41.80	------	3.30	-2.30	------
(D-4-10)28baa	8.10	25.30	------	------	17.20	------	------	------
(D-4-10)29ddc	0.90	5.60	9.10	9.50	4.70	3.50	0.40	8.60
(D-4-10)30bdd	12.00	25.10	29.80	16.80	13.10	4.70	-13.00	4.80
(D-4-10)31daa	2.70	6.50	------	------	3.80	------	------	------
(D-4-11)06dcc	12.10	14.50	10.50	11.30	2.40	-4.00	0.80	-0.80
(D-5-8)2aaa	10.80	23.50	52.70	54.30	12.70	29.20	1.60	43.50
(D-5-8)4ccb	18.80	39.90	53.10	------	21.10	13.20	------	------
(D-5-8)5bba	15.90	45.30	63.50	------	29.40	18.20	------	------
(D-5-8)7baa	9.60	43.30	57.50	------	33.70	14.20	------	------
(D-5-8)9aad	56.30	83.70	75.70	80.60	27.40	-8.00	4.90	24.30
(D-5-8)9dac	------	------	------	13.80	------	------	------	------
(D-5-8)10add	54.60	69.20	59.30	39.00	14.60	-9.90	-20.30	-15.60
(D-5-8)10bad	79.20	95.70	109.80	------	16.50	14.10	------	------
(D-5-8)11cdc	22.80	36.20	------	------	13.40	------	------	------
(D-5-8)17bbb2	------	19.20	------	------	------	------	------	------
(D-5-9)2abd	1.30	8.80	13.60	5.50	7.50	4.80	-8.10	4.20
(D-5-9)5ccd	-7.90	------	------	------	------	------	------	------
(D-5-9)6aac	------	------	76.40	------	------	------	------	------
(D-5-9)9aba	-0.60	12.50	------	------	13.10	------	------	------
(D-5-9)9dad	-0.80	9.50	------	------	10.30	------	------	------

[1]Base water-level measurement made during January 1983.

Table 5.--Average change in ground-water levels and change in aquifer storage

Subarea	Distance downstream, in miles	Average change in ground-water levels, in feet: Base[1] to November 1983	Base to January 1984	Base to March 1984	Base to April 1984	November 1983 to January 1984	January to March 1984	March to April 1984	November 1983 to March 1984	November 1983 to April 1984
All wells	--	8.9	17.6	24.2	18.3	8.2	3.4	-1.1	12.2	8.7
Subarea 1	0-15	5.1	14.6	25.9	20.0	6.9	1.0	-1.2	7.4	6.2
Subarea 2	15-22	5.9	41.9	59.4	48.7	17.2	10.9	-1.1	30.5	22.4
Subarea 3	22-40	5.8	16.7	20.7	18.2	9.9	3.7	-0.0	14.0	12.5
Subarea 4	40-71	7.9	12.0	14.2	11.8	4.9	1.7	-2.0	5.9	4.6

Change in aquifer storage[2]

Subarea	Area, in acres	Change in storage, base to March, in acre-feet
Subarea 1	22,720	88,000
Subarea 2	12,544	112,000
Subarea 3	53,184	165,000
Subarea 4	129,280	275,000
	Total	640,000

[1]Base water-level measurement made during January 1983.
[2]Change in aquifer storage from Ashurst-Hayden Dam to the confluence with the Salt River.

water level; and general site information (table 6). Construction data included well depth and location of perforations. General site information included altitude of the well above sea level; distance from the center of the channel of the Gila River, in miles; downstream distance from Ashurst-Hayden Dam, in miles; a code to indicate if a geologic or drillers' log was available; and the percent sand and gravel content in the sediments (pl. 2). Scatter diagrams and regression equations for several pairs of variables were developed to evaluate the effects of well construction, geology, depth to water, distance from channel, and distance downstream on water-level changes.

GEOHYDROLOGIC SETTING

The study area is a sediment-filled valley surrounded by mountains (pl. 2). The valley includes the channel and flood plain of the

Table 6.--General site information for selected wells

[Deshes indicate no data; Y, Yes; N, No]

Well number	Depth of well, in feet	Altitude of land surface, in feet above sea level	Availability of drillers' logs	Top of perforations below land surface, in feet	Distance from center of channel, in miles	Distance from Ashurst-Hayden Dam, in miles
(D-1-1)3add	-----	976	N	-----	2.56	68.67
(D-1-1)13ddd1	740	1,010	N	-----	2.10	65.50
(D-1-2)7cba	425	1,015	Y	-----	3.18	66.50
(D-1-2)19aaa	201	1,023	N	-----	2.62	64.72
(D-1-2)20add	300	1,050	Y	90	3.28	63.88
(D-1-2)31aca	1,496	1,017	N	-----	1.15	63.26
(D-2-2)15cbb	-----	1,039	N	-----	0.66	59.16
(D-2-2)29adb	595	1,048	Y	-----	1.54	59.20
(D-2-3)1bda	800	1,154	N	-----	7.54	53.23
(D-2-3)1dac1	-----	1,145	N	-----	7.48	52.67
(D-2-3)9abc2	800	1,130	N	-----	4.26	55.26
(D-2-3)11bab	800	1,140	N	-----	5.61	55.00
(D-2-3)21cdc	800	1,105	Y	100	2.13	54.72
(D-2-3)22ddd	242	1,113	Y	100	3.77	52.16
(D-2-3)25add	250	1,185	Y	-----	4.10	48.72
(D-2-3)25baa	-----	1,131	N	-----	4.26	49.50
(D-2-4)25ddd	610	1,181	Y	250	3.93	42.72
(D-3-2)23acd	-----	1,105	Y	-----	3.70	53.16
(D-3-2)23add	780	1,095	Y	-----	3.54	53.00
(D-3-2)25aaa	1,834	1,095	Y	800	3.54	52.33
(D-3-4)1aaa	552	1,183	Y	152	2.82	42.50
(D-3-4)24cda	661	1,176	N	-----	0.59	40.85
(D-3-4)25bda	558	1,182	N	-----	1.21	41.56
(D-3-4)32dab	1,064	1,165	N	-----	2.62	45.88
(D-3-4)33adc	958	1,173	N	-----	2.59	45.00
(D-3-4)34dbb	225	1,175	N	-----	2.79	44.52
(D-3-4)35dcb	-----	1,188	N	-----	3.02	42.50
(D-3-5)4aad2	817	1,211	Y	222	3.54	39.43
(D-3-5)4bbc	250	1,201	Y	-----	3.54	39.82
(D-3-5)13add1	-----	1,236	N	-----	3.02	36.82
(D-3-5)14ddd	762	1,230	N	-----	2.03	37.13
(D-3-5)25cda	-----	1,230	N	-----	0.88	36.00
(D-3-5)29bcb	174	1,197	Y	36	0.66	40.23
(D-3-5)30ccc	390	1,188	Y	90	1.48	40.92
(D-3-5)30dad	-----	1,195	N	-----	0.92	40.13
(D-3-5)31abb2	342	1,189	Y	100	1.48	40.43
(D-3-5)33aaa	-----	1,212	N	-----	0.85	38.00
(D-3-5)33cdd	232	1,214	Y	-----	1.80	38.23
(D-3-6)17bdd	1,140	1,288	Y	346	3.93	35.39
(D-3-6)29add	760	1,277	Y	-----	2.39	33.88
(D-3-6)31aba	605	1,235	Y	470	1.38	34.82
(D-4-3)1aac	-----	1,159	N	-----	3.61	47.33
(D-4-3)2cbb	507	1,147	N	-----	4.33	48.46
(D-4-3)9cdd PZ1	1,777	1,147	Y	-----	6.06	49.00
(D-4-3)9cdd PZ2	430	1,147	Y	420	6.06	49.00
(D-4-3)12ddd	-----	1,170	N	-----	5.08	46.88
(D-4-4)1aaa	455	1,198	Y	-----	2.62	40.59
(D-4-4)1ccc1	440	1,198	Y	60	3.74	40.92
(D-4-4)1ccc2	-----	1,197	N	-----	3.74	40.92
(D-4-4)3ddd	-----	1,183	N	-----	4.23	42.26
(D-4-4)7cdd	-----	1,170	N	-----	5.11	46.66
(D-4-4)16cdd	600	1,189	Y	65	6.23	44.79
(D-4-4)16ddd	600	1,195	Y	65	6.33	44.16
(D-4-5)2bcb	865	1,225	N	-----	1.31	35.88
(D-4-5)6baa	260	1,201	N	-----	2.39	40.26

Table 6.--General site information for selected wells--Continued

Well number	Depth of well, in feet	Altitude of land surface, in feet above sea level	Availability of drillers' logs	Top of perforations below land surface, in feet	Distance from center of channel, in miles	Distance from Ashurst-Hayden Dam, in miles
(D-4-5)10ccd	376	1,281	N	-----	2.95	35.72
(D-4-5)11bba	661	1,235	N	-----	1.80	35.72
(D-4-5)12bbd	600	1,239	N	-----	1.25	34.88
(D-4-5)14dbb	394	1,308	Y	138	2.75	34.88
(D-4-5)15bda	480	1,292	Y	110	3.18	35.50
(D-4-6)4aaa	650	1,273	Y	-----	1.31	32.00
(D-4-6)4cad	-----	1,264	N	-----	0.59	32.23
(D-4-6)4ddd	-----	1,266	N	-----	0.39	31.59
(D-4-6)7add	400	1,252	Y	250	0.79	33.50
(D-4-6)8ddd	-----	1,263	Y	245	0.75	32.33
(D-4-6)12dad	170	1,298	N	-----	0.30	28.50
(D-4-6)21bbb	-----	1,313	N	-----	1.74	31.92
(D-4-6)23baa	450	1,287	Y	68	1.31	29.82
(D-4-6)24bbb	600	1,292	N	-----	1.21	29.00
(D-4-7)19bbc	-----	1,300	N	-----	1.15	28.06
(D-4-7)19ccc	571	1,310	N	-----	1.77	27.75
(D-4-7)28add	360	1,341	N	-----	1.08	24.82
(D-4-7)30daa	500	1,309	N	-----	1.87	26.30
(D-4-7)34aaa	992	1,356	N	-----	1.31	23.66
(D-4-7)34bad	368	1,360	Y	218	1.61	24.10
(D-4-7)35dad	410	1,373	Y	220	1.54	22.52
(D-4-7)36dcc	250	1,384	Y	50	1.48	21.79
(D-4-8)31dda	-----	1,373	N	-----	0.49	20.23
(D-4-8)32add	-----	1,380	N	-----	0.43	19.39
(D-4-8)33ddb	321	1,395	Y	-----	0.79	18.52
(D-4-8)35daa	323	1,424	Y	100	1.48	16.10
(D-4-9)28cca	-----	1,468	N	-----	0.98	11.92
(D-4-9)28dac	610	1,473	N	358	0.82	11.33
(D-4-9)30ccd	-----	1,445	N	-----	1.48	13.49
(D-4-9)32baa	-----	1,448	N	-----	0.88	12.82
(D-4-10)10dad	-----	1,534	N	-----	0.10	3.33
(D-4-10)12aab	-----	1,585	N	-----	0.30	1.39
(D-4-10)16acc	-----	1,524	N	-----	0.30	5.10
(D-4-10)18dcd PZ1	-----	1,565	N	1,250	0.56	6.73
(D-4-10)18dcd PZ2	-----	1,565	N	580	0.56	6.73
(D-4-10)21acd	-----	1,535	N	-----	0.75	5.20
(D-4-10)28baa	-----	1,540	N	-----	1.15	5.82
(D-4-10)29ddc	-----	1,544	N	-----	1.74	6.82
(D-4-10)30bdd	300	1,490	N	-----	0.49	7.92
(D-4-10)31daa	-----	1,540	N	-----	1.57	8.16
(D-4-11)6dcc	400	1,570	Y	200	0.26	0.69
(D-5-8)2aaa	230	1,419	Y	30	0.88	15.95
(D-5-8)4ccb	647	1,388	N	-----	0.23	18.72
(D-5-8)5bba	634	1,376	N	100	0.49	19.46
(D-5-8)7baa	645	1,395	Y	150	1.87	19.82
(D-5-8)9aad	165	1,397	Y	40	0.62	17.79
(D-5-8)9dac	-----	1,409	N	-----	0.98	17.70
(D-5-8)10add	200	1,414	Y	-----	0.46	16.85
(D-5-8)10bad	875	1,395	N	-----	0.36	17.36
(D-5-8)11cdc	650	1,425	Y	85	0.88	16.43
(D-5-8)17bbb2	820	1,410	Y	-----	2.03	18.52
(D-5-9)2abd	520	1,490	Y	140	1.24	10.33
(D-5-9)5ccd	505	1,431	Y	140	0.66	14.85
(D-5-9)6aac	504	1,425	Y	120	0.16	13.67
(D-5-9)9aba	-----	1,462	N	-----	1.34	12.06
(D-5-9)9dad	406	1,493	Y	-----	2.06	12.16

Gila River and is underlain by water-bearing deposits of clay, silt, sand, and gravel. The surrounding mountains, whose formations extend beneath the valley floor and underlie the aquifer, are composed mainly of granitic and metamorphic rocks that yield little or no water. The aquifer is overlain by unsaturated alluvium and receives abundant recharge from infiltration of periodic streamflow. Movement of water from the river to the aquifer is influenced by local geologic heterogeneities that aid or restrict the flow of water in the subsurface.

Geology

Consolidated rocks are composed of a wide variety of granitic, metamorphic, volcanic, and sedimentary rocks of Precambrian to Tertiary age (Wilson and others, 1969). Similar rocks lie at depth beneath the channel and flood plain of the Gila River and may locally transmit water where fractured, but generally impede the flow of water in the subsurface. Granitic rocks, which crop out extensively in the east half of the study area, and lie at generally shallow depths beneath the river (pl. 2), may restrict the downward and lateral migration of streamflow infiltration. Water levels in this area may show a greater rise than water levels in an area with more extensive alluvium.

The valley is underlain by Tertiary to Quaternary sedimentary deposits that are hundreds to thousands of feet thick (U.S. Bureau of Reclamation, 1976). These deposits include clay, silt, sand, gravel, caliche, mudstone, siltstone, sandstone, conglomerate, and evaporites (Thomsen and Baldys, 1985). Three geohydrologic units—the lower conglomerate, the middle fine-grained unit, and the upper alluvium—are recognized in the subsurface (U.S. Bureau of Reclamation, 1976). As subdivided in this report, the lower conglomerate and middle fine-grained units are equivalent to the lower basin-fill deposits of Freethey and others (1986) in south-central Arizona and the lower sedimentary unit mapped by Laney and Hahn (1986) in the adjacent eastern part of the Salt River Valley north of the study area. The upper alluvium, which is composed of basin fill in the lower part and stream alluvium in the upper part, is equivalent to the upper basin-fill deposits and stream alluvium of Freethey and others (1986) and the middle and upper sedimentary units mapped by Laney and Hahn (1986). The lower conglomerate is a variably cemented deposit of locally derived pebble- to cobble-size fragments. Where penetrated by wells, the middle fine-grained unit consists mainly of silt, clay, mudstone, and evaporites. The upper alluvium consists mainly of gravel, sand, silt, and clay and ranges in thickness from a few tens of feet to several hundred feet. In the Florence area, the stream alluvium underlying the flood plain of the Gila River is as much as 100 ft thick and consists of silty sand to boulder-size clasts (Laney and Pankratz, 1987).

The lower conglomerate, the middle fine-grained unit, and the upper alluvium are saturated at depth and form a regional-aquifer system (U.S. Bureau of Reclamation, 1976; Freethey and others, 1986). In the study area, water in the aquifer generally is unconfined, but may be confined in some places where the lower conglomerate is overlain by the middle fine-grained unit. The channel and flood plain of the Gila River are underlain by unsaturated sediments of the upper alluvium that transmit recharge from the river to the aquifer during periods of streamflow. Grain-size and bedding characteristics of the upper alluvium may greatly affect the movement of recharge in the subsurface. Study of selected well cuttings from the area indicate that the unit is highly interbedded in places and consists of sand and gravel from less than 20 percent to more than 80 percent (pl. 2). Grain-size and bedding characteristics indicate that the movement of recharge may vary considerably from place to place depending on local geologic heterogeneities. Preferential movement of recharge may occur as a result of interbedding and lensing of fine- and coarse-grained sediments. Perching of water may occur in areas underlain by extensive clay bodies.

Streamflow

The Gila River is a major tributary of the Colorado River and originates in the mountains of western New Mexico (fig. 1). In the study area, streamflow in the Gila River occurs periodically in response to uncontrolled tributary inflow and releases or spills from San Carlos Reservoir (fig. 1). Major tributaries of the Gila River that contribute to streamflow in the study area include Dripping Springs Wash, San Pedro River, Mineral Creek, Queen Creek, and Santa Cruz River (fig. 1). San Carlos Reservoir, Dripping Springs Wash, the San Pedro River, and Mineral Creek are upstream from the study area, and flows from these sources may be diverted for irrigation. Diversion of water occurs at Ashurst-Hayden Dam east of Florence.

Maximum diversion into the Florence-Casa Grande Canal is about 1,000 ft^3/s. Flows in excess of 1,000 ft^3/s, such as that of October 1983, spill over or are released from Ashurst-Hayden Dam. Releases of less than 1,000 ft^3/s generally infiltrate the channel within the study area.

Streamflow in the Gila River between Ashurst-Hayden Dam and the confluence of the Salt River ranges from zero during dry periods to as much as tens of thousands of cubic feet per second during rare floods. Flow durations generally range from several hours to several days but may be much longer, especially if flow is the result of releases from San Carlos Reservoir. Infiltration of streamflow may contribute tens of thousands of acre-feet of recharge to the aquifer in an average year.

Infiltration and Aquifer Characteristics

Streamflow that infiltrates the channel and flood plain of the Gila River moves downward through the unsaturated zone to the water table. The rate of flow through the unsaturated zone is moisture dependent, and the maximum flow rate, which is about equal to the infiltration rate, occurs during periods of sustained infiltration. Periodic infiltration of streamflow is accompanied by the buildup of a recharge mound in the aquifer beneath the channel and flood plain of the river. The areal extent, volume, and dissipation of the mound depends on the duration of the recharge period and the hydraulic diffusivity of the aquifer. Infiltration and aquifer characteristics that control recharge vary considerably from place to place and with time. Antecedent conditions may greatly affect the infiltration-recharge relations for a particular flow event.

The volume and areal distribution of recharge depend on the infiltration rate in the stream channel and the flood plain and the rate of vertical movement through the unsaturated zone. Infiltration rates along the Gila River have not been measured but range from less than 1 to as much as 7 ft/d on the basis of estimates (Paul Gregory, hydrologist, U.S. Bureau of Indian Affairs, written commun., 1986) and measurements in the Salt River, Queen Creek, and Vekol Wash (Babcock and Cushing, 1942; Briggs and Werho, 1966; Marie, 1985). Infiltration rates vary depending on sediment characteristics, soil moisture, and streamflow conditions. Infiltration rates of 7 ft/d are most likely to occur in permeable coarse-grained channel deposits during periods of sustained low flow when the water generally is free of suspended sediments. Infiltration rates of 1 ft/d or less are most likely to accompany sediment-laden floodflows that spread across fine-grained flood-plain deposits. The magnitude and range of infiltration rates that accompanied the flood of October 1983 and subsequent releases of water from the San Carlos Reservoir are unknown. Infiltration rates, however, probably were greatest—perhaps as much as 7 ft/d—after December 1983 near Florence where the channel of the Gila River crosses coarse sediments of the upper alluvium.

The movement and storage of recharge beneath the Gila River depend on the hydraulic conductivity, transmissivity, and specific yield of the aquifer. The lower conglomerate and middle fine-grained units store large volumes of water but are much less permeable than the upper alluvium. The upper alluvium contains the most permeable and porous sediments in the aquifer and transmits and stores the largest volumes of recharge. In January 1983, the saturated thickness of the upper alluvium ranged from 0 to more than 500 ft. Saturated thickness of the upper alluvium generally is greatest in the western part of the study area (pl. 2).

Hydraulic conductivity and transmissivity of the upper alluvium range from about 20 to 500 ft/d and 10,000 to 60,000 ft^2/d, respectively, on the basis of regional stratigraphic correlations and aquifer-test data in the western part of the study area and in the adjacent eastern part of the Salt River Valley (Gary Weesner, geologist, Franzoy-Corey Engineering Company, written commun., 1986; Laney and Hahn, 1986). Hydraulic conductivity averages about 20 ft/d for sediments containing less than 20 percent sand and gravel and 100 ft/d for sediments containing concentrations of sand and gravel greater than 80 percent (Laney and Hahn, 1986). Vertical hydraulic conductivity of the upper alluvium may range from as much as 3 to 7 ft/d (Marie, 1985), which is about 8 to 20 times less than the average horizontal hydraulic conductivity parallel to sediment layering. Composite values of transmissivity determined from wells open to multiple aquifer layers generally range from about 1,500 to 30,000 ft^2/d but are as much as 100,000 ft^2/d in places (Anderson, 1968). Transmissivity and hydraulic conductivity of the lower conglomerate and middle fine-grained units are much lower than those of the upper alluvium for equivalent grain-size ranges (Laney and Hahn, 1986).

Specific yield of the aquifer ranges from less than 10 to as much as 25 percent (Freethey and others, 1986) and averages from 10 to 19 percent (Anderson, 1968; Babcock, 1970). Deposits of clay and silt generally have a much lower specific yield than deposits of well-sorted sand and gravel. Specific yield of clay and silt ranges from near 0 to 10 percent, whereas sand and gravel yield water to gravity drainage equal to 15 to 25 percent of the volume (Freethey and others, 1986). In computing the quantity of recoverable ground water in storage beneath the study area, Babcock (1970) used a specific yield of 15 percent for the upper 600-foot interval of sediments and 10 percent for the 600- to 1,000-foot interval. Estimates of the total amount of recoverable ground water in storage beneath the area range from about 12 to 17 million acre-ft (Babcock, 1970; U.S. Bureau of Reclamation, 1976; Osterkamp and Ross, 1976).

EVALUATION OF GROUND-WATER RECHARGE

The flood of October 1983 was the largest flood in the study area since 1928 when Coolidge Dam was built to store runoff from the upper Gila River drainage basin in San Carlos Reservoir. Thousands of acre-feet of streamflow infiltrated the channel and flood plain, resulting in widespread recharge to the aquifer. Measurements of ground-water levels before and after the flood confirmed the occurrence of recharge. Streamflow losses in the Santa Cruz River; irrigation return flow; and seepage from unlined canals, sumps, and ponds also contributed to the recharge.

Streamflow

Most of the flow in the early part of October 1983 was the result of runoff from the San Pedro River and other smaller tributaries. Flow after October 5, 1983, was mainly the result of releases from San Carlos Reservoir 49 mi upstream from Kelvin. On October 5, releases from the reservoir increased and except for November remained above pre-flood releases through most of January 1984. Flow into the study area from Ashurst-Hayden Dam was intermittent after January 25, 1984.

Daily mean flows in the Gila River at Kelvin in October ranged from 861 to 50,000 ft^3/s; in November from 599 to 1,040 ft^3/s; and in December from 670 to 2,020 ft^3/s (White and Garrett, 1987). Measurements and estimates of streamflow indicate that large volumes of surface water infiltrated the channel and flood plain of the Gila River between Ashurst-Hayden Dam and Laveen during and after the flood of October 1983. During the flood period, more than 1,000 acre-ft of water was diverted into the Florence-Casa Grande Canal. Streamflow was not diverted from October 5 to November 17, 1983.

Streamflow losses between Ashurst-Hayden Dam and Gila River near Laveen—a 60-mile reach—were about 252,000 acre-ft from October 1983 through March 1984. Assuming that streamflow losses were uniform at about 4,200 acre-ft/mi throughout the study reach, 46,000 acre-ft of streamflow may have infiltrated the channel and flood plain of the Gila River between Gila River near Laveen and the confluence of the Salt River (table 2). Streamflow losses between Ashurst-Hayden Dam and the east boundary of the Gila River Indian Reservation and between Ashurst-Hayden Dam and the abandoned Sacaton Dam near Olberg were about 71,000 acre-ft and 126,000 acre-ft, respectively.

The percentage of streamflow losses generally increased with decreasing flow rate during and after the flood. Only 25 percent of the flow was lost to infiltration during the flood period. During the rest of October 1983 when the average daily flow at the gaging station at Kelvin was 2,030 ft^3/s, 61 percent of the flow was lost to infiltration. The total streamflow loss in October between Ashurst-Hayden Dam and the gaging station at Gila River near Laveen was 104,000 acre-ft. In November 1983, 70 percent of the flow was lost when the average daily flow was 752 ft^3/s. In December 1983, 74 percent of the flow was lost when the average of the mean daily flow was about 1,660 ft^3/s. Streamflow loss in November and December was about 91,000 acre-ft.

Response of the Ground-Water System

Infiltration of streamflow during and after the flood of October 1983 was accompanied by a rise in ground-water levels throughout the study area. Repeated measurements of water levels in wells before and after the flood indicated that the water-level changes varied greatly in magnitude, space, and time. The relations between change in water levels and distance downstream and distance from the channel, respectively, are shown in figures 3 and 4. Although much scatter is evident in the diagrams, water-level change generally was less in wells farthest downstream from Ashurst-Hayden Dam and farthest from the river. A diagram of superposed lines of predictive equations (fig. 5) based on a best-fit linear regression analysis of the data sets from figure 4 shows an apparent trend related to time. The increase in negative slope of the lines through time indicates an apparent continued buildup of a recharge mound near the river from November 1983 to March 1984. The decrease in slope in April indicates an apparent dissipation of the recharge mound near the river that is related either to pumping effects, cessation of streamflow infiltration, or a combination of both factors.

In some wells, the depth to water after the flood was greater than the depth to water measured in January 1983 (figs. 3 and 4) resulting in negative water-level changes. These negative water-level changes may have been the result of unmeasured declines related to pumping that occurred between the time of the base water-level measurements and the flood of October 1983. The number of wells with negative water-level changes, which decrease through time, indicate that, in some places, observed positive changes may have been greater than shown.

Water-level changes from base water-level measurements to measurements in November 1983 ranged from -14.3 to +79.2 ft and averaged +8.9 ft for 102 wells (tables 4 and 5). The largest changes occurred between the time of the base water-level measurements and measurements of March 1984. The changes ranged from -0.4 to +109.8 ft and averaged +24.2 ft for 74 wells. From March to April 1984, water levels indicated an overall decline. Negative changes from March to April are probably the result of widespread pumping after the recharge event. The largest changes between successive water-level measurements made after the flood were

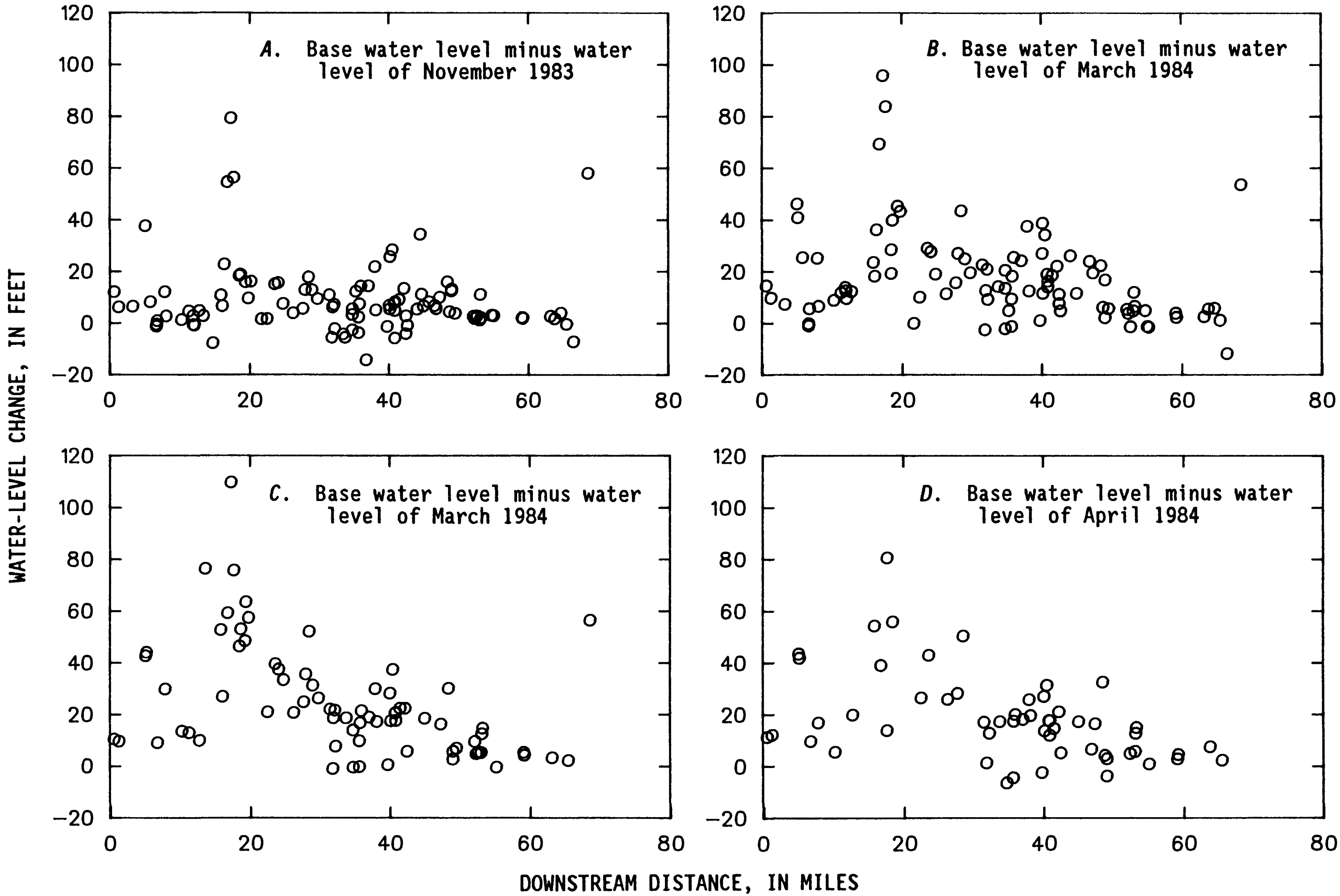


Figure 3.--Relation of distance of well from Ashurst-Hayden Dam to water-level change. Base water levels are measurments made in January 1983.

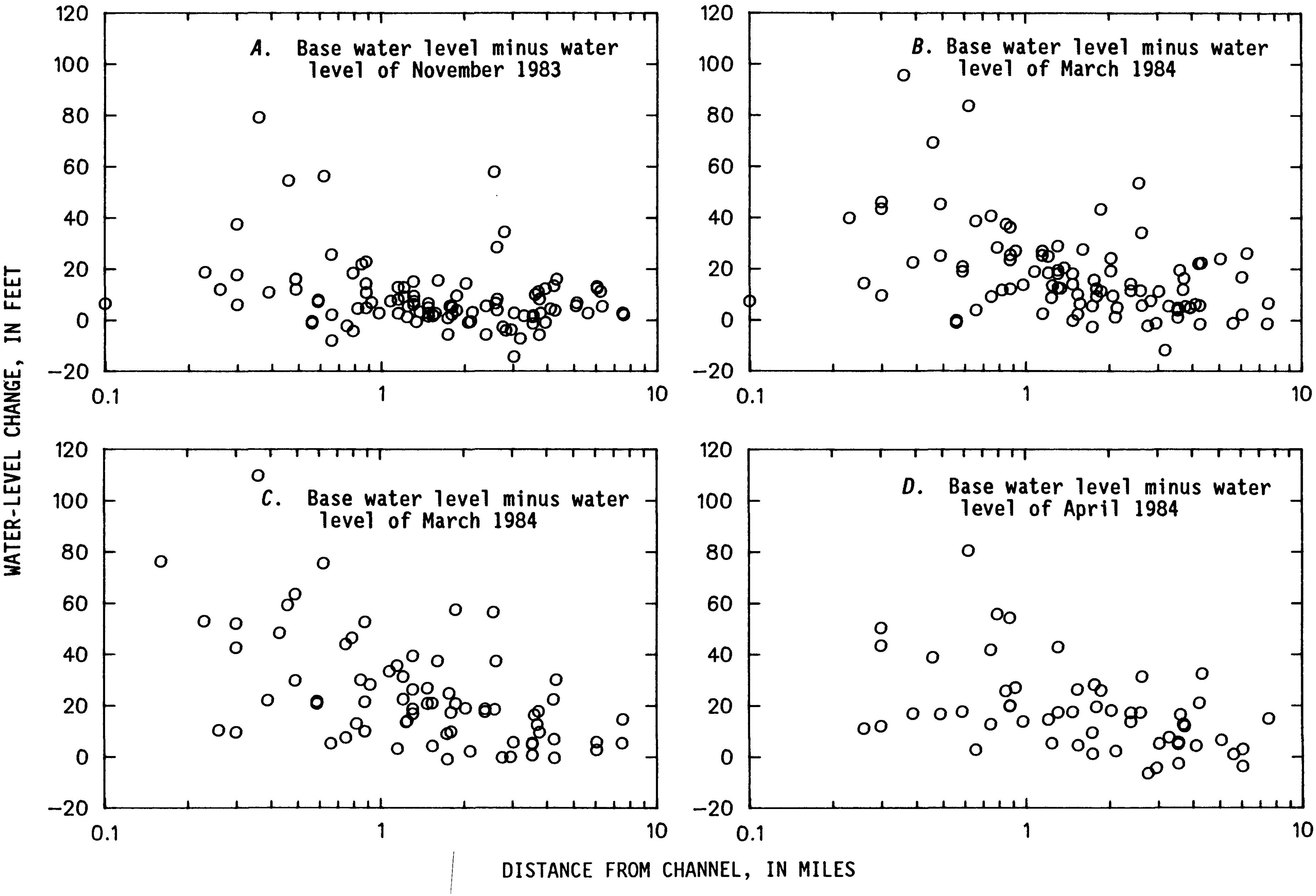


Figure 4.--Relation of distance of well from channel to water-level change. Base water levels are measurements made in January 1983.

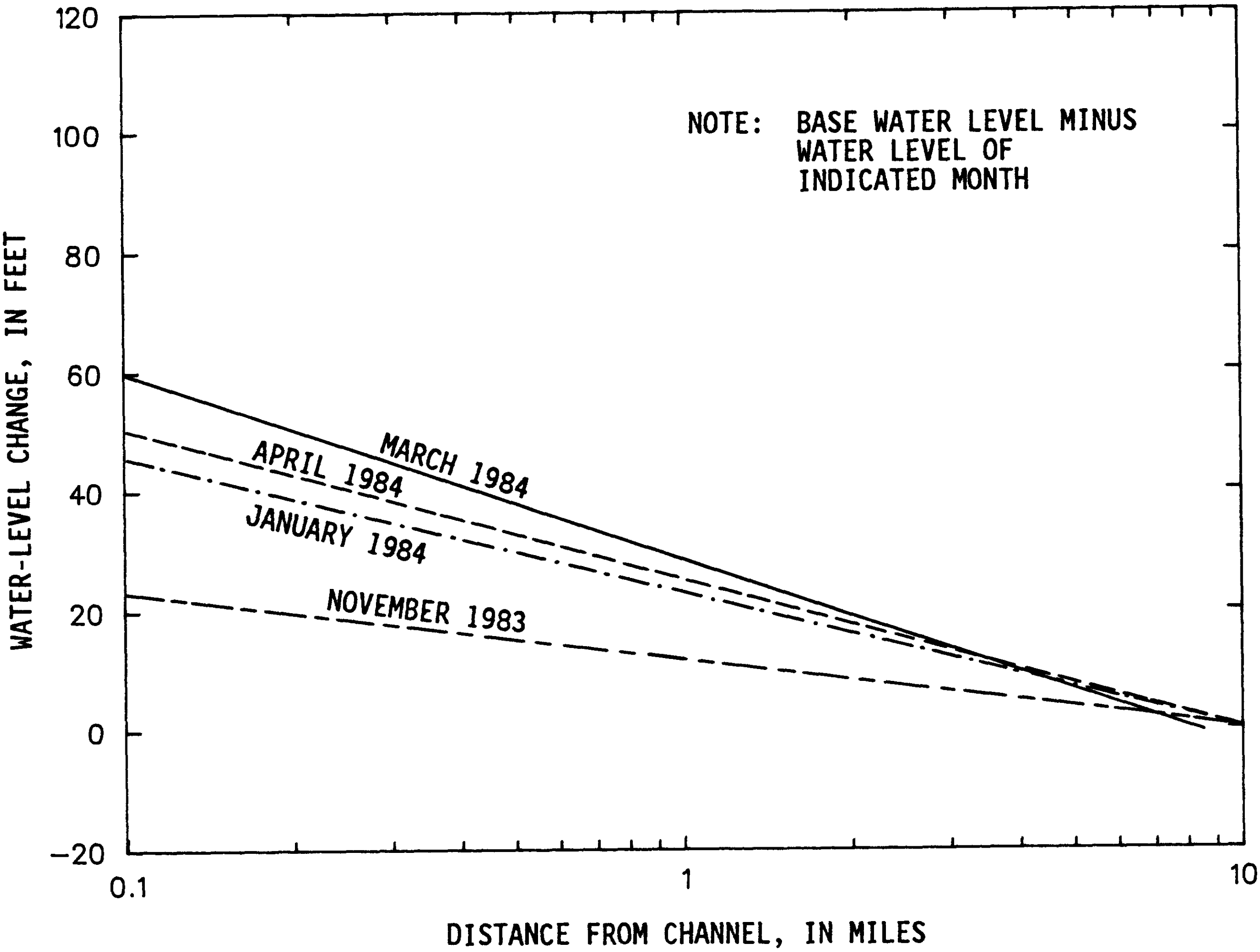


Figure 5.--Superposition of best-fit lines for four data sets. Base water levels are measurements made in January 1983.

between November 1983 and January 1984 and ranged from -10.3 to +33.7 ft and averaged +8.2 ft for 92 wells.

Average water-level changes varied significantly between different parts of the study area (table 5). Average water-level changes were greatest in subarea 2, which includes the area from river mile 15 to 22 (pl. 1). In subarea 2, the water-level changes between base measurements and measurements in March 1984 ranged from +26.9 to +109.8 ft and averaged +59.4 ft for 10 wells. The smallest average water-level change occurred in subarea 4, which includes the area from river mile 40 to the confluence of the Salt River. In subarea 4, the water-level changes between the base measurements and measurements in March 1984 ranged from -0.4 to +56.5 ft and averaged +14.2 ft for 28 wells.

Variation in water-level response to streamflow infiltration between subareas probably was due to the quantity of water available, duration of its availability, and general or localized differences in geologic characteristics. For example, subarea 2, which had the largest average water-level change, is underlain by clay and silt-rich sediments on the south and crystalline rocks on the north (pl. 2). Sediments and rocks that underlie subarea 2 are only slightly permeable to impermeable at shallow depths, which may have affected the response of the aquifer to streamflow infiltration by restricting its downward and lateral migration. In contrast, the geologic characteristics of subarea 4, which had the smallest average water-level change, may have favored a greater lateral migration of recharge. Sediments that underlie subarea 4 are laterally extensive and contain moderate amounts of permeable sand and gravel. Interbedding and lensing of fine- and coarse-grained sediments may have caused localized water-level response to streamflow infiltration in all areas. Perching of ground water may have occurred in areas underlain by extensive clay bodies, especially in and near subarea 2. Some large water-level changes in subarea 2 may have been the result of perching or local confined conditions within the aquifer. Cascading water was reported in several wells throughout the study area (pl. 1). Cascading water occurs when a well is open to two water-bearing units. Water may then cascade from one unit to another through the well.

Ground-water recorders were installed on two wells on December 1, 1983 (pl. 1). Water-level response to recharge and pumping from December 1, 1983, to September 30, 1984, at each well is shown by hydrographs in figure 6. Well (D-3-5)28cbb is near the Gila River and adjacent to the area inundated by the flood. Well (D-4-4)1aaa is several miles from the river and the inundated area and about 3.5 mi southwest of well (D-3-5)28cbb. The water level in well (D-3-5)28cbb was minimally affected by pumping and responded directly to flow in the river. The water level was at its highest point in late January and rapidly decreased to almost preflood levels when flow in the river ceased. Well (D-4-4)1aaa is near cultivated fields and responds to nearby ground-water pumping. The shallowest depth to water during the study period in this well occurred near the end of February about a month after flow in the river ceased. Although subsequent pumping from nearby wells temporarily lowered the water level in the well throughout April, the water level recovered several feet by the end of the month.

Increase in Aquifer Storage

The increase in aquifer storage was estimated to range from 449,000 acre-ft to 640,000 acre-ft from January 1983 when base water-level measurements were made to March 1984 when pumping began to deplete gains attributed to the flood. Estimates of increased aquifer storage are based on water-budget calculations for a minimum estimate and on measured water-level changes for a maximum estimate. Water-budget calculations indicate that more than 80 percent of the increase in aquifer storage from January 1983 to March 1984 was the result of streamflow infiltration and more than 60 percent of the increase occurred from October 1983 to March 1984. The rest of the increase is attributed to irrigation return flow and

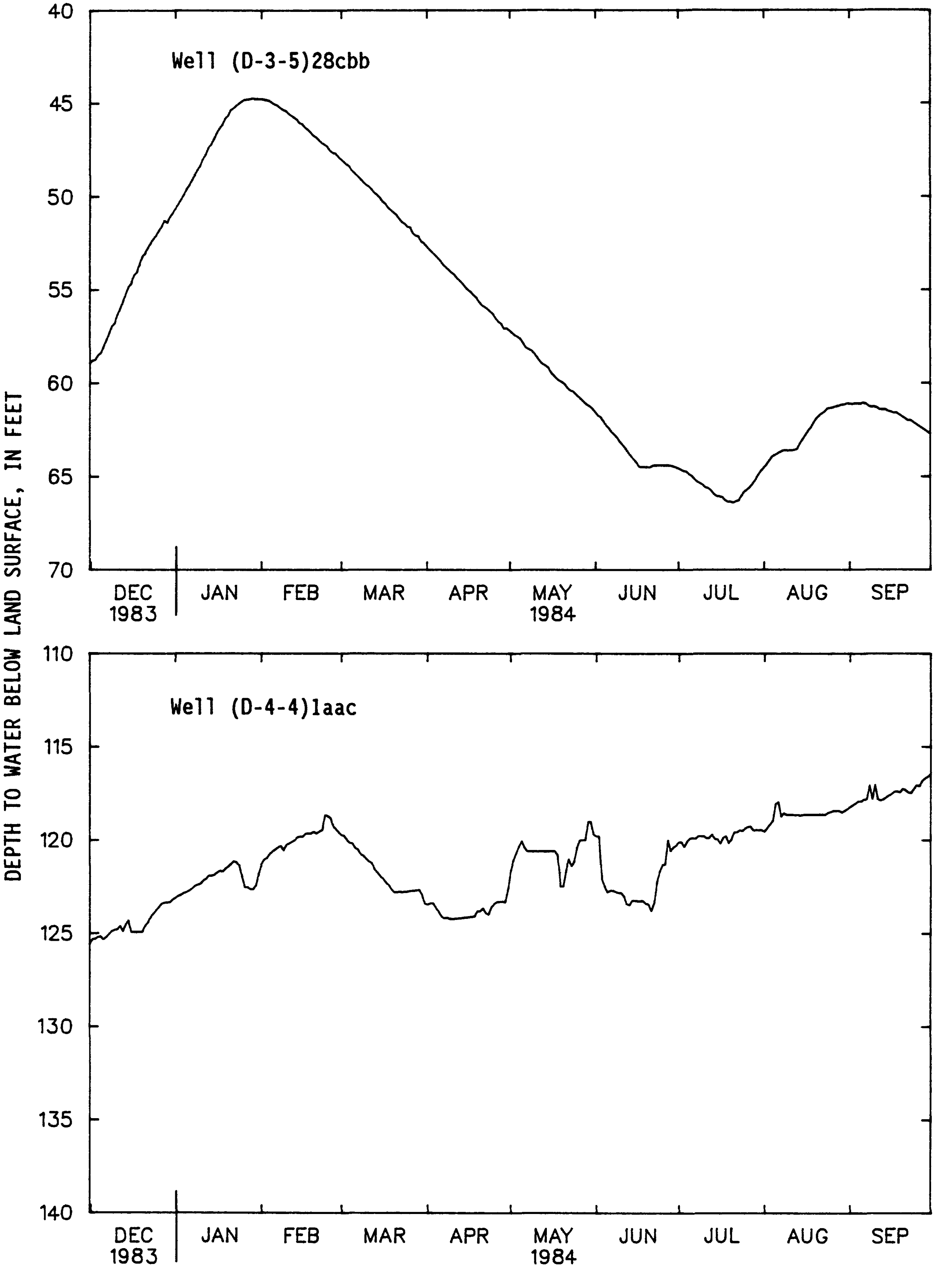


Figure 6.--Depth to water in wells, December 1983 to September 1984.

seepage from unlined canals, sumps, and ponds. Recharge estimates include streamflow infiltration that occurred during the spring and summer of 1983 before the flood of October 1983. Measurements and estimates of streamflow volumes during and after the flood period indicate that infiltration losses were about 252,000 acre-ft from October 1983 to March 1984 from Ashurst-Hayden Dam to Laveen.

Recharge to the aquifer from January 1983 to March 1984 added substantially to ground-water supplies in the study area. Estimates of the increase in aquifer storage ranged from 4 to 5 percent of the total recoverable ground water in storage. From 1934 to 1982, average annual pumpage by the San Carlos Irrigation Project was about 85,700 acre-ft; 46,100 acre-ft of that amount was the average yearly withdrawal from the Gila River Indian Reservation. From January 1983 to March 1984, recharge to the aquifer ranged from 5 to 7 times the average annual pumpage by the San Carlos Irrigation Project and from 10 to 14 times the average annual withdrawal from the reservation. Increase in aquifer storage was one to two times greater than the 322,000 acre-ft pumped from the reservation during the 10 years preceding the flood.

Evaluation of Specific Yield

An average specific yield of 15 percent was used to estimate the recharge to the ground-water system with the water-level change method. By comparing the results obtained using the water-budget method with the results using the water-level change method, different specific yields can be obtained (table 7). Specific yield was computed by dividing the volume of recharge, as computed by the water-budget method for different time periods, into the volume of sediments used to compute recharge by the water-level change method. Using this technique, the specific yield of the zone affected by water-level change ranged from 11 to 16 percent (table 7). A specific yield of 16 percent was indicated by water-level change data and water-budget results for January to November 1983. Values of 11 to 13 percent were indicated for later periods.

Sources of Errors in Recharge Estimates

Estimates of recharge attributed to the flood of 1983 are considered poor but probably are within the range determined from water-budget calculations and measured changes in ground-water levels. Recharge estimates determined by the two methods differ from 9 to 30 percent for equivalent periods of time. The differences may be a result of several factors, including errors in specific yield or streamflow loss. Using water-budget calculations, specific yield in the sediments affected by water-level change ranged from 11 to 16 percent after the flood of October 1983. Estimates of recharge determined from changes in ground-water levels, however, are based on an average specific yield of 15 percent (Babcock, 1970). If specific yields as determined from water-budget calculations are correct, recharge volumes determined from changes in ground-water levels may be overestimated. If streamflow losses

Table 7.--*Change in ground-water storage and specific-yield estimates*

[Values are in acre-feet except as indicated]

Period[1]	Change in ground-water storage: Water-level change method	Change in ground-water storage: Water-budget method	Specific-yield estimates, in percent
Base to November 1983....	228,000	248,000	16
Base to January 1984.....	495,000	429,000	13
Base to March 1984.......	640,000	449,000	11

[1]Base water-level measurement made during January 1983.

were greater than those estimated from reconstructed hydrographs of the flood event, however, specific yields and recharge volumes determined from water-budget calculations may be underestimated.

The degree to which ground-water pumping, canal seepage, irrigation return flow, evapotranspiration, and streamflow infiltration from the Santa Cruz River affected estimates of recharge is unknown. The Santa Cruz River, which flowed for a short period during October 1983, probably contributed some recharge to the area upstream from Laveen. Estimates of recharge, however, assumed zero streamflow loss from the river because flow duration was short and losses could not be determined. Potential recharge along the Gila River probably was reduced slightly by evapotranspiration. The amount of the reduction, however, was considered negligible because recharge was large in relation to the potential for evapotranspiration during fall and winter months when streamflow infiltration occurred. Canal seepage and irrigation return flow were considered in water-budget calculations, but the assumption was made that all diversions minus consumptive use during the period migrated to the aquifer by seepage from unlined canals and by percolation beneath irrigated fields.

Two opposing effects of ground-water pumping that may have caused errors in measurements of water-level change were not considered in recharge estimates because they could not be adequately determined. Localized pumping during the spring and summer of 1983 lowered ground-water levels in parts of the study area to below the levels measured in January 1983. During the same period, some areas probably were affected by rising ground-water levels in response to reduced pumping brought about by the "Payment-In-Kind" (PIK) program (U.S. Geological Survey, 1985). Assumptions concerning the effects of ground-water pumping, canal seepage, irrigation return flow, evapotranspiration, and streamflow infiltration from the Santa Cruz River may have introduced errors in estimates of recharge, but the magnitude of error probably is small compared to the overall streamflow loss and recharge volumes attributed to flooding along the Gila River.

SUMMARY

The flood of October 1983 substantially affected ground-water levels along a 71-mile reach of the Gila River from Ashurst-Hayden Dam to the confluence of the Salt River. Most streamflow in early October originated in the San Pedro River drainage. After October 6, 1983, flow was mainly from controlled releases from San Carlos Reservoir. About 252,000 acre-ft of runoff infiltrated the channel and flood plain of the Gila River from October 1983 through March 1984 in the reach from Ashurst-Hayden Dam to Laveen. Streamflow losses were accompanied by a rise in regional ground-water levels. From January 1983 through March 1984, water levels in 74 wells rose an average of 24.2 ft.

Geologic characteristics may have had a part in controlling the magnitude and distribution of recharge to the aquifer. Aquifer response to streamflow infiltration may have been affected by variability in sediment layering, grain size, and permeability. In places, particularly in the eastern part of the study area, shallow buried granitic rocks may have affected the response of the aquifer to streamflow infiltration by restricting its downward and lateral migration.

A water-budget method and a water-level change method were used to estimate the recharge from January 1983 through March 1984 from Ashurst-Hayden Dam to the confluence with the Salt River. Estimates of the recharge from January 1983 to March 1984 range from 449,000 to 640,000 acre-ft; at least 46 to 66 percent of the increase was the result of streamflow infiltration from the Gila River during October 1983 to March 1984. Water-level rises during the period also may have been affected by reduced pumping, canal seepage, irrigation return flow, and streamflow infiltration from the Santa Cruz River.

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