IV – WATERHSED CHARACTERISTICS

4-01. General Characteristics

The drainage area above Alamo Dam, approximately 4,770 square miles (12,354 sq Km) in size, is generally mountainous, and lies in west-central Arizona. The drainage area is bounded on the north by Cottonwood Cliffs; on the east by the Juniper and Santa Maria Mountains; on the south by Date Creek and the Harcuvar Mountains; and on the west by the Hualpai Mountains.

The Bill Williams River is formed about 47 miles (75.6 Km) upstream from its mouth by the confluence of the Big Sandy and Santa Maria Rivers. From the confluence, the flow is southwest for about 8 miles (12.9 Km) on an average gradient of 18 feet (5.5 m) per mile to Alamo Dam. Bullard Wash is the largest tributary along this reach. Below Alamo Dam, the river flows almost due west to its confluence with the Colorado River.

The Big Sandy River, the larger of the two main tributaries to the Bill Williams River, drains an area of about 2,840 square miles (7,355.6 sq Km, Photo 4-01). This stream, which is formed by the confluence of Trout and Knight Creeks, flows southward about 49 miles (78.9 Km) on an average stream gradient of 38 feet (11.6 m) per mile to its confluence with the Santa Maria River. Burro Creek is the largest tributary in this reach.

The Santa Maria River drains an area of about 1,550 square miles (4,014.5 sq Km, Photo 4-02). This stream, which is formed by the confluence of Kirkland and Sycamore Creeks, flows southwestward about 51 miles (82 Km) to its junction with the Big Sandy River. The stream gradient of the Santa Maria River is about 30 feet (9.1 m) per mile. Date Creek is the largest tributary in this reach. The streambed gradients of many of the minor upstream tributaries in the Bill Williams River system are greater than 100 feet (30.5 m) per mile. Streambed profiles for the Bill Williams system are presented on Plate 4-01.

4-02. <u>Topography</u>

The drainage area consists essentially of broad desert valleys and irregularly distributed ranges of rugged mountains. Relief is moderate to high. Elevations in the drainage area vary from about 990 feet (301.8 m) above sea level at the base of the dam to 8,226 feet (2,507.3 m) at Hualpai Peak on the northwest boundary. Plate 4-01a shows the topography of the Alamo Dam drainage area.

4-03. <u>Geology and Soils</u>

The Bill Williams River is a perennial stream, although subterranean in some reaches. The river, along the upstream part of its course, has cut a deep narrow canyon between the Buckskin Mountains on the south and the Rawhide Mountains on the north. The Alamo dam site is within a narrow part of this canyon, about 2.5 miles (4.0 Km) downstream from Alamo Crossing. The site is in a region of rugged mountains with rough and steep slopes that are broken by ledges and cliffs and dissected by narrow defiles and gullies. The gullies are separated by sharp-crested, irregular ridges. The Bill Williams River drainage area upstream from the dam site consists of broad desert valleys and short, rugged mountain ranges. The basin is bounded on the north by the Peacock Mountains and the Cottonwood cliffs; on the east, by the Juniper and Santa Maria Mountains and the Sierra Prieta; on the south, by the Weaver, Date Creek, and Harcuvar Mountains; on the west by the Buckskin, Rawhide and Hualapai Mountains.

Downstream from the junction of the Big Sandy and Santa Maria Rivers, the Bill Williams River flows about 6 miles (9.7 Km) southwestward through a sandy flood plain that broadens to a mile in width. The river in this reach is bordered on each side by dissected bluffs composed of alluvial fan debris. The alluvial fans extend in gently ascending slopes for several miles north and south of the river.

Downstream from the sandy flood plain, the Bill Williams River flows about 7 miles (11.3 Km) through a narrow rock-walled canyon. The Alamo Dam site is about 1 mile (1.6 Km) downstream from the head of the canyon. At the dam site, the rock walls of the canyon rise abruptly about 300 feet (91.4 m) above the canyon floor, which ranges in width from 50 to 150 feet (15.2 to 45.7 m). The ground surface of the stream channel along the axis of the dam is at a minimum elevation of 982 feet (299.3 m) above mean sea level. The bedrock surface under the overburden of the stream channel is at a minimum elevation of 918.4 feet (279.9 m).

As previously mentioned, flow in some segments of the Bill Williams River is subterranean, except during periods of high runoff or releases. The longest segment is between Lincoln Ranch and Planet Ranch (Photo 4-03), a distance of approximately 23 river miles (37 Km). Comparison of surface flows at either end of this segment were made for the period October 1929 through September 1946, when the USGS stream gages at the Alamo Dam site (No. 09426000) and at Planet Ranch (No. 09426500) were concurrently in use. The comparison indicated that the aquifer stored a significant portion of the higher flows recorded near the Alamo Dam site and discharged a significant amount of the higher base flows recorded at Planet, when flows at the Alamo site were minimal. Additionally, the aquifer is recharged by runoff originating from tributary basins along its course; water in the aquifer is also withdrawn through wells that serve irrigation and domestic uses. The principal water bearing unit of the aquifer is fill deposit (boulder to pebble size conglomerate).

Rock formations in the vicinity of the dam site and reservoir consist of metamorphic rocks of Precambrian age and younger, sedimentary strata (rock beds) of Tertiary age or older, and volcanic rocks of Tertiary age. Alluvium in the region is Recent and older.

The metamorphic rocks occur at the dam site in the general vicinity of the Rawhide Mountains and the Buckskin Mountains. The metamorphic rocks consist of banded gneiss, which comprise a lower section of rock in the vicinity of the dam site, is of rather widespread occurrence, and extend to great, but undetermined depths. The granitic gneiss occurs in the ridge of the right abutment. The undifferentiated rocks, which have been intensely contorted by ancient folding, occur in the upper part of both abutments and in the general vicinity of the dam site. The contact between the gneiss and the overlaying undifferentiated metamorphic rocks shows a regional upstream dip ranging from about 10 to 20 degrees in the dam site area.

The sedimentary strata (red beds), consisting of alternating layers of reddish hard siltstone and sandstone of unknown thickness, crop out along the Bill Williams River about a mile (1.6 Km) upstream from the dam site. Outcrops of these sedimentary strata begin at the upstream limits of the metamorphic rocks and extend about 6 miles (9.7 Km) upstream. The volcanic rocks occur in a narrow band between the metamorphic rocks and the sedimentary strata.

The Recent alluvium along the axis of the cutoff trench at the streambed has a maximum thickness of about 65 feet (19.8 m). The Recent alluvium along the channels of the Bill Williams River and its tributaries upstream from the dam site is of unknown thickness. The older alluvium, which comprises the bluffs along the sides of the river channel upstream from the dam site, ranges in thickness from 10 to 25 feet (3.0 to 7.6 m). The older alluvium is underlain by the sedimentary strata.

Bedrock at the dam site consists of banded gneiss, undifferentiated rocks, and granitic gneiss; alluvium at the site is Recent. The banded gneiss occurs in the lower parts of both abutments and under the alluvium in the river channel; the granitic gneiss occurs in the ridge at the spillway site; the undifferentiated rocks occur in the upper parts of the left and right abutments and on the upstream and downstream slopes of the ridge at the spillway. The Recent alluvium fills the canyon bottom of the Bill Williams River.

Surface soils in the southern and central parts of the drainage area and in the district along the Big Sandy River vary in texture from fine gravels to clay. Shallow, rocky soils occur in a few isolated areas near the mountain summits.

4-04. Sediment

The estimate of sediment that would accumulate in Alamo Lake is based on recorded data for nearby streams and for existing reservoirs in the general area. The storage space required for a 100-year accumulation of sediment was estimated to be 200,000 acre-feet (24,670 ha-m). This estimate was obtained by applying a sedimentation rate of 0.42 acre-feet (0.05 ha-m) per square mile per year to the drainage area of 4,770 square miles (12,354 sq Km). The sediment was assumed to be distributed in proportion to the reservoir area up to the water surface for the reservoir design flood.

The original reservoir area survey was made in March 1963. The results of this survey were modified somewhat by a bottom survey of May 1968 and by new capacity computations in June 1977. A bathymetric survey of the reservoir was conducted in 1985 to determine the sediment accumulation over a 17-year period. The survey encompassed the reservoir elevation range from the bottom up through elevation 1120 feet (341.4 m). The current (1993) reservoir elevation-storage curve (Plate 2-10) and reservoir elevation-storage table (Table 2-01) reflect the results of the bathymetric survey along with assumptions made on accumulation of sediment above elevation 1120 feet (341.4 m).

In order to check sedimentation periodically, six index ranges were established in the reservoir area and four index ranges were established along the downstream channel. Locations of these ranges are shown on Plates 4-02 and 4-03, respectively. Index ranges in the reservoir area are labeled "A" and index ranges in the downstream channel are labeled "C" on the aforementioned plates.

4-05. Climate

The climate is typically desert in character over the lower elevations of the basin, with short, mild winters and long, hot summers. In the higher elevations, the summers are milder, and the winters colder and longer. The Alamo basin has two distinct rainfall seasons: winter and summer, with a dry fall and a very dry late spring. A summary of climatological data for five Arizona stations, each just outside the drainage area above Alamo Dam, is given in Table 4-01 (Refer to the Tables section of this manual). These data are reproduced from the National Oceanographic and Atmospheric Administration (NOAA) publication, Climatography of the United States No. 20, for Arizona. The stations are: Parker, Kingman, Chino Valley, Prescott, and Wickenburg. These stations range in elevation from 425 feet (129.5 m) NGVD (below the elevation of Alamo Dam) to 5,510 feet (1679.5 m, representative of the higher elevation portions of the drainage) NGVD. There are no stations within the Alamo drainage area for which data are published.

a. Temperature. Table 4-01 (pgs. T4-1 through T4-6) lists, among other items, the mean daily maximum and minimum temperature and record highest and lowest temperature for each month of the year at the five stations surrounding the Alamo drainage area. Average daily minimum and maximum temperatures (degrees Fahrenheit) over the lower portions of the watershed range from about 65 and 35 respectively in winter to about 108 and 75 in summer (see Table 4-01: Parker and Wickenburg). In the higher elevations of the watershed, the values are about 15 to 25 degrees lower (see Table 4-01: Chino Valley and Prescott). High diurnal (day-to-night) temperature variations are characteristic of the region. All-time high and low temperature extremes are about 120 and 15, respectively; in the lower elevations, to about 100 and minus 20 in the highest mountains of the drainage. Significant periods of minimum temperatures below freezing are rare in the lower desert areas, but are common during the winter above 4,000 feet (see Table 4-01: Kingman, Chino Valley, and Prescott).

b. Precipitation. The 90-year (1868-1957) normal annual precipitation (Plate 4-04) ranges from about 8 inches (20.3 cm) at the dam to about 22 inches (55.9 cm) over the higher mountains of the headwater area with an average of 14.7 inches (37.3 cm) for the drainage area. The heaviest precipitation occurs in the summer, with about one-third of the annual precipitation normally occurring in July and August and one-half during the fall and winter months. The driest time of the year is late spring (see Table 4-01).

Table 4-01 lists the mean and maximum monthly and annual precipitation and snowfall, as well as the maximum precipitation (both daily and monthly) and maximum monthly snowfall for each month of the year, at the five stations. Also listed in Table 4-01 are the probabilities (from 5 to 95 percent) for each month of the year that the monthly total precipitation will be equal to or less than the indicated amounts. This table demonstrates that there can be great year-to-year variability in annual, monthly, and daily precipitation. The minimum observed monthly precipitation values are usually zero or near zero.

A description of general winter storms, general summer storms, and local thunderstorms, all of which produce precipitation in the basin, are given in the following subparagraphs:

(1) General Winter Storms. General winter storms usually occur during the period from December through March. They originate over the Pacific Ocean and move slowly eastward across Arizona. These storms last anywhere from a few hours to several days and can result in widespread precipitation over western Arizona, with snow at the higher elevations.

(2) General Summer Storms. General summer storms usually occur during the period August through early October. They are associated with an influx of tropical maritime air originating over Mexico and the adjacent tropical Pacific Ocean and enter the area from a south or southeast direction. Such storms are often associated with the remnants of a tropical cyclone. General summer storms are often accompanied by relatively heavy precipitation over large areas for periods of from 12 hours to 4 days.

(3) Local Thunderstorms. The local thunderstorms can occur at any time of the year, either during general storms or as isolated phenomena. However, they are most common during the period July through September, when the basin is frequently covered by moist, unstable air originating over Mexico or the Gulf of California. These storms cover comparatively small areas and result in high-intensity precipitation of short duration (up to 3 hours).

c. Snow. Snow falls occasionally at the higher elevations in the basin, but usually melts within a few days. Although snow rarely falls below 3,000 feet (914.4 m, Table 4-01: Parker and Wickenburg), it has occasionally fallen at the dam. Above 4,000 feet (1,219.2 m), snow becomes increasingly common with elevation (Table 4-01: Chino Valley and Prescott); over the higher mountains nearly all winter precipitation falls as snow. Most snow in the Alamo drainage below 6,000 feet (1,828.8 m) usually melts or sublimates (evaporates directly) within a few days after falling. Snowmelt is normally not a major factor in runoff generation in the Alamo drainage; but snowmelt, teamed with antecedent rainfall, can assist in saturation of the ground prior to a major flood-producing rainstorm.

d. Evaporation. Evaporation data for Alamo Dam (available from 1974 through 2000) indicate that mean monthly reservoir evaporation ranges from under 2 inches (5.1 cm) in early winter to more than 12 inches (30.5 cm) in early summer. Table 4-02 shows this seasonal variation in mean monthly pan evaporation, and also reveals the great variation that occurs from one well-exposed location to another. Individual daily values show that evaporation can greatly exceed 1 inch (2.54 cm) per day during very dry, windy conditions.

Table 4-02
Monthly Lake Evaporation at Alamo Dam

Month	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Mean Evaporation (in)	5.87	2.64	1.18	1.37	1.99	4.33	7.63	10.91	13.33	12.8	10.92	8.34
Mean Evaporation (cm)	14.91	6.71	2.99	3.48	5.05	11.0	19.38	17.71	33.86	32.51	27.74	21.18
Years of Data	26	26	25	24	25	25	26	26	26	26	27	26

Notes:
1) Period of record from March 1974 to September 2000. Location: Longitude (deg-min-sec) 34-13-51, Latitude (deg-min-sec) 112-36-28. Elevation: 1265 ft, NGVD.
2) Data for Alamo Dam are compiled from Corps of Engineers records.
3) Each evaporation station consists of a National Weather Service Class A Pan Readings are adjusted for observed rainfall to yield net evaporation. Reservoir evaporation values herein reflect measured pan evaporation multiplied by pan coefficient of 0.7. The pan coefficient remains fairly consistent at approximately 0.7 throughout the year.

e. Wind. The prevailing winds are from the east and are usually light, although severe windstorms occur on occasion as the result of local thunderstorms, tropical storms, intense winter storms, or unusually strong Great Basin high pressure cells.

4-06. Storms and Floods

Historical accounts indicate that many damaging floods have occurred in the Bill Williams River watershed, particularly within the following years: 1884, 1891, 1905, 1906, 1910, 1916, 1927, 1931, 1932, 1937, 1938, 1939, 1940, 1941, 1951, 1954, 1978, 1979, 1980, 1983, and 1993. A summary of annual peak discharges at the Alamo Dam site for water years 1927 and 1929-1999 seasons are included in Table 4-03. Indications are that these floods were the result either of general storms or, in a few cases, of tropical cyclones centered in or near the Bill Williams River watershed. Table 4-03a shows the cumulative annual damages prevented for with project conditions. Within the last 20 years, there was one year (1983) where significant flood damages were reported by the City of Yuma. Total damages were estimated to be $2,944,000.

Table 4-03
Recorded Annual Peak Discharges at Alamo Dam Site*

Water Year	Discharge (cfs)	Discharge (cms)	Water Year	Discharge (cfs)	Discharge (cms)
1927	125,000	3,540	1967	38,900	1,102
1929**	28,884	818	1968	16,000	453
1930	73,474	2,081	1969	9,940	281
1931	92,152	2,609	1970	5,117	145
1932	58,793	1,665	1971	5,115	145
1933	252	7	1972	598	17
1934	1,187	34	1973	8,458	240
1935	18,416	521	1974	90	3
1936	3,462	98	1975	537	15
1937	106,531	3,017	1976	43,396	1,229
1938	70,296	1,991	1977	250	7
1939	86,000	2,435	1978	78,007	2,209
1940	2,700	76	1979	65,408	1,852
1941	46,000	1,303	1980	82,245	2,329
1942	407	12	1981	623	18
1943	2,480	70	1982	5,095	144
1944	11,000	311	1983	69,225	1,960
1945	7,380	209	1984	9,751	276
1946	972	28	1985	28,433	805
1947	7,230	205	1986	7,990	226
1948	2,070	59	1987	207	6
1949	2,900	82	1988	14,324	406
1950	1,850	53	1989	193	5
1951	65,100	1,843	1990	2,575	73
1952	37,600	1,065	1991	70,967	2,010
1953	193	6	1992	50,273	1,424
1954	34,700	983	1993	104,667	2,964
1955	4,610	131	1994	207	6
1956	162	5	1995	62,743	1,777
1957	12,100	343	1996	241	7
1958	13,000	368	1997	4,966	141
1959	2,900	82	1998	12,094	342
1960	3,420	97	1999	40	1
1961	16,300	462	2000	2687	76
1962	8,400	238	2001	3796	107
1963	10,300	292	2002	176	5
1964	25,600	725			
1965	12,300	348			
1966	41,900	1,186			

*From 1927-1939, discharges are correlated from gage at Planet. From 1939 to 1968, discharges are from gage at Alamo. From 1968 to present, discharges are computed inflows into Alamo Lake.

**Peak discharge for 1928 not available.

Table 4-03a. Alamo Dam and Lake - Cumulative Annual Damages Prevented

Fiscal Year	Damages Prevented	Fiscal Year	Damages Prevented
1982	$1,511,000	1993	$14,511,000
1983	$1,511,000	1994	$14,511,000
1984	$1,511,000	1995	$21,511,000
1985	$1,511,000	1996	$21,511,000
1986	$1,511,000	1997	$21,511,000
1987	$1,511,000	1998	$21,511,000
1988	$1,511,000	1999	$21,511,000
1989	$1,511,000	2000	$21,511,000
1990	$1,511,000	2001	$21,762,000
1991	$1,511,000	2002	$21,762,000
1992	$1,511,000		

Note:

1. Damages prevented information not available for prior to 1982.

Brief descriptions of the more significant past storms and floods are given in the following subparagraphs:

a. <u>Early Storms and Floods</u>. Several of the greatest floods on record on the Bill Williams River occurred prior to 1930. The U.S. Geological Survey (USGS) has made estimates of the peak flows on the Bill Williams River at Planet (below the site of the present Alamo Dam), going back to the year 1883-84 and measurements beginning in the water year 1928-29. Annual peak discharge estimates include more than 100,000 cfs (2,832 cms) in February or March 1884, more than 200,000 cfs (5,663 cms) in February 1891, approximately 185,000 cfs (5,239 cms) in January 1916, and approximately 125,000 cfs (3,540 cms) in February 1927. Each of these flows resulted from an unusually heavy low-latitude warm winter storm that occurred over ground thoroughly saturated by other such storms during the previous days or weeks. Not published with these figures were the floods of January and February 1862, which resulted from some of the greatest storminess of this type ever known. Daily precipitation for selected stations in and near the Alamo drainage for 13 storms from 1905 through 1941 are published as Tables 8-20 in <u>Hydrology, Alamo Reservoir, Bill Williams River, Arizona</u>, U.S. Engineer Office, Los Angeles, California, 29 March 1946. Three of these storms and floods, as well as more modern events, are described below:

b. Storm and Flood of 6-9 February 1937. After a very cold January, with snowfall to unusually low elevations, a series of warm, low-latitude storms moved into Arizona from out of the west, dropping relatively heavy rain in the mountains. Prescott recorded 4.05 inches (10.29 cm), while Wikieup measured 3.90 inches (9.91 cm). The peak discharge on the Bill Williams River at Planet, which may have been aided at least slightly by snowmelt, was measured by the USGS at 92,500 cfs (2,619 cms).

c. Storm and Flood of 26 February - 5 March 1938. This flood resulted from a series of several very heavy low-latitude storms that moved across southern California (with record flooding) and into western and northern Arizona. Precipitation totals included 4.91 inches (12.47 cm) at Prescott, 4.78 inches (12.14 cm) at Yarnell, 3.73 inches (9.47 cm) at Bagdad, and 3.65 inches (9.27 cm) at Wikieup. The heaviest rain fell on 2 and 3 March, where one-day totals up to 3.21 inches (8.15 cm) were measured at Prescott, with 2.88 inches (7.32 cm) at Yarnell. This storm resulted in a peak discharge on the Bill Williams River at Planet of 61,000 cfs (1,727 cms).

d. Storm and Flood of 3-8 September 1939. This storm had two centers covering large areas, one northeast of the Imperial Valley in California and one from Needles and Parker to Truxton and Wikieup in Arizona. The unusually heavy precipitation during the storm was associated with three tropical cyclones originating off the west coast of Mexico, one of which traveled northward through the Gulf of California and dissipated over the lower Colorado River Valley. A total of 6 to 7 inches (17.78 cm) of precipitation fell over an area of more than 2,300 square miles (5,957 sq Km) within the center near Imperial Valley and over an area of more than 3,000 square miles (7,770 sq Km) within the center of the storm over Arizona. Totals in and near the Alamo drainage included 7.03 inches (17.86 cm) at Wikieup, 6.55 inches (16.51 cm) at Truxton, 6.50 inches (16.51 cm) at Yarnell, and 5.45 inches (13.84 cm) each at Kingman and Parker. Many stations reported more than 4 inches (10.16 cm). The maximum precipitation intensities in this storm were also high. The recording gage at Yuma measured 2.17 inches (5.51 cm) in 90 minutes; and at Phoenix, 2.41 inches (6.12 cm) fell in 6 hours. The Bill Williams River at Planet measured a peak discharge of 73,000 cfs

(2,067 cms), while the USGS estimated 77,000 cfs (2,180 cms) on the Bill Williams River near the Alamo Dam site. The Big Sandy River below Burro Creek, at Signal, Arizona, had a peak discharge of about 100,000 cfs (2,832 cms) from an area of 2,670 square miles (6,915 sq Km). Peak discharges for the storm are given in Table 4-04.

Table 4-04
Peak discharges from 3-8 September 1939 storm

Location	Peak Discharge (CFS)	Date
Big Sandy River near Signal	*100,000	6 September 1939
Santa Maria River near Alamo	22,300	6 September 1939
Bill Williams River near Alamo	86,000	6 September 1939
Bill Williams River at Planet	73,000	7 September 1939

* Estimated

e. <u>Storm and Flood of 27 – 30 August 1951</u>. The storm of late August 1951 was the heaviest general summer storm to hit the Alamo drainage basin during the period of record. A strong flow of tropical air from the south invaded Arizona during the latter half of August. This was augmented during the last several days of the month when a tropical storm crossed northern Baja California and dissipated over the mouth of the Colorado River, sending its remnants into western Arizona. Total storm precipitation ranged from less than 3 inches (7.62 cm) in the center of the Alamo basin to more than 8 inches (20.32 cm) in the mountains of the eastern portion of the Santa Maria River drainage. The station, Bagdad 8NE, measured 7.40 inches (18.80 cm), all falling in just over 36 hours. Camp Wood recorded 7.10 inches (18.03 cm), and Bagdad 2E recorded 5.24 inches (1331 cm). The basin average was computed at 3.86 inches (9.80 cm). The peak inflow was measured at 64,500 cfs (1,826 cms) on 29 August at 1730 hours.

f. <u>Storm and Flood of 28 February – 3 March 1978</u>. During a series of low-latitude winter storms, one especially intense storm stalled just off the southern California coast, pumping abundant tropical moisture into western and central Arizona. Some very heavy rainfall totals resulted, with a basin average of 3.82 (9.70 cm) inches in 78 hours. The heaviest rain occurred on saturated ground early 1 March, with basin-average precipitation up to 0.31 inch (0.79 cm) for 1 hour and effective rain of 0.20 inches (0.51

cm) in 1 hour. Total storm effective runoff was 0.79 inch (2.01 cm). The observed flood hydrograph on the Bill Williams at Alamo Dam shows a triple peak on 1 March. The third peak, of 77,500 cfs (2,195 cms) at 1400 hours, was slightly higher than the other two (see Plate 4-05).

g. Storm and Flood of 17-19 December 1978. Following a very sharp cold spell in early December 1978, a deep low-pressure area formed off the Southern California coast in mid-month. The circulation around this low brought abundant tropical moisture into Arizona from well south of the tip of Baja California. This moisture was forced up against the mountains and lifted orographically, producing very heavy rainfall in foothill and upslope areas. A number of stations reported more than 3-4 inches (7.62 – 10.16 cm) for the storm. In the Alamo drainage, basin-wide precipitation aver-ages only 0.10 to 0.15 inch (0.25 – 0.38 cm) per hour, but rain fell for most of 48 hours, and the accumulation of 2.46 inches (6.25 cm, basin average) on the cold ground resulted in a broad flood hydrograph with a peak discharge of 67,000 cfs (1,897 cms) on 18 December at 2100 hours (see Plate 4-06).

h. Storm and Flood of 28-30 January 1980. At the end of January 1980, a low-latitude low developed off the Southern California coast similar to that of March 1978. The resultant flow of tropical moisture against the mountains, which was plowed into by a sharp cold front, brought more than 48 hours of intermittent precipitation to the Alamo drainage, with a basin-average total of 2.51 inches (6.38 cm). This rain included several hours of intensities greater than 0.20 inch (0.51 cm) per hour basin-wide, climaxed by one hour of 0.30 inch (0.76 cm) followed by one hour of 0.28 inch (0.71 cm). Effective precipitation was high, and the resulting flood hydro-graph of inflow to Alamo Lake shows a peak discharge of 76,000 cfs (2,152 cms) on 30 January at 1000 hours (see Plate 4-07).

i. Storm and Flood of 13-22 February 1980. During mid-February 1980 a series of six warm, low-latitude Pacific storms moved inland across Southern California and Arizona, resulting in several periods of intense rainfall. The Alamo watershed received virtually continuous light precipitation between 13 and 15 February, punctuated by a very heavy two-hour burst around noon on 14 February, with basin-average rates of up to 0.41 inch (1.04 cm) in one hour. This produced a peak discharge into Alamo Lake of 53,000 cfs (1,500 cms) on 15 February from 0600-0700 hours. After occasional light rain on 17-18 February, two bursts of rain up to 0.18 inch (0.46 cm) in one hour fell on 19 February. With the ground saturated, effective rates were up to 0.12 inch (0.30 cm) per hour. This produced a peak inflow of 82,000 cfs (2,322 cms) on 20 February from 0200-0300 hours (see Plate 4-07). The total basin-average precipitation for the storm was 4.80 inches (12.19 cm).

j. <u>Storm and Flood of 27 February - 4 March 1983</u>. The winter season of 1982-83 was characterized by several series of low-latitude Pacific storms that moved across Southern California and Arizona from the west, driven by a very prominent El Niño condition in the equatorial Pacific Ocean. The climax of the season occurred from 27 February through 4 March, when storms stalled just southwest of San Diego and produced large quantities of tropical moisture in western Arizona. Nearly 2.5 inches (6.35 cm) fell at Alamo Dam, mostly on 3 and 4 March, while the upper portions of the basin received an estimated 3-4 inches (7.62 – 10.16 cm). The ground had been saturated by antecedent rainfall, and the rainfall was highly effective. The peak inflow to Alamo Lake was 69,070 cfs (1,956 cms) on 3 March at 1500 hours (see Plate 4-08).

k. <u>Storm and Flood of 8 January-28 February 1993</u>. The winter season of 1992-93 was characterized by a series of low-latitude Pacific storms that moved across Southern California and Arizona from the west, driven by cooler than normal temperatures across the North Pacific Ocean. The first significant storm period occurred from 7 to 19 January. The Bagdad precipitation station recorded 2.05 inches (5.21 cm) in a 24-hour period between 7 and 9 January. The second significant storm period occurred between 8 and 28 February. The Bagdad station recorded 3.87 inches (9.83 cm) between 8 and 10 February and 3.22 inches (8.18 cm) between 19 and 20 February. Antecedent precipitation in December 1992 partially saturated the ground, thus serving to increase the effective runoff of the 1993 storm events. The peak 24-hour inflow to Alamo Lake was 52,159 cfs (1,477 cms) on 20 February (see Plate 4-09).

4-07. Runoff Characteristics

Rapid concentration of water in the main channel produces runoff characterized by high peaks and channel velocities. Runoff is relatively high because of a combination of well-entrenched streams having steep gradients, impervious soil formations, fanshaped collecting systems, and irregular distribution of rainfall. Perennial inflow in some reaches of the Bill Williams, Santa Maria, and Big Sandy Rivers results from rising water at subterranean bedrock constrictions. Normally, natural streamflow occurs only during and immediately following major storms, except for occasional snowmelt runoff from headwater areas. Table 4-04a shows the available annual average inflow data to Alamo Lake for the period of record.

Table 4-04a. Annual Average Inflow to Alamo Lake

Year	Flow (cfs)	Flow (cms)	Year	Flow (cfs)	Flow (cms)
1969	48	1.4	1985	206	5.8
1970	39	1.1	1986	78	2.2
1971	20	0.6	1987	9	0.25
1972	8	0.2	1988	85	2.4
1973	218	6.2	1989	7	0.2
1974	4	0.1	1990	8	0.2
1975	4	0.1	1991	157	4.4
1976	1	0.03	1992	156	4.4
1977	4	0.1	1993	973	27.6
1978	444	12.6	1994	-4 *	-.01
1979	442	12.5	1995	335	9.5
1980	754	21.4	1996	3	0.08
1981	12	0.4	1997	22	0.6
1982	78	2.2	1998	150	4.2
1983	373	10.6	1999	8	0.2
1984	48	1.4	2000	11	0.3

* Evaporation was greater than inflow to the lake.

4-08. Water Quality

The Corps, for many years, has conducted a water quality monitoring program at Alamo Dam and Lake. The water quality parameters sampled and analyzed include the following categories: (1) limnological (temperature, pH, dissolved oxygen, specific conductance, and oxidation-reduction potential); (2) chemical (nitrogen, phosphorous, sulfides, sulfates, chlorophyll, pheno-phytin, and various ions of the aforementioned); and (3) bacteriological (total coliform, fecal coliform, and fecal streptococci). The latest "Annual Report on Water Quality Management." for Water Year 2002, dated January 2003, reported the following results for each parameter within the categories tested. These parameters measured high or exceeded their range of values, however, comparing results from prior years of water quality testing, they have been fairly consistent with no notable changes:

Alkalinity (Range: 0 – 300 mg/L): Measured in Lab at 235 mg/L
Dissolved Solids (Range: 0 – 1000 mg/L): Measured in Lab at 419mg/L
Total Residue (Range: 0 – 50 mg/L): Measured in Lab at 425 mg/L
Magnesium (Range: 0 – 25 mg/L): Measured in Lab at 22.1 mg/L
Manganese (Range: 0 – 25 ug/L): Measured in Lab at 23 ug/L

The water quality data sampled and analyzed are incorporated into SPL's Annual Report on Water Quality Management and are transmitted into the Environmental Protection Agency's STORET water quality database, and the results discussed in the "Annual Report on Water Quality Management."

Generally, water quality concern is primarily with the anaerobic conditions that continue to exist at Alamo Lake, when the lake becomes fully stratified and the lake hypolimnion forms. The anaerobic water causes the generation of hydrogen-sulfide gas at significant concentration levels, which, in turn, permeate into the outlet works. The presence of hydrogen-sulfide gas in the outlet works often precludes routine inspection and maintenance of the outlet works because of hazardous conditions for operation/maintenance personnel. Additionally, corrosion on various electrical components within the dam is attributed to hydrogen sulfide gas. Deterioration of the concrete in the outlet works has also been caused by the presence of dissolved hydrogen sulfide in the water released. Recreational activity around the reservoir results in a nominal nutrient loading that contributes to the anaerobic conditions in the reservoir hypolimnion. The upstream watershed has little impact upon the quality of water in the lake. Because downstream releases are generally small, normally 10-50 cfs (0.28 – 1.42 cms), the water quality in Alamo Lake has little, if any, impact on the water quality downstream and on the Colorado River.

4-09. Channel and Floodway Characteristics

The Bill Williams River downstream from Alamo Dam flows through a series of narrow canyons alternating with wide valleys. The canyons are, in places, 200 feet (61 m) or less in width. Within the valleys, the river meanders to widths of 1 to 1.5 miles (1.61 – 2.41 Km). The average slope of the river between Alamo Dam and the mouth is 16 feet (4.88 m) per mile. Although 7,000 cfs (198.2 cms) has been designated as the maximum non-damaging channel capacity, the 7,000 cfs (198.2 cms) release made during the storm and flood of 1993 destroyed the road through the Bill Williams River National Wildlife Refuge. The road, which provides access to Planet Ranch, had not been repaired at the time this Water Control Manual was published. In the past the road had suffered washouts from releases of 2,000 cfs (56.63 cms), or greater. Additionally, stream fords in the Planet Ranch area have become impassable from releases of as little as 500 cfs (14.16 cms). Table 4-05 shows the travel times of spillway flow at various locations downstream of Alamo Dam. A schematic of capacities for the Bill Williams River channel is presented on Plate 4-10.

Table 4-05. Spillway Flow Travel Times Downstream of Alamo Dam

Distance from Alamo Dam (miles)	Distance from Alamo Dam (Km)	Location	Average Elevation (ft, NGVD)	Average Elevation (m, NGVD)	Time (hours)
3.4	5.5	D/S of Alamo Dam Outlet	966	294	0.25
7.9	12.7	Near Lincoln Ranch at Reid Valley	872	266	1.0
8.5	13.7	At Rankin Ranch Road	812	247	1.25
15.9	25.6	-	685	209	3.5
18.5	29.8	-	643	196	4.0
22.5	36.2	At Planet Ranch Road	582	177	5.0
25.0	40.2	-	542	165	5.5
28.7	46.2	-	482	147	9.0
35.4	57.0	D/S of Parker Dam	374	114	8.25
41.2	66.3	-	375	114	9.5
45.0	72.4	-	371	113	10.5
46.5	74.8	-	368	112	11.0
50.1	80.6	Parker Valley	351	107	12.0
53.6	86.3	Parker Valley	343	105	13.0
59.9	96.4	Parker Valley	335	102	14.0
66.8	107.5	Parker Valley Indian Reservation	315	96	17.0
69.4	111.7	Parker Valley Indian Reservation	310	94	19.0
73.7	118.6	Parker Valley Indian Reservation	300	91	21.0
79.9	128.6	Palo Verde Valley	290	88	22.0
82.7	133.1	Palo Verde Valley Indian Reservation	283	86	25.0
85.6	137.8	Colorado River Indian Reservation	278	85	28.0
90.7	146.0	Palo Verde Valley	267	81	30.0
97.3	156.6	Palo Verde Valley	253	77	50.0
99.4	160.0	Palo Verde Valley	250	76	50.5
106.4	171.2	Palo Verde Valley	242	74	59.5
113.4	182.5	Cibola Valley	235	72	62.5
121.3	195.2	Cibola Valley Refuge	216	66	65.0
129.5	208.4	-	210	64	70.0
134.7	216.8	Taylor Lake	206	63	71.5
145.8	234.6	Martinez Lake	197	60	78.5
152.5	245.4	Imperial Dam	192	59	81.5
156.7	252.2	Mittry Lake	154	47	85.0
160.4	258.1	North Gila Valley	144	44	91.0
161.7	260.2	North Gila Valley	135	41	91.25
166.6	268.2	Fort Yuma Indian Reservation	130	40	93.0
169.6	272.9	Fort Yuma Indian Reservation	123	37	97.5
172.6	277.8	Near U.S. Marine Corps Air Station	116	35	97.5
177.3	285.3	Yuma Valley Cocopah Indian Reservation	109	33	118.0
183.5	295.3	Yuma Valley	95	30	130.0
187.2	301.3	Yuma Valley	77	23	135.0

Note: This information is from the Alamo Dam Emergency Action and Notification Subplan prepared in June 1986. The Inundation maps, which are part of this plan, are located at U.S. Army Corps of Engineers, Los Angeles District, Reservoir Operation Center, and also at the dam site.

4-10. <u>Upstream Structures</u>

There are no hydraulic control structures upstream of Alamo Dam.

4-11. <u>Related Structures</u>

Alamo Dam operation is closely coordinated with the operation of the U.S. Bureau of Reclamation dams on the lower Colorado River (Hoover, Davis, Parker and Imperial Diversion). The coordination is designed to optimize flood control, hydropower, water supply, water quality, and recreational benefits on the Colorado River. The maximum controlled release of 7,000 cfs (198.2 cms) from Alamo Dam was derived assuming a Colorado River channel capacity of 25,000 cfs (707.9 cms) below Parker Dam and an 18,000 cfs (509.7 cms) release from Hoover Dam.

Table 4-05 contains the names and locations (in river miles) of other dams on the lower Colorado River below Parker Dam whose operations could be affected by Alamo Dam regulation.

Table 4-06
Dams on lower Colorado River below Parker Dam.

Dam	Distance (River Mile)	Distance (Km)
Morelos	22.1	35.6
Laguna	43.2	69.5
Imperial	49.2	79.2
Palo Verde Diversion	133.8	215.3
Headgate Rock	177.9	286.3

4-12. <u>Economic Data</u>

a. Population. Alamo Dam affords protection to all property downstream from Parker Dam to Mexico. The area protected has a population of approximately 1,172,000.

Table 4-07a lists pertinent population data for the regions affected by operation of Alamo Dam.

Table 4-07a. Population Data for Alamo Dam Watershed and Downstream

	1980	1990	1998*
Watershed Area City or Indian Reservation (County)			
Bagdad (Yavapai County)	2,349	1,858	2,613
Downstream Area along the Colorado River City or Indian Reservation (County)			
Colorado River Indian Reservation (La Paz)	2,504	3,035	3,318
Parker (La Paz)	2,542	2,897	2,990
Enrenberg (La Paz)	1,210	1,226	1,561
Blythe (Riverside)	NA	NA	2,150
Cocopah Indian Reservation (Yuma)	835	515	894
San Luis (Yuma)	1,946	4,212	11,090
Somerton (Yuma)	3,969	5,282	6,625
Yuma (Yuma)	42,481	54,923	68,160
San Luis Rio Colorado, Sonora, Mexico	NA	NA	200,000
Mexicali, Baja California, Mexico	NA	NA	800,000
Calexico, California	NA	NA	25,650
Source: Arizona Department of Commerce Alamo Dam Risk Assessment Study Department of Finance California * Latest data available to date			

b. Industry. Table 4-07b and 4-07c lists pertinent industrial data in relation to employment and agriculture for the regions affected by operation of Alamo Dam. The data presented on these tables are the latest available, at the time in which this manual was completed.

Table 4-07b. Agricultural Data for Alamo Dam (1997*)

Acreages for Various Crops						
	Watershed Area	Downstream Area along the Colorado River				
Crop	Yavapai	Riverside	Imperial	La Paz	Mohave	Yuma
Corn	NA	0	0	NA	NA	8,077
Wheat	NA	25,606	78,48	7,540	NA	35,116
Barley	NA	2,235	NA	NA	320	2,313
Cotton	0	12,71	6,058	23,228	3,977	27,972
Hay-Alfalfa	3,305	90,926	232,734	59,065	7,469	42,520
Vegetables	197	38,041	86,816	8,293	NA	86,329
Orchards	167	68,191	7,479	164	18	24,370

Source: United States Department of Agriculture
* Latest available data to date

Table 4-07c. Unemployment Rate and Number People Employed by Sector (2001*)

For Alamo Dam Watershed and Downstream Areas						
	Yavapai	La Paz	Mohave	Yuma	Riverside	Imperial
Labor Force	70,821	6,417	66,777	64,487	711,500	43,700
Unemployment Rate	2.93%	6.3%	4.5%	24.4%	5.2%	21.3%
Employment by Sector						
Agriculture	0	648	461	22,902	16,300	12,600
Manufacturing	3,375	300	3,200	2,350	53,600	1,900
Mining and Quarrying	1,075	0	100	0	500	0
Construction	4,875	100	4,700	2,800	52,500	1,600
Transportation, Comm. and Public Utilities	1,325	100	2,225	1,475	15,100	2,000
Trade	13,700	1,650	12,375	11,600	117,200	10,400
Finance, Insurance, and Real Estate	1,575	100	1,425	1,325	15,900	1,300
Services and Miscellaneous	15,275	550	10,775	10,125	127,300	5,700
Government	9,975	2,150	7,600	11,975	90,300	16,100

Source: Arizona Department of Commerce
California Employment Development Department
* Latest available data to date

c. Flood Benefits. Plate 4-12 shows the area that would have been inundated by the reservoir design flood prior to the construction of Alamo Dam. Practically all economic development protected by Alamo Dam is along the lower Colorado River; very few improvements are located on the Bill Williams River below the dam. Property of significant value is situated in the lowlands of the Colorado River between Parker Dam and the Mexican border, a distance of about 200 river-miles. The principal downstream areas are designated as: Parker Dam to Parker, Parker Valley, Palo Verde and Cibola Valleys, and Yuma Valley. Areas susceptible to damage contain residential, business, and industrial property, and various facilities such as irrigation and flood control works, highways, and public facilities. The Alamo Dam Risk Assessment estimated the value of the depreciated replacement of the property located in the floodplain to be $5,615,258,000.

Table 4-08 herein, shows the damage-discharge relationships for various points along the Colorado River below Alamo Dam. The table also shows the respective annual exceedance probability of these discharges from Alamo Dam. The probabilities are based on operating Alamo Dam according to the revised operating plan and are computed from the available period of record 1929-1998.

Table 4-08
Damage-Discharge Data Below Alamo Dam

Discharge (cfs)	Exceedance[2] (Percent)	Exceedance (Years)	Damage (Parker)	Damage (Blythe)	Damage (Yuma)
20,000	2.88	35	$0	$0	$0
30,000	1.94	50	$0	$0	$0
40,000	1.52	65	$0	$0	$60,679,000
60,000	0.96	100	$0	$0	$99,008,000
70,000	0.84	120	$13,470,000	$0	$117,087,000
80,000	0.74	135	$25,976,000	$0	$123,169,000
90,000	0.64	156	$29,801,000	$0	$123,169,000
100,000	0.56	180	$31,898,000	$0	$129,252,000
150,000	0.32	310	$48,726,000	$33,779,000	$138,588,000

1. Based on 2002 price levels.
2. Based on computed probability curve.

A damage discharge curve was created based on the information provided on Table 4-08, as shown on Plate 4-11, and can be used as a gauge by Reservoir Regulation Section to estimate the amount of damages that would occur if the corresponding discharge occurred at the particular location on the Colorado River. The value of these damages, however, is expected to change in the future as the price levels and hydraulic conditions changes. SPL's Economic Section will be responsible for calculating the changes in the flood damages due to changes in the price level. The changes in the price level should be based on the price indexes provided by Marshall & Swift Valuation Service, or equivalent.

Photo 4-01. Big Sandy River Basin.

Photo 4-02. Santa Maria River Basin

Photo 4-03. Sediment of Bill Williams River between Lincoln Ranch and Planet Ranch, where normal flows are subterranean. Photo was taken immediately upstream of Planet Ranch.