After providing for the primary supplies, the reservoir would be operated in general to deliver as much water as possible from the supplies available up to the maximum capacity of utilization under conditions of present development for both direct surface application and ground water storage. In the study of reservoir operation, the needs of the Madera unit were given first consideration after satisfying requirements for primary supply because of the assumed right initiated by the Madera Irrigation District to acquire San Joaquin River water. An attempt was made to furnish a surface irrigation supply of 150,000 acre-feet per season in accord with the irrigation demand shown in Table 123 with a minimum amount of not less than 31,000 acre-feet in a season of minimum yield. This basis of delivery of surface irrigation supplies to the Madera unit was generally adhered to, except during the month of August for a few seasons during the period studied when it was found necessary to deliver more of the water available to the units south of the San Joaquin River. In addition to the surface irrigation supply, water was delivered to the Madera unit, up to the maximum capacity of 1500 second-feet in the Madera Canal, for ground water storage and subsequent utilization by pumping, during periods when Friant Reservoir was spilling and during the months of March, April and May in seasons of above normal run-off when the reservoir stages were rising. The amount of water furnished the Madera unit on this basis was found to be adequate for present developments and it was assumed that this would be satisfactory to the Madera Irrigation District, provided the district would be protected in the matter of its assumed right to acquire about 350,000 acre-feet seasonally under conditions of ultimate development.

After providing for delivery of water to the Madera unit on the foregoing basis, the remainder of the supply available was delivered to the areas south of the San Joaquin River up to the maximum capacity of 3000 second-feet of the San Joaquin River-Kern County Canal during the months of March to October inclusive, and at a rate of 2300 second-feet in the remaining months.

Based upon the foregoing bases of operation of Friant Reservoir, the seasonal utilization of the impaired run-off of the San Joaquin River at Friant under conditions of immediate initial development which would have been effected during the 40-year period 1889–1929 is shown for each season in Table 153. There are set forth in this table the seasonal supplies provided for crop land rights, the amounts of in-season and out of season water diverted to the upper San Joaquin Valley through the Madera and San Joaquin River-Kern County canals, the evaporation loss from the reservoir, the unregulated waste past the reservoir and the net seasonal accretion or depletion in reservoir storage. The table also shows the averages of these items for the 40-, 20-, 12-, 8-, and 5-year periods to and including 1929. The data in this table of the seasonal amounts of water furnished for the crop lands and for delivery to the upper San Joaquin Valley are graphically depicted on Plate LXX, "Yield From Grass Land Rights and Surplus Waters of San Joaquin River at Friant Under Plan of Immediate Initial Development."

TABLE 153

SEASONAL UTILIZATION OF THE IMPAIRED RUN-OFF OF THE SAN JOAQUIN RIVER AT FRIANT RESERVOIR UNDER CONDITIONS OF IMMEDIATE INITIAL DEVELOPMENT, 1889-1929

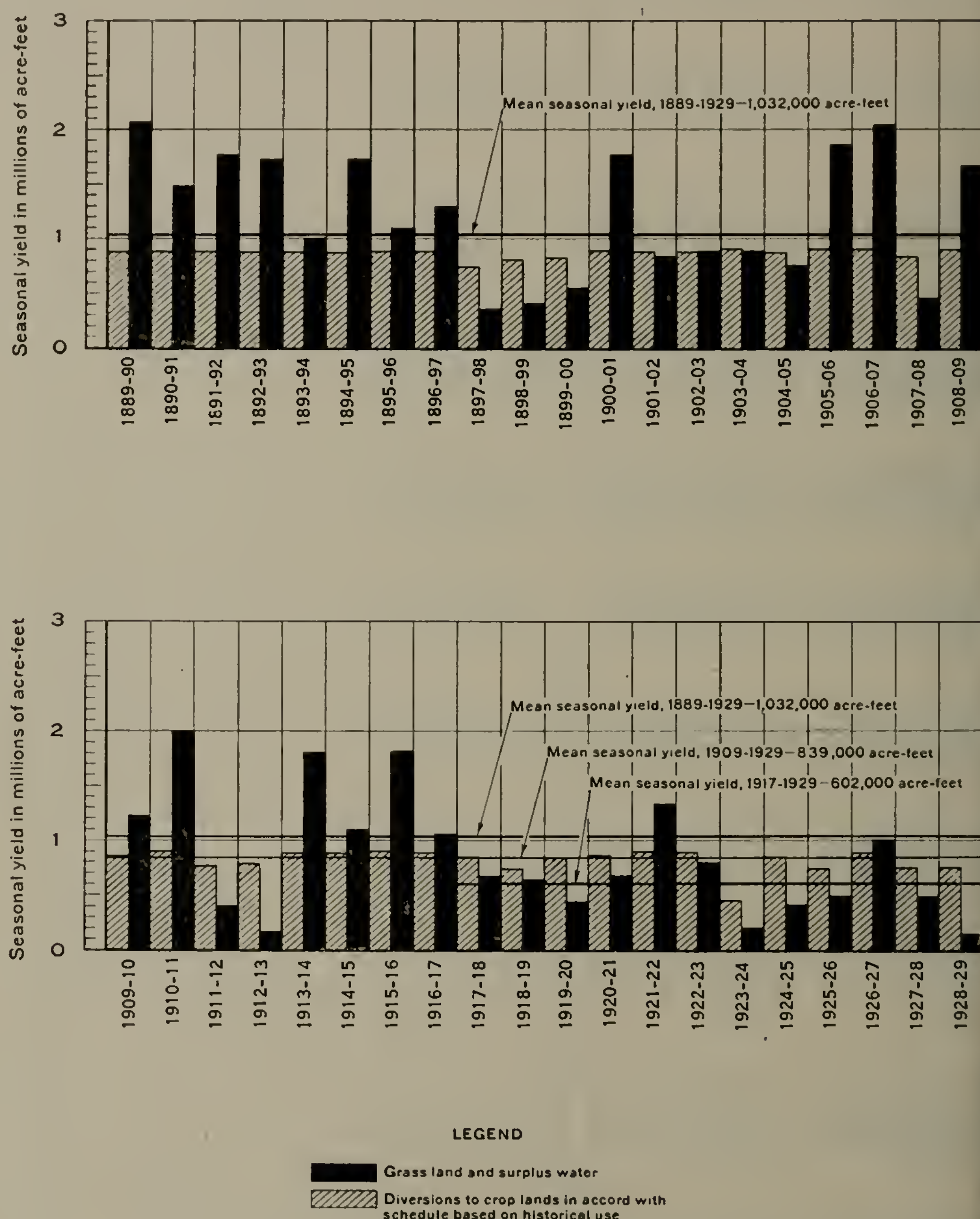
Quantities in Acre-feet

Season	Prior crop land rights	Diversions for upper San Joaquin Valley							Reservoir evaporation loss	Waste past reservoir	Net contribution to reservoir storage	Total impaired run-off[1]
		Madera Canal			San Joaquin River-Kern County Canal			Totals				
		In season	Out-of-season	Totals	In season	Out-of-season	Totals					
1889-90	895,700	150,000	331,200	481,200	849,000	747,500	1,596,500	2,077,700	15,100	1,442,100	0	4,430,600
1890-91	895,200	132,100	113,700	245,800	684,600	561,400	1,246,000	1,491,800	11,200	0	0	2,398,200
1891-92	895,700	141,400	151,400	292,800	793,500	687,000	1,480,500	1,773,300	13,700	235,600	0	2,918,300
1892-93	895,700	141,400	136,200	277,600	792,400	660,300	1,452,700	1,730,300	13,500	132,400	0	2,771,900
1893-94	888,800	132,100	0	132,100	560,400	296,200	856,600	988,700	10,900	0	0	1,888,400
1894-95	895,700	141,400	113,700	255,100	802,900	680,400	1,483,300	1,738,400	13,200	102,400	0	2,749,700
1895-96	893,600	126,100	10,000	136,100	654,000	316,900	970,900	1,107,000	12,500	0	0	2,013,100
1896-97	882,400	131,600	70,700	202,300	664,600	433,600	1,098,200	1,300,500	12,500	42,800	0	2,238,200
1897-98	739,900	62,500	0	62,500	202,300	77,400	279,700	342,200	10,900	0	0	1,093,000
1898-99	801,500	103,300	0	103,300	277,600	0	277,600	380,900	10,900	0	0	1,193,300
1899-90	806,900	96,000	0	96,000	337,900	91,700	429,600	525,600	10,900	0	0	1,343,400
1900-01	895,700	141,400	146,500	287,900	764,500	683,900	1,448,400	1,736,300	14,100	225,900	0	2,872,000
1901-02	862,900	116,200	0	116,200	555,800	146,000	701,800	818,000	11,000	0	0	1,691,900
1902-03	872,300	116,200	0	116,200	591,800	171,200	763,000	879,200	11,900	0	0	1,763,400
1903-04	891,000	132,100	0	132,100	587,700	166,000	753,700	885,800	12,300	0	0	1,789,100
1904-05	859,500	116,200	0	116,200	446,700	171,800	618,500	734,700	10,900	0	0	1,605,100
1905-06	895,700	150,000	267,500	417,500	818,600	623,900	1,442,500	1,860,000	14,500	1,041,700	+81,300	3,893,200
1906-07	895,700	150,000	296,400	446,400	860,000	715,400	1,575,400	2,021,800	14,100	74,400	—81,300	2,924,700
1907-08	836,800	62,500	0	62,500	275,700	126,500	402,200	464,700	10,900	0	0	1,312,400
1908-09	895,700	141,400	115,400	256,800	765,500	645,700	1,411,200	1,668,000	13,200	196,300	0	2,773,200
1909-10	861,600	116,200	6,700	122,900	459,300	633,400	1,092,700	1,215,600	10,700	0	0	2,087,900
1910-11	895,700	150,000	330,600	480,600	853,800	666,400	1,520,200	2,000,800	15,000	624,300	0	3,535,800
1911-12	757,700	90,300	0	90,300	287,500	23,300	310,800	401,100	10,900	0	0	1,169,700
1912-13	785,200	31,000	0	31,000	107,000	0	107,000	138,000	10,500	0	—4,800	928,900
1913-14	895,700	148,300	189,900	338,200	807,500	658,700	1,466,200	1,804,400	14,200	4,300	+4,800	2,723,400
1914-15	890,600	132,100	0	132,100	745,400	226,700	972,100	1,104,200	12,000	0	0	2,006,800
1915-16	895,700	141,400	259,100	400,500	771,600	649,200	1,420,800	1,821,300	13,700	28,900	0	2,759,600
1916-17	887,600	132,100	0	132,100	666,100	261,800	927,900	1,060,000	11,700	0	0	1,959,300
1917-18	864,000	116,200	0	116,200	464,500	90,000	554,500	670,700	11,200	0	0	1,545,900
1918-19	728,500	90,500	0	90,500	396,200	137,000	533,200	623,700	10,900	0	0	1,363,100

1919–20	843,600	104,900	0	104,900	288,900	52,300	341,200	446,100	10,900	0	0	1,300,600
1920–21	870,500	116,200	0	116,200	460,000	102,300	562,300	678,500	10,900	0	0	1,559,900
1921–22	892,100	132,100	113,700	245,800	753,200	338,300	1,091,500	1,337,300	12,100	38,000	0	2,279,500
1922–23	886,900	132,100	0	132,100	453,600	200,000	653,600	785,700	10,900	0	0	1,683,500
1923–24	460,800	32,700	0	32,700	147,100	2,500	149,600	182,300	10,900	0	0	654,000
1924–25	861,100	104,900	0	104,900	275,900	20,700	296,600	401,500	10,900	0	0	1,273,500
1925–26	736,900	90,500	0	90,500	335,100	58,600	393,700	484,200	10,900	0	0	1,232,000
1926–27	878,800	130,400	0	130,400	598,300	266,600	864,900	995,300	11,600	0	0	1,885,700
1927–28	739,400	90,500	0	90,500	314,100	74,500	388,600	479,100	10,900	0	0	1,229,400
1928–29	768,300	32,700	0	32,700	108,000	0	108,000	140,700	10,500	0	—3,100	916,400
40-year average, 1889–1929	845,000	115,000	66,300	181,300	539,500	311,600	851,100	1,032,400	12,000	104,700	—100	1,994,000
20-year average, 1909–1929	820,000	105,800	45,000	150,800	464,700	223,100	687,800	838,600	11,600	34,800	—200	1,704,800
12-year average, 1917–1929	794,200	97,800	9,500	107,300	382,900	111,900	494,800	602,100	11,100	3,200	—300	1,410,300
8-year average, 1921–1929	778,000	93,300	14,200	107,500	373,200	120,100	493,300	600,800	11,100	4,800	—400	1,394,300
5-year average, 1924–1929	796,900	89,800	0	89,800	326,300	84,100	410,400	500,200	11,000	0	—600	1,307,500

[1] Existing upstream power storage assumed to be operated without interference with crop land schedule.

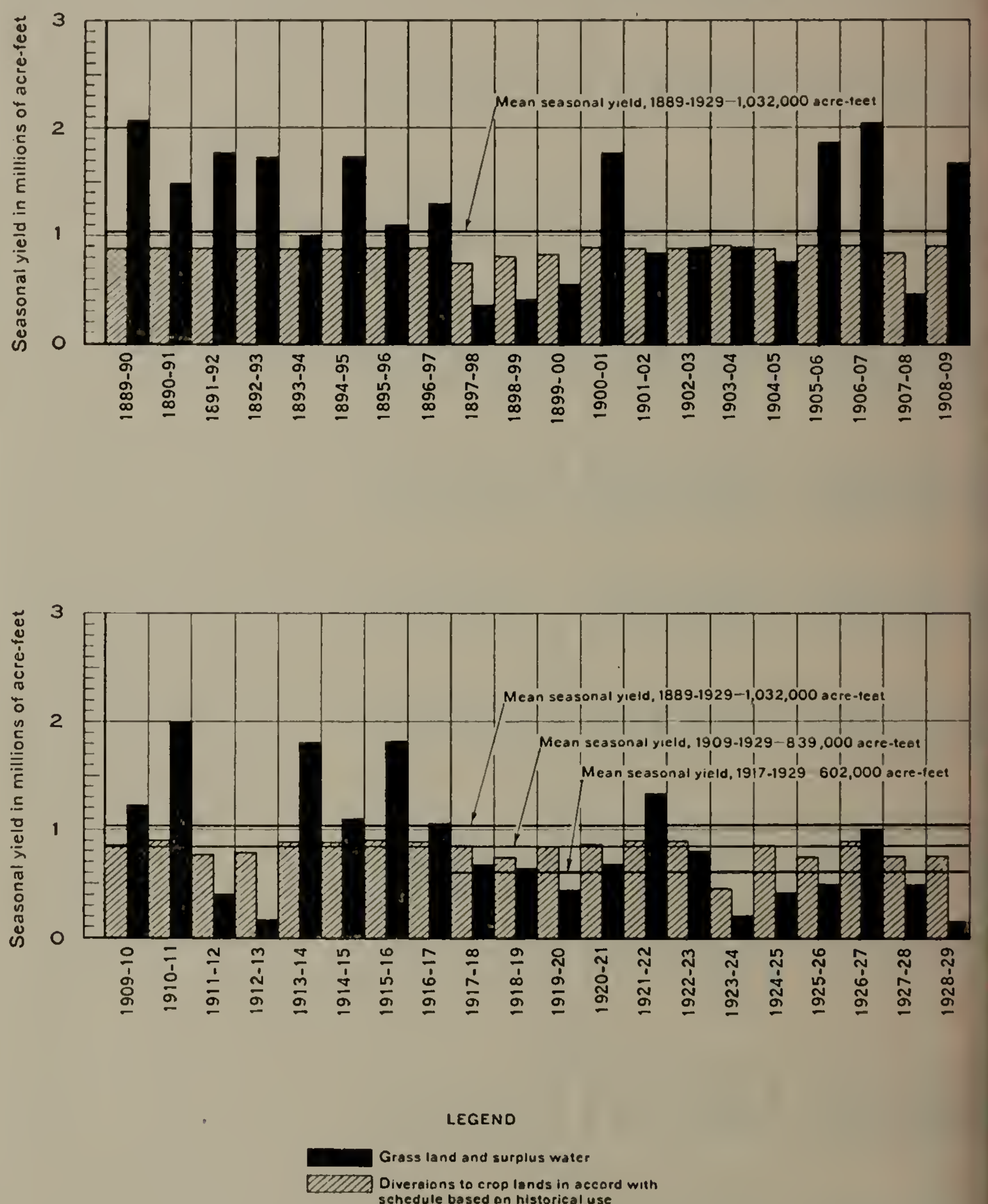
PLATE LXX



YIELD FROM
GRASS LAND RIGHTS AND SURPLUS WATERS
OF
SAN JOAQUIN RIVER AT FRIANT
UNDER
PLAN OF IMMEDIATE INITIAL DEVELOPMENT

Season	September		The Season		
	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Totals
1889-90	10,800	114,900	481,200	1,596,500	2,077,700
1890-91	2,200	15,700	245,800	1,246,000	1,491,800
1891-92	2,200	19,500	292,800	1,480,500	1,773,300
1892-93	2,200	18,400	277,600	1,452,700	1,730,300
1893-94	2,200	12,000	132,100	856,600	988,700
1894-95	2,200	32,600	255,100	1,483,300	1,738,400
1895-96	2,200	15,100	136,100	970,900	1,107,000
1896-97	2,200	10,800	202,300	1,098,200	1,300,500
1897-98	2,200	10,800	62,500	279,700	342,200
1898-99	2,200	10,800	103,300	277,600	380,900
1899-00	2,200	10,800	96,000	429,600	525,600
1900-01	2,200	18,500	287,900	1,448,400	1,736,300
1901-02	2,200	10,800	116,200	701,800	818,000
1902-03	2,200	10,800	116,200	763,000	879,200
1903-04	2,200	20,600	132,100	753,700	885,800
1904-05	2,200	10,800	116,200	618,500	734,700
1905-06	10,800	178,500	417,500	1,442,500	1,860,000
1906-07	10,800	91,200	446,400	1,575,400	2,021,800
1907-08	2,200	10,800	62,500	402,200	464,700
1908-09	2,200	36,600	256,800	1,411,200	1,668,000
1909-10	2,200	23,700	122,900	1,092,700	1,215,600
1910-11	10,800	86,800	480,600	1,520,200	2,000,800
1911-12	2,200	10,800	90,300	310,800	401,100
1912-13	2,200	10,800	31,000	107,000	138,000
1913-14	10,800	94,800	338,200	1,466,200	1,804,400
1914-15	2,200	16,000	132,100	972,100	1,104,200
1915-16	2,200	13,100	400,500	1,420,800	1,821,300
1916-17	2,200	10,800	132,100	927,900	1,060,000
1917-18	2,200	18,900	116,200	554,500	670,700
1918-19	2,200	10,800	90,500	533,200	623,700
1919-20	2,200	10,800	104,900	341,200	446,100
1920-21	2,200	10,800	116,200	562,300	678,500
1921-22	2,200	10,800	245,800	1,091,500	1,337,300
1922-23	2,200	12,400	132,100	653,600	785,700
1923-24	2,200	10,800	32,700	149,600	182,300
1924-25	2,200	10,800	104,900	296,600	401,500
1925-26	2,200	10,800	90,500	393,700	484,200
1926-27	2,200	10,800	130,400	864,900	995,300
1927-28	2,200	10,800	90,500	388,600	479.100
1928-29	2,200	10,800	32,700	108,000	140,700
Averages 1889-1929	3,300	26,700	181,300	851,100	1,032,400

PLATE LXX



YIELD FROM

GRASS LAND RIGHTS AND SURPLUS WATERS

OF

SAN JOAQUIN RIVER AT FRIANT

UNDER

PLAN OF IMMEDIATE INITIAL DEVELOPMENT

TABLE 154

MONTHLY DIVERSIONS FROM SAN JOAQUIN RIVER AT FRIANT RESERVOIR TO UPPER SAN JOAQUIN VALLEY UNDER CONDITIONS OF IMMEDIATE INITIAL DEVELOPMENT, 1889-1929

Quantities in Acre-feet

Season	October		November		December		January		February		March	
	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal
1889-90	2,100	32,000	0	36,200	0	49,700	0	141,400	1,600	127,700	92,200	184,400
1890-91	2,100	46,500	0	29,700	0	28,400	0	111,900	1,600	119,200	10,500	178,900
1891-92	2,100	44,300	0	35,300	0	33,800	0	121,400	1,600	132,300	10,500	184,400
1892-93	2,100	43,400	0	33,400	0	31,500	0	122,800	1,600	127,700	10,500	184,400
1893-94	2,100	36,200	0	23,600	0	18,900	0	84,400	1,600	95,500	10,500	112,300
1894-95	2,100	39,300	0	12,200	0	47,400	0	141,400	1,600	127,700	10,500	179,300
1895-96	2,100	37,000	0	19,300	0	6,400	0	115,400	1,600	78,500	10,500	127,800
1896-97	2,100	27,900	0	29,400	0	17,500	0	41,900	1,600	118,500	10,500	133,700
1897-98	2,100	30,200	0	36,200	0	28,600	0	34,900	1,600	37,900	10,500	18,800
1898-99	1,500	5,500	0	1,100	0	1,100	0	2,200	300	3,300	10,500	35,800
1899-00	2,100	6,000	0	7,500	0	6,600	0	108,900	1,600	13,300	10,500	59,100
1900-01	2,100	15,000	0	64,300	0	19,000	0	141,400	7,100	127,700	37,800	184,400
1901-02	2,100	44,700	0	30,400	0	26,400	0	47,400	1,600	42,600	10,500	71,700
1902-03	2,100	27,800	0	18,900	0	3,100	0	52,800	1,600	46,200	10,500	57,200
1903-04	2,100	26,200	0	8,300	0	1,100	0	2,200	1,600	8,300	10,500	109,300
1904-05	2,100	89,100	0	27,800	0	5,700	0	42,400	1,600	63,200	10,500	104,100
1905-06	2,100	16,600	0	1,100	0	1,100	0	92,600	1,600	58,000	92,200	184,400
1906-07	2,100	128,400	0	18,100	0	23,600	0	101,500	1,600	118,000	67,200	184,400
1907-08	2,100	47,800	0	19,700	0	17,600	0	62,300	1,600	57,200	10,500	85,300
1908-09	2,100	12,900	0	1,100	0	1,100	0	141,400	1,600	127,700	10,500	180,200
1909-10	2,100	36,800	0	34,800	0	134,100	0	141,400	1,600	113,100	10,500	182,500
1910-11	2,100	36,800	0	18,000	0	14,900	0	141,400	1,600	127,700	92,200	184,400
1911-12	2,100	37,700	0	16,100	0	4,600	0	33,000	1,600	22,300	10,500	25,900
1912-13	400	5,500	0	1,100	0	1,100	0	2,200	300	3,300	2,200	7,500
1913-14	400	5,500	0	1,100	0	1,100	0	141,400	1,600	127,700	10,500	184,400
1914-15	2,100	41,100	0	14,100	0	5,300	0	45,600	1,600	85,400	10,500	92,000
1915-16	2,100	27,600	0	8,500	0	11,200	0	141,400	1,000	132,300	92,200	184,400
1916-17	2,100	53,400	0	20,700	0	17,200	0	48,700	1,600	123,600	10,500	73,900
1917-18	2,100	28,200	0	8,700	0	1,100	0	2,200	1,600	22,200	10,500	109,200
1918-19	2,100	78,500	0	11,500	0	5,000	0	30,200	1,600	47,400	10,500	48,100
1919-20	400	5,500	0	1,100	0	1,100	0	2,200	300	3,300	2,200	7,500
1920-21	2,100	13,100	0	10,400	0	1,100	0	21,800	1,600	57,400	10,500	116,800
1921-22	2,100	26,200	0	1,100	0	1,300	0	41,400	1,600	73,900	10,500	85,700
1922-23	2,100	26,200	0	18,500	0	56,600	0	63,500	1,600	54,200	10,500	63,600
1923-24	2,100	38,100	0	11,100	0	1,100	0	2,200	300	3,300	2,200	7,500
1924-25	400	5,500	0	1,100	0	1,100	0	2,200	300	3,300	2,200	7,500
1925-26	2,100	28,500	0	1,100	0	1,100	0	2,200	1,600	17,800	10,500	45,500
1926-27	400	5,500	0	3,400	0	1,100	0	19,000	1,600	127,600	10,500	98,600
1927-28	2,100	32,000	0	43,500	0	16,200	0	29,800	1,600	33,700	10,500	71,700
1928-29	2,100	6,500	0	1,100	0	1,100	0	2,200	300	3,300	2,200	7,500
Averages 1889-1929	1,900	32,400	0	17,000	0	16,100	0	65,600	1,500	70,300	19,700	104,100

Season	April		May		June		July		August		September		The Season		
	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Madera Canal	San Joaquin River-Kern County Canal	Totals
1889-90	89,200	178,500	92,200	184,400	89,200	178,500	92,200	184,400	11,700	184,400	10,800	114,900	481,200	1,596,500	2,077,700
1890-91	25,500	178,500	92,200	184,400	89,200	178,500	20,100	159,000	2,400	15,300	2,200	15,700	245,800	1,246,000	1,491,800
1891-92	63,200	178,500	92,200	184,400	89,200	178,500	20,100	184,400	11,700	183,700	2,200	19,500	292,800	1,480,500	1,773,300
1892-93	48,000	178,500	92,200	184,400	89,200	178,500	20,100	184,400	11,700	165,300	2,200	18,400	277,600	1,452,700	1,730,300
1893-94	25,500	84,000	35,300	164,900	32,400	175,000	20,100	34,500	2,400	15,300	2,200	12,000	132,100	856,600	988,700
1894-95	25,500	178,500	92,200	184,400	89,200	178,500	20,100	184,400	11,700	177,600	2,200	32,600	255,100	1,483,300	1,738,400
1895-96	19,500	16,800	35,300	77,100	42,400	178,500	20,100	184,400	2,400	114,600	2,200	15,100	136,100	970,900	1,107,000
1896-97	39,300	178,500	92,200	184,400	32,400	178,500	19,600	161,800	2,400	15,300	2,200	10,800	202,300	1,098,200	1,300,500
1897-98	25,500	18,300	7,300	14,600	6,700	16,900	4,200	17,200	2,400	15,300	2,200	10,800	62,500	279,700	342,200
1898-99	25,500	79,900	24,300	21,900	32,400	83,500	4,200	17,200	2,400	15,300	2,200	10,800	103,300	277,600	380,900
1899-00	5,300	11,500	35,300	89,000	32,400	84,400	4,200	17,200	2,400	15,300	2,200	10,800	96,000	429,600	525,600
1900-01	25,500	178,500	92,200	184,400	89,200	178,500	20,100	184,400	11,700	152,300	2,200	18,500	287,900	1,448,400	1,736,300
1901-02	25,500	83,000	35,300	125,700	32,400	178,500	4,200	25,300	2,400	15,300	2,200	10,800	116,200	701,800	818,000
1902-03	25,500	39,500	35,300	184,400	32,400	178,500	4,200	128,500	2,400	15,300	2,200	10,800	116,200	763,000	879,200
1903-04	25,500	49,900	35,300	184,400	32,400	178,500	20,100	149,600	2,400	15,300	2,200	20,600	132,100	753,700	885,800
1904-05	25,500	25,000	35,300	99,000	32,400	118,900	4,200	17,200	2,400	15,300	2,200	10,800	116,200	618,500	734,700
1905-06	25,500	178,500	92,200	184,400	89,200	178,500	92,200	184,400	11,700	184,400	10,800	178,500	417,500	1,442,500	1,860,000
1906-07	79,400	178,500	92,200	184,400	89,200	178,500	92,200	184,400	11,700	184,400	10,800	91,200	446,400	1,575,400	2,021,800
1907-08	25,500	37,500	7,300	14,600	6,700	16,900	4,200	17,200	2,400	15,300	2,200	10,800	62,500	402,200	464,700
1908-09	27,200	178,500	92,200	184,400	89,200	178,500	20,100	184,400	11,700	184,400	2,200	36,600	256,800	1,411,200	1,668,000
1909-10	25,500	178,500	42,000	184,400	32,400	30,900	4,200	17,200	2,400	15,300	2,200	23,700	122,900	1,092,700	1,215,600
1910-11	89,200	178,500	91,600	184,400	89,200	178,500	92,200	184,400	11,700	184,400	10,800	86,800	480,600	1,520,200	2,000,800
1911-12	5,300	11,500	29,600	21,900	32,400	94,500	4,200	17,200	2,400	15,300	2,200	10,800	90,300	310,800	401,100
1912-13	5,300	11,500	7,300	14,600	6,700	16,900	4,200	17,200	2,400	15,300	2,200	10,800	31,000	107,000	138,000
1913-14	58,500	178,500	92,200	184,400	89,200	178,500	63,300	184,400	11,700	184,400	10,800	94,800	338,200	1,466,200	1,804,400
1914-15	25,500	101,000	35,300	127,700	32,400	178,500	20,100	184,400	2,400	81,000	2,200	16,000	132,100	972,100	1,104,200
1915-16	89,200	178,500	92,200	184,400	89,200	178,500	20,100	184,400	11,700	176,500	2,200	13,100	400,500	1,420,800	1,821,300
1916-17	25,500	70,800	35,300	113,700	32,400	178,500	20,100	184,400	2,400	32,200	2,200	10,800	132,100	927,900	1,060,000
1917-18	25,500	34,400	35,300	78,400	32,400	178,500	4,200	57,400	2,400	15,300	2,200	18,900	116,200	554,500	670,700
1918-19	25,500	62,300	35,300	184,400	6,700	22,500	4,200	17,200	2,400	15,300	2,200	10,800	90,500	533,200	623,700
1919-20	25,500	21,800	35,300	172,700	32,400	82,700	4,200	17,200	2,400	15,300	2,200	10,800	104,900	341,200	446,100
1920-21	25,500	43,400	35,300	108,000	32,400	145,300	4,200	18,900	2,400	15,300	2,200	10,800	116,200	562,300	678,500
1921-22	25,500	141,800	92,200	184,400	89,200	178,500	20,100	184,400	2,400	162,000	2,200	10,800	245,800	1,091,500	1,337,300
1922-23	25,500	56,800	35,300	184,400	32,400	68,900	20,100	33,200	2,400	15,300	2,200	12,400	132,100	653,600	785,700
1923-24	5,300	11,500	7,300	14,000	6,700	16,900	4,200	17,200	2,400	15,300	2,200	10,800	32,700	149,600	182,300
1924-25	25,500	38,000	35,300	141,100	32,400	53,500	4,200	17,200	2,400	15,300	2,200	10,800	104,900	296,600	401,500
1925-26	25,500	153,200	35,300	84,100	6,700	16,900	4,200	17,200	2,400	15,300	2,200	10,800	90,500	393,700	484,200
1926-27	25,500	114,300	35,300	184,400	32,400	178,500	20,100	106,400	2,400	15,300	2,200	10,800	130,400	864,900	995,300
1927-28	25,500	27,200	35,300	74,300	6,700	16,900	4,200	17,200	2,400	15,300	2,200	10,800	90,500	388,600	479,100
1928-29	5,300	11,500	7,300	14,000	6,700	16,900	4,200	17,200	2,400	15,300	2,200	10,800	32,700	108,000	140,700
Averages 1889-1929	31,700	96,400	51,400	131,500	46,000	125,100	20,800	97,500	5,000	68,400	3,300	26,700	181,300	851,100	1,032,400

Table 154 shows the monthly diversions to the upper San Joaquin Valley through the Madera and San Joaquin River-Kern County canals for each season during the 40-year period. The diversions through the latter canal are graphically shown on Plate LXXI, "Yield From Friant Reservoir for San Joaquin River-Kern County Canal Under Plan of Immediate Initial Development, 1889–1929."

Under the proposed plan of operation, Friant Reservoir would have furnished a primary surface irrigation supply of 138,000 acre-feet each season with 31,000 acre-feet delivered to the Madera unit and 107,000 acre-feet to the non-absorptive areas served by the San Joaquin River-Kern County Canal south of the San Joaquin River. The average seasonal supply for the 40-year period 1889–1929 would have been 1,032,000 acre-feet of which the Madera area would have received 181,000 acre-feet. The average for the 20-year period 1909-1929 would have been 839,000 acre-feet of which the Madera area would have received 151,000 acre-feet. The averages for the 12-, 8-, and 5-year periods would have amounted respectively to 602,000, 601,000 and 500,000 acre-feet of which the Madera area would have received 107,000, 108,000 and 90,000 acre-feet, respectively.

Comparing the average seasonal amounts of water supply that would have been made available for the upper San Joaquin Valley during the 8-year period 1921–1929 with the average seasonal deficiencies shown in Table 142, it is evident that the amount of supplemental water supply would be more than sufficient to meet these deficiencies in all areas requiring immediate relief in the upper San Joaquin Valley. The average seasonal supplemental supply for the Madera area during the 8-year period 1921–1929 would have been 108,000 acre-feet as compared to an estimated average seasonal deficiency of 61,000 acre-feet. For the area south of the San Joaquin River, the average seasonal supplemental supply would have been 493,000 acre-feet as compared to an estimated average seasonal deficiency of 326,000 acre-feet. The amount of supplemental supply in excess of deficiencies could have been utilized to replenish the underground reservoirs and also to furnish a supply to the areas north of lower Kings River adjacent to the valley trough, which are troubled with mineralized ground water.

The allocation of the supplemental water supplies furnished from Friant Reservoir to the areas requiring immediate relief on the east side of the upper San Joaquin Valley south of the San Joaquin River has been based not only upon the average deficiencies in supply and estimated needs for immediate relief but also upon the needs for ground water replenishment in the absorptive areas of deficient water supply. The need and desirability of reducing present pumping lifts by ground water replenishment and raising of ground water levels in these absorptive areas varies with the depth of depletion. Therefore, the total lowering of the ground water levels, together with the volume of depletion during the period of record 1921–1929, was used as a factor in estimating the relative requirements for these ground water units under conditions of initial development.

The combined requirements for meeting the present deficiencies in supply and providing for the desirable amount of ground water replenishment are estimated for the Kaweah, Tule-Deer Creek, Earlimart-Delano and McFarland-Shafter ground water units at 103,000, 80,000, 104,000 and 95,000 acre-feet, respectively. These relative quantities would be used for proportioning to ground water units the supplemental water supplies which do not exceed the average for the period 1921–1929. A modification in seasons of large run-off would be required because of low rates of absorption in certain areas and the value of excess supply for reducing pumping lifts of local and imported water in highly absorptive areas. Furthermore, actual irrigation requirements would become the prime factor in determining redistribution when ground water in these areas would have been replenished.

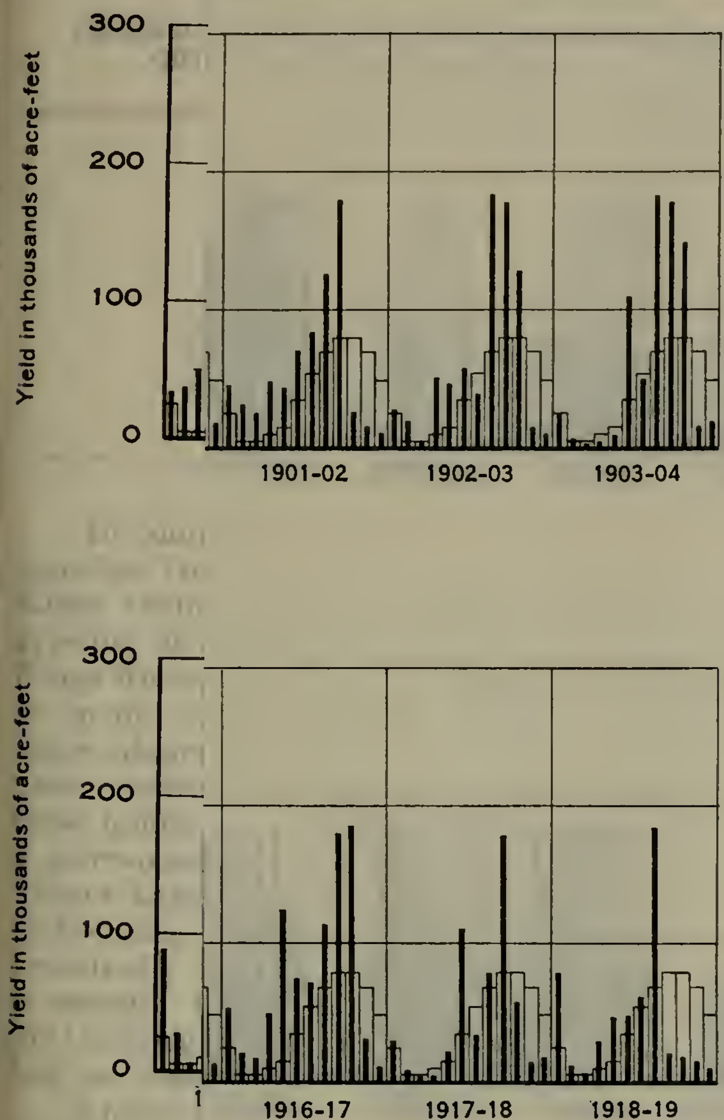
The desirable supplemental water supply for the area north of the lower Kings River is not known, but it is estimated that a seasonal supply of 35,000 acre-feet on the average would be adequate. The desirable amounts of primary surface irrigation supplies for the principal non-absorptive areas are estimated at 35,000 acre-feet for the Alta-Foothill unit of 16,000 acres, 6000 acre-feet for the Magunden-Edison unit of 2600 acres and 35,000 acre-feet for the Lindsay unit of 22,000 acres.

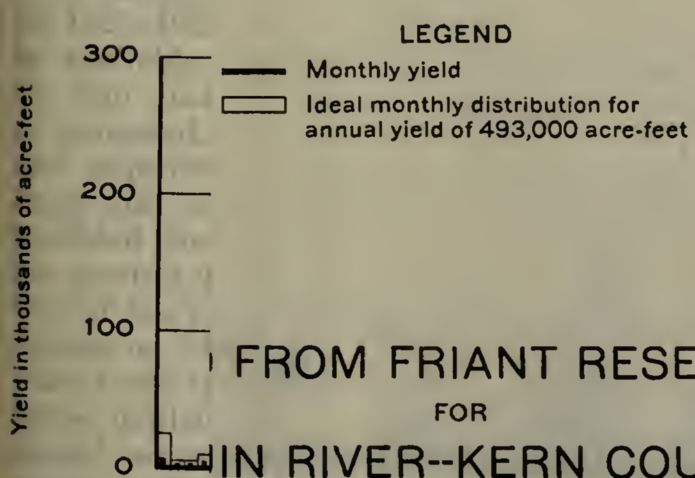
On the foregoing bases of allocation and consideration of the methods of irrigation practiced in the several areas, it is concluded that an equitable distribution of the average seasonal amount of supplemental water supply which would have been furnished from Friant Reservoir during the period 1921–1929 would be in accordance with the amounts set forth in Tables 155 and 156. Table 155 gives the distribution by units and Table 156 by counties. The amount of water allocated to the Tule-Deer Creek unit includes a supplemental supply for about 5000 acres of developed land lying east of this unit.

TABLE 155

DISTRIBUTION BY GROUND WATER UNITS OF WATER SUPPLY FOR AN AVERAGE SEASON OBTAINABLE FROM SURPLUS AND "GRASS LAND" RIGHTS OF SAN JOAQUIN RIVER, 1921-1929

Unit	Average seasonal water supply available at Friant reservoir, in acre-feet
Madera	108,000
Alta-Foothill (comprising Foothill Irrigation District and 5,000 acres in Alta Irrigation District)	35,000
Kaweah	103,000
Lindsay	35,000
Tule-Deer Creek	80,000
Earlimart-Delano	104,000
McFarland-Shafter	95,000
Magunden-Edison (portion of Edison-Arvin)	6,000
Lower Kings River area	35,000
Total	601,000





FROM FRIANT RESERVOIR

FOR

IN RIVER--KERN COUNTY CANAL

UNDER

OF IMMEDIATE INITIAL DEVELOPMENT

104,000 and 95,000 acre-feet, respectively. These relative quantities would be used for proportioning to ground water units the supplemental water supplies which do not exceed the average for the period 1921–1929. A modification in seasons of large run-off would be required because of low rates of absorption in certain areas and the value of excess supply for reducing pumping lifts of local and imported water in highly absorptive areas. Furthermore, actual irrigation requirements would become the prime factor in determining redistribution when ground water in these areas would have been replenished.

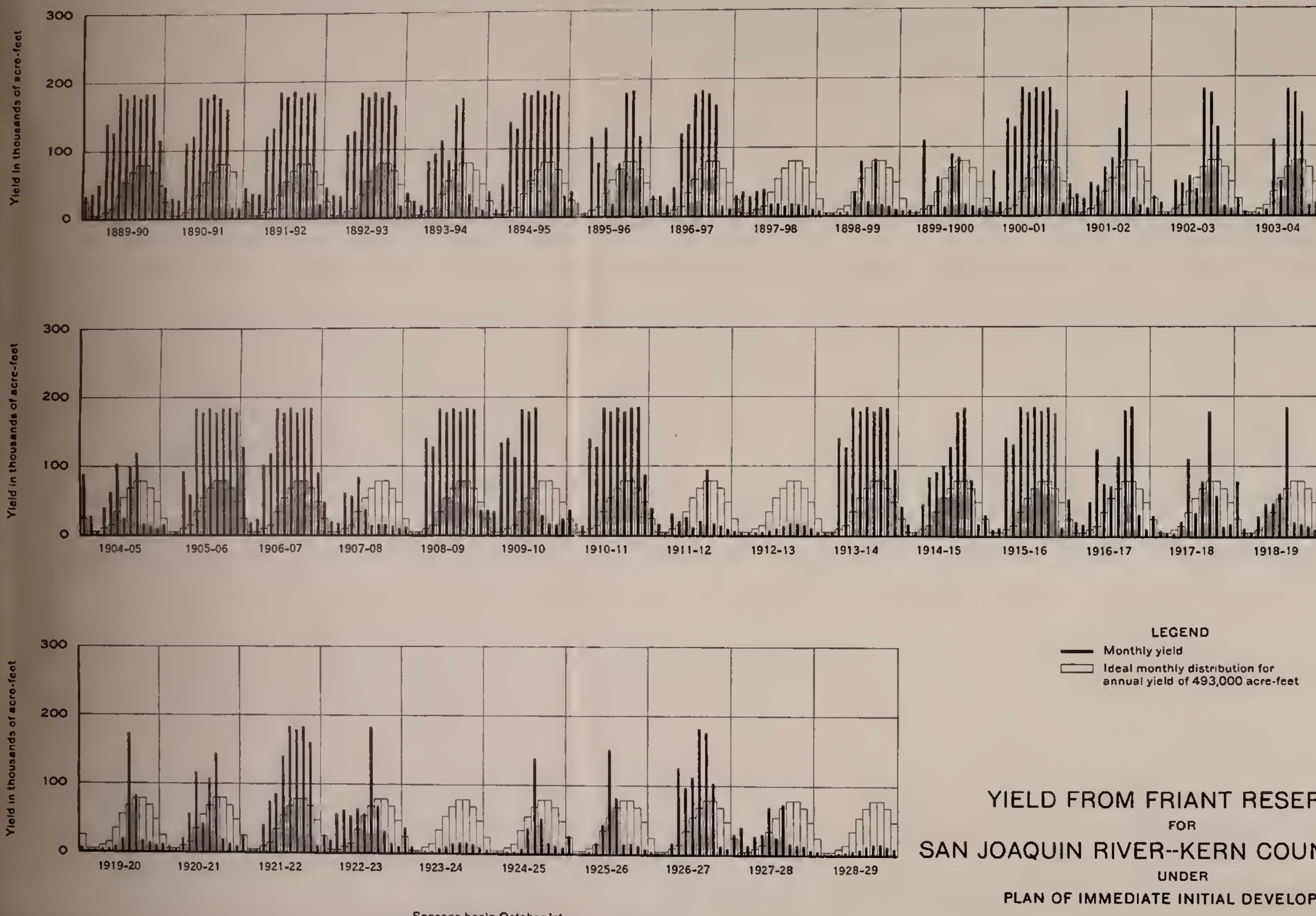
The desirable supplemental water supply for the area north of the lower Kings River is not known, but it is estimated that a seasonal supply of 35,000 acre-feet on the average would be adequate. The desirable amounts of primary surface irrigation supplies for the principal non-absorptive areas are estimated at 35,000 acre-feet for the Alta-Foothill unit of 16,000 acres, 6000 acre-feet for the Magunden-Edison unit of 2600 acres and 35,000 acre-feet for the Lindsay unit of 22,000 acres.

On the foregoing bases of allocation and consideration of the methods of irrigation practiced in the several areas, it is concluded that an equitable distribution of the average seasonal amount of supplemental water supply which would have been furnished from Friant Reservoir during the period 1921–1929 would be in accordance with the amounts set forth in Tables 155 and 156. Table 155 gives the distribution by units and Table 156 by counties. The amount of water allocated to the Tule-Deer Creek unit includes a supplemental supply for about 5000 acres of developed land lying east of this unit.

TABLE 155

DISTRIBUTION BY GROUND WATER UNITS OF WATER SUPPLY FOR AN AVERAGE SEASON OBTAINABLE FROM SURPLUS AND "GRASS LAND" RIGHTS OF SAN JOAQUIN RIVER, 1921-1929

Unit	Average seasonal water supply available at Friant reservoir, in acre-feet
Madera	108,000
Alta-Foothill (comprising Foothill Irrigation District and 5,000 acres in Alta Irrigation District)	35,000
Kaweah	103,000
Lindsay	35,000
Tule-Deer Creek	80,000
Earlimart-Delano	104,000
McFarland-Shafter	95,000
Magunden-Edison (portion of Edison-Arvin)	6,000
Lower Kings River area	35,000
Total	601,000



YIELD FROM FRIANT RESERVOIR
FOR
SAN JOAQUIN RIVER--KERN COUNTY CANAL
UNDER
PLAN OF IMMEDIATE INITIAL DEVELOPMENT

TABLE 156

DISTRIBUTION BY COUNTIES OF WATER SUPPLY FOR AN AVERAGE SEASON OBTAINABLE FROM SURPLUS AND "GRASS LAND" RIGHTS OF SAN JOAQUIN RIVER, 1921-1929

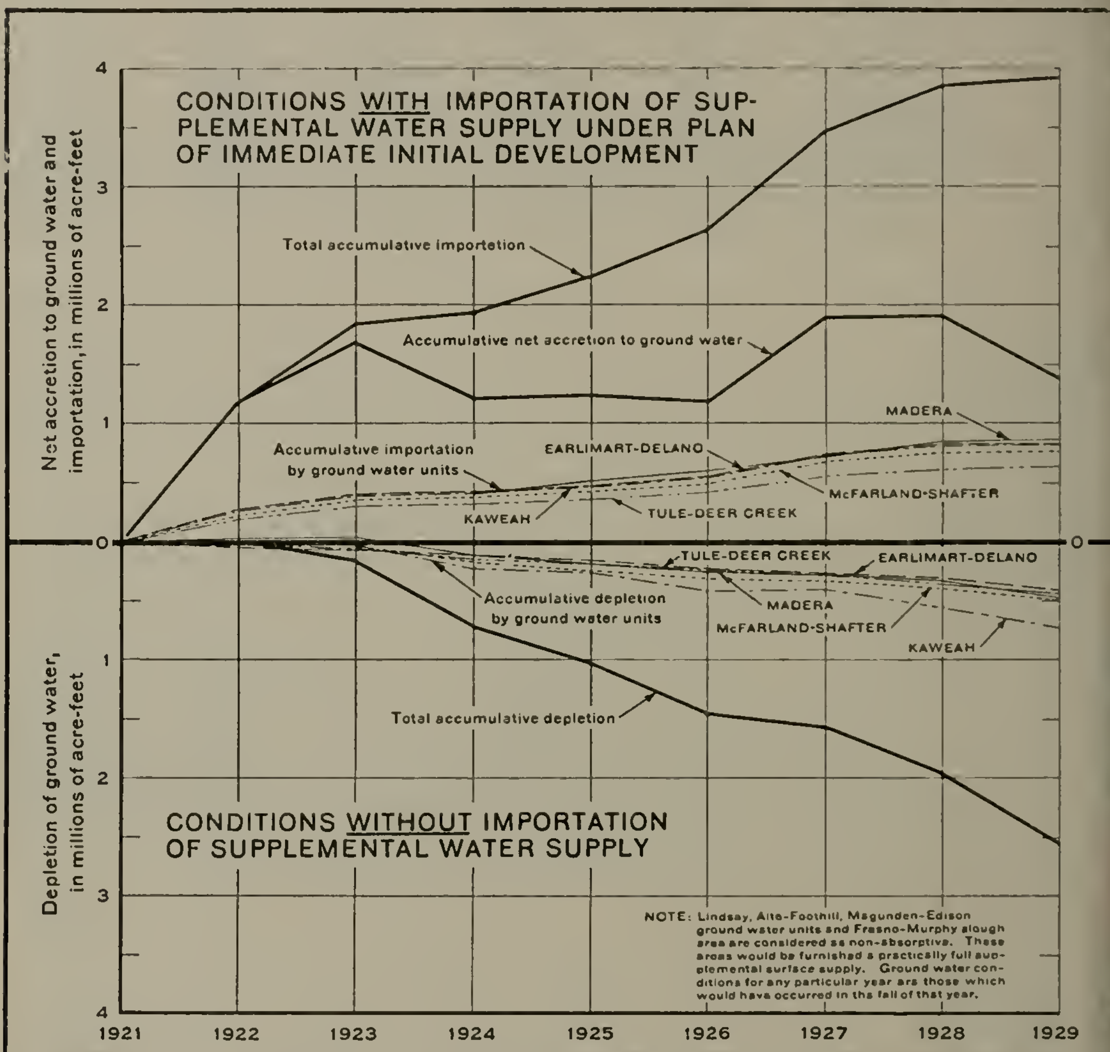
County	Average seasonal water supply available at Friant reservoir, in acre-feet
Madera	108,000
Fresno	50,000
Tulare	318,000
Kern	125,000
Total	601,000

In connection with the foregoing allocation of supplemental water supplies from the San Joaquin River, it is assumed that lands in Kings County lying in and east of Tulare Lake now used chiefly for growing of annual crops could be furnished a supply either from the Kings River, if properly regulated, or by pumping supplies, which could be made available under immediate initial development, from the lower absorptive areas of the Kaweah and Tule deltas. If it should prove desirable and necessary to furnish a direct surface supply to these lands, water would be available for that purpose, however, with a corresponding reduction in supply to some of the other areas. In Tulare Lake there are about 50,000 acres of land used for grain and in the area to the east of the lake there are about 20,000 acres used principally for growing of cotton. These acreages vary from season to season. If allowed a full surface supply from the imported water for the irrigation of these crops, it is estimated that about 90,000 acre-feet per season would be adequate.

Under the proposed plan of operation of Friant Reservoir for immediate initial development, the supplemental water supplies which could have been furnished by the regulation of surplus and grass land waters in the San Joaquin River, based upon the period of run-off 1921–1929, would have been fully adequate to meet the deficiencies in available local supplies and maintain present developed areas in the San Joaquin Valley, with the allocation of supplemental supplies as proposed. Not only would the deficiencies between local supply and requirements during the period 1921–1929 have been met but there also would have been water in excess of net use requirements provided for ground water replenishment. The resulting effect on the ground water reservoirs in the absorptive areas, under the operation of the plan, is illustrated on Plate LXXII, "Ground Water Conditions in Absorptive Areas in Upper San Joaquin Valley." On this plate there is shown, for each unit and for the entire area, the accumulative depletion under conditions without importation of a supplemental supply, and the accumulative importations of supplemental water; and also, for the entire area, the accumulative net accretion to ground water with the importations of supplemental water as proposed. As a result of the proposed plan of operation during the 8-year period 1921–1929, there would have been 1,361,000 acre-feet more water available in the underground reservoirs at the end of the period than at the beginning.

It has been shown that, under the plan of immediate initial development, the average seasonal supplemental supply during the eight-year period would have been 601,000 acre-feet. The importation of

PLATE LXXII



GROUND WATER CONDITIONS
IN
ABSORPTIVE AREAS IN UPPER SAN JOAQUIN VALLEY
WITH AND WITHOUT
SUPPLEMENTAL IMPORTATION UNDER PLAN OF IMMEDIATE INITIAL DEVELOPMENT
1921-1929

this supply into the areas of permanent deficiency not only would have more than doubled the utilizable water supply of these areas but also would have improved the characteristics of occurrence of the present deficient supplies. A substantial part of the seasonal inflow into these areas occurs now in months outside of the irrigation season. During the eight-year period 1921–1929, 41 per cent on the average so occurred, while 59 per cent occurred within the irrigation season. For the imported supplemental supply, the corresponding figures would have been 22 and 78 per cent and with the combination of the local and imported supplies, 32 and 68 per cent, respectively. Therefore, it is seen that with this plan not only would the present supplies have been more than doubled, but the characteristics of occurrence of the supply as related to demand would have been much improved. Table 157 sets forth these relative average values, for each of the areas receiving a supplemental water supply, for the eight-year period 1921–1929 and the twelve-year period 1917–1929 as well as corresponding values for typical seasons within the period.

The imported supplemental supplies provide only for the areas of permanent deficiency in the upper San Joaquin Valley. The data previously presented show that certain other areas, particularly the Fresno-Consolidated and Alta units, have had deficiencies in surface water supply in some seasons during dry periods such as that since 1921. However, experience demonstrates that such deficiencies are temporary and that, even though the water table is lowered by pumping water from underground in amounts exceeding the replenishment in dry seasons, ground water levels recover with seasons of more normal run-off before serious depletion occurs. For both areas of permanent and temporary deficiency in water supply in the upper San Joaquin Valley, it is assumed that ground water storage and pumping would be utilized to the fullest practicable extent. If substantial drafts were not made on ground water reservoirs in seasons of deficient surface supply, little or no space would be made available for the storage underground of surface run-off in excess of irrigation requirments in more normal seasons and substantial amounts of the local supply now conserved and utilized by underground storage and pumping would be wasted out of the basin.

Studies were made to ascertain what the conditions would be in the Fresno-Consolidated and Alta units, if they were furnished supplemental surface supplies during a dry period such as that since 1921. These studies showed that a seasonal importation each year of any large amounts of supplemental water would result in the maintenance of high ground water levels and the water-logging of large areas in the lower portions of the units. Actual experience in past years has demonstrated that large areas in both of these units have been water-logged even under the utilization of local supplies. The lowering of ground water levels which has taken place in more recent dry years has improved conditions and has permitted some of the previously water-logged lands to be brought back into production. It appears that an importation every year of regulated supplemental supplies would not be desirable for these areas taken as a whole, but that small amounts of supplemental water in seasons of deficient local surface supplies could be used to advantage in certain parts of these units and would result in a reduction in cost of ground water pumping.

The supplemental water supply available under the immediate initial development, based upon the run-off during the period 1917–1929, is sufficient in amount to care for the areas of permanent deficiency, only. If it should prove desirable or economical to furnish a certain amount of imported supplemental water to areas of temporary deficiency in dry seasons, the construction of the plan of complete initial development, at least in part, would be required.

TABLE 157

CHARACTERISTICS OF LOCAL AND IMPORTED SUPPLEMENTAL WATER SUPPLIES FOR AREAS IN UPPER SAN JOAQUIN VALLEY RECEIVING SUPPLEMENTAL WATER UNDER PLAN OF IMMEDIATE INITIAL DEVELOPMENT

Area	Local water supplies					Imported water supplies				
	In-season		Out-of-season		Total acre-feet	In-season		Out-of-season		Total acre-feet
	Acre-feet	Per cent	Acre-feet	Per cent		Acre-feet	Per cent	Acre-feet	Per cent	
Average, 8-Year Period, 1921-1929—										
Madera	46,400	42	65,000	58	111,400	94,000	87	14,000	13	108,000
Foothill-Alta	0	0	0	0	0	35,000	100	0	0	35,000
Kaweah	156,000	62	94,800	38	250,800	73,000	71	30,000	29	103,000
Lindsay	13,900	100	0	0	13,900	35,000	100	0	0	35,000
Tule-Deer Creek	47,400	51	44,900	49	92,300	57,000	71	23,000	29	80,000
Earlimart-Delano	1,500	54	1,300	46	2,800	74,000	71	30,000	29	104,000
McFarland-Shafter	37,000	95	1,900	5	38,900	68,000	72	27,000	28	95,000
Magunden-Edison	0	0	0	0	0	6,000	100	0	0	6,000
Lower Kings			No data			25,000	71	10,000	29	35,000
Totals	302,200	59	207,900	41	510,100	467,000	78	134,000	22	601,000
Average, 12-Year Period, 1917-1929—										
Madera	46,400	43	61,600	57	108,000	98,000	92	9,000	8	107,000
Foothill-Alta	0	0	0	0	0	35,000	100	0	0	35,000
Kaweah	159,600	63	95,400	37	255,000	75,000	73	28,000	27	103,000
Lindsay	14,000	100	0	0	14,000	35,000	100	0	0	35,000
Tule-Deer Creek	49,100	53	44,300	47	93,400	59,000	74	21,000	26	80,000
Earlimart-Delano	1,500	56	1,200	44	2,700	77,000	73	28,000	27	105,000
McFarland-Shafter	38,200	96	1,800	4	40,000	70,000	73	26,000	27	96,000
Magunden-Edison	0	0	0	0	0	6,000	100	0	0	6,000
Lower Kings			No data			26,000	74	9,000	26	35,000
Totals	308,800	60	204,300	40	513,100	481,000	80	121,000	20	602,000
Season, 1923-1924—										
Madera	18,300	76	5,700	24	24,000	32,700	100	0	0	32,700
Foothill-Alta	0	0	0	0	0	35,000	100	0	0	35,000
Kaweah	88,000	100	0	0	88,000	17,600	97	600	3	18,200
Lindsay	13,700	100	0	0	13,700	35,000	100	0	0	35,000
Tule-Deer Creek	29,200	99	400	1	29,600	13,600	96	500	4	14,100

Earlimart-Delano	0	0	0	0	0	17,700	97	600	3	18,300
McFarland-Shafter	0	0	0	0	0	16,200	96	600	4	16,800
Magunden-Edison	0	0	0	0	0	6,000	100	0	0	6,000
Lower Kings			No data			6,000	97	200	3	6,200
Totals	149,200	96	6,100	4	155,300	179,800	99	2,500	1	182,300
Season, 1926-1927—										
Madera	53,800	37	89,800	63	143,600	130,400	100	0	0	130,400
Foothill-Alta	0	0	0	0	0	35,000	100	0	0	35,000
Kaweah	171,700	42	233,500	58	405,200	129,100	66	65,800	34	194,900
Lindsay	13,300	100	0	0	13,300	35,000	100	0	0	35,000
Tule-Deer Creek	53,900	37	92,700	63	146,600	100,100	66	51,200	34	151,300
Earlimart-Delano	2,000	43	2,700	57	4,700	130,400	66	66,400	34	196,800
McFarland-Shafter	77,500	95	4,500	5	82,000	118,900	66	60,800	34	179,700
Magunden-Edison	0	0	0	0	0	6,000	100	0	0	6,000
Lower Kings			No data			43,800	66	22,400	34	66,200
Totals	372,200	47	423,200	53	795,400	728,700	73	266,600	27	995,300
Season, 1928-1929—										
Madera	41,800	67	20,300	33	62,100	32,700	100	0	0	32,700
Foothill-Alta	0	0	0	0	0	35,000	100	0	0	35,000
Kaweah	163,800	84	31,000	16	194,800	7,900	100	0	0	7,900
Lindsay	15,500	100	0	0	15,500	35,000	100	0	0	35,000
Tule-Deer Creek	47,600	70	20,600	30	68,200	6,100	100	0	0	6,100
Earlimart-Delano	1,000	53	900	47	1,900	8,000	100	0	0	8,000
McFarland-Shafter	3,900	81	900	19	4,800	7,300	100	0	0	7,300
Magunden-Edison	0	0	0	0	0	6,000	100	0	0	6,000
Lower Kings			No data			2,700	100	0	0	2,700
Totals	273,600	79	73,700	21	347,300	140,700	100	0	0	140,700

In making provision for proper utilization of imported water, consideration should be given to the method of distributing both the "in-season" water falling within the irrigation demand and the excess flows not within the irrigation demand both in and out of season for replenishment of ground water storage. It is proposed that the "in-season" water falling within the irrigation demand be supplied to the irrigated lands by means of surface conduits and ditches in accord with the demand for irrigation water. The water outside of the irrigation demand would be introduced underground by application on absorptive lands for irrigation in greater quantities than net use requirements; through seepage losses from unlined canals and ditches, both existing and proposed; through absorption in streambeds of natural channels; and by the construction of spreading works or by other artificial means of accelerating percolation. The water thus introduced underground would be recovered later by pumping. Areas of ground water storage therefore would require wells and pumping plants as under present conditions of development and utilization of the local water supplies. Under the proposed plan, however, the proportion of the mean seasonal supply which would be obtained by pumping, as well as the average pumping lift, would be materially reduced.

The distribution of the portion of the water supply made available through ground water utilization in each of the absorptive areas of permanent deficiency might be somewhat nonuniform with respect to the degree of its accessibility to meet the requirements over the entire area of a particular unit. However, it is considered that local pumping and conveyance facilities available at present or which could be made available would be used to control and distribute the supply so that all lands to be served in each unit would receive ample water. No detailed plans have been considered for the operation of such local pumping and distribution facilities under the initial State Water Plan. The plan as formulated provides the required water supply for each unit as a whole, leaving the detailed plans of local distribution to later consideration with local interests. However, sufficient investigations have been made in each area to demonstrate that the water supplies furnished under the initial plan of development could be distributed and utilized to meet the requirements of all developed lands to be served in each area, by utilization of present pumping and conveyance facilities and practicable additions or enlargements thereof.

Operation and Accomplishments in San Joaquin Delta Region—Under the immediate initial development in the San Joaquin River Basin, the relief of the developed lands in the San Joaquin Delta and adjacent upland areas would be effected through the operation of the initial storage unit of the State Water Plan in the Sacramento River Basin, namely Kennett Reservoir. Detailed data as to the physical features and operation and accomplishments of this initial storage unit are presented in other reports.* In addition to meeting the water requirements in the Sacramento Valley, this reservoir would be operated to provide regulated supplies to supplement the unregulated inflow into

*Bulletin 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930.
Bulletin 26, "Sacramento River Basin," Division of Water Resources, 1931.

the Sacramento-San Joaquin Delta from both the Sacramento and San Joaquin river systems and fully meet the needs of the entire delta, the adjacent delta uplands and areas in the upper San Francisco Bay region.

Under the method of operation designated as "Method II" in the reports cited, the operation and accomplishments of Kennett Reservoir under the plan of immediate initial development are briefly summarized as follows:

Space would have been reserved in the reservoir for flood control, and stored water would have been released in such manner as to supplement the flows from unregulated streams in the Sacramento River Basin or those regulated by present developments, from return irrigation waters in the Sacramento Valley, and from inflows to the Sacramento-San Joaquin Delta from the San Joaquin River Basin under conditions with the immediate initial development of the State Water Plan in that basin in operation, to make supplies availabile for irrigation, navigation, salinity control and the generation of power. The following would have been accomplished:

1. The space reserved in the reservoir each season for flood control would have prevented flood flows from exceeding 125,000 second-feet at Red Bluff.
2. A navigable depth on the Sacramento River of five to six feet would have been maintained from the city of Sacramento to Chico Landing, with a substantial increase in present depths from Chico Landing to Red Bluff.
3. Irrigation demands on the Sacramento River above Sacramento would have been supplied, without deficiency, up to 6000 second-feet maximum draft in July. A full irrigation supply would have been furnished in all years to all lands along the Sacramento River above the delta. There would have been over 700,000 acre-feet more water available, in accordance with the irrigation schedule, for these lands in 1924.
4. An irrigation supply, without deficiency, would have been furnished the Sacramento-San Joaquin Delta for its present requirements.
5. A fresh water flow of not less than 3300 second-feet would have been maintained past Antioch into Suisun Bay, controlling salinity to the lower end of the Sacramento-San Joaquin Delta.
6. A water supply, without deficiency, would have been made available in the delta for the developed industrial and agricultural areas along the south shore of Suisun Bay in Contra Costa County.
7. An annual average of 1,591,800,000 kilowatt hours of hydroelectric energy would have been generated, incidental to other uses.

The water that would have been made available in the channels of the Sacramento-San Joaquin Delta to meet the immediate requirements within the delta and the adjacent areas requiring immediate relief, under the plan of immediate initial development with Kennett and Friant reservoirs operated as previously set forth, has been estimated by means of the detailed month by month studies of the operation of

TABLE 158

SEASONAL NET RUN-OFF FROM SAN JOAQUIN RIVER BASIN INTO SAN JOAQUIN DELTA FOR THE PERIOD 1917-1929 UNDER CONDITIONS OF IRRIGATION AND STORAGE DEVELOPMENTS AS OF 1929, AND MUNICIPAL DIVERSIONS AS OF 1940, WITH DIVERSIONS FROM SAN JOAQUIN RIVER UNDER PLAN OF IMMEDIATE INITIAL DEVELOPMENT

Season	Run-off, in acre-feet							Pumping diversions from San Joaquin River, between Newman and Vernalis, in acre-feet	Run-off into San Joaquin Delta, in acre-feet
	San Joaquin River, at Newman	Tuolumne River, at confluence with San Joaquin River	Stanislaus River, at confluence with San Joaquin River	Calaveras River, at Jenny Lind	Mokelumne River, below Woodbridge	Dry Creek, near Ione	Cosumnes River, below Michigan Bar		
1917-1918	959,100	1,002,100	644,100	212,200	439,000	46,200	220,700	89,300	3,434,100
1918-1919	703,500	840,000	497,400	97,300	484,100	61,100	258,300	89,300	2,852,400
1919-1920	447,900	819,000	436,900	83,200	384,400	34,100	168,500	89,300	2,284,700
1920-1921	913,900	1,394,600	930,100	221,900	646,300	108,000	404,200	89,300	1,529,700
1921-1922	2,180,100	1,908,600	1,148,100	220,500	768,600	86,300	423,200	89,300	6,646,100
1922-1923	1,165,700	1,241,800	841,100	181,100	600,800	135,000	435,500	89,300	4,511,700
1923-1924	227,500	493,700	147,600	23,700	326,800	3,300	42,200	89,300	1,175,500
1924-1925	488,600	1,092,800	884,000	159,100	475,700	83,700	255,900	89,300	3,350,500
1925-1926	460,400	729,200	432,200	65,300	416,900	32,200	146,400	89,300	2,193,300
1926-1927	1,125,800	1,276,900	1,031,300	181,000	606,400	96,100	449,800	89,300	4,678,000
1927-1928	590,100	1,077,300	743,700	130,400	570,600	69,100	313,100	89,300	3,405,000
1928-1929	281,800	658,400	248,600	41,000	401,500	22,200	113,400	89,300	1,677,600
Mean for period, 1917-1929	795,400	1,044,500	665,400	134,700	510,100	64,800	269,300	89,300	3,394,900

these reservoirs and the inflow from the tributaries of the Sacramento and San Joaquin rivers under present conditions of development. The utilization of the surplus and grass land waters of the San Joaquin River by regulation in Friant Reservoir under the plan of immediate initial development would have the effect of reducing the flow into the San Joaquin River Delta. Based upon the proposed plan of operation with diversions from Friant Reservoir as previously presented for the plan of immediate initial development, the flow of the San Joaquin River System into the San Joaquin Delta is shown for each season during the period 1917–1929 in Table 158. The quantities shown in this table, except for the modifications of flow resulting from the proposed operation of Friant Reservoir, are based upon irrigation and storage developments as of 1929 and on municipal diversions as of 1940. By comparing the amounts of seasonal run-off into the delta shown in Table 7 in Chapter II, the amount of reduction in seasonal inflow resulting from the proposed plan of immediate initial development may be ascertained. The average seasonal reduction in delta inflow from the San Joaquin River Basin during that period would have amounted to 385,000 acre-feet.

The net inflow into the Sacramento-San Joaquin Delta from both the Sacramento and San Joaquin river systems, the immediate water requirements of the delta and adjacent areas to be served therefrom and the surplus of supply over requirements that would have flowed into Suisun Bay under the plan of immediate initial development are shown for each year of the 10-year period 1919–1929 in Table 159.

The water requirements of the developed areas in the delta uplands between Vernalis and Antioch, which are now supplied by pumping from the delta channels, are not set up under the requirements shown in Table 159. The present requirements for these uplands have been taken care of by deducting the net use from the quantities of inflow from the San Joaquin River Basin set forth in Table 158. The net inflows from the San Joaquin Valley in Table 159 differ from those in Table 158 by the amounts deducted for present net use requirements in the delta uplands which amounts total about 93,000 acre-feet annually.

The data set forth in Table 159 show not only that ample water would have been available in the delta under the plan of immediate initial development to fully satisfy the requirements in the delta and the adjacent areas but also a substantial surplus over and above all requirements. The bulk of this surplus would occur during the winter and spring months but there would have been considerable amounts of surplus water in most years of this period during eight or nine months. The amount of surplus water above all requirements and the flow into Suisun Bay are shown by months for the years of maximum and minimum run-off during the period 1919–1929 and the average amounts for the whole period in Table 160. The excess flows into Suisun Bay combined with the minimum flows provided for controlling saline invasion at the lower end of the delta would result in the continuous maintenance of fresh water in the delta channels free from saline invasion from the bay, would improve salinity conditions in Suisun Bay and make them practically equivalent to those which would have obtained under natural conditions before the expansion of irrigation, storage and reclamation development in the Sacramento and San Joaquin river basins.

TABLE 159

ANNUAL WATER REQUIREMENTS AND SURPLUS IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY UNDER OPERATION OF UNITS FOR IMMEDIATE INITIAL DEVELOPMENT OF STATE WATER PLAN IN GREAT CENTRAL VALLEY, 1919-1929

Year	Net flow into delta, in acre-feet[1]			Requirements from net flow into delta, in acre-feet				Surplus water above all requirements, in acre-feet	Total flow into Suisun Bay, in acre-feet
	From Sacramento Valley	From San Joaquin Valley[2]	Total from both valleys	Total gross allowance for delta	Salinity control to lower end of delta	Industrial and irrigation use in developed areas along south side of Suisun Bay	Total		
1919	16,340,000	2,769,000	19,109,000	1,083,000	2,389,000	44,000	3,516,000	15,593,000	17,982,000
1920	12,625,000	2,312,000	14,937,000	1,083,000	2,395,000	44,000	3,522,000	11,415,000	13,810,000
1921	22,041,000	4,440,000	26,481,000	1,083,000	2,389,000	44,000	3,516,000	22.965,000	25,354,000
1922	19,755,000	6,997,000	26,752,000	1,083,000	2,389,000	44,000	3,516,000	23,236,000	25,625,000
1923	12,339,000	4,116,000	16,455,000	1,083,000	2,389,000	44,000	3,516,000	12,939,000	15,328,000
1924	7,302,000	1,108,000	8,410,000	1,083,000	2,395,000	44,000	3,522,000	4,888,000	7,283,000
1925	15,617,000	3,432,000	19,049,000	1,083,000	2,389,000	44,000	3,516,000	15,533,000	17,922,000
1926	14,819,000	2,190,000	17,009,000	1,083,000	2,389,000	44,000	3,516,000	13,493,000	15,882,000
1927	24,714,000	4,688,000	29,402,000	1,083,000	2,389,000	44,000	3,516,000	25,886,000	28,274,000
1928	17,216,000	3,295,000	20,511,000	1.083,000	2,395,000	44,000	3,522,000	16,989,000	19,384,000
Averages	16,277,000	3,535,000	19,812,000	1,033,000	2,391,000	44,000	3,518,000	16,294,000	18,685,000

[1] Includes regulated water from Kennett, Friant and existing reservoirs, unregulated run-off and return waters.

[2] Quantities shown for the inflows from the San Joaquin Valley differ from those in Table 158 in that the net use requirements of the delta uplands from Vernalis to Antioch supplied by pumping from the delta channels have been deducted from the amounts of run-off shown in Table 158 to obtain the quantities shown in Table 159. The present net use requirements for these delta uplands total about 93,000 acre-feet annually.

TABLE 160

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY UNDER OPERATION OF IMMEDIATE INITIAL STATE WATER PLAN IN GREAT CENTRAL VALLEY, 1919-1929

Month	Year of maximum run-off, 1927		Year of minimum run-off, 1924		Average for period 1919-1929	
	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet
January	2,521,000	2,724,000	613,000	816,000	1,794,000	1,997,000
February	7,514,000	7,697,000	1,038,000	1,228,000	3,142,000	3,328,000
March	3,883,000	4,086,000	533,000	736,000	2,674,000	2,877,000
April	4,066,000	4,262,000	462,000	658,000	2,537,000	2,733,000
May	2,904,000	3,107,000	64,000	267,000	2,174,000	2,377,000
June	1,853,000	2,049,000	10,000	206,000	1,088,000	1,284,000
July	239,000	442,000	0	203,000	201,000	404,000
August	118,000	321,000	0	203,000	87,000	290,000
September	177,000	373,000	63,000	259,000	150,000	346,000
October	348,000	551,000	364,000	567,000	350,000	553,000
November	1,179,000	1,375,000	762,000	958,000	888,000	1,084,000
December	1,084,000	1,287,000	979,000	1,182,000	1,209,000	1,412,000
Totals	25,886,000	28,274,000	4,888,000	7,283,000	16,294,000	18,685,000

Economic and Financial Aspects—The capital cost of the plan for immediate initial development for the San Joaquin Valley, based on State financing and including general expense and cost of water rights as set forth in Table 149, is estimated at $50,400,000. This figure does not include any portion of the cost for storage development proposed in the plan for immediate initial development in the Sacramento River Basin. As previously stated, the initial storage unit (Kennett Reservoir) in the Sacramento River Basin is considered essential to the immediate initial plan of development in the San Joaquin River Basin because it is required to provide supplemental supplies for the Sacramento-San Joaquin Delta and adjacent areas not only to meet present deficiencies therein but also to replace water of the San Joaquin River diverted at Friant. It is believed that no transfer of water from the San Joaquin River to the upper San Joaquin Valley would be possible of effectuation without provision of full supplies for the delta and adjacent uplands and the removal of the salinity menace in the delta. The consideration of the financial aspects of the plan for immediate initial development in the San Joaquin River Basin must be combined with that in the Sacramento River Basin, as the initial units in both basins are interdependent and interrelated and together comprise a unified project of coordinate development for the immediate initial State Water Plan in the entire Great Central Valley.

The gross annual cost of the units for immediate initial development in the San Joaquin Valley would vary with the amortization period and interest rate on bonds. The costs for three periods of amortization and with an assumed interest rate of 4½ per cent with State financing are given below. These figures include interest, amortization of capital investment on a 4 per cent sinking fund basis, depreciation of physical works and operation and maintenance expense.

Amortization period in years	Gross annual cost
40	$3,796,000
50	3,603,000
70	3,417,000

The foregoing figures include the amortization of the capital investment of $1,500,000 in Friant power plant in ten years.

The anticipated direct revenues from the project would be obtained from:

1. Sale of electric energy.
2. Sale of water.

Electrical energy would be generated at the Friant Power Plant, a 30,000 kilovolt ampere installation. On the average, 105,000,000 kilowatt-hours would be generated annually. It is estimated that the value of this power at the switchboard would be 3.5 mills per kilowatt-hour. The annual revenue on this basis would be $367,000. The unit value of 3.5 mills is based on the cost of producing an equivalent amount of electric energy of the same characteristics with a steam electric plant located in the area of consumption, taking into account the cost of transmission and transmission losses from the point of generation to the load center. The annual revenue from power is the total amount which would be realized when the energy output is fully utilized, and it is assumed herein that arrangements would be made with producing and marketing agencies to plan their development so that the entire output from Friant power plant would be absorbed into the power market at the time of its completion.

The revenues which could be expected from the sale of water, at main canal side, to the lands in production, adjudged in need of immediate relief under the State plan for the upper San Joaquin Valley, have been estimated on the basis of the ability of the producing lands to pay for irrigation water by consideration of the following controlling factors:

1. Acreage of various crops.
2. Permissible annual charges for water at the land for various crops.
3. Characteristics of imported water supply.
4. Cost of distributing imported water, including cost of pumping to areas above main canals.
5. Depths to ground water.
6. Cost of pumping ground water contributed by both local and imported supplies.

Table 161 sets forth, for the several areas considered as having a permanent deficiency in water supply, the acreage in various crops in 1929.

The permissible annual charges per acre for water delivered at the land for various crops are given in Table 162. These are taken from Table 1, page 14 of Bulletin No. 34, "Permissible Annual Charges for Irrigation Water in Upper San Joaquin Valley," Division of Water Resources, 1930. The figures set forth are considered permissible for a full supply of water delivered at the land on which it is to be used and

TABLE 161

CROP CLASSIFICATION IN IRRIGATED AREAS OF PERMANENT DEFICIENCY IN WATER SUPPLY, FOR 1929, IN ACRES

Area	Citrus	Deciduous and olives	Grapes	Grain	Alfalfa	Field crops	Cotton	Pasture	Truck	Total
Madera Ground Water Unit		8,200	25,300		16,200	2,000	27,400	1,300	600	81,000
Foothill District	3,600	3,000	4,400							11,000
Rim lands in Alta District	800	1,700	2,500							5,000
Kaweah Ground Water Unit	12,000	23,500	22,000	2,000	38,000	6,000	14,500	*3,900	1,000	122,900
Lindsay Ground Water Unit	13,000	4,000	2,800		500	400	1,200		100	22,000
Tule-Deer Creek Ground Water Unit	3,700	5,800	8,000	1,100	9,500	2,400	34,000	5,200	500	70,200
Area east of Tule-Deer Creek Unit	4,000	600	400							5,000
Earlimart-Delano Ground Water Unit	500	1,000	13,000		1,000	1,000	14,000			30,500
McFarland-Shafter Ground Water Unit		8,400	11,700		10,000	7,500	12,200			49,800
Edison-Magunden Unit	1,000	1,600								2,600
Totals	38,600	57,800	90,100	3,100	75,200	19,300	103,300	10,400	2,200	400,000

* An additional 5,600 acres of pasture is not included as an area of deficiency.

are intended to include all items such as interest and principal payments on capital expenditures for irrigation works and water supply, costs of maintenance and operation of irrigation works, as ordinarily understood, and supplemental pumping. These figures are somewhat lower than the excess of income over all other costs of producing and harvesting the crops, including interest on the capital investment, as estimated in Bulletin No. 34. The difference varies from 10 to 50 per cent.

TABLE 162

PERMISSIBLE ANNUAL CHARGES FOR IRRIGATION WATER AT THE LAND IN UPPER SAN JOAQUIN VALLEY, FOR VARIOUS CROPS

Data from Table 1, Bulletin No. 34, "Permissible annual charges for irrigation water in Upper San Joaquin Valley," Division of Water Resources, 1930

Crop	Permissible annual charge, per acre
Oranges	$30 00
Deciduous fruits	7 50
Grapes, more common varieties	5 00
Grapes, more profitable table varieties	7 50
Grain, Tulare Lake lands, only	6 00
Cotton	7 50
Alfalfa	8 00
Miscellaneous crops	5 00

The permissible total charges for irrigation water at the land in the areas of permanent deficiency in water supply have been estimated by applying unit charges set forth in Table 162, to each of the various crops set forth in Table 161. They are set forth in Table 163. Under conditions of immediate initial development, a small amount of expansion in the present irrigated areas devoted to the more valuable crops is quite probable. Therefore permissible total charges with the citrus area increased by 25 per cent also are given in the tabulation. Since the permissible unit charges are from 10 to 50 per cent less than the excess of income over all other costs of producing and harvesting the crops as estimated in Bulletin No. 34, total permissible charges for irrigation water with an increase of 25 per cent also are set forth.

TABLE 163

PERMISSIBLE TOTAL CHARGES FOR IRRIGATION WATER AT THE LAND IN AREAS OF PERMANENT DEFICIENCY IN WATER SUPPLY IN UPPER SAN JOAQUIN VALLEY

Crop	Area irrigated in 1929, in acres	Permissible unit charge per acre	Total permissible charge	Total permissible charge, with a 25 per cent increase in citrus areas	Total permissible charge, based on 1929 irrigated areas, and an increase of 25 per cent in permissible unit charges
Citrus fruits	38,600	$30 00	$1,158,000	$1,448,000	$1,448,000
Deciduous fruits and olives	57,800	7 50	433,000	433,000	541,000
Grapes	90,100	7 50	676,000	676,000	845,000
Alfalfa	75,200	8 00	602,000	602,000	752,000
Cotton	103,300	7 50	775,000	775,000	969,000
Miscellaneous	35,000	5 00	175,000	175,000	219,000
Totals	400,000	----------	$3,819,000	$4,109,000	$4,774,000

The characteristics of the water supply which could have been made available to the areas of permanent deficiency in water supply for different periods and seasons from 1917 to 1929, segregated as to its time of occurrence within or without the irrigation season, has been set forth in Table 157. Table 164 recapitulates and combines the average annual amounts of in-season and out of season water available from local and imported sources for the 8-year period 1921–1929. The corresponding supplies for the minimum season 1923–1924 also are set forth.

TABLE 164

WATER SUPPLIES AVAILABLE FOR AREAS OF PERMANENT DEFICIENCY UNDER CONDITIONS OF IMMEDIATE INITIAL DEVELOPMENT

Area	Average seasonal water supply for 8-year period, 1921-1929, in acre-feet					
	In-season water			Out-of-season water		
	Local supply	Imported supply	Totals	Local supply	Imported supply	Totals
Madera	46,400	94,000	140,400	65,000	14,000	79,000
Alta-Foothill	0	35,000	35,000	0	0	0
Kaweah	156,000	73,000	229,000	94,800	30,000	124,800
Lindsay	13,900	35,000	48,900	0	0	0
Tule-Deer Creek	47,400	57,000	104,400	44,900	23,000	67,900
Earlimart-Delano	1,500	74,000	75,500	1,300	30,000	31,300
McFarland Shafter	37,000	68,000	105,000	1,900	27,000	28,900
Magunden-Edison	0	6,000	6,000	0	0	0
Totals	302,200	442,000	744,200	207,900	124,000	331,900
	Water supply for minimum season 1923-24, in acre-feet					
Totals	149,200	173,800	323,000	6,100	2,300	8,400

The costs of distributing both the imported and local supplies are assumed as $1.00 per acre-foot for in-season water and $0.15 per acre-foot for out of season water. The latter figure is on the basis of operating costs only, assuming that the former figure includes all fixed charges on the distribution system.

In addition to areas to be served imported in-season water by gravity distribution from the San Joaquin River-Kern County Canal, there are areas of permanent deficiency requiring regulated supplies of in-season water, which lie at an elevation above the canal and would be served by local pumping projects. These higher areas are fairly of in-season water, which lie at an elevation above the canal and would be 66 feet and the average seasonal quantity to be delivered about 80,000 acre-feet. The additional cost of distribution above that allowed for gravity distribution is estimated at $2.00 per acre-foot or $0.03 per foot acre-foot.

One-third of the in-season water, all of the out of season water and one-fifth of all water pumped from wells are considered as contributions to ground water. With an annual net use requirement of two acre-feet per acre, it is assumed that the main canal delivery for areas irrigated entirely by a surface supply would be three acre-feet per acre and, for areas served entirely by wells and pumping plants, would be 2.5 acre-feet per acre. The unit costs of ground water pumping have been based on analyses presented in Chapter VI, the results of which are set forth in detail in Table 101. The general average unit values for estimating the cost of ground water pumping in the upper San Joaquin Valley have been determined as two cents per foot acre-foot for fixed charges and three cents per foot acre-foot for energy charges. The average depths to ground water in absorptive areas of permanent deficiency are set forth in Table 165 for the fall of 1921 and the fall of 1929. The total pumping lifts would exceed these depths by the amount of well drawn down during the period of operation, for which full allowance has been made in estimating pumping costs.

TABLE 165

AVERAGE DEPTHS TO GROUND WATER IN AREAS OF PERMANENT DEFICIENCY IN UPPER SAN JOAQUIN VALLEY

Ground water unit	Gross area, in square miles	Average depth to ground water, in feet	
		Fall of 1921	Fall of 1929
Madera	343	23.9	35.2
Kaweah	468	19.2	37.2
Tule-Deer Creek	373	39.5	62.1
Earlimart-Delano	150	84.2	117.6
McFarland-Shafter	310	42.3	67.1
Total area and weighted average depths	1,644	35.0	55.4

As shown by Plate LXXII, the accumulated net depletion of ground water during the 8-year period 1921–1929 totaled 2,560,000 acre-feet, resulting in an average weighted lowering in ground water levels of 20 feet in absorptive areas of permanent deficiency in the upper San Joaquin Valley. This depletion was at the average rate of 128,000 acre-feet per foot of lowering.

For conditions of irrigation development and water supply utilization as of 1929, the total net use requirement for the areas of permanent deficiency, comprising about 400,000 acres of developed lands excluding the lower Kings River area, is estimated at 917,000 acre-feet per season. The average seasonal local and imported supplies available for these areas, for the 8-year period 1921–1929, would have been 744,000 acre-feet of in-season water and 332,000 acre-feet of out of season water or a total of 1,076,000 acre-feet. The average supply would have exceeded the 1929 net use requirements by 159,000 acre-feet per season which excess amount would have been available for underground storage. Based upon the relation between depletion and ground water lowering which actually occurred from 1921 to 1929, namely 128,000 acre-feet per foot of lowering, it is estimated that an average seasonal accretion to ground water storage of 159,000 acre-feet would result in an average seasonal rise of 1.24 feet varying from 0.4 feet in the Madera unit to 3.8 feet in the Earlimart-Delano unit, with the average amounts of regulated and local water supplies as of the period 1921–1929 and with net use requirements as of 1929.

With the average depths to ground water as of 1929, and allowing for 20 feet of well drawn down, the total average lift for ground water pumping would be 75 feet. With ten years operation of the plan and an average seasonal water supply equal to the average for the eight-year period 1921–1929, the average lift would be reduced to 63 feet; and with 20 years of similar operation and water supply, to 50 feet.

Based upon the foregoing data on water supply, pumping lifts, and unit costs for distribution and pumping, the annual cost of distribution and application of water from main canal side to the land is estimated as follows: The annual cost of distribution of in-season water at $1.00 per acre-foot would be $744,000; of out of season water at $0.15 per acre-foot, $50,000. The additional cost of lifting a surface supply of 80,000 acre-feet through lifts averaging 66 feet above San Joaquin River-Kern County Canal at $2.00 per acre-foot would be $160,000. With the 744,000 acre-feet of in-season water distributed on a basis of three acre-feet per acre to serve 248,000 acres, the remaining area of deficiency to be served by ground water pumping would be 152,000 acres. With a pumping requirement of 2.5 acre-feet per acre, the average quantity to be pumped would be 380,000 acre-feet per season. At $0.03 per foot acre-foot, the annual energy charge with the water levels as of 1929 would be $855,000. With the decreased pumping lift resulting from an average seasonal rise in ground water levels of 1.24 feet from replenishment of the underground reservoirs, the energy charge after 10 years of operation would be $718,000 and after 20 years $570,000. For the minimum season, 323,000 acre-feet of in-season water would have been available. If distributed on a basis of three acre-feet per acre, the remaining area to be served by ground water pumping in that season would have been 292,000 acres. With a pumping requirement of 2.5 acre-feet per acre, the maximum required installed capacity would be 730,000 acre-feet for a lift of 75 feet. There would undoubtedly be some shortage of installed pumping capacity in the peak months of a season of minimum yield, although the total seasonal quantity pumped might closely approach the requirement. The maximum pumping installation is estimated on a basis of 500,000 acre-feet or 68 per cent of the peak requirement in the season of 1923–1924. Based upon this amount and a lift of 75 feet, the total fixed charge on wells and pumping plants at $0.02 per foot acre-foot would be $750,000.

Table 166 summarizes the data previously presented on annual costs for distribution and utilization of water from main canal side to the land and the permissible annual charges for water at the land; and sets forth the resulting estimated limits of permissible annual charges for water at main canal side. These are presented on three different assumptions as to ground water conditions and for three different assumptions as to permissible charges for water at the land.

It can be readily observed that as the depth to ground water decreases, the margin between production costs and returns increases rapidly. When considered over longer periods, during which the average seasonal in-flow would be much greater than assumed in the analysis, the margin would be considerably larger. Probably the rise for a twenty-year period would be twice that indicated by applying the average seasonal supply for the eight-year period. In addition to the reductions shown in energy charges with the rise in ground water, there also would be some reduction in fixed charges after the useful life of the

TABLE 166

LIMIT OF PAYMENT FOR IMPORTED WATER AT MAIN CANAL SIDE FOR AREAS OF PERMANENT DEFICIENCY IN WATER SUPPLY IN UPPER SAN JOAQUIN VALLEY

Based on the Average Seasonal Water Supply for the 8-year Period, 1921-1929

Item	With ground water conditions as of 1929	With ground water conditions after 10 years of operation, and an average seasonal water supply equal to that of the 8-year period 1921-1929	With ground water conditions after 20 years of operation, and an average seasonal water supply equal to that of the 8-year period 1921-1929
Distribution of in-season water	$744,000	$744,000	$744,000
Additional cost for pumping a portion of the supply to areas above canal	160,000	160,000	160,000
Distribution of out-of-season water	50,000	50,000	50,000
Fixed charges on wells and pumping plants	750,000	750,000	750,000
Energy charges for pumping ground water	855,000	718,000	570,000
Total annual cost of distribution and utilization	$2,559,000	$2,422,000	$2,274,000
Total permissible annual charges for water at land based on area irrigated in 1929	$3,819,000	$3,819,000	$3,819,000
Limit of payment for imported water at main canal side	1,260,000	1,397,000	1,545,000
Per acre-foot (566,000 acre-feet)	2.23	2.47	2.73
Total permissible annual charges for water at land based on irrigated acreage in 1929 but with a 25 per cent increase in citrus areas	$4,109,000	$4,109,000	$4,109,000
Limit of payment for imported water at main canal side	1,550,000	1,687,000	1,835,000
Per acre-foot (566,000 acre-feet)	2.74	2.98	3.24
Total permissible annual charges for water at land increased 25 per cent, based on area irrigated in 1929	$4,774,000	$4,774,000	$4,774,000
Limit of payment for imported water at main canal side	2,215,000	2,352,000	2,500,000
Per acre-foot (566,000 acre-feet)	3.91	4.16	4.42

originally installed pumping equipment expired, as all replacements would be installed for lower lifts. Fixed charges used in obtaining the $0.02 per foot acre-foot value have been based on an average life of 18 years for the entire pumping plant installation. For shorter periods, some exchange of motors for smaller capacities or the removal of a bowl from the pumps may result in small reductions in fixed charges.

From all of the foregoing data it is concluded that $3.00 per acre-foot at main canal side is a reasonable estimate of a permissible average charge for imported water for the areas in the upper San Joaquin Valley receiving such a supply under the initial State Water Plan. Although the analyses used in arriving at this value have been based on the ability of the producers of the various crops to pay for imported water, it is not suggested that water charges be made to the individual on a crop basis. Differential rates based on anything except character of service would be difficult to apply. Much of the citrus area is above the importation canal on relatively impervious soils so that fully regulated service would be required. This in turn requires primary water storage at Friant Reservoir. Such primary service could be put on a higher rate and supplied mainly to citrus areas. In-season secondary water in accord with the irrigation demand that would directly replace ground water pumping, chiefly for general crops, would have a considerably lower rate. Out of season water or that in excess of the irrigation demand to be utilized for raising ground water levels and applicable for irrigation use only by pumping would carry a still lower rate commensurable with the cost and value of such service. No final determination has been made in this report of charges for imported water based upon character of service. However, for the purpose of presenting one possible basis for water charges with different rates as related to character of service, a tentative set-up is shown in Table 167. Total charges shown in the table are based upon the average seasonal supply available for importation for the 8-year period 1921–1929 and result in an average rate of $3.15 per acre-foot.

TABLE 167

TENTATIVE CHARGES FOR IMPORTED WATER AT MAIN CANAL SIDE FOR AREAS IN UPPER SAN JOAQUIN VALLEY, BASED ON CHARACTER OF SERVICE

Character of service	Average seasonal yield from Friant Reservoir, for the 8-year period 1921-1929, in acre-feet	Tentative charges for imported water	
		Rate per acre-foot	Total
Primary water	138,000	$8 00	$1,104,000
Secondary, in-season, water	329,000	2 00	658,000
Secondary, out-of-season, water	134,000	1 00	134,000
Totals	601,000	$3 15	$1,896,000

In addition to the units of the San Joaquin Valley for which costs and revenues have been presented, the immediate initial development in the entire Great Central Valley provides for the construction of Kennett Reservoir on the Sacramento River and the Contra Costa County Conduit to deliver water from the delta to the upper San Francisco Bay region. Discussion of these units including plans of development and estimates of costs and revenues have been published in other reports.* Electrical energy would be generated at the power plants of the Kennett Reservoir, with an average annual output of 1,591,800,000 kilowatt hours. It is estimated that this power would have a value at the switch board of 2.65 mills per kilowatt hour to yield an annual revenue of $4,218,000. About 43,500 acre-feet annually could be diverted from the delta by the Contra Costa County Conduit. It is estimated that a revenue of $300,000 per year could be obtained from the sale of this water. In order to control salinity in the Sacramento-San Joaquin Delta and furnish a full supply to the lands under irrigation along the Sacramento River and in the delta, an average annual release of about 420,000 acre-feet of stored water from Kennett Reservoir would be required. The estimated average cost of such stored water, with Kennett Reservoir operated entirely for irrigation purposes and with proper allowances for power credit, is $1.00 per acre-foot. Therefore, it is

*Bulletin No. 26, "Sacramento River Basin," Division of Water Resources, 1931.
Bulletin No. 28, "Economic Aspects of a Salt Water Barrier," Division of Water Resources.

estimated that the Sacramento Valley and delta interests might be reasonably expected to make an average annual payment of $420,000 for stored water furnished to them from Kennett Reservoir. No deductions have been made for this possible revenue, however, in obtaining the net annual cost in Table 168, but it is included in the financial analyses set forth in Table 169.

The capital and gross annual costs and anticipated revenues under the plan of immediate initial development in the Great Central Valley are presented in Table 168. The annual costs include operation and maintenance charges, interest at 4½ per cent per annum, amortization on a forty-year sinking fund basis at four per cent, and depreciation on a four per cent sinking fund basis with different lengths of service for the various elements of each unit. The revenues are estimated as the total amounts which would be realized when the supplies provided are fully utilized and sold at the unit prices indicated.

TABLE 168

COSTS AND REVENUES FOR IMMEDIATE INITIAL DEVELOPMENT OF STATE WATER PLAN IN GREAT CENTRAL VALLEY

Item	Capital cost	Gross annual cost	
Capital and Annual Costs—			
Kennett reservoir and power plant	$84,000,000	$5,297,000	
Contra Costa County conduit	2,500,000	300,000	
Friant reservoir and power plant	15,500,000	1,062,000	
Madera canal	2,500,000	213,000	
San Joaquin River-Kern County Canal	27,300,000	2,225,000	
Magunden-Edison Pumping system	100,000	18,000	
Water rights and general expense	7,000,000	389,000	
Total	$138,900,000	$9,504,000	$9,504,000
Annual Revenues—			
Electric energy sales:			
1,591,800,000 kilowatt-hours at $0.00265	$4,218,000		
105,000,000 kilowatt-hours at $0.0035	367,000		
Total electric energy sales		$4,585,000	
Water sales:			
600,000 acre-feet for upper San Joaquin Valley, based on average for twelve-year period, 1917-1929, at $3.00 per acre-foot	$1,800,000		
43,500 acre-feet for Contra Costa County conduit at $6 90 per acre-foot	300,000		
Total water sales		$2,100,000	
Total revenues, electric energy and water		$6,685,000	$6,685,000
Net Annual Cost in Excess of Revenues			$2,819,000

It may be seen from the foregoing tabulation that, with State financing at 4½ per cent interest and amortization of the capital investment in 40 years, the gross annual cost exceeds the anticipated revenues from the sale of power and water from the project by $2,819,000. If the possible revenue from the sale of stored water for use in the Sacramento Valley and Sacramento-San Joaquin Delta be considered, the excess of gross annual cost above anticipated revenues would be reduced about $420,000.

Many interests, other than those who actually would receive water in the upper San Joaquin Valley, also would be greatly benefited. In the Sacramento Valley there would be many beneficiaries. The reduction of floods on the Sacramento River would furnish an additional degree of protection to the overflow lands in the Sacramento Flood Control Project, resulting in a reduction of potential annual flood damages.

The Federal and State governments, the various districts and individual landowners would be interested in this feature. The improvement of navigation on the Sacramento River for 190 miles above the city of Sacramento is a feature in which the Federal government would be interested and is a basis upon which it might be expected to participate financially. The furnishing of a full supply to the lands under irrigation along the Sacramento River and in the Sacramento-San Joaquin Delta would be of great benefit to the lands above the city of Sacramento in their being assured of an adequate supply in all years without being curtailed in their diversions because of navigation requirements or the possibility of being enjoined by the water users below the city of Sacramento. Some of the lands above Sacramento also would be benefited in all years, and particularly in dry years, by decreased pumping charges due to higher water levels in the Sacramento River channel. This would be a substantial sum in dry years. The city of Sacramento would be benefited as to the quality of its water supply, which it obtains from the Sacramento River. In all years, a flow of not less than 5000 second-feet would be passing the intake of its pumping plant. In 1920, the mean flow during one 24-hour period in July was as low as 440 second-feet. On this day there was a reversal of flow upstream amounting to a maximum of 2300 second-feet.

The control of salinity to the lower end of the Sacramento-San Joaquin Delta would relieve the salt water menace in that area and would furnish the irrigated lands a fresh water supply at all times. The furnishing of an adequate and suitable water supply to the industrial and agricultural areas along Suisun Bay not only would benefit the immediate area, but also the metropolitan areas of Oakland and San Francisco.

The relief afforded the upper San Joaquin Valley by the consummation of this plan would prevent the retrogression of a large area of agricultural land. The maintenance of these lands in production would prevent a loss of taxable wealth in the southern valley counties, help to restore agricultural credit, maintain and increase business in communities of the affected areas and between those areas and the large metropolitan centers, and assist in the protection of public utility and banking investments in these areas.

It is believed that direct contributions by the State and Federal governments might be reasonably anticipated to meet a portion of the cost of the development, in amounts justified by national and state-wide benefits. It is possible that, in financing the project, funds could be borrowed at a lower rate of interest, particularly if arrangements were made for a loan from the Federal government. It is possible also that the State could obtain money at an interest rate of less than $4\frac{1}{2}$ per cent. The amortization period might be extended from 40 years to 50, 60 or 70 years and thereby reduce the annual costs. The present legal limitation for State bonds is 75 years.

Analyses were made of many plans of financing the immediate initial project based on various interest and sinking fund rates, amortization periods and Federal and State contributions. For purposes of comparison, fourteen of these analyses are summarized in Table 169. In these analyses, a revenue of $420,000 annually is assumed from sale of water to the Sacramento Valley and Sacramento-San Joaquin Delta.

TABLE 169

FINANCIAL ANALYSES OF PLAN OF IMMEDIATE INITIAL DEVELOPMENT GREAT CENTRAL VALLEY PROJECT WITH VARIOUS ASSUMED INTEREST RATES, AMORTIZATION PERIODS AND STATE AND FEDERAL CONTRIBUTIONS

Basis of financing	Capital cost	Gross annual cost	Annual direct revenue from water and power sales[1]	Net annual cost (—), or return (+)
Without Direct Federal or State Contributions—				
Plan 1. Interest at 4½ per cent and 40-year amortization on a 4 per cent sinking fund basis	$138,900,000	$9,504,000	$7,105,000	—$2,399,000
Plan 2. Interest at 4½ per cent and 50-year amortization on a 4 per cent sinking fund basis	138,900,000	8,960,000	7,105,000	—1,855,000
Plan 3. Interest at 4½ per cent and 70-year amortization on a 4 per cent sinking fund basis	138,900,000	8,438,000	7,105,000	—1,333,000
Plan 4. Interest at 4 per cent and 50-year amortization on a 4 per cent sinking fund basis	137,400,000	8,179,000	7,105,000	—1,074,000
Plan 5. Interest at 3½ per cent and 50-year amortization on a 3½ per cent sinking fund basis	136,000,000	7,564,000	7,105,000	—459,000
Plan 6. Interest at 3 per cent and 50-year amortization on a 3 per cent sinking fund basis	134,500,000	6,975,000	7,105,000	+130,000
Plan 7. No interest and repayment of principal sum in 40 equal annual installments	125,400,000	4,767,000	7,105,000	+2,338,000
With Direct Federal and State Contributions—				
Plan 8. Same as Plan 1, with direct Federal contribution of $6,000,000 in the interest of navigation and State contribution of $3,400,000 for the relocation of State highway above Kennett Reservoir	*$129,500,000	$8,980,000	$7,105,000	—$1,875,000
Plan 9. Same as Plan 2, with Federal and State contributions as in Plan 8	*129,500,000	8,475,000	7,105,000	—1,370,000
Plan 10. Same as Plan 3, with Federal and State contributions as in Plan 8	*129,500,000	7,989,000	7,105,000	—884,000
Plan 11. Interest at 4½ per cent and refunding bonds, with same Federal and State contributions as in Plan 8	*129,500,000	7,512,000	7,105,000	—407,000
Plan 12. Same as Plan 5 with Federal and State contributions as in Plan 8	*126,600,000	7,188,000	7,105,000	—83,000
Plan 13. Same as Plan 12 with Federal contribution increased to $20,000,000	*112,600,000	6,591,000	7,105,000	+514,000

*Direct Federal and State contributions not included.
[1] Includes a revenue of $420,000 for sale of stored water in the Sacramento Valley and Sacramento-San Joaqui Delta, not shown in Table 168.

Complete Initial Development of State Water Plan in San Joaquin River Basin

The complete initial development of the State Water Plan in th San Joaquin River Basin differs from the immediate initial plan o development in that a much larger supply of water would be furnishe to provide with greater certainty for the complete relief of the presen developed areas in the upper San Joaquin Valley, for more substantia ground water replenishment and for expansion of irrigated areas o lands adjacent to present developments in accord with reasonabl anticipations of growth in the immediate future. Under the propose plan for immediate initial development as previously presented, it ha been shown that the utilization of the grass land and surplus waters o the San Joaquin River through regulation in Friant Reservoir woul provide supplemental water supplies which, in combination with loca supplies, would meet the full requirements of present developed area and replenish the underground reservoirs in the upper San Joaqui Valley, based upon a detailed study of operation during the subnorma period of run-off 1917–1929. However, it can not be certain in futur years that there will not be seasons or periods of run-off even mor subnormal than during the period 1921–1929 on which the wate supply studies were based and it may be found that additional supplemental water supplies would be required to provide adequate and dependable relief to the present developed areas of deficient water supply in the upper San Joaquin Valley. Moreover it appears reasonable to anticipate that economic conditions in the future would justify an expansion of irrigated agriculture in the San Joaquin Valley, necessitating additional water supplies from outside sources.

The only dependable and practicable source of such additional supplemental supplies would be the Sacramento River Basin. Therefore, when water supplies in addition to the amounts which could be made available from the proposed plan of immediate initial development are required in the upper San Joaquin Valley, either for the purpose of more adequately meeting the needs of present developed areas for actual net use requirements and ground water replenishment, or for expansion of irrigated areas, or for both purposes, importation of Sacramento River Basin water will be required. It is considered that this would be a second step in the initial development and, as previously stated, it is believed that the construction of units to provide for importation of Sacramento River Basin water to the San Joaquin Valley could be deferred. However, in view of the possible need for additional supplemental water supplies from this source to adequately meet the full requirements in a plan of initial development, provision should be made in any plan of financing for the initial development for funds to cover the cost of the physical works required for importation of Sacramento River Basin water to the upper San Joaquin Valley.

Alternate Plans Investigated—In the formulation of a plan for the importation of water from the Sacramento River Basin to the upper San Joaquin Valley, several alternate plans were investigated. Of these, four have been selected for presentation in the following discussion, with comparisons of capital and annual costs. Two of the plans would not fit in with the proposed plan of immediate initial development as previously set forth and therefore would not be in the nature of a second step in the initial development but rather independent plans for initial development in one step.

Among the plans investigated for the conveyance of water from the Sacramento River Basin to the upper San Joaquin Valley was one with a concrete lined gravity canal extending from the Middle Fork of the Feather River to the Kern River. A field reconnaissance and cost estimate were made for such a canal with a maximum capacity of 3000 second-feet on this location. The route was located on U. S. Geological Survey topographic maps. Grades of .0001 foot per foot were used for canals, .0008 for tunnels and .001 for high head siphons. Allowances were made for suitable losses of head for minor structures. The diversion elevation at the Middle Fork of the Feather River would be 852 feet; at South Fork of Feather River, 835 feet; at Yuba River, 790 feet; at North Fork of American River, 743 feet; and at South Fork of American River, 735 feet. The water surface elevation at the San Joaquin River siphon would be 475 feet. The location from the San Joaquin River to Kern River would be the same as the San Joaquin River-Kern County Canal of the adopted State Plan. The diversion intakes of this conduit on the Sacramento River tributaries would be above the proposed locations of most of the major reservoirs of the State Water Plan and hence the canal could not obtain regulated supplies therefrom. It would also be above watershed areas from which originates a large part of the potential surplus water of the Sacramento River Basin. It would be necessary to develop storage above the canal to provide the supplies required for importation during several months of most years. The conduit would tortuously follow a grade contour on steep mountain hillsides, wind in and out around rocky spurs and into receding ravines, pass under granite peaks and ridges in tunnels and cross innumerable drainage channels in high head siphons. The total length would be about 558 miles.

A second plan investigated, which would involve an exchange of water supplies on the upper San Joaquin River, was a gravity conduit with a capacity of 3000 second-feet extending from the Folsom Reservoir on the American River to Mendota on the San Joaquin River, where canals which now serve large irrigated areas in the lower San Joaquin Valley, head. The diversion elevation of 345 feet at the Folsom dam site would require about 150,000 acre-feet of dead storage in Folsom Reservoir. This conduit would include ten miles of tunnels, nine miles of major tributary river crossing pressure siphons and more than 150 miles of canal located in pervious and rocky hillside formation, necessitating a concrete lined section. Its total length would be 215 miles. The plan would also include all units of the immediate initial development in the upper San Joaquin Valley. It would involve the construction of Folsom Reservoir and hence some modification of the initial plan of development in the Sacramento River Basin.

A scheme, differing from but similar in some respects to the first and second plans considered, was investigated, which would provide for exchange of supplies by means of canals from one stream to another on the east side of the valley from the Feather River to the Kern River. This scheme would involve water right adjustments on each stream and would be more costly than the second plan investigated because of the additional diversion and regulatory storage works required on each stream and the more unfavorable topographic conditions for locating the various exchange conduits above present irrigation development. The quantity of water which could be imported by such an exchange system would be limited by the flow of the stream having the smallest yield. Because of its obvious infeasibility, no cost estimates are presented for this scheme.

A third plan studied was a direct pumping system from the delta channels of the Sacramento and San Joaquin rivers to the upper San Joaquin Valley, with only a partial exchange of supplies on San Joaquin River. The San Joaquin River Pumping System, as set forth in detail in the adopted plan subsequently presented, would convey water to Mendota. From this point a pumping system and conduit would be extended southward to the vicinity of Bakersfield thereby utilizing imported water on the lower valley floor lands and releasing local supplies now used on such lands for use on higher areas. The San Joaquin River grass land and surplus waters would be regulated in Friant Reservoir to serve the Madera and Kings River areas. All other demands on the lower valley floor lands of the upper San Joaquin Valley would be satisfied by imported water. Including the utilization of Fresno Slough for the first twelve miles, the conveyance channel and pumping system from Mendota would extend southeasterly for 41 miles to a point about three miles north of Riverdale and thence easterly a distance of 19 miles, crossing the Kings River just above its point of bifurcation about 2 miles south of Kingsburg at elevation 293 feet. In this first 60 miles there would be six lifts of 27 feet each. It would then traverse a southeasterly direction for an additional 19 miles, crossing the St. John's branch of the Kaweah River two and one-half miles northeast of Visalia at elevation 362 feet. There would be three lifts of 27 feet each on the latter ten miles of this reach of the canal along the St. John's River. From the St. John's River the canal would extend southeasterly 10 miles to a point about midway between Exeter and Lindsay and thence somewhat west of south for an additional 10 miles to a crossing on the Tule River at elevation 348 feet from which point it would follow the Tule River southeasterly a distance of 4 miles to a point about 5 miles west of Porterville at elevation 402 feet. There would be two lifts of 27 feet each on the 5-mile reach of canal along the Tule River. From Tule River south to the terminus at Kern River the location would be identical with that of the proposed San Joaquin River-Kern County Canal. The total lift would be 297 feet and the total length of the canal from Mendota to Kern River 161 miles. It would have a capacity of 2000 second-feet to Poso Creek and 1500 second-feet from Poso Creek to Kern River. Other items included in this plan would be:

1. The Sacramento-San Joaquin Delta Cross Channel and the San Joaquin River Pumping System, in accord with the plan subsequently set forth.
2. A reservoir at Friant with a gross capacity of 200,000 acre-feet and a net capacity of 150,000 acre-feet above elevation 420 feet.
3. The Madera Canal with a capacity of 1500 second-feet as proposed in the State Plan.
4. A canal from Friant reservoir to Kings River about 30 miles in length having a diversion elevation of 420 feet, a terminus about 2 miles southeast of Sanger at elevation 325 feet and a capacity of 1000 second-feet.

The fourth plan investigated and finally selected for adoption provides for the diversion of the supplemental water supply from the Sacramento River Basin by pumping from the Sacramento-San Joaquin Delta. The physical units of the plan would comprise the Sacramento-San Joaquin Delta Cross Channel as described in detail in Chapter VI, the San Joaquin River Pumping System with a maximum capacity of 3000 second-feet, and all of the units of the proposed immediate initial development. Sacramento River water pumped from the delta, together with return flow and surplus waters of the lower San Joaquin Valley intercepted by the pumping system, would be substituted for San Joaquin River water now used on crop lands in the lower San Joaquin Valley above the mouth of Merced River. By means of this exchange, practically the entire flow of the San Joaquin River would be regulated in Friant Reservoir and would be made available for diversion to and utilization in the upper San Joaquin Valley.

Alternate Plans for San Joaquin River Pumping System—Many different plans and routes were considered for a pumping system to convey water from the delta to Mendota. These varied in range from that of a plan to attain the total elevation required by a series of pumping lifts located on the shortest line possible from a point near Paradise Dam westerly toward the foothills and thence continuing southerly through a constructed gravity canal along the west slope of the valley to Mendota, to a plan with a series of dams and pumping lifts utilizing the channel of the San Joaquin River throughout its entire length from the delta to Mendota. In all of the alternate plans of the San Joaquin River Pumping System studied, the same three main channels would be utilized for the conveyance of water from the terminus of the Sacramento-San Joaquin Delta Cross Channel at Central Landing to the first pumping plant. The most easterly of these channels would be the Stockton Deep Water Channel and the San Joaquin River. The other two main channels would be Old River and Salmon Slough, and Middle River with artificial connections already constructed such as the Victoria-North Canal and the Grant Line Canal. With some enlargement in portions of these channels, the conveyance capacity would be adequate to meet the requirements for exportation of water to the San Joaquin Valley and also for delta irrigation use. Descriptions of seven of the alternate plans studied follow herewith.

Plan No. 1, following a route designated as "West Side High Line," would consist of a dredged cut about two miles long from the river channel at Paradise Dam to the first pumping plant, then eight successive lifts of 27 feet each, connected by concrete lined canals, with a total length of about seven miles to the foothills on the west side of the valley. From this point the canal location would skirt the foothills for about 100 miles, terminating at Mendota at elevation 159. This location traversing the coarser and more pervious soils would necessitate the construction of a concrete lined canal as all water would be lifted 216 feet at the intake of the system and canal losses could not be recovered economically for utilization.

Plan No. 2, following a route designated as the "All River Channel" location, would consist of 14 mechanically operated steel leaf dams in the river channel between the delta and Mendota with a pumping plant at each dam, and a branch channel extending into Salt Slough above Dam No. 6 with three lifts delivering a portion of the pumped supply into the present main canal system near Los Banos. The remaining quantity would be pumped through the other eight river lifts to elevation 159, immediately above the present Mendota Weir. The river channel is exceedingly variable, both in grade and cross-section. Therefore, it would be necessary to space the dams at irregular intervals and design each pumping plant for its particular lift. The heights of lift would vary from 11 to 18 feet. From the mouth of the Merced River northerly, the water surface above each proposed dam would be maintained as nearly as possible at ground level to afford a minimum obstruction to the spreading of flood flows. Upstream from the Merced River, levees would be provided of sufficient height and distance apart to confine flood flows as regulated by the proposed Friant reservoir. The heights of lift in this section would be such that the water surface elevation above each dam would be about that of the maximum flood plane level. This limits the elevation of the surface of pumped water to about seven feet above the general ground elevation immediately above the dams. Provision would be made for widening, straightening and deepening the river channel, where necessary, below dams, to give the required conveyance capacity without excessive head losses. Movable knockdown wing dams about 8 feet high would be provided across the overflow channels. These wing dams would connect the mechanically operated steel leaf dams in the river channel with the flood control levees. Levees would be constructed partly from outside borrow pits which would be utilized to collect and convey irrigation drainage water to the pool below each dam. These levees would traverse both banks of the large tributary drainage channels to the required flood control elevation. The pumping plants would be so designed and located that they would be fully protected from damage even with extreme floods.

Plan No. 3, following a route designated as the "West Side Valley Trough" location, would consist of 98 miles of unlined canal through the west side trough of the valley and eight pumping plants with uniform lifts of 26 feet each making delivery to Mendota, and one pumping plant having a lift of 23 feet discharging into the present main west side canal system near Los Banos. The canal would traverse largely an impervious soil of poor quality for agricultural use but underlaid and intercepted by flowing sand "kidneys" of considerable volume and extent. A return flow pick-up channel from the river would intercept the canal below each main pumping lift, so that seepage losses would be largely recoverable below each plant as in the "All River Channel" route. Spillway structures and channels to the river would be provided between lifts at suitable elevations. This plan would have uniform lifts and pumping units throughout, and would leave the river channel unaltered except at a few extreme westerly bends where topography makes economical its utilization as part of the conveyance channel and the substitution of new flood channels therefor. An examination of the logs of a number of wells throughout the valley trough between Newman and Mendota showed that flowing sand was encountered at depths of from six to eight feet from the surface along this route. Consideration of the difficulties which would be encountered in the construction of this system with lifts of 26 feet, requiring heavy cuts in flowing sand which might prevent excavation to the required depths and make canal maintenance at reasonable cost impossible, led to the tentative abandonment of this plan. Intensive exploration, including the procuring of soil samples to greater depths at close intervals, might result in discovering a route that would make this plan feasible.

Plan No. 4 would include the first five dams and pumping lifts of Plan No. 2, utilizing the river channel from the delta to the Merced River. Leaving the river at this point the system would consist of five 26.5 foot lifts connected by unlined canals running some 61 miles through the valley trough on the east side of the river southerly to Mendota. These canals would be located west of all "Class 1 and 2 lands" on the east side of the river and nearly the full capacity would be lifted to Mendota for distribution on the west side of the valley.

Plan No. 5 would include the first five dams and pumping lifts of Plan No. 2, utilizing the river channel to Fremont Ford, seven miles above Merced River, from which point an unlined canal would convey the water from the river to Pumping Plant No. 6, where it would be lifted 26.5 feet. Above Plant No. 6 a system of successive lengths of unlined canal following the same route as Plan No. 3 and utilizing west side slough channels wherever possible, with uniform pumping lifts of 26.5 feet, would convey part of the water into the present west side canal system near Los Banos and the remaining supply to Mendota. This plan was tentatively abandoned for the same reason as Plan No. 3.

Plan No. 6 would be a high line location similar to Plan No. 1, with the exception that there would be provided two sets of lifts, the first extending westerly from a point near Paradise dam and the second near Los Banos. A portion of the pumped supply would be delivered into the present canal system near Los Banos before pumping through the second set of lifts.

Plan No. 7 would include the first five dams and pumping lifts of Plan No. 2, utilizing the channel of the San Joaquin River from the first pumping plant, located just above the point of bifurcation of the San Joaquin and Old River, to the mouth of Merced River, a distance of 72 miles. By means of a series of five successive dams and pumping plants, water would be conveyed from the delta and raised to an elevation of 62 feet U. S. Geological Survey datum. The dams used for this portion of the conveyance system would be of the collapsible type so that the river channel could be opened to permit free discharge in case of large flows. From the pond above Plant No. 5 i is proposed to depart from the river with a constructed canal extending southerly along the most favorable topography. By means o three pumping lifts in a distance of seven miles the water would b raised to an elevation of 137 feet at the discharge of Plant No. 8 an would continue a distance of sixteen miles to Plants Nos. 9 and 10 about five miles west of Los Banos. An exchange would be mad with existing systems serving lands lying below Plant No. 9. Fro the discharge of Plant No. 10, at an elevation of 180 feet, the can would extend southerly about 38 miles to the Mendota Weir, delive ing water at an elevation of 159 feet. The pond above the Mendot Weir would be the source of supply for lands now served by diversio at and near this point. The design and layout of Plan No. 7, excep for canal and pumping capacity, are identical with the plan of th San Joaquin River Pumping System for ultimate development as s forth in Chapter VI. Estimates of cost are presented on two base first, with a concrete lined canal throughout and, secondly, with concrete lined canal from the river to Los Banos Creek and unline canal for the last 36 miles located in relatively impervious soils fro Los Banos Creek to Mendota.

Cost of Alternate Plans for Complete Initial Development—Esti mates of capital and annual cost of the four alternate plans investigat for complete initial development, including detailed estimates for ea of the major conveyance units of each plan and of each of the alterna plans considered for the San Joaquin River Pumping System, are s forth in Tables 170 to 182, inclusive. The estimates of the respecti units are strictly comparable both as to type of construction and unit prices used. All estimates are based on the same types of construction as described in Chapter VI for the units of the ultimate State Water Plan. Unit prices for Friant dam are the same as set forth in Table 66, those of the pumping systems the same as in Table 105 and those for canals the same as in Table 108. The unit prices of construction, set forth in the tables in Chapter VI above referred to, are for the items in place and are exclusive of amounts for administration, engineering, contingencies and interest during construction. To each cost estimate there has been added 10 per cent for administration and engineering, 15 per cent for contingencies, and interest for the estimated period of construction at 4.5 per cent, computed on a basis of financing at the beginning of each six months and compounded to the end of the construction period. Estimates of annual costs including those for interest and amortization on bonds, depreciation, operation and maintenance are presented for each unit. Annual electric energy costs are estimated for conveyance units having pumping plants. The bases for estimating annual costs are the same as set forth in Chapter VI for storage and conveyance units of the ultimate State Plan.

TABLE 170

COST OF GRAVITY CANAL FEATHER RIVER TO KERN RIVER

Feather River to American River		
Section length, 118 miles. Capacity, 3,000 second-feet.		
Diversion dams	$900,000	
Tunnels	10,530,000	
Siphons	4,941,000	
Canal	18,657,000	
Minor structures	410,000	
Right of ways and fencing	160,000	
		$35,598,000
American River to San Joaquin River		
Section length, 284 miles. Capacity, 3,000 second-feet.		
Tunnels	$18,810,000	
Siphons	6,964,000	
Canal	43,361,000	
Minor structures	1,120,000	
Right of ways and fencing	350,000	
		70,605,000
San Joaquin River to Tule River		
Section length, 98 miles. Capacity, 3,000 second-feet.		
Tunnels	$392,000	
Siphons	1,064,000	
Canal	11,021,000	
Minor structures	1,270,000	
Right of ways and fencing	1,122,000	
		14,869,000
Tule River to Deer Creek		
Section length, 7 miles. Capacity, 2,500 second-feet.		
Siphons	$70,000	
Canal	539,000	
Minor structures	74,000	
Right of ways and fencing	33,000	
		716,000
Deer Creek to Poso Creek		
Section length, 27 miles. Capacity, 2,000 second-feet.		
Siphons	$75,000	
Canal	1,892,000	
Minor structures	329,000	
Right of ways and fencing	147,000	
		2,443,000
Poso Creek to Kern River		
Section length, 24 miles. Capacity, 1,500 second-feet.		
Canal	$1,445,000	
Minor structures	160,000	
Right of ways and fencing	99,000	
		1,704,000
Subtotal		$125,935,000
Administration and engineering, at 10 per cent		12,593,000
Contingencies, at 15 per cent		18,890,000
Interest during construction, based on an interest rate of 4.5 per cent per annum		25,030,000
Total capital cost		**$182,448,000**
Total annual cost		**$14,778,000**

TABLE 171

COST OF GRAVITY CANAL AMERICAN RIVER TO MENDOTA

Length, 215 miles. Capacity, 3,000 second-feet.

Tunnels	$11,770,000	
Siphons	7,230,000	
Canal	20,418,000	
Minor structures	1,600,000	
Right of ways and fencing	522,000	
Subtotal		$41,540,000
Administration and engineering, at 10 per cent		4,154,000
Contingencies, at 15 per cent		6.231,000
Interest during construction, based on an interest rate of 4.5 per cent per annum		5,546,000
Total capital cost		$57,471,000
Total annual cost		$4,581,000

ADDITIONAL STORAGE CAPACITY REQUIRED AT FOLSOM RESERVOIR

Assuming the Folsom reservoir included in the plan of initial development, its height would be increased 20 feet to compensate for the loss of effective storage below the diversion elevation of the American River-Mendota Canal. The height of dam would be increased from 190 to 210 feet, the gross storage capacity from 355,000 to 500,000 acre-feet and the high water surface from elevation 390 to 410 feet.

Capital cost of additional storage	$3,365,000
Annual cost of additional storage	$202,000
Total costs—	
Capital cost	$60,836,000
Annual cost	$4,783,000

TABLE 172

COST OF MENDOTA-BAKERSFIELD PUMPING SYSTEM

Fresno Slough to Tule River

Length, 91.8 miles. Capacity, 2,000 second-feet.

Excavation and embankment:		
Unlined cut from Fresno Slough to first lift, 1,050,000 cubic yards at $0.15	$158,000	
For concrete lined canal in deep cut and fill sections near pumping plants, 10,560,000 cubic yards at $0.20 to $0.23	2,270,000	
For regular concrete lined canal, earth, 1,603,000 cubic yards at $0.18	289.000	
Concrete lining, reinforced, 36,060,000 square feet at $0.15	5,409,000	
Pumping plants, with a capacity of 2,000 second-feet and a lift of 27 feet each, 11 at $272,000	2,992,000	
Minor structures:		
Intake control	20,000	
Kings River siphon	127,000	
St. Johns River siphon	35,000	
Cottonwood Creek siphon	46,000	
Tule River siphon	46,000	
Railroad crossings, 5 at $20,000	100,000	
Highway crossings, 12 at $9,500	114,000	
County road crossings, 45 at $6,000	270,000	
Secondary road crossings, 30 at $3,300	99,000	
Underdrains, 45 at $1,300	59,000	
Checks and outlets, 3 at $10,700	32,000	
Spillway structures, 11 at $10,000	110,000	
Right of ways and fencing	450,000	
		$12,626,000

Tule River to Poso Creek

Length, 33.8 miles. Capacity, 2,000 second-feet.

Excavation:		
For regular concrete lined canal: earth, 1,950,000 cubic yards at $0.18	$351,000	
Concrete canal lining, reinforced, 13,757,000 square feet at $0.15	2,064,000	
Minor structures:		
Deer Creek siphon	57,000	
White River siphon	25,000	
Rag Gulch siphon	25,000	
Poso Creek siphon	25,000	
Railroad crossing	20,000	
Highway crossings, 2 at $9,500	19,000	
County road crossings, 31 at $6,000	186,000	
Secondary road crossings, 15 at $3,300	50,000	
Underdrains, 38 at $3,000	114,000	
Checks and outlets, 2 at $10,700	21,000	
Right of ways and fencing	180,000	
		3,137,000

TABLE No. 172—Continued

Poso Creek to Kern River

Length, 23.8 miles. Capacity, 1,500 second-feet.

Excavation:		
For regular concrete lined canal, earth, 1,061,000 cubic yards at $0.18	$191,000	
Concrete canal lining, reinforced, 8,358,000 square feet at $0.15	1,254,000	
Minor structures:		
Railroad crossing	17,000	
Highway crossing	9,000	
County road crossings, 5 at $4,500	23,000	
Secondary road crossings, 15 at $3,000	45,000	
Underdrains, 68 at $900	61,000	
Check and outlets	8,000	
Right of ways and fencing	99,000	
		$1,707,000
Subtotal		$17,470,000
Administration and engineering, at 10 per cent		1,747,000
Contingencies, at 15 per cent		2,620,000
Interest during construction, based on an interest rate of 4.5 per cent per annum		2,332,000
Total capital cost		$24,169,000
Annual cost, exclusive of energy		$2,059,000
Average annual energy charge, 308,887,000 kilowatt-hours at $0.0055		1,699,000
Total annual cost		$3,758,000

TABLE 173

COST OF CANAL FROM FRIANT RESERVOIR TO SERVE KINGS RIVER AREA, ONLY

Diversion elevation, 420 feet. Capacity, 1,000 second-feet. Length, 30 miles.

First 9 Miles in Foothills		
Excavation:		
Rock, 80,000 cubic yards at $1.00	$80,000	
Earth overlying rock, 100,000 cubic yards at $0.25	25,000	
Hardpan 310,000 cubic yards at $0.60	186,000	
Earth, 180,000 cubic yards at $0.18	32,000	
Rock trimming, 300,000 square feet at $0.10	30,000	
Concrete lining: 2,025,000 square feet at $0.16	324,000	
Structures:		
Little Dry Creek siphon	100,000	
Minor siphons, 3 at $10,000	30,000	
Highway crossing	6,000	
Road crossings, 6 at $3,500	21,000	
Railroad crossing	12,000	
Underdrains, 3 at $2,000	6,000	
Right of ways and fencing	20,000	
		$872,000
From Edge of Foothills to Centerville Bottoms Length 18 Miles		
Excavation: Earth, 870,000 cubic yards at $0.18	$157,000	
Concrete lining: 5,300,000 square feet at $0.15	795,000	
Structures:		
Dry Creek siphon	10,000	
Railroad crossings, 3 at $12,000	36.000	
Highway crossings, 3 at $6,000	18,000	
Road crossings, 30 at $3,500	105,000	
Underdrains, 5 at $2,000	10,000	
Main canal crossings, 2 at 6,000	12,000	
Minor canal crossings, 20 at $3,000	60,000	
Control and turnout structures, 8 at $4,000	32,000	
Drop into Centerville Bottoms	12,000	
Right of ways and fencing	300,000	
		1,547,000
Enlargement of Natural Channels in Centerville Bottoms Length 3 Miles		
Excavation: Earth, 150,000 cubic yards at $0.15	$23,000	
Right of ways and fencing	10,000	
		33,000
Subtotal		$2,452,000
Administration and engineering, at 10 per cent		245,000
Contingencies, at 15 per cent		368,000
Interest during construction, based on an interest rate of 4.5 per cent per annum		213,000
Total capital cost		$3,278,000
Total annual cost		$261,000

TABLE 174

COST OF SAN JOAQUIN RIVER PUMPING SYSTEM PLAN No. 1, WEST SIDE HIGH LINE ROUTE

Central Landing to Paradise Dam		
Length 36 miles.		
Excavation and embankment:		
Enlargement of delta channels 4,800,000 cubic yards at $0.10	$480,000	
Right of ways:		
For channel enlargement and spoil areas	120,000	
		$600,000
Paradise Dam to Los Banos Creek		
Length, 69 miles. Capacity, 3,000 second-feet.		
Excavation:		
Unlined cut from Paradise dam to first lift, 1,100,000 cubic yards at $0.15	$165,000	
For concrete lined canal in deep cut and fill sections near pumping plants, 1,125,000 cubic yards at $0.20 to $0.23	240,000	
For regular concrete lined canal; earth, 4,560,000 cubic yards at $0.18	821,000	
Hardpan, 460,000 cubic yards at $0.60	276,000	
Concrete lining, reinforced: 29,560,000 square feet at $0.15	4,434,000	
Pumping plants: With a capacity of 3,000 second-feet and a lift of 27 feet each, 8 at $408,000	3,264,000	
Siphon: Diameter 23 feet, length 5,500 feet	850,000	
Minor structures:		
River intake control	25,000	
Railroad crossing	25,000	
Underdrains, 27 at $2,000	54,000	
Road crossings, 22 at $7,000	154,000	
Minor siphons, 3 at $10,000	30,000	
Right of ways and fencing	210,000	
		10,548,000
Los Banos Creek to Mendota		
Length, 39 miles. Capacity, 2,000 second-feet.		
Excavation:		
For regular concrete lined canal: Earth, 2,400,000 cubic yards at $0.18	$432,000	
Hardpan, 40,000 cubic yards at $0.60	24,000	
Concrete canal lining, reinforced: 14,839,000 square feet at $0.15	2,226,000	
Minor structures:		
Railroad crossing	20,000	
Underdrains, 5 at $1,600	8,000	
Road crossings, 18 at $6,000	108,000	
Minor siphon	9,000	
Right of ways and fencing	90,000	
		2,917,000
Subtotal		$14,065,000
Administration and engineering, at 10 per cent		1,406,000
Contingencies, at 15 per cent		2,110,000
Interest during construction, based on an interest rate of 4.5 per cent per annum		1,878,000
Total capital cost		$19,459,000
Annual cost, exclusive of energy		$1,680,000
Average annual energy charge, 332,000,000 kilowatt hours at $0.0055		1,826,000
Total annual cost		$3,506,000

TABLE 175

COST OF SAN JOAQUIN RIVER PUMPING SYSTEM PLAN No. 2, ALL RIVER CHANNEL ROUTE

Central Landing to Merced River	
Length, 102 miles. Capacity varies from 2,000 to 2,500 second-feet.	
Excavation and embankment:	
Enlargement of delta channels below Dam No. 1, 4,000,000 cubic yards at $0.10	$400,000
Channel changes and enlargement between dams, 1,685,000 cubic yards at $0.10	168,000
Levee embankment above dams, 518,000 cubic yards at $0.15	78,000
Pumping plants:	
Lift No. 1, capacity, 2,000 second-feet; height of lift, 18 feet	235,000
Lift No. 2, capacity, 2,000 second-feet; height of lift, 13 feet	213,000
Lift No. 3, capacity, 2,500 second-feet; height of lift, 13 feet	266,000
Lift No. 4, capacity, 2,500 second-feet; height of lift, 13 feet	265,000
Lift No. 5, capacity, 2,500 second-feet; height of lift, 13 feet	265,000
Steel leaf dams:	
Dam No. 1	172,000
Dam No. 2	172,000
Dam No. 3	123,000
Dam No. 4	208,000
Dam No. 5	147,000

TABLE 175—Continued

Minor structures:				
Drainage culverts through levees			$20,000	
Control works at Paradise Dam			25,000	
Maintaining existing bridges during construction			50,000	
Right of ways:				
Delta channel enlargement and spoil areas			100,000	
River levees and spoil areas			90,000	
				$2,997,000

Merced River to Mendota

Length, 88 miles. Capacity varies from 3,000 to 2,000 second-feet.

	Cost of main dams	Cost of A-frame dams between main dams and flood control levees		
Excavation and embankment:				
Channel changes and enlargement between dams, 6,415,000 cubic yards at $0.10			$642,000	
Changes in existing canal locations, 400,000 cubic yards at $0.15			60,000	
Levees along main river, 8,682,000 cubic yards at $0.15			1,302,000	
Levees along Mariposa Slough, Bear River, Fresno River, Ash Creek and Berenda Slough, 2,800,000 cubic yards at $0.15			420,000	
Pumping plants:				
Lift No. 6, capacity, 3,000 second-feet; height of lift, 13 feet			319,000	
Lift No. 7, capacity, 2,000 second-feet; height of lift, 13 feet			213,000	
Lift No. 8, capacity, 2,000 second-feet; height of lift, 11 feet			204,000	
Lift No. 9, capacity, 2,000 second-feet; height of lift, 11 feet			204,000	
Lift No. 10, capacity, 2,000 second-feet; height of lift, 11 feet			204,000	
Lift No. 11, capacity, 2,000 second-feet; height of lift, 13 feet			213,000	
Lift No. 12, capacity, 2,000 second-feet; height of lift, 13 feet			213,000	
Lift No. 13, capacity, 2,000 second-feet; height of lift, 13 feet			213,000	
Lift No. 14, capacity, 2,000 second-feet; height of lift, 11 feet			204,000	
Steel leaf dams:				
Dam No. 6	$123,000	$84,000	$207,000	
Dam No. 7	98,000	87,000	185,000	
Dam No. 8	98,000	87,000	185,000	
Dam No. 9	98,000	87,000	185,000	
Dam No. 10	123,000	85,000	208,000	
Dam No. 11	123,000	85,000	208,000	
Dam No. 12	233,000	73,000	306,000	
Dam No. 13	178,000	78,000	256,000	
Dam No. 14	233,000	73,000	306,000	
Minor structures:				
Drainage culverts through levees			80,000	
Maintaining existing bridges during construction			50,000	
Right of ways			750,000	
				7,337,000

Salt Slough and Salt Slough Extension to Los Banos

Length, 21 miles. Capacity, 1,000 second-feet.

Excavation and embankment:		
Channel excavation in Salt Slough, 800,000 cubic yards at $0.10	$80,000	
Levees on Salt Slough, 1,500,000 cubic yards at $0.15	225,000	
Extension canal, for concrete lined section, 510,000 cubic yards at $0.20 to $0.23	110,000	
Concrete lining, reinforced; 1,925,000 square feet at $0.15	289,000	
Pumping plants:		
Lift No. 6A, capacity, 1,000 second-feet; height of lift, 18 feet	118,000	
Lift No. 6B, capacity, 1,000 second-feet; height of lift, 16 feet	114,000	
Lift No. 6C, capacity, 1,000 second-feet; height of lift, 16 feet	114,000	
Minor structures:		
Siphon under railroad and highway	25,000	
Road crossings, 5 at $7,000 and 5 at $3,000	50,000	
Right of ways	55,000	
		1,180,000
Subtotal		$11,514,000
Administration and engineering, at 10 per cent		$1,152,000
Contingencies, at 15 per cent		1,727,000
Interest during construction, based on an interest rate of 4.5 per cent per annum		1,537,000
Total capital cost		$15,930,000
Annual cost, exclusive of energy		$1,445,000
Average annual energy charges, 175,132,000 kilowatt-hours at $0.0055		963,000
Total annual cost		$2,408,000

TABLE 176

COST OF SAN JOAQUIN RIVER PUMPING SYSTEM PLAN No. 3, WEST SIDE VALLEY TROUGH ROUTE

Central Landing to Paradise Dam		
Length, 36 miles.		
Excavation and embankment:		
Enlargement of delta channels: 4,800,000 cubic yards at $0.10	$480,000	
Right of ways: Channel enlargement and spoil areas	120,000	
		$600,000
Paradise Dam to Los Banos Branch Canal		
Length, 58 miles. Capacity, 3,000 second-feet.		
Excavation and embankment:		
Main canal, unlined, 11,250,000 cubic yards at $0.15	$1,688,000	
Spillway and return flow pick up channels and minor stream channel changes, 990,000 cubic yards at $0.15	148,000	
Pumping plants: 5 with a lift of 26 feet each, at $408,000	2,040,000	
Minor structures:		
River intake control	25,000	
Road crossings, 34 at $8,000	272,000	
Patterson canal crossing	10,000	
Puerto Creek siphon	30,000	
Orestimba Creek siphon	30,000	
Spillway structures, 4 at $15,000	60,000	
Return water intake structures, 4 at $25,000	100,000	
Underdrains, 11 at $3,000	33,000	
Drainage inlets, 5 at $5,000	25,000	
Right of ways and fencing	250,000	
		4,711,000
Los Banos Branch Canal		
Length, 3.6 miles. Capacity, 1,000 second-feet.		
Excavation and embankment:		
Canal, unlined, 440,000 cubic yards at $0.15	$66,000	
Pumping plant, lift, 23 feet	130,000	
Minor structures:		
Control at branch	5,000	
Railroad and highway crossing	25,000	
Road crossings, 3 at $5,000	15,000	
Structure at intersection with existing canal	5,000	
Right of ways and fencing	15,000	
		261,000
Los Banos to Mendota		
Length, 36 miles. Capacity, 2,000 second-feet.		
Excavation and embankment:		
Main canal, unlined 6,050,000 cubic yards at $0.15	$908,000	
Spillway channels and stream channel changes, 230,000 cubic yards at $0.15	34,000	
Pumping plants: 3 with a lift of 26 feet each at $272,000	816,000	
Minor structures:		
Road crossings, 10 at $6,500	65,000	
Poso Canal siphon	8,000	
Spillway structures, 3 at $10,000	30,000	
Drainage inlets, 6 at $3,000	18,000	
Outlets, 3 at $3,000	9,000	
River control	50,000	
Return water intake	25,000	
Right of ways and fencing	215,000	
		2,178,000
Subtotal		$7,750,000
Administration and engineering, at 10 per cent		$775,000
Contingencies, at 15 per cent		1,162,000
Interest during construction, based on an interest rate of 4.5 per cent per annum		1,035,000
Total capital cost		$10,722,000
Annual cost exclusive of energy		$933,000
Average annual energy charge, 291,500,000 kilowatt-hours at $0.0055		1,603,000
Total annual cost		$2,536,000

TABLE 177

COST OF SAN JOAQUIN RIVER PUMPING SYSTEM PLAN No. 4, RIVER CHANNEL ROUTE TO MERCED RIVER UNLINED CANAL EAST SIDE OF VALLEY TROUGH, MERCED RIVER TO MENDOTA

Central Landing to Merced River		
Length, 102 miles. Capacity varies from 2,000 to 2,500 second-feet.		
Excavation and embankment:		
Enlargement of delta channels below Dam No. 1, 4,000,000 cubic yards at $0.10	$400,000	
Channel changes and enlargement between dams, 1,685,000 cubic yards at $0.10	168,000	
Levee embankments above dams, 518,000 cubic yards at $0.15	78,000	
Pumping plants:		
Lift No. 1, capacity, 2,000 second-feet; height of lift, 18 feet	235,000	
Lift No. 2, capacity, 2,000 second-feet; height of lift, 13 feet	213,000	
Lift No. 3, capacity, 2,500 second-feet; height of lift, 13 feet	266,000	
Lift No. 4, capacity, 2,500 second-feet; height of lift, 13 feet	265,000	
Lift No. 5, capacity, 2,500 second-feet; height of lift, 13 feet	265,000	
Steel leaf dams:		
Dam No. 1	172,000	
Dam No. 2	172,000	
Dam No. 3	123,000	
Dam No. 4	208,000	
Dam No. 5	147,000	
Minor structures:		
Drainage culverts through levees	20,000	
Control works at Paradise Dam	25,000	
Maintaining existing bridges during construction	50,000	
Right of ways:		
Delta channel enlargement and spoil areas	100,000	
River levees and spoil areas	90,000	
		$2,997,000
Merced River to Mendota		
Length, 63 miles. Capacity, 3,000 second-feet.		
Excavation and embankment:		
Dredging on Merced River, 1,050,000 cubic yards at $0.10	$105,000	
Main canal, unlined, 12,280,000 cubic yards at $0.15	1,842,000	
Spillway channels, 120,000 cubic yards at $0.15	18,000	
Pumping plants: 5 with a lift of 26.5 feet each at $408,000	2,040,000	
Minor structures:		
Intake control at Merced River	25,000	
Bear Creek siphon	30,000	
Mariposa Slough siphon	40,000	
Chowchilla River siphon	50,000	
Ash Slough siphon	40,000	
Berenda Slough siphon	25,000	
Fresno Slough siphon	120,000	
Road crossings, 26 at $8,000	168,000	
Spillway structures, 4 at $15,000	60,000	
Canal crossings, 3 at $10,000	30,000	
Intake from Fresno River	15,000	
Minor drainage inlets, 3 at $5,000	15,000	
Underdrains, 5 at $3,000	15,000	
Right of ways and fencing	225,000	
		4,863,000
Subtotal		$7,860,000
Administration and engineering, at 10 per cent		$786,000
Contingencies, at 15 per cent		1,179,000
Interest during construction, based on an interest rate of 4.5 per cent per annum		1,049,000
Total capital cost		$10,874,000
Average annual cost, exclusive of energy		977,000
Average annual energy charge, 238,000,000 kilowatt-hours at $0.0055		1,309,000
Total annual cost		$2,286,000

TABLE 178

COST OF SAN JOAQUIN RIVER PUMPING SYSTEM PLAN No. 5, RIVER CHANNEL ROUTE TO FREEMONT FORD UNLINED CANAL WEST SIDE OF VALLEY TROUGH, FREEMONT FORD TO MENDOTA

Central Landing to Fremont Ford		
Length, 109 miles. Capacity varies from 2,000 to 2,500 second-feet.		
Excavation and embankment:		
Enlargement of delta channels below Dam No. 1, 4,000,000 cubic yards at $0.10	$400,000	
Channel changes and enlargements between Dam No. 1 and Freemont Ford, 2,890,000 cubic yards at $0.10	289,000	
Levee embankments above dams, 518,000 cubic yards at $0.15	78,000	
Pumping plants:		
Lift No. 1, capacity, 2,000 second-feet; height of lift, 18 feet	235,000	
Lift No. 2, capacity, 2,000 second-feet; height of lift, 13 feet	213,000	
Lift No. 3, capacity, 2,500 second-feet; height of lift, 13 feet	266,000	
Lift No. 4, capacity, 2,500 second-feet; height of lift, 13 feet	265,000	
Lift No. 5, capacity, 2,500 second-feet; height of lift, 13 feet	265,000	
Steel leaf dams:		
Dam No. 1	172,000	
Dam No. 2	172,000	
Dam No. 3	123,000	
Dam No. 4	208,000	
Dam No. 5	147,000	
Minor structures:		
Drainage culverts through levees	20,000	
Control works at Paradise Dam	25,000	
Maintaining existing bridges during construction	50,000	
Right of ways:		
Delta channel enlargement and spoil areas	100,000	
River levees and spoil areas	100,000	
		$3,128,000
Fremont Ford to Los Banos Branch Canal		
Length, 18.5 miles. Capacity, 3,000 second-feet.		
Excavation and embankment:		
Main canal, unlined 3,390,000 cubic yards at $0.15	$509,000	
Pumping plants: 2 with a lift of 26.5 feet each at $408,000	816,000	
Minor structures:		
Control works at Fremont Ford	25,000	
Road crossings, 10 at $8,000	80,000	
Return water pick up structure at Salt Slough	20,000	
Drainage inlets, 3 at $5,000	15,000	
Right of ways and fencing	70,000	
		1,535,000
Los Banos Branch Canal		
Length, 3.6 miles. Capacity, 1,000 second-feet.		
Excavation and embankment:		
Canal, unlined, 440,000 cubic yards at $0.15	$66,000	
Pumping plant, lift 23 feet	130,000	
Minor structures:		
Control at branch	5,000	
Railroad and highway crossing	25,000	
Road crossings, 3 at $5,000	15,000	
Structure at intersection with existing canal	5,000	
Right of ways and fencing	15,000	
		261,000
Los Banos to Mendota		
Length, 36 miles. Capacity, 2,000 second-feet.		
Excavation and embankment:		
Main canal, unlined, 6,050,000 cubic yards at $0.15	$908,000	
Spillway channels and stream channel changes, 230,000 cubic yards at $0.15	34,000	
Pumping plants: 3 with a lift of 26 feet each at $272,000	816,000	
Minor structures:		
Road crossings, 10 at $6,500	65,000	
Poso Canal siphon	8,000	
Spillway structures, 3 at $10,000	30,000	
Drainage inlets, 6 at $3,000	18,000	
Outlets, 3 at $3,000	9,000	
River control	50,000	
Return water intake	25,000	
Right of ways and fencing	215,000	
		2,178,000
Subtotal		$7,102,000
Administration and engineering, at 10 per cent		710,000
Contingencies, at 15 per cent		1,065,000
Interest during construction, based on an interest rate of 4.5 per cent per annum		948,000
Total capital cost		$9,825,000
Annual cost, exclusive of energy		$884,000
Average annual energy charge, 208,750,000 kilowatt-hours at $0.0055		1,148,000
Total annual cost		$2,032,000

TABLE 179

COST OF SAN JOAQUIN RIVER PUMPING SYSTEM PLAN No. 6
MODIFIED WEST SIDE HIGH LINE ROUTE

Central Landing to Paradise Dam		
Length, 36 miles.		
Excavation and embankment:		
Enlargement of delta channels, 4,800,000 cubic yards at $0.10	$480,000	
Right of ways:		
Delta channel enlargement and spoil areas	120,000	
		$600,000
Paradise Dam to Los Banos		
Length, 60 miles. Capacity, 3,000 second-feet.		
Excavation and embankment:		
Unlined cut from Paradise Dam to first lift, 100,000 cubic yards at $0.15	$15,000	
Concrete lined canal in deep excavation and embankment sections near pumping plants, 1,600,000 cubic yards at $0.20 to $0.23	344,000	
Canals with regular concrete lined section:		
Earth, 4,300,000 cubic yards at $0.18	774,000	
Hardpan, 80,000 cubic yards at $0.60	48,000	
Concrete canal lining, reinforced: 26,670,000 square feet at $0.15	4,000,000	
Pumping plants: 6 with a lift of 26.5 feet each at $408,000	2,448,000	
Minor structures:		
River intake control	25,000	
Railroad crossing	25,000	
Underdrains, 20 at $2,000	40,000	
Road crossings, 47 at $7,000	329,000	
Minor siphons, 7 at $10,000	70,000	
Right of ways and fencing	237,000	
		8,355,000
Los Banos to Mendota		
Length, 40 miles. Capacity, 2,000 second-feet.		
Excavation:		
Concrete lined canal in deep excavation and embankment sections near pumping plants, 250,000 cubic yards at $0.20 to $0.23	$54,000	
Canals with regular concrete lined section:		
Earth, 2,400,000 cubic yards at $0.18	432,000	
Hardpan, 40,000 cubic yards at $0.60	24,000	
Concrete canal lining, reinforced: 15,280,000 square feet at $0.15	2,292,000	
Pumping plants: 2 with a lift of 26.5 feet each at $272,000	544,000	
Minor structures:		
Railroad crossing	20,000	
Underdrains, 5 at $1,600	8,000	
Road crossings, 18 at $6,000	108,000	
Minor siphon	9,000	
Right of ways and fencing	114,000	
		3,605,000
Subtotal		$12,560,000
Administration and engineering, at 10 per cent		$1,256,000
Contingencies, at 15 per cent		1,884,000
Interest during construction, based on an interest rate of 4.5 per cent per annum		1,677,000
Total capital cost		$17,377,000
Annual cost, exclusive of energy		$1,506,000
Average annual energy charge, 299,000,000 kilowatt-hours at $0.0055		1,644,000
Total annual cost		$3,150,000

TABLE 180

COST OF SAN JOAQUIN RIVER PUMPING SYSTEM PLAN No. 7 ADOPTED PLAN, WITH ALL CANALS CONCRETE LINED

Central Landing to Hills Ferry		
Length, 102 miles. Capacity varies from 2,000 to 2,500 second-feet.		
Excavation and embankment:		
Enlargement of delta channels below Dam No. 1, 4,000,000 cubic yards at $0.10	$400,000	
Channel changes and enlargement between dams, 1,685,000 cubic yards at $0.10	168,000	
Levee embankments above dams, 518,000 cubic yards at $0.15	78,000	
Pumping plants:		
Lift No. 1, capacity, 2,000 second-feet; height of lift, 18 feet	235,000	
Lift No. 2, capacity, 2,000 second-feet; height of lift, 13 feet	213,000	
Lift No. 3, capacity, 2,500 second-feet; height of lift, 13 feet	266,000	
Lift No. 4, capacity, 2,500 second-feet; height of lift, 13 feet	265,000	
Lift No. 5, capacity, 2,500 second-feet; height of lift, 13 feet	265,000	
Steel leaf dams:		
Dam No. 1	172,000	
Dam No. 2	172,000	
Dam No. 3	123,000	
Dam No. 4	208,000	
Dam No. 5	147,000	
Minor structures:		
Drainage culverts through levees	20,000	
Control works at Paradise Dam	25,000	
Maintaining existing bridges during construction	50,000	
Right of ways:		
Delta channel enlargement and spoil areas	100,000	
River levees and spoil areas	90,000	
		$2,997,000
Hills Ferry to Mendota		
Length, 63 miles. Capacity varies from 3,000 to 2,000 second-feet.		
Excavation:		
Canals in deep cut and fill sections near pumping plants, 1,895,000 cubic yards at $0.20 to $0.23	$424,000	
Canals with regular concrete lined section:		
Earth, 4,029,000 cubic yards at $0.18	725,000	
Hardpan, 111,000 cubic yards at $0.60	67,000	
Spillway channel near Los Banos, 170,000 cubic yards at $0.15	25,000	
Concrete canal lining, reinforced: 24,306,000 square feet at $0.15	3,646,000	
Pumping plants:		
Lift No. 6, capacity, 3,000 second-feet; height of lift, 26.5 feet	408,000	
Lift No. 7, capacity, 3,000 second-feet; height of lift, 26.5 feet	408,000	
Lift No. 8, capacity, 3,000 second-feet; height of lift, 26.5 feet	408,000	
Lift No. 9, capacity, 2,000 second-feet; height of lift, 26.5 feet	272,000	
Lift No. 10, capacity, 2,000 second-feet; height of lift, 26.5 feet	272,000	
Minor structures on portion of canal having a capacity of 3,000 second-feet:		
Intake gates in cut near Hills Ferry	25,000	
Siphons, 3 at $10,000	30,000	
Railroad crossing	25,000	
Road bridges, 20 at $7,000	140,000	
Spillway channel control	10,000	
Bridges on spillway channel, 3 at $4,000	12,000	
Outlets, 2 at $5,000	10,000	
Underdrains, 3 at $2,000	6,000	
Minor structures on portion of canal having a capacity of 2,000 second-feet:		
Road bridges, 18 at $6,000	108,000	
Siphon	9,000	
Railroad crossing	20,000	
Outlets, 2 at $5,000	10,000	
Underdrains, 5 at $1,600	8,000	
Right of ways and fencing	296,000	
		7,364,00
Subtotal		$10,361,00
Administration and engineering, at 10 per cent		$1,036,00
Contingencies, at 15 per cent		1,554,00
Interest during construction, based on an interest rate of 4.5 per cent per annum		1,383,00
Total capital cost		*$14,334,00
Annual cost, exclusive of energy		$1,266,00
Average annual energy charge, 207,000,000 kilowatt-hours at $0.0055		1,139,00
Total annual cost		*$2,405,00

* Capital and annual costs of $15,000,000 and $2,500,000, respectively, have been adopted for the estimate of th San Joaquin River Pumping System in order to make provision in the plan of financing for the construction of any of th alternative plans that more intensive exploration and study may reveal to be the most feasible and advantageous for a purposes, including those of navigation and flood control. See Chapters IX and X.

MODIFIED ADOPTED PLAN, WITH UNLINED CANAL BETWEEN LOS BANOS CREEK AND MENDOTA

Items of capital cost same as above, except that cost of excavation would be increased by addition of 1,761,000 cubi yards at $0.18 or $317,000; cost of concrete lining would be decreased by elimination of 13,816,000 square feet at $0.1 or $2,073,000; and overhead costs would be decreased corresponding to the net reduction in cost of these items. Annu cost, exclusive of electric energy charges, would also be reduced correspondingly.

Total capital cost	$11,714,0
Total annual cost	$2,182,0

Table 181 sets forth a comparative summary of capital and annual costs of the alternate plans investigated for the San Joaquin River Pumping System.

TABLE 181

SUMMARY OF COSTS OF ALTERNATE PLANS FOR SAN JOAQUIN RIVER PUMPING SYSTEM

Plan	Capital cost	Annual cost
No. 1, West Side High Line; all concrete lined canal	$19,459,000	$3,506,000
No. 2, All River Channel Route	15,930,000	2,408,000
No. 3, West Side Valley Trough Route, all unlined canal	10,722,000	2,536,000
No. 4, River Channel to Merced River, unlined canal east side of valley trough, Merced River to Mendota	10,874,000	2,286,000
No. 5, River Channel to Fremont Ford, unlined canal west side of valley trough, Fremont Ford to Mendota	9,825,000	2,032,000
No. 6, Modified West Side High Line Route; all concrete lined canal	17,377,000	3,150,000
No. 7, Adopted Plan, River Channel to Merced River and Canal to Mendota:		
With entire canal concrete lined	14,334,000	2,405,000
With unlined canal from Los Banos Creek to Mendota	11,714,000	2,182,000

Of the plans considered with various alternate routes for the San Joaquin River Pumping System, Plans 3 and 5 were tentatively eliminated because of flowing sand conditions. Plans 1 and 6 are eliminated from consideration because of higher capital and annual costs. Of the remaining Plans 2, 4 and 7, Plan No. 7 with an unlined canal from Los Banos Creek to Mendota would be cheaper in annual cost than either Plans 2 and 4. Plan No. 4 would be somewhat cheaper in annual cost than Plan No. 7 with a concrete lined canal throughout. Although Plan No. 7 with an unlined canal from Los Banos Creek to Mendota appeared after careful study and comparison and in the light of present knowledge to present the greatest advantages from all viewpoints, it was concluded that this plan with provision for a concrete lined canal throughout should be adopted as a basis for estimating the cost of the San Joaquin River Pumping System in order to assure ample funds for the construction of this unit in accord with any final plan that more intensive exploration and study may reveal to be the most feasible and advantageous for all purposes. The capital and annual costs for the San Joaquin River Pumping System used in the subsequent cost analyses have been set up as $15,000,000 and $2,500,000, respectively.

Navigation could be restored on the San Joaquin River as far upstream as Salt Slough by the incorporation of locks in the dams of the tentatively adopted plan. If it should be desirable to extend navigation to Mendota it could be accomplished by the adoption of Plan No. 2, and the incorporation of locks in all of the dams.

In Table 182 there are presented comparative summaries of the capital and annual costs of the four alternate plans investigated for complete initial development. These estimates do not include any portion of the cost of storage units which would be required in the Sacramento River Basin to provide regulated supplies for importation to the San Joaquin Valley or any other costs involved in the plan for complete initial development in the Sacramento River Basin. In all the plans considered storage would be required and the cost would vary to some extent under the different plans. The net cost of storage on the Feather, Yuba and American rivers would be greater than on the

Sacramento River in Kennett Reservoir. If storage costs were included, the differences in net annual costs between the gravity canal plans and the pumping plans would be more than indicated.

TABLE 182

SUMMARY OF CAPITAL AND ANNUAL COSTS OF ALTERNATE PLANS FOR COMPLETE INITIAL DEVELOPMENT OF STATE WATER PLAN IN SAN JOAQUIN RIVER BASIN PROVIDING FOR IMPORTATION OF SUPPLEMENTAL WATER SUPPLIES FROM SACRAMENTO RIVER BASIN TO UPPER SAN JOAQUIN VALLEY

Plan	Capital cost	Annual cost
Gravity Canal, Feather River to Kern River Without Exchange of Supplies on San Joaquin River		
Canal, capacity 3,000 second-feet	$182,448,000	$14,778,000
Water rights and general expense	1,000,000	56,000
Totals	$183,448,000	$14,834,000
Gravity Canal, American River to Mendota and Exchange of Supplies on San Joaquin River		
American River-Mendota Canal, capacity 3,000 second-feet	$60,836,000	$4,783,000
Friant Reservoir, gross capacity 400,000 acre-feet, net capacity above elevation 467 feet, 270,000 acre-feet	14,000,000	840,000
Madera Canal, capacity 1,500 second-feet	2,500,000	213,000
San Joaquin River-Kern County Canal, capacity 3,000 second-feet	27,300,000	2,225,000
Water rights and general expense	5,000,000	278,000
Totals	$109,636,000	$8,339,000
San Joaquin River and Mendota-Bakersfield Pumping Systems, with Only Partial Exchange of Supplies on San Joaquin River		
Sacramento-San Joaquin Delta Cross Channel, one-half cost	$2,000,000	$150,000
San Joaquin River Pumping System, capacity 3,000 second-feet	15,000,000	2,500,000
Mendota-Bakersfield Pumping System, capacity 2,000 second-feet	24,169,000	3,758,000
Friant Reservoir, gross capacity 200,000 acre-feet, net capacity above elevation 420 feet, 150,000 acre-feet	7,000,000	420,000
Madera Canal, capacity 1,500 second-feet	2,500,000	213,000
Friant-Kings River Canal, capacity 1,000 second-feet	3,278,000	261,000
Water rights and general expense	5,000,000	278,000
Totals	$58,947,000	$7,580,000
San Joaquin River Pumping System and Exchange of Supplies on San Joaquin River		
Sacramento-San Joaquin Delta Cross Channel, one-half cost	$2,000,000	$150,000
San Joaquin River Pumping System, capacity 3,000 second-feet	15,000,000	2,500,000
Friant Reservoir, gross capacity 400,000 acre-feet, net capacity above elevation 467 feet, 270,000 acre-feet	14,000,000	840,000
Madera Canal, capacity 1,500 second-feet	2,500,000	213,000
San Joaquin River-Kern County Canal, capacity 3,000 second-feet	27,300,000	2,225,000
Water rights and general expense	5,000,000	278,000
Totals	$65,800,000	$6,206,000

Selection of Plan for Complete Initial Development—The selection of the most desirable plan for complete initial development must be based not only upon a consideration of capital and annual costs of the various alternative plans of development considered but also upon legal aspects with respect to interference with water rights and the adaptability of each plan in a progressive development looking towards the consummation of the ultimate plan of development. The desirability of providing a plan of complete initial development which would fit in with the proposed plan of immediate initial development and be in the nature of a second progressive step must also be considered.

The first two of the alternative plans considered, with gravity canals from the Sacramento River Basin, would divert water above the owners of riparian water rights and appropriative water rights with large diversions in the Sacramento Valley. The difficulty and confusion which would arise in making adjustments for such interference, which would be satisfactory to the present riparian and appropriative water right owners, would be large. In the light of present knowledge of the operation of the riparian doctrine, it would appear infeasible to divert supplemental supplies above these riparian lands. With respect to the second plan providing for diversion from the American River, such diversion would take water which would be required for ultimate development not only in the Sacramento River Basin but also in hydrographic divisions 12 and 13 of the lower San Joaquin Valley. However, in addition to these undesirable features of the first and second plans considered, the capital and annual costs for both of these plans greatly exceed those of the third and fourth plans.

The choice as to the most desirable plan for complete initial development therefore rests between the all pumping plan, with a pumping system from the delta to the vicinity of Bakersfield, and the plan providing a pumping system from the delta only to Mendota. Both of these plans would divert water from the delta channels below all riparian and appropriative water users and hence would not interfere with these vested rights. The supplemental supplies diverted from the delta would be obtained from surplus waters remaining after all appropriative and riparian rights on both the Sacramento and San Joaquin rivers had been satisfied. The third plan would involve exchanges of water on the San Joaquin, Kings, Kaweah and Tule rivers while the fourth plan would involve exchange of water only on the San Joaquin River. The third plan would not be well adapted to the consummation of a plan of initial development in two progressive steps nor would it fit in as well as the fourth plan with the proposed plan of ultimate development. The third plan would involve greater costs than the fourth plan for both immediate initial and ultimate developments. As a final consideration, the cost analyses show that the annual cost of the third plan involving a pumping system from the delta to Bakersfield would be considerably in excess of the annual cost of the fourth plan.

Based upon the foregoing considerations, the fourth plan has been selected as the most desirable plan for adoption. Of all plans investigated, the selected plan is the one that would entail the least annual cost, would involve the least interference with vested rights, and would be best adapted to a progressive development as related to both the immediate initial and the ultimate plans for the San Joaquin River Basin. Even if an annuity were added to the annual cost of the selected plan which with interest at 4 per cent would create at the end of forty years a fund, the interest on which at 4 per cent would pay electric energy charges for pumping of water for all time, the selected plan would still be smaller in annual cost than any plan involving a gravity canal that has been suggested or investigated. The annual cost with such an annuity added thereto would be increased to a total of $6,505,000. However, considering that both amortization and depreciation are included in the annual costs and that funds would be available on this basis to completely amortize the project in 40 years and also to rebuild each unit when its useful life had expired, the comparison including the creation of a fund to pay for the cost of electric energy is not justifiable. It is mentioned merely to point out that, by the most severe standards of measurement, pumping for all time under the selected plan would be more economical than a plan providing a gravity diversion from the Sacramento River Basin.

Proposed Plan for Complete Initial Development

The proposed plan for complete initial development would comprise, in addition to the units for proposed immediate initial development, the San Joaquin River Pumping System and the Sacramento-San Joaquin Delta Cross-Channel. All of these units have been previously described. Their locations are shown on Plate XXVI and other features of design are further delineated on Plate LXIX. In addition to these units, the initial storage unit (Kennett Reservoir) in the Sacramento River Basin is considered to be a part of the plan for the San Joaquin River Basin because it will be required to furnish regulated supplies in the delta, not only to meet the requirements of the San Joaquin Delta and adjacent uplands in the northerly end of the San Joaquin River Basin but also for conveyance through the San Joaquin River Pumping System for use in the San Joaquin Valley.

Operation and Accomplishments—Under the proposed plan of complete initial development, the requirements of the Sacramento-San Joaquin Delta, the adjacent delta uplands, and the industrial and agricultural areas south of Suisun Bay in the upper San Francisco Bay region would be fully met by regulated supplies furnished from Kennett Reservoir to supplement the inflow into the delta from unregulated streams and those regulated by present developments and under conditions of operation for complete initial development from the Sacramento and San Joaquin river systems. This would include the provision of regulated flows required to control salinity at the lower end of the delta to maintain continuous fresh water in the delta channels. The water requirements supplied in the Sacramento-San Joaquin delta region for these purposes would be as previously set forth in the discussion of the immediate initial development (see Table 159). In addition to meeting these requirements there would have been made available in the delta channels from the surplus shown in Table 159, during the period 1919–1928, an irrigation supply without deficiency sufficient in amount to meet the full requirements of the "crop lands" in the lower San Joaquin Valley above the mouth of the Merced River now being served by San Joaquin River water. This supply would be conveyed through the San Joaquin River Pumping System to Mendota and substituted for the San Joaquin River water now used on the crop lands. By means of this exchange and with the grass land rights purchased, practically the entire flow of the San Joaquin River would be available for regulation in and diversion from Friant Reservoir for use in the upper San Joaquin Valley. With the entire impaired flow of the San Joaquin River available for regulation in Friant Reservoir, the reservoir would be operated in the same manner as under ultimate development with detailed operation and utilization of water supplies as set forth in Chapter VII. Based upon the run-off during the 40-year period 1889–1929, the average seasonal supply from Friant Reservoir for the upper San Joaquin Valley would have been 1,726,000 acre-feet. For the twelve-year period 1917–1929, the combined average seasonal utilizable yield from the local streams of the upper San Joaquin Valley comprising the Chowchilla, Fresno, Kings, Kaweah, Tule and Kern rivers, through direct surface application and underground storage and pumping would have been about 2,208,000 acre-feet. For the same period, the combined average seasonal utilizable yield from the San Joaquin River and local streams would have amounted to 3,574,000 acre-feet, or sufficient supply for the irrigation of 1,787,000 acres, or about one and one-half times the irrigated area now supplied from these local streams on the east side of the upper San Joaquin Valley.

In the actual operation of the San Joaquin River Pumping System, return flow and surplus waters from the lower San Joaquin Valley would be intercepted above the several dams of the pumping system in order to reduce pumping charges to a minimum. Such amounts of intercepted surplus and return flow waters which would have reached the delta if not intercepted would have to be replaced in the delta channels by Sacramento River Basin water in order to meet the full requirements of the delta region. Therefore, the supplemental water requirements to be supplied from the Sacramento River Basin under the plan of complete initial development would not be reduced in amount by the interception and utilization of these surplus and return flow waters. The only effect would be a reduction in pumping costs in the San Joaquin River Pumping System. During certain months of the year the surplus and return flow waters from the lower San Joaquin Valley would be sufficient to meet the requirements to be served under the San Joaquin River Pumping System including the areas now served by pumping diversions on the west side of the lower San Joaquin Valley between Newman and Paradise Dam. During other months of the year, the larger portion or all of the water supply required for the crop lands above the mouth of the Merced River would have to be diverted from the delta channels from supplies furnished from the Sacramento River Basin.

In order to determine the proper and economic size of pumping installation for each lift and to estimate the electrical energy required for pumping, a detailed study for the period 1917–1929 was made of the amounts and time of occurrence of the return water and other flows which could be intercepted and utilized. In making this study, it was assumed that the present conditions of irrigation development and operation would have existed during the period studied and that the Hetch Hetchy Project of the City and County of San Francisco would have been in operation and diverting water from the Tuolumne watershed in accord with the anticipated demands for the year 1940.

The monthly contributions of surplus and return flow waters from the lower San Joaquin Valley for each season during the twelve-year period 1917–1929, are set forth in Table 183. The monthly demands of the "crop lands" also are given. The quantities shown for inflow to the delta are the estimated amounts of surplus and return flow waters as measured immediately above Dam No. 1 of the San Joaquin River Pumping System. They comprise the estimated flow of the San Joaquin River above Merced River, adjusted for the operation of Friant Reservoir and diversions through the Madera and San Joaquin River-Kern County canals and for greater return flow due to increased supply to the lower San Joaquin Valley "crop lands" under the plan

TABLE 183

UTILIZATION OF RETURN FLOW AND UNREGULATED SURPLUS WATERS IN LOWER SAN JOAQUIN RIVER UNDER IRRIGATION AND STORAGE CONDITIONS AS OF 1929 AND MUNICIPAL DIVERSIONS AS OF 1940 TO SUPPLY LOWER SAN JOAQUIN VALLEY CROP LANDS

Quantities in acre-feet

Season	Item	October	November	December	January	February	March	April	May	June	July	August	September	Season
	Demand of Lower San Joaquin Valley crop lands	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700
1917-18	Inflow to delta*	72,200	84,100	84,100	83,500	98,000	384,800	495,900	484,800	441,800	95,200	53,300	53,800	2,431,500
	Excess	44,300	75,700	77,700	73,500	70,100	333,200	381,200	326,100	278,800	0	0	0	1,660,600
	Deficiency	0	0	0	0	0	0	0	0	0	46,800	55,000	23,000	124,800
1918-19	Inflow to delta*	98,500	79,300	111,500	91,600	108,900	167,100	268,600	616,900	176,300	53,300	59,200	55,000	1,886,200
	Excess	70,600	70,900	105,100	81,600	81,000	115,500	153,900	458,200	13,300	0	0	0	1,150,100
	Deficiency	0	0	0	0	0	0	0	0	0	88,700	49,100	21,800	159,600
1919-20	Inflow to delta*	77,500	82,700	85,500	83,800	79,000	68,900	133,800	405,800	345,500	54,000	54,400	51,800	1,522,700
	Excess	49,600	74,300	79,100	73,800	51,100	17,300	19,100	247,100	182,500	0	0	0	793,900
	Deficiency	0	0	0	0	0	0	0	0	0	88,000	53,900	25,000	166,900
1920-21	Inflow to delta*	75,900	75,900	105,600	252,000	279,600	312,400	379,500	676,500	679,700	104,600	49,300	51,500	3,042,500
	Excess	48,000	67,500	99,200	242,000	251,700	260,800	264,800	517,800	516,700	0	0	0	2,268,500
	Deficiency	0	0	0	0	0	0	0	0	0	37,400	59,000	25,300	121,700
1921-22	Inflow to delta*	72,600	86,000	91,000	249,200	449,700	527,900	519,100	1,180,800	1,517,300	368,100	51,800	55,000	5,168,500
	Excess	44,700	77,600	84,600	239,200	421,800	476,300	404,400	1,022,100	1,354,300	226,100	0	0	4,351,100
	Deficiency	0	0	0	0	0	0	0	0	0	0	56,500	21,800	78,300
1922-23	Inflow to delta*	72,100	88,300	189,500	224,000	235,500	156,800	524,900	792,000	462,100	186,600	53,000	60,300	3,045,100
	Excess	44,200	79,900	183,100	214,000	207,600	105,200	410,200	633,300	299,100	44,600	0	0	2,221,200
	Deficiency	0	0	0	0	0	0	0	0	0	0	55,300	16,500	71,800
1923-24	Inflow to delta*	77,600	84,700	96,600	91,600	98,200	45,300	71,400	46,300	35,400	47,000	26,600	29,700	750,400
	Excess	49,700	76,300	90,200	81,600	70,300	0	0	0	0	0	0	0	368,100
	Deficiency	0	0	0	0	0	6,300	43,300	112,400	127,600	95,000	81,700	47,100	513,400
1924-25	Inflow to delta*	37,000	74,200	80,500	40,400	163,800	171,700	448,300	765,600	398,300	71,200	45,300	55,900	2,352,200
	Excess	9,100	65,800	74,100	30,400	135,900	120,100	333,600	606,900	235,300	0	0	0	1,611,200
	Deficiency	0	0	0	0	0	0	0	0	0	70,800	63,000	20,900	154,700
1925-26	Inflow to delta*	66,300	79,000	96,600	72,500	125,300	119,700	351,000	381,700	51,200	43,500	32,700	43,100	1,462,600
	Excess	38,400	70,600	90,200	62,500	97,400	68,100	236,300	223,000	0	0	0	0	886,500
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	118,800	98,500	75,600	33,700	319,600

1926–27	Inflow to delta*	29,900	60,400	117,900	129,300	337,600	351,500	504,600	782,700	731,000	98,500	41,900	45,400	3,230,700
	Excess	2,000	52,000	111,500	119,300	309,700	299,900	389,900	624,000	568,000	0	0	0	2,476,300
	Deficiency	0	0	0	0	0	0	0	0	0	43,500	66,400	31,400	141,300
1927–28	Inflow to delta*	68,200	135,600	126,700	116,700	127,700	434,700	470,300	515,600	120,400	42,600	35,900	44,600	2,239,000
	Excess	40,300	127,200	120,300	106,700	99,800	383,100	355,600	356,900	0	0	0	0	1,589,900
	Deficiency	0	0	0	0	0	0	0	0	42,600	99,400	72,400	32,200	246,600
1928–29	Inflow to delta*	105,600	105,600	75,500	99,900	115,200	97,900	76,600	169,800	101,700	30,700	24,300	30,800	1,033,600
	Excess	77,700	97,200	69,100	89,900	87,300	46,300	0	11,100	0	0	0	0	478,600
	Deficiency	0	0	0	0	0	0	38,100	0	61,300	111,300	84,000	46,000	340,700
Mean, 1917–1929	Inflow to delta*	71,100	86,300	105,100	127,900	184,900	236,600	353,700	568,200	421,700	99,600	44,000	48,100	2,347,200
	Excess	43,200	77,900	98,700	117,900	157,000	185,500	245,800	418,900	287,300	22,600	0	0	1,654,800
	Deficiency	0	0	0	0	0	500	6,800	9,400	28,600	65,000	64,300	28,700	203,300

* Quantities shown for inflow to the delta are the estimated amounts of surplus and return flow waters as measured immediately above Dam No. 1 of the San Joaquin River Pumping System. They comprise the estimated flow of the San Joaquin River above Merced River, adjusted for the operation of Friant Reservoir and diversions through the Madera and San Joaquin River-Kern County canals and for greater return flow due to increased supply to the lower San Joaquin Valley "crop lands" under the plan of complete initial development; and the estimated flow of the Merced, Tuolumne, and Stanislaus rivers at their junction with the San Joaquin River under irrigation and storage conditions as of 1929 and municipal diversions as of 1940, with deductions for west side pumping diversions from Patterson Colony to Banta-Carbona Irrigation District, inclusive.

of complete initial development; and the estimated flow of the Merced, Tuolumne, and Stanislaus rivers at their junctions with the San Joaquin River under irrigation and storage conditions as of 1929 and municipal diversions as of 1940, with deductions for west side pumping diversions from Patterson Colony to Banta-Carbona Irrigation District, inclusive. The excesses shown are the residual amounts of return flow and surplus waters which would have reached the delta after deducting the demands of the lower San Joaquin Valley "crop lands." The deficiencies shown are the amounts of water which would have been required in addition to surplus and return flow waters available for utilization and which would have been supplied by importation from the delta channels through the San Joaquin River Pumping System, in order to satisfy completely the demands of the "crop lands."

Based upon similar analyses of amounts of excesses and deficiencies in surplus and return flow waters as related to requirements of "crop lands" and west side pumping diversions above each dam of the pumping system, the amounts of water to be pumped through each pumping lift were determined. In Table 184, there are set forth by months for the period 1917–1929 the amounts of water which would have been pumped through each lift under conditions of complete initial development and the required installed capacities of pumps and motors for each lift. The table also gives, by seasons, the electrical energy which would have been consumed at each pumping plant based on an assumed over-all plant efficiency of 60 per cent. At the foot of the table, a summary is given showing for each lift the installed capacities of pumps and motors, the total and average seasonal amounts of water pumped, the total and average seasonal amounts of electrical energy consumed and the average seasonal energy costs for the twelve-year period.

PUMPING LIFTS AND CAPACITIES, AMOUNTS OF WATER PUMPED AND ENERGY CONSUMPTION FOR SAN JOAQUIN RIVER PUMPING SYSTEM UNDER CONDITIONS OF COMPLETE INITIAL DEVELOPMENT, 1917-1929

PUMPING PLANT AT DAM No. 1

Height of lift, 18 feet. Installed capacity, 2,000 second-feet, 5,500 horse power.

Season	Water pumped, in acre-feet													Energy consumption, in kilowatt hours
	October	November	December	January	February	March	April	May	June	July	August	September	Totals	
1917–18	0	0	0	0	0	0	0	0	0	46,800	55,000	23,000	124,800	3,835,700
1918–19	0	0	0	0	0	0	0	0	0	88,700	49,100	21,800	159,600	4,905,300
1919–20	0	0	0	0	0	0	0	0	0	88,000	53,900	25,000	166,900	5,129,700
1920–21	0	0	0	0	0	0	0	0	0	37,400	59,000	25,300	121,700	3,740,400
1921–22	0	0	0	0	0	0	0	0	0	0	56,500	21,800	78,300	2,406,600
1922–23	0	0	0	0	0	0	0	0	0	0	55,300	16,500	71,800	2,206,800
1923–24	0	0	0	0	0	6,300	43,300	112,400	119,000	103,600	81,700	47,100	513,400	15,779,300
1924–25	0	0	0	0	0	0	0	0	0	70,800	63,000	20,900	154,700	4,754,700
1925–26	0	0	0	0	0	0	0	0	111,800	98,500	75,600	33,700	319,600	9,822,900
1926–27	0	0	0	0	0	0	0	0	0	43,500	66,400	31,400	141,300	4,342,900
1927–28	0	0	0	0	0	0	0	0	42,600	99,400	72,400	32,200	246,600	7,579,300
1928–29	0	0	0	0	0	0	38,100	0	61,300	111,300	84,000	46,000	340,700	10,471,400
Totals													2,439,100	74,975,000
Average													203,300	6,248,000

PUMPING PLANT AT DAM No. 2

Height of lift, 12.9 feet. Installed capacity, 2,000 second-feet, 4,000 horse power.

Season	October	November	December	January	February	March	April	May	June	July	August	September	Totals	Energy consumption, in kilowatt hours
1917–18	0	0	0	0	0	0	0	0	0	44,500	53,100	23,100	120,700	2,658,600
1918–19	0	0	0	0	0	0	0	0	0	87,600	48,200	22,800	158,600	3,493,400
1919–20	0	0	0	0	0	0	42,600	0	0	86,700	52,800	25,800	207,900	4,579,400
1920–21	0	0	0	0	0	0	0	0	0	38,400	57,600	25,900	121,900	2,685,100
1921–22	0	0	0	0	0	0	0	0	0	0	54,900	22,200	77,100	1,698,300
1922–23	0	0	0	0	0	0	0	0	0	0	53,700	17,000	70,700	1,557,300
1923–24	0	0	0	0	0	8,200	43,500	105,500	119,000	96,800	79,300	46,900	499,200	10,995,800
1924–25	0	0	0	0	0	0	0	0	0	70,000	61,000	21,000	152,000	3,348,100
1925–26	0	0	0	0	0	0	0	0	108,600	96,600	73,900	34,100	313,200	6,898,800
1926–27	400	0	0	0	0	0	0	0	0	45,400	65,400	33,600	144,800	3,189,500
1927–28	0	0	0	0	0	0	0	0	53,400	96,600	72,000	33,400	255,400	5,625,600
1928–29	0	0	0	0	0	0	38,700	23,000	90,400	112,500	83,300	48,500	396,400	8,731,400
Totals													2,517,900	55,461,300
Average													209,800	4,622,000

TABLE 184—Continued

PUMPING LIFTS AND CAPACITIES, AMOUNTS OF WATER PUMPED AND ENERGY CONSUMPTION FOR SAN JOAQUIN RIVER PUMPING SYSTEM UNDER CONDITIONS OF COMPLETE INITIAL DEVELOPMENT, 1917-1929

PUMPING PLANTS AT DAMS No. 3 AND No. 4

Height of lift, 12.9 feet. Installed capacity, 2,500 second-feet, 4,900 horse power.

Season	Water pumped, in acre-feet													Energy consumption, in kilowatt hours
	October	November	December	January	February	March	April	May	June	July	August	September	Totals	
1917-18	6,200	0	4,100	7,300	14,800	0	0	0	0	68,700	73,300	43,100	217,500	4,790,800
1918-19	0	2,700	0	0	0	0	40,300	20,400	20,500	111,800	68,400	42,800	306,900	6,760,000
1919-20	1,800	0	1,800	2,600	8,000	16,500	58,500	136,000	8,600	110,900	73,000	45,700	463,400	10,207,200
1920-21	3,300	6,600	1,800	0	0	0	15,000	0	0	62,600	77,800	45,800	212,900	4,689,500
1921-22	6,400	0	5,300	0	0	0	0	0	0	0	75,100	42,100	128,900	2,839,200
1922-23	6,700	0	0	0	0	6,200	0	0	0	52,100	73,900	36,900	175,800	3,872,300
1923-24	1,300	0	500	2,800	0	32,100	58,500	116,300	143,200	115,000	98,300	65,700	633,700	13,958,400
1924-25	13,700	0	0	0	10,600	37,900	60,200	0	50,300	93,500	78,400	43,100	387,700	8,539,800
1925-26	2,400	0	0	0	0	30,200	35,400	0	130,100	121,500	94,600	54,500	468,700	10,323,900
1926-27	20,300	0	0	0	0	0	0	0	0	75,000	86,000	55,200	236,500	5,209,300
1927-28	11,000	0	0	0	0	0	10,400	26,300	103,000	121,200	92,500	54,300	418,700	9,222,600
1928-29	11,100	0	0	0	0	11,900	82,600	137,400	136,800	135,800	102,700	67,700	686,000	15,110,300
Totals													4,336,700	95,523,300
Average													361,400	7,960,000

PUMPING PLANT AT DAM No. 5

Height of lift, 12.9 feet. Installed capacity, 2,500 second-feet, 4,900 horse power.

Season	October	November	December	January	February	March	April	May	June	July	August	September	Totals	Energy consumption, in kilowatt hours
1917-18	4,300	0	4,600	7,800	15,300	0	0	0	0	60,800	66,800	38,900	198,500	4,372,300
1918-19	0	3,200	0	0	0	0	37,400	10,700	12,000	103,900	61,900	38,600	267,700	5,896,600
1919-20	0	500	2,300	3,100	8,500	14,500	55,600	126,300	100	103,000	66,500	41,500	421,900	9,293,100
1920-21	1,400	7,100	2,300	0	0	0	12,100	0	0	54,700	71,300	41,600	190,500	4,196,100
1921-22	4,500	0	5,800	0	0	0	0	0	0	0	68,600	37,900	116,800	2,572,700
1922-23	4,800	0	0	0	0	4,200	0	0	0	44,200	67,400	32,700	153,300	3,376,700
1923-24	0	0	1,000	3,300	0	30,100	55,600	106,600	134,700	107,100	91,800	61,500	591,700	13,033,200
1924-25	11,800	0	0	0	11,100	35,900	57,300	0	41,800	85,600	71,900	38,900	354,300	7,804,100
1925-26	500	0	0	0	0	28,200	32,500	0	121,600	113,600	88,100	50,300	434,800	9,577,200
1926-27	18,400	200	0	0	0	0	0	0	0	67,100	79,500	51,000	216,200	4,762,200
1927-28	9,100	0	0	0	0	0	7,500	16,600	94,500	113,300	86,000	50,100	377,100	8,306,300
1928-29	9,200	0	0	0	0	9,900	79,700	127,700	128,300	127,900	96,200	63,500	642,400	14,150,000
Totals													3,965,200	87,340,500
Average													330,400	7,278,000

PUMPING PLANTS AT CANAL LIFTS No. 6, No. 7 AND No. 8

Height of lift, 26.5 feet. Installed capacity, 3,000 second-feet, 12,000 horse power.

Season	Water pumped, in acre-feet													Energy consumption, in kilowatt hours
	October	November	December	January	February	March	April	May	June	July	August	September	Totals	
1917-18	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
1918-19	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
1919-20	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
1920-21	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
1921-22	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	0	142,000	108,300	76,800	732,700	33,153,800
1922-23	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
1923-24	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
1924-25	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
1925-26	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
1926-27	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
1927-28	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
1928-29	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700	40,529,300
Totals													10,585,400	478,976,100
Average													882,100	39,914,000

PUMPING PLANTS AT CANAL LIFTS No. 9 AND No. 10

Height of lift, 26.5 feet. Installed capacity, 2,000 second-feet, 8,000 horse power.

Season	October	November	December	January	February	March	April	May	June	July	August	September	Totals	Energy consumption, in kilowatt hours
1917-18	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
1918-19	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
1919-20	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
1920-21	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
1921-22	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	0	94,700	72,200	51,200	488,400	22,099,000
1922-23	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
1923-24	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
1924-25	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
1925-26	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
1926-27	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
1927-28	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
1928-29	18,600	5,600	4,300	6,600	18,600	34,400	76,400	105,800	108,700	94,700	72,200	51,200	597,100	27,018,000
Totals													7,056,500	319,297,000
Average													588,000	26,608,000

TABLE 184—Continued

PUMPING LIFTS AND CAPACITIES, AMOUNTS OF WATER PUMPED AND ENERGY CONSUMPTION FOR FOR SAN JOAQUIN RIVER PUMPING SYSTEM UNDER CONDITIONS OF COMPLETE INITIAL DEVELOPMENT, 1917-1929

SUMMARY

Pumping plant	Height of lift, in feet	Installed capacity		12 year total		Average seasonal		
		Pumps, second-feet	Motors, horse power	Water pumped, in acre-feet	Energy consumption, in kilowatt hours	Water pumped, in acre-feet	Energy consumption, in kilowatt hours	Energy cost, at $0.0055 per kilowatt hour
No. 1	18.0	2,000	5,500	2,439,000	74,975,000	203,000	6,248,000	$34,000
No. 2	12.9	2,000	4,000	2,518,000	55,461,000	210,000	4,622,000	25,000
No. 3	12.9	2,500	4,900	4,337,000	95,523,000	361,000	7,960,000	44,000
No. 4	12.9	2,500	4,900	4,337,000	95,523,000	362,000	7,960,000	44,000
No. 5	12.9	2,500	4,900	3,965,000	87,340,000	330,000	7,278,000	40,000
No. 6	26.5	3,000	12,000	10,585,000	478,976,000	882,000	39,914,000	220,000
No. 7	26.5	3,000	12,000	10,586,000	478,976,000	882,000	39,914,000	220,000
No. 8	26.5	3,000	12,000	10,585,000	478,976,000	882,000	39,914,000	220,000
No. 9	26.5	2,000	8,000	7,057,000	319,297,000	588,000	26,608,000	146,000
No. 10	26.5	2,000	8,000	7,056,000	319,297,000	588,000	26,608,000	146,000
Totals	202.1		76,200		2,484,344,000		207,026,000	$1,139,000

Economic and Financial Aspects—Consideration of the economic and financial aspects of the proposed plan for complete initial development in the San Joaquin River Basin must be combined with the plan for the Sacramento River Basin because the initial units in both basins are interdependent and interrelated and together comprise a unified project of coordinate development of the complete initial State Water Plan in the entire Great Central Valley. The major units of the proposed complete initial development for the entire Great Central Valley, including a conduit to deliver water from the delta to the upper San Francisco Bay region, are as follows:

1. Kennett Reservoir and Power Plant, capacity 2,940,000 acre-feet.
2. Sacramento-San Joaquin Delta Cross Channel.
3. Contra Costa County Conduit, capacity 120 second-feet.
4. San Joaquin River Pumping System, capacity 3000 second-feet.
5. Friant Reservoir and Power Plant, gross capacity 400,000 acre-feet. Net capacity 270,000 acre-feet.
6. Madera Canal, capacity 1500 second-feet.
7. San Joaquin River-Kern County Canal, capacity 3000 second-feet.
8. Magunden-Edison Pumping System, capacity 20 second-feet.

The capital and gross annual costs and anticipated revenues under the plan of complete initial development in the Great Central Valley are presented in Table 185. The annual costs include operation and maintenance charges, interest at 4½ per cent per annum, amortization on a forty-year sinking fund basis at 4 per cent, and depreciation on a 4 per cent sinking fund basis with different lengths of service for the various elements of each unit. The basis for estimating the anticipated revenues from the sale of water and power have been previously set forth under the presentation of the economic and financial aspects of the immediate initial development. Revenue from the sale of water in the upper San Joaquin Valley is based upon the average seasonal supply that would have been made available during the forty-year period 1889–1929 totaling 1,720,000 acre-feet and applying thereto a rate of $3.00 per acre-foot. The annual output of electric energy would be slightly reduced at Kennett Reservoir and would be considerably reduced at Friant Reservoir as compared to the immediate initial development. Total revenues are estimated as the total amounts which would be realized when the supplies provided are fully utilized and the water and power sold at the unit values estimated.

With State financing at 4½ per cent interest and amortization of the capital investment in forty years, the gross annual cost exceeds the anticipated revenues from the sale of water and power by $2,816,000 or practically the same amount as under the immediate initial development. Possible revenue from sale of stored water from Kennett Reservoir for use in the Sacramento Valley and Sacramento-San Joaquin Delta would reduce the net annual cost by about $420,000. In addition to the direct anticipated revenues, it is believed that the large benefits which would accrue to many interests, not only local but also national and state-wide, might reasonably justify the anticipation of direct contributions by the Federal and State governments to defray a portion of the cost of the project. These have been pointed out in the discussion previously presented for the immediate initial development. With such direct contributions and with the further possibility of financing the project at a lower rate of interest than that assumed and with the amortization period increased, the annual cost, including interest and amortization on capital expenditures to be directly borne by the project, might be reduced to such an extent that the revenues would be sufficient. Analyses were made of several plans of financing based upon various interest and sinking fund rates, amortization periods and Federal and State contributions. The data prepared are similar to those set forth in Table 169 and are presented in Table 186.

TABLE 185

COSTS AND REVENUES COMPLETE INITIAL DEVELOPMENT OF STATE WATER PLAN IN GREAT CENTRAL VALLEY

Item	Capital cost	Gross annual cost	
Capital and annual cost—			
Kennett reservoir and power plant	$84,000,000	$5,297,000	
Sacramento-San Joaquin Delta cross channel	4,000,000	300,000	
Contra Costa County conduit	2,500,000	300,000	
San Joaquin River pumping system	15,000,000	2,500,000	
Friant reservoir and power plant	14,500,000	885,000	
Madera canal	2,500,000	213,000	
San Joaquin River-Kern County canal	27,300,000	2,225,000	
Magunden-Edison pumping system	100,000	18,000	
Right of ways, water rights and general expense	8,000,000	444,000	
Total	$157,900,000	$12,182,000	$12,182,000
Annual revenues—			
Electric energy sales:			
1,581,100,000 kilowatt hours at $0.00242	$3,826,000		
23,000,000 kilowatt hours at $0.0035	80,000		
Total electric energy sales		$3,906,000	
Water sales:			
1,720,000 acre-feet for upper San Joaquin Valley, based on average for forty-year period, 1889-1929, at $3 per acre-foot	$5,160,000		
43,500 acre-feet for Contra Costa County conduit at $6.90 per acre-foot	300,000		
Total water sales		5,460,000	
Total revenues, electric energy and water		$9,366,000	9,366,000
Net annual cost in excess of revenues			$2,816,000

TABLE 186

FINANCIAL ANALYSES OF PLAN OF COMPLETE INITIAL DEVELOPMENT GREAT CENTRAL VALLEY PROJECT WITH VARIOUS ASSUMED INTEREST RATES, AMORTIZATION PERIODS AND STATE AND FEDERAL CONTRIBUTIONS

Basis of financing	Capital cost	Gross annual cost	Annual direct revenue from water and power sales[1]	Net annual cost (—), or return (+)
Without Direct Federal or State Contributions				
Plan 1. Interest at 4½ per cent and 40-year amortization on a 4 per cent sinking fund basis	$157,900,000	$12,182,000	$9,786,000	—$2,396,000
Plan 2. Interest at 4½ per cent and 50-year amortization on a 4 per cent sinking fund basis	157,900,000	11,556,000	9,786,000	—1,770,000
Plan 3. Interest at 4½ per cent and 70-year amortization on a 4 per cent sinking fund basis	157,900,000	10,956,000	9,786,000	—1,170,000
Plan 4. Interest at 4 per cent and 50-year amortization on a 4 per cent sinking fund basis	156,200,000	10,649,000	9,786,000	—863,000
Plan 5. Interest at 3½ per cent and 50-year amortization on a 3½ per cent sinking fund basis	154,700,000	9,945,000	9,786,000	—159,000
Plan 6. Interest at 3 per cent and 50-year amortization on a 3 per cent sinking fund basis	152,900,000	9,253,000	9,786,000	+533,000
Plan 7. No interest and repayment of principal sum in 40 equal annual installments	142,900,000	6,673,000	9,786,000	+3,113,000
With Direct Federal and State Contributions				
Plan 8. Same as Plan 1, with direct Federal contribution of $6,000,000 in the interest of navigation and State contribution of $3,400,000 for the relocation of State Highway above Kennett Reservoir	*148,500,000	11,658,000	9,786,000	—1,872,000
Plan 9. Same as Plan 2, with Federal and State contributions as in Plan 8	*148,500,000	11,071,000	9,786,000	—1,285,000
Plan 10. Same as Plan 3, with Federal and State contributions as in Plan 8	*148,500,000	10,507,000	9,786,000	—721,000
Plan 11. Interest at 4½ per cent and refunding bonds, with same Federal and State contributions as in Plan 8	*148,500,000	10,099,000	9,786,000	—313,000
Plan 12. Same as Plan 5 with Federal and State contributions as in Plan 8	*145,300,000	9,613,000	9,786,000	+173,000
Plan 13. Same as Plan 12 with Federal contribution increased to $20,000,000	*131,300,000	9,016,000	9,786,000	+770,000

* Direct Federal and State contributions not included.

[1] Includes a revenue of $420,000 for sale of stored water in Sacramento Valley and Sacramento-San Joaquin Delta, not shown in Table 185.

NOTE.—If financed under the provisions of Title II of the National Industrial Recovery Act of 1933, with a direct federal contribution of 30 per cent of the cost of labor and materials and a Federal loan to finance the balance of the cost with interest at 4 per cent and amortization on a 4 per cent sinking fund basis in 50 years, the gross annual cost of the project for complete initial development would be considerably less than the anticipated annual revenue from water and power sales.

CHAPTER IX

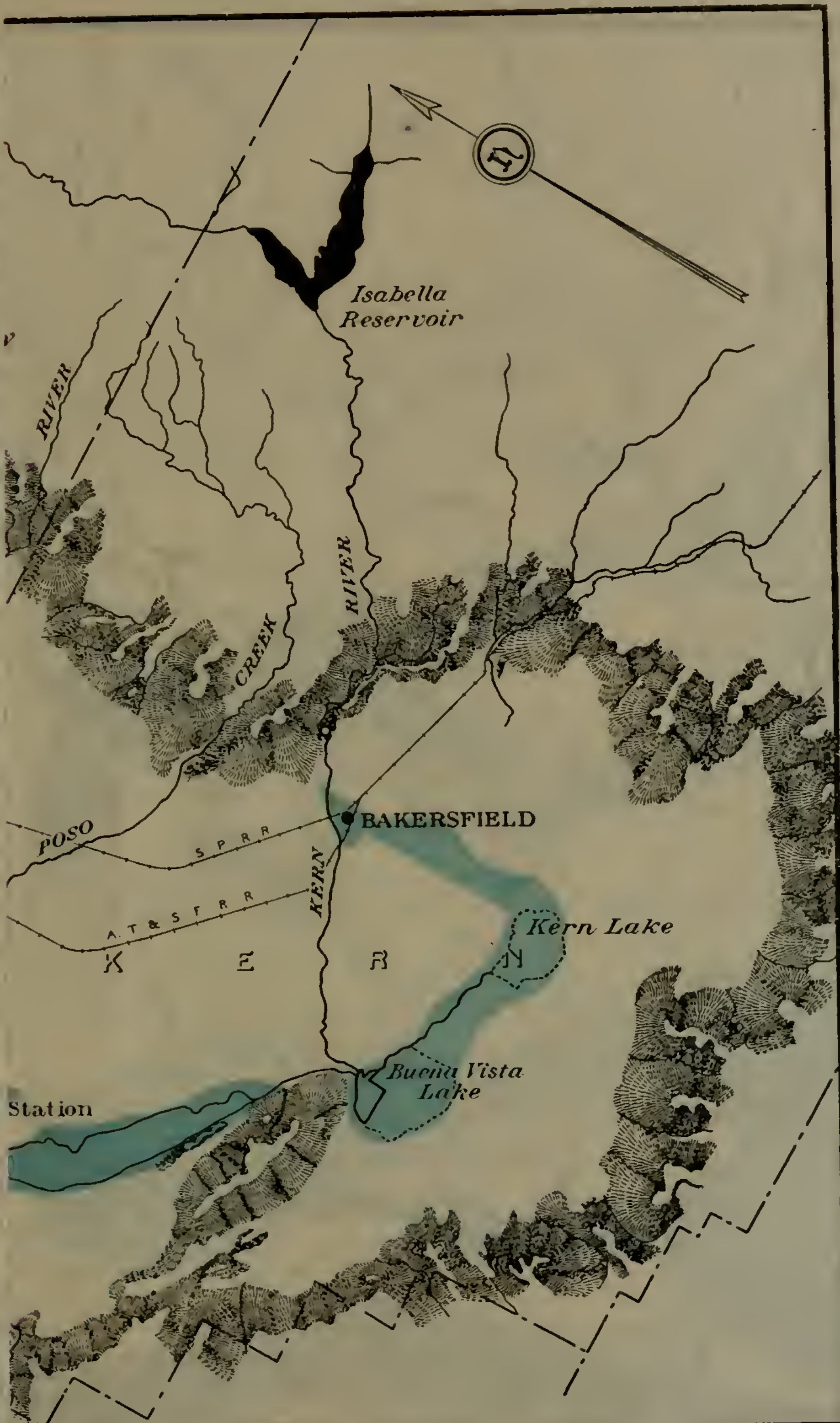
FLOOD CONTROL

Prior to the settlement of the San Joaquin Valley by white men and the beginning of its use for agriculture, large areas of land were subject to annual or periodic inundation by flood waters from the San Joaquin River and its tributaries and the streams flowing into Tulare and Buena Vista lakes. It is difficult to determine the exact boundaries of these overflow areas because of the lack of authentic records. A map of the land subject to overflow has been prepared, however, utilizing the best available data, and is presented herewith as Plate LXXIII, "Lands Naturally Subject to Overflow in the San Joaquin Valley." The data used in the preparation of this plate were obtained from a map made by Wm. Ham. Hall, State Engineer, in 1887, and from maps of the Sacramento-San Joaquin Drainage District and proposed extensions of that district. The purpose of the plate is to show in a general way the locations and magnitudes of the areas in the San Joaquin Valley naturally subject to inundation. Small areas may be included within the boundary which are not or were not subject to overflow and, on the other hand, small areas which may have been overflowed or are subject to overflow may have been omitted. No attempt has been made to indicate overflow lands in the Kaweah and Tule river deltas as they are scattering tracts. The area subject to inundation by floods of the Calaveras River and adjacent minor streams is shown on this map although it was omitted from a map in a previous report * which shows the area in the vicinity of Stockton subject only to backwater flooding from the delta channels. The total area of lands naturally subject to overflow shown on this map is somewhat more than one and three-quarters million acres.

The overflow lands, due to their character or position, have been divided into four groups. In the first group are included all lands in the upper San Joaquin Valley south of the San Joaquin River; in the second group, the lands lying along the San Joaquin River from Herndon to the mouth of the Merced River; in the third group, the lands along the San Joaquin River from the mouth of the Merced River to Paradise Dam at the head of the San Joaquin Delta; and in the last group, the lands in the San Joaquin Delta, and bordering lands.

The control of floods in the San Joaquin Valley is closely associated with the conservation features of the State Water Plan since much of the land on the valley floor which ultimately would receive the regulated water supplies made available through the operation of the State Water Plan lies within the area which is subject to periodic inundation. These lands which will be developed through increased water supplies and will have increased property values must be protected from flood hazard. With the larger storage reservoirs of the State Water Plan constructed and operated for flood control, a substantially increased degree of

* Bulletin No. 27, "Variation and Control of Salinity in the Sacramento-San Joaquin Delta and Upper San Francisco Bay," Division of Water Resources, 1931.



LANDS NATURALLY SUBJECT TO OVERFLOW

IN THE

SAN JOAQUIN VALLEY

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protection would be furnished to the areas now protected from inundation by existing works, the cost of works to protect additional lands would be greatly reduced, and the lands would be given a greater degree of protection than they would have with works constructed for protection against uncontrolled flows. Not only would the property owners be interested in such developments but also the Federal and State governments which have already contributed, in cooperation with the landowners, large sums of money for the construction of flood control works in the Sacramento Valley. Therefore, it is important and desirable that inquiry be made to determine what additional degree of protection could be afforded areas already leveed, what additional lands could be economically protected and what savings in cost of protection could be effected, by means of the operation of the large major storage reservoirs of the State Water Plan for flood control.

Present Status of Flood Control in the San Joaquin Valley.

The San Joaquin Valley has no flood control project similar to that in the Sacramento Valley which has been adopted by the United States and the State of California and in conformity with which all protection works must be constructed. However, much of the land in the basin subject to inundation now has some degree of protection.

The flood protection works in the San Joaquin Valley have been constructed almost entirely by the landowners with only such assistance from the Federal and State governments as was incidental to the improvement and maintenance of navigation and, in recent years, some assistance from the State in bank and levee protection work. In addition to the Stockton diverting canal hereinafter referred to, the United States has constructed the Stockton Ship Canal and in cooperation with the State has straightened several delta channels. These works undoubtedly have some effect in bettering flowage conditions in the delta.

Upper San Joaquin Valley South of San Joaquin River—Most of the lands subject to inundation in the upper San Joaquin Valley south of the San Joaquin River lie south of the ridge between the San Joaquin and Kings rivers. The connecting channel between the streams south of this ridge and the San Joaquin River is Fresno Slough which joins the river near Mendota. Flood waters in this section of the valley are contributed almost entirely by the Sierra Nevada streams. Most of the flooding under natural conditions, occurred in the Kings, Kaweah, Tule and Kern River deltas and in the beds of Tulare, Kern and Buena Vista lakes. Flooding in the delta areas, however, is of short duration and practically no levees have been constructed except in the Kings River Delta and around Bakersfield. Tulare Lake, lying to the south of the Kings River Delta, receives all waters from the Kings, Kaweah and Tule rivers which are not diverted for irrigation or absorbed into the underground basins, except the amounts which reach Fresno Slough. Some water is also diverted to the lake from Kern River. The lake has covered an area varying from nothing in dry cycles to about 760 square miles in 1862. A large percentage of the area subject to inundation in the Kings River Delta and the bed of Tulare Lake is now included in organized reclamation districts having an aggregate area of about 295,000 acres. Of this area, about 235,000 acres are within levees which give varying degrees of protection. However, much of the leveed land in Tulare Lake might be inundated during wet cycles. The land in the lowest portion of the lake bed has the smallest degree of protection.

Lying to the south of the Kern River Delta, there is a depression in the lowest part of which are the beds of Kern and Buena Vista lakes. Waters of Kern River which naturally reach Kern Lake have been diverted and the lake bed is now dry and under cultivation. Buena Vista Lake receives such flood waters from the Kern River and smaller local streams as are not used for irrigation or absorbed into the underground basins in the Kern River Delta. A portion of this lake has been leveed off and is used as an irrigation storage reservoir and the remainder is now under cultivation. This cultivated portion, however, is available for the storage of water from major floods. Excess waters which can not be stored in Buena Vista Lake are diverted toward Tulare Lake through a channel following the trough of the upper San Joaquin Valley. Lying adjacent to this channel, there is one reclamation district, with an area of about 86,000 acres, which is partially protected by levees. Data on expenditures for flood protection works in the upper San Joaquin Valley are not available.

Upper and Lower San Joaquin Valleys—Herndon to Mouth of Merced River—In the section of the valley lying along the San Joaquin River upstream from the mouth of the Merced River, the flood plain is several miles in width. The total gross area including river and slough channels is about 305,000 acres. Across this flood plain run the winding courses of several sloughs, some of which are as large as the main river channel and in their natural condition carried a large portion of the flood flow. For the most part, such protection as exists in this portion of the valley is afforded by irrigation canal banks constructed along the high ground near the river banks. These works provide protection, of varying degrees, from overflow by the smaller summer and winter floods for about 125,000 acres of land. No costs of flood protection for these lands can be estimated, however, because the primary object of the investment in the canals was for irrigation, and the location of these canals along the river banks was due to considerations of topography and economy.

Lower San Joaquin Valley—Mouth of Merced River to Paradise Dam—The group of overflow lands lying along the San Joaquin River from the mouth of the Merced River to the head of the delta at Paradise Dam has a length of about 34 miles and is so narrow that the gross area is only about 83,000 acres. It is generally conceded that complete or even a high degree of protection against unregulated winter floods through this division of the valley is not economically feasible because a flood channel of sufficient width to accomplish such protection would utilize a large percentage of the best agricultural lands and the burden of cost falling upon the protected area would be greater than the value of the protection. A fair degree of protection from summer and small winter floods is feasible, however, and about 32,000 acres have been wholly or partially protected from such floods at an estimated cost of about $1,500,000.

San Joaquin Delta and Bordering Lands—The San Joaquin Delta comprises low marsh areas consisting of peat and alluvial soils which their natural condition were subject not only to inundation from flood waters but also to tidal overflow since much of the area is below sea level. Bordering the delta there are alluvial rim lands which were subject to inundation from flood waters only. The total area in this group is about 500,000 acres of which several thousand acres lie in the existing waterways.

Protection of the delta lands began early in the history of agriculture in the valley and has been in progress for over sixty years. During this period, practically all of the delta lands have been brought within levees which provide about the maximum degree of protection that can be obtained by this method of flood control. This degree of protection, however, would be far from adequate during a period of major flood occurrence. Levees as a rule follow the winding courses of river channels and connecting sloughs with the result that the delta is made up of a large number of islands. The levees around these islands have been built gradually to the limiting heights that their unstable foundations will support. Although the channels are many, their total flood carrying capacity is far less than the amount they may be called upon to carry in any season of major flood occurrence. Toward the head of the delta the number of channels decreases to two, the natural channel of the main San Joaquin River and an artificial channel called Paradise Cut. Although the levees here are higher than those of the lower delta and might be constructed to even greater heights, the total present safe channel capacity is only about 60,000 second-feet, or less than half the estimated discharge of the 1911 flood through this section of the valley. This capacity is much less than the capacity of the combined lower delta channels. The cost of existing protection works in the San Joaquin Delta is estimated to be about $17,000,000.

The city of Stockton lying on the eastern rim of the delta is endangered not only by San Joaquin River floods but also by the flood waters of the Calaveras River. The Calaveras River channel for a considerable distance below Bellota has practically no carrying capacity and most of the flood waters flow into Mormon Slough and other channels and originally passed through the city of Stockton. Several years ago, the Federal government in order to assist in maintaining navigation in the lower end of Mormon Slough and in Stockton Channel, by keeping debris brought down by floods out of these channels, constructed a canal to the east of Stockton to intercept Mormon and other sloughs and divert their flows back into the Calaveras River at a point where it has a larger capacity, and thence directly into the San Joaquin River. This canal by diverting some of the flood waters of the Calaveras River, affords some protection to the city of Stockton from floods from the east. To further protect itself from such floods, the city in 1930 constructed a reservoir of 76,000 acre-feet capacity on the Calaveras River near Valley Springs for the purpose of controlling its flood flows.

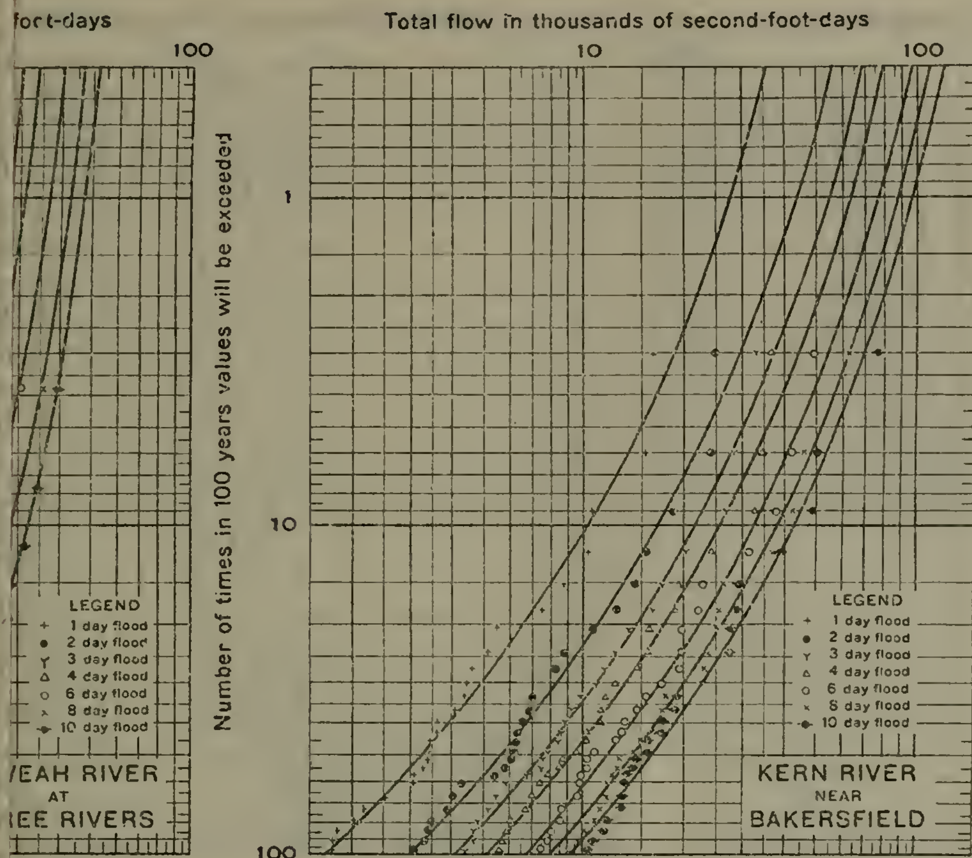
Size and Frequency of Flood Flow.

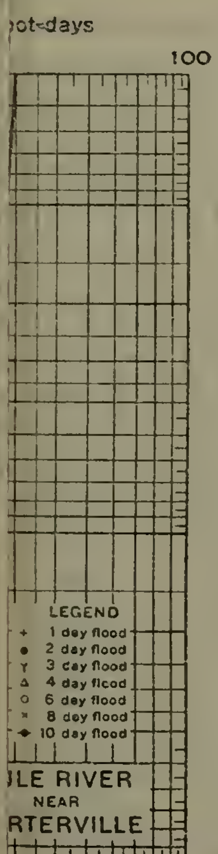
To estimate the probable sizes of floods which may be expected in different sections of the San Joaquin River Basin and the frequency with which they may occur, analyses were made of all available data on flood flows. Studies were made of the flood flows at the gaging station on each of the main streams near the foothill line and also at several selected points of flood concentration on the valley floor.

The data available for these studies are chiefly the records of flood flows obtained by the United States Geological Survey at its gaging stations. The period of record at each station and the maximum and minimum mean daily flows of the major streams of the San Joaquin River Basin have been presented in Chapter II. Data have been obtained for only a relatively short period when consideration is given to the sizes of floods that may occur at long intervals of time such as once in 100 and once in 1000 years. Also, it is difficult to obtain the amounts of flow at times of floods, and the peak and mean daily flows at the crest of a flood must often be estimated from extended rating curves or from stream cross sections and observed surface velocities. While the data, therefore, are not exact and a much longer period of record would be desirable, the studies have been based on these data and are believed to give the best results now obtainable.

Winter and Summer Floods—Floods in the San Joaquin River Basin are of two general classes—winter floods from rain water and summer floods from melting snow. The winter floods occur during the season from November to May and are caused by run-off from rain storms in the lower mountain and valley watersheds or by rain storms combined with melting snow. They are generally characterized by relatively sharp peak flows and the entire flood is of only a few days duration. Flood flows in the San Joaquin River at points on the valley floor, and in the Sacramento-San Joaquin Delta are caused by the concentration of the flood flows of the tributary streams at these points. The peak flow at any point, therefore, depends on the combination of flows from the tributary streams and is subject to wide variation. It is always less than the sum of the peak flows from all of the tributary streams because, on account of the rate and direction of storm travel and the variation in distance of the watersheds of the tributary streams from the point of concentration, the separate peak flows do not all reach the point of concentration at the same time, and also because the peak flows are reduced by channel storage before reaching the point of concentration.

The summer floods occur during the period April to August and are most pronounced on the larger streams whose headwaters are in the high Sierra Nevada. They are caused by the rapid melting of the snow which has accumulated during the winter in the mountains at the higher elevations and are sometimes augmented by spring rains. Summer floods are usually of much greater duration than winter floods and may continue for a period of a month or more. They have no sharp peaks and the maximum flows are not as large as the maximum or peak flows of winter floods. Since the summer floods are of considerable duration, however, the total volume of run-off during such floods may be much greater than in the largest winter floods. Also, since the flows extend over a relatively long period, the flows at points of concentration on the valley floor may more nearly approach the sum of the maximum flows in the tributary streams than they do in winter floods. However, there is practically no run-off from the streams from the lower mountains and the valley floor in the summer and the maximum summer flood flows at the points of concentration on the valley floor are smaller than the peak flows during winter floods.



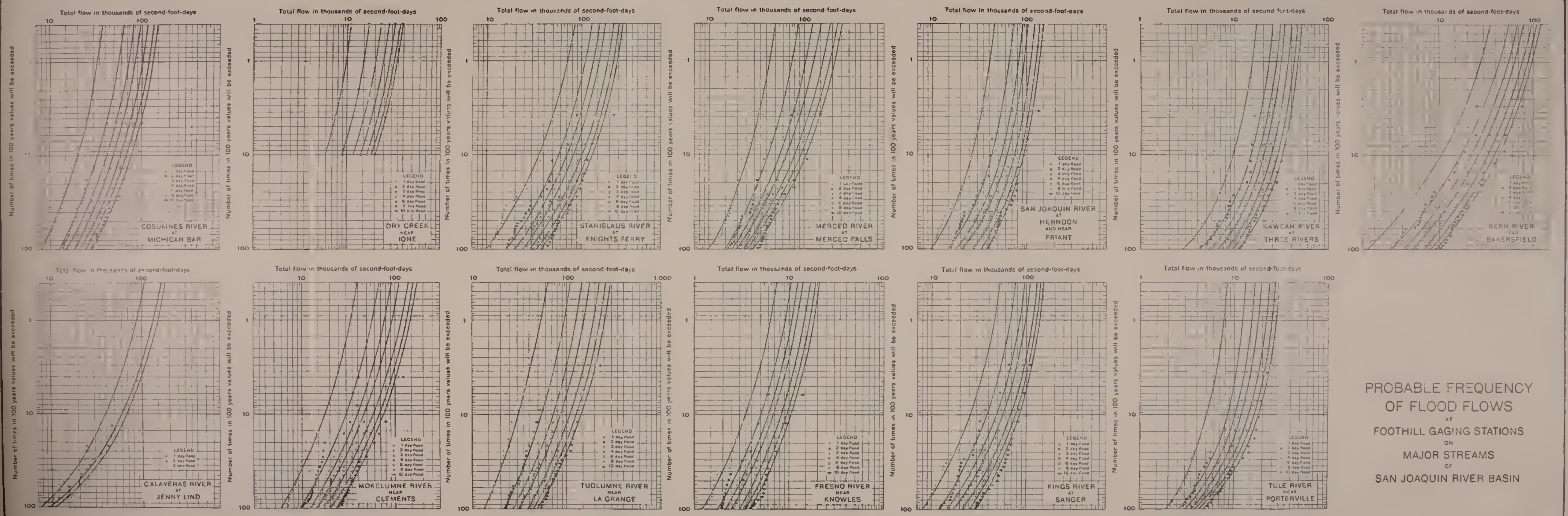


PROBABLE FREQUENCY
OF FLOOD FLOWS
AT
FOOTHILL GAGING STATIONS
ON
MAJOR STREAMS
OF
SAN JOAQUIN RIVER BASIN

The data available for these studies are chiefly the records of flood flows obtained by the United States Geological Survey at its gaging stations. The period of record at each station and the maximum and minimum mean daily flows of the major streams of the San Joaquin River Basin have been presented in Chapter II. Data have been obtained for only a relatively short period when consideration is given to the sizes of floods that may occur at long intervals of time such as once in 100 and once in 1000 years. Also, it is difficult to obtain the amounts of flow at times of floods, and the peak and mean daily flows at the crest of a flood must often be estimated from extended rating curves or from stream cross sections and observed surface velocities. While the data, therefore, are not exact and a much longer period of record would be desirable, the studies have been based on these data and are believed to give the best results now obtainable.

Winter and Summer Floods—Floods in the San Joaquin River Basin are of two general classes—winter floods from rain water and summer floods from melting snow. The winter floods occur during the season from November to May and are caused by run-off from rain storms in the lower mountain and valley watersheds or by rain storms combined with melting snow. They are generally characterized by relatively sharp peak flows and the entire flood is of only a few days duration. Flood flows in the San Joaquin River at points on the valley floor, and in the Sacramento-San Joaquin Delta are caused by the concentration of the flood flows of the tributary streams at these points. The peak flow at any point, therefore, depends on the combination of flows from the tributary streams and is subject to wide variation. It is always less than the sum of the peak flows from all of the tributary streams because, on account of the rate and direction of storm travel and the variation in distance of the watersheds of the tributary streams from the point of concentration, the separate peak flows do not all reach the point of concentration at the same time, and also because the peak flows are reduced by channel storage before reaching the point of concentration.

The summer floods occur during the period April to August and are most pronounced on the larger streams whose headwaters are in the high Sierra Nevada. They are caused by the rapid melting of the snow which has accumulated during the winter in the mountains at the higher elevations and are sometimes augmented by spring rains. Summer floods are usually of much greater duration than winter floods and may continue for a period of a month or more. They have no sharp peaks and the maximum flows are not as large as the maximum or peak flows of winter floods. Since the summer floods are of considerable duration, however, the total volume of run-off during such floods may be much greater than in the largest winter floods. Also, since the flows extend over a relatively long period, the flows at points of concentration on the valley floor may more nearly approach the sum of the maximum flows in the tributary streams than they do in winter floods. However, there is practically no run-off from the streams from the lower mountains and the valley floor in the summer and the maximum summer flood flows at the points of concentration on the valley floor are smaller than the peak flows during winter floods.



PROBABLE FREQUENCY OF FLOOD FLOWS AT FOOTHILL GAGING STATIONS ON MAJOR STREAMS OF SAN JOAQUIN RIVER BASIN

Flood Flows at Foothill Gaging Stations—In estimating the probable amounts of flood discharge at a gaging station for specified frequencies, the total recorded volumes of flood flow during periods of one, two, three, four or more days were tabulated in descending order of magnitude, thus giving the number of times of occurrence, or frequency, of a flood of a certain duration and magnitude during the period of stream flow record. The probable number of times that each volume of flow would have occurred in 100 years was obtained by multiplying the order of the frequency by 100 divided by the number of years in the period of record. These values were plotted on logarithmic paper with the vertical scale representing the frequency with which the volumes of flow would be exceeded in 100 years on the average and the horizontal scale the volume of the flow. Curves drawn to conform to the trend of these plotted points were extended to give the volumes of flood flow which may be expected to be exceeded once in 250 years on an average. Curves for winter floods drawn in this manner are shown for each of the stations studied on Plate LXXIV, ''Probable Frequency of Flood Flows at Foothill Gaging Stations on Major Streams of San Joaquin River Basin.'' In selecting the data for the development of these curves, a flood was considered to be a winter or rain water flood, even if it occurred in April, if the increase in flow over that in preceding days appeared to have been caused by rainfall or by rainfall and melting snow caused by the rain. Similar curves were drawn for summer floods of 1, 3, 6, 12, 24 and 36 days duration but are not shown in this report. In selecting the data for the development of these latter curves, a flood was considered to be a summer or snow water flood, even as early as April, if it appeared to have been caused primarily by melting snow and even if some slight increases of flow in May were due to spring rains. The total run-offs and mean flows during both summer and winter floods, which it is estimated may occur with certain frequencies at the foothill gaging stations on the major streams of the San Joaquin River Basin, were obtained from the frequency curves and are shown in Tables 187 to 199, inclusive. Table 200 gives the probable maximum mean daily flows which may be exceeded with certain frequencies at the same foothill gaging stations. ''Mean daily flow'' is the uniform flow throughout a calendar day which would give a total run-off equal to that which actually occurred with variable rates of flow. For the Calaveras River, total run-offs and mean flows are given for periods of 24, 48 and 72 hours. These hour periods are those including the maximum run-off without regard to calendar day limits.

TABLE 187

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF FLOOD FLOWS OF KERN RIVER NEAR BAKERSFIELD

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
					Winter Floods					
1	20,400	10,300	32,900	16,600	43,400	21,900	55,100	27,800	71,000	35,800
2	33,300	8,400	52,000	13,100	68,800	17,350	87,300	22,000	111,000	28,000
3	43,200	7,270	66,100	11,100	86,900	14,600	109,100	18,330	135,900	22,830
4	51,400	6,480	78,000	9,820	101,800	12,820	126,500	15,950	157,700	19,880
6	64,700	5,430	97,200	8,170	124,600	10,470	152,700	12,830	191,400	16,080
8	75,600	4,760	113,700	7,160	143,400	9,040	174,500	11,000	220,200	13,880
10	84,900	4,280	126,900	6,400	158,700	8,000	194,400	9,800	242,000	12,200
					Summer Floods					
1	12,500	6,300	16,400	8,300	19,400	9,800	23,000	11,600	28,200	14,200
3	35,500	6,000	46,800	7,900	55,700	9,400	65,500	11,000	80,300	13,500
6	67,600	5,700	88,100	7,400	104,300	8,800	123,000	10,300	148,800	12,500
12	126,000	5,300	163,600	6,900	194,400	8,200	229,900	9,700	278,500	11,700
24	234,100	4,900	309,400	6,500	365,000	7,700	428,400	9,000	519,700	10,900
36	335,200	4,700	438,400	6,100	519,700	7,300	612,900	8,600	743,800	10,400

TABLE 188

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF FLOOD FLOWS OF TULE RIVER NEAR PORTERVILLE, NOT INCLUDING SOUTH FORK

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
					Winter Floods					
1	10,200	5,150	12,500	6,300	13,900	7,000	15,200	7,650	16,700	8,400
2	16,900	4,250	20,200	5,100	22,400	5,650	24,200	6,100	26,000	6,550
3	20,200	3,400	25,200	4,230	28,000	4,700	30,300	5,100	32,500	5,470
4	23,400	2,950	29,000	3,650	32,300	4,080	35,500	4,480	38,300	4,820
6	28,400	2,380	35,100	2,950	39,500	3,320	43,200	3,630	46,800	3,930
8	32,500	2,050	40,500	2,550	45,600	2,880	49,600	3,120	53,400	3,360
10	36,300	1,830	45,200	2,280	50,800	2,560	55,300	2,790	59,300	2,990
					Summer Floods					
1	2,500	1,250	3,900	1,960	5,100	2,580	6,500	3,270	8,500	4,290
3	6,400	1,080	10,100	1,690	13,200	2,210	16,500	2,780	21,400	3,600
6	11,400	950	17,400	1,460	22,300	1,880	28,200	2,370	36,300	3,050
12	19,800	830	29,400	1,230	37,900	1,590	47,400	1,990	60,700	2,550
24	35,200	740	51,600	1,080	65,500	1,380	81,100	1,700	100,800	2,120
36	49,600	690	71,400	1,000	89,700	1,260	110,100	1,540	137,300	1,920

NOTE.—The flows in Table 188 are for the main stream only and do not include those for the South Fork. The sizes of flood for various frequencies for the combined flows of the main river and the South Fork (as measured at Success), below their confluence, would be about one-third larger than those shown in the table.

TABLE 189

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF FLOOD FLOWS OF KAWEAH RIVER AT THREE RIVERS

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
					Winter Floods					
1	19,100	9,650	23,800	12,000	27,200	13,700	30,100	15,200	33,900	17,100
2	29,600	7,450	36,500	9,200	41,500	10,450	45,400	11,450	50,200	12,650
3	35,700	6,000	44,000	7,400	49,600	8,330	54,700	9,200	60,500	10,170
4	40,900	5,150	49,600	6,250	56,100	7,080	61,500	7,750	67,800	8,550
6	48,800	4,100	59,700	5,020	67,000	5,630	73,400	6,170	80,900	6,800
8	56,500	3,560	69,200	4,360	77,400	4,880	84,900	5,350	93,200	5,880
10	64,100	3,230	77,600	3,910	86,300	4,350	94,200	4,750	103,100	5,200
					Summer Floods					
1	8,700	4,400	10,700	5,400	12,500	6,280	14,300	7,200	16,900	8,500
3	24,400	4,100	30,100	5,070	34,900	5,870	40,100	6,730	47,200	7,930
6	45,800	3,850	56,900	4,780	65,900	5,530	76,000	6,380	89,700	7,530
12	85,500	3,590	106,100	4,460	122,600	5,150	140,800	5,920	165,600	6,960
24	152,700	3,210	190,400	4,000	220,200	4,620	251,900	5,290	297,500	6,250
36	214,200	3,000	267,800	3,750	309,400	4,330	355,000	4,970	414,600	5,810

TABLE 190

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF FLOOD FLOWS OF KINGS RIVER AT PIEDRA

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
					Winter Floods					
1	51,200	25,800	67,400	34,000	80,300	40,500	92,200	46,500	105,700	53,300
2	76,400	19,250	100,200	25,250	118,000	29,750	134,900	34,000	152,700	38,500
3	96,200	16,170	126,900	21,330	148,800	25,000	169,600	28,500	190,400	32,000
4	112,100	14,120	146,800	18,500	171,600	21,620	194,400	24,500	216,200	27,250
6	135,900	11,420	177,500	14,920	204,300	17,170	231,100	19,420	255,900	21,500
8	152,700	9,620	196,400	12,380	226,100	14,250	255,900	16,120	281,700	17,750
10	168,600	8,500	213,200	10,750	245,000	12,350	275,700	13,900	302,500	15,250
					Summer Floods					
1	37,700	19,000	44,800	22,600	50,200	25,300	55,900	28,200	63,900	32,200
3	109,700	18,400	128,900	21,700	143,400	24,100	158,300	26,600	178,500	30,000
6	208,300	17,500	244,000	20,500	271,700	22,800	298,500	25,100	337,200	28,300
12	382,800	16,100	450,300	18,900	499,800	21,000	551,400	23,200	622,800	26,200
24	674,400	14,200	793,400	16,700	890,600	18,700	985,800	20,700	1,118,700	23,500
36	940,200	13,200	1,110,800	15,600	1,235,700	17,300	1,374,600	19,200	1,563,000	21,900

TABLE 191

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF FLOOD FLOWS OF SAN JOAQUIN RIVER NEAR FRIANT

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
					Winter Floods					
1	52,800	26,600	64,900	32,700	73,200	36,900	81,300	41,000	91,200	46,000
2	84,700	21,350	104,100	26,250	118,000	29,750	130,300	32,850	145,800	36,750
3	107,100	18,000	131,900	22,170	148,200	24,900	163,600	27,500	182,500	30,670
4	123,000	15,500	150,700	19,000	168,000	21,180	186,400	23,500	206,300	26,000
6	146,800	12,330	178,500	15,000	200,300	16,830	222,200	18,670	244,000	20,500
8	169,600	10,690	203,300	12,810	226,100	14,250	249,900	15,750	275,700	17,380
10	185,500	9,350	222,200	11,200	246,000	12,400	271,700	13,700	301,500	15,200
					Summer Floods					
1	41,900	21,100	50,000	25,200	55,300	27,900	60,900	30,700	67,400	34,000
3	117,000	19,700	138,400	23,300	152,700	25,700	168,200	28,300	187,400	31,500
6	222,200	18,700	261,800	22,000	287,600	24,200	315,400	26,500	343,100	28,800
12	402,700	16,900	478,000	20,100	521,700	21,900	559,300	23,500	612,900	25,800
24	714,100	15,000	839,000	17,600	912,400	19,200	973,900	20,500	1,061,200	22,300
36	983,800	13,800	1,162,300	16,300	1,259,500	17,600	1,348,800	18,900	1,457,900	20,400

TABLE 192

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF WINTER FLOOD FLOWS OF FRESNO RIVER NEAR KNOWLES

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
1	6,980	3,500	9,120	4,600	10,900	5,500	12,600	6,350	14,700	7,400
2	10,100	2,550	13,100	3,300	15,500	3,900	17,900	4,500	20,600	5,200
3	12,100	2,030	15,700	2,630	18,400	3,100	21,200	3,570	24,400	4,100
4	13,700	1,720	17,700	2,220	21,000	2,650	24,000	3,020	27,800	3,500
6	16,500	1,380	21,200	1,780	25,200	2,120	28,800	2,420	33,300	2,800
8	18,800	1,190	24,200	1,520	28,600	1,800	32,700	2,060	37,900	2,390
10	20,800	1,050	26,800	1,350	31,700	1,600	36,100	1,820	41,500	2,090

TABLE 193

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF FLOOD FLOWS OF MERCED RIVER AT MERCED FALLS

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
					Winter Floods					
1	52,200	26,300	66,100	33,300	76,800	38,700	87,300	44,000	100,400	50,600
2	84,300	21,200	111,100	28,000	129,900	32,800	149,800	37,800	175,500	44,200
3	111,100	18,700	149,800	25,200	179,900	30,200	208,300	35,000	246,000	41,300
4	130,900	16,500	178,500	22,500	214,200	27,000	253,900	32,000	303,500	38,200
6	159,100	13,400	220,200	18,500	269,800	22,700	317,400	26,700	380,800	32,000
8	185,500	11,700	257,900	16,200	317,400	20,000	374,900	23,600	450,300	28,400
10	210,300	10,600	289,600	14,600	361,000	18,200	422,500	21,300	503,800	25,400
					Summer Floods					
1	22,000	11,100	26,400	13,300	29,800	15,000	33,100	16,700	37,300	18,800
3	62,100	10,400	74,200	12,500	83,100	14,000	92,800	15,600	104,700	17,600
6	116,600	9,800	138,800	11,700	156,700	13,200	175,500	14,800	198,500	16,700
12	218,200	9,200	263,800	11,100	295,500	12,400	331,200	13,900	370,900	15,600
24	392,700	8,200	476,000	10,000	533,600	11,200	593,100	12,500	666,500	14,000
36	535,500	7,500	652,600	9,100	729,900	10,200	809,300	11,300	910,400	12,700

TABLE 194

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF FLOOD FLOWS OF TUOLUMNE RIVER NEAR LA GRANGE

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
Winter Floods										
1	62,300	31,400	78,500	39,600	92,200	46,500	106,100	53,500	125,400	63,200
2	108,700	27,400	140,000	35,300	164,200	41,400	186,800	47,100	218,200	55,000
3	144,400	24,300	186,400	31,300	222,200	37,300	251,900	42,300	291,600	49,000
4	173,600	21,900	225,100	28,400	265,800	33,500	305,500	38,500	353,100	44,500
6	217,200	18,200	283,600	23,800	333,200	28,000	384,800	32,300	440,300	37,000
8	253,900	16,000	333,200	21,000	392,700	24,800	452,200	28,500	515,700	32,500
10	285,600.	14,400	376,900	19,000	442,300	22,300	509,800	25,700	581,200	29,300
Summer Floods										
1	35,500	17,900	40,300	20,300	43,800	22,100	47,600	24,000	52,000	26,200
3	101,200	17,000	116,000	19,500	126,000	21,200	135,900	22,800	148,800	25,000
6	194,400	16,300	222,200	18,700	242,000	20,300	261,800	22,000	285,600	24,000
12	355,000	14,900	408,600	17,200	444,300	18,700	482,000	20,200	531,600	22,300
24	656,500	13,800	749,800	15,800	825,100	17,300	890,600	18,700	779,900	20,500
36	912,400	12,800	1,041,300	14,600	1,140,500	16,000	1,229,800	17,200	1,348,800	18,900

TABLE 195

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF FLOOD FLOWS OF STANISLAUS RIVER AT KNIGHTS FERRY

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
					Winter Floods					
1	71,800	36,200	99,200	50,000	121,000	61,000	142,800	72,000	170,600	86,000
2	115,000	29,000	156,700	39,500	188,400	47,500	222,200	56,000	253,900	64,000
3	142,800	24,000	192,400	32,300	230,100	38,700	269,800	45,300	311,400	52,300
4	166,600	21,000	224,100	28,200	265,800	33,500	311,400	39,200	359,000	45,200
6	206,300	17,300	277,700	23,300	331,200	27,800	382,800	32,200	440,300	37,000
8	238,000	15,000	319,300	20,100	380,800	24,000	440,300	27,800	501,800	31,600
10	263,800	13,300	351,100	17,700	416,500	21,000	480,000	24,200	545,500	27,500
					Summer Floods					
1	25,200	12,700	30,500	15,400	34,900	17,600	39,300	19,800	44,400	22,400
3	72,000	12,100	86,900	14,600	97,800	16,400	109,100	18,300	123,000	20,700
6	137,300	11,500	164,600	13,800	183,500	15,400	204,300	17,200	226,100	19,000
12	251,900	10,600	301,500	12,700	335,200	14,100	370,900	15,600	412,600	17,300
24	456,200	9,600	541,500	11,400	603,000	12,700	658,500	13,800	733,900	15,400
36	632,700	8,900	743,800	10,400	821,200	11,500	892,600	12,500	977,700	13,700

TABLE 196

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF WINTER FLOOD FLOWS OF CALAVERAS RIVER AT JENNY LIND

Number of hours of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
24	78,100	39,400	114,100	57,500	144,800	73,000	174,500	88,000	212,200	107,000
48	119,000	30,000	173,600	43,800	220,200	55,500	265,800	67,000	321,300	81,000
72	134,900	22,700	196,400	33,000	246,000	41,300	299,500	50,300	359,000	60,300

TABLE 197

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF FLOOD FLOWS OF MOKELUMNE RIVER NEAR CLEMENTS

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
Winter Floods										
1	35,300	17,800	47,200	23,800	57,100	28,800	66,800	33,700	78,300	39,500
2	59,300	15,000	80,100	20,200	96,800	24,400	114,100	28,800	134,900	34,000
3	78,900	13,300	107,900	18,100	129,900	20,800	153,700	25,800	183,500	30,800
4	92,600	11,700	126,900	16,000	154,700	19,500	183,500	23,100	220,200	27,800
6	115,000	9,700	159,700	13,400	194,400	16,300	230,100	19,300	275,700	23,200
8	133,900	8,400	183,500	11,600	222,200	14,000	261,800	16,500	313,400	19,800
10	149,800	7,600	202,300	10,200	244,000	12,300	285,600	14,400	341,200	17,200
Summer Floods										
1	18,500	9,400	22,400	11,300	26,000	13,100	29,400	14,800	34,300	17,300
3	51,800	8,700	62,100	10,400	71,200	12,000	79,900	13,400	91,600	15,400
6	95,800	8,100	117,000	9,800	132,900	11,200	149,800	12,600	174,500	14,700
12	176,900	7,400	218,200	9,200	251,900	10,600	283,600	11,900	331,200	13,900
24	315,400	6,600	384,800	8,100	442,300	9,300	503,800	10,600	591,100	12,400
36	422,500	5,900	511,700	7,200	583,100	8,200	660,500	9,300	769,600	10,800

TABLE 198

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF WINTER FLOOD FLOWS OF DRY CREEK NEAR IONE

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
1	11,900	6,000	15,100	7,600	17,500	8,800	19,400	9,800	21,800	11,000
2	18,000	4,550	23,000	5,800	27,000	6,800	30,000	7,550	33,900	8,550
3	23,400	3,930	30,500	5,130	35,700	6,000	40,300	6,770	45,600	7,670
4	28,600	3,600	36,900	4,650	43,400	5,480	48,800	6,150	55,100	6,950
6	32,900	2,770	42,800	3,600	50,200	4,220	56,700	4,770	64,500	5,420
8	36,900	2,320	48,000	3,020	55,900	3,520	63,300	3,990	73,000	4,600
10	40,300	2,030	52,200	2,630	60,700	3,060	68,200	3,440	78,300	3,950

TABLE 199

PROBABLE SIZES AND FREQUENCIES OF OCCURRENCE OF WINTER FLOOD FLOWS OF COSUMNES RIVER AT MICHIGAN BAR

Number of days of flow	Flood which may be exceeded on average of									
	Once in 10 years		Once in 25 years		Once in 50 years		Once in 100 years		Once in 250 years	
	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet	Total run-off, in acre-feet	Mean flow, in second-feet
1	40,300	20,300	50,800	25,600	58,900	29,700	65,900	33,200	74,200	37,400
2	67,000	16,900	84,900	21,400	99,200	25,000	112,500	28,400	126,900	32,000
3	84,700	14,200	109,500	18,400	127,300	21,400	144,400	24,300	163,200	27,400
4	98,800	12,400	127,900	16,100	149,200	18,800	168,600	21,200	191,400	24,100
6	119,400	10,000	153,700	12,900	178,900	15,000	204,300	17,200	232,100	19,500
8	137,900	8,700	177,500	11,200	206,300	13,000	236,000	14,900	267,800	16,900
10	154,700	7,800	199,300	10,000	232,100	11,700	263,800	13,300	297,500	15,000

TABLE 200

PROBABLE FREQUENCY OF MAXIMUM MEAN DAILY FLOOD FLOWS AT FOOTHILL GAGING STATIONS ON MAJOR STREAMS OF SAN JOAQUIN RIVER BASIN

Stream aud location of gage	Probable maximum mean daily flow[1], in second-feet, exceeded on average of once in				
	10 years	25 years	50 years	100 years	250 years
Kern River near Bakersfield	10,300	16,600	21,900	27,800	35,800
Tule River near Porterville	5,150	6,300	7,000	7,650	8,400
Kaweah River at Three Rivers	9,650	12,000	13,700	15,200	17,100
Kings River at Piedra	25,800	34,000	40,500	46,500	53,300
San Joaquin River near Friant	26,600	32,700	36,900	41,000	46,000
Fresno River near Knowles	3,500	4,600	5,500	6,350	7,400
Merced River at Merced Falls	26,300	33,300	38,700	44,000	50,600
Tuolumne River near La Grange	31,400	39,600	46,500	53,500	63,200
Stanislaus River at Knights Ferry	36,200	50,000	61,000	72,000	86,000
Calaveras River at Jenny Lind	[2]39,400	[2]57,500	[2]73,000	[2]88,000	[2]107,000
Mokelumne River near Clements	17,800	23,800	28,800	33,700	39,500
Dry Creek near Ione	6,000	7,600	8,800	9,800	11,000
Cosumnes River at Michigan Bar	20,300	25,600	29,700	33,200	37,400

[1] All flows are for winter floods. Maximum mean daily flows during summer floods are smaller than those during winter floods in all cases.
[2] Flows are mean for 24 hour period of maximum run-off.

Winter Flood Flows at Selected Points of Concentration on Lower San Joaquin Valley Floor—Knowledge of the amounts of flood flow at points within the area subject to inundation is essential to the design of works for the protection from floods of the valley lands affected. Studies were made, therefore, to estimate the winter flood flows and the probable frequency of their occurrence at several points of concentration on the San Joaquin Valley floor. Winter floods were chosen for this study since the concentrated flows during maximum floods of this type are larger than the concentrated summer flood flows and works for full protection would therefore be designed for winter flood flows. A study was also made of flows during the 1906 summer flood, which is the largest of record, and the amounts of flow are given later in this chapter in connection with plans for protection against such a flood.

Flows in the San Joaquin River at points on the valley floor are made up of the combined flows of the larger tributary streams, the flows of which are measured at points near the edge of the valley floor; the flows from smaller mountain and foothill streams for which there are no records of flow; run-offs from valley floor areas, which are also unmeasured. The flow of the main San Joaquin River is measured at two points on the valley floor, one just below the mouth of the Merced River near Newman, and the other just below the mouth of the Stanislaus River near Vernalis. Flows at these stations include those which are measured at the line of the valley floor, and those which are not measured in the tributary streams. Records of flows at the Newman station have been obtained by the United States Geological Survey throughout the year since April, 1912, but no records of the flows at the Vernalis station have been obtained during the winter months and records at this station are therefore of no use in studies of winter flood flows.

The valley floor points at which flood flows were estimated, the total area of the mountain drainage basin tributary to each point, and the division of this total area into areas having measured run-off and areas having no measured run-off except for the measurements taken at the Newman and Vernalis stations, are shown in Table 201.

TABLE 201

CLASSIFICATION OF AREAS OF MOUNTAIN DRAINAGE BASINS TRIBUTARY TO SELECTED POINTS OF CONCENTRATION ON LOWER SAN JOAQUIN VALLEY FLOOR

Point of concentration	Mountain drainage areas				
	Total in square miles[1]	With measured run-off		Without measured run-off	
		In square miles	In per cent of total	In square miles	In per cent of total
San Joaquin River below confluence of San Joaquin and Merced rivers	5,108	[2]2,955	58	2,153	42
San Joaquin River below confluence of San Joaquin and Tuolumne rivers	6,915	4,498	65	2,417	35
San Joaquin River below confluence of San Joaquin and Stanislaus rivers	8,014	5,481	68	2,533	32
San Joaquin and Sacramento rivers at confluence	31,793	25,722	81	6,071	19

[1] Areas south of San Joaquin River not included in total areas. Areas are from Bulletin No. 5, "Flow in California Streams," Division of Engineering and Irrigation, 1923.
[2] Includes Fresno River.

Flood flows at each selected point of concentration may be estimated by combining measured flows at the gaging stations on the major streams above the point with estimated flows from the tributary areas which have no measured run-offs, with proper allowances for time of travel of the flows and for channel storage. The areas without measured run-off are large, however, as shown by Table 201, and it is difficult to estimate flood discharges from these areas. They can not be estimated by comparison with the measured flows of the major streams because there is little similarity in the drainage basins of adjacent unmeasured and measured streams in position, elevation, and shape of watershed. Therefore, no attempt was made in these studies of flood concentration to estimate flood flows from areas having no measured run-off. Flows at the selected points of concentration were estimated instead from measured flows at the foothill gaging stations and at the Newman gaging station. The method used for each selected point is briefly described in the following paragraphs. The period used in these studies was 1896 to 1929 and since stream flow records are not available for all of the major tributary streams for the entire period, it was necessary to estimate flows for some years for each stream, except the Tuolumne River, by comparison with the flow records of the Tuolumne, Kings and American rivers. The estimated flood concentrations are necessarily not exact and must be so considered.

The amounts of flood flow in the San Joaquin River below its confluence with the Merced River, for the period since 1912, were obtained from the published records for the Newman gaging station. Amounts prior to that date were estimated from the relation of flows at the Newman gaging station to the combined mean daily flows of the Merced River at Merced Falls or Exchequer and those of the San Joaquin River at Friant or Herndon, with the proper allowances for the time of concentration, channel storage, and the relation of peak to mean daily flow. Use was also made of a detailed analysis made some years ago by the State Division of Engineering and Irrigation of concentrations and the relation of peak to mean daily flow during the flood of January, 1911.

The amount of the concentrated flood flow of the San Joaquin River below its confluence with the Tuolumne River was estimated by combining the flood flow of the San Joaquin River below the mouth of the Merced River with the flow of the Tuolumne River at the La Grange gaging station, with corrections for the relative time of flood travel from each of these latter points to the point of concentration below the mouth of the Tuolumne River, and for channel storage. In a similar manner, the concentrated flood flow of the San Joaquin River below its confluence with the Stanislaus River was estimated by combining the flood flow in the San Joaquin River below the mouth of the Tuolumne River with the flow in the Stanislaus River at Knights Ferry, with corrections for time of flood travel and channel storage.

Another point at which amounts of concentrated flood flows were estimated is the confluence of the San Joaquin and Sacramento rivers. In estimating the flow at this point, the concentrated flow in the San Joaquin River below the mouth of the Stanislaus River was combined with the flow from the Sacramento Valley as estimated during the preparation of a report* on the flood concentration in the valley, and the flows into the San Joaquin Delta from the Cosumnes, Mokelumne and Calaveras rivers. Allowance was made in each case for the time of travel from the point at which each of these flows was estimated to the confluence of the main rivers, and for channel storage.

Flood flows at the selected points of concentration, estimated as above described, were then analyzed to estimate the probable sizes of floods at the same points which may be expected to be exceeded at various intervals of time on the average. The method used was the same as that used for the same purpose for the foothill gaging stations. The curves so derived are shown on Plate LXXV, "Probable Frequency of Flood Flows at Points of Concentration on San Joaquin Valley Floor," and are in each case the right-hand curve for each station, designated "without reservoir control." Table 202 shows the estimated maximum flows that would occur with certain frequencies at the points of concentration.

TABLE 202

PROBABLE FREQUENCIES OF WINTER FLOOD FLOWS AT SELECTED POINTS OF CONCENTRATION ON LOWER SAN JOAQUIN VALLEY FLOOR

Without Reservoir Control

Stream and point of concentration	Probable maximum mean daily flow, in second-feet, exceeded on average of once in				
	10 years	25 years	50 years	100 years	250 years
San Joaquin River below confluence of San Joaquin and Merced rivers	42,000	53,000	62,000	69,500	79,500
San Joaquin River below confluence of San Joaquin and Tuolumne rivers	64,000	80,000	92,000	103,000	117,000
San Joaquin River below confluence of San Joaquin and Stanislaus rivers	86,000	104,000	118,000	133,000	154,000
San Joaquin and Sacramento rivers at confluence	490,000	592,000	680,000	780,000	925,000

* Bulletin No. 26, "Sacramento River Basin," Division of Water Resources, 1931.

31—80997

Methods of Flood Control.

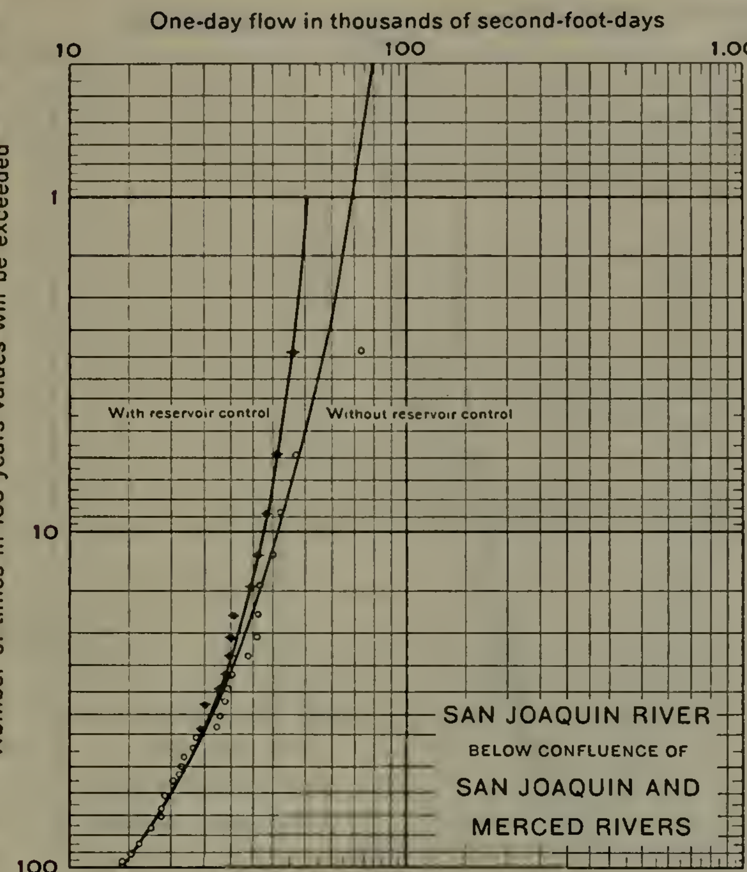
There are two general methods for controlling floods. One method is to convey the flood waters of the streams undiminished in volume past the area subject to overflow by means of leveed channels constructed either along the natural waterways, or, where the natural waterways are inadequate in capacity, through leveed by-passes. The other method is to reduce the flood flows by retention in surface reservoirs of flows in excess of the capacity of the natural waterways and to later release the water from these reservoirs at a rate which does not exceed the natural channel capacity.

The first method is the more common and is that used on the Mississippi River and in the Sacramento Valley. The only examples of the second method in California are the Los Angeles County flood control project and the city of Stockton project on the Calaveras River. The first method is usually the less costly. The second method, where the reservoirs are used for flood control purposes alone, is justified only where high property values make flood channels costly or undesirable and where close settlement and high values in the territory protected permit greater expenditures for this protection. In most instances, however, even with floods controlled by reservoirs, some leveed channels are required, so that control by this method generally resolves itself into a plan of reservoir control combined with levee systems. Sometimes this method of flood control is combined with the spreading of flood waters over absorptive areas to introduce these waters into the underground basin for storage. Where flood control by reservoirs can be combined successfully with conservation, the cost chargeable to flood control is thereby reduced.

Plans for Flood Control with Flows Uncontrolled by Reservoirs.

As previously stated, no comprehensive plan for the protection of overflow lands or for the control of floods in the San Joaquin Valley has been adopted. However, following the formulation of a general flood control plan for the Sacramento Valley, attention was turned to the preparation of a similar plan for the San Joaquin Valley and the California Debris Commission and the Department of Engineering of California, cooperating, made surveys and formulated a tentative flood control plan for the lower San Joaquin Valley and the San Joaquin Delta.

Upper San Joaquin Valley South of San Joaquin River—In the San Joaquin Valley south of the San Joaquin River, a large part of any inundation by floods would occur in the beds of Buena Vista and Tulare lakes. It is anticipated that during large floods Buena Vista Lake will be flooded, and the lands are reserved for this purpose. Water in excess of the amount which will flood the reservoir lands will flow northward toward Tulare Lake. Tulare Lake lands will also be flooded by water collecting in the bed of the lake and it is, therefore, the total volume of run-off into the lake that is important as a flood menace, and not the peak or mean daily stream flow. Waters from the Kern, Tule, Kaweah and Kings rivers now reach the lake bed. The area flooded is dependent upon the amounts of excess water in any one or series of years since physical conditions are such that the flood waters entering Tulare Lake, the lowest point in which is elevation 179 feet,



PROBABLE FREQUENCY
OF FLOOD FLOWS
AT
POINTS OF CONCENTRATION
ON
SAN JOAQUIN VALLEY FLOOR
WITH AND WITHOUT RESERVOIR CONTROL

Methods of Flood Control.

There are two general methods for controlling floods. One method is to convey the flood waters of the streams undiminished in volume past the area subject to overflow by means of leveed channels constructed either along the natural waterways, or, where the natural waterways are inadequate in capacity, through leveed by-passes. The other method is to reduce the flood flows by retention in surface reservoirs of flows in excess of the capacity of the natural waterways and to later release the water from these reservoirs at a rate which does not exceed the natural channel capacity.

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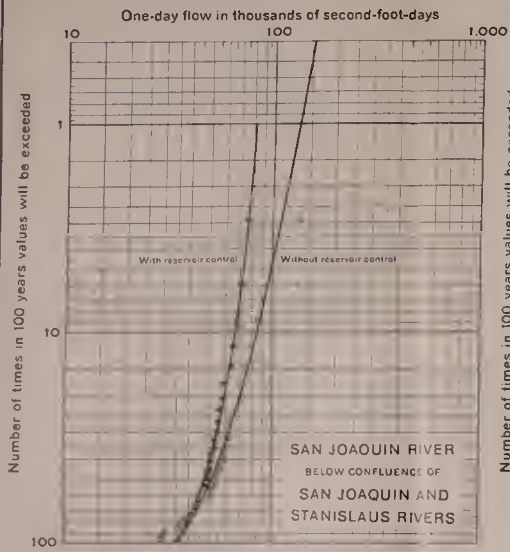
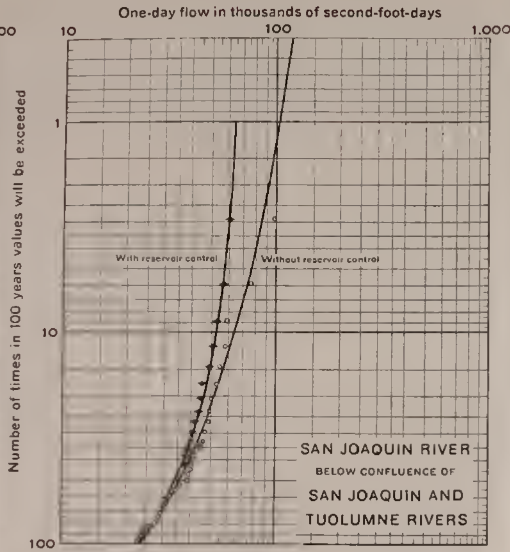
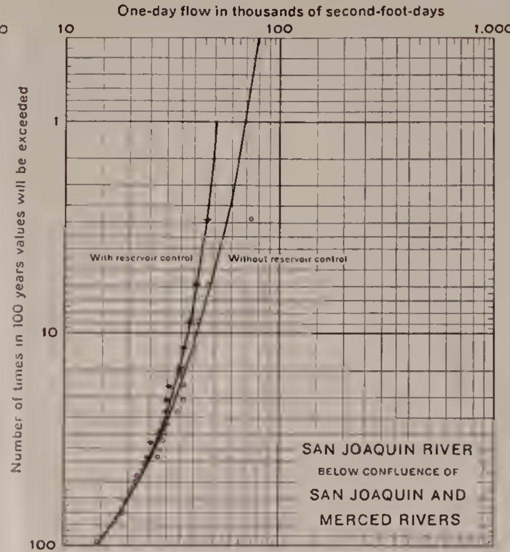
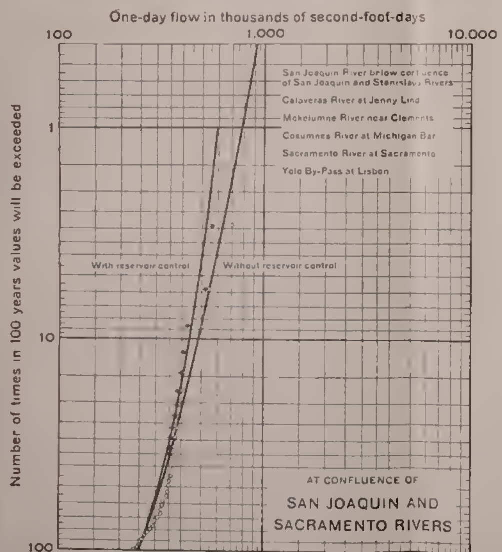
Upper San Joaquin Valley South of San Joaquin River—In the San Joaquin Valley south of the San Joaquin River, a large part of any inundation by floods would occur in the beds of Buena Vista and Tulare lakes. It is anticipated that during large floods Buena Vista Lake will be flooded, and the lands are reserved for this purpose. Water in excess of the amount which will flood the reservoir lands will flow northward toward Tulare Lake. Tulare Lake lands will also be flooded by water collecting in the bed of the lake and it is, therefore, the total volume of run-off into the lake that is important as a flood menace, and not the peak or mean daily stream flow. Waters from the Kern, Tule, Kaweah and Kings rivers now reach the lake bed. The area flooded is dependent upon the amounts of excess water in any one or series of years since physical conditions are such that the flood waters entering Tulare Lake, the lowest point in which is elevation 179 feet,









FLOWS AT EDGE OF VALLEY FLOOR
WITH RESERVOIR CONTROL

Exceeded once in 100 years on the average

SAN JOAQUIN RIVER BASIN

Kings River at Piedra	15,000 second-feet
San Joaquin River near Friant	15,000 second-feet
Merced River at Exchequer	25,000 second-feet
Tuolumne River near La Grange	15,000 second-feet
Stanislaus River at Knights Ferry	15 000 second-feet
Calaveras River at Jenny Lind	25,000 second-feet
Mokelumne River near Clements	10,000 second-feet
Dry Creek near Ione	5,000 second-feet
Cosumnes River at Michigan Bar	15,000 second-feet

SACRAMENTO RIVER BASIN

Sacramento River at Red Bluff	125,000 second-feet
Feather River at Oroville	100,000 second-feet
Yuba River at Smartsville	70,000 second-feet
Bear River at Van Trent	20,000 second-feet
American River at Fairoaks	100 000 second feet

PROBABLE FREQUENCY OF FLOOD FLOWS

AT

POINTS OF CONCENTRATION

ON

SAN JOAQUIN VALLEY FLOOR

WITH AND WITHOUT RESERVOIR CONTROL

must raise the lake surface to an elevation of 205 to 210 feet before they can escape northward into Fresno Slough and the San Joaquin River. Some of the levees in the lake bed may withstand such elevations but many are constructed to an elevation of not over 195 feet and many thousands of acres of land would be flooded by a lake level of 210 feet.

Under present plans for the reclamation of Tulare Lake lands, the north half of Township 22 South, Range 20 East, M.D.B. and M., is reserved for the storage of surplus waters, and for major floods, the south half of the township and the land south of the township to elevations of 192 to 195 feet would also be used. This gives storage capacities of 260,000 to 350,000 acre-feet before inundating additional lands. These storage capacities are insufficient to store all of the water which would reach the lake under present conditions of development in the tributary drainage area.

To relieve Tulare Lake of waters in excess of the capacity of the storage reservoir in the lake bed, two plans were proposed several years ago by A. D. Schindler, engineer for landowners in the lake bed. Under both plans, the surplus waters of Kings River would be diverted directly to Fresno Slough and the San Joaquin River. Under the first plan, the surplus waters from the Kern River area would be by-passed through a canal around the west side of the lake from a point near Harts Station to Summit Lake, and thence down Fresno Slough. Surplus water from the Kaweah and Tule rivers would be diverted southward through unimproved territory, combined with the Kern River water at Harts Station, and diverted northward around the lake in the by-pass canal. The capacity of the canal from Harts Station to Summit Lake would be 8500 second-feet with an emergency capacity of about 10,000 second-feet. The cost of this canal and one from the Kaweah and Tule rivers to Harts Station, together with diversion works on these rivers, was estimated by A. D. Schindler in 1917 to be about $2,200,000.

Under the second plan proposed, all excess waters which would reach Tulare Lake would be discharged into the reservoir in the lake bed and the reservoir would be vented northward by means of a deep cut through Summit Lake Ridge to Fresno Slough. The bottom of this cut or canal would be as low as the bottom of the lake and it would have a capacity of about 3200 second-feet. It was estimated by A. D. Schindler that this canal would have controlled flood waters to such an extent that no flooding would have occurred on lands surrounding the lake reservoir under such extreme conditions as existed in 1906 and 1916. The cost of this canal and appurtenant works was estimated by A. D. Schindler in 1917 to be $1,060,000. This estimate was revised to $1,200,000 by S. T. Harding in a report to the Tulare Lake Water Storage District in 1924.

Upper and Lower San Joaquin Valleys—Herndon to Mouth of Merced River—In the section of the valley from Herndon to the mouth of the Merced River, the flood plain is several miles in width and it is believed that in this section protection against both winter and summer floods could be provided, since only a small portion of the lands subject to inundation would be required for overflow channels. Several preliminary plans for protecting these lands from uncontrolled flows were laid out and preliminary estimates of cost were made some years ago by the State Division of Engineering and Irrigation. Two of these plans have recently been revised by the Division of Water Resources and preliminary estimates made of the costs of constructing the works.

Under one of these plans, a by-pass would be constructed from the San Joaquin River at a point in Section 30, Township 13 South, Range 16 East, M.D.B. and M., to the mouth of the Merced River. This by-pass would be about 3000 feet wide and have sufficient capacity to carry all flood waters in excess of 7000 second-feet, which would pass down the river channel. East side tributaries would enter the by-pass through leveed channels extending to high ground. Backwater levees would be constructed along both banks of the river and Salt Slough for a sufficient distance upstream from the mouth of the Merced River to prevent overflow. A diversion weir would be constructed across the San Joaquin River just below the head of the by-pass to divert flows in excess of the capacity of the river channel. From the south end of the weir, a single levee would be constructed along the contour of the country to intercept the flow of Fresno Slough and divert it to the head of the by-pass. The by-pass would have capacities increasing from 46,000 second-feet at the inlet to 82,000 second-feet at the Merced River. It is estimated that the cost of these works, including the incidental reconstruction of irrigation canals and roads and the care of drainage, would be about $7,850,000. The area protected would be about 280,000 acres and the cost per acre about $28.

Under the other plan proposed, there would be no by-pass and the uncontrolled flood flows would be confined to a flood channel following the course of the San Joaquin River. The east levee of this channel would extend up the right bank of the river to high ground about eleven miles above Mendota Dam, and the west levee would extend up the left bank of Fresno Slough to high ground. East side tributaries would enter this channel through rectified leveed channels with the levees extended to high ground. A system of intercepting canals would conduct the run-off from the small creeks and drains into the heads of these inlet channels. Drainage from the west side would be collected and stored in the many large slough channels back of the levees and admitted to the main channel through culverts after the passage of the flood. The flood channel would vary from one-quarter to one-half mile in width, the average width being nearer the former figure. It would have capacities starting with 53,000 second-feet near the mouth of Fresno Slough and increasing as tributary streams enter through side channels to about 90,000 second-feet at the mouth of the Merced River. The cost of these works, including the incidental reconstruction of irrigation canals, roads and bridges, is estimated to be about $8,250,000. About 297,000 acres of land would be protected, however, and the cost would be a little less than $28 per acre, which is practically the same cost as under the other plan of protection.

Lower San Joaquin Valley—Mouth of Merced River to Paradise Dam—A flood control plan to protect lands along the San Joaquin River from the Merced River to Paradise Dam from maximum uncontrolled winter flood flows was formulated some years ago by the State Division of Engineering and Irrigation. Under this plan, levees would be constructed on each side of the river at a sufficient distance from its banks to provide a channel having the following capacities:

	Second-feet
Mouth of Merced River to mouth of Tuolumne River	105,000
Mouth of Tuolumne River to mouth of Stanislaus River	138,000
Mouth of Stanislaus River to Paradise Dam	160,000

All of these flows may be expected less than once in 250 years on the average.

The channel required for a flood of such magnitude would average 2400 to 3000 feet in width and about 15 per cent of the gross area subject to inundation would be required for levee right of ways and the flowage channel. The cost of such a project has been estimated during this investigation to be about $5,900,000, and as previously stated, the project is not considered economically feasible.

Flood damages in this section of the valley have been caused to a large extent by summer floods which have inundated the bottom lands during the early part of the growing season. Protection against such floods would also provide protection against the smaller winter floods. Therefore, a plan for protection against summer floods has been considered all that is required at the present time and, pending the adoption of a comprehensive plan for flood control for the entire valley, it has been the policy of the State Reclamation Board to grant permits for levee construction along this section of the river on the basis of protection against summer floods.

A flood control plan to provide for maximum uncontrolled summer flood flows was also formulated some years ago by the State Division of Engineering and Irrigation. Under this plan, levees would be constructed on each side of the river, but at a less distance apart than for protection against winter floods. The flood flows for which channel capacity would be provided are approximately those of the summer flood of 1906, and are as follows:

	Second-feet
Mouth of Merced River to mouth of Tuolumne River	56,000
Mouth of Tuolumne River to mouth of Stanislaus River	70,000
Mouth of Stanislaus River to Paradise Dam	79,000

These summer flood flows correspond to winter flood flows which may be exceeded once in 33 years, once in 14 years, and once in seven years, on the average, respectively. The degree of protection against uncontrolled winter floods, therefore, would not be the same along the different sections of the stream.

With this plan for flood protection, the levees would average 1500 to 1800 feet apart and about 4700 acres less land would be required for levee right of ways and the flowage channel than with adequate protection against maximum winter floods. The cost of the project from the mouth of the Merced River to Paradise Dam has been estimated during this investigation to be about $3,500,000 or $2,400,000 less than the cost of a project for the same area with protection against maximum uncontrolled winter floods.

San Joaquin Delta—It has been stated in a foregoing section of this chapter that although practically all of the San Joaquin Delta lands are now leveed, they are not protected against major floods. Analyses made by the State Division of Engineering and Irrigation and the United States Army Engineers of the carrying capacity of the existing channels in the delta under present conditions, shows that from Paradise Dam to the head of Middle River the channels have a capacity of 60,000 second-feet and from the head of Middle River to the Atchison, Topeka and Santa Fe Railroad, they have a capacity of about 100,000 second-feet. Below the Santa Fe railroad more channel capacity exists, especially since the dredging of the Stockton Ship Canal. However, owing to the small capacity of the San Joaquin River main channel from the head of Middle River to its junction with the Ship Canal, the total flood carrying capacity of the lower channels does not become available to floods of the San Joaquin Valley until the vicinity of Venice Island is reached. It may be said, therefore, that the lands lying between Paradise Cut and Tom Paine Slough and between Paradise Cut and the San Joaquin and Middle rivers, and those lands east of the main San Joaquin River from Paradise Dam to and including the city of Stockton, comprising about 50,000 acres of reclaimed lands, have protection against a flood of only 60,000 second-feet discharge. Allowing for encroachment on the levee freeboard, it is possible that 70,000 second-feet might pass without breaking the levees and inundating the lands. The frequency curves for the San Joaquin River below its confluence with the Stanislaus River on Plate LXXV, show that a flow of 70,000 second-feet may occur, under conditions without reservoir control, on an average of 21 times in 100 years. For that portion of the delta lying west of the San Joaquin River and between the head of Middle River and Venice Island, it is estimated that reasonable protection is afforded by existing works against a flood of 100,000 second-feet. Reference to the frequency curves on Plate LXXV shows that a flow of this size may be exceeded on an average of about five times in 100 years.

Several plans for protecting the delta lands against winter floods uncontrolled by reservoirs were formulated several years ago by the United States Army Engineers, the State Reclamation Board, and the State Division of Engineering and Irrigation, cooperating. One of these plans appears to be as effective as any of the others and considerably less expensive. In general, this plan calls for a by-pass and the enlargement of existing channels from Paradise Dam to the vicinity of the Atchison, Topeka and Santa Fe Railroad. North of the railroad, the overflow channels of Middle and Old River would be kept clear of trees and brush and the existing channels, including the Stockton Ship Canal, would carry the flood waters to the lower San Joaquin River through which they would pass to Suisun Bay. Some channel improvement and raising of levees along several of the existing channels would be necessary. The by-pass would follow Paradise Cut with a width of about 2500 feet. It would then cross Union Island, where its width would be 1050 feet, and follow Middle River, with a width of about 1800 feet, to the Santa Fe railroad. The system was designed for a flood carrying capacity of 175,000 second-feet at Paradise Dam with increased quantities below the mouths of the Calaveras and Mokelumne rivers. With such a plan, however, flood plane elevations in the channels north of the Santa Fe railroad would range from about twelve feet,

U. S. Army Engineer datum, near the mouth of Dutch Slough, to fifteen to seventeen feet near the Santa Fe railroad. It has been stated* by G. A. Atherton, general manager of the California Delta Farms, Inc., that in his opinion elevation 13.3 feet, United States Engineer datum, would be a reasonable elevation at which the levees in the lower delta could be maintained permanently. It would appear, therefore, that the flood plane elevations of the proposed flood control plan for the delta would cause the overtopping or breaking of levees in the lower delta. It was roughly estimated by the Army Engineers at the time this plan was formulated that the necessary works, including the lengthening of Paradise Dam, would cost about $10,000,000.

Since the estimated flood flow at Paradise Dam during a summer flood similar to that of 1906 is 79,000 second-feet and the capacity of the San Joaquin River and Paradise Cut below that point is only 60,000 to 70,000 second-feet, some flooding by levee breaks between Paradise Dam and the head of Middle River would probably occur. Protection from such breaks could be provided by improving the channel of Paradise Cut, or that of the San Joaquin River above Middle River, to give greater capacity. Below the head of Middle River the present capacity of 100,000 second-feet would be sufficient. No cost for such improvement has been estimated, but it would not be a large amount.

Control of Floods by Reservoirs.

The control of floods by reservoirs has been a subject of intensive study. It has been believed by some persons that any reservoir constructed for power or irrigation purposes will diminish flood flows. Reservoirs utilized for these purposes alone, however, may be allowed to fill as rapidly as water is available and remain full until after the flood season has passed. They, therefore, are apt to have no reserve space, or only a small amount of space, available for controlling floods when they occur, and dependence can not be placed upon them for this purpose. On the other hand, reservoirs constructed and operated for flood control purposes alone will usually make the cost of protection by this means greater than if it were obtained by leveed channels and by-passes. In such reservoirs, the entire space is dedicated to flood control and after the passage of a flood the reservoir is emptied and held empty in anticipation of a succeeding flood.

The control of floods by reservoirs was considered in 1910 by the California Debris Commission at the time it was formulating its plan for flood control in the Sacramento Valley. It, however, investigated the effect of reservoirs which were relatively small compared with the major reservoir units of the State Water Plan. The sites also were located at points well above the valley floor and controlled only a small portion of the drainage area. Since the reservoir capacity was small, the flood controlled was only a small portion of that at the valley floor line, and the reservoirs were to be utilized only for flood control purposes, it was the conclusion of the Debris Commission that partial control by reservoirs was not economical and this feature was not

* Bulletin No. 22, "Report on Salt Water Barrier," Division of Water Resources, 1929, page 46.

included in the plan. It did include in its report,* the following statement:

> "While favoring the use of reservoirs as far as possible, and considering that one of the advantages of the project herein proposed is that it lends itself to future storage possibilities, the Commission believes that it is not economical to construct reservoirs for flood control, but that such construction should be deferred until these reservoirs prove desirable for power and irrigation purposes."

In the studies of the control of floods by reservoirs by this office, particular attention has been given to the coordination of flood control with conservation in the utilization of reservoirs and a report** was rendered on this subject. It is demonstrated in that report that by utilizing varying amounts of space in a reservoir, guided by the times of occurrence of floods and the preceding climatological conditions, a substantial degree of flood control can be obtained on the larger streams of California without impairment of the conservation value of major reservoirs on those streams.

Utilization of Reservoirs of State Water Plan for Flood Control.

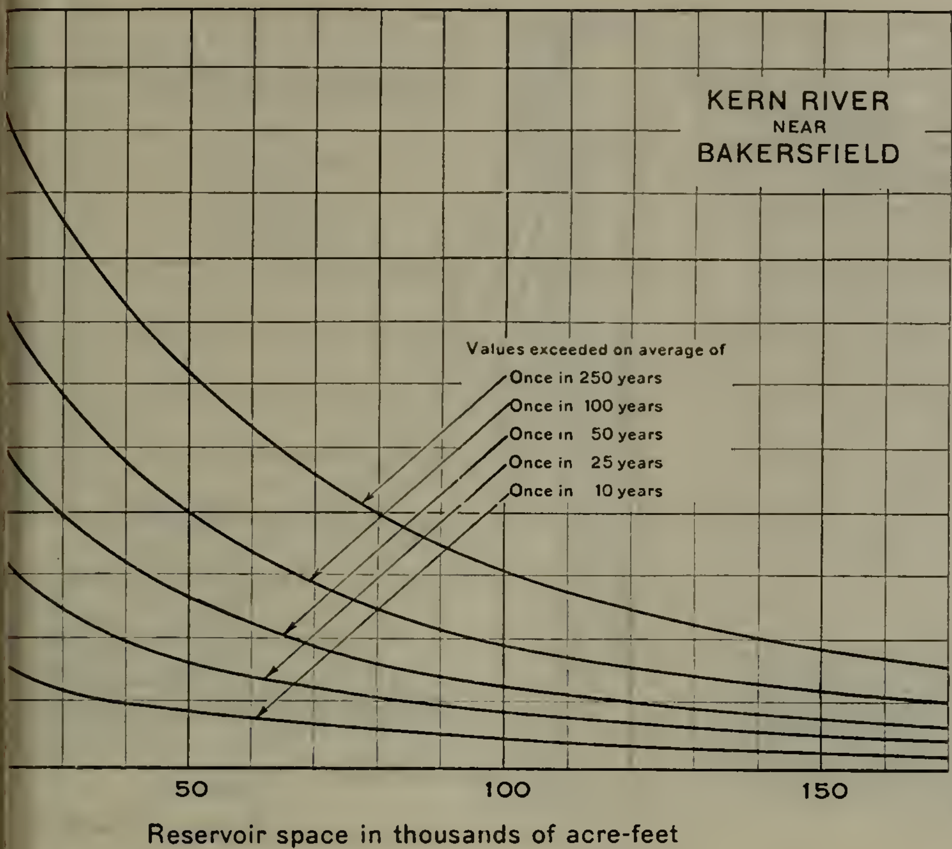
The major reservoir units of the State Water Plan in the San Joaquin River Basin would be located near the line of the valley floor, and therefore offer favorable opportunities for the reduction of flood flows on the major streams of the basin at the points where they would discharge onto the valley floor. This reduction would increase the degree of protection afforded by the works already constructed or permit lower levees and smaller channels in the portions of the valley not yet protected. To obtain the greatest flood control value, the reservoirs would be operated for this purpose as one of their primary functions. If not operated specifically for flood control, they might absorb many of the medium and small floods but would fail to control floods in years of large run-off since the reservoir would probably be filled or have insufficient reserve space in such years.

The volumes of flood discharge during winter floods at the foothill gaging stations, as indicated by the frequency curves shown on Plate LXXIV, and at points of concentration below stream confluences on the valley floor, as indicated by the right-hand curves on Plate LXXV, are those that may be expected to occur under natural conditions with no artificial interference other than the confinement of flood flows to leveed channels across the valley floor areas. To control these flows to smaller amounts, the flood waters could be stored in major reservoir units of the State Water Plan and released at a predetermined rate. The amounts of reservoir space required in the vicinity of each foothill gaging station to reduce floods at that point to certain controlled flows, and also the frequency with which these controlled flows may be exceeded with the space reserved for this control, were estimated from studies made for that purpose.

The amounts of reservoir space which would be exceeded at certain frequencies in controlling the winter floods at each of the gaging stations to various controlled flows are shown by the curves on Plate LXXVI, "Reservoir Space Required to Control Floods on Major Streams of San

* House Document No. 81, 62d Congress, First Session.

** Bulletin No. 14, "The Control of Floods by Reservoirs," Division of Engineering and Irrigation, 1928.



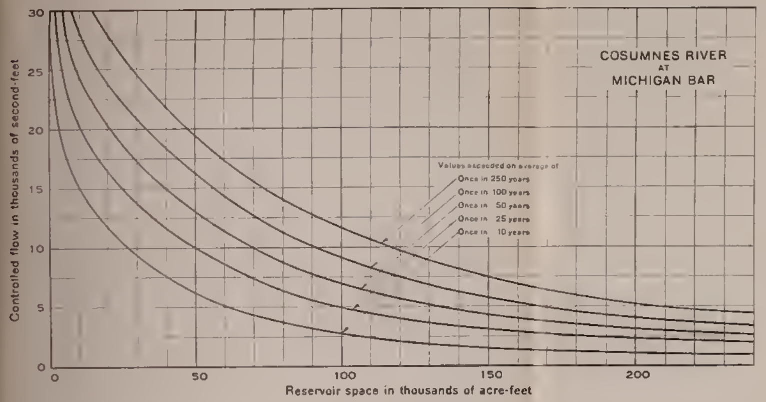
ESERVOIR SPACE REQUIRED TO CONTROL FLOODS

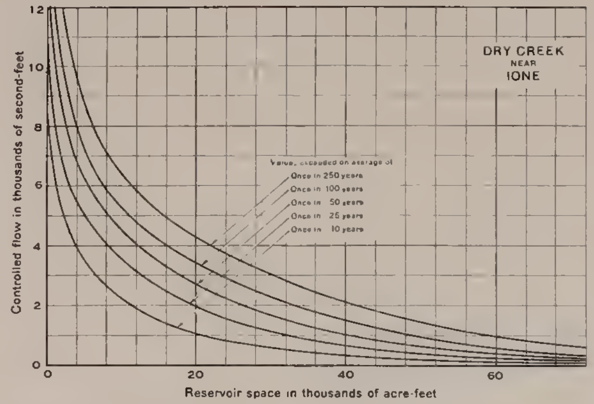
ON

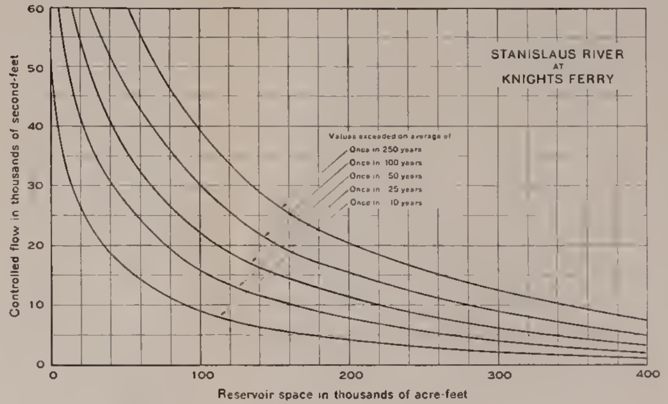
MAJOR STREAMS

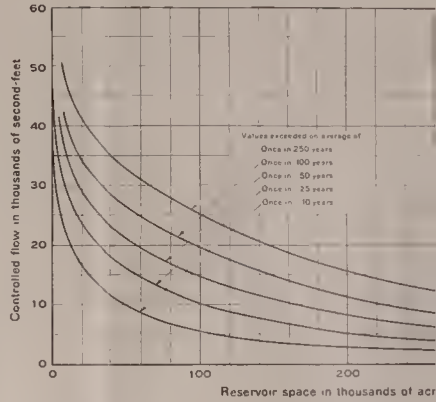
OF

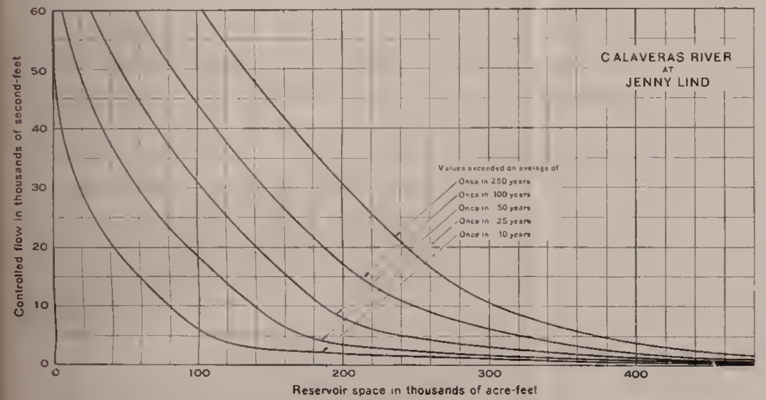
SAN JOAQUIN RIVER BASIN

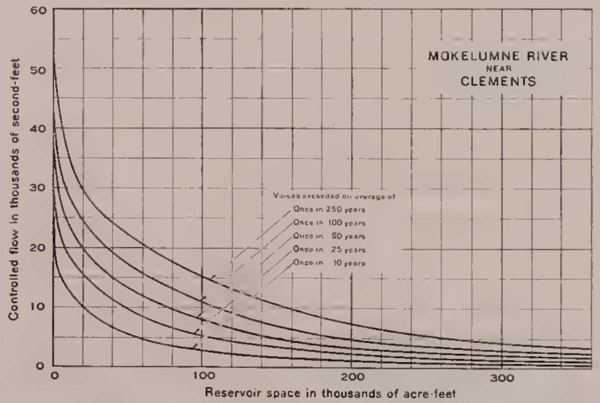

COSUMNES RIVER AT MICHIGAN BAR
Values exceeded on average of
Once in 250 years
Once in 100 years
Once in 50 years
Once in 25 years
Once in 10 years
Controlled flow in thousands of second-feet
Reservoir space in thousands of acre-feet

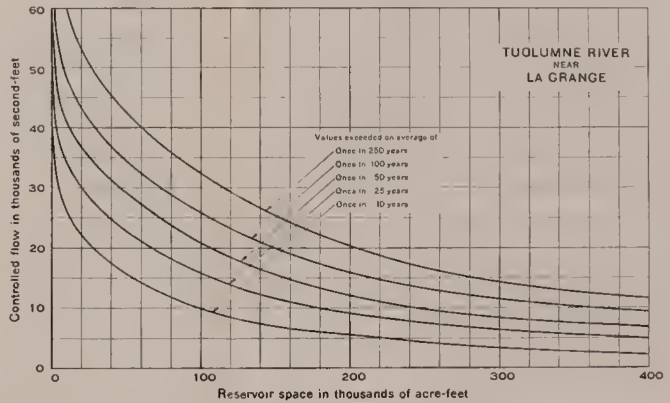

DRY CREEK NEAR IONE
Values exceeded on average of
Once in 250 years
Once in 100 years
Once in 50 years
Once in 25 years
Once in 10 years
Controlled flow in thousands of second-feet
Reservoir space in thousands of acre-feet

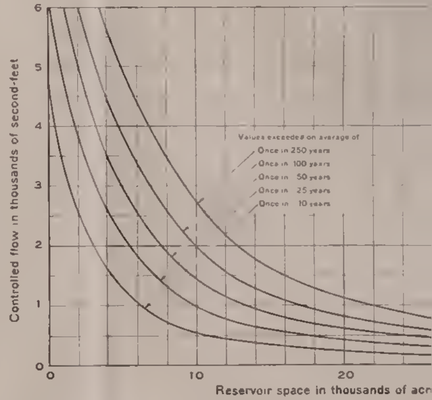

STANISLAUS RIVER AT KNIGHTS FERRY
Values exceeded on average of
Once in 250 years
Once in 100 years
Once in 50 years
Once in 25 years
Once in 10 years
Controlled flow in thousands of second-feet
Reservoir space in thousands of acre-feet

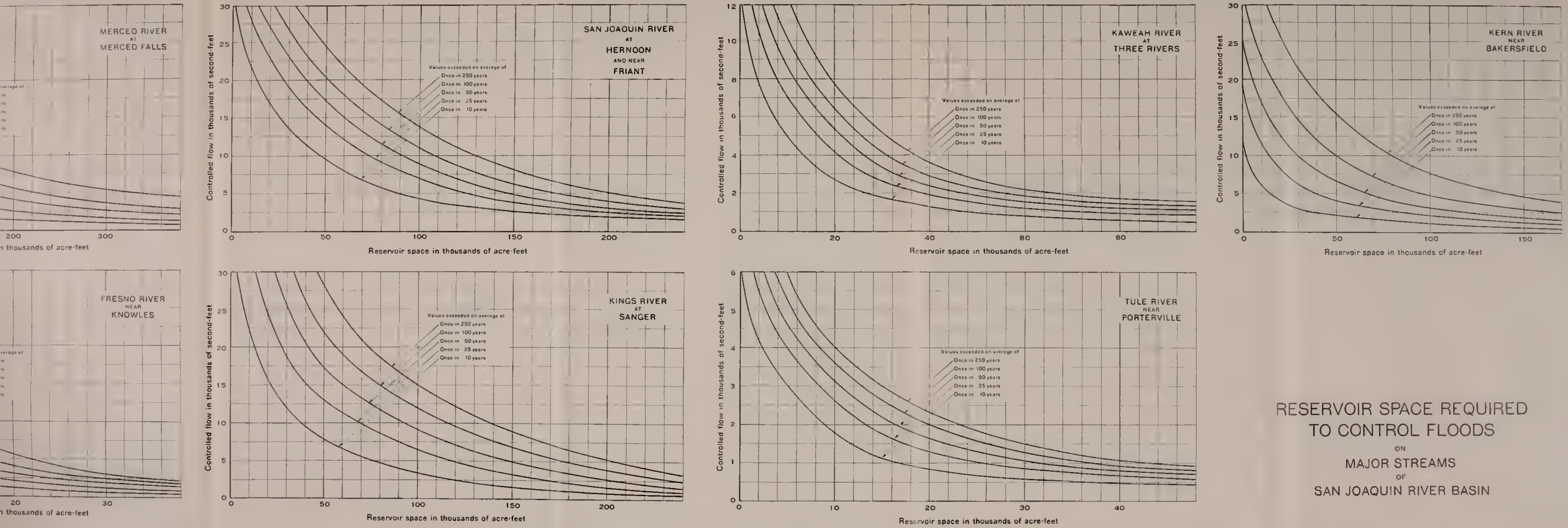

Values exceeded on average of
Once in 250 years
Once in 100 years
Once in 50 years
Once in 25 years
Once in 10 years
Controlled flow in thousands of second-feet


CALAVERAS RIVER AT JENNY LIND
Values exceeded on average of
Once in 250 years
Once in 100 years
Once in 50 years
Once in 25 years
Once in 10 years
Controlled flow in thousands of second-feet
Reservoir space in thousands of acre-feet


MOKELUMNE RIVER NEAR CLEMENTS
Values exceeded on average of
Once in 250 years
Once in 100 years
Once in 50 years
Once in 25 years
Once in 10 years
Controlled flow in thousands of second-feet
Reservoir space in thousands of acre-feet


TUOLUMNE RIVER NEAR LA GRANGE
Values exceeded on average of
Once in 250 years
Once in 100 years
Once in 50 years
Once in 25 years
Once in 10 years
Controlled flow in thousands of second-feet
Reservoir space in thousands of acre-feet


Values exceeded on average of
Once in 250 years
Once in 100 years
Once in 50 years
Once in 25 years
Once in 10 years
Controlled flow in thousands of second-feet



RESERVOIR SPACE REQUIRED
TO CONTROL FLOODS
ON
MAJOR STREAMS
OF
SAN JOAQUIN RIVER BASIN

Joaquin River Basin." The data from which these curves were developed were taken from Tables 187 to 199, inclusive. These tables show the probable winter or rain water flood flows and run-offs, which would be exceeded at selected intervals of time, on the average, in the major streams of the San Joaquin River basin, as indicated by the frequency curves on Plate LXXIV. The method by which the reservoir space curves were developed was the same for each stream and for each selected frequency. It is given in the following description of the development of the curve of reservoir space which would be exceeded once in 100 years on the average in controlling the Tuolumne River. This analysis has been based on the data presented in Table 194, columns 8 and 9, in which are listed the total run-offs in acre-feet and the mean flows in second-feet for periods one to ten days in length. In this table the probable volume of flow for a one-day period is 106,100 acre-feet and the mean flow for that period is 53,500 second-feet. If the flow were all stored so that there would be none below the dam, the amount of reservoir space in use at the end of the day would be 106,100 acre-feet. If a flow of 53,500 second-feet below the dam were permissible, no reservoir space would be in use at the end of the day.

Points representing these two pairs of flow and reservoir space values were plotted on a graph on which the horizontal scale represented reservoir space in acre-feet and the vertical scale controlled flow in second-feet, and a straight line connecting the two points was drawn. This line was the locus of all points representing the reservoir space in use at the end of the one-day period for any selected controlled flow. Similar lines were developed for the 2, 3, 4, 6, 8 and 10-day periods for which data were available. An inspection of Table 194, columns 8 and 9, shows that the one-day period has the largest mean flow in second-feet of any period studied, and the smallest total run-off in acre-feet, while the ten-day period has the smallest mean flow in second-feet and the largest total run-off in acre-feet. When drawn on the graph, therefore, the lines representing the relation between controlled flow and reservoir space for each time period formed a grid of intersecting lines bounded on the right by a broken line extending from the point representing a controlled flow of 53,500 second-feet and zero reservoir space along the line for a one-day period to its intersection with the two-day period line, along that line to its intersection with the three-day period line, and so on along each period line in turn to the intersection of the ten-day period line with the line of zero controlled flow at a reservoir space of 509,800 acre-feet. Had the increment of time of each period been infinitely small, each segment of this broken line would have been infinitely short and the line would have been a curve. This curve, however, would intersect the line of zero storage at a controlled flow value equal to the crestflow of the flood and would approach a controlled flow value equal to the mean daily flow of the river at infinity. Since the accuracy of the stream flow data available does not justify further refinement, the curve shown on Plate LXXVI for the once in 100 year frequency was drawn tangent to each segment of the broken line and the two ends were located as described in the last preceding sentence.

The amounts of reservoir space required to control floods to certain flows exceeded with various frequencies, as obtained from the curves on Plate LXXVI, are given in Table 203.

TABLE 203

RESERVOIR SPACE REQUIRED TO CONTROL WINTER FLOODS ON MAJOR STREAMS OF SAN JOAQUIN RIVER BASIN

Stream and location of point of control	Controlled flow, in second-feet	Reservoir space, in acre-feet, required to prevent controlled flow being exceeded on average of more than once in:				
		10 years	25 years	50 years	100 years	250 years
Kern River near Bakersfield	7,500	5,900	23,000	43,200	67,000	101,500
	10,000	1,700	14,000	29,100	49,500	79,100
	15,000	0	4,000	13,800	28,900	51,800
	20,000	0	0	5,300	15,500	31,000
Tule River near Porterville*	2,000	8,900	13,300	16,400	19,800	23,000
	4,000	2,400	4,900	6,700	8,500	10,100
	6,000	200	1,400	2,500	3,700	4,900
Kaweah River at Three Rivers	2,000	26,200	37,100	46,600	55,000	65,700
	6,000	7,300	13,000	17,400	21,500	26,200
	12,000	400	2,400	4,600	6,900	10,500
Kings River at Piedra	5,000	76,500	118,500	148,500	178,000	204,500
	15,000	21,500	41,500	60,000	80,000	100,000
	25,000	7,500	19,500	31,500	42,500	57,500
San Joaquin River near Friant	5,000	89,000	125,000	117,000	172,500	203,000
	15,000	26,000	45,000	60,000	75,000	92,000
	25,000	5,500	15,500	25,000	34,500	48,000
Fresno River near Knowles	750	7,800	12,400	16,700	21,400	26,700
	3,000	1,400	3,200	5,000	6,900	9,200
	4,500	100	1,300	2,600	4,000	5,800
Merced River at Merced Falls	10,000	50,000	101,000	162,000	223,000	327,000
	20,000	12,500	32,000	57,000	95,000	146,000
	25,000	6,000	16,500	33,000	59,000	100,000
	30,000	2,500	8,500	18,000	34,000	66,500
Tuolumne River near La Grange	15,000	56,000	108,500	156,000	214,000	284,000
	20,000	29,000	68,000	107,000	149,500	204,000
	30,000	5,000	21,000	46,500	73,500	116,000
	40,000	500	3,500	12,500	30,000	61,500
Stanislaus River at Knights Ferry	10,000	90,000	162,000	221,000	279,000	315,000
	15,000	56,000	106,000	153,000	201,000	262,000
	30,000	14,000	41,500	68,000	101,000	136,000
	40,000	5,500	22,000	41,500	68,000	98,000
Calaveras River at Jenny Lind	7,500	91,500	153,000	205,000	280,000	335,000
	15,000	59,000	115,000	162,000	211,000	269,000
	25,000	29,000	75,000	122,000	165,000	223,000
	45,000	3,000	25,500	59,500	97,500	150,000
Mokelumne River near Clements	5,000	56,000	101,000	147,000	192,000	264,000
	10,000	21,000	48,500	78,000	110,000	157,000
	20,000	1,500	8,000	20,000	36,000	61,000
	30,000	0	500	3,500	8,000	19,500
Dry Creek near Ione	2,000	11,500	19,800	26,300	33,200	41,500
	4,000	4,100	8,300	12,400	16,300	22,000
	5,000	2,500	5,200	8,400	11,300	15,900
	6,000	1,500	3,200	5,600	7,800	11,400
Cosumnes River at Michigan Bar	5,000	61,200	98,000	133,000	166,000	209,000
	15,000	10,500	25,100	39,800	56,300	73,300
	25,000	1,000	4,600	9,400	17,200	28,800

*Figures apply to main fork of Tule River only. For the combined flows of the main river and the South Fork (as measured at Success), the reservoir space required to obtain controlled flows, exceeded not more than once on the average in 100 years, of 2,000, 4,000, and 6,000 second-feet would be 33,800, 17,200 and 8,600 acre-feet respectively.

In the San Joaquin River Basin, it will be necessary to control summer floods as well as winter floods if the desired controlled flow is less than the maximum flow during a summer flood less diversions for irrigation and absorption into the underground basins. Records are now being obtained each year of the water content of snow packs in the Sierra Nevada on various dates and of stream flows throughout the year. It should be possible, therefore, to establish a fairly definite relation between snow pack and stream flow and from this to predict summer flows. With such predicted flows on any stream, the amount of reservoir space required to control these flows to a fixed amount can be determined and reserved as long as it may be required. After giving due consideration to the type, size and character of floods in the San Joaquin River Basin, the following general rule has been formulated for use in operating the reservoirs of the State Water Plan in that basin for flood control:

> Some space shall be held in reserve for flood control from November 1st to May 1st whenever the total precipitation up to any date in that period is more than 50 per cent of the normal precipitation to the same date. The flood control reserve shall be increased at a uniform rate from zero on November 1st to the maximum amount on December 1st. The maximum space shall be held in reserve from December 1st to April 1st, except for the decrease during the control of flood flows, and then decreased at a uniform rate to zero on May 1st, except as follows: When snow surveys indicate that flows after April 1st will exceed the sum of the controlled flow and releases from the reservoir for irrigation and underground storage, space for flood control shall be reserved during such periods and in such amounts as to obtain the desired controlled flow.

This rule would give satisfactory operation of reservoirs on streams rising at high elevations since these reservoirs would have snow water run-off after April 1st to fill the space reserved for flood control. However, to obtain satisfactory water supplies for irrigation from reservoirs dependent entirely or largely upon rain water run-off for a water supply, it is probable that the amount of reserve space should and would be varied with climatological conditions affecting run-off throughout the year.

There are given in Table 204 for each reservoir in the San Joaquin River Basin in which it is proposed to reserve space for flood control, the maximum amount of space to be reserved, the controlled flow just below the reservoir, and the frequency with which the controlled flow would be exceeded with the space reserved. These data are based on studies of winter floods. Other studies, however, show that with the same or a smaller amount of space reserved in each reservoir for controlling summer floods, the controlled flow during such floods would not exceed the controlled flow shown in the table plus diversions near

TABLE 204

SPACE TO BE RESERVED IN RESERVOIRS OF STATE WATER PLAN FOR CONTROLLING FLOODS TO CERTAIN SPECIFIED AMOUNTS

Reservoir	Stream	Point of control	Controlled flow, in second-feet	Maximum space reserved, in acre-feet	Number of times controlled flow will be exceeded, on the average
Isabella	Kern River	Near Bakersfield	7,500	67,000	Once in 100 years
Pine Flat	Kings River	Piedra	15,000	80,000	Once in 100 years
Friant	San Joaquin River	Near Friant	15,000	75,000	Once in 100 years
Exchequer	Merced River	Merced Falls	25,000	59,000	Once in 100 years
Don Pedro	Tuolumne River	Near La Grange	15,000	214,000	Once in 100 years
Melones	Stanislaus River	Knights Ferry	15,000	204,000	Once in 100 years
Valley Springs	Calaveras River	Jenny Lind	25,000	165,000	Once in 100 years
Pardee	Mokelumne River	Near Clements	10,000	[1]0	Once in 100 years
Ione	Dry Creek	Near Ione	5,000	[1]121,000	Once in 100 years
Nashville	Cosumnes River	Michigan Bar	15,000	56,000	Once in 100 years

[1] Floods which would cause flows in excess of the controlled flow of 10,000 second-feet in the Mokelumne River at Clements would be diverted from the Pardee Reresvoir to Dry Creek by the Jackson Creek spillway and the water stored in Ione reservoir.

the reservoir for irrigation and underground storage. A channel having sufficient capacity to carry controlled winter flows below these points of diversion, therefore, would also have sufficient capacity to carry controlled summer floods.

Assuming that the reservoirs listed in Table 204 had been constructed and operated for flood control during the period of stream flow record in the San Joaquin River Basin and that winter floods had been controlled to the amounts shown in the table, estimates were made of the winter flood flows at the points of concentration just below the confluences of the San Joaquin River with the Merced, Tuolumne, Stanislaus and Sacramento rivers. These estimates were made in the same manner as in the previous studies of concentrated flows except that controlled flows were used instead of the uncontrolled ones. For the station at the confluence of the San Joaquin and Sacramento rivers, the concentration values are affected by the contributions from the Sacramento River and were computed by adding to the estimated concentrations of the Sacramento River at Sacramento and the Yolo By-pass at Lisbon, with reservoir control,* the estimated controlled flows in the San Joaquin River below its confluence with the Stanislaus River and the controlled flows from the Calaveras River at Jenny Lind, Mokelumne River near Clements, and Cosumnes River at Michigan Bar.

With the values of concentrated flows thus obtained, frequency curves were drawn in the same manner as previously described for the foothill gaging stations. These curves are shown on Plate LXXV and are in each case the left-hand curve for the station, designated "with reservoir control." The amounts of flow at the four points of concentration that would be exceeded with certain frequencies are shown in Table 205.

TABLE 205

PROBABLE FREQUENCIES OF WINTER FLOOD FLOWS AT SELECTED POINTS OF CONCENTRATION ON LOWER SAN JOAQUIN VALLEY FLOOR

With Reservoir Control

Stream and point of concentration	Probable maximum mean daily flow, in second-feet, exceeded on average of once in:			
	10 years	25 years	50 years	100 years
San Joaquin River below confluence of San Joaquin and Merced rivers	37,500	44,000	48,000	51,000
San Joaquin River below confluence of San Joaquin and Tuolumne rivers	52,500	58,500	62,000	64,000
San Joaquin River below confluence of San Joaquin and Stanislaus rivers	67,000	74,500	78,000	82,000
San Joaquin and Sacramento rivers at confluence	435,000	505,000	550,000	595,000

In Table 206, comparisons are made for four frequencies of occurrence, of the sizes of floods which would concentrate at the four valley floor points without and with reservoir control.

Flood Control Benefits from Reservoirs of State Water Plan.

Since the degree of protection afforded by levees in some parts of the San Joaquin Valley is difficult to determine, comparison of degrees of protection without and with flood control by reservoirs in all parts

* Bulletin No. 26, "Sacramento River Basin," Division of Water Resources, 1931, page 129.

TABLE 206

COMPARISON OF WINTER FLOOD FLOWS AT SELECTED POINTS OF CONCENTRATION ON LOWER SAN JOAQUIN VALLEY FLOOR

Without and With Reservoir Control

Frequency with which floods may be exceeded—times in 100 years on the average	Probable maximum mean daily flow, in second-feet, in San Joaquin River below confluence of San Joaquin River and:							
	Merced River		Tuolumne River		Stanislaus River		Sacramento River	
	Without reservoir control	With reservoir control[1]	Without reservoir control	With reservoir control[1]	Without reservoir control	With reservoir control[1]	Without reservoir control	With reservoir control[2]
1	69,500	51,000	103,000	64,000	133,000	82,000	780,000	595,000
2	62,000	48,000	92,000	62,000	118,000	78,000	680,000	550,000
4	53,000	44,000	80,000	58,500	104,000	74,500	592,000	505,000
10	42,000	37,500	64.000	52,500	86,000	67,000	490,000	435.000

[1] With flows controlled to amounts shown in Table 204.

[2] With flows in San Joaquin Valley controlled to amounts shown in Table 204 and the following controlled flows in the Sacramento Valley: Sacramento River at Red Bluff, 125,000 second-feet; Feather River at Oroville, 100,000 second-feet; Yuba River at Smartsville, 70,000 second-feet; Bear River at Van Trent, 20,000 second-feet, and American River at Fair Oaks, 100,000 second-feet.

has not been attempted. It is possible, however, to estimate some of the savings which may be effected in protecting the land in some parts of the valley if flood control by reservoirs is provided, and the increased degree of protection afforded by present works in other parts.

Upper San Joaquin Valley South of San Joaquin River—Present conditions in the San Joaquin Valley south of the San Joaquin River and plans for protecting the lands from floods uncontrolled by reservoirs have been described in earlier parts of this chapter. It was shown that the waters of the Kern, Tule and Kaweah rivers which are not used for irrigation or underground storage, and those of the Kings River which are not used for the same purpose or do not flow northward to Fresno Slough, reach the bed of Tulare Lake. It was also shown that if these waters reach the lake in sufficient quantities, some lands in the lake bed will be inundated, although they now have levee protection.

The construction of the reservoirs of the State Water Plan and their utilization for conservation purposes under a condition of ultimate development would materially benefit the lands in Tulare Lake by reducing the amounts of water reaching the lake. With the reservoirs operated for conservation purposes alone, however, more water would reach the lake in a wet year than could be cared for by the reservoir in the bed of the lake and flooding of other lands adjacent to the reservoir would occur. To prevent this, the by-pass canal around the west side of the lake or the cut from Tulare Lake reservoir to Fresno Slough, previously described, would probably be required although the capacity of either channel would probably be less than under present conditions without any storage reservoirs.

It is proposed in the operation of the State Water Plan, however, to use the Isabella and Pine Flat reservoirs for conservation and flood control and the Pleasant Valley reservoir for conservation only. The utilization of 67,000 acre-feet of storage space in the Isabella Reservoir for flood control would reduce winter floods in the Kern River near Bakersfield to 7500 second-feet exceeded once in 100 years on the average. This flow could be confined to the present natural and leveed channels, and canals below Bakersfield, without damage to adjacent lands. During summer floods it is proposed to control the flows to 9000 second-feet at the reservoir since 1500 second-feet would be diverted into the Kern River canal of the State Water Plan at a point near the mouth of Kern River Canyon. Since summer flows of record have exceeded 9000 second-feet by only small amounts and for relatively short periods, it is probable that only a small portion of the 67,000 acre-feet of reservoir space will ever be required for the control of summer floods.

For the control of floods on the Kings River, it is proposed to utilize 80,000 acre-feet of space in the Pine Flat reservoir. With this reserve space, winter floods could be controlled to 15,000 second-feet exceeded once in 100 years on the average, through the Kings River Delta. This flow would be carried through existing channels and, if desired, could be diverted northward into the San Joaquin River through Fresno Slough. In any case, 10,000 second-feet of this flow would have to be diverted to Fresno Slough, unless some water is diverted for irrigation or underground storage uses, because the channel leading to Tulare Lake has a capacity of only 5000 second-feet. During summer floods, the flow from the reservoir would be controlled to 15,000 second-feet plus the amounts of water which could be diverted through canals taking water out of Kings River. The maximum capacity of these canals is about 10,000 second-feet and all or nearly all of this capacity could be used during the passage of the peak flow of a summer flood. The controlled flow below all diversions would not exceed 15,000 second-feet. Since records of summer floods indicate that flows in excess of 25,000 second-feet will occur infrequently and for only a short time, it is probable that the reserve storage space required to control such floods will be only a small portion of that required for winter floods.

In order to determine the effect of the operation of the State Water Plan on flood conditions in the upper San Joaquin Valley, and especially in Tulare Lake, a study was made carrying the operation through several years. In this study, it was assumed that all works of the plan were constructed and in full operation to supply water for irrigation and absorption into the underground basins as described in Chapter VII, and that the Isabella and Pine Flat reservoirs were operated to control winter and summer floods as described in the foregoing paragraphs. It was further assumed that surplus Kern River water would have been stored in Buena Vista Lake until both the irrigation reservoir and the reserve space were filled and that water spilled from the lake would have flowed northward to Tulare Lake, which it would have reached undiminished in quantity. It is likely, however, that a considerable portion of this water would be used before reaching Tulare Lake and the amount of filling of the lake would not be as great as estimated.

Tulare Lake was practically empty in 1905 and would undoubtedly have been dry under conditions of ultimate development in the upper San Joaquin Valley. The study was therefore started with this year, and was carried through 1929. This period includes several winter floods of major importance and the summer flood of 1906 which was the largest summer flood of record. In the study, 5000 second-feet of the controlled flow of the Kings River was diverted to Tulare Lake during winter floods but all of the residual 15,000 second-feet of controlled flow was diverted to Fresno Slough and the San Joaquin River during summer floods.

Under these conditions, the 209,000 acre-feet of capacity in Buena Vista Lake would have been fully utilized in 1906 and 1916 only. In 1906, 8700 acre-feet of water would have been spilled from the lake and 484,000 acre-feet would have spilled in 1916. This spill water was assumed to have reached Tulare Lake undiminished in quantity. After receiving this spill water from Buena Vista Lake, Tulare Lake would have filled to a maximum stage of 175,000 acre-feet in 1906 and to a stage of 532,000 acre-feet in 1916. These are the only two years in which the capacity of 140,000 acre-feet below elevation 192, or a level three feet below the tops of the surrounding levees, in the reservoir in the north half of Township 22 South, Range 20 East, M.D.B. and M., would have been exceeded. The surplus water in 1906 would not have exceeded the capacity of the auxiliary reservoir in the south half of the same township. The large amount of water reaching the lake in

1916, however, would have exceeded the 350,000 acre-foot capacity of the main and auxiliary reservoirs below elevation 195, the level of the tops of the surrounding levees, and at least two adjacent reclaimed areas, with an area of 13,700 acres, would have been required. Even with these areas flooded, the water would have stood at elevation 194.5 or almost to the tops of most of the levees in the vicinity. However, since this critical condition in Tulare Lake was caused mainly by Kern River water, considerable improvement would have resulted from spreading part of this water on the area between Buena Vista and Tulare lakes.

In controlling the summer floods which occurred during the period studied, the maximum reserve space required in the Isabella reservoir would have been 4500 acre-feet and the maximum space required in the Pine Flat reservoir would have been 5000 acre-feet. During most of the winter floods, the reservoirs would not have filled to flood control stage until well after the peak flows had passed and it would never have been necessary to release the full controlled flow during such floods. During some of the larger summer floods, however, the full controlled flow on the Kern River would have reached Buena Vista Lake for a considerable period and the 15,000 second-foot flow from Kings River would have flowed down Fresno Slough to join the San Joaquin River flows for three days in June, 1906, and a maximum of about 10,000 second-feet from Kings River would have reached the San Joaquin River in June, 1909.

The foregoing study shows that with the exception that the crops on 13,700 acres of land in the bed of Tulare Lake outside of the area reserved for storage would probably have been flooded and lost in one year, the same protection from floods would have been provided to lands in the bed of Tulare Lake by the operation of the units of the State Water Plan for conservation and flood control as would have been provided by the cut through Summit Lake Ridge proposed by A. D. Schindler and hereinbefore described. The operation of the units of the State Water Plan would therefore result in a saving of at least $1,200,000 in the cost of flood protection works. If the comparison is made using the by-pass canal around the lake instead of the Summit Lake Ridge cut, the saving in cost is about $2,200,000. With the by-pass canal, however, the auxiliary lake bed reservoir would probably not be required.

Under the initial development of the State Water Plan, no reservoir units are proposed in the San Joaquin Valley south of the San Joaquin River. While there would be some benefit from the spreading of water and its absorption into the underground basin under this development, the benefit from the storage of flood flows would be lacking and both rates and volumes of flow during some floods would be such as to cause considerable damage.

Upper and Lower San Joaquin Valleys—Herndon to Mouth of Merced River—In estimating flood flows in the San Joaquin River above the mouth of the Merced River with floods controlled by the reservoirs of the State Water Plan, flows from the upper San Joaquin Valley south of the San Joaquin River, as estimated in the study just described, were combined with controlled flows from the Friant reservoir and inflows from tributary streams between the reservoir and the Merced River.

The controlled flow from the Friant Reservoir during winter floods was limited to 15,000 second-feet but it was found that the flow below the dam would never have reached this amount, because the reservoir was always below flood control stage during the passage of flows in excess of 15,000 second-feet. Summer flows were controlled by the reservoir to 15,000 second-feet downstream from the diversions of the Madera and San Joaquin River-Kern County canals. The Madera Canal was assumed to divert 1500 second-feet throughout all summer floods and the San Joaquin River-Kern County Canal was assumed to divert 3000 second-feet at all times throughout the summer when local supplies from the Kern, Tule and Kaweah rivers were not so great that this amount could not be used for consumptive use and absorption in the area served by the canal. Drafts from the reservoir during summer floods, therefore, were 19,500 second-feet except during parts of May and June, 1906.

With the foregoing conditions, the maximum combined flow from the upper San Joaquin Valley at Mendota Dam, would have been 30,000 second-feet during the summer flood of 1906. From this amount about 5000 second-feet would have been diverted into canals in the vicinity of Mendota Dam, leaving 25,000 second-feet to be cared for by the San Joaquin River flood channel. Studies of summer flood frequencies indicate that the maximum mean daily flow in the San Joaquin River at Friant during the 1906 flood was of a magnitude which may be expected to be exceeded about twice in 100 years on the average and that the maximum total 36-day run-off during the same flood may be expected to be exceeded only about once in 100 years on the average.

For the reach of the San Joaquin River from Mendota Dam to the mouth of the Merced River, the estimated flood concentrations resulting from a winter flood similar to that of 1911, with the releases from the Pine Flat and Friant reservoirs controlled as stated in the foregoing paragraphs, are as follows:

Mendota Dam to Fresno River	16,000 second-feet
Fresno River to Chowchilla River	26,000 second-feet
Chowchilla River to Mariposa Creek	33,000 second-feet
Mariposa Creek to Bear Creek	36,000 second-feet
Bear Creek to Salt Slough	42,000 second-feet
Salt Slough to Merced River	50,000 second-feet

It is estimated that the 1911 winter flood in this section of the valley was one which would be exceeded about once in 100 years on the average and the foregoing flows, therefore, may be expected to be exceeded with the same frequency.

To care for the flows given in the foregoing table in the San Joaquin River channel, only 16,000 second-feet capacity would be required between Mendota Dam and the mouth of Fresno River. However, since the minor tributaries contribute very little or no flow to the summer floods, the flood channel from Mendota Dam to the mouth of the Merced River would safely carry summer floods similar to that of 1906 if it were designed to have a capacity of 25,000 second-feet, instead of 16,000 second-feet, from Mendota Dam to the mouth of Fresno River. This has been done in the following estimate of cost.

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To provide protection against flows of the foregoing amounts, a flood channel following the course of the San Joaquin River would be adequate. The cost of such a channel, together with all incidental works such as drainage culverts, the construction of levees to high ground along the streams entering the San Joaquin River from the east side, and the extension of existing bridges, is estimated to be about $4,000,000. With such works there would be about 297,000 acres of land protected and the cost would be about $13.50 per acre. Reference to the foregoing estimate of cost for the protection of the same lands against uncontrolled flows with a similar plan for a flood channel shows that the operation of the State Water Plan as hereinbefore described would reduce the cost of protection along the San Joaquin River from Herndon to the Merced River about $4,250,000 and the cost per acre about $14.50. The degree of protection in both cases would be the same.

The foregoing benefits are those which would accrue from the operation of the State Water Plan under conditions of ultimate development. Under the initial development of the plan, the Friant Reservoir would be the only reservoir unit constructed in the valley above the Merced River. This reservoir while being operated for conservation purposes would have a material effect in reducing flood flows in the San Joaquin River, and its operation for flood control would increase this effect. A study of the reservoir under conditions of initial development shows that during the floods of 1911, the maximum mean daily flow in January of about 36,000 second-feet which would have occurred under present conditions of storage in the mountain watershed above Friant would have been reduced by the operation of the Friant Reservoir to about 3500 second-feet. Another maximum mean daily flow in March, 1911, of about 19,000 second-feet would have been reduced to about 10,500 second-feet. The controlled flows during summer floods would be the same as with the operation of the reservoir under conditions of ultimate development.

Lower San Joaquin Valley—Mouth of Merced River to Paradise Dam—As previously stated, it is judged uneconomical to provide protection against uncontrolled winter floods in the San Joaquin River from the mouth of the Merced River to Paradise Dam, and protection has been and probably will be provided only against uncontrolled summer floods similar to that of 1906, the flows during which are estimated to be:

Merced River to Tuolumne River	56,000 second-feet
Tuolumne River to Stanislaus River	70,000 second-feet
Stanislaus River to Paradise Dam	79,000 second-feet

When protection has been provided against such floods, the degree of protection in each division against uncontrolled and controlled winter floods, as shown by the curves on Plate LXXV, will be:

Division—	Number of times in 100 years flows would be exceeded — Without reservoir control	With reservoir control
Merced River to Tuolumne River	3	Less than 1
Tuolumne River to Stanislaus River	7	Less than 1
Stanislaus River to Paradise Dam	14	1.7

It is seen, therefore, that with floods controlled by the reservoirs of the State Water Plan, the degree of protection afforded against winter floods by works designed for summer flood flows, in this section of the valley, would be from more than three to about eight times greater than without reservoir control. With a slight increase in the amount of regulation on the Stanislaus River and some increase in flood channel capacity from the Stanislaus River to Paradise Dam, the same protection would be provided lands in this division as would be afforded in the other two. The degree of protection with reservoir control would be greater than that provided by the existing flood control project of the Sacramento Valley.

It has been shown in the section of this chapter on flood control plans for the San Joaquin River from the Merced River to Paradise Dam, with floods uncontrolled by reservoirs, that protection of the lands in this division of the valley against uncontrolled summer flood flows would cost about $3,500,000 and that protection against uncontrolled winter floods would cost about $5,900,000. The uncontrolled winter flood flows used for designing the works on which the cost estimate was based, however, would be exceeded less than once in 250 years on the average, whereas the works designed for summer flows would be endangered by controlled winter flows on an average of somewhat less than one to about 1.7 times in 100 years, as shown in the foregoing tabulation. No estimate has been made of the cost of works to protect the lands against uncontrolled winter floods exceeded once to 1.7 times in 100 years, on the average, but this cost probably would be very little less than that of works for floods exceeded about once in 250 years on the average. Therefore, the flood control benefit in this section of the valley from the operation of the State Water Plan under conditions of ultimate development, and with the reservoirs operated for flood control, would be almost $2,400,000.

San Joaquin Delta—It has been shown in the section of this chapter on flood control plans for the San Joaquin Delta with floods uncontrolled by reservoirs, that the maximum capacity of the present channels from Paradise Dam to the head of Middle River is about 70,000 second-feet. With floods uncontrolled by reservoirs in the San Joaquin Valley above Paradise Dam, this flow may be exceeded 21 times in 100 years on the average. If flood control were provided by the reservoirs of the State Water Plan, it may be seen from Plate LXXV that a flow of 70,000 second-feet below the confluence of the San Joaquin and Stanislaus rivers would be exceeded only seven times in 100 years on the average. This would give an increase in degree of protection for the 50,000 acres of land lying between Paradise Cut and Tom Paine Slough, between Paradise Cut and the San Joaquin and Middle rivers, and east of the San Joaquin River from Paradise Dam to and including Stockton, of three times that now provided.

It was also shown in the same section of this chapter that the delta channels between the head of Middle River and Venice Island have a present capacity of 100,000 second-feet and that below that point there is a larger capacity, especially since the dredging of the Stockton Ship Canal. If the upper 1.75 miles of Paradise Cut were improved to enable the cut to carry 60,000 second-feet and the cut were cleared below the Southern Pacific Railroad, there would be a channel capacity through the entire delta of 100,000 second-feet. Under these conditions and with floods controlled by the reservoirs of the State Water Plan, the delta lands would have protection against a flood that would be exceeded considerably less than once in 250 years on the average.

As previously stated, the estimated cost of works required to care for uncontrolled flood flows through the delta is about $10,000,000. It was also pointed out that with such works, flood plane elevations in parts of the delta would be so great that levees could not be constructed to safely provide for them. The cost of improving Paradise Cut to enable it to carry 60,000 second-feet would be relatively small and the saving in the cost of flood control works for the San Joaquin Delta, therefore, with reservoir control, would be almost $10,000,000 and the degree of protection would be much greater than with channels provided for uncontrolled flows.

Summary—Summarizing the savings in costs of works to protect the lands in the San Joaquin Valley with floods controlled by the reservoirs of the State Water Plan, over what they would cost with uncontrolled flows, the following probable minimum amounts are obtained:

Upper San Joaquin Valley south of San Joaquin River	$1,200,000
Upper and lower San Joaquin Valleys—Herndon to Merced River	4,250,000
Lower San Joaquin Valley—Merced River to Paradise Dam	2,400,000
San Joaquin Delta	10,000,000
Total	$17,850,000

This total does not include any saving in the cost of works along the Calaveras, Mokelumne and Cosumnes rivers and along Dry Creek, for which no estimates have been made.

CHAPTER X

NAVIGATION

One of the important objectives of the State Water Plan in the Great Central Valley is improvement of navigation. Within the San Joaquin River Basin, the navigable waterways comprise the main San Joaquin River, the tributary Mokelumne River and many miles of interconnecting natural and artificial channels in the San Joaquin Delta. The Sacramento River, chief navigable waterway in the Sacramento River Basin, joins the San Joaquin River in the delta and the combined streams discharge through a common mouth into Suisun Bay, which forms the easterly arm of the great harbor of San Francisco Bay. The Federal Government has recognized these streams as navigable waterways since the seventies and has exercised jurisdiction over them, through the corps of engineers of the United States War Department, in the interest of improvement and maintenance of navigation. Commanding a reach of over 250 miles and extending through the heart of the Great Central Valley from Red Bluff on the north to Mendota on the south, the Sacramento and San Joaquin rivers are actually or potentially navigable and together afford an inland waterway system of great importance and value, which, if adequately improved, would provide a medium of economical transportation for a major portion of the State, not only for local commerce but also for interstate and foreign commerce. At present commercial navigation is confined for the most part to the lower reaches of both the San Joaquin and Sacramento rivers below Stockton and Sacramento respectively. Improvement works will be required to provide dependable navigation depths for the operation of commercial craft on the upper sections of these waterways above these cities. Accordingly, in the formulation of plans for the coordinate development and utilization of the water resources of the Great Central Valley, consideration has been given to the need for water transportation and the possibilities and feasibility of further navigation improvement.

Studies with respect to navigation on the Sacramento River are presented in another report.* This chapter is devoted to a presentation of data and studies with respect to water transportation and improvement of navigation in the San Joaquin Valley, particularly on the San Joaquin River. Much of the data set forth are taken from reports of the United States Army engineers, including particularly a recent report† and other data and studies made available from subsequent investigations and studies regarding further improvement of navigation on the San Joaquin River.

History of Navigation on the San Joaquin River.

Commercial navigation on the San Joaquin River may be considered to have had its beginning with the discovery of gold in California in 1848. Although there had been some navigation on the

*Bulletin 26, "Sacramento River Basin," Division of Water Resources, 1931.

†House of Representatives Document No. 791, 71st Congress, third session, "Partial Report on the Sacramento, San Joaquin and Kern rivers, California."

river prior to that time starting with exploring expeditions as early as 1817 and continuing in later years during the Mexican regime, only small craft were operated and there was no important amount of commerce. Stockton was founded in 1847 and regular communication with San Francisco was first provided by whale boats. In September, 1848, the sailing craft "Maria" owned by Captain Weber started regular trips as a mail packet between Stockton and San Francisco.

Following the discovery of gold, the San Joaquin River and the Sacramento River, as well, assumed great importance as the main arteries of communication and transportation to and from the early settlements of California and the outside world. The depths in these streams were sufficient during most of the year for the type of vessel then used on the high seas. Passengers and freight were carried from foreign ports or from the Atlantic coast around Cape Horn or via the Isthmus of Panama to the main settlements along these rivers. In addition, a large volume of traffic sprang up between San Francisco and the inland settlements. Thousands of gold seekers rushed to the mines and it was found that the few sailing craft then in operation were inadequate for the transportation of passengers and supplies from San Francisco to the inland ports. This led to the construction of steamers for use on the San Joaquin River. One of the first steamers to navigate to Stockton is said to have been the "Merrimac" which was assembled in San Francisco after having been shipped in sections around Cape Horn. This boat was followed by numerous others, notably the "John A. Sutter" whose maiden trip was the occasion of a great celebration in Stockton.

The rate on freight in 1850 was $20 per ton and passenger fares were $18 for cabin and $12 for deck accommodations. Competition arose quickly and in 1852 one steamer reduced deck fare to $1.50 and another promptly offered to carry passengers for nothing. In April, 1852, there were seven steamers making daily trips to and from Stockton. In 1854, the California Navigation Company secured a monopoly of all navigation by either purchasing or taking into a combination every river steamer operating on the Sacramento and San Joaquin rivers. This company was absorbed by the Central Pacific Railroad in 1869 which, in that year, completed the transcontinental railroad.

Following the inrush of settlers with the discovery of gold in California, the demand for agricultural products rapidly increased and many of the early settlers started farming the rich agricultural lands in the San Joaquin and Sacramento valleys. Transportation of products and supplies from and to the farming lands in the San Joaquin Valley was for many years provided by water carriers operating on the upper San Joaquin River, starting as early as the fifties. In February, 1858, the steamer "Peytona" started on a trial trip up the San Joaquin River above Stockton but was forced to turn back at a point about twelve miles above the mouth of the Merced River due to the low stage of the river. In April of the same year, after a large increase in the stream flow, the steamer "Henrietta" proceeded to Fresno City which was then located on Fresno Slough, and maintained a regular schedule for several months. This boat, however, had a draft of only about eighteen inches. In the flood season of 1862, an attempt was made to run a stern-wheel steamer from the San Joaquin River to Tulare Lake from which water was flowing. The steamer grounded, the flood subsided and the boat was left stranded on the dry plain.

Between the years 1860 and 1870, freight to and from the San Joaquin Valley was transported on the San Joaquin River, with river craft navigating to Mendota and occasionally as far upstream as Herndon about twelve miles northwest of Fresno. About 1870, navigation above Mendota was discontinued. It was about this time also that the railroad from Stockton to Fresno was completed, thereby supplying rail transportation for the east side of the San Joaquin Valley. It was not until 1889 that the railway on the west side of the valley was built. Prior to that time the river was the only transportation outlet for that area. Hills Ferry was considered the head of navigation, although boats operated to Firebaugh about eleven miles below Mendota for a few weeks each year. Steamers continued to operate to Hills Ferry, with an occasional trip to Firebaugh until 1896. Insufficient water in the river, however, made navigation more or less seasonal. Since 1896, boats have gone as far upstream as Grayson (54 miles above Stockton) when the discharge past that point was 6000 second-feet or more, and to San Joaquin City (35 miles above Stockton) when the discharge past that point was 4000 second-feet or more.

From earliest years, navigation on the San Joaquin River above Stockton has always been seasonal in character because of the marked variability in flow of this stream. After the melting of the snows in the high Sierras, which is usually completed by mid-July, the flow in this stream is reduced to a relatively small quantity which has always been insufficient to provide navigation depths in most of the section above Stockton. The period of low stream flow normally extends for several months in the summer and fall until the storms of the succeeding winter increase the discharge to a sufficient amount for navigation. In addition to these unfavorable natural conditions, irrigation diversions on the San Joaquin River and its tributaries have still further reduced the flow during the summer months and have tended to increase the period of insufficient flow for navigation.

The effect of tidal action extends to a point a few miles above Lathrop on the San Joaquin River. From this point to Suisun Bay, the river gradient is rather flat. Mean tide level at Stockton is only about one and one-half feet above mean sea level at the lower end of San Francisco Bay. Therefore, the lower San Joaquin River and especially the portion from Stockton downstream is not greatly affected by the reduced stream flow. The river channels below Stockton are naturally rather deep and were not greatly affected by deposition of hydraulic-mining debris such as occurred along the Sacramento River. However, above Stockton and especially in the section of the San Joaquin River above Lathrop, the possibility of navigation is entirely dependent upon the magnitude of streamflow. From the railroad bridge (San Joaquin Bridge) near Lathrop to Hills Ferry, the average river gradient is about 0.8 foot per mile at low water. The average fall of the stream between Hills Ferry and Mendota is about one foot per mile and about two feet per mile from Mendota to Herndon.

Because of the naturally unfavorable condition of an insufficient stream flow to provide navigation depths during a large portion of the year on the upper San Joaquin River, navigation activities above Stockton gradually decreased until, in recent years, there has been virtually no commercial craft plying the stream above Lathrop, or for all practical purposes above Stockton. The service of the water carriers was never dependable in the upper San Joaquin River and the transportation requirements of the San Joaquin Valley naturally drifted to other agencies including first the railroads and in more recent years truck transportation as well.

Since the beginning of commercial navigation on the San Joaquin River, water transportation has flourished, especially on the section below Stockton, where adequate navigation improvements have been provided by the Federal Government. The records of tonnage and passenger movement on the San Joaquin River since 1880, compiled from the annual reports of the chief of engineers of the United States War Department, are shown in Table 207. The segregation of the

TABLE 207

WATER-BORNE TRAFFIC ON SAN JOAQUIN RIVER, 1880 TO 1929

Compiled from Annual Reports of Chief of Engineers, United States War Department

Year	Freight		Passengers	Year	Freight		Passengers
	Tons	Value			Tons	Value	
1880	305,093	----------	----------	1905	373,186	----------	----------
1881	----------	----------	----------	1906	440,300	$18,293,401	----------
1882	----------	----------	----------	1907	736,472	25,374,699	----------
1883	432,250	----------	----------	1908	509,233	21,716,334	50,000
1884	442,950	----------	----------	1909	773,945	31,275,925	110,000
1885	664,370	----------	----------	1910	631,681	32,878,108	125,000
1886	470,475	----------	----------	1911	600,128	35,768,215	100,556
1887	470,850	----------	----------	1912	632,591	38,854,539	107,687
1888	----------	----------	----------	1913	820,399	35,479,741	207,249
1889	371,200	----------	55,000	1914	772,156	36,358,240	189,667
1890	----------	----------	57,840	1915	831,234	42,179,160	213,915
1891	527,684	----------	57,840	1916	824,222	50,367,700	182,486
1892	370,000	----------	56,000	1917	1,890,856	65,204,825	206,131
1893	395,000	----------	90,000	1918	[1]766,236	65,186,292	236,379
1894	346,094	----------	154,500	1919	647,156	54,100,043	221,259
1895	401,684	----------	100,178	1920	[2]673,241	42,201,289	[3]242,238
1896	431,736	----------	61,531	1921	646,657	37,263,122	206,783
1897	454,955	----------	13,671	1922	678,751	34,291,675	188,807
1898	287,524	----------	112,039	1923[4]	697,773	38,027,909	163,566
1899	270,013	----------	64,975	1924	727,499	38,185,313	133,017
1900	270,887	----------	133,832	1925	849,687	47,192,499	131,520
1901	357,746	----------	108,637	1926	934,809	56,455,662	113,452
1902	322,000	----------	84,842	1927[5]	1,152,743	51,604,962	99,320
1903	376,883	----------	----------	1928	984,326	43,378,146	80,828
1904	360,486	----------	74,974	1929	941,139	42,759,858	77,993

[1] There were in addition 1,348,146 tons of water transported.
[2] There were in addition 19,065 tons of water transported valued at $1,922.
[3] Includes 27,075 passengers carried in ferry traffic.
[4] Subsequent to 1922 Government materials used in improvement of river are not included in tonnage.
[5] Since 1927, traffic in New York Slough which does not pass over other sections of river has been included.

amounts between the sections of the river above and below Stockton are not available. The data include all traffic on the San Joaquin River from its mouth to the present head of navigation at Hills Ferry but do not include the traffic on the Mokelumne River.

The records set forth in Table 207 show the greatest tonnage and number of passengers carried in the year 1917, which probably reflects war time conditions. However, with this exception, the records indicate a continuous and fairly steady growth of waterborne tonnage since about 1900 to a present movement of nearly 1,000,000 tons, having a value of $40,000,000 to $50,000,000. Most of this movement is on the lower river below Stockton, where adequate and dependable all-year navigation has been maintained. Over 50 individuals or companies operate freight-carrying vessels below Stockton, comprising stern-wheel steamers, motor-screw tow boats and freighters, and barges. Stern-wheel steamers are gradually being displaced by diesel equipment. The growth of water-borne traffic on this section of the river clearly evidences the demand for water transportation in the San Joaquin Valley and indicates that there would be a large amount of tonnage moved by water over the upper San Joaquin River if dependable all-year navigation were provided.

Navigation on the Mokelumne River was first accomplished by a steamboat proceeding up that river to Lockeford in April, 1862, a year of high water. Following this, navigation was maintained to Woodbridge and occasionally to Lockeford. In 1865, the Mokelumne River Improvement Company was organized under an act of the State Legislature. They were entitled to collect a tax of ten cents per ton for twenty years for clearing the river from Georgiana Slough to Athearns Bridge, but long before the twenty years had expired conditions had so changed that there was no freight on which the tax could be collected. Navigation on the Mokelumne River has been improved and maintained to some extent by the Federal Government since 1882, but only a relatively small amount of about $50,000 has been expended for improvement and maintenance in the lower channels between its mouth and the Galt-New Hope Bridge. Tidal action extends throughout most of this improved section. The records in the annual reports of the chief of engineers of the United States War Department show an annual movement since 1926 of 70,000 to 80,000 tons, having a normal value of from $5,000,000 to $6,000,000.

Existing Navigation Project on San Joaquin River.

Navigation improvements on the San Joaquin River were initiated by acts of Congress starting in 1876 and continued under modifications of subsequent acts up to the act creating the latest approved project passed on January 27, 1927. The acts of August 14, 1876, March 3, 1881, July 5, 1884, August 11, 1888, July 13, 1892, August 18, 1894, and June 3, 1896, provided for cutting off sharp bends and making cut-offs below the mouth of Stockton Channel, dredging Mormon Slough, constructing wing dams in the river between Stockton and Hills Ferry without adopting any specific channel dimensions; the act of June 25, 1910, provided for a 9-foot channel up to Stockton (H. Doc. No. 1124, 60th Cong., 2d sess.); the act of July 25, 1912, provided for the improvement of Fremont Channel and McLeod Lake (H. Doc. No. 581, 62d Cong., 2d sess.); and the act approved January 21, 1927, provided for the 26-foot project (H. Doc. No. 554, 68th Cong. 2d sess.).

The existing project, as outlined in House Doc. No. 791, previously cited, provides for a channel 26 feet* deep at mean lower low water and 100 feet wide at the bottom (except in New York Slough, where the

*The 26-foot depth provided under the existing project for the Stockton Ship Canal has recently (1933) been increased to a depth of 30 feet under a modification in plans approved by the Chief of Engineers of the U. S. War Department.

width is to be 300 feet), from the mouth of New York Slough to the city of Stockton, a distance of 45 miles, with suitable passing places and a turning basin at Stockton; for dredging Mormon Slough to a depth of 9 feet for a distance of 1.7 miles above its mouth; for a depth of 9 feet at mean lower low water in Fremont Channel and McLeod Lake; for cutting off sharp bends, making cut-offs and closing side channels in the river; and for snagging, removing overhanging trees, and constructing wing dams from Stockton Chanel to Hills Ferry, 86 miles, to facilitate light-draft navigation on this part of the river during higher stages of water.

According to information made available by the Division Engineer of the Pacific Division, United States War Department, the total cost of work on the San Joaquin River to June 30, 1930, was $1,272,101.69 of which $579,586.53, including $56,606.85 contributed funds, was for new work and $692,515.16 for maintenance. The estimated cost for new work revised in 1927 is $4,046,400, of which local interests are to contribute $1,307,500. The latest approved estimate of annual cost of maintenance is $181,000 during the first year and $111,000 thereafter. In addition, the entire expense of right of way and terminal facilities for the Stockton Ship Canal is to be borne by the city of Stockton. It is reported that an expenditure of some $3,000,000 will be involved for these purposes.

Present Limits of Navigation on San Joaquin River.

Under present conditions, navigation on the San Joaquin River is virtually limited to the section below Stockton. This section is now being improved to a depth of 26 feet to accommodate ocean-going vessels, thus adding Stockton as a port to the San Francisco Bay harbor. It is estimated by the United States War Department that the entire 26-foot project will be completed early in 1933. Above Stockton, navigation conditions are fair for most of the year as far as the San Joaquin Bridge near the town of Lathrop or within the limits of tidal action on this stream. Above tidal action, south of the San Joaquin Bridge, navigation is not practicable during low stages of the river. It is stated by the Division Engineer that there is usually a depth of six feet in the river between Stockton and Hills Ferry from April to June. Although the flow in the river has been diminished to some extent by irrigation diversions in recent years, conditions as to navigability are not very much different than in former years before the growth in irrigation development. The lack of dependable navigation depths has discouraged shipment of freight by water and there has been no commercial navigation of importance for many years on the San Joaquin River above Stockton.

Economic Value of Further Improvement of Navigation on the San Joaquin River.

The San Joaquin River from its mouth to Mendota offers a potential inland waterway through the heart of the San Joaquin Valley which, if adequately improved, would provide a means of cheap water transportation for the large and increasing volume of tonnage moving to and from the San Joaquin Valley and San Francisco Bay points and other states and foreign nations as well. The improved portion of the river from Stockton to its mouth is already functioning as one of the most important and successful internal waterways in the Nation. The demand for cheap water transportation on the lower improved section of this stream indicates that a large amount of tonnage would be moved by water over the upper San Joaquin River if it were adequately improved to provide dependable all-year navigation. It appears that cheap water transportation would be of great value to the future economic welfare of the San Joaquin Valley.

The navigable portion of the upper San Joaquin River is paralleled on both sides by the Southern Pacific Railroad and on the east side by The Atchison, Topeka & Santa Fe Railroad. Motor trucks operate on a network of improved highways. Hence, water transportation on the upper San Joaquin River would be subject to competition with railroads and motor trucks.

Based upon data made available by the Division Engineer of the Pacific Division, United States War Department, the present tonnage movement to and from the area which would be tributary to an improved waterway on the upper San Joaquin River from Stockton to Mendota aggregates 927,000 tons annually. This represents the estimated tonnage moving by truck and rail, parallel to the waterway, to and from six counties in the San Joaquin Valley, comprising Stanislaus, Merced, Madera, Fresno, Tulare and Kings. Of this total estimated present tonnage movement, the Division Engineer considers that the movement to and from Stanislaus County probably would not go by water because it could be hauled more cheaply directly to and from the port of Stockton. Based upon a study of comparative rail, truck and water rates and tonnage movement, the Division Engineer estimates that, of the total present tonnage to and from the remaining five counties, nearly 60 per cent could be moved by water over an improved upper San Joaquin River channel at an average saving of about 55 cents per ton considering all movement to and from the port of Stockton.

From studies made of past growth and possibilities of future development in the San Joaquin Valley, the Division Engineer estimates that the tonnage movement to and from the San Joaquin Valley tributary to an improved waterway will triple in 50 years and double in 25 years. On this basis, the Division Engineer estimates that the average annual prospective tonnage during the next 50 years to and from the tributary area of an improved upper San Joaquin River channel, excluding Stanislaus County, would be twice the present tonnage or 1,530,000 tons; and that of this total 40 per cent would move over an improved waterway at an average saving of 55 cents per ton or a total annual saving of $335,000. Deducting the cost of maintenance and operation, estimated as subsequently shown at $110,000, the net annual saving would be $225,000. Capitalizing this net saving at four per cent, the Division Engineer estimates the economic value of improving the upper San Joaquin River from Stockton to Mendota at $5,625,000.

Although no detailed study has been made by this division for this report of the economic value of further improvement of navigation on the San Joaquin River, it is believed that a more comprehensive study of present and future tonnage movement than that made by the Division Engineer of the War Department would show a considerably greater tonnage for actual movement by water than that estimated.

Moreover, it is believed that a greater average saving per ton than that estimated by the Division Engineer could be effected by water transportation. As a further consideration, it would appear proper that the economic value of savings in transportation costs by water for the entire San Joaquin River from its mouth to Mendota should be compared with the cost of improving the entire waterway rather than comparing the benefit values with the cost of improvement separately for each section of the waterway above and below Stockton. It is believed that such a comparison would show that the benefit values from savings in transportation costs for the entire waterway considered as a single improvement and economic unit would be considerably in excess of the cost of complete improvement from the mouth to the head of navigation at Mendota. In addition to the direct savings in transportation costs for tonnage actually moving by water, there would also be savings in transportation costs on tonnage moving by rail or truck effected through the reduction of rail and truck rates to meet water competition. It is believed that the benefit value of such savings should be credited to the waterway. With such modification in the methods for estimating the economic value of further improvement on the San Joaquin River, it appears probable that the benefit values which could be reasonably anticipated would be more than sufficient to justify the expenditure required for providing dependable navigation from Stockton to Mendota in accord with the proposed plan of canalization subsequently presented.

Proposed Plan for Further Improvement of Navigation on the San Joaquin River.

In accord with the investigation made by the United States War Department, the portion of the San Joaquin River which is worthy of consideration with a view to further improvement in the interest of navigation lies between Stockton and Mendota. It is stated that above Mendota the characteristics of the river are so unfavorable to improvement that manifestly the cost would be greater than the value of the benefits reasonably to be expected.

The following description of the proposed plan and estimates of cost for navigation improvement are taken from data made available by the Division Engineer of the Pacific Division, United States War Department. The plan of improvement recommended provides for the canalization of the river from Stockton to Mendota. This is considered to be the only practicable plan of improvement for this section of the river. It is proposed to provide a minimum navigation depth of six feet. This would require the construction of 13 movable dams equipped with locks with lifts varying from 9 feet to 18 feet and averaging about 13 feet. Locks are proposed with dimensions of 45 by 300 feet in the clear.

In the stretch from the mouth of Stockton Channel to Hills Ferry Bridge, a distance of 85.9 miles by the existing river channel, 5 locks and dams will be required with an aggregate lift of 63 feet. Fourteen cut-offs will be desirable, which in conjunction with the widening of certain sloughs will effect a reduction of 20.6 miles in the present river channel distance for this section.

In the stretch from Hills Ferry Bridge to Mendota Dam, a distance of 88.2 miles by the existing river channel, 8 locks and dams will be required with an aggregate lift of 88.4 feet. In this stretch 21 cut-offs will be desirable, which will effect a reduction of 10.2 miles in the present distance by river for this section.

In addition to the locks, dams and cut-offs, levees are proposed at the lower ends of pools and some excavation near the upper ends. The cost of improvement by canalization, as estimated by the Division Engineer, including levees and excavation as required for navigation only, is shown in Table 208.

TABLE 208

CAPITAL COST OF DAMS AND LOCKS FOR CANALIZATION OF SAN JOAQUIN RIVER FROM STOCKTON TO MENDOTA

Estimate by Division Engineer, Pacific Division, U. S. War Department

Section of river	Distance via improved channel, in miles	Number of lifts	Total lift, in feet	Capital cost		
				Locks	Project less locks*	Total
Stockton Channel to Hills Ferry Bridge	65.3	5	63.0	$2,500,000	$2,000,000	$4,500,000
Hills Ferry Bridge to Mendota Dam	78.0	8	88.4	3,500,000	4,000,000	7,500,000
Totals	143.3	13	151.4	$6,000,000	$6,000,000	$12,000,000

* Includes dams, levees, spillways, channel excavation, right of ways, drainage, etc.

The Division Engineer's estimate of annual cost of maintenance and operation of the locks and dams, including dredging in the pools but excluding maintenance of levees, is $110,000.

It will be noted that the Division Engineer's estimate of the economic value of improvement is slightly less than the estimated cost of the locks alone for the proposed plan of canalization. However, as previously stated, it is believed that the benefits in transportation savings effected by the proposed improvement would show an economic value considerably greater than estimated by the Division Engineer and probably would be sufficient in amount to justify the entire expenditure required of $12,000,000 for dams, locks and appurtenant works.

Coordination of Proposed Plan for Navigation Improvement on San Joaquin River With State Water Plan for San Joaquin River Pumping System.

In accord with the State Water Plan for the San Joaquin River Basin, the San Joaquin River Pumping System is proposed as one of the major conveyance units to transport water from the Sacramento-San Joaquin Delta channels to Mendota. The plan for this conveyance unit is set forth in detail in Chapter VIII. From the delta to the mouth of the Merced River (approximately at Hills Ferry) it provides for a system of dams and pumping plants for conveying the water up the river channel, lifting the water to an elevation of 62 feet (United States Geological Survey datum). From this point the proposed pumping system departs westerly from the river through a constructed canal extending to Mendota. The proposed plan for the pumping system was selected as being the most economical after careful consideration of numerous alternate plans and routes of which seven are presented in detail in Chapter VIII, including one plan which would utilize the river channel through its entire length from the delta to Mendota with a system of dams and pumping lifts in the river channel. The plan as proposed would canalize the river from the delta to Salt Slough, nine miles above the mouth of Merced River. If the dams were equipped with locks, slack water navigation would be provided to Salt Slough. The location of these dams as proposed in the San Joaquin River Pumping System differs to some extent with the plan as proposed by the United States War Department. However, the canalization effected would provide a minimum depth of six feet for navigation from Stockton to Salt Slough and would be equivalent to the plan outlined by the Army Engineers for this section of the river. A plan and profile, showing the canalization of this lower section of the San Joaquin River which would be effected in conjunction with the San Joaquin River Pumping System, are presented on Plate LXXVII, "Canalization of San Joaquin River in Conjunction with San Joaquin River Pumping System, Stockton Deep Water Channel to Salt Slough."

With a concrete lined canal in the upper portion of the selected plan for the San Joaquin River Pumping System, the capital and annual costs are only slightly less than the alternate all-river channel route. The estimates of capital and annual costs for this unit have been based on construction of a concrete lined canal in this upper section. However, it is entirely possible that final designs and studies for this unit would show that a large part of the concrete lining could be omitted and thus materially decrease the capital and annual costs of the adopted plan and route, with resulting costs substantially less than those for the all-river channel route. Therefore, the final consideration of the most desirable plan and route to adopt for the San Joaquin River Pumping System will depend largely upon the need and benefit values of navigation improvement on the San Joaquin River to Mendota and particularly upon the expenditures which would be justified by the Federal Government in the interest of further improvement of navigation. The Division Engineer's estimate of economic value of navigation improvement, as previously set forth, indicates that the Federal Government would be justified in constructing the necessary locks for all dams in a combined pumping and canalization project. As previously stated, it is believed that the benefit values for improvement of navigation would be greater than estimated by the Division Engineer. It appears probable that expenditures by the Federal Government in the interest of navigation would be justified by the benefit values, not only for the construction of the necessary locks in the dams but also for a portion and perhaps all of the cost of the dams required to effect canalization. The most desirable plan would be one which would combine and coordinate the works required for conveyance of water and for improvement of navigation in the entire section of the river from Stockton to Mendota. If sufficient funds are made available in the interest of navigation to pay for the cost of the locks and a portion of the dams for a combined canalization and conveyance project on the San Joaquin River from Stockton to Mendota, the all-river channel route for the San Joaquin River Pumping System would be the most advantageous plan for adoption.


Note:
For design of typical dam, lock and pumping plant see Plate XL.
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25
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GENERAL PLAN AND PROFILE
SHOWING
CANALIZATION OF SAN JOAQUIN RIVER
IN CONJUNCTION WITH SAN JOAQUIN RIVER PUMPING SYSTEM
STOCKTON DEEP WATER CHANNEL TO SALT SLOUGH
SCALE OF MILES
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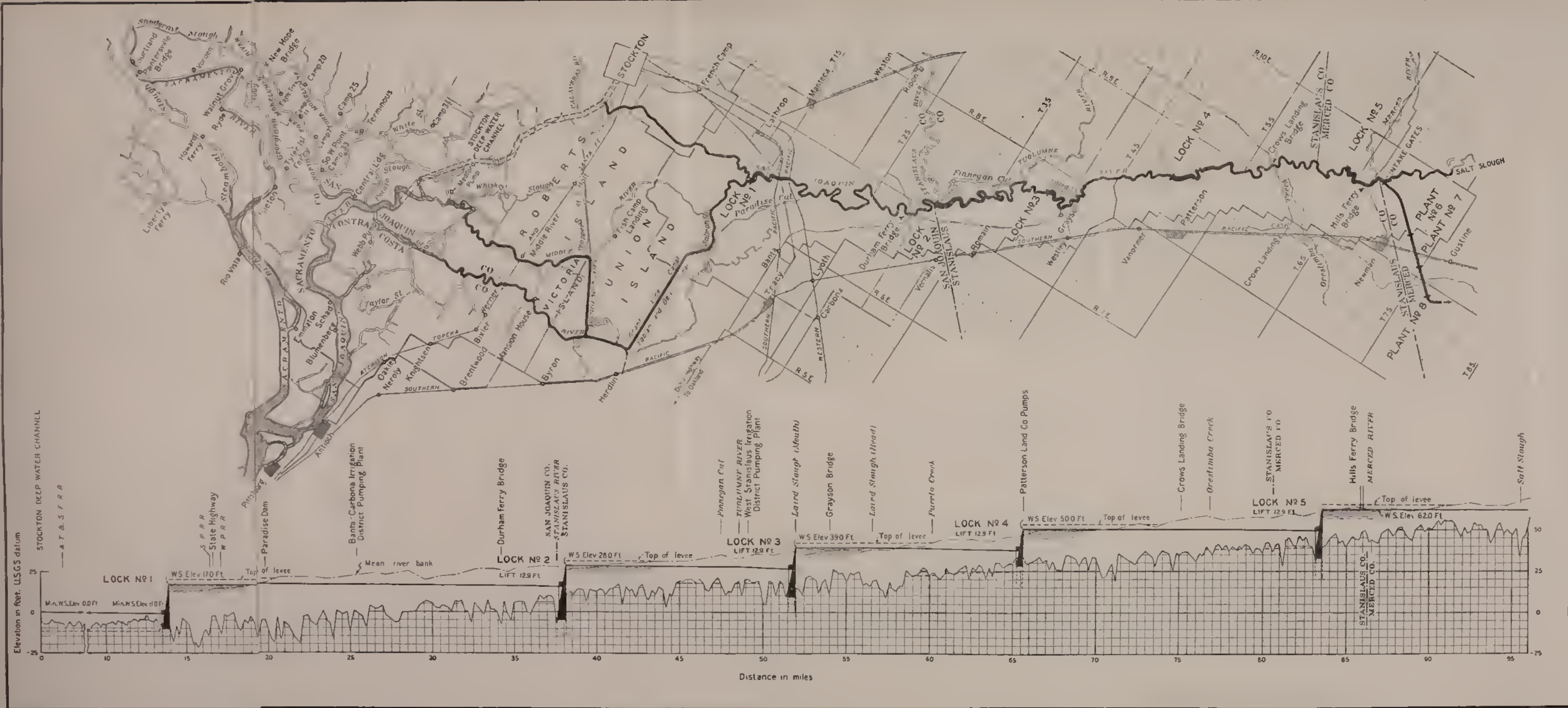
sideration of numerous alternate plans and routes of which seven are presented in detail in Chapter VIII, including one plan which would utilize the river channel through its entire length from the delta to Mendota with a system of dams and pumping lifts in the river channel. The plan as proposed would canalize the river from the delta to Salt Slough, nine miles above the mouth of Merced River. If the dams were equipped with locks, slack water navigation would be provided to Salt Slough. The location of these dams as proposed in the San Joaquin River Pumping System differs to some extent with the plan as proposed by the United States War Department. However, the canalization effected would provide a minimum depth of six feet for navigation from Stockton to Salt Slough and would be equivalent to the plan outlined by the Army Engineers for this section of the river. A plan and profile, showing the canalization of this lower section of the San Joaquin River which would be effected in conjunction with the San Joaquin River Pumping System, are presented on Plate LXXVII, "Canalization of San Joaquin River in Conjunction with San Joaquin River Pumping System, Stockton Deep Water Channel to Salt Slough."

With a concrete lined canal in the upper portion of the selected plan for the San Joaquin River Pumping System, the capital and annual costs are only slightly less than the alternate all-river channel route. The estimates of capital and annual costs for this unit have been based on construction of a concrete lined canal in this upper section. However, it is entirely possible that final designs and studies for this unit would show that a large part of the concrete lining could be omitted and thus materially decrease the capital and annual costs of the adopted plan and route, with resulting costs substantially less than those for the all-river channel route. Therefore, the final consideration of the most desirable plan and route to adopt for the San Joaquin River Pumping System will depend largely upon the need and benefit values of navigation improvement on the San Joaquin River to Mendota and particularly upon the expenditures which would be justified by the Federal Government in the interest of further improvement of navigation. The Division Engineer's estimate of economic value of navigation improvement, as previously set forth, indicates that the Federal Government would be justified in constructing the necessary locks for all dams in a combined pumping and canalization project. As previously stated, it is believed that the benefit values for improvement of navigation would be greater than estimated by the Division Engineer. It appears probable that expenditures by the Federal Government in the interest of navigation would be justified by the benefit values, not only for the construction of the necessary locks in the dams but also for a portion and perhaps all of the cost of the dams required to effect canalization. The most desirable plan would be one which would combine and coordinate the works required for conveyance of water and for improvement of navigation in the entire section of the river from Stockton to Mendota. If sufficient funds are made available in the interest of navigation to pay for the cost of the locks and a portion of the dams for a combined canalization and conveyance project on the San Joaquin River from Stockton to Mendota, the all-river channel route for the San Joaquin River Pumping System would be the most advantageous plan for adoption.



Note
For design of typical dam lock and pumping plant see Plate XL

GENERAL PLAN AND PROFILE
SHOWING
CANALIZATION OF SAN JOAQUIN RIVER
IN CONJUNCTION WITH SAN JOAQUIN RIVER PUMPING SYSTEM
STOCKTON DEEP WATER CHANNEL TO SALT SLOUGH

SCALE OF MILES

APPENDIX A

CLASSIFICATION OF VALLEY FLOOR LANDS IN SAN JOAQUIN RIVER BASIN

By

S. T. Harding

Consulting Engineer

December, 1930

TABLE OF CONTENTS

CLASSIFICATION OF VALLEY FLOOR LANDS IN SAN JOAQUIN RIVER BASIN

The following discussion of lands in the San Joaquin Valley pertains only to the main area of the valley floor. The field work on the adjacent plains and foothill areas to the east, from the San Joaquin River northward was handled under different supervision and standards of classification and is not included. The same colors are used on the map showing the land classification to indicate like numbered classes of lands in the valley and foothill areas. The division between the two areas is discussed in the description of the local areas. In general, the plains and foothills extend into the eastern portions of Hydrographic Divisions 8, 9 and 11 delineated on Plate VI and incorporated in Chapter III of this bulletin.

The area described herein extends from the southern end of the valley northward to the southern boundary of Hydrographic Divisions 10 and 12. It includes the principal agricultural areas in the eight main counties of the San Joaquin Valley. The resulting classification is shown on Plate V included in Chapter III of this bulletin. The resulting areas of each class, together with the areas of included foothill lands, also are shown in the tables of land classification in Chapter III.

The classification described herein embodies the results of various investigations by the State Engineer in the San Joaquin Valley during the last ten years. Several of these investigations have related to the areas to be included and the feasibility of proposed irrigation districts in connection with proceedings before the State Engineer in relation to their organization or financing procedure. Areas so included were reviewed and other areas have been examined in making this classification. The actual field work for this report was done by the writer in the areas south of the San Joaquin River and the area in the six northern irrigation districts on the east side of the valley, and by Harry Barnes for the remainder of the area, including principally lands in Madera County and along the San Joaquin River.

The results of the field work were submitted to the San Joaquin Valley Water Committee, representing the eight valley counties, and by them referred to the sub-committee for each county. These committees accepted the resulting classification with minor exceptions. C. H. Holley made a comprehensive and independent classification of the lands in Tulare County and some adjacent areas, partly for the Tulare County Committee and partly for the State Engineer. The results were in general agreement with those presented herein.

Any study of irrigation development in this area, either for present construction or for future ultimate plans, requires a consideration of the quality of the land. It is recognized by everyone that lands of all qualities, varying from the very best to the hopelessly poor, occur in the San Joaquin Valley. It is essential that the extent and location of the different classes be known in preparing plans for the possible service of lands of satisfactory quality, and also, so that lands not able to meet costs for irrigation may be excluded. While land classification is necessarily to some extent a matter of judgment, it is essential that a uniform standard be applied to the whole area. The present classification was planned to meet these requirements.

Basis of Classification.

A classification of land in relation to irrigation is more than a soil survey. Irrigability involves soil texture, alkali and roughness, as well as the cost of water delivery. The value of land for irrigation is the composite result of all of its physical factors. For practical application it is necessary to limit the results to a few classes. Each of such classes includes a zone of quality rather than a single grade of land usefulness.

Five classes of land were used in the field work on which this report is based. Their basis was established prior to the field work and maintained. Boundaries between the classes were located on field maps on a scale of two inches per mile. The quadrangle sheets of the U. S. Geological Survey were used where available. Full use also was made of the Reconnaissance Soil Survey maps of the U. S. Bureau of Soils. Field notes were placed directly on the field maps. To indicate the basis for the rating, a system of letters was used to show the causes for reduced rating. These consisted of "a" to indicate hardpan, "b" for alkali, "c" for channel cut areas near streams, "d" for general roughness, and "e" for generally poor fertility. As the smaller scale of the land classification map does not permit showing these distinctions, the reason for reduced ratings is stated in general terms in the descriptions of the local areas.

Class 1 Lands—Class 1 has been used to designate lands of good quality which do not have any defects that materially reduce their value under irrigation. They are good lands capable of good yields at low or moderate costs of preparation for irrigation. Alkali, roughness or hardpan may be present, but not to a sufficient extent to limit the feasibility of their irrigation. All soil textures may be included, except where the texture reduces yields or increases costs so as to reduce the value of the land under irrigation.

Class 1 includes the best lands in the valley. It represents a zone of quality, however, rather than merely the very best land. Some areas of poorer Class 1 land were indicated on the field sheets as Class 1 minus. This land is shown on the smaller scale of the classification map as Class 1, however.

Lands rated as Class 1 represent areas where the quality of the land will not be a limiting factor in the feasibility of irrigation. The limit of feasible costs will be the general one set by crop values in relation to costs for lands that can produce normal average yields at low to moderate costs of preparation.

Class 2 Lands—As the name implies, these are second grade lands. They are fairly good areas in which some factor either increases the cost of preparation for irrigation so that settlement of new lands would be delayed, or decreases the crop yields so as to reduce the ability to meet irrigation costs to a material extent. Class 2 lands may be profitable to irrigate under favorable cost conditions and many of the Class 2 areas are now being irrigated under canals having rights in local streams or by pumping from wells. While no exact standard of division can be used, Class 2 lands represent areas grading down from lands which might meet two-thirds as large a cost for irrigation as adjacent areas of Class 1 lands, to those approaching Class 3.

Class 3 Lands—Class 3 was used for lands of poorer quality than Class 2. Some of this land can not now meet the usual charges for water from even local sources, and offers little prospect of being able to meet such costs under any probable forecast of conditions that may arise in the future, but with changes in economic or other factors, their use eventually may be feasible.

Class 3 lands, as classified in this work, should all be excluded from any plans for irrigation. It may be that ultimately something can be done with them, but the small prospect of this and the long time before it may occur do not justify present expenditures on their account. While it is very doubtful if Class 3 lands ever will justify irrigation, except with water at very low cost, they represent areas where the uncertainties regarding the future justify a higher rating than the nonirrigable lands of Class 5.

Class 4 Lands—Class 4 was used in this work to cover a local crop practice, as well as soil properties. These are the flooded pastures or so-called grass lands. There are large areas now flooded with surplus waters for such pasturage as may be obtainable where the quality of the land does not justify attempts at cultivated crops. Due to such flooding, a rating as nonirrigable is not justified; neither would a rating indicating the land to be suited for irrigation of ordinary crops be applicable. The Class 4 rating has been used also for lands not now flooded for pasture, but of similar quality and suitable for such flooding if water at very low cost were available. The Class 4 lands occur mainly along the San Joaquin River where such flooding is an extensive practice.

The value of such use of the grass lands is quite small. The usual condition is that of swamping at times of plentiful water supply rather than periodic applications. As the amount of water used is large in relation to the returns, such lands are suited only to localities having surplus flood waters not needed for higher types of use. These lands are generally alkaline and unproductive in general crops. Except to some extent for rice, Class 4 lands if rated for general crops would be mainly Class 5 with some Class 3. Class 4 lands are necessarily smooth enough for flooding as the value of their use will not justify leveling.

Class 5 Lands—Class 5 has been used for lands of such poor quality that the probability of any future use is regarded as too remote to justify consideration. It represents lands permanently nonirrigable as far as may be foreseen at this time. They should not be considered for irrigation service in any plans for irrigation. There may be an occasional spot of somewhat better land included in Class 5 areas, but such spots are too small, few or scattered to justify their segregation for irrigation. Class 5 land is now mainly used, to such extent as it is used at all, for dry pasture.

Factors Affecting Classification.

The value of land under irrigation is affected by soil texture, alkali, hardpan, roughness and fertility. The variations in these factors for the lands in the San Joaquin Valley, with their effect on the resulting classification, are discussed for the valley as a whole, followed by description of the general conditions in local areas.

Soil Texture—In general the San Joaquin Valley is surrounded by rough and stony areas that are nonagricultural. Adjacent to and below these areas disintegration has occurred to a sufficient depth to result in soils of residual type. Below these are old valley filling materials which have been modified in place. While these old valley filling materials have adequate general depth, hardpan is widely distributed in several of the soil series. Below and in some cases across the old valley filling soils are the recent alluvial types which extend along the tributary stream channels to the valley trough. In the valley trough the soils in the lower areas are generally heavier textured alluviums deposited under submergence or semisubmergence. These soils are partly old valley filling material and partly recent alluvial soils. There also are some areas of wind laid materials.

The areas covered in this field work are included in the three reconnaissance soil survey reports on the San Joaquin Valley by the U. S. Bureau of Soils and the California Agricultural Experiment Station. These reports and maps were utilized in this classification as the basis of soil texture. The following comments on soil types are based very largely on the U. S. Soil Survey.

Residual soils are generally unimportant in the areas covered in the present classification. This is due to their roughness and steepness, as well as to their shallow depth. For the small mean annual rainfall in the San Joaquin Valley, the residual soils have not disintegrated to a sufficient depth to form Class 1 land. Where conditions in local areas were considered to justify it some residual soils on the east side of the valley have been rated as high as Class 2. There are some similar residual soils rated as high as Class 2 on the west side. However, the main intrusions of residual soil into the valley, such as Kettleman Hills, were rated as Class 3 or 5 because of roughness.

The old valley filling soils represent the largest area of any general type of irrigable lands in the San Joaquin Valley. These soils are derived from unconsolidated water laid deposits, which have been subject to change since their deposition due to weathering, leaching and translocation of materials.

Of the several series of old valley filling soils, shown on the U. S. Soil Map, two—the San Joaquin and Madera series—are underlaid by the red or iron cemented types of hardpan. This hardpan in its typical form does not disintegrate under irrigation and is an important factor in root and moisture penetration. If broken, it does not recement. For dry farming, it may be an aid in retaining moisture, for irrigation it retards percolation and limits root penetration. It may be continuous or irregular and may be underlaid by soil or other rock. It may occur as thin strata easily broken by subsoiling or as thick masses impractical of removal. Blasting for trees has been practiced in many areas. This type of hardpan land covers extensive areas on the east side of the valley from Tulare County north. Much of the present orchard and vineyard development is on these lands. For the smoother areas with hardpan not too close to the surface or too thick to prevent good crop results, many areas were rated Class 1. Other areas were rated as Class 2 or 3, depending on the character of the hardpan. A somewhat more liberal rating was used for developed areas where the cost of preparation of the land had been incurred, than for areas where the expense of such work would retard settlement.

The Fresno series of old valley filling soils contains a compact silty subsoil equivalent to a hardpan. This is an extensively distributed soil and occurs on many well developed areas. This hardpan being silty and calcareous, blasting and subsoiling are not permanently effective in breaking it. It is generally not as continuous as that of the red type. The Fresno soils frequently contain alkali which reduces their rating. Where free from alkali these soils, except for some of the sandier areas, generally rate as Class 1.

There are other series of old valley filling soils, which do not contain hardpan extensively and are usually free from alkali. These are more extensive on the east side of the southern part of the valley. These rate Class 1 unless rough.

Some of the soils in the valley trough, which have not been modified by recent deposits of alluvium, are also classed as old valley filling types. These are usually fairly heavy in texture. Their quality varies with the extent of former submergence. The frequently submerged areas are generally of better quality with less alkali.

The Soil Survey uses the term "recent alluvial" to describe soils derived from recent stream deposits that have undergone little, if any, change by weathering since they were laid down. They occur on the areas affected by the present or recent channels of the principal streams. The Panoche series covers most of the west side plains area. These are derived from erosion in the Coast Range. The Hanford series are derived mainly from granitic rocks and vary from sands to sandy loams. Where well drained and free from alkali they are among the best soils in the valley.

In addition to the types described above, there are some areas of wind laid and lake laid materials.

Crop Adaptability—There are some lands of poorer quality for which it is difficult to assign any single defect. These lands may produce a good crop for a short period, but are unable to maintain good yields. A separate suffix was used on the field maps to indicate this condition where it resulted in lower ratings. Such lands are usually excessively sandy or have inert subsoils. Many of the more sandy soils are rated below Class 1 because of roughness, rather than general texture. General infertility was used to reduce some areas to Class 2.

Crop adaptability, as affected by climatic conditions, affects the value of land for irrigation. Such climatic factors as frost hazard are preferably rated separately from the quality of the land. A somewhat more liberal rating for roughness or hardpan was used in some areas suitable for citrus as the cost of leveling would be a less important item in such areas. Somewhat rougher lands were rated as Class 1 in areas where furrow crops, such as orchards, are to be anticipated, than in areas where flooded crops would probably be grown. The differences allowed were small, however.

Similarly, liability of overflow was not used as a factor in rating the land itself. Prevention of such overflow in such areas represents part of the cost of development to be considered with the cost of its water supply for irrigation.

Alkali—Alkali is widely distributed in the San Joaquin Valley. It occurs in amounts varying from slight to very heavy concentrations. In many areas the lines of demarcation along the boundaries of alkali areas are definite and easily located in the field. In other areas the quality of the land changes slowly and the divisions are difficult to make.

Continuous alkali is less difficult to classify. However, in many areas the alkali is spotted. Fields in which good crops may be grown on much of the area are to be found, with spots on which little or no yield can be obtained, so intermingled that detail classification is not practicable. For such areas average ratings were used.

Lands have become alkaline from both natural and artificial causes. Lower lands along streams are frequently alkaline from naturally high ground water or overflow. Other areas have become alkaline due to the rise of ground water resulting from irrigation. Ground water conditions change and this changes alkali conditions. Recent changes have generally been toward a lowering of the ground water and an improvement in alkali conditions. Methods of neutralizing or removing alkali also are being improved. These conditions make it difficult to rate alkali lands where long periods may elapse before the purposes of the classification are accomplished. The following general basis was used in this work:

1. It is not considered probable that additional areas will become alkaline. Extensive pumping is controlling and will continue to control the ground water and additional water logged areas need not be feared.
2. Lands heavily alkaline from natural causes prior to irrigation have not been reclaimed and can not be expected to be reclaimed by any practical means now in prospect.
3. Lands which have become alkaline due to irrigation may be restored by drainage, leaching, cropping or other treatment. Such restoration will be slow and expensive where the injury has been extensive. It will be difficult on lands having impervious strata interfering with leaching. Such lands do not justify any higher rating than those naturally alkaline.
4. Lands injured by alkali from irrigation, which are free from hardpan or other impervious subsoils and where the alkali is not large in amount, may be gradually restored by the maintenance of a lowered water table and proper soil treatment. The time required and cost, however, will not justify a high rating on such lands. Improvements in ground water conditions and in methods of alkali treatment will not justify rating alkali lands much higher than their present condition, but have been used to place some Class 2 lands in Class 1 minus and some better

present Class 3 lands in Class 2. The ratings used on Class 2 alkali lands in this work are considered to be as liberal as can be justified. Such lands are not suitable for inclusion in projects of high irrigation cost. Alkali removal represents a present expense for removal and a continuous loss in crop return over several years while production is being restored to normal. While the present status of alkali reclamation may justify some hopes for such ultimate restoration, such reclamation will be slow and expensive and lands now alkali can be given only limited recognition for such prospects.

Roughness—There are several kinds of roughness that affect the quality of land in this area. Along the overflow channels of the larger streams are lands that are channel cut to a sufficient extent to affect the cultivable area. The smoother portions may rate Class 1, but there may be enough lost area to justify an average rating of Class 2.

There are also extensive areas of "hog wallow" land. This term is applied to lands having hummocks and depressions with difference in elevation two to four feet spaced 25 to 50 feet apart. The size, spacing and height vary. Such lands occur mainly on the older valley filling soils underlaid by hardpan. Where the general area is smooth the leveling of "hog wallows" alone is not difficult. Much of the hog wallow land is also rolling and with shallow hardpan which interferes with leveling. Hog wallows alone would not materially reduce the rating of the land but in combination with rolling topography and hardpan they result in many areas of Class 2. Such rating was used for undeveloped lands where the costs of preparation for irrigation would retard development.

General roughness is found in areas along the sides of the valley. Reduced ratings for roughness were used where the cost of leveling would be excessive or where the general topography would require adapting the distribution of water to the land with resulting irregular areas and higher costs for application. The area covered in this work did not include much land of steep slope, except for included hill areas such as Kettleman Hills. Usually the steeper lands also are rough and shallow so that the reduced rating is due to a combination of factors. Such hill areas generally rate in Class 3 or 5.

Description of Lands by Local Areas.

The application of the standards of classification used can best be described by local areas. In the other portions of the water resources investigations the valley areas have been divided into hydrographic divisions. These are shown on Plate VI and have been used as the basis for the following descriptions. The hydrographic divisions are numbered from the south to the north.

Hydrographic Division 1—The area of Hydrographic Division No. 1 agrees with the part of Kern County in the San Joaquin Valley, except that the north three miles of the county is in Division No. 2.

Division No. 1 includes a wide variety of soils. On the east side the area of generally tertiary formation results in a zone of rolling, soil-covered hills before the rough and rocky land is reached. Residual soils occupy the higher areas. There are old valley filling soils on the higher valley lands with recent alluvial types on the stream deltas. The trough lands extending northward from Buena Vista Slough are older sedimentary soils. In general, there is less hardpan land than in the counties to the north. Alkali is widely distributed.

On the east side, north of Kern River and above present canals, the soils are free from hardpan and alkali. Much of the area would make good orchard land. For such use the rolling topography would not be as disadvantageous as for field crops. There is no definite topographic basis for fixing the upper line of the irrigable area. The area covered in this work probably goes higher than necessary for practical uses. Class 1 was used until roughness reduced the quality to Class 2. The areas under the present canals and under pumping plants near Shafter, Wasco and McFarland consist of a large body of good land fully justifying a Class 1 rating. Present development extends westward to the beginning of alkali soils.

Between the Class 1 land on the east and the lands along Buena Vista Slough is a wide area of poor land. This includes Buttonwillow and Semitropic ridges. Numerous efforts at irrigation from wells have been made, and many abandoned farms occur. Nearer the better lands on the east a generally narrow strip was rated as Class 2. The remainder was generally rated as Classes 3 and 5 as shown on the land classification map. This area does not justify consideration for irrigation. Along Goose Lake Slough are some better areas, but none justify a Class 1 rating.

The trough lands extending northwestward from Buena Vista Lake are rated Class 1 at the south with decreasing quality toward the north. The trough lands suited to irrigation are south of Wasco Road, except for a small area of Class 2 land near the north line of the division, which is within the area affected by Tulare Lake.

The west side plains consist of Panoche soil series. This is all rated as Class 1, except where roughness requires a lower rating.

The recent alluvial soils of Kern Delta have been rated in Classes 1 to 5. The different classes are badly mixed and are difficult to segregate. Much of the area regularly irrigated has a generally high ground water level which has resulted in reduced production. Prior to irrigation, the upper delta lands would have rated Class 1 and it is thought that with drainage much of this area can be restored to this class. Up to the present time drainage has not been undertaken. For its present condition the areas of Class 1 land are limited and the larger part of the present canal-served lands rate as Class 2.

The former bed of Kern Lake was rated as Class 1. Although the ground water level is high, alkali accumulation has not occurred at the surface. There is an area of very heavily alkaline land extending around the south of Kern Lake and between the canal-served areas south of Bakersfield, which is rated as Class 5. The lower portions of the delta near Buena Vista Lake also contain much alkali and have been rated as Class 3 or 5.

Buena Vista Lake rates as Class 1 for the lower portions, as far as soil is concerned, but is subject to submergence in years of large stream flow. In general, the upper soils high enough to have had natural drainage and the depressions subject to regular and deeper submergence are good land, except as some areas may have been injured by overirrigation. Intermediate areas of naturally high ground water level or marginal to the areas of regular submergence are heavily alkaline.

The higher slopes around the south end of the valley are generally Class 1. This includes the developed areas near Arvin and the south end around to the oil fields near Taft. The Class 1 rating applies out to the edge of the valley lands where steepness or roughness results in lower grades. There are minor areas of cultivable land on some of the local side streams which were not covered in this work as they are above the San Joaquin Valley area.

Hydrographic Division 2 — This division covers the southern portion of Tulare and Kings counties. The eastern portion of the division rates mainly as Class 1. It includes the upper portion of the Tule River Delta and the higher valley lands to the south. The upper delta lands are recent alluvial soils. The remainder of the higher lands are old valley filling soils. These are of the red hardpan types in the northern portion. The areas toward the south consist of soils relatively free from hardpan. At the north, the valley lands extend east to the contact with rough and stony land as classified by the U. S. Soil Survey. This represents the outcrop of the granitic formations of the higher areas. Toward the south end of this division, there is an intermediate area of tertiary formation between the valley and the higher foothills which consists mainly of residual soils. The upper limit of irrigable land is less definite here. The field work was extended as far as justified by practical considerations. The valley lands were generally rated as Class 1. This rating is fully applicable in the developed areas where any costs for leveling or breaking hardpan have already been incurred. Some undeveloped rougher areas were given a lower rating. Much of these higher lands are adapted to citrus culture and justify a more liberal rating on cost factors because of this, although little difference due to crop adaptibility was made in this work.

The smaller streams in the southern part of this division have not had sufficient flow to form deltas of any extent. The valley filling soils are less disturbed in this area. The outer areas in which the local run-off has spread contain Class 2 and 3 land, due to alkali in areas where such waters have collected.

The western portion of southern Tulare County approaches the general trough of the valley. The Class 1 lands of the upper deltas give way to the poorer lands of the outer deltas. These outer areas were not subject to sufficiently continuous or deep submergence to form the better type of lake bed land. Some areas have practically no agricultural value and were rated as Class 5, particularly in the southwestern part of the county. Marginal areas of Class 3 and Class 2 were rated as shown on Plate V. These lands of lower rating are all alkaline.

The southwestern portion of the division is within the area affected by Tulare Lake. The prevailing winds across Tulare Lake are from the northwest. There is a wide beach area at the southeast of the lake. The higher portions are not generally alkaline, although some alkali areas occur. Some of these lands do not show well sustained crop yields and were rated Class 2 because of such general conditions, rather than roughness or alkali. There is only limited irrigation in this area at present, except that of the Alpaugh Irrigation District. The better lands in this district were rated as Class 1, although they are not equal to the better Class 1 lands as this grade was used in this work.

The southern part of Tulare Lake is included in this division. The lower lands in the lake rate as Class 1, subject to their liability to overflow in years of large run-off. There is a marginal area of poorer land at the southwest side of the lake before the Class 1 lands of the west side plains are reached. The Class 1 area east of Kettleman Hills is relatively narrow. West of the outlying hills are some additional Class 1 valley lands. The hills are rated mainly as Class 5 because of roughness, but a few areas of better land occur.

Hydrographic Division 3—This division covers the Kaweah River Delta and adjacent higher valley lands to the east. The valley extends eastward to the contact with the granitic outcrop. Higher lands, except along the stream courses, are classified as rough and stony areas on the U. S. Soil Maps. These would rate as Class 5 due to roughness and shallow soil.

The higher valley lands, except where Kaweah River has eroded them, are generally old valley filling soils containing the red hardpan. These have generally been rated as Class 1, except for some rougher portions. There is much high class development on these lands.

The upper portions of the Kaweah Delta generally rate as Class 1. Some areas, where high ground water has resulted in alkali accumulation, are rated as Class 2. Parts of the delta consist of spotted soil where detail segregation is difficult. The rating shown includes some spots of Class 2 land in the Class 1 areas, in addition to those large enough to be shown separately.

Around the outer edges of the Kaweah River Delta, the lands are more largely of the lower grades. The outer areas subject to overflow and evaporation are largely alkaline. This generally grades from the Class 1 areas through Classes 2 and 3 to some very heavily alkaline Class 5 land. Only limited areas in this division were rated below Class 3. These areas of poorer land are found between the deltas of Kaweah and Kings rivers and between Kaweah and Tule rivers, as well as around the outer edge of the Kaweah Delta where they extend toward Tulare Lake.

Hydrographic Division 4—This division covers the general Kings River area, from the San Joaquin River on the north to the Kaweah River area on the south, and in the south includes the larger part of the Tulare Lake Basin.

The field work was extended to the outcrop of the granite on the east, which is shown as rough and stony land on the U. S. Soil Map. This represents the eastern limit of valley land. There are only narrow margins of Class 2 and 3 lands along the eastern boundary, as Class 1 areas extend nearly to the valley's edge. Some Class 2 channel cut land is shown along Kings River in Centerville Bottoms. With these exceptions, nearly all the east side area is Class 1 until the lower alkali lands toward the west are reached. Scattered through this area are small depressions, or pot holes, which formerly contained water, but which now are generally dry. Some of these areas are rated as Class 2 or 3.

Westerly from the canal-served areas of the Fresno and Consolidated Irrigation Districts, and extending to the formerly overflowed lands along Fresno Slough, is a large area of generally poor land. Due to high ground water levels, this area is alkaline. The degree of alkali varies, in general increasing toward the lower ground at the northwest. Some alkali extends into the western portions of the Fresno and Consolidated districts. These lands are rated as Class 2, 3 or 5, depending on the extent of the alkali.

Along the various overflow channels of Kings River toward the north, the trough or slough lands are less alkaline and of better quality. The better areas of these lands have been rated as Class 1, although the heavier soil texture and general conditions make such lands less easily handled than the better Class 1 lands of higher elevation. Some areas having alkali or where the cultivable areas are reduced or rough, due to channel cutting, have been rated as Class 2.

South of Kings River, the upper lands are similar to those on the north. These are mainly red hardpan lands now largely developed in the Alta Irrigation District and rated generally as Class 1. These extend eastward to the outcrop of the rough and stony land. There are areas of Class 1 recent alluvial soils near Kings River, northwestward from Hanford. There is a large area of poorer land around the southern side of the Kings River Delta, extending into the area between the deltas of Kings and Kaweah rivers. This is alkaline and rates as Classes 2, 3 or 5, depending on the degree of alkalinity. Some parts of these areas are understood to have been productive in the past; others have always been alkaline. The marginal areas were rated as Class 2. Some of the Class 3 land is similar to Class 5 in its present condition, but was rated Class 3 in recognition of the possibility that methods of reclamation may eventually be developed to restore areas that formerly were productive.

The bed of Tulare Lake is now largely reclaimed and cultivated. Due to the menace of flooding, crops are mainly grain. The lower lake lands and those near the stream inflow are generally of good quality. These have been rated Class 1 for the soil although their value for irrigation also requires consideration of the conditions relating to overflow. Class 1 also was used for the general area near Corcoran, except for some lands of generally poorer quality justifying a Class 2 rating.

Hydrographic Division 5—This division covers the lower west side plains, from Mendota south to Kettleman Hills. The surface is very smooth, with an even slope, so that little leveling is required. Along the east side, the lower areas include the Class 5 self-rising alkali land, so called locally due to the pulverizing of the surface soil when dry. Above the Class 5 land are narrow strips of Class 2 and 3 before the main area of Class 1 is reached.

Hydrographic Division 5B—This division covers the higher portions of the west side plains, from Mendota south to Kettleman Hills. It is not materially different from the adjacent lower portions of the plains in Division No. 5, except for elevation. The main valley area consists of very even and smooth Class 1 lands. The higher portions are of lighter soil texture, which will affect their water requirements. Surface ground water is alkaline and recovery of seepage and percolation losses would be of doubtful practicability in this area. The plains are recent alluvial soil of the Panoche series. The irrigable areas extend slightly into the higher residual soils. These rate Class 2 or lower, due to roughness, steepness and shallowness. The classification was extended into the higher cove valleys around Coalinga as shown on the land classification map.

Hydrographic Division 6—This division covers the lands on the east side of the valley, between San Joaquin and Chowchilla rivers, in Madera County. The area covered in this field work coincides closely on the east side with the boundary of the Division 6. The higher foothill lands are in Division 6A.

The higher valley lands are old valley filling soils, except where cut by local streams. These lands are rolling in surface and contain red hardpan, much of which is thick and occurs at shallow depths. A large part of the less favorable land was rated as Class 3. These are generally the higher lands on which the hardpan is thicker and more difficult to handle than in other areas of similar soil. Areas of less rolling surface, or with deeper or thinner hardpan, were rated as Class 2.

An area of Class 1 land extends across the county between the poorer hardpan lands to the east, and the lower alkaline lands to the west. This area includes some hardpan soils on which existing developments indicate that good crop results have been obtained. At the northwest, near Chowchilla, the lands are mixed Classes 1 and 2, so spotted in character that detail classification was impractical. About two-thirds of this area would rate as Class 1. The division between these lands and the Class 4 areas follows the revised boundary of the Madera Irrigation District, which was based on a similar land classification.

To the west of the Class 1 lands, the alkali increases rapidly. Except for a narrow zone of Class 2 or 3 land, the main area west to the lands near the San Joaquin River was rated as Class 4. This area is now largely flooded for pasture and represents typical land to which the description of Class 4 applies. If not rated as Class 4 for pasture, it would rate as Class 5 for crops.

Near the San Joaquin River, more regular overflow has resulted in better lands. Some of these were rated as Class 1, other areas of generally good soil, but channel cut, were rated as Class 2.

Hydrographic Division 7—This division covers the west side lands from Mendota to Tracy. The south end is a continuation of the Class 1 west side plains of Divisions 5 and 5B. There are narrow strips of Class 2 land along the San Joaquin River.

The west side trough lands extend from near Dos Palos northward to the vicinity of Newman. These lands are of heavy soil containing alkali and rate as Class 4 in the main area. They are known locally as grass lands and are used and useful only for pasture under swamping. Adjacent marginal areas were rated in Classes 2 or 3 where some crop use is or may be developed. The trough lands are located between the higher lands to the west, and the better lands, also higher, near the

San Joaquin River. Along the San Joaquin River are considerable areas of Class 1 land, with other areas rated as Class 2, due to being cut by old channels, although much of the included smoother small areas are Class 1 soil. West of the trough lands the Class 1 higher lands are narrower than the similar areas further south. The field work was carried to the rougher Class 2 and 3 areas toward the west.

From Newman north to Tracy, the west side area is nearly all Class 1. The lands slope up from near the San Joaquin River with no intervening area of low alkali trough lands. Along the river are some areas of Class 2 land, due to channel erosion or alkali. Near the hills the field work was carried through the Class 2 and into the Class 3 rough lands. The Class 1 lands are evenly sloping and require very little leveling for irrigation.

Hydrographic Division 8—This division covers the valley lands on the east side between the Merced and Chowchilla rivers. The field work, on which this report is based, was extended easterly to the Class 5 rolling lands of shallow depth. These upper lands later were reclassified in accordance with the standards used in the foothill areas. The classification herein discussed does not apply to the classification shown on the map for the part of Division 8 lying generally above Amsterdam and Yosemite Lake, and a narrow area along the east edge to the south. The soils in Division No. 8 are more variable than those in the areas to the north or south.

In the eastern part of the area covered, the lands are mainly rolling shallow hardpan soils. The field work was carried through the Class 2 and 3 lands to the higher Class 5 areas, as these classes were defined in this work. Development has proceeded much more slowly on the Class 2 hardpan lands, when water has been made available, than on the adjacent Class 1 areas. Below the Class 2 and 3 land is an area of Class 1 land extending across the division from north to south. Below this is a wide area of alkali land at the south and rough sandy land at the north. The better portions of these areas were rated Class 2. These are now largely in crop with poorer average results than on the Class 1 areas. The Class 3 lands are those rated as of very doubtful usefulness under irrigation. Below these lands are extensive areas useful only for grass land use, which have been rated as Class 4. Near the San Joaquin River are some better areas rated as Class 2. Near Stevinson the land is badly mixed in quality and the rating shown on the map is as definite as it is practicable to make it.

Hydrographic Division 9—This division extends along the east side of the valley from Merced River, north of the Tuolumne River, to include the areas of the Modesto and Waterford Irrigation districts. The field work herein discussed was extended east to the Class 5 rough lands. These later were reclassified with the areas in the foothills by the standards used there. The discussion herein applies only to the part of Division 9 extending eastward to around Dallas Lake, along the Tuolumne River, near Montpelier, and up Dry Creek and Merced River.

The higher east side areas are more mixed in quality than those in other parts of the valley and have been shown in more detail on the map. These higher lands consist partly of old valley filling soils of hardpan type and partly of residual soils. There are some bottom lands along local streams that are fairly smooth. Some of the heavier soils near Paulsell are used for rice. There are some areas too rough or too shallow to be rated higher than Class 5. While some scattered areas of Class 1 occur, the larger part of the better lands were rated as Class 2, with many areas, too poor for consideration in any present project, placed in Class 3. The Class 2 rolling hardpan lands have come into irrigation much more slowly than the adjacent Class 1 areas when canal service has been made available.

There is a wide area of Class 1 land extending across this division, from north to south, between the higher hardpan lands on the east and the poorer areas along the San Joaquin River. This consists largely of Fresno series of soils. It includes the larger part of the areas in the Modesto and Turlock Irrigation districts. Soils of light texture predominate particularly at the south end of the area near Delhi. The rougher portions of the sandy land were rated in Class 2.

Toward the San Joaquin River the soils become alkaline and were rated as Class 2 or 3, depending on the amount of alkali. Along the river some otherwise good lands were rated as Class 2, due to the proportion of the gross area which is channel cut.

Hydrographic Division 11—This division covers lands on the east side of the valley, from Mormon Slough south to the Stanislaus River, together with the lands south of the Stanislaus River in the Oakdale Irrigation District. As in other adjacent divisions further south, the basis of classification used in the valley lands was applied until Class 5 land, by these standards, was reached. The higher lands have been classified by the standards used in the foothill areas to the east. The eastern portion of Division 11, as shown on the map, is not included in the following discussion.

The upper lands covered by this work are shallow hardpan and residual soils rated as Classes 2 or 3. The Class 3 lands were so rated, on hardpan or shallowness and on roughness. The Class 2 areas are usually somewhat rolling as well as having hardpan. Under the irrigation systems in this area, even the Class 2 hardpan lands have come into use very slowly.

Near the San Joaquin River are areas of Class 2, due, in some parts, to alkali and in others to roughness caused by channel cutting. Some Class 2 alkali land extends into the general area of Class 1.

Summary.

The results of the classification of the valley floor lands covered by the survey described in this report and in accordance with the standards set forth herein are summarized by hydrographic divisions in the following table compiled in the office of the State Division of Water Resources.

Class 1 lands are those which are able to meet the maximum costs of irrigation and represent 52 per cent in the upper San Joaquin Valley and 41 per cent in the Lower San Joaquin Valley of the total gross area covered by the survey in each respective portion of the valley. Class 2 lands have some defect in quality, which reduces their ability to meet the costs for water. The average in this class represents, of the total in each respective portion of the valley, 19 per cent in the upper and 28 per cent in the lower San Joaquin Valley. Classes 3, 4 and 5 are lands of too poor quality to justify permanent use of water, even of local supplies, under present economic standards. In aggregate, they include 29 per cent of the gross area in the upper and 31 per cent in lower San Joaquin Valley portions covered by the survey and report.

CLASSIFICATION OF VALLEY FLOOR LANDS IN SAN JOAQUIN RIVER BASIN BY HYDROGRAPHIC DIVISIONS

For land classification areas, see Plate V.
For boundaries of Hydrographic Divisions, see Plate VI.
Figures in table are for areas covered in survey only.

Hydrographic Division	Gross area in acres					
	Class 1	Class 2	Class 3	Class 4	Class 5	Total
Upper San Joaquin Valley—						
1	706,141	316,259	310,923	5,565	240,077	1,578,965
2	469,971	231,305	111,842		138,051	951,169
3	233,749	101,976	45,961		14,525	396,211
4	793,482	237,200	167,487	8,963	164,237	1,371,369
5	304,316	21,034	22,950		53,576	401,876
5B	239,182	37,608	8,628		25,592	311,010
6	140,061	106,160	104,897	156,135	11,371	518,624
Lower San Joaquin Valley—						
7	305,700	124,149	63,342	128,901	1,173	623,265
8	114,416	154,078	83,753	85,201	3,382	440,830
9	184,062	134,732	95,686		16,922	431,402
11	160,560	106,630	76,845		7,395	351,430

APPENDIX B

GEOLOGY AND UNDERGROUND WATER STORAGE CAPACITY OF SAN JOAQUIN VALLEY

by

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July, 1930

34—80997

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GEOLOGY AND UNDERGROUND WATER STORAGE CAPACITY OF SAN JOAQUIN VALLEY

The object of this investigation and report is the determination of the locations and capacities of underground water storage reservoirs which may be utilized in the irrigation development of the San Joaquin Valley. The study divides itself logically into two parts; first, that of the general geology of the region through which the underground storage areas can be broadly delineated and, second, the detailed consideration of local areas to establish the location of underground storage reservoirs, to estimate their capacity and to determine the practicability of their utilization for the storage and extraction of water supplies in irrigation development.

GENERAL GEOLOGY

The geologic history of the San Joaquin Valley is determined in part through the study of the geologic structure and formations of the mountain ranges bordering the valley plain, in part through the study of the present surface topography, in part through the study of the characteristics of the material penetrated in well drilling, but in a large part through the study of the chemical character and temperature of waters brought up from varying depths and horizons through water wells, and the well water levels under varying conditions of pumping or nonpumping and seasonal or cyclic changes.

Taking up first the geologic history of the San Joaquin Valley, as revealed by geologic evidences read from the formations and their structure, as exposed over the Coast Range, and the geologic development of the Sierra Nevada briefly, it is found that during late Cretaceous time the Franciscan rocks protruded above the sea from a point south of Livermore as an elongated island some 15 to 20 miles wide at the north and extending with lesser widths southeasterly to a point west of Tulare Lake. The Sierra Nevada area consisted of granitic intrusions in older crustal rocks whose height separated the Great Basin from the sea. Lying between the Sierra Nevada shore line and the islands was the San Joaquin geosynclinal trough. At the close of Cretaceous time occurred the Coast Range uplift which entirely enclosed the central geosynclinal trough except at the southern end.

The accumulation of a great thickness of sediments, derived through erosion from the Sierra Nevada and Coast Range areas, continued uninterrupted in this geosynclinal trough under varying crustal conditions until late Tertiary time. These crustal conditions consisted largely of the depression of the continental areas after deposition built up the floor of the geosynclinal trough near the land bodies. The body of water occupying the trough varied in depth and in character from a deep channel to a land locked gulf during all this time, never losing, however, its marine character and the sediments laid down were marine deposits.

From the late Tertiary through Pleistocene time occurred the mountain-making uplift, which was an earth movement of great magnitude and which raised the Sierra Nevada to their present height. It was accompanied by volcanic activity and outflow of lava over wide areas, the rejuvenation of the Sierra drainage with its development of the present Sierra topography, and the uplift of the deformation of the sediments laid down on the floor of the sea, resulting in the land mass of the Coast Ranges and Coast Valleys and the development of the Tehachapi Mountains enclosing the valley on the south.

Geologic Structure.

In a broad way, the structure of the Diablo or Coast Range is anticlinal and its eastern flank is composed of a great monocline of sedimentary strata dipping toward the San Joaquin Valley. This monocline is broken in regularity, through being subjected to compressional forces, by a series of anticlinal and synclinal folds, the most easterly of those now exposed being the Kettleman Hills-Coalinga anticline and which is continued in the Lost Hills structure.

The Tertiary uplift of the Sierra raised the western flank, without distortion or displacement, above sea level and the marine sediments lie exposed against the Sierra north of the San Joaquin River as a series of unaltered beds of clay, shale, loosely cemented sandstones and gravelly formations. The Fresno, Chowchilla, Merced, Tuolumne, Stanislaus, Calaveras and Mokelumne rivers are all intrenched in these formations at their upper valley portions. This area, that embracing the Coast Range uplands and the San Joaquin Valley trough intervening, laid beneath the sea during the major portion of geologic time from the Jurassic to the end of the Miocene. Consequently, the marine sediments found exposed and eroded over the uplands should lie, with possibly some variation as to thickness, in the same geologic sequence under the entire San Joaquin Valley region. Through uplift they have been brought relatively close to sea level over portions of the valley trough. The compressive forces accompanying the uplift found relief through possibly additional folding and faulting in the valley trough area parallel to the Coast Range structural trend. All of this structure and marine sedimentary bedding now is buried under a thickness of alluvium and the buried geologic features are largely controlling in the ground water hydrology of the region. The buried features have not all been revealed, but with continued deep well exploration in search of petroleum the knowledge of subsurface conditions is being continually augmented. In the present state of knowledge certain structure features have been established, possibly with some indefiniteness, but sufficiently to be used as a guide in the present study. These may be enumerated as follows:

(1) A profound fault displacement with the downthrow on the west extending from one of the northwest-southeast faults of the Tehachapi Mountains, possibly the Poso Creek fault, northerly along a line which passes in the vicinity of Corcoran, Mendota and Tracy.

(2) The block displacement along this line has caused both blocks to rise toward the north, the depth to marine sediments of a given age, which has no indication on the surface, becoming increasingly greater southerly.

(3) General uplift of the Sierra Nevada, raising their western flank to elevations above sea level.

(4) Possibly some additional folding due to compression of the beds west of the fault, raising portions of the buried marine sediments closer to the present ground surface.

(5) A long period of stability during late Tertiary and Pleistocene time during which detrital material was carried down to the valley, building up a great valley plain to heights well above sea level, followed by a subsidence (still in progress) in the valley area along the valley fault, causing the Sierra streams to achieve new base levels and favoring the erosion of their older alluvial cones nearer the mountains and deposition of modern alluvium at lower elevations, which all presented:

(6) A rugged or uneven topography now partially buried by the more or less uniform geologically modern sediments of the San Joaquin Valley plain.

Valley Sediments.

The sediments that lie beneath the floor of the San Joaquin Valley vary somewhat in their physical characteristics and density through the upper thousand feet, and the mineral content of the waters contained therein vary with the conditions under which they were laid down and the physical character of the sediments. The material brought from the Sierra was carried into bodies of water. The heaviest boulders and gravel were dropped close to the Sierra shores, building up a subaqueous delta, which, as it grew in proportion, finally extended as a land body into the water body. Great thicknesses of finer sediments, however, were first distributed over the bottom of the inland branch of the sea and later over the bottom of the large fresh water lakes which occupied the San Joaquin Valley trough. Off-shore currents sorted and distributed these sediments into thicknesses of sands and clays. Upon consolidation, which varied with the age, the beds changed to loosely cemented sandstone and shale and entrapped the waters, salt or fresh, in which they had been deposited.

The San Joaquin River and its northerly lying tributaries have been sufficiently constant in carrying large quantities of water to maintain an open drainage channel through the San Joaquin Valley to Suisun Bay. The extensive deltas of the Kings, Kaweah and Tule rivers have continuously built land bodies outward into water bodies from the Sierra foothills and recent alluvial deposits have covered over the older formations exposed to the north and south. At Lindsay, wells of a few hundred feet in depth penetrate to or into marine deposits and yield salty water. Between the Tule and Kern rivers there is no important drainage. Tertiary beds of soft sandstone, clay and gravel bordering the Sierra are there exposed. The Kern River is intrenched in its upper valley portion in these older formations, but has built up a great alluvial delta over the southern portion of the San Joaquin Valley.

During the period of sedimentation, while the marine conditions were being displaced by fresh water conditions, the sediments laid down were those embraced within what is now known as the Tulare formation. The base of the formation is marine in origin and yields fossil shells and salty water. It differs from the older formations, so far referred to, in that the origin is in part marine, in part fresh water and in part probably subaerial. It is marked, at its marginal positions along the valley, by the prevalence of prominent beds of boulder gravel, which is more coarse and abundant than in any of the Tertiary formations. It probably marks the transition from salt to fresh water conditions to the establishment of present land conditions. Distortion, tilting and displacement continued for a long period over the Coast Range region and the Tulare formation, in its later subaerial and fresh water phases as well as marine, is raised and exposed in the Kettleman Hills. This formation is slightly consolidated, but otherwise it does not vary in its physical characteristics from the alluvial material which makes up the present surface of the valley floor.

Surface Topography.

The more recent geologic history is revealed to some extent by the present surface topography of the valley. The history of the Sierra streams has changed with the occurrence of crustal movement and climatic changes. Prior to the late Tertiary uplift, Sierra slopes were gentle; sedimentation took place in part upon land surfaces and great bodies of sand and gravel were deposited by the streams along their channels. After the disturbance, the streams cut new channels, abandoning these old sand and gravel bodies, some of which had been buried by lava flows. These bodies are known as the Tertiary gravels, from which gold has been obtained through placer mining developments. The more southerly Sierra streams became rejuvenated and, with increased slope, their powers of erosion were greatly increased. All the Sierra streams, and Coast Range streams as well, have carried far greater quantities of water and enormously greater loads of sediment than they now carry.

The climate over the region during early Quaternary time was cold and humid. Great ice sheets protruded far into the United States and glaciers of the Alpine type covered the high Sierra. The melting of the glaciers, as the climate tended to the semi-arid, established the Sierra drainage and great quantities of sediment were carried into and through the San Joaquin Valley trough from the Sierra. In the past, as now, rainfall decreased southerly. The streams south of the San Joaquin River were less constant in flow, subject to wide variation seasonally and within the season as to quantity of water carried. Glaciers were not as heavy nor did they descend to as low an elevation as further north. Hence through drainage, as existed for the northerly streams, was not established by the Kings River and those to the south. Furthermore, few northerly Sierra streams were opposed by any important drainage from the west, while great stream deltas, such as those of Kings River and Los Gatos Creek, were built up in the south to oppose each other through deposition of sediments until they protruded above the surface of the sea and divided the valley into great basins. The fresh water of the streams was discharged into these basins, displacing the salt water until there were formed large fresh water lakes.

The San Joaquin River flows in a southwesterly direction to Mendota, thence turns northwesterly, probably controlled by the geologic structure, to collect the water of its tributaries. From the San Joaquin River north the surface topography reveals the past history. While fluctuating lakes existed in this region, they were better drained and were not the continuous and extensive features as were those to the south. South of the San Joaquin River, the Kings, Kaweah and Tule rivers and minor creeks, and the Kern River have built up great alluvial fans or deltas at the base of the Sierra Nevada on the east, while Los Gatos Creek has done the same thing from the west. The fans or deltas extend into the Tulare Lake Basin and retain the water from these streams, at least temporarily, in the area. The sediments have been largely retained, resulting in the alluviation of an extensive structural depression. Sedimentation has continued to build up delta barriers and raise the bottom of the fresh water lakes until the whole valley floor has been brought up to its present level and condition.

The climate, tending toward the arid, has been characterized by wet and dry cycles such as are being experienced at present. The northerly lakes, being better drained, were intermittent in character, depending upon wet cycles for their lake characteristics and in dry cycles being reduced to swamps. Wind blown sand, carried over these swamps, formed the sand beds that, with the next wet cycle, were covered by lake waters which deposited a clay bed over them. The intermittency of flow and the building up of delta barriers have favored the occurrence of more constant large bodies of fresh water south of the San Joaquin River. The surface of these lakes has fluctuated in elevation and extent with the occurrence and recurrence of wet and dry cycles, but they have been present to some extent during the process of the upbuilding of the valley right up to the present time. During dry cycles the stream deposits have been laid down over dry lake beds, and wind-blown sands have covered dry lake or swamp areas and built up a broad level plain area through which many drainage sloughs passed. Between this plain and the Sierra foothill belt, in which the streams have entrenched themselves, are limited areas of stream built alluvial fans or deltas. West of the plain, north of Mendota, there has been built up a piedmont slope to the Coast Range which is fairly uniform and lacking in extensive alluvial fan or cone development.

Throughout a long period of Quaternary time this process was proceeding until a great valley plain was built up to well above sea level and occupying the present area of the Sacramento and San Joaquin valleys. Modern geologic time has been marked by a continued, gradual subsidence of the central valley area and San Francisco Bay area, being greater in amount (over 300 feet) at the Golden Gate and decreasing north and south along the coast and along the valley fault. This subsidence has allowed the intrusion of sea water into the San Francisco Bay and the San Joaquin Delta regions. It caused the Sierra streams to achieve new base levels and favored the erosion of their older alluvial cones at their apexes, leaving those surfaces as boulder capped hills in the foothills and compact (Madera and San Joaquin type) soil areas on the upper plains bordering the entrenched modern stream channels, with the lower plains being composed of a cover of open recent alluvial deposits (Hanford soil type) marking the geologically modern alluvial fans of the Sierra streams.

Well Penetration Records.

The fresh water lake condition of the trough of the San Joaquin Valley has disappeared to some extent through climatic changes, but largely because man has diverted the waters which formerly passed directly down stream channels to replenish the lakes, and has spread them widely over the valley to be dissipated through evaporation and plant transpiration and absorbed by the porous sediments. The connecting swamps have been drained through the excavation of channels.

Past conditions are readily discernible from the present surface topography, and in addition lake bed, or, as they are termed, lacustrine materials, are uniformly brought up from relatively shallow wells over the central portion of the valley.

It is usual for the logs of wells in the trough area to show alternate bedding of sands and clays that, with depth, are consolidated into shaley or cemented, packed, or hard beds which can be readily identified as indicating lacustrine conditions. The clay beds, being lacustrine in origin, while not constituting a wide spread unbroken blanket at one level, are extensive and continuous in contrast to the higher lying and overlying lenticular bodies of clay found in stream-formed alluvial deposits. Furthermore, being laid down as finely divided mud underneath water, they contain no living vegetable matter and are quite impervious in contrast to alluvial clays, which contain numerous openings due to shrinkage upon drying and the rotting out of rootlets and other vegetable growths.

For that reason, throughout the east central portion of the San Joaquin Valley from Buena Vista Lake north, wells which penetrate to depths in excess of 100 to 150 feet enter into a horizon in which the materials were laid down, at least to 600 feet in depth, under more uniform conditions of lake bed distribution alternating with alluvial deposition. The materials making up this horizon, although permeable and saturated, resist the upward or downward movement of water so strenuously that for all practical purposes its shingle-like structure separates it from the overlying alluvium. The water originally contained in this horizon was so confined by the resistance of the materials to direct upward movement that it developed a head which a well, on removing the resistant material, allows to be registered as artesian flow or water level. Similarly, when water is pumped from the horizon and the pressure reduced, provided the well casings are not perforated at higher levels, the same resistance that developed the head prevents the surface ground water from lowering to the horizon drawn upon.

The full thickness of the marine sediments is not known, but wells drilled in the valley have penetrated to them and into them, bringing up fossil evidence and producing water whose chief mineral constituents are marine salts. Due to the fault displacement, the marine sediments are reached at greater depth over the southwesterly portion of the valley and in the Tulare Lake region than on the east side and in the north end of the valley, yet the deeper water wells on the west side and in the Tulare Lake region penetrate into beds of Tertiary age and yield salty water and carbonic and hydrocarbon gasses.

Three wells drilled by the Associated Oil Company east of the fault on Sections 26 and 14 of Township 15 South, Range 18 East, and Section 35, Township 13 South, Range 16 East, which lie south and west of Fresno, to depths around 6000 feet showed that fine grained shales, sandy shale and coarse sand, without organisms, were to be found from the surface to about 4000 feet. This represents the Recent alluvium, Tulare and Etchegoin Pliocene formations, with probably the Recent and Tulare occupying the first 3000 feet. As the Tulare formation varies in thickness from 2000 to 3000 feet along exposed sections near Coalinga and cores were not taken above 1800 feet in the wells drilled, it is impossible to determine the thickness of Recent alluvium overlying the Tulare from these or other oil drilling records. In fact, well logs are of little aid in this relation, as there is but little physical distinction between the two formations.

GROUND WATER RESERVOIRS OF THE SAN JOAQUIN VALLEY

It is apparent, from the geologic history of the region, that the San Joaquin Valley, as outlined by its present-day surface, is not a unit mass of unconsolidated sediments which will readily absorb water passing over the surface and transmit it uniformly throughout and to great depth. Rather, it is made up of a great many aquifers of varying types, which may consist of formations in whole or in part water-bearing. These aquifers all have distinctive properties in relation to the absorption, retention and transmission of water. They may be separated from each other laterally or horizontally, or both, by non-water bearing or relatively impermeable formations or parts of formations; and there exist areas, horizons and zones in which the ground water contained has widely variant physical and chemical properties. For example, the water derived by pumping from the sand beds within the Tulare horizon or more recent lacustrine deposits is free to circulate within them and has been and may be fed into them laterally from the coarse material of the upper or higher portions of stream deltas over wide areas which have free horizontal connection with those sand beds. Vertical replacement or replenishment, however, can only take place in the sand beds beyond the limit of their confining clay beds. This phenomenon has been proved through the physical effect of pumping for drainage from the Turlock Irrigation District south.

Areas of the Valley Not Adapted to Ground Water Storage.

The areas of the San Joaquin Valley adapted to ground water storage are those which will readily absorb the water passed over their surface to replenish water drawn from storage for irrigation use. Such areas can be defined broadly through the elimination of areas not so adapted.

That area lying west of the valley fault, the eastern boundary of which is a line extending southeastward from Newman to Corcoran, with a width of five miles at Newman and 20 miles or more at Corcoran, is not adapted to the desired use. The waters from shallow wells in the recent delta deposits of the Sierra streams are uniformly soft, while waters from shallow wells on Los Gatos Creek fan and those to the north, which are fed by streams from the Coast Range, are high in sulphates and low in HCO_3 and Cl. The Tulare formation and marine sediments are reached at relatively shallow depths over the area and the deep wells—over 400 to 500 feet deep—contain no sulphates, but are high in HCO_3, with the alkali bases exceeding the calcium and magnesium content. The deepest wells—from 800 feet up—are bringing up marine water high in chlorine and containing other toxic salts (Boron). The soils of this area are inclined to be hard and contain somewhat impervious or hardpan layers in which the salts, including possibly those that are toxic in effect, have accumulated.

Surface water spread in irrigation over this area must be kept in downward circulation and the area thoroughly drained by pumping and wasting the recovered water into the San Joaquin River, where it can be mixed with large quantities of fresh water. Unless such provision is made to keep the salt content down and remove it from the soil there will occur pronounced crop injury. It might be stated that with the use of well water in this area to date, with few exceptions, the salt concentration in the top soil has become sufficient to injure certain crops.

The Tulare Lake bed area and its continuation southerly to the Buena Vista Lake bed area is not adapted to ground water replenishment. The encroachment of the deltas of the Kings, Kaweah, Tule and Kern rivers over the lacustrine deposits has superimposed recent alluvial sediments of shallow thickness, but as a general rule thickness sufficient to be adapted to ground water charge and recovery lies northeast of a line passing through Corcoran, Alpaugh, Semitropic, along Goose Lake Slough to Connor, thence eastward.

Types of Ground Water Reservoirs.

It might be well to consider the type and character of the recent alluvial deposits now occupying the uppermost thickness of the San Joaquin Valley in relation to their ability to absorb, contain and deliver water.

First, the series of topographic depressions which were filled with water, either marine or through stream flow from the surrounding land. Material in suspension carried into the depressions was deposited and the material in solution concentrated by evaporation so as to be precipitated. In this way the depressions in time were completely filled. Such deposits contain materials of such a cemented and compact nature as to be rendered relatively impervious. Where a stream entered the bodies of water the current was checked, but not immediately stopped, at its mouth. If the stream carried abundant sediments, much of the heavier material would be dropped at the first checking of velocity and deposition would continue from the stream current as it became more and more checked and diffused through the body of standing water. At the same time the building up of the delta land tended to check the current in the upper channel and thus alluvial deposits, continuous with the delta, were extended landward.

In the course of the upbuilding of such deltas in an inland branch of the sea or lake, crustal movements that halt in deposition or changes in climatic conditions have been such that the stream and wind depositions of sand are overlaid by still water deposition of coloidal material, forming a "clay blanket." This clay is composed of extremely finely divided rock flour and flakes, contains no vegetable matter in a living form, is high in mineral salt content, is extremely plastic so no cracks or joints can form and is practically impervious. Thus, there have been deposited a series of porous and permeable sediments lying in horizons and zones between relatively impermeable materials.

The east central portion of the valley is underlaid by such a series of alternating sand and clay beds, of both the Tulare and later periods. In places the sand beds are a relatively small percentage of the vertical section. Further to the east the sand beds become coarser, and in places gravelly, and form a greater percentage of the vertical section. The confined sand beds were originally completely charged, and the water contained therein was under artesian pressure. Draft from wells penetrating the artesian horizons has lowered the water level to far below ground surface. The raising of the ground water level over areas which undoubtedly are the sources of water and hydrostatic head of these artesian waters has not had the effect of restoring the artesian conditions.

The Sierra foothill belt surface is made up of a series of soils which might be termed residual, as distinct from the stream deposited alluvial soils in that their origin is through the weathering and modification of older Tertiary sediments and rocks of many varieties. The top soil is modified by vegetation and cultivation, but the subsoil is heavy textured and compact, containing harpan layers and seams of calcareous material. At lower elevations these soils represent the surface of earlier (Pleistocene) stream deltas below which the modern streams have cut. The soils are the compact Madera and San Joaquin type, having a red color which distinguishes them from the modern alluvium, but in drilling samples the differentiation is difficult if at all possible, because both produce sands consisting of quartz grains with undecomposed fragments of feldspars and flakes of mica. With increasing age the decomposition or oxidation of the ferromagnesium mineral flakes contained in the older alluvium near its surface provided the iron oxide which gives it the characteristic color and acts with calcium carbonate as a cementing material which has caused the formation of an "iron" hardpan in the upper thicknesses. Beyond the reach of oxidizing agencies the color is not marked, except where ground water circulation through certain gravel and sand channels or members has carried on the oxidizing and cementing processes, thus sealing otherwise good aquifers. As a whole, the formation is largely made up of the products of decomposition, kaolin (clay) from the feldspars which fill the interstices between the stable quartz fragments, and is not one which absorbs water readily, nor does it yield water freely to wells, in large quantities. The surface soils, with their hardpan content, will not freely absorb surface water or pass it underground. Consequently water is shed and drainage patterns develop as stream valleys or streamways eroded in the predeposited alluvial material, and sediment transported by these minor streams is deposited in their beds within the confines of close spaced banks or over adjoining areas as a thin veneer of open textured sands. With changes in amount of stream flow or grade of the channel, these deposits accumulate in the streamway with the subsequent stream flow passing over their surface. In this manner limited absorptive areas of shallow depth are formed but they are not of general economic importance in connection with the present study.

It is apparent, that the underground storage capacity, subject to the greatest charge and recharge from surface water sources, and best adapted to the desired uses, will be limited largely to the geologically modern alluvial deposits. Their extent is shown generally on Plate B-I and comprises the modern alluvial fans of the major Sierra Nevada streams of the San Joaquin Valley, the alluvial slopes or plains formed by the mergence of these fans with each other, flood plain terraces bordering these streams in their upper entrenched channels, and the present and recently abandoned streamways.

The modern alluvial fan deposit can be characterized as a heterogeneous mass of fragmental stable rock material which is the product of disintegration rather than decomposition, containing limited lenses of well assorted sand and gravel laid down as stream channels. These channels were abandoned by the stream and their depressions were grown over by vegetation and filled in with fine wind transported material. They were cut at intervals throughout their lengths by subsequent surface stream erosion in the establishment of new channels and are thus left as lenticular bodies of sand and gravel imbedded in a matrix of finer or poorly assorted material. Sections of such a formation or deposit, as exposed in railroad cuts or other excavations, show no continuity of materials of like texture or grain size, but rather a chaotic mass in which fairly well defined lenticular bodies of gravel will give way abruptly to bodies of finer material. In this way the deposited materials are merged by the ramifications and cutting of surface stream channels into one unassorted alluvial fill, in whose upbuilding wind action and vegetation also have played an important part. All the materials making up the deposits are porous and permeable, the degree of porosity and permeability varying widely throughout the deposited materials, but the whole capable of absorbing water at relatively high rates and yielding it freely to wells. In the San Joaquin Valley many fans have developed in proximity to each other, expanding laterally, and merging into one broad and extensive alluvial slope which terminates in a relatively flat alluvial plain.

Flood-plain terraces are the minor alluvial plain deposits, left in the form of terraces along the major tributaries as the stream's history advanced. These river terraces are remnants of former flood-plains, below which the streams which made them have cut their channels. These stream terraces are ideal areas for the spreading of surface water in recharging underground storage. They have a permeability and absorptive capacity exceeded only by the streamway itself. Few materials in their natural formation possess the degree of homogeneity, in reference to porosity and transmissibility, which characterizes the deposits making up the present or recently abandoned beds of streams. The interstital space in such a deposit usually ranges from 40 to 50 per cent of the mass and seldom is it less than 33 per cent. Thus, highly permeable deposits of better assorted detrital material underlie the surface streamway or river channel. It is more or less definitely limited at its bottom and sides by material of lower permeability, and is quickly recharged by the passage of surface water over it. In fact, surface water does not proceed until the streamways are filled. The capacity is somewhat limited, but it tends to recharge the less permeable material, which absorbs water at slower rates and through which the stream has cut its way.

Capacities of Ground Water Reservoirs.

The determination of the storage capacities of ground water reservoirs was aided materially by studies of records of water levels in wells scattered throughout the San Joaquin Valley, well logs and locations and capacities of pumping plants. The provisions for replacement of water were studied in sufficient detail to determine that ground water recharge was feasible from a physical standpoint. Stream and ditch channels were examined in the field as to carrying and absorptive capacities and possible spreading areas were located. Available stream and canal seepage measurements were collected and additional data on absorption in certain stream channels were obtained by field measurements. From a study of these data, which are voluminous, average seepage factors were deduced for canal and ditch systems on modern alluvial fans, for natural channels and depressions, for river bed sands and for spreading areas on sandy loam soils of alluvial deltas. These seepage factors are set forth in Table B-1. They show the average rates of absorption under various conditions. These rates may or may not be continuous. The values shown for excavated canal and ditch systems on modern alluvial fans are generally continuous throughout the irrigation season. The factors for natural channels and depressions may be reduced to those of adjacent material having lower permeability, after a certain period of operation. The factor shown for river bed sands would be reduced, in many instances, after becoming charged due to a lower rate of absorption of less permeable adjacent or underlying material. The factors given for spreading areas on sandy loam soils are based on the assumption that water would not be applied more often than one day in each fifteen.

TABLE B-1

SEEPAGE FACTORS FOR CHARGING GROUND WATER RESERVOIRS IN SAN JOAQUIN VALLEY

Conditions of charging	Seepage factor	
	Depth per day per unit of area covered, in feet	Per square foot of wetted perimeter, in second-feet
Excavated canal and ditch systems on modern alluvial fans	1.3	0.000015
Natural channels and depressions	3.4	0.000040
River bed sands		0.0004 to .0005
Spreading areas on sandy loam soils of alluvial deltas	2.0 to 3.0	

Irrigation activity in the San Joaquin Valley was largely dependent upon surface water during the twelve year wet period 1905–06 through 1916–17. Irrigation water was distributed by means of canals and ditches, the irrigated areas being for the most part limited to those convenient to surface water sources. Ground water levels rose under these areas to heights close to ground surface. Excess flows passed into Kern, Buena Vista and Tulare lakes and northerly into the San Joaquin River.

In the fall of 1905 the Tulare Lake bed was dry. The excess flows of 1905–06 carried about 1,000,000 acre-feet of water to the lake, raising its level to the 192-foot contour. Continued flow kept the lake bed covered to varying depths until 1918. The evaporation from the surface water body (based upon tests made at Tulare Experimental Station) was 4.4 feet in depth per annum. Ground water levels were brought to heights, allowing evaporation loss over wide areas and the accumulation of alkali salts in the top soil so that, for the period 1905–06 through 1916–17, there occurred large wastage of water.

Subsequent to 1917, high prices for agricultural products encouraged the development of lands without surface water supplies. The falling off of stream flow during the twelve year dry period, 1917–1929, and the mechanical development in wells and pumping equipment caused an increasing draft to be made upon ground water for an irrigation supply. The lowering of the water table was progressive, with the accumulative result that in the fall of 1929 the water table over the greater portion of the valley was lowered to depths below ground surface which prevented evaporation loss and aided in the reclamation of alkali lands.

The lowering of the water table level through pumping during periods, seasonal or cyclic, of deficient run-off provides a water supply and storage space in which to conserve excess or surplus water during periods of excess run-off. Such conservation is effective and desirable when the proper balance is maintained through a combination of pumping and replacement. Areas wholly irrigated from surface waters, brought to and spread over the area through unlined canals and ditches, have direct replenishment to ground water storage, but unless free natural drainage is present or pump drainage is practiced ground water levels are brought to detrimental heights. Areas depending solely, or to a large extent, upon pumped ground water supplies must have replacement provided through diversion and transportation of excess surface water from sources without the area, to be applied directly to the area, as in irrigation, or placed in channels for absorption. Soil and subsoil characteristics most favorable to the absorption and transmission of water underground are found to allow only slow movement of limited quantities of water so that only a small portion of the overlying land can be served from ground water sources without a progressive lowering of the water table beneath the area, unless such replacement provides an excess of absorption over draft during certain periods. With adequate replacement provisions and the maintenance of average water table levels, it appears physically possible that ground water storage can be created in sufficient amount to provide perfect irrigation service and probably complete conservation of the waters of the San Joaquin Valley.

The types of ground water reservoirs previously described comprise distinct physiographic units making up the modern alluvial floor of the San Joaquin Valley. Twelve days were spent in the field mapping the surface extent of these absorptive areas, using U. S. Geological Survey maps, scale two inches equals one mile, as a base. The subsurface characteristics of these units were revealed through a study of a large number of penetration records of wells widely scattered over the valley. A comparison of the characteristics so revealed with the yield of the wells and a comparison of the lowering of the water table from 1917 to 1929 with the irrigation demands of areas dependent wholly or partially upon ground water supplies, allowed estimates to be made of the average effective capacity of the soil volume drained per foot of water table lowering. These results were checked with indicated drainage factors obtained by analyses presented in Chapter IV in the body of this report for present developed areas, in which quantities of depletion and water table lowering could be determined. The effective voids of the materials were found to vary from 10 to 20 per cent so an average factor of 15 per cent was assumed for alluvial fans of the major streams, 12½ per cent for interareas in the southern end of the valley, and 10 per cent for the sand and clay areas in the northerly end of the valley trough.

Ground Water Storage Capacity South of San Joaquin River.

For the purpose of broad consideration, absorptive areas in modern alluvium on the eastern slope of the San Joaquin Valley subject to subdivision in the consideration of local ground water reservoir areas in relation to the rate and method of charging their capacity and utilization of that capacity, are outlined on Plate B-1. The areas south of San Joaquin River are located in divisions 1 to 4, inclusive. Division 5, on the western slope, has been previously eliminated from consideration as a ground water storage area. The ground water storage capacity of each of the larger units was determined by obtaining the surface area from the large scale topographic maps, obtaining from the same source the average ground surface elevation over each township or fraction thereof and reducing that elevation, where necessary, to compensate for reduction of effective storage levels due to natural drains; determining the average ground water elevation from the 1929 ground water contour maps for corresponding townships or fractions thereof and assuming that the available storage space is that lying between the 1929 water table level and a level ten feet below the average ground surface and applying the assumed drainage factor to the storage space. In areas surface irrigated during the past dry years, the 1929 water table level is relatively high and reduction of this level by pumping draft or reallocation of surface water is assumed, in certain areas, to make available ground water storage capacity.

**Hydrographic Division 1.* The modern alluvial fans of the Kern River and the Poso Creek fan in Kern County, south of the seventh standard parallel, occupy a surface area of 525,000 acres. Over a considerable portion of this area the water table is maintained at a high level through canal seepage and irrigation return. The drilling of wells and installation of pumping plants in the high ground water area, within the past few years, has proved so successful in the matter of yields, low cost and complete control of irrigation supply, that it is not beyond the range of probabilities that portions of the surface water supply may be allocated to ''rim'' lands not so fortunately situated as to ground water resources, and ground water storage be made available through draft upon and replacement of ground water over the reservoir area. An average lowering of the water table to 60 feet below ground surface would provide about 3,750,000 acre-feet of storage capacity which is probably in excess of that required for complete conservation through underground storage.

Hydrographic Division 2. The northerly three miles of Kern County and that portion of Tulare and Kings counties lying south of the area, now surface irrigated from the Kaweah and Kings rivers, consists of a modern alluvial veneer laid down by Deer Creek, White River and lesser streams over the more compact cemented older alluvium and Tertiary sediments and the modern alluvial fan of Tule River. The streams have entrenched themselves at higher elevations in the older sediments and the stream flood plain deposits fill the limited

* For boundaries of Hydrographic Divisions see Plate V, Chapter II.

trenches and form underflow conduits previously described. The well logs of the area show the modern alluvial fan of Tule River and the accumulation of sediments bordering the Tulare Lake bed to have attained sufficient thickness to constitute an important ground water reservoir. Taking into consideration all types of ground water containers, the surface area totals 322,000 acres.

The greatest water table lowering during the past twelve years occurred over those portions of the area where the water entrapped in the older sediments, which are not subject to ready replenishment, has been withdrawn. Such areas will have to be served surface water to satisfy the irrigation demand. The surface watershed directly tributary to the area is limited and the run-off therefrom has been negligible during the past twelve years. Tule River the main stream of the area including South Folk had a mean daily flow of but 112 second-feet as against 272 second-feet for the period 1905–06 through 1916–17. The average depth of the water table below ground over the absorptive area considered, based on the 1929 level, is 56 feet, allowing 46 feet of storage space between elevations ten feet below ground surface and present water level. Upon this basis 2,224,000 acre-feet of storage space are available. Pumping lifts of 100 feet are not uncommon in portions of the present developed area.

Hydrographic Division 3. The modern alluvial fan of the Kaweah River merges with that of the Tule River on the south and the Kings River on the west and provides a highly absorptive body of material having a surface area of 308,000 acres. It is bordered on the east and northeast by an area comprised of older alluvium covered with modern alluvial veneer derived from Cottonwood, Yokohl and Lewis creeks and minor streams which is limited in thickness and width. The water table level in these border areas has been drawn down, during the past twelve years, to elevations requiring high pumping lifts. Little replacement can be exercised locally, but water supplies can be stored underground in contiguous areas of more favorable character and drawn upon to serve the less favorable. Surface irrigation has maintained a relatively high water table over that portion of the area bordering the major streams and covered by the principal or first right canal systems. Southwest of this area, irrigation draft has effected a considerable lowering since 1917. The mean daily flow of the Kaweah River for the twelve years, 1905–06 through 1916–17, during which ground water accumulation was had, equalled 707 second-feet. For the twelve year period subsequent to 1917 the mean daily flow dropped 40 per cent to 424 second feet. The average water level, as of 1929, was 36 feet below ground surface, representing a storage capacity to elevations ten feet below ground surface of 1,212,000 acre-feet. An additional lowering of 20 to 25 feet, on the average, provided replacement provisions are carried on to assure somewhat average conditions throughout the area, could be accomplished if such be necessary to meet the requirements of a 100 per cent supply or complete ground water conservation.

The balance within the area could be maintained by the establishment of well fields at points particularly favorable as to ground water storage capacity, accessibility to surface sources for replenishment, low land value and proximity to point of use. Four such local areas have

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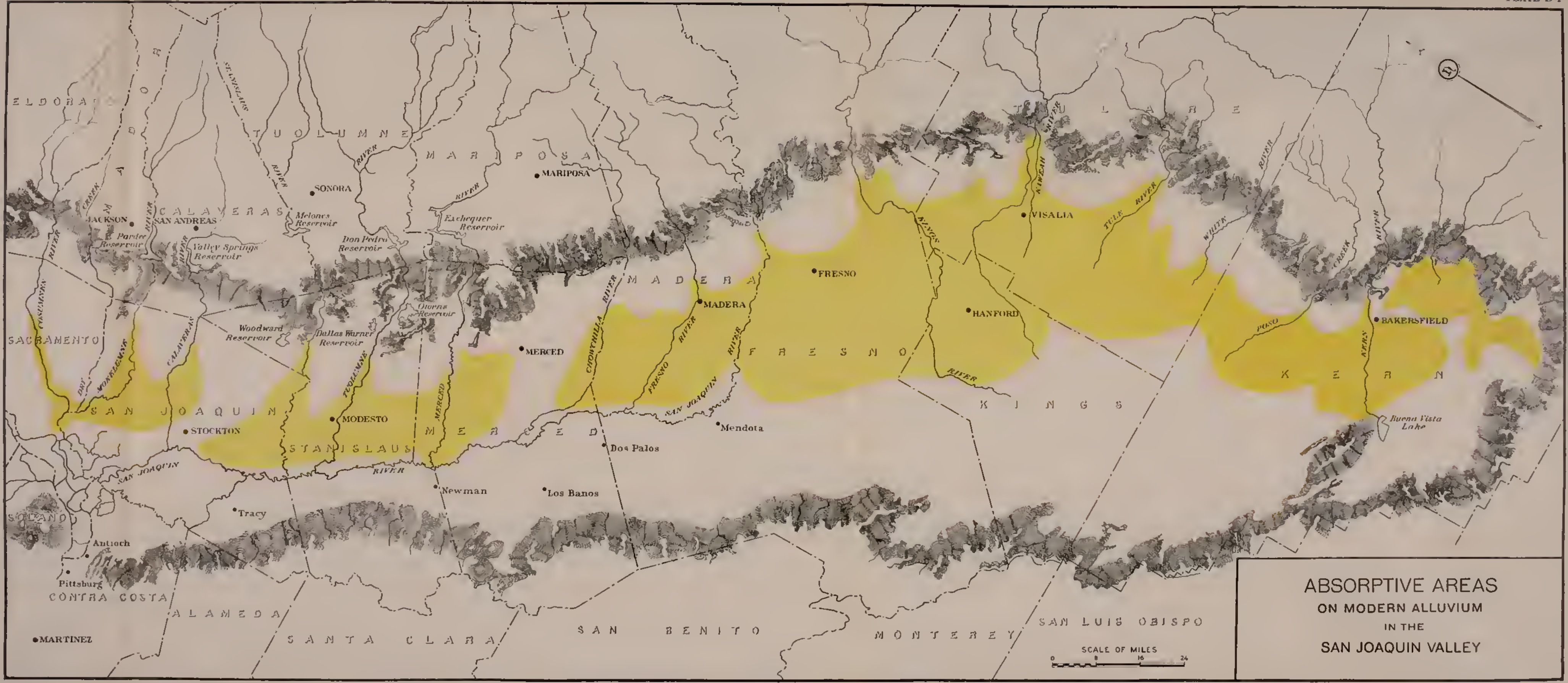


ABSORPTIVE AREAS
ON MODERN ALLUVIUM
IN THE
SAN JOAQUIN VALLEY

been examined on the ground. In addition thereto balance could be maintained by the diversion and spreading of surface water during times of excess flow over areas of heavy irrigation draft, and the pumping of irrigation water from ground water sources, over the area served by canals and ditches during the latter part of the irrigation season, could be practiced in order to maintain the water table below ten feet from ground surface as a drainage and conservation measure. The ground water stood at less than six feet below ground surface for the summer months of 1917 over an area of about 130,000 acres. The ground water discharge or wastage through evaporation probably equalled 150,000 acre-feet with accompanying alkali concentration.

Hydrographic Division 4. The Kings River delta merges with that of the San Joaquin River and is bordered on the east by more indurated materials. The physiographic and ground water conditions of this division are very similar to Division 3 and present the same problems as to maintenance of ground water balance. In 1917 the water table stood less than six feet below ground surface over a large portion of the area. Ground water discharge through evaporation from moist soils allowed wastage of large volumes of water and concentrated alakali salts in the top soil. The lowering of the water table to 1929 levels has rectified this condition somewhat, but lowering to greater depths below ground surface in certain areas would be beneficial and allow for more complete conservation of water through underground storage.

The total absorptive area in the division is 996,000 acres. The average water table level (1929) is but seventeen feet below ground surface. The ground water storage available under present conditions is limited to 1,097,000 acre-feet. The Kings and San Joaquin rivers provide large quantities of stream flow during wet cycles, the mean daily flow of Kings River for the period 1905–06 through 1916–17 being 3000 second-feet. The mean daily flow during the period of water level recession, 1917–18 through 1928–29, was 1800 second-feet about 60 per cent of the preceding period of the same length. In order

TABLE B-2

STORAGE CAPACITIES OF GROUND WATER RESERVOIRS IN HYDROGRAPHIC DIVISIONS 1 TO 4, INCLUSIVE, UPPER SAN JOAQUIN VALLEY

Hydrographic Division	Gross absorptive area, in acres	Estimated drainage factor, in per cent	Depth of storage space, in feet		Storage capacity, in acre-feet	
			Between elevations 10 feet below ground surface and 1929 water levels	Between elevations 10 feet below ground surface and assumed limits of pumping	Between elevations 10 feet below ground surface and 1929 water levels	Between elevations 10 feet below ground surface and assumed limits of pumping
1	525,000	15 and 12½	*	50	**3,707,000	3,750,000
2	322,000	15	46	76	2,224,000	3,650,000
3	308,000	15	26	50	1,212,000	2,300,000
4	996,000	15	7	53	1,097,000	8,000,000
Totals	2,151,000				8,240,000	17,700,000

*Not determined.
**Estimated.

to effect conservation or provide for 100 per cent irrigation supply, ground water draft to the extent necessary to pull down the water table to an average depth of 50 to 60 feet below ground surface may be warranted at the end of a long dry period.

San Joaquin River Drainage Area—Divisions 6 to 12, inclusive.

Divisions 7 and 10 lie west of the San Joaquin River, the region previously eliminated from consideration as ground water storage areas. The divisions lying east of the San Joaquin River can be subdivided physiographically into uplands, modern alluvial fans, valley trough plains and swamp and overflow areas. Of these subdivisions the modern alluvial fans and plains comprise areas over which the surface and subsurface soil materials have the requisite characteristics in relation to absorption and transmission of water which make them ground water reservoirs of economic importance.

The upland areas are the higher lying lands bordering and making up the low foothills of the Sierra. Considerable portions thereof are of alluvial origin, but have become somewhat indurated through age so that much of the rainfall upon its surface is shed, this run-off in turn developing drainage patterns through erosion and filling or covering depressions on border lands with a thin veneer of relatively fine textured modern sediments reworked from the older alluvium. The latter are limited in depth and width and, while comprising local absorptive areas subject to replenishment, they are not important in relation to the broad extent of the uplands.

The older alluvium making up the ancient stream deltas contains ground water derived from the streams that laid them down and held them as the formation became indurated. Furthermore, irrigation activities during the past 25 years have caused the water table beneath these lands to rise from 15 to 50 feet through slow absorption. Ground water has thus accumulated in storage over the period. However, wells drilled in the uplands generally yield water derived through slow drainage of communicating permeable members at relatively low rates, and the stored ground water is soon exhausted when heavily drawn upon for irrigation supply. It is not subject to ready lateral replenishment because of the low transmissibility of the media. Hardpan and compact clayey material is prevalent in the surface soil and causes the water applied to or falling upon the surface in quantity, to be shed rather than absorbed so that ready recharge can not be accomplished.

The valley trough plain is to a large extent lacustrine in origin. It consists of absorptive top soils, with interbedded sand and clay to great depths. The clay members take up a sufficient portion of the soil column to reduce the drainage factor. They also prevent ready recharge from the surface. There exists, however, lateral replenishment to some extent. The fact that this area was formerly one of artesian flow and that the artesian water levels have lowered, although the water level over higher lying lands has risen or remains the same, indicates lateral replenishment is at rates less than the rate of pumping draft. Artesian conditions will only be restored with lateral replenishment in excess of draft for a relatively long period.

The surface topography of the immediate valley trough is that produced by swamp and overflow conditions. The surface soils range from adobe to clay loam. Ground water is near the surface, but difficult to extract from the heavy fine material. Along the borders of this area wells penetrate few sand strata imbedded in dark clays. On the whole the swamp and overflow areas, which includes the delta island region at the northerly end of the valley, are to be eliminated from consideration as ground water storage reservoirs.

Hydrographic Division 6. Division 6 lies between the Chowchilla and San Joaquin rivers in the region covered largely by the Madera Irrigation District. The Madera type soils predominate, but the hardpan characteristics of the type are limited to the top soil and not extensive enough to render it nonabsorptive. Wells of the region, of which there are about 750 producing between 1200 and 1800 gallons of water per minute for irrigation supplies, penetrate sand and clay strata and are landed at about a depth of 200 feet. There were about 81,000 acres of land, in the absorptive area of this division, irrigated in 1929, chiefly by pumping from ground water. This area has a total seasonal water requirement of about 200,000 acre-feet, an amount equal to nearly twice the natural ground water replenishment, for the period of ground water record, with the result that the water level has been dropping an average of one and four-tenths feet per year since 1920. The water table of the fall of 1929 varied from five to 75 feet below ground surface, with an average depth of 35 feet below ground surface over the absorptive area. The surface extent of the absorptive area is 281,000 acres. The ground water storage capacity available between the 1929 water level and an average level 10 feet below ground surface, on the basis of an 18 per cent drainage factor is 760,000 acre-feet.

Pumping lifts of 75 feet now prevail over portions of the area. The utilization of the ground water storage capacity presupposses the recharge of that capacity by spreading of surface water in periods of excess run-off.

Hydrographic Division 8. Division 8 is bounded by the Chowchilla, San Joaquin and Merced rivers, its absorptive area, however, being limited to 146,000 acres. The Merced Irrigation District includes an area of 190,000 acres. A large part of the area is nonabsorptive. Over a portion of this, the excess irrigation water applied to the surface has raised the general water table to close to the ground surface and locally hardpan conditions have caused the swamping of lands by holding water perched above the general water table. Pumping for drainage in this area is being practiced with varying results, one well yielding 800 gallons of water per minute and having an effective radius of about one-eighth mile. Ground water balance over the nonabsorptive areas can be better maintained through control of surface water allotments to that necessary to produce crops without excessive waste. Considering the irrigation district as a whole, the depth to ground water has averaged four and five-tenths feet below ground surface in 1927, five feet in 1923 and five and four-tenths feet in 1929. In 1929 about 80,000 acre-feet of water were pumped from drain wells and it is estimated that 90,000 acre-feet was pumped in 1930.

The Merced District has a regulated irrigation supply with surface storage. Utilization of ground water storage is necessary as a protective measure if not for conservation. In 1927 when ground water stood at its peak for the season, about 80,000 acres south of Merced and west of the Santa Fe Railroad required drainage. Ground water stood from three to five feet below the surface over an area of about 35,000 acres and less than three feet from the surface over about 10,000 acres. The area sufficiently impregnated with alkali to affect crop production is about 5000 acres. This condition has been greatly improved by expansion of the drainage well system. The surface extent of the absorptive area having an estimated 15 per cent drainage factor totals 129,000 acres and 17,000 acres lie within the estimated 10 per cent drainage factor area. Under present ground water conditions the available ground water storage capacity is charged. With the present irrigation practice a pump extraction sufficient to lower the water table to eight feet below ground surface and maintain present drainage would require a rate of approximately 115,000 acre-feet per year for three years.

Hydrographic Division 9. Division 9 comprises the area lying between the Stanislaus, San Joaquin and Merced rivers which is served by the Modesto and Turlock Irrigation Districts. These districts also have a regulated irrigation supply. The control of irrigation deliveries is better practiced and less wastage of water is had than over the Merced district. During the summer of 1917 the water table stood at less than six feet (with an average of four) below ground surface over the irrigated area. Natural drainage is had through the Merced, Tuolumne, Stanislaus and San Joaquin river channels. Pumped drainage also is practiced. The Turlock district, having the greater number of wells, pumped 84,400 acre-feet of water during 1929 and obtained an average water table six and one-half feet below ground surface in the fall of that year.

The surface extent of the absorptive area of the division is 198,000 acres having an estimated 15 per cent drainage factor and 17,000 acres with an estimated 10 per cent. Under present water table conditions ground water storage is filled. In the Turlock district during the 1929 season, a gross surface diversion of 443,000 acre-feet of surface water served 134,000 acres of land. Of the quantity diverted, there was an evaporation loss of 9000 acre-feet in the distribution reservoir. The return flow was 159,000 acre-feet. The total net contribution was 275,000 acre-feet or 2.06 acre-feet per net acre irrigated. There was an average rise in ground water during this period of 0.7 feet. An average seasonal inflow of 1.9 acre-feet per acre irrigated would maintain a stable ground water level. Conservation could be effected by drawing upon ground water to meet the peak irrigation demand in amounts sufficient to maintain the water table below a level eight to ten feet below ground surface.

Hydrographic Division 11. The absorptive area of division 11 consists of the modern alluvial fan of the Stanislaus River, having a surface extent of 83,000 acres, of which 15,000 acres are estimated to have a lesser (10 per cent) drainage factor. The South San Joaquin Irrigation District has a gross area of 71,000 acres of which 54,000 acres were irrigated in 1929. In addition, 14,000 acres of nonirrigated crops received some subirrigation. The diversions into the district totaled about 225,000 acre-feet. In addition about 50 drainage wells were operated and the discharge added to the irrigation deliveries. It is estimated that the return flow was about 90,000 acre-feet, leaving 135,000 acre-feet of water to serve crop needs, be lost through evaporation and effect a net contribution to ground water. The water table has been relatively high over the district since irrigation was inaugurated and protection and conservation warrants a heavy draft upon ground water during the irrigation season.

Hydrographic Division 12. Division 12 includes the flood plains of the Mokelumne and Calaveras rivers, the absorptive area of which covers 104,000 acres. Tests made in the Mokelumne area give, as an average result, a drainage factor of about 10 per cent. The division is similar to No. 6, the Madera area, in that its irrigation supply is derived largely from ground water. Pumping draft has been in excess of replenishment, with a resultant water table lowering on the average of about one and one-half feet per year since 1920. The average water table in the fall of 1929 was 25 feet below ground surface. The ground water storage capacity between the 1929 water level and a level 10 feet below ground surface equals 160,000 acre-feet.

Summary of Hydrographic Divisions 6 to 12, Inclusive. Ground water storage capacity over the greater portion of the area is charged, under existing conditions of irrigation development, and can only be made available with the lowering of the water table through pumping draft. Pumping is now practiced for drainage purposes, but not to the extent necessary to create ground water storage which can be considered of cyclic value. The total use of the surface water available in the ultimate development of the irrigable lands would probably necessitate some draft from the ground water storage of these areas. Upon the basis of 40 feet of lowering below the 1929 water table level at the end of a dry cycle, considerable ground water storage can be made available and is so noted in the general summary.

TABLE B-3

STORAGE CAPACITIES OF GROUND WATER RESERVOIRS IN HYDROGRAPHIC DIVISIONS 6 TO 13, INCLUSIVE, SAN JOAQUIN VALLEY

Hydrographic Division	Gross absorptive area, in acres	Estimated drainage factor, in per cent	Depth of storage space, in feet		Storage capacity, in acre-feet	
			Between elevations 10 feet below ground surface and 1929 water levels	Between elevations 10 feet below ground surface and assumed limits of pumping	Between elevations 10 feet below ground surface and 1929 water levels	Between elevations 10 feet below ground surface and assumed limits of pumping
6	281,000	18	15.0	45.5	760,000	2,300,000
8	129,000	15				
	17,000	10	0	40.0	0	850,000
9	198,000	15				
	17,000	10	0	40.0	0	1,260,000
11	68,000	15				
	15,000	10	0	40.0	0	470,000
12	104,000	10	15.4	50.0	160,000	520,000
13	*10,000	10				
Totals	839,000				920,000	5,400,000

*Along stream channel not utilizable for ground water storage.

TABLE B-4

SUMMARY OF STORAGE CAPACITIES OF GROUND WATER RESERVOIRS, SAN JOAQUIN VALLEY

Hydrographic Division	Gross absorptive area, in acres	Storage capacity, in acre-feet	
		Between elevations 10 feet below ground surface and 1929 water levels	Between elevations 10 feet below ground surface and assumed limits of pumping
1	525,000	[1]3,707,000	3,750,000
2	322,000	2,224,000	3,650,000
3	308,000	1,212,000	2,300,000
4	996,000	1,097,000	8,000,000
5			
6	281,000	760,000	2,300,000
7			
8	146,000	0	850,000
9	215,000	0	1,260,000
10			
11	83,000	0	470,000
12	104,000	160,000	520,000
13	[2]10,000		
Totals	2,990,000	9,160,000	23,100,000

[1] Estimated.
[2] Along stream channel; not utilizable for ground water storage.

The data in the foregoing table reveal that the greater surface extent of absorptive lands and consequently the greater ground water storage capacity lie in the upper San Joaquin Valley or Tulare Lake Drainage Area. However, there is a deficiency of run-off in the upper San Joaquin Valley with which to charge this capacity, and while the lower San Joaquin has an excess surface run-off above that necessary to serve irrigable lands with which to charge ground water storage, storage capacity does not exist under present ground water conditions in divisions 8, 9 and 11. The ultimate development of all irrigable lands in the San Joaquin Valley will require the absorption of excess run-off (above irrigation demand) into ground water storage and draft from ground water during periods of deficient run-off in order to meet the irrigation demand.

APPENDIX C

GEOLOGICAL REPORTS ON DAM SITES IN SAN JOAQUIN RIVER BASIN

by

HYDE FORBES
Engineer Geologist

December, 1930

TABLE OF CONTENTS

GEOLOGIC REPORTS ON DAM SITES IN SAN JOAQUIN RIVER BASIN

NASHVILLE DAM SITE ON COSUMNES RIVER
AND
MELONES DAM SITE ON STANISLAUS RIVER

The object of the investigation of the Nashville dam site on the Cosumnes River and the Melones dam site on the Stanislaus River, the general topographic and geologic features of which are shown on Plates C-I and C-II, was to determine the general feasibility of constructing relatively high dams (270 feet at Nashville and 460 feet at Melones) at these sites or to locate more favorable sites in the vicinity and estimate the stripping necessary for consideration in preliminary estimates of cost. No exploration was had at either site, nor was the geology mapped in detail. Sufficient observation was made to cover the object stated, that is, to determine the kind of rock occurring at the dam sites, how it originated, its present position and strength, its structural weaknesses and the effect of weathering upon it.

Geography and Topography.

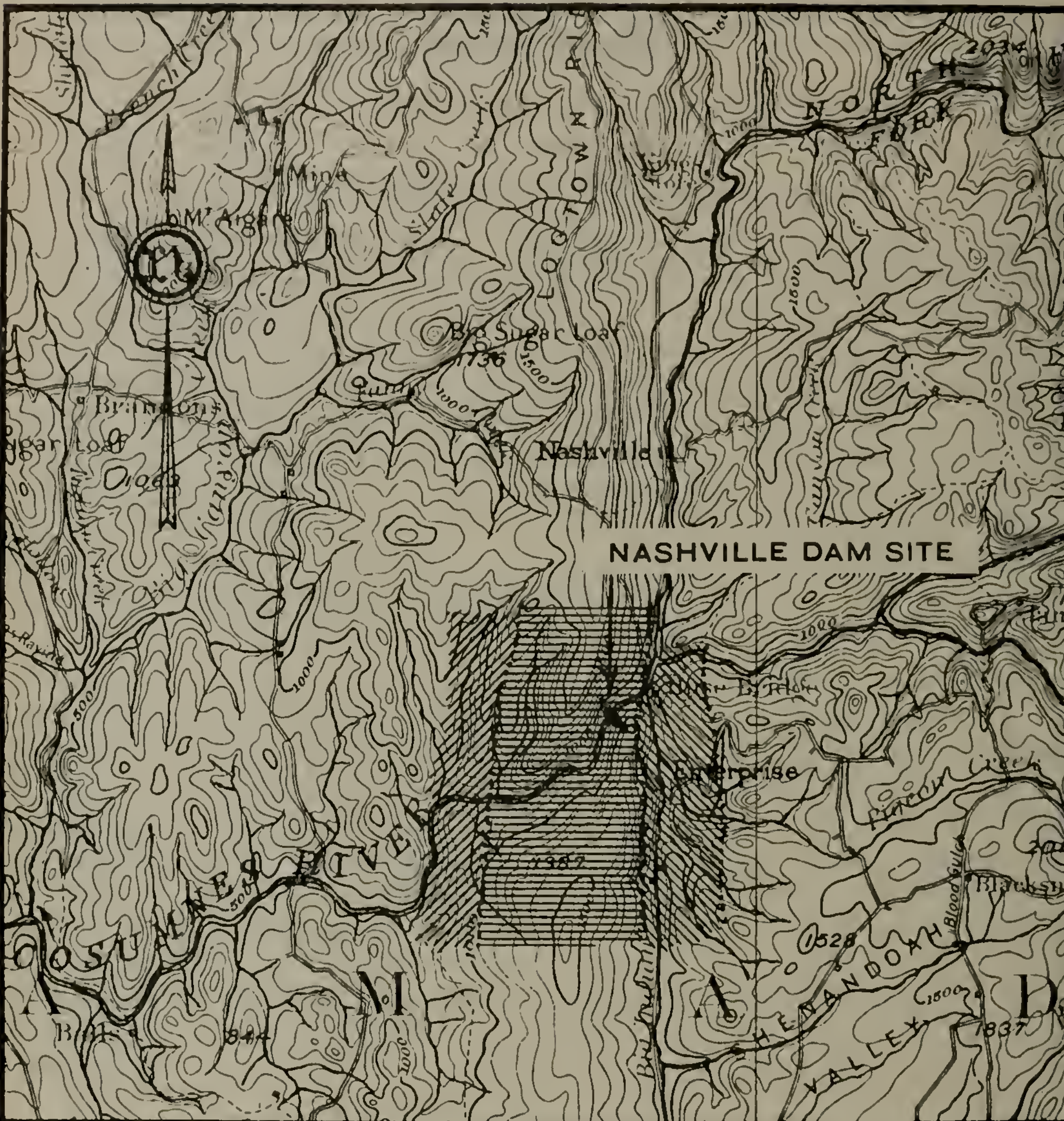
The dam sites examined lie in the Gold Belt of California, the Nashville site upon the Cosumnes River five miles north of Plymouth and the Melones site upon the Stanislaus River eight miles south of Angels Camp. The topographic and geologic features at both sites are similar. Drainage has developed topographic ridges and draws striking northwest-southeast and controlled by the prevalence of bands of rock varying in hardness and resistance to erosion. The drainage joins to form the major streams which have cut gorges across the strike of the resistant rock ridges in attaining a westerly course. This gorge development provides dam sites with reasonable crest lengths for proposed heights above stream beds of the dams under consideration.

General Geology.

The Sierran bedrock complex (so called in the U. S. Geological Survey folios) attains its greatest complexity in the Gold Belt. It is described by F. L. Ransome, geologist, in Folio 63 as follows:

"The bedrock complex consists of both sedimentary and igneous rocks. The sedimentary rocks were originally beds of mud, sand and gravel. They represent the mechanical waste of ancient land surfaces which were long ago deformed and have been carved by erosion into new forms or buried under later sediments and perhaps partly fused by invading, deep-seated igneous intrusions. The sediments derived from this old land mass remain, but the land mass itself has disappeared during the slow progress of geological change. Carried down by the streams, this material was spread by waves and currents over the sea bottom in nearly horizontal layers. There were periods of volcanic activity during the deposition of these early sediments. Igneous material, thrown out either as loose fragments or as volcanic mud, was also spread over the sea bottom, accompanied probably by flows of molten lava. These beds and the associated volcanic rocks have been folded and compressed chiefly in a northeast-southwest direction, and have been irregularly introduced by masses of igneous rocks, such as granite, diorite and gabbro. The sediments have been hardened and changed by the long-continued action of underground solutions, the pressure and movement of folding, and the heat of igneous intrusions until they often bear no resemblance to their original condition. The bedrock complex is therefore made up of both sedimentary and igneous rocks. It is an intricate assemblage of many different kinds of rocks, differing considerably in age. It contains probably more than one sedimentary series, as that term is commonly used in geology. For these reasons it seems best to speak of it as a complex."

PLATE C-I



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
NASHVILLE DAM SITE
ON
COSUMNES RIVER

SCALE OF MILES

0 1 2 3 4

LEGEND

Calaveras formation

Diabase

Mariposa formation

PLATE C–II

GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
MELONES DAM SITE
ON
STANISLAUS RIVER

SCALE OF MILES

0 1 2 3 4

LEGEND

Diabase

In the vicinity of the dam sites the rocks of sedimentary origin consist of a body of grey colored clay slates, with well defined cleavage planes which may or may not conform to the original bedding planes. At the Nashville site the contact between the slates and the rock of igneous origin lying downstream therefrom is fairly well marked. At the Melones dam site the slates grade downstream into thin bedded rock, which probably originated as tuff, and more massive rock is found farther down stream through Iron Canyon.

The rocks of igneous origin have undergone considerable alteration due to the stresses to which they have been subjected and the passage of gasses and solutions through them. The metamorphism is profound and has resulted in hard crystalline rock masses, which have been designated diabase and porphyrite in previous reports, following the terminology used in the early reports of the United States Geological Survey. The term diabase includes original beds of loosely consolidated tuff and volcanic breccia, which have been altered by the development of secondary green basic minerals so that the whole has been converted into hard crystalline rock, as well as the more massive eruptive or intrusive green rock containing small crystals of augite and magnetite in a glassy ground mass.

Geologic Structure.

In common with other Sierran regions, the original rock masses here have been folded and compressed into bands which strike northwest-southeast. The stresses were so intense that the sedimentary rocks were altered to slates and schists in which were developed cleavage and schistocity planes along which the rocks part readily into thin slabs or plates. The same stresses transformed the volcanic tuff beds into somewhat thicker schistose bands and the extrusive or intrusive rocks into more massive bands of rock. Such open joints and faults as developed during the period of folding have been closed and healed by the deposition of secondary quartz so the mass at reasonable depth below ground surface is sound. Subsequent crustal movement developed stresses which caused the mass to joint without parting or movement of the joint walls. No active faults are known.

Nashville Dam Site.

Big Indian Creek and the North Fork of the Cosumnes River have eroded their gorges along the contact between a grey colored slate and a formation of igneous origin. Erosion has carried the stream beds into the slates to their juncture with the South Fork, where they turn at right angles to traverse the igneous rock. At the contact, the igneous rock is a coarse textured green rock containing large tabular crystals of augite and hornblende, termed porphyrite. This continues downstream for about 500 feet, becoming finer textured until it merges with a close textured green rock diabase, consisting of small crystals of augite and magnetite in a glassy ground mass. The diabase is a more resistant hard rock and the stream through it has cut a narrow "V" shaped gorge with cliff profile to 125 feet above stream bed. The site is entirely satisfactory, from both geologic and topographic considerations, for a high concrete structure.

The igneous rocks probably originated as flows over the surface of clay shale. The series of formations later were subjected to folding and distortion accompanied by intense pressures. These dynamic forces caused a hardening of the shale into slates, and recrystallization and hardening of the igneous series resulted in the present rock forms. The stresses caused the diabase and porphyrite to become banded, with the bands striking north 40 degrees west across the stream and dipping almost vertically so that the same mass exposed on one abutment continues beneath the stream to great depth and up the opposite abutment and probably for long distances across country.

The massive rock has developed joint systems, the principal jointing striking with the stream south 60 degrees west at right angles to the banding and dipping 65 degrees from the horizontal. An intersecting joint dipping north 60 degrees east about 80 degrees and a horizontal joint dipping due south about 10 degrees are the other main joints. Minor joints have developed in loose joint blocks, but are not profound features continuous in the mass.

This jointing has weakened the mass so that, while rock appears continuously up both abutments, outcrops are joint blocks loosened from the mass. Their removal and the removal of underlying loose blocks probably would necessitate an average depth of stripping of 20 feet on the right abutment and 25 feet on the left. The joints are structural features which persist to great depth, but should be found closed and relatively tight at these distances below ground surface. The joint walls are sound and, should they be found to part, could be closed with grout. The stream bed consists of fresh water-worn and potholed bed rock, which probably would have to be cut into an average of ten feet to produce an even surface and key in the structure. The joints in the fresh rock in stream bed are closed tight features and probably would refuse grout.

There is no suitable construction material available at or in the immediate vicinity of the dam site. The spillway should be provided over the structure, preferably in the center, to discharge to stream bed over the fresh sound rock in the channel.

Melones Dam Site.

The topographic and geologic features at the Melones dam site are a duplicate of those existing at the Nashville site. The northwest-southeast drainage has developed along the contact between slate and altered rocks of igneous origin. This drainage joins and passes southwest across a more massive diabase in which it has eroded a deep narrow gorge.

The site proposed for a high dam lies between an eighth and a quarter of a mile downstream from the present dam. It is the best site geologically and topographically in this section of the stream. At this point lies a dike-like rock mass, consisting of a fine grained, dark green diabase which is banded, the bands striking north 40 degrees west across the stream with the trend of the topographic development. The stream has developed a deep "V" shaped gorge with cliff profile (called Iron Canyon) through the mass. The right abutment has rock outcropping to the crest of the ridge with uneven eroded surfaces. The left abutment consists of fairly uniform steps at the lower levels, developed along major joints which dip due west 25 degrees from the horizontal, and an uneven rocky slope to the top. An intersecting joint dipping north 70 degrees east 80 degrees also is well developed, but the multitude of minor joints found upstream are absent from the diabase.

Stripping allowance of fifteen feet on the average at right angles to the slope on the right abutment and 20 feet on the left abutment should provide for the removal of all loose material and reveal rock which, though jointed, could be rendered sound by pressure grouting. The width of the channel at stream bed varies from 30 to 50 feet. It carries some large joint blocks and probably fifteen feet of gravel over a potholed bed rock. The latter site in Iron Canyon fills all the requirements for a high concrete structure.

IONE DAM SITE ON DRY CREEK

The Ione Reservoir would be created by construction of a dam across Dry Creek in the vicinity of Ione. The reservoir area consists of broad valleys and rounded ridges developed by post-Neocene erosion of a gently dipping plane which was the top of an accumulation of sedimentary beds lying along the base of the western foothills of the Sierra Nevada. The sedimentary formation contains but few resistant members, so the dam site available is limited to a relatively wide and heavily alluviated stream flood plain lying between two long ridges.

The site, if occupied by a dam 120 feet high, would necessitate building two auxiliary dams in topographic saddles due north. The reservoir capacity so created would necessitate diversion of Mokelumne River water through a spillway now built as part of the Pardee Dam project in order for it to be utilized to fullest practicable extent.

General Geology.

The geologic development of the western slope of the Sierra Nevada is generally considered to have closed with the cessation of the great volcanic eruptions accompanying the Sierra uplift of Neocene time. During that period the streams were heavily burdened with detritus, chiefly in the form of ash, cinders and bombs of volcanic origin, and often to such extent as to become mud flows. This detritus reached the Tertiary sea, which occupied the great valley depression, was distributed over its bottom in rapid accumulation and was raised above sea level and became hardened as it dried and aged during Pleistocene time. The result was a gently dipping thick series of marine sedimentary beds of tuffaceous and siliceous shales, fine to coarse grained tuffaceous sandstones, conglomeratic sandstone and conglomerate. This series of sediments are contemporaneous with the shore gravel found south and east of the reservoir site and the gold bearing Tertiary stream gravels found at higher elevations. South of the reservoir site the shore and stream gravel is buried beneath a capping of lava and tuff.

Geologic Structure.

The streams, freed of their sediment burden and with steeper gradients, have cut down into the sedimentary formation and developed the existing topography. The topographic expression is the result of differential weathering and erosion upon an almost horizontal series of sediments capped by lava and tuff south of the reservoir site and overlying diabase. No faults were found or are known to exist in the region.

Ione Dam Site.

The general topographic and geologic features in the vicinity of this site are shown on Plate C-III. The sedimentary (Ione) formation at the dam site consists of nearly horizontally stratified fine to coarse grained tuffaceous sandstone beds interbedded with siliceous shale members and conglomerate. The vertical section exposed along the abutment ridge, through which the stream has cut at the dam site, evidences all these phases as the result of the frequency in change of character of detritus carried to the region and changes due to crustal movements in the marginal areas from deep to shallow water and stream deltas. The uppermost bed is a conglomerate carrying water-worn gravel and boulders derived from the older rock of the upper watershed areas, as well as water-worn fragments of lava and pumice. About 75 feet above stream bed a tuffaceous sandstone, consisting of light colored ash and sand, is found on the left abutment, while a coarser grained and darker colored formation of similar character is found on the right abutment. This bed is underlain by a thick conglomerate consisting almost entirely of volcanic fragments, some water-worn, in a matrix of tuffaceous material. Underlying is a thin bed (four to six inches) of siliceous shale topping another sandstone bed which varies from fine to coarse textured and conglomeratic laterally and vertically down to stream bed elevation.

The cementation varies widely, some portions being difficult to break with a hammer, and upon submersion in water, while absorbing water, does not disintegrate or lose particles with rubbing. Other portions are readily broken, absorb water so rapidly upon submersion that it causes heavy effervescence of interstitial air and can be worked down with the fingers. As a whole, the formation is too ''spotted'' to make a foundation for a concrete structure, but entirely satisfactory for an earthen dam.

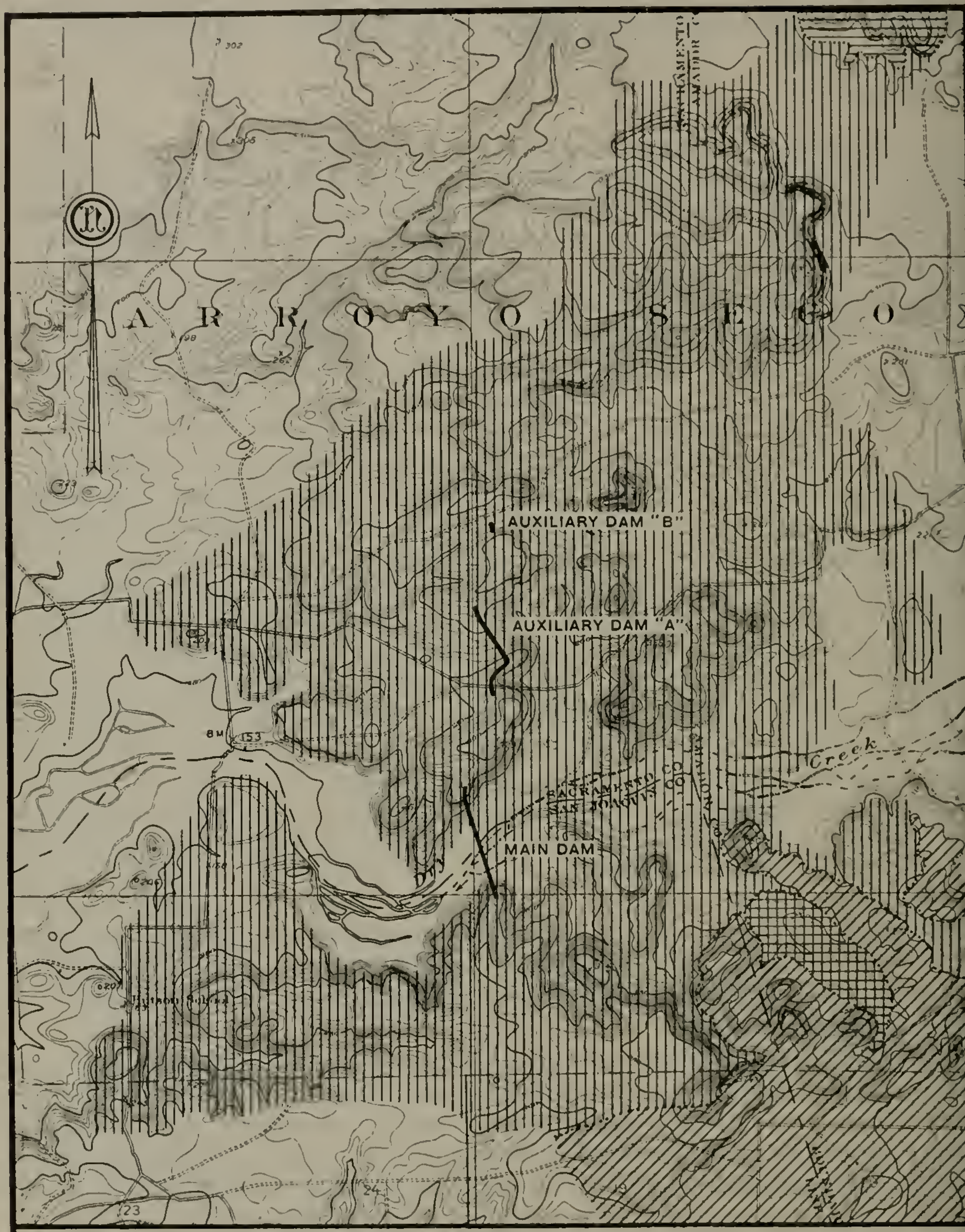
Weathering has attacked the formation with varying results. On the steeper side slopes sound rock is exposed or exists under shallow soil cover. On the upper slopes and crests of ridges a red-brown clay soil containing gravel and cobbles exists, probably at an average depth of ten feet over sound rock. The stream has cut a ''U'' shaped trench with a fairly wide bottom covered by flood plain material, which probably has an average thickness of 35 feet over sound rock.

Exploration of the dam site was made by Stephen E. Keiffer, consulting engineer. A descriptive log of the holes is appended to this report. Their locations are shown on Plate C-IV. A. Werner Lawson, geologist, reported to Mr. Kieffer of the site and analyzed the cores as follows:

"For the purpose of determining the character of the flat lying strata beneath the valley floor several vertical diamond drill holes were bored into it along the line of the proposed structure. These penetrated the bedrock to a depth of 50 feet beneath the alluvial covering. The cores from the bore-holes show the rocks beneath the valley to be of essentially the same character as those exposed in the sides. They are alternating strata, varying from fine to coarse textured, hard to relatively softer, but firm, well compacted sandstones and dense, well compacted sandy clays.

Owing to the variations in character of the material forming the rocks at the dam site, both in its horizontal and vertical distribution, no large part of the structure will be of the same kind of material, or on the same stratum."

PLATE C–III



GENERAL TOPOGRAPHIC
AND
GEOLOGIC FEATURES
IN THE VICINITY OF
IONE DAM SITE
ON
DRY CREEK

SCALE OF MILES
0 1 2

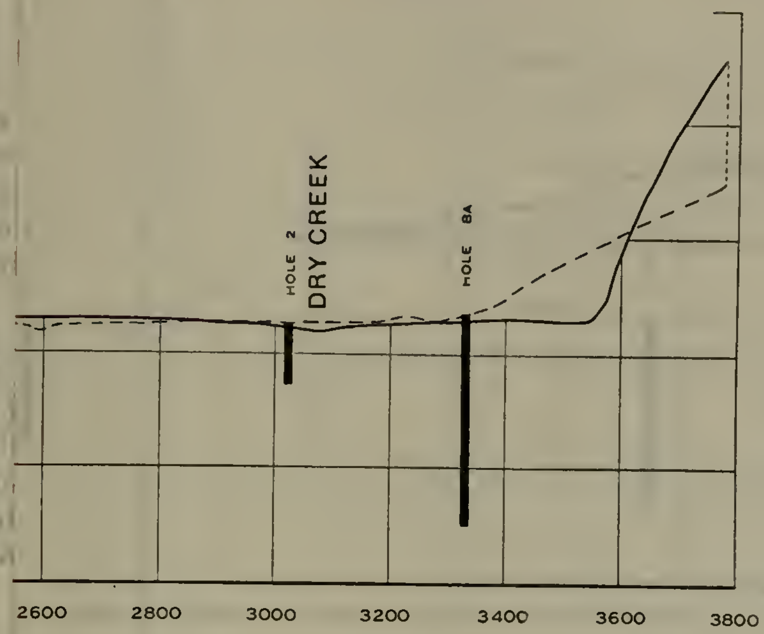
LEGEND

Underlying diabase bedrock complex

Ione - sandstone - shale conglomerate - tertiary

Volcanics - lava and tuff - tertiary

Stream and shore gravels - tertiary



LOCATION OF

DIAMOND DRILL BORINGS

AT

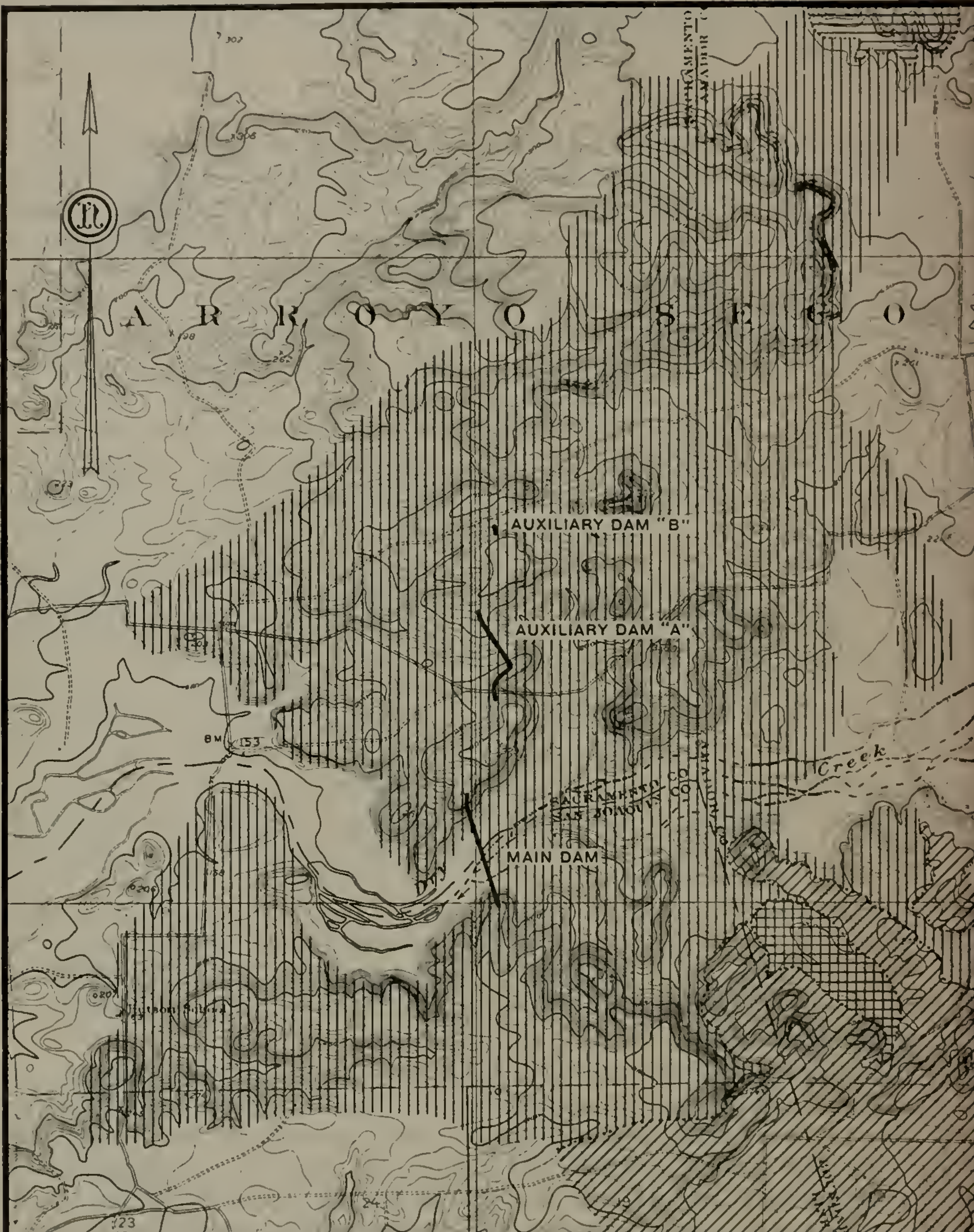
IONE DAM SITE

ON

DRY CREEK

BORINGS MADE IN 1924

PLATE C–III



GENERAL TOPOGRAPHIC
AND
GEOLOGIC FEATURES
IN THE VICINITY OF
IONE DAM SITE
ON
DRY CREEK

SCALE OF MILES
0 1 2

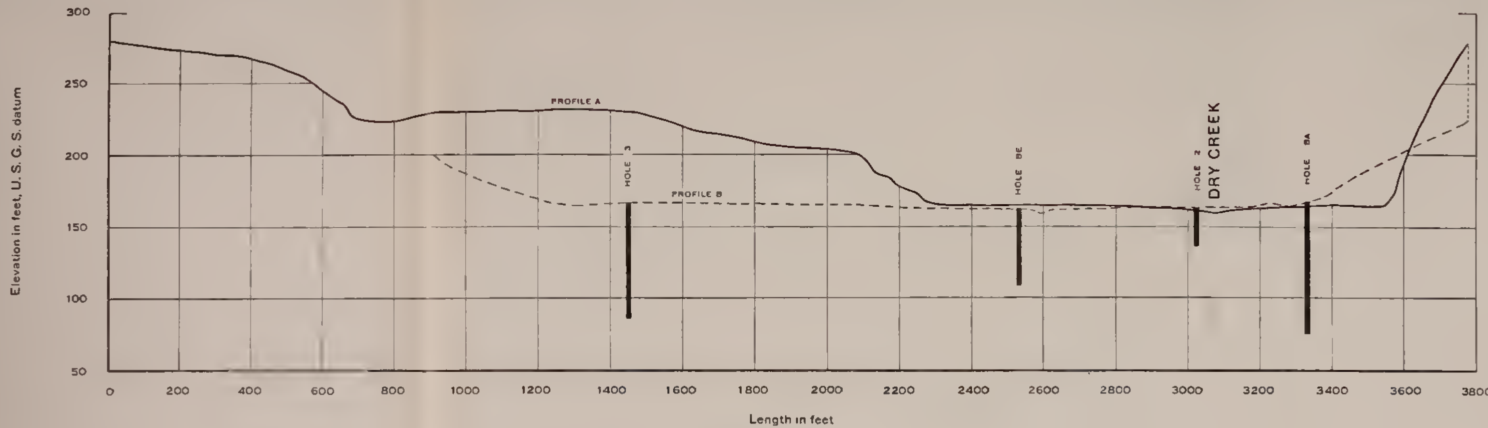
LEGEND

Underlying diabase bedrock complex

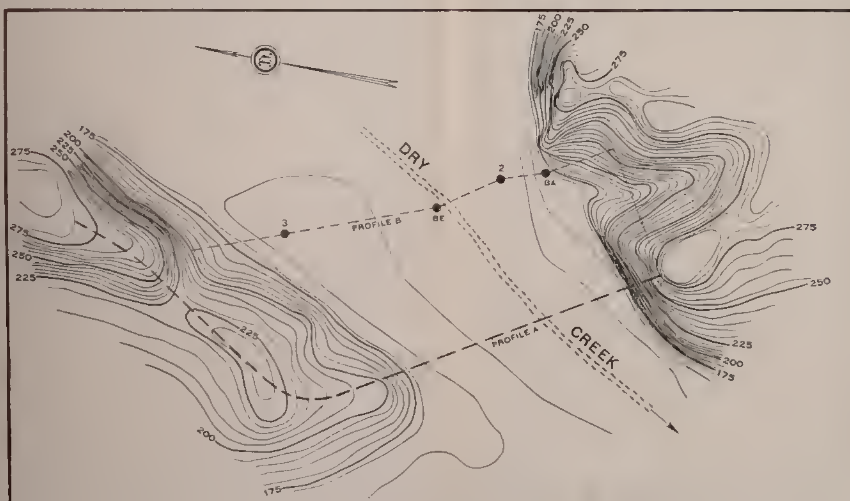
Ione - sandstone - shale conglomerate - tertiary

Volcanics - lava and tuff - tertiary

Stream and shore gravels - tertiary



PROFILES A AND B
LOOKING UPSTREAM



PLAN OF DRILL HOLES

FEET
0 400 800

LOCATION OF
DIAMOND DRILL BORINGS
AT
IONE DAM SITE
ON
DRY CREEK
BORINGS MADE IN 1924

Stripping could be limited to the removal of the high humus content soil. A deep cut-off below rock line would be unnecessary. The rock, though porous, is sufficiently fine textured in the sandstone and conglomerate matrix as to be practically impervious. It is too soft to allow open joints to persist.

The gravel and cobble filled clay loam weathering product found capping the ridges is ideal material for rolling in construction of the upstream third of an earth fill dam, and the flood plain alluvium should provide satisfactory material in sufficient quantity for the balance.

The site, with water surface elevation at 270 feet, would require two auxiliary dams. One would have to be about 50 feet high and abut against the same rock series as the upper 50 feet of the main structure, while the other would have to occupy a saddle whose crest is about elevation 265. Rock is close to the surface and would provide sound foundation for a concrete spillway structure which should be provided with a protective apron for several hundred feet downstream.

LOGS OF DIAMOND DRILL BORINGS AT IONE DAM SITE ON DRY CREEK, JANUARY 1924

Depths, in feet	Descriptions of formations and cores
HOLE No. 3—	
0 to 6	Black clay soil with small amount of cobbles and gravel. A three-inch standard pipe was washed down and seated in the sandstone.
6 to 21	Sandstone composed of sand cemented with clay. Core ground up by small gravel.
21 to 26.5	Sandstone. Good core.
26.5 to 31	Sandstone. Core same as above.
31 to 32	Clay.
32 to 38	Sandstone. Core.
38 to 55	Sandstone. Core; decreasing amount of clay.
55 to 63	Partially consolidated sandstone. No core.
63 to 65	Partially consolidated sandstone somewhat harder than 55 to 63. Showed traces of clay. No core.
65 to 80	Partially consolidated sandstone similar to section 55 to 63. No cave in hole and all water returned with pressure of 125 to 175 pounds.
HOLE "B E"—	
0 to 3	Sandy loam.
3 to 15	Close grained clay soil. No water.
15 to 17	Sand and gravel. Water.
17 to 25	"Quick" sand.
25 to 30	Sand and clay.
30 to 40	"Ione" clay.
40 to 42	Clay changing to sandstone.
42 to 51	Sandstone. Good core.
51 to 53	Sandstone. Gravel incorporated with sandstone, making drilling difficult.
HOLE "B A"—	
0 to 27	Silt, sand and clay. Water at eight feet.
27 to 28	Sandstone.
28 to 31	Sandstone, coarse-grained sand and gravel. Had to use chipping bit. Could not use Diamond bit because of gravel.
31 to 36	Sandstone. Small amount of clay. No core.
36 to 41	Sandstone. Very fine grain, with considerable amount of clay.
41 to 46	Sandstone. Good material.
46 to 51	Coarse sandstone.
51 to 56	Sandstone.
56 to 61	Sandstone, decreasing amount of clay. No core.
61 to 66	Similar to 56 to 61. No core.
66 to 76	Sandstone with increasing amount of clay. No core.
76 to 91	Sandstone. Very dense and hard. Good core.
91 to 92	Sandstone with gravel. No core.
HOLE No. 2—	
0 to 26	Sand, clay.
26	Sandstone.

Holes drilled with an "A.S." bit, making a one-inch core.

DON PEDRO DAM SITE ON TUOLUMNE RIVER AND EXCHEQUER DAM SITE ON MERCED RIVER

The object of the investigation of the Don Pedro dam site on the Tuolumne River and the Exchequer dam site on the Merced River, upon which concrete structures have been built, was the determination of the geologic feasibility of raising these structures. The results of previous geological examinations were made available in reports of A. J. Wiley on Don Pedro Dam and that of Herbert N. Witt, consulting geologist, upon the geology and results of diamond drilling of the Exchequer dam site. No additional exploration was had, nor was the geology mapped in detail at either site.

Geography and Topography.

The geography and topography is shown on the Sonora Quadrangle sheet of the U. S. Geological Survey, attached as Plate C-V. The dam sites lie in the stream canyons just above the foothills of the Sierra Nevada, the ridges of the region reaching an altitude of little over 1,000 feet above sea level. At the dam sites the rivers have a southwesterly trend through restricted gorges cut across the northwest-southeasterly trending ridges. Above the dam sites the drainage, for the most part, follows the topographic trend, and wider valleys, which provide reservoir areas of considerable capacity for the height of dam proposed, have developed.

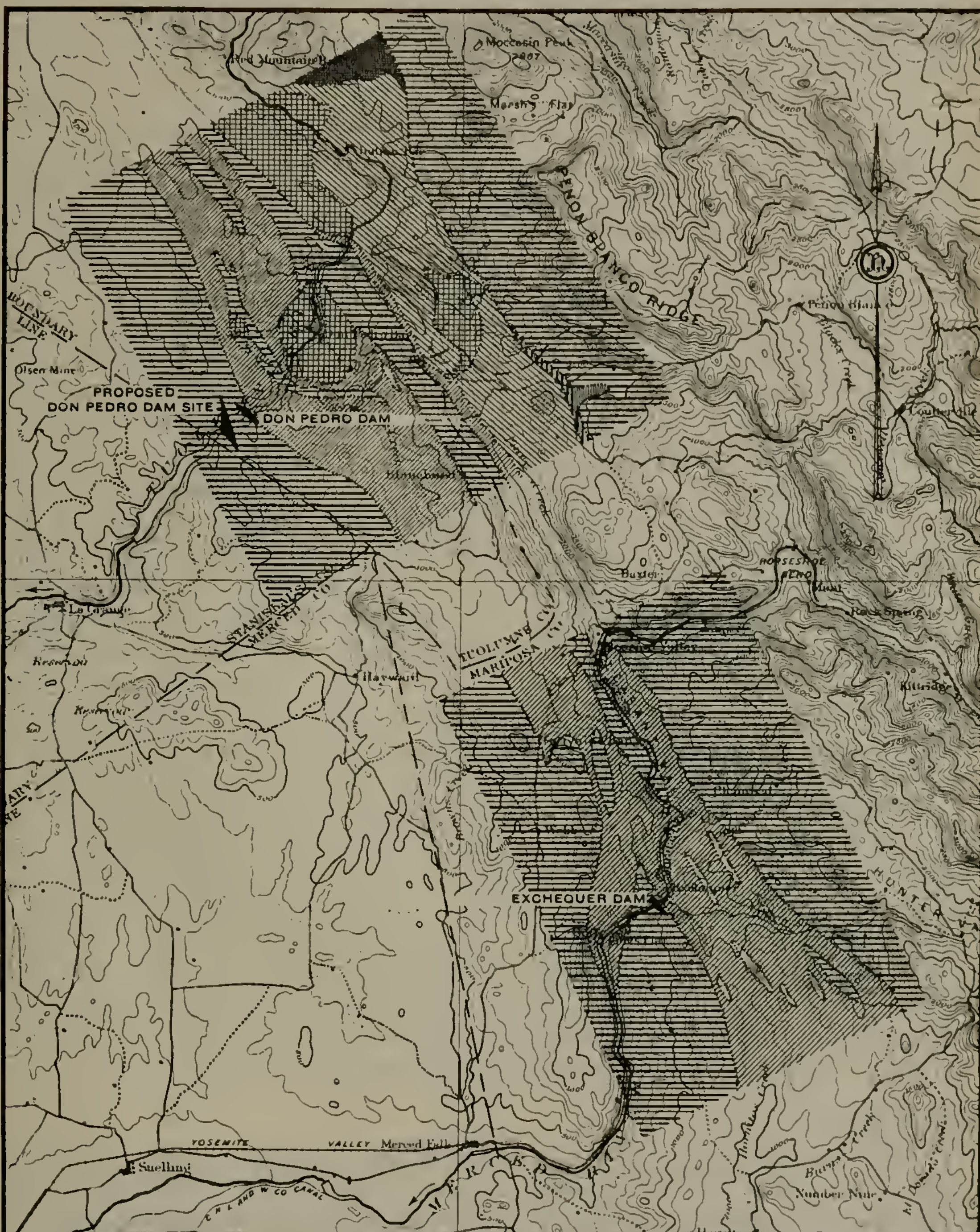
General Geology.

The general geology of the area is published in the Sonora Folio of the U. S. Geological Survey. Briefly, the rocks of the region are of many kinds and occur in complex associations. In origin they are, within relatively short distances, in part sedimentary, in part volcanic, being the products of igneous eruption and extrusion, and in part igneous intrusions. All have subsequently suffered considerable displacement, compression and alteration. The original structure, clastic, fragmental, or massive igneous, as the case may be, is lost in folding and banding, due to compression, and the primary minerals are changed to alteration products through recrystallization under the stresses to which the rock masses were subjected, so that petrographic distinctions are extremely difficult and of little value to the engineer. The principal questions of interest are the soundness of the rock mass and the extent to which weathering has attacked and weakened the rock surfaces.

Don Pedro Dam Site.

The stream gorge, at the upper end of which is constructed the present Don Pedro Dam, begins at the contact between slate and a relatively thin bedded green rock which is probably a metamorphosed tuff. Just below the present dam the rock layers have been sharply folded and somewhat faulted along joint planes. The upstream leg of the fold upon which the dam rests dips more gently. The folding, however, weakened the rock mass to the extent that weathering attacked it and left but a low ridge on the right abutment. Therefore, the topographic development and geologic structure prohibit construction of a higher dam on the site of the present one.

PLATE C–V



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES

IN THE VICINITY OF

DON PEDRO AND EXCHEQUER DAM SITES

ON

TUOLUMNE AND MERCED RIVERS

SCALE OF MILES

0 1 2 3 4 5 6

LEGEND

Shore and river gravels
Mariposa formation
Alluvium
Grano - diorite and granite
Porphyrite
Amphibolite
Serpentine

The westerly leg of the sharply folded anticline dips more gently progressively downstream and the cross jointing becomes less pronounced. The rock bands become thicker and more resistant to the attack of the weather and erosion, so the canyon walls rise higher.

At a point about one-half mile downstream from the present dam a thick bedded or banded series of rocks strike across the stream. The rock bands are somewhat vesicular at their boundaries and the petrographic characteristics suggest a series of basic lava flows, resembling rocks described in previous reports and termed diabase. The beds or bands dip south 25 degrees west 60 to 65 degrees downstream, or into the earth about 175 feet vertically in every 100 feet horizontally.

The right abutment is somewhat jointed, and probably would require an average stripping depth of ten feet over the stream bed and to the top of the cliff line 150 feet above stream bed and an average of 20 feet from that point to the dam crest in order to remove loose joint blocks and reach reasonably sound rock in which the joints could be pressure grouted. The left abutment carries a heavier soil cover and is somewhat wooded. Rock in place outcrops up a topographic draw, but on the slopes rock is found only as disintegrated joint blocks. Stripping allowance should be 15 feet to 150 feet above stream bed and 25 feet to the crest of the ridge. Two systems of joints are prominent, one following the strike and dipping northeast, intersecting the planes of banding, and the other a nearly vertical joint system cutting obliquely across the strike and along some of which there appears to have been some movement, now long dead. Such faults are healed with quartz, but topographic draws have developed along the fault zones.

In order to take the best advantage of the topographic development, yet conform to the rock structure, the center line of the dam should preferably lie across the strike of the rock bands, where the bands are relatively thick. So laid out, the site would be entirely satisfactory for a concrete gravity or arch type dam.

A spillway could be provided at the left end of the dam crest with but little excavation to control and carry the overflow to the river channel about 1000 feet downstream from the toe of the dam.

There is no suitable construction material available at the site.

Exchequer Dam Site.

The economic advantage of incorporating the present Exchequer Dam in a higher dam may counterbalance the excessive stripping that would be necessary up the right abutment to the top of the ridge.

The rocks of the dam site have been described as the altered volcanics of the Mariposa formation and later granular intrusives. Alteration, however, in places is such that the origin of the rocks is less obscure than any site examined in the Gold Belt. The rocks of the left abutment consist, upstream to downstream, of tuff beds altered to light colored schist and dark green amphibolite schist, with the planes of schistocity striking north 40 to 50 degrees west, and along which the Cotton Creek topographic draw has developed; then a series of ancient andesite breccias and andesite flows in which the alteration varies, but, although hardened and with the original jointing closed and healed through the introduction of secondary quartz, it resembles petrographically the younger and softer Tertiary andesite flows and breccias found in other Sierra regions.

Diamond drill borings in this material resulted in good core recovery and satisfactory pressure tests. Above the crest of the present dam the surface rock is considerably jointed. Stripping allowance of fifteen feet to 700-foot elevation and 25 feet to the proposed dam crest, on the average, over the left abutment should be sufficient.

The right abutment presents a different rock type. The metamorphosed andesite and andesitic breccias found on the left abutment occupy the stream bed and up the right abutment to about the 500-foot contour. Above this is found the metamorphosed basic lava and tuffs previously termed diabase.

The diabase, a massive green rock, is exposed in the old quarry above the right abutment and outcrops at progressively lower elevations over the surface to the present dam. Outcropping above the diabase is another series of metamorphosed andesitic flows and tuffs, somewhat schistose in places. The diabase is a very hard rock and diamond drilling therein produced better than 95 per cent core recovery.

The rock outcropping above, and lying at and above the crest of the right abutment of the present dam, is softer, considerably jointed and weathered more deeply. Furthermore, an old fault, now entirely healed and along which it is unlikely movement will occur in the future, intercepts the right abutment at the crest of the present dam. This fault zone consists of considerably shattered rock in which the joint blocks are displaced.

The diamond drill holes crossing the fault at depth in the gorge lost core at these locations and lost water under pressure test, but not to the extent that grouting could not rectify these difficulties. It is difficult to estimate the distance from ground surface at which sound rock will be found in the shear zone. It is limited in width, but may need as much as 100 feet of excavation. Exploration of this feature should be carried on before any final plans for a higher dam are considered. For preliminary estimate purposes it would be well to allow an average depth of twelve feet stripping to the 700-foot elevation and 60 feet above that on the right abutment.

BUCHANAN DAM SITE ON CHOWCHILLA RIVER AND WINDY GAP DAM SITE ON FRESNO RIVER

The Chowchilla and Fresno rivers drain that portion of the Sierra Nevada watershed tributary to the Madera area of the San Joaquin Valley. The Madera Irrigation District has, in addition to sites on the San Joaquin River previously reported upon, investigated, surveyed and partially explored dam sites on these rivers. That on the Chowchilla River near Buchanan is located in the southeast quarter of Section 20, Township 8 South, Range 18 East, M. D. B. and M., at stream bed elevation 410. The Windy Gap site on the Fresno River lies just downstream from Fresno Flats in the east half of the southeast quarter of Section 2, Township 7 South, Range 20 East, M. D. B. and M. Both sites lie within the area mapped on the Mariposa Quadrangle of the U. S. Geological Survey.

The topographic development of the region is the result of post-Tertiary erosion of the middle western slope of the Sierra Nevada. This erosion has developed drainage patterns which lack the regular arrangement of continuous parallel ridges and draws conforming to the rock structure in the more northerly Sierra regions and the prevailing course of the regional drainage is more south than west in conformance with the inclination given the western slope of the Sierra during late Tertiary time. The region is one of moderate rainfall and neither stream reaches far enough toward the crest to be snow fed in summer, so the stream bed is dry or carrying low flow over considerable stretches for long periods during the year. Atmospheric weathering keeps pace with stream erosion, so that the channels are bordered by gently sloping hills rather than stream cut canyons, the two dam sites occupying the only two exceptions noted.

General Geology.

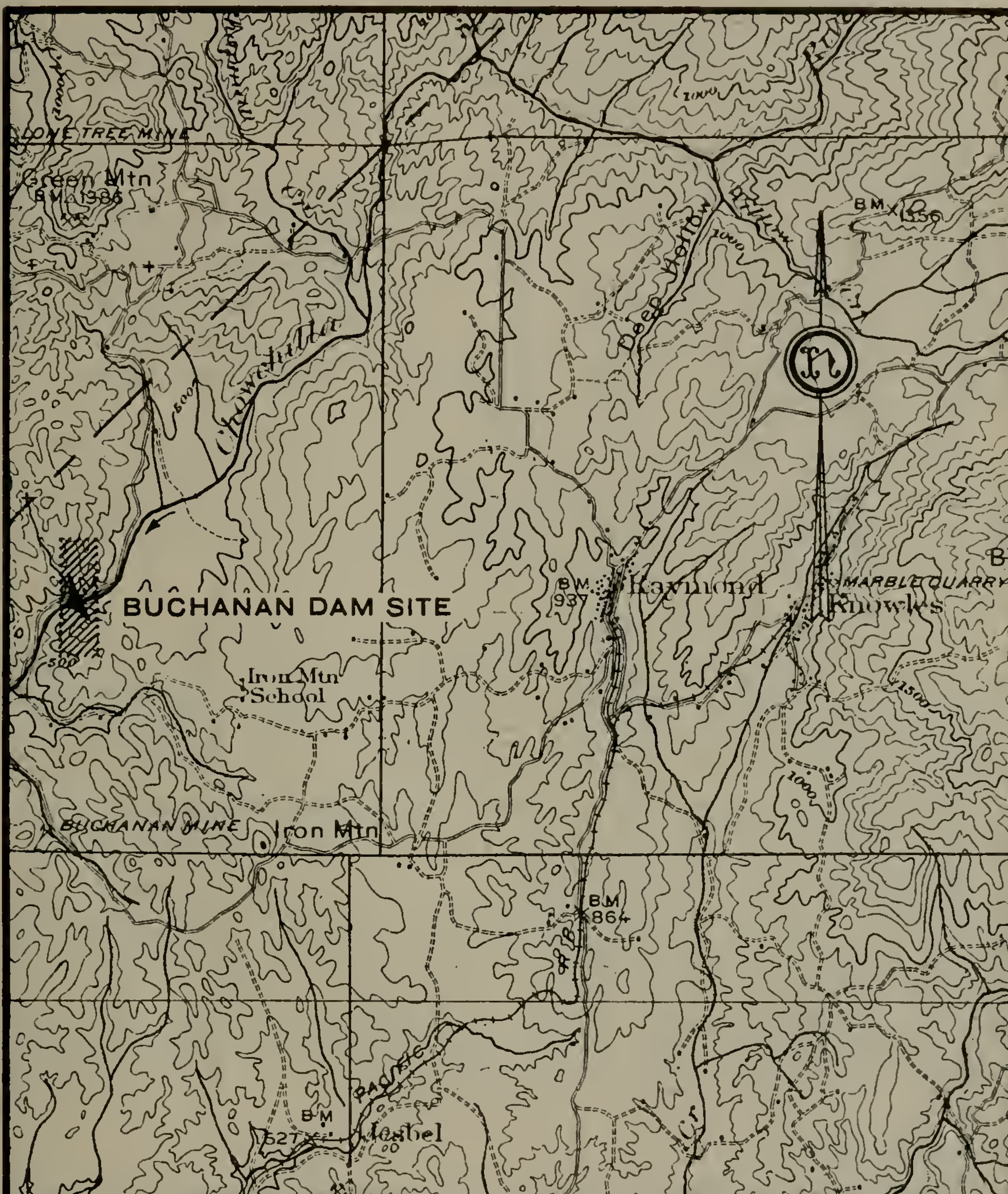
The topographic development is due largely to the character of the bed rock of the region, which consists principally of pre-Jurassic sediments into which granitic rocks have intruded. The original sediments are so altered that they have been rendered crystalline with an increase in hardness. The altered rocks, where examined, consist principally of a black micaceous slate and mica schist. The granites preserve their original structure, texture and mineral constituents, which vary considerably from place to place. The topographic development in the granitic areas has produced rounded hills and the conspicuous ridges are made up of belts of the metamorphic rocks.

Buchanan Dam Site.

The Buchanan Dam site, shown on Plate C-VI, lies at a point where the Chowchilla River has cut through a rock ridge, consisting of mica schist, across the planes of schistocity. The schistose texture is fully developed, due to the alignment of thin sheet crystals of the bronze colored mica-muscovite alternating with sheets of minute quartz crystals. Some facies of the rock contain the smaller crystals of the black mica-biotite and the schistocity is less marked, while others present large inclusions of primary quartz. The whole makes up a hard crystalline rock mass containing lines of weakness or parting planes which strike across the channel and dip north 35 degrees east 75 to 80 degrees from the horizontal upstream.

The site was partially excavated over thirty years ago, revealing the same bands of rock carrying from one abutment across the stream bed and up the opposing abutment. The weathered rock surfaces show parting along the planes of schistocity. In addition, the rock mass has developed three main joints, one dipping north 70 degrees west 80 to 85 degrees from the horizontal, one dipping south 40 degrees west about 18 degrees, and the other dipping south 80 degrees east 40 to 50 degrees, which cause the mass to break into rectangular blocks under weathering at the surface. At fresh exposures in the stream bed, the schistocity planes and joints are closed features. The condition of these lines of weakness below ground surface is revealed by diamond drill borings made for Madera Irrigation District. The locations of borings are

PLATE C–VI



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
BUCHANAN DAM SITE
ON
CHOWCHILLA RIVER

SCALE OF MILES

0 1 2 3 4

LEGEND

Mica-schist

shown on Plate C-VII, and logs of the holes are given in the table below. The planes and joints appear from the logs to be closed features, except in a limited zone from 45 to 60 feet below stream bed where water was lost. The cores were not examined, but the rock type is such as to contain no joint openings that could not be closed by pressure grouting.

Rock outcrops continuously across the stream bed and an average cut of six feet should be all that would be necessary to even up the rock foundation and key in the structure. The same rock bands extend up both abutments to the crest of the ridge and present the best structure, with planes dipping upstream, for dam foundation. Partial stripping has been done and an average of ten feet additional stripping should be ample provision for sound foundation. Construction material is available in gravel bars above and below the site.

The following data on foundation material including rock classifications and logs of diamond drill borings were obtained from a report by Harry Barnes, Chief Engineer, Madera Irrigation District, who made an inspection of the cores obtained and studied the driller's daily records. Reference is made to four classifications.

ROCK CLASSIFICATIONS BUCHANAN DAM SITE

No. 1—A uniform close grained rock, hardness about five, classed as a mica schist. This rock shows the presence of considerable mica, but it is fairly heavy, compact and homogeneous, cores well and carries no evidence of disintegration or weathering. In places this schistose rock shades almost into a gneiss or granite, and occasionally may include a seam of very hard, compact and almost non-crystalline rock. It was the aim to carry each hole down until rock of this character was encountered.

No. 2—Mica schist, hardness about four. Coarser grained than No. 1, streaked with rust and may contain narrow seams or sheets of oxide with a general discoloration thereof. On the whole a fairly compact hard rock that cores well, but cores inclined to break where rust streaks occur.

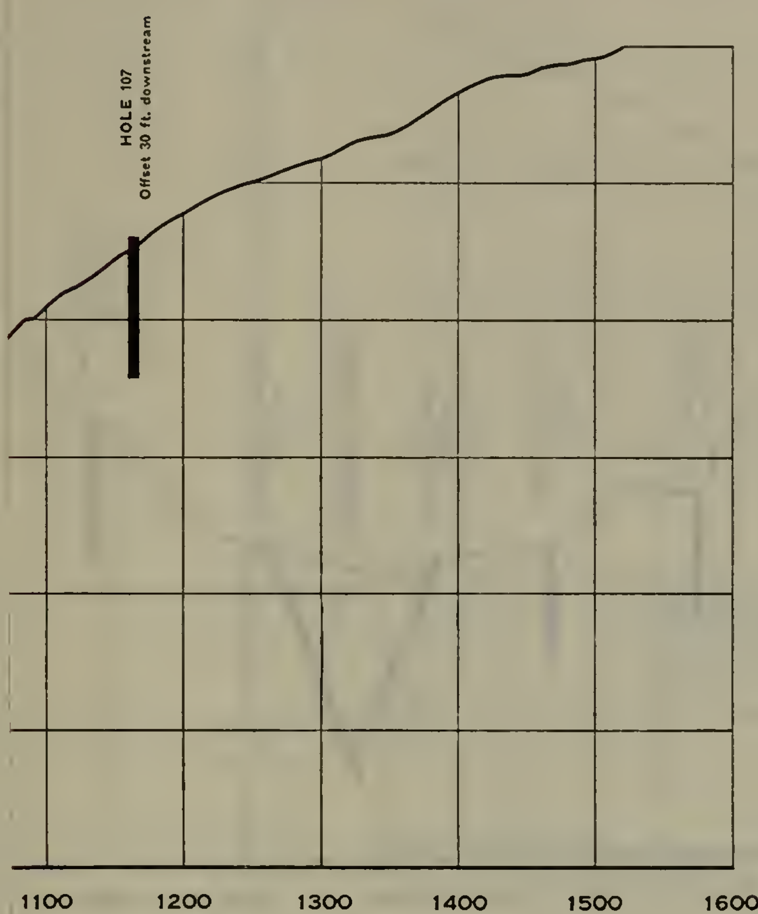
No. 3—Soft, coarse, micaceous sandy rock. Much of this rock seems like a rotten sandstone, possesses laminations but no cleavage, and can be easily broken with the fingers. Yellow oxide streaks occur throughout, the rock being relatively light and apparently more or less porous. In some the mica occurs as rather large flakes, in other pieces it is almost microscopic, being practically a micaceous sand. Short cores obtainable, but easily broken or ground up by the bits.

No. 4—Includes the surface soil and weathered or disintegrated rock. Such rock as is included in this class is of a coarsely micaceous sandy nature, contains considerable yellow oxide and does not core well, the drill yielding small irregular fragments or else buttons. This rock is easily broken with the fingers and shows the results of exposure to water and the elements.

Windy Gap Dam Site.

At Windy Gap, shown on Plate C-VIII, the Fresno River leaves Fresno Flats through a gorge cut across a prominent topographic ridge —Crook Mountain-Potter Ridge—which locally is comprised of a black micaceous slate converted in part into mica schist, consisting of small crystals of the black mica biotite and quartz and representing the original sedimentary deposit into which the granite intruded and compressed into bands and altered into a hard crystalline rock mass. The bands strike across the stream bed and dip nearly vertical, north 30 degrees east 85 degrees. In some of the bands the schistocity is hardly discernible, but others present well developed planes along which the rock cleaves under weathering.

The schistocity and banding strike and dip the same, being caused by the same dynamic stresses. Later compression stresses, due to crustal movement, have developed two major joints in the mass, one dipping south 20 degrees west 35 degrees and the other dipping south



LOCATION OF
DIAMOND DRILL BORINGS
AT
BUCHANAN DAM SITE
ON
CHOWCHILLA RIVER
BORINGS MADE IN 1923

LOGS OF DIAMOND DRILL BORINGS AT BUCHANAN DAM SITE ON CHOWCHILLA RIVER, JANUARY, 1923

Depths, in feet	Classification	Material	Description of formations and cores
HOLE No. 101—			
0–6	1	Mica schist	About fifteen inches of two and one-half inch core was saved; 0 to 2 was probably sand; 2 to 6 top boulders.
6–40.5	1	Mica schist	Solid rock. Core shows an occasional close fitting seam. Quartz vein at 29.
40.5–76	1	Mica schist	Solid rock. Occasional close fitting seams. At 54 feet a flow of water was struck. While the tools were in the hole and no water flowing into the hole from the drilling, underground water would continue to flow out the top. When the tools were removed it did not flow out the top, but while drilling hole No. 105, the water was lost at 54 feet and the water from 107 came out of 101. Hole No. 101 is lower than 107.
76–98	1	Mica schist	Solid rock. Occasional close fitting seam. Indications of copper were very pronounced near the bottom of hole. Core shows some copper stains.
HOLE No. 102—			
0–5		Sand and mica schist	No core saved.
5–10	1	Mica schist	Close fitting seam about every four inches. Very
10–40	1	Mica schist	close fitting seams occur about every eight inches. Core broken at 23 to 24 and more seamy. Hard rock.
40–51	1	Mica schist	Few close fitting seams. Hard rock. Core somewhat broken by blocking of drill.
HOLE No. 103—			
0–12	2	Mica schist	Core is very much broken up. Some of it coming out much like pebbles. Contains much mica, is of a darker color than the rest of the core in the hole and is seamy.
12–18	2	Mica schist	Five feet of core saved. Four feet of core saved. Slightly less broken than from 0 to 12, but about the same amount of mica and the same color.
18–43	1	Mica schist	Hard rock with a few close fitting seams.
43–51.5	1	Mica schist	Hard rock with a few close fitting seams.
HOLE No. 104—			
0–5			No core saved. Drillers report shows talc and schist. There is no talc here.
5–34	2	Mica schist	Of a light brown color, fine grained, with close fitting seams about every three inches. More broken and more seams near the top of section. Report shows seam at 23.5 feet. There is no indication of a seam in the box.
34–56	1	Mica schist	Light gray color. Hard with occasional close fitting seam. Some broken at 49 to 50.
56–64.5	1	Mica schist	Hard rock with a few close fitting seams.
HOLE No. 105—			
0–8	1	Mica schist	Two and one-half inch core. Three feet of core saved. Close fitting seams running parallel with hole.
12–42	1	Mica schist	Very few close fitting seams.
42–79	1	Mica schist	Very few close fitting seams. (NOTE.—Water was lost at 48 and came up out of hole 101 on north side of river. No indications in Box 2 of any seam at that elevation.)
79–115	1	Mica schist	Very few close fitting seams.
115–121.5	1	Mica schist	No seams.
HOLE No. 106—			
0–5	1	Mica schist	Two and one-half inch core. Some close fitting seams.
5–37	1	Mica schist	Hard rock with a few close fitting seams.
37–57	1	Mica schist	Hard rock with very few close fitting seams.
HOLE No. 107—			
0–14	2	Mica schist	Two feet of core saved. What core is saved is No. 2, very broken and seamy.
14–20	2	Mica schist	Contains much mica, is broken into about two-inch lengths, and is full of small seams. Dark brown color. Lost water at eighteen feet.
20–50	1	Mica schist	Some close fitting seams. Quartz seam at 30 and 42.
50–59	1	Mica schist	Some close fitting seams. Core is somewhat broken at bottom of hole, caused by lack of water pressure.

PLATE C–VIII

GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
WINDY GAP DAM SITE
ON
FRESNO RIVER

SCALE OF MILES

0 1 2 3 4

LEGEND

Mica-schist

70 degrees east 85 degrees at nearly right angles to the banding. These lines of weakness, shown in Plate C-VIII, allow the mass to break into blocks at the surface under weathering.

The same bands of rock outcrop continuously from the crest of one abutment, across the stream bed and up the opposing abutment. The joint planes are closed tight features over fresh stream bed exposures, and probably would refuse grout at relatively short distances below ground surface. On the abutments, weathering has loosened joint blocks from the mass and produced a soil cover which probably would require an average excavation of fifteen feet to reach sound rock. Rock reefs are continuous across the stream channel and an average of ten feet excavation below stream bed should be sufficient to provide a key way for a concrete structure or core wall for a rock fill or earthen structure, the site being entirely suited to either type.

FRIANT, FORT MILLER, AND TEMPERANCE FLAT DAM SITES ON SAN JOAQUIN RIVER

The San Joaquin River drains the west flank of the Sierra Nevada and enters the San Joaquin Valley at about its center. Above the valley plain the river has cut a wide stream trench through the foothill area for a distance of approximately ten miles to the town of Friant, upstream from which the erosive development of the stream trench has provided narrower canyons with steep side slopes topographically suited for dam site purposes. The lowest of these in point of elevation is the Friant dam site located about one mile above Friant in section 5, township 11 south, range 21 east. Another, the Fort Miller dam site, is located on about the north line of sections 34 and 35, township 10 south, range 21 east. The narrowest gorge and steepest cliff profile development on the lower river is found at the Temperance Flat dam site, which crosses the river at about the center of the north line of section 25, township 10 south, range 21 east.

The topographic development of the region investigated is the result of the Sierra Nevada uplift in mid-Tertiary time, with the river erosive activity or base leveling processes being of geologic recent time. Rocks of the Tertiary age have been cut through, with but small remnants now remaining, and the underlying geologically ancient basement complex formation, with its somewhat younger intrusions, forms the rock mass into which the stream is vigorously cutting and out of which the stream trench has been carved. The topographic development is entirely due to differential erosion on a crystalline rock mass consisting of material which varies in its resistance to erosion and weathering, rather than being controlled by geologic structure. Horizontal corrosion and weathering has attacked the lesser resistant rock masses in places, widening the stream trench and producing gentle side slopes, but at the dam sites selected, stream erosion has proceeded more rapidly than atmospheric erosion of a more or less resistant rock mass and there the topographic development ranges from narrow canyon to gorges with cliff profile.

General Geology of Region.

The foothill region downstream from Friant consists of horizontal or gently dipping beds of sandstone and clay-shale, exposed as the capping of Table Mountain, overlying granitic rock. These beds are probably identical with the Ione formation of Tertiary Age. The underlying rock, as exposed below Friant is a coarse textured grano-diorite consisting of quartz, feldspar and hornblende, with occasional dikes of true granite or granitic rock containing the mica biotite. Overlying this formation at Friant is a heavy deposit of river gravel and alluvium occupying the present stream trench and an old river terrace deposit somewhat higher in elevation than the stream bed.

The formations were studied in sufficient detail and over an area wide enough to allow determination of their relationship to each other. This relationship is shown on Plate C-IX which purports to be general as but little time was given to its preparation in the field. The Tertiary sediments lie as a capping over the granite north of Friant. The terrace gravels are not distinguished from the present stream deposition, except by their topographic position.

The rocks of the basement complex, or "Bed Rock" series of Pre-Jurassic age, so designated by the publications of the U. S. Geological Survey, vary in origin and mineral constituents, but most have undergone change due to dynamic and/or contact metamorphism. Dynamic metamorphism, due to the intense distortion and pressure suffered by the rock formations during the great early (Jurassic) granitic intrusions, has, in this region, produced schists. The schistose structure strikes northwest-southeast across the region and the mineral constituents of the schists change in bands or zones from west to east. The predominant bands consist of mica schist, with quartz schist bands included, and talc schist near the contact. The basin above the schist area is made up largely of coarse textured granitic rocks containing dikes of fine-grained grano-diorite, alaskite, hornblende rock, and a basic rock consisting principally of magnetite. In this basin is a deposit of subaerial tuff consisting of extremely uniform and finely divided volcanic glass known commercially as pumicite. This deposit lies between 500 and 580 feet elevation and overlies disintegrated granite. There are also river terrace deposits overlying the granite.

It is possible that in this region granitic rocks were intruded at two different periods, the earlier intrusion being the coarse textured granite of the foothills and Fort Miller basin and the later intrusion being the fine textured grano-diorite of the Temperance Flat gorge; or the grano-diorite may be contemporaneous with the granite intrusion, and being closer textured was more resistant to weathering and more recently attacked by the stream through piracy of the upper San Joaquin by the Fine Gold Creek drainage. The latter rock is distinguished by a fresh and sound appearance in contrast to the disintegration and aged weathering which characterizes the surface of the basin rock. The dike rocks of radically different character also are absent and the whole presents a formation resistant to erosion and weathering.

Geologic Structure.

No faults of consequence were observed nor are any known in the region. The overlying Tertiary strata lie nearly horizontal and indicate that the mountain range has been uplifted without distortion or compression in more recent times. The joint planes and shear zones

PLATE C–IX

GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
TEMPERANCE FLAT
FORT MILLER AND FRIANT DAM SITES
ON
SAN JOAQUIN RIVER

SCALE OF MILES
0 1 2

LEGEND

Alluvium and terrace gravels
Tertiary sediments
Volcanics
Close textured grano-diorite
Coarse textured granitic rocks
Metamorphic series-mica schist

originating during the period of granitic intrusion are healed by the deposition of quartz and other infiltration products. Therefore any faults or shear zones in the rock masses are Pre-Tertiary, long dead and thoroughly healed fractures.

The earth stresses, due to the Tertiary uplift, produced new jointing common to all Sierra Nevada rocks. The formations are broken by several systems of joint planes, which are structural features persisting to considerable depth below ground surface without displacement along or parting of the joint walls. At the surface, rock blocks of varying sizes have parted from the mass along the joint planes and weathering has attacked certain of the joint walls, causing them to allow water penetration and effect some disintegration of the rock. The effect of this will be taken up in consideration of the detailed geology at each dam site.

Detailed Geology—Friant Dam Site.

The Friant dam site, occupies an area of complex metamorphic rocks which has been given the general name of mica schist. This rock contains several facies of granitic rocks in which intense crustal movement, with its accompanying pressures, have altered the original formations into gneisses and schists, accompanied by an increase in crystallization and hardness with the change in texture. The schistose rocks are those which predominate in mica, the brown muscovite being present in fairly large thin sheet crystals in some faces, with very little or without primary quartz, and with smaller crystals of the black biotite and quartz in others. The gneissoid rock might be termed a quartz schist, as large crystals of primary quartz predominate over the mica. Interspersed with the schist are rock bands in which the schistosity is hardly discernible and the rock is massive and close textured. These variations in rock character "band" the formation through variation in rock texture and mineral constituents, but, as all facies are perfectly crystalline, the mass is a strong fabric of interlocking crystals without any apparent texture weaknesses.

In the main the banding and schistosity strikes northwest-southeast and dips 50 to 60 degrees from the horizontal upstream, but the compressive forces which caused its development were such as to produce locally tortuous or contorted planes, which resemble shear zones and vary in strike to east and west and in dip to vertical and downstream.

The angle of dip of the planes of schistosity is important in relation to the strength of the rock as they are lines of cleavage along which the rock parts. The compressive strength of the rock varies from about 12,500 pounds per square inch, with the load applied at right angles to the planes, to about 3500 pounds per square inch when applied at an angle of 45 degrees to the planes. As the planes dip generally upstream and the resultant of the weight of the dam structure and the arch thrust components is inclined and dips downstream the rock mass will present its most effectual resistance to the combined stresses.

The rock is somewhat jointed with the most persistent jointing striking across the planes of schistosity and dipping southwesterly about 40 degrees from the horizontal. Shear zones and spaces caused by the parting of the rock under the original compression are entirely healed with secondary quartz filling, and no open fissures should persist beyond shallow depth. The net work of joints encountered in the cores is probably the result of the Tertiary uplift as they pass through quartz veins in the schist. The cores frequently have broken along these joint planes and most of the joints show water stain, but few are so open that water may circulate and, as the rock is stable and insoluble, there are none so enlarged through the action of percolating water to cause serious leakage from a reservoir.

On the whole the rock is one that resists erosion and weathering to a much greater extent than the granite adjoining it. It has long been exposed to the same agencies, yet sound rock is found at the surface in the stream bed and at moderate depths below the side slope surface. No extensive topographic draws, which would be evidence of zones of rock weakness have been developed on the slopes.

The rock at stream level is fresh and water-worn with the development of small potholes. The jointing exposed is irregular and not continuous and there has been no parting or weathering along the joints in the fresh rock. In some bands of rock along the fresh exposures of the stream bottom and in the cores examined, the schistosity is hardly discernible and the whole is shown to be a sound crystalline mass. The character of the bed rock in the stream bed is massive, regardless of the texture differences. This massive rock contains some few joints which, in the cores, are stained to depths of 25 feet below stream bed, but, as the stain could very readily have been produced by capillary moisture, it is believed the joints are of no consequence in allowing uplift effect on a dam or leakage under it and probably would refuse grout. These observations, however, in no way obviate the necessity for drilling and testing through water pressure or pressure grouting the joint planes in the foundation rock and up the abutments as part of the construction program.

The results of the core analyses, with detailed descriptions of physical characteristics of the cored rock, are given on subsequent pages. In connection with this analysis a prediction is made as to the depth of stipping necessary and the depth to which joints, which will take grout, persist. The estimated limit of stipping is shown graphically upon Plate C-X, "Location of Diamond Drill Borings and Test Pits at Friant Dam Site."

The bed rock forming the abutments on both sides of the river is the same, but the extent of soil and alluvial covering varies. The mantle of soil, consisting of disintegrated rock fragments imbedded in clay soil, which is the product of the decomposition of the rock, is relatively thin, ranging from one foot to three feet in the test pits examined. Underlying the soil cover, as revealed by the drill cores and pits, is disintegrated or partially broken down rock, which at depths of eight to twelve feet below ground surface merge with sound rock containing joints the walls of which have become somewhat disintegrated and which affect the soundness of the mass. The sound rock should be found along the limit of excavation indicated, and would require an average stripping of about 25 feet measured at right angles to the slope on the south abutment.

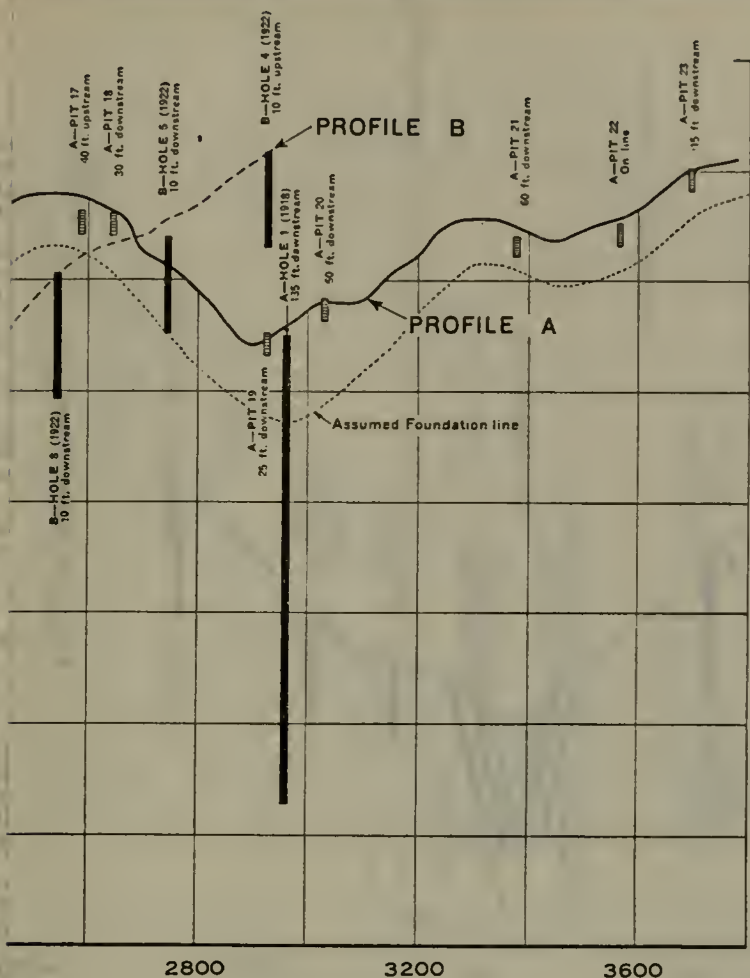
The north abutment contains an old stream terrace which represents the stream trench at a time its surface was 50 to 75 feet higher than the present stream bed. The carving out of this trench channel should be similar in contour to the present trench and as the drill holes were not closely enough spaced to definitely determine the contour it has been approximated in order to estimate the depth of stripping. Erosion had carried the gravels from the old channel down over the slope to the present stream bed. They are exposed in place to a depth of seventeen feet in Test Pit 3 and the core record of Hole 17 nearby, ten feet deep in Hole 19, seventeen feet deep in Hole 18, and but ten feet deep in Hole 20. All the pits from 2 to 7 show terrace gravels in place or as a wash soil covering over the slope.

The core of Hole 18 shows a depth of 54 feet before sound rock is reached, that of Hole 19 some disintegration of joint walls at 41 feet, and that of Hole 20 some disintegration of joint walls at 54 feet. It may be that stripping to a depth of 40 to 50 feet would be necessary over that portion of the north abutment occupied by the old terrace and it would be well to allow for an average depth of 40 feet stripping requirement over the entire north abutment in the estimate of cost. It is probable, however, that upon shallower stripping and the drilling and testing of joints showing some disintegration, grout would serve to prepare and provide a sound rock mass for the abutment.

The character of the bed rock is such as to be entirely satisfactory as foundation for a concrete arch or gravity type structure the full height of the proposed dam. The site provides a spillway location at the crest of the south abutment which would discharge the water down a topographic draw developed in the schist formation and into the stream about a half mile below the dam site. This schist formation is as resistant, below the soil cover and disintegrated zone, as the rock exposed at stream level. No exploration has been made as to depth to sound rock above Pit 25 at 600 feet elevation. Hole 25 showed sound mica schist at 30 to 40 feet below ground surface at a topographic saddle.

The stream bed and terrace gravels are now being worked commercially at Friant and would provide a nearby source of construction materials.

The following characteristics of rock and formations in open test pits, excavated during August and September, 1924, were compiled from records furnished by Harry Barnes, Chief Engineer, Madera Irrigation District, and from personal examination in March, 1930.



LOCATION OF

DIAMOND DRILL BORINGS

AND

TEST PITS

AT

FRIANT DAM SITE

ON

SAN JOAQUIN RIVER

BORINGS MADE IN 1918 AND 1922

than the present stream bed. The carving out of this trench channel should be similar in contour to the present trench and as the drill holes were not closely enough spaced to definitely determine the contour it has been approximated in order to estimate the depth of stripping. Erosion had carried the gravels from the old channel down over the slope to the present stream bed. They are exposed in place to a depth of seventeen feet in Test Pit 3 and the core record of Hole 17 nearby, ten feet deep in Hole 19, seventeen feet deep in Hole 18, and but ten feet deep in Hole 20. All the pits from 2 to 7 show terrace gravels in place or as a wash soil covering over the slope.

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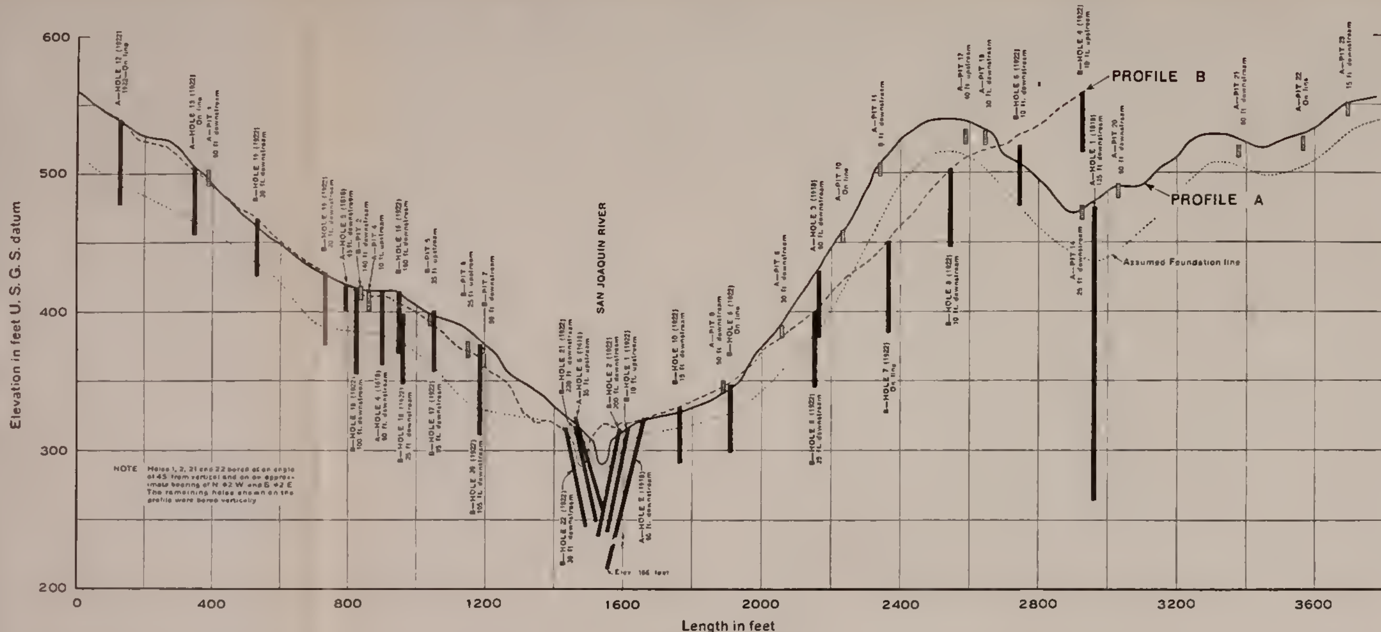
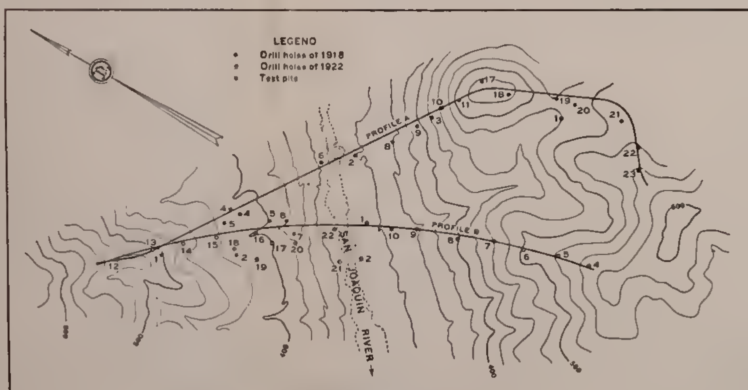


PROFILES A AND B
LOOKING UPSTREAM



PLAN OF DRILL HOLES
AND TEST PITS

FEET
0 400 800

LOCATION OF

DIAMOND DRILL BORINGS

AND

TEST PITS

AT

FRIANT DAM SITE

ON

SAN JOAQUIN RIVER

BORINGS MADE IN 1918 AND 1922

80997

TEST PITS—FRIANT DAM SITE

Pit No. 1, located by drill hole No. 13, elevation 505 more or less. Depth three feet, all hand work. One foot sandy loam soil, two feet of mixed gray and brown rock. Brown stain occurs irregularly throughout. No regular seams. Very micaceous, schistose texture, rock decomposition.

Pit No. 2, located by drill hole No. 18, elevation 415, on lower dam site. Depth 25 feet more or less, all hand work, through clay and terrace gravels to bottom. Landed in brownish stained coarse-textured disintegrated rock.

Pit No. 3, located by drill hole No. 17, elevation 400 on lower dam site. Depth 25 feet, more or less, all hand work. Ten feet of soil merging into light colored silty hardpan. Landed on brown and grayish rock of irregular occurrence.

Pit No. 4, located at old drill hole No. 4, elevation 418 more or less. Hole shot; ten feet, more or less, deep. Six feet of sandy clay loam, then gray rock, micaceous, schistose texture. Close irregular seams throughout carrying brown stain.

Pit No. 5, located at elevation 397 more or less, north of river. Hole shot; seven feet more or less deep. Three feet sandy clay loam. Four feet brown and gray mixed schistose. Laminated, micaceous, coarse granular structure, almost decomposed.

Pit No. 6, located at elevation 388 more or less, north of river. Hole shot; eight feet deep. Three feet sandy clay loam, one foot clay hardpan, two feet dry packed silt, two feet gray rock. Coarse schistose texture, somewhat micaceous with laminations. Close irregular seams carrying brown stain. Disintegrated.

Pit No. 7, located at elevation 374 more or less, north of river. Hole shot; seven feet more or less deep. One foot sandy loam; two feet water washed gravel, sizes up to four inches, then six inches of stratified pure clay and three and one-half feet of gray and brownish gray micaceous crystalline rock with irregular seams and with brown stain irregular throughout. Disintegrated.

Pit No. 8, located south of river, elevation 362 more or less. Hole shot; eight feet deep. Six inches of sandy loam. Rock grayish, stained with brown irregularly to eight feet. Irregular structure, seamy micaceous, schistose texture.

Pit No. 9, located south of river, elevation 418 more or less. Hole shot; eight feet, more or less, deep. Six inches of sandy loam. Rock gray, stained with brown for two feet, micaceous from three feet to eight feet. Brown stain in seams only, fine schistose texture.

Pit No. 10, located south of river, elevation 454. Hole shot; eight feet, more or less, deep. Twelve inches of sandy loam. Rock grayish, coarse schistose texture, very micaceous, grades to fine schistose texture. Irregular close tight seams; brown stain in seams, but occurring irregularly.

Pit No. 11, located at elevation 512 more or less. Hole shot; eight feet, more or less, deep. Rock similar to that of Pit No. 10, but coarser and easier to break.

Pit No. 12, located by drill hole No. 9, south of river. Hand work, eight feet more or less. One foot sandy clay loam, balance coarse grained decomposed quartz schist stained in irregular seams.

Pit No. 13, located south of river, elevation 391 more or less. Thirteen feet deep, hand work. Three feet sandy clay loam, ten feet grayish stained rock, irregular and very similar to Test Pit No. 8. Brown stain about two and one-half feet below this stain on seams.

Pit No. 14, located south of river, elevation 456 more or less, seven feet deep, hand work. Three feet soil and decomposed rock, three feet rather disintegrated rock with seams of decomposed rock and soil. Brownish stained rock, slab like structure at bottom. Bottom rock of decomposed fine grained schistose structure.

Pit No. 15, located south of river, elevation 504 more or less, by drill hole No. 4. Hand work, eight feet deep. Twelve inch soil; gray micaceous rock, much better than Test Pit No. 14, interspersed with brown irregular rock, with admixture of quartz, etc. Close seams carrying brown stains.

Pit No. 16, located south of river, elevation 544 more or less. Very micaceous, brownish, schistose rock, stained throughout, tight seams on schist structure, laminated, but fine texture.

LOGS OF DIAMOND DRILL BORINGS AT FRIANT DAM SITE, 1918

Location of Drill Holes Shown on Plate C-X

Hole	Direction	Depths in feet	Description of formations and cores
HOLE 1	Vertical	0– 8	Surface dirt and boulders.
		8– 11	Dirt and decomposed rock; landed casing at eleven feet.
		11– 20	Soft schist.
		20– 30	Schist, getting harder, micaceous.
		30– 50	Schist, less mica, nearly full core.
		50–109	Schist, practically full core.
HOLE 2	45° under river	0– 10	Sand, clay and boulders.
		10– 14	Schist, full core.
		14– 17	Schist; hole cased 5–10; landed.
		17– 92	Schist, full core.
		92– 93	Soft and lost water.
		93–105	Schist; cemented hole to hold water.
		105–141	Schist with quartz admixture.
		141–221	Schist and quartz schist.
HOLE 3	Vertical	0– 6	Decomposed schist, too soft to core.
		6– 17	Schist, too soft to core; landed casing.
		17– 38	Soft schist; eight foot core with double core barrel.
		38– 50	Schist, full core.
HOLE 4	Vertical	0– 10	Surface dirt and boulders; casing.
		10– 24	Clay and decomposed schist.
		24– 26	Soft and schist.
		26– 63	Schist and full core.
HOLE 5	Vertical	0– 10	Surface dirt and boulders.
		10– 17	Soft schist, micaceous.
		17– 18	Schist.
HOLE 6	40° under river	0– 10	Schist.
		10–112	Schist, full core.

Summary of Holes Drilled

Hole	Depths	Shifts	Footage per shift, actual drilling time
1	209	18	11.6
2	221	23	9.6
3	50	5	10.0
4	63	5	12.6
5	18	1	18.0
6	112	11	10.2
Totals	673	63	10.7 weighted mean

The above data compiled from log notes on file in office of secretary of Madera Irrigation District, by Harry Barnes, Chief Engineer.

Laboratory Certificate

SMITH-EMERY COMPANY
Chemical Engineers and Chemists
Los Angeles

April 19, 1923.

Laboratory No. 47253-6-7-8

Sample—Rock Cores Received—4/5/1923

Marked (See below)

Submitted by—Madera Irrigation District, c/o Quinton, Code and Hill, Hollingsworth Building, Los Angeles, California

COMPRESSION TESTS

	Dimensions, in inches	Area in square inches	Maximum load, in pounds	Crushing strength, pounds per square inch
HOLE No. 3— 4 feet deep	1.13 diameter x 1 1/8	1.00	1,550	1,550
HOLE No. 7	1.17 diameter x 1 3/16	1.08	2,130	1,970
HOLE No. 11— 7 feet deep	1.08 diameter x 1 1/8	0.92	3,990	4,340
HOLE No. 14— 111.2 feet deep	1.78 diameter x 1 3/4	2.49	9,100	3,640

Respectfully submitted,

SMITH-EMERY CO.
Inspecting and Testing Engineers

Smith-Emery Co.
Seal

LOGS OF DIAMOND DRILL BORINGS AT FRIANT DAM SITE, 1922

Location of Drill Holes Shown on Plate C-X

Depth in feet	Material	Description of formations and cores
HOLE No. 1—		
0-5	Mica schist	The core was two and one-half inches and does not appear in the box.
5-11	Mica schist	From 6 to 9 seamy material, some quartz filling. One seam about 8.5 shows material much ground up, but portions are hard.
11-21	Mica schist	Water stained. Hard rock core in four-inch to one-foot six-inch lengths broken by blocking of drill.
21-26	Mica schist	Joints some water stained. Hard rock only broken near 26-foot
26-31	Mica schist	level by blocking of.drill.
31-38	Mica schist	Hard rock only broken by the twist in the drill when blocking.
38-70	Mica schist	Hard rock, good cores only broken at the blocking points.
70-81	Mica schist	Hard rock and good cores.
81-86	Mica schist	At 83 feet the drillers lost the water in the hole. The core shows evidence of the drill vibration caused by striking diagonally the seams in the rock. A slight difference in hardness of the rock probably causes this vibration. The water came to the top of the hole when the 108 or 110-foot depth was reached. The core at 83 does not show any open joints or disintegration.
86-102	Mica schist	Hard rock showing some quartz veins.
102-112	Mica schist	Hard rock showing some quartz veins and some granitic formation.
HOLE No. 2—		
1-3	Mica schist	2½-inch core and was not put in box. Contained some seams, water stained.
3-7	Mica schist	Seam at 4 and 5. At 4 feet rock rather broken but broken portions are hard. No disintegration.
7-25^{5}	Mica schist	Continuous core but broken by drill into about three-inch pieces. Small seam was found at 17½. Water was lost at 25½ where a
25^{5}-37	Mica schist	small seam was found. Continuous core but broken into about three-inch pieces by drill.
37-58	Mica schist	Hard fine mica schist with no seams.
58-70	Mica schist	Hard fine mica schist with some quartz. No open seams. Joints clean and tight.
70-90	Mica schist	Hard fine mica schist with no seams.
90-92	Mica schist	Broken by drill.
92-102	Mica schist	Hard mica schist, schistosity hardly discernible.
102-108^{9}	------	Hard mica schist.
HOLE No. 3—		
0-4	Top soil	Material other than earth too soft to core.
4-9^{9}	Disintegrated schist	Much broken up with smallseams and does not core well. Maximum length of portions of core about two inches.
9^{9}-19^{9}	Mica schist	Broken core, seamy with clay seams at 11 and 15 and some talc at 19.
19^{9}-32	Mica schist	Disintegrated. Many small seams. Core comes out in about two-inch and three-inch pieces, although some better pieces at 22 and 29.
32-43^{4}	Mica schist	Some few small seams following the cleavage. Water stained. Some disintegration on seam at 30 feet.
HOLE No. 4—		
0-6^{4}	Top soil	Broken sandstone too soft to core.
6^{4}-17^{4}	Mica schist	Seamy mica schist, one-inch to two-inch pieces, water stained.
17^{4}-32	Mica schist	Seamy mica schist, two-inch to three-inch pieces. Hard, but some
32-43	Mica schist	close-fitting joints. Water stained, but no disintegration.
HOLE No. 5—		
0-7	Top soil	Too soft to core.
7-22	Mica schist	Broken seamy soft rock. Some large joint openings, water stained and disintegrated. Core comes out in about average of one-inch length. Lost water at 21 feet.
22-30	Mica schist	Close-fitting jointed rock about two joints per foot. Water stained.
30-43^{8}	Mica schist	One close-fitting joint at 35 feet, water stained. Core broken by drill.
HOLE No. 6—		
0-9^{5}	Hardpan	Too soft to core. Hardpan argillaced 10-12 feet some clay and sand streaks.
9^{5}-29^{5}	Mica schist	Soft seamy formation mostly too soft to core. Disintegrated and water stained.
29^{5}-35	Mica schist	Seamy schist.
35-37	Mica schist	Compact rock.
37-50	Mica schist	Rock is hard, but has joints about every three to four inches.
50-55^{9}	Mica schist	Hard schist with occasional close-fitting joint, water stained.

LOGS OF DIAMOND DRILL BORINGS AT FRIANT DAM SITE, 1922—Continued

Location of Drill Holes Shown on Plate C-X

Depth in feet	Material	Description of formations and cores
HOLE No. 7—		
0–9^{8}	Top soil	Too soft to core, chiefly washes away with the water. No core saved.
9^{8}–12	Disintegrated rock	Too soft to core. Small portions saved.
12–30	Mica schist	Soft rock containing a great deal of mica and full of seams, one about every two or three inches. Disintegrated.
30–43	Mica schist	Seams are close fitting, tight, and no disintegration.
43–46	Mica schist	About three joints in mica schist. Water stained.
46–60	Mica schist	Close-fitting joints about every two inches. Water stained.
60–66^{3}	Mica schist	Hard rock with very close-fitting joints one about every half foot.
HOLE No. 8—		
0–10^{3}	Top soil	Too soft to core and no core saved.
10^{3}–14^{3}	Mica schist	Small seams about every two inches. Disintegrated.
14^{3}–23	Mica schist	Small close-fitting joints about one every two or three inches. Water stained, but no disintegration.
23–53^{5}	Mica schist	Small close-fitting joints about one every two or three inches.
HOLE No. 9—		
0–12^{8}	Top soil	Driller's report shows ground too soft to core above 12^{8}. The beginning of the core at 12^{8} shows rock above that elevation. No other information is available above that elevation. Ground surface shows earth and broken rock.
12^{8}–20	Mica schist	Close-fitting seams about every three inches. Water stained.
20–25	Mica schist	Joints about every two inches. No disintegration.
25–26	Quartz	Broken by blocking drill.
26–28	Mica schist	No seams.
28–30	Mica schist	Hard rock.
30–34	Mica schist	Close-fitting joints.
34–40	Mica schist and quartz	Mica schist portion is soft and the quartz is hard.
40–48^{7}	Mica schist	Hard rock with few close fitting joints. While joints show water stain, it is probable they would refuse grout.
HOLE No. 10—		
0–8^{3}	Top soil	Report shows no core from 0 to 5 feet and from 5 to 8^{3} decomposed ground. No core is shown in box above 8^{3}.
8^{3}–14^{5}	Mica schist	Disintegrated rock. Seams 14 feet. Lost water. Other small, close-fitting seams.
14^{5}–17	Mica schist	Small close-fitting joints.
17–36	Mica schist	No seams, close-fitting joints.
36–38	Talc rock	No seams, close-fitting joints.
38–39^{3}	Mica schist	No seams, close-fitting joints.
HOLE No. 11—		
0–12	Clay and hardpan	Too soft to core.
12–18	Mica schist	No wide seams. Joints water stained.
19–29	Mica schist	Small close-fitting joints.
29–41^{3}	Mica schist	Small close-fitting joints about every foot, sound rock.
HOLE No. 12—		
0–10	Top soil	No material saved.
10–19	Disintegrated	Very soft and decomposed schistose formation, but very granular.
19–47	Disintegrated schist	Decomposed and broken down. Six-inch clay seam at 40 feet.
47–50	Mica schist	Some close fitting joints. Water stained.
50–59	Mica schist	Hard rock with few close fitting joints. Some water stained.
59–62	Mica schist	Close-fitting joints.
HOLE No. 13—		
0–18	Top soil	Too soft to core.
18–26	Mica schist	Very seamy and broken. Disintegrated.
26–27	Mica schist	No seams.
27–39	Mica schist	Close-fitting joints. Water stained.
39–49^{1}	Mica schist	Close-fitting joints about one per foot.
HOLE No. 14—		
0–10^{6}	Top soil	Decomposed sandy rock and clay.
10^{6}–14	Mica schist	Decomposed and seamy.
14–18	Mica schist	Seams about every one-half foot. Clay seam at 18 feet. Disintegrated rock.
18–25	Mica schist	Decomposed seamy rock.
25–30	Mica schist	Close-fitting joint, one about every foot. Water stained.
30–41	Mica schist	Close-fitting joint, one about every foot.
HOLE No. 15—		
0–10	Top soil	Too soft to core and no core saved.
10–16	Disintegrated	Seams every four inches.
16–27	Mica schist	Mica schist, very seamy.
27–35	Mica schist	Many close-fitting joints. Water stained.
35–39	Mica schist	Close-fitting joints. Water stained.
39–45	Mica schist	Close-fitting joints, some water stained.
45–47	Mica schist	Sound rock.
47–52	Mica schist	Solid rock.

LOGS OF DIAMOND DRILL BORINGS AT FRIANT DAM SITE, 1922—Continued

Depth in feet	Material	Description of formations and cores
HOLE No. 16—		
0–43	Top soil	Sand, clay and decomposed schist, too soft to core much.
43–50	Mica schist	No seams. Close-fitting joints not water stained. Total of nine feet of core from this hole. Apparently in terrace gravel pocket.
HOLE No. 17—		
0–17	Top soil	Sand, clay and gravel; casing 17 feet.
17–21	Mica schist	Seams, partially disintegrated rock.
21–30	Mica schist	Close-fitting seams. Lost water at 26 feet. Two additional joints showing some water, weathering and disintegrating.
30–44 [4]	Mica schist	Close-fitting joints, some water stained.
HOLE No. 18—		
0–17	Top soil	Decomposed schist, sand and clay and terrace gravel formation.
17–21		
21–24 [5]		
24 [5]–29	Mica schist	Too soft to core. Disintegrated.
29–51	Mica schist	Too soft to core. Lost water 44 feet.
51–53 [6]	Talc and clay	Report shows talc and clay. No core shown.
53 [6]–59 [1]	Mica schist	Clean joint walls.
HOLE No. 19—		
0–5	Top soil	No core saved.
5–9	River wash	No core saved. Gravel, debris, etc.
9–16	Mica schist	Close-fitting seams showing some water stain.
16–20		Report shows clay showing some water stain, but no disintegration.
20–35 [6]	Mica schist	Close-fitting joints showing some water stain, but no disintegration. (NOTE.—Lost water at 35 feet).
35–44 [6]	Mica schist	Seam at 39 and 41. Disintegrated.
HOLE No. 20—		
0–10	Top soil	Too soft to core.
10–35	Mica schist	Too seamy to core.
34–44	Mica schist	Seams about every three inches showing disintegration and water stains.
44–46	Quartz schist	
46–55	Mica schist	One small seam at 54 feet. Close-fitting joints.
HOLE No. 21—		
0–7	Mica schist	One small seam at about three and seven with three close-fitting seams between. Water stained.
7–13 [6]	Mica schist	No seams.
13 [5]–16 [6]		Seam at 14 and 15.5. Water stained.
16 [6]–33	Mica schist	Hard rock with no seams.
33–36	Mica schist	Two close-fitting joints, water stained.
36–66	Mica schist	Mica schist streaked with quartz. Very hard, with an occasional close-fitting joint.
66–81	Mica schist	Mica schist streaked with some quartz. One small close-fitting seam at 77.
81–98	Mica schist	Hard, with only an occasional close-fitting joint.
HOLE No. 22—		
0–3	Mica schist	Three close-fitting joints. Water stained.
3–22	Mica schist	Close-fitting joints at 3, 7, 8, 9, 17, 19.5, 19.7, 20.8. Somewhat larger seam at 21.8. Firm, sound rock.
22–32	Mica schist	Close-fitting joints at 22.5 and 23.2. Rock is streaked with quartz.
32–38	Mica schist	Rock is mixed with quartz and jointed to break up, there being only about three feet of core saved. Probably some close-fitting joints between the quartz and mica schist. Schistosity is hardly discernible.
38–70	Mica schist	Close-fitting seams at 40, 42, 47.5, 48 and 64. (NOTE.—The drill report shows that water was lost at 68 feet. From 65 to 70 the core is continuous without a break and shows no seam.)
70–100 [2]	Mica schist	Solid rock of probably more a granite formation than a mica schist. No seams.

Laboratory Certificate

ABBOT A. HANKS, INC.

Lab. No 19911 to 19924, Incl. Date Sept, 25, 1924.

Sample—Rock cores

Received—9/23/24

Marked Diamond Drill Rock Cores
Samples A to N, from
Dam Site Near Friant

Compression Tests

Submitted by—San Joaquin River Water Storage District, Los Banos, California.

We wish to report the results of the compression tests of the rock samples, marked "A" to "N," inclusive, which you submitted to our laboratories.

The samples were received in the form of diamond drill cores and we were able to prepare one test piece from each sample, each specimen having the height equal to the diameter.

As the relation of the direction of the applied load to the plane of bedding, grain or cleavage in a rock has a direct effect on the compression test results, we have recorded this angle wherever it was apparent.

RESULTS OF INDIVIDUAL TESTS

Laboratory Number	Sample	Cylinder size		Area in square inches	Angle "C" in degrees	Compression strength	
		Height in inches	Diameter in inches			Maximum load in pounds	Pounds per square inch
19911	A	1.14	1.18	1.093	40	2,980	2,725
19912	B	1.10	1.14	1.020	5	3,710	3,635
19913	C	1.10	1.18	1.093	0	13,340	12,198
19914	D	1.10	1.18	1.093	20	9,690	8,861
19915	E	1.10	1.19	1.112	15	6,620	5,952
19916	F	1.12	1.20	1.131	20	9,620	8,506
19917	G	1.14	1.18	1.093	25	4,650	4,252
19918	H	1.16	1.16	1.056	30	3,010	2,848
19919	I	1.16	1.15	1.038	25	3,910	3,764
19920	J	0.98	1.20	1.131	30	4,750	4,200
19921	K	1.18	1.15	1.038	45	3,660	3,524
19922	L	1.10	1.16	1.056	35	5,790	5,479
19923	M	1.16	1.19	1.112	45	5,120	4,603
19924	N	1.18	1.19	1.112	45	3,900	3,506

Remarks.—The test specimens were in cylinder form, the height and diameter of which is recorded. The slight variation in diameters of the cores is undoubtedly due to variations in character of rock.

The angle "C" is the angle between the vertical axis of the cylinder and the apparent plane of cleavage in the specimen.

We will be pleased to answer any further questions in connection with these tests and will store the samples for this purpose.

Respectfully submitted.

(Seal of Abbot A. Hanks, Inc.) R. E. NOBLE AND COMPANY

By Theo. P. Dresser, Jr.,
Chief Engineer

Detailed Geology—Fort Miller Dam Site.

About one-half mile upstream from the Friant dam site the contact between the metamorphic, or schist formation, and the granitic intrusion passes through the reservoir site. The contact is bordered by a series of weaker rocks in the metamorphic series and a coarse textured granite rock which has weathered down to form the wide basin bordering the stream trench. The coarse textured rock extends through the Fort Miller dam site to about the mouth of Fine Gold Creek. It contains many dike rocks of differing mineral constituents. The whole makes up a crystalline mass in which the crystal fabric has been broken down at the surface through the action of the weather and the penetration of water. This has resulted in a residuum of so-called rotten granite, from which the unstable minerals have been decomposed and removed, overlying a sound crystalline rock. The strength of the sound rock is unquestioned, but the depth to sound rock at the dam site is extremely uncertain and in the absence of subsurface pit or core drill exploration can only be inferred from certain evidences.

The "basin" on which the Fort Miller dam site lies is presumably an older surface than the Temperance Flat dam site and has been subjected to a long time weathering. The pumicite deposits, which are probably of Tertiary age, rest upon residuum from granitic rocks at about elevation 500. The slope of the stream is but eight feet per mile from the mouth of Fine Gold Creek to the Friant dam site and the stream bed elevation at Friant dam site is 310 feet. The base level for the drainage that formerly emptied through the basin area long has been achieved. There is no fresh bed rock exposed at the stream bed level and such rock as does outcrop is found to be considerably jointed, having disintegrated along joint planes. Where joints are close (a few inches to two feet) together, the rock has completely disintegrated between the joints and there is but little sound rock exposed in place.

Because of these conditions and experience had with similar rock exposed or drilled to depth below ground surface, it is estimated sound rock which could be used as foundation with reasonable grout preparation of weathered joint planes will lie, on the average, about 50 to 60 feet deep at right angles to the ground surface slope.

Joints through which water may circulate and which contain the stable products of decomposition—quartz sand—which make pressure grouting difficult may extend another 60 feet below rock line. On the whole the Fort Miller dam site is the least desirable from a geological standpoint of those examined on the San Joaquin River.

The upper abutments consist of the same coarse textured granite and have a fairly heavy soil cover, with but few outcrops of rock in place. Just above the dam site, granite outcrops appear near the crest of the ridge and the rock has a lighter soil cover. It is probable the lavas capping the ridge to the south, extended to the abutment ridge and were a protecting factor through which the topography has more recently developed, thus accounting for the freshness of the upper abutment rock. A spillway location is available in this rock at the crest of the north abutment of the dam site.

Detailed Geology—Temperance Flat Dam Site.

At the mouth of Fine Gold Creek the river emerges from a gorge cut through a close textured granitic rock—granodiorite. The fall of the river through the gorge and Temperance Flat averages about 20 feet to the mile, but for the first five miles above the flat the fall is 40 feet per mile. This development of a base level, taken in connection with the topographic development of Auberry Valley, suggests the pirating of the upper San Joaquin River by the Fine Gold drainage, with the geologic recent cutting of the gorge.

This active erosion and the fact that the rock is closer textured upstream from the mouth of Fine Gold Creek accounts for the apparent freshness of the exposed rock. The rock is a crystalline mass, being fairly uniform in texture and mineral constituents for a distance of 1000 feet upstream from the mouth of Fine Gold Creek. It is sound, stable and has great strength. In the mass it has resisted erosion so that a narrow gorge having a steep sloping cliff has been developed.

The formation is considerably jointed, with the main joint system striking across the stream and dipping downstream about 75 degrees from the horizontal and being intercepted by joint planes striking with the stream and dipping about 50 degrees toward the east. Two other minor joint systems intercept these at oblique angles and they, as well as other irregular joints, are accentuated at the surface, but have little importance in the mass. In fact, though the joints are structural defects in the rock mass, they are not to be considered as greatly weakening the mass nor detrimental to a structure founded thereon. The crustal movement which produced them did not cause any movement along the joints or parting of the joint walls. Though the movement long has been complete, there is no sign of infiltration products deposited on the wall rocks of joints opened by surface weathering.

The joint walls are sound and show no signs of disintegration at the surface. At the stream edge, in the freshly eroded rock, the joints were tightly closed and should be found closed at short distances below ground surface and incapable of transmitting water or water pressure below the stream bed or on the abutments.

At the dam site the lower section above stream bed has developed a narrow gorge with a smooth rock cliff profile along the joint plane paralleling the stream and dipping toward it from the left. Along the left abutment, parallel to the surface, a joint block has loosened and partially spalled off. Subsurface exploration is necessary to determine whether or not parting has occurred along parallel joints. The right abutment below the cliff line appears to be sound and necessary stripping could be limited to that required to remove loose joint blocks and key in a structure. The upper portion of both abutments consists of rock in place, with dislodged or loose joint blocks and a shallow soil covering spotting the steep slopes. The depth of rock over the stream channel should be but little in excess of the projection of the side slopes, with some limited pothole development.

The site is such that the geological and topographical conditions combine to make an excellent site and foundation for a concrete arch type structure. There is no natural spillway location so the spillway would necessarily be part of the structure and the overflow had over the same resistant rock that is exposed in the stream channel and which is not subject to rapid erosion.

PINE FLAT DAM SITE ON KINGS RIVER

Kings River emerges from the foothills about ten miles north of Reedley and for a distance of eight miles upstream from that point to Piedra passes down a comparatively wide stream trench.

The Pine Flat dam site lies about four miles upstream from Piedra in Section 2 of Township 13 South, Range 24 East. Above, through Pine Flat, and below to Avocado, stream erosion and weathering has widened the stream trench and produced gentle side slopes. At the dam site erosion has been confined to a canyon, slopes are precipitous and sound rock is in place close to the surface.

General Geology.

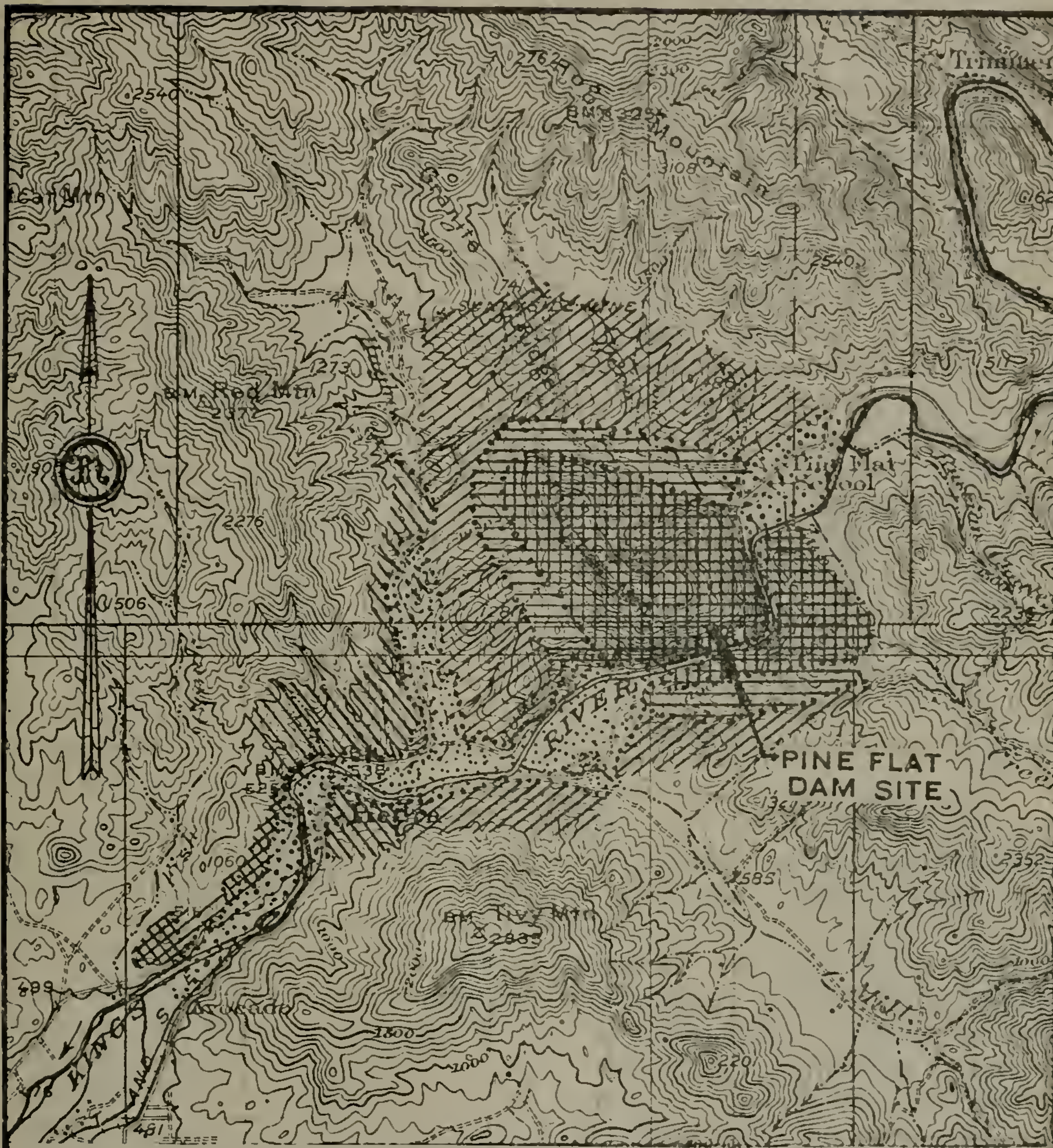
The relation of the topographic development to the geology of the region is shown on Plate C-XI. In common with the western flank of the Sierra Nevada, the rock formations here consist of a series of geologically ancient rock, now known as the basement complex metamorphics, in contact with igneous rock bodies whose intrusion into the mass are responsible for the metamorphism or change it has undergone. The original rocks have been recrystallized through the intense pressure accompanying the intrusion and their chemical constituents have undergone change through reaction with the gases under the heat from the molten magmas then at a great depth below the surface. Such action upstream from Avocado has produced a series of schists, slate and granitized rocks in which granitic dikes are found. Then follows a band of serpentized rock with true serpentine and its weathered product, magnesite, in limited zones, further altered along the contact with a larger granitic plug or dike from a plug. Upstream from the granitic rocks is found another zone of granitized rocks which becomes hornblendic, going from grano-diorite to diorite in a gradual mergence with a large body of extremely fine grained hornblendic metamorphic rock in which the dam site lies.

The schists and serpentine are rocks readily attacked by atmospheric weathering and stream erosion. The granite lying above is coarse textured and subject to weathering. The fine textured hornblendic rock, however, is dense and hard and thereby resistant to weathering and stream erosion, which accounts for the narrow canyon and steep slope development at the dam site.

Geologic Structure.

The region investigated, in common with the west flank of the Sierra Nevada, is one in which no geologically recent crustal disturbance has taken place. The intrusions of the granitic rock bodies, which caused great folding and faulting of the preexisting rock formations, took place in Jurassic time. Through the subsequent ages all fault and shear zones have become thoroughly healed by the deposition of infiltration products and, with the recrystallization of original rock masses due to metamorphism, the whole presents a structural unit unbroken by faults or zones of rock weakness. The stresses that caused the metamorphism were such as to band the formations. The banding generally strikes northwest-southeast and the rock bands change in chemical constituents and texture across the bands. The topography is the result of differential erosion of the mass, horizontal

PLATE C–XI



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
PINE FLAT DAM SITE
ON
KINGS RIVER

SCALE OF MILES
0 1 2 3 4

LEGEND

Alluvium
Granitic rocks
Serpentized rocks
Schists
Granitized rocks
Meta-diorite

corrosion attacking the less resistant rock bands to form draws tributary to the major stream and widening its trench, and the more resistant rock bands withstanding this attack with stream erosion developing gorge or canyon profiles.

The later Tertiary uplift of the region was accomplished without great distortion, but the compressive stresses which accompanied it produced several systems of joints which break the rock masses into relatively small blocks, though without displacement of the joint blocks or parting of the joint walls. That the jointing is a structural feature is attested to by the fact that the present topography has been developing since Tertiary time, and the present surface is hundreds or thousands of feet below the Tertiary surface. As the topography developed, rock blocks of various sizes parted from the mass along joint planes, gravitated to stream bed and were carried away. Weathering attacks the rock surfaces and joint walls, accomplishing decomposition and disintegration of the rock in place and allowing the penetration of water to carry on its work, chemically and mechanically, to effect a breakdown of the surface of the mass. These processes are surfacial in effect and the presence of joints beyond the depth of the reach of weathering, even though carrying some water stain, are not evidence of a weakened rock mass.

Detailed Geology—Pine Flat Dam Site.

The rock mass in which Kings River has entrenched itself at the Pine Flat dam site is a "greenstone," the chief rock-making member of which is hornblende. The latter is the result of metamorphism or alteration of the original crustal rock—probably diorite—due to intense pressure, heat and gases accompanying the granitic intrusion. The changes brought about through compressive forces have been such that the original rock cannot be readily recognized except that it must have been composed of basic minerals which, through recrystalization, have increased in hardness and compactness so that the result is a massive crystalline rock of great strength. At the dam site it is an extremely fine textured dark green rock consisting principally of minute crystals of hornblende and alkali feldspar. It has developed limited schistocity, due to the parallel arrangement of hornblende crystals, the foliations of which resemble shear zones. The whole mass is banded, as shown by the outcrops on the north abutment, with the bands dipping northeasterly about 40 degrees. This banding is an old structural feature and is not due to bedding of the rocks or changes in rock character, other than texture changes. The greater portion of the bands are comprised of fine grained massive rock which is extremely hard, fresh and strong. Under the hammer a greenish gray powder, which consists of minute grains of hornblende and feldspar, develops.

Along the center line of the dam site, between 850 and 1,000 feet elevation in the south abutment, the texture and character of the rock changes in a gradual mergence with rocks which have not suffered the same degree of change or have become granitized from the intrusion. The actual contact between the granitic intrusion and the older crustal rocks lies over the south abutment ridge and is marked by development of a topographic draw. The rock mass is weakened only at the contact, along which is found quartz veins carrying hornblende crystals, and between the contact and the massive rock, just described, occur granitic dikes, dikes of diorite and dikes of hornblende rock. The surface rock and the cores show the mergence to be a thoroughly knit crystalline fabric without any weakness due to heat, shrinkage and contact metamorphism, such as accompanies the line separating an igneous intrusion from the rocks into which it has intruded. Therefore, the whole presents a rock of great strength and hardness upon which to found a dam.

Jointing. The jointing, previously referred to as having originated during Tertiary time, while being a universal structural defect of the rock mass, is not to be considered as greatly reducing the strength of the whole or the safety of a structure founded upon it. The principal joints at the dam site consist of one striking at approximately right angles to the banding and dipping about 80 degrees, one approximately parallel with the banding and dipping northeasterly, and another intersecting these at an oblique angle and dipping about 50 degrees westerly. These joints are accentuated at the weathered surface and, though the course of the stream is not dictated by their presence, their topographic development along the south abutment is influenced by the jointing. Joint blocks have parted from the mass and gravitated out of place, allowing more ready attack of the weather. Hand samples picked from surface float, when struck with a hammer part in thin layers somewhat resembling irregular slaty cleavage along a multitude of irregular joints. In the sound rock these joints are hair lines which part under hammering, leaving smooth, clean surfaces.

In the cores examined (the analysis of which is appended to this report and the location of the holes and their inclination shown in Plate C-XII) some joints were noted below the stream bed, but the joint walls, being composed of hard, insoluble rock, were not disintegrated, nor did they show signs of water circulation. At depths greater than five feet below rock line the joints were closed and tight. Such crevices noted in drilling were quartz filled and the whole joint system probably would refuse grout at shallow depth when drilled and tested as part of the construction program. They in no way need be considered as means of effecting uplift on or leakage under a dam.

At the surface, the rock has parted along joint planes and has completely broken down to a clay soil carrying rock fragments for depths up to three feet and become partially disintegrated to depths of three to fifteen feet in addition. Below this depth are some joints along which water has circulated and caused some disintegration of the mass. These conditions, as revealed by the subsurface exploration, are spotted over the site. On the average, it should not be necessary to strip below fifteen feet. Some portions will require but five to eight feet, while limited areas, in topographic draws, will require as much as thirty feet. Most of the joints at those depths will be found tight, though carrying some water stain. Pressure grouting could be used effectively in closing all open joints up the abutments.

The character of the rock and the topographic development at the site is admirably suited to the construction of a concrete arch dam. The rocks making up the reservoir embankments are all stable, insoluble and incapable of passing water. A natural spillway is lacking, so the spill should be part of the dam structure, preferably at the north abutment, where the overflow would pass down the slope at right angles to the massive rock bands, which would resist erosion and require only a structure to retain it from working around to the toe of the dam.

The stream bed gravels and sand above and below the dam site provide a near-by source of construction material.

SUMMARY OF DATA RELATING TO DIAMOND DRILL EXPLORATIONS OF PINE FLAT DAM SITE, WITH CORE ANALYSIS

Hole No. 1—Elevation 554.8—Total depth 100 feet; core recovery 95 feet; broken to five foot joints clean and tight; some quartz filling.
Material—Massive amphibolite encountered three feet below surface. Lost two feet of core 46–60; one water stained joint; no disintegration.

Hole No. 2—Elevation 552.8—Total depth 100 feet; core recovery 93 feet; 0–5 feet cased; lost core 10–12 feet.
Material—Massive amphibolite encountered two feet below surface. Lost core 24–25 feet broken by quartz veins. Lost core 52–54 feet broken and creviced, no signs of water.

Hole No. 3—Elevation 563.2—Total depth 120.5 feet; core recovery 116.6 feet; 0–4 feet cased; lost 2 feet of core.
Material—Massive amphibolite encountered two feet below surface. Creviced at 17 feet, 18½ feet, 29 feet and 30 feet, but no sign of water; probably coarser less altered rock; 24–27 feet lost two feet of core, broken and creviced.

Hole No. 4—Elevation 562.2—Total depth 120.6 feet; core recovery 116.7 feet; no core to 7½ feet, jointed rock; some disintegration.
Material—Broken and considerably water stained joints first twelve feet and somwhat jointed to 27½ foot depth, remainder massive amphibolite. This hole required 27 feet of casing. Joints reported at 90, 96, 101 and 102½ feet; some slight water stain at 101 feet, but joint walls are stable rock; no disintegration.

Hole No. 5—Elevation 569.02—Total depth 33.8 feet; core recovery 29.9 feet; lost three feet of core 0–16 feet.
Material—Massive amphibolite two feet below surface; joints to 9–15 feet all healed closed features.

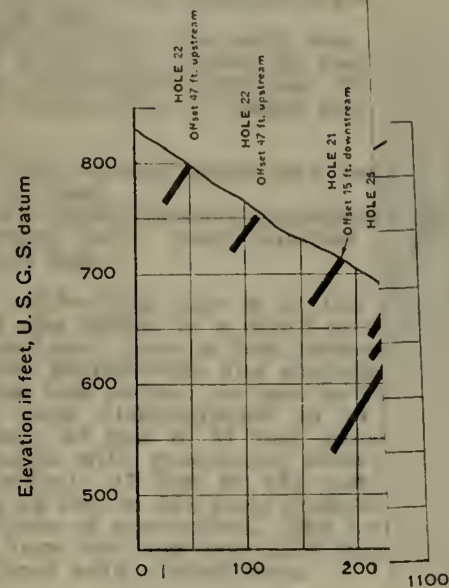
Hole No. 6—Elevation 573.4—Total depth 30.9 feet; two feet of soil at surface. Total core recovery sixteen and nine-tenths feet. Lost three feet of core 17–30 feet.
The upper fourteen feet of this hole was thoroughly broken by joints. Lost seven feet of core through which a casing was necessary. The rock below this point was hard amphibolite, but somewhat jointed, resulting in broken cores, but joints were clean, tight and probably would refuse grout.

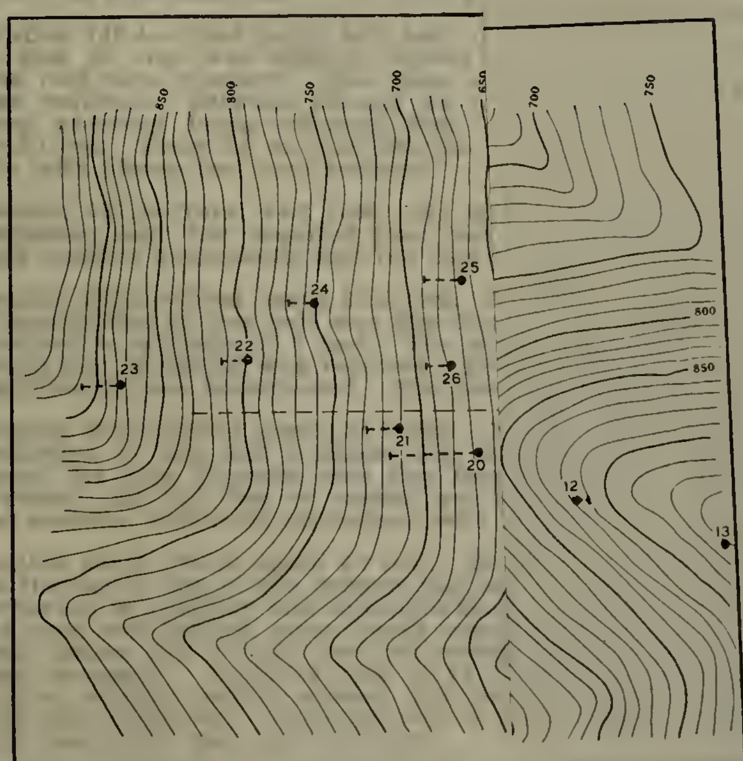
Hole No. 7—Elevation 596.1—Total depth 30.5 feet; core recovery 26 feet; lost first three feet jointed.
Material—Massive amphibolite below 5 feet.

Hole No. 8—Elevation 688.4—Total depth 29.9 feet; two feet clay and disintegrated rock at surface. Below this two feet of broken and creviced rock requiring, in all, four feet of casing.
From 4 to 14 feet, rock somewhat jointed and at depth 5 to 6 feet the water escaped. Below at depth 14 feet to 23 feet, seven feet of core recovered. Broken and jointed between depths 16 to 17 feet. No water stains, no disintegration below 7 feet. Depth 23 feet to 29.9 feet solid rock.

Hole No. 9—Elevation 765.6—Total depth 38.2 feet; one foot soil and loose rock on surface. Total core recovery 19 feet.
From depth 1 to 17 feet the rock was more or less jointed, but the water escaped only at depth 10 to 11 feet. This section required nine feet of casing. Lost nine feet of core; 9 to 17 feet jointed with water stains. No disintegration. In the section, depth 17 to 32 feet, the rock was jointed, but no water escaped. From 32 to 38.2 feet the rock was solid.

Hole No. 10—Elevation 810.0—Total depth 30 feet overburden three feet. Lost core to 9 feet.
From depth 3 feet to 21 feet jointed rock was encountered and required sixteen feet of casing. The water escaped at depth 9 to 10 feet. The core recovery in this section was six feet. From 21 to 30 feet massive amphibolite was encountered with nine feet of core recovery.





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to the massive rock bands, which would resist erosion and require only a structure to retain it from working around to the toe of the dam.

The stream bed gravels and sand above and below the dam site provide a near-by source of construction material.

SUMMARY OF DATA RELATING TO DIAMOND DRILL EXPLORATIONS OF PINE FLAT DAM SITE, WITH CORE ANALYSIS

Hole No. 1—Elevation 554.8—Total depth 100 feet; core recovery 95 feet; broken to five foot joints clean and tight; some quartz filing.
Material—Massive amphibolite encountered three feet below surface. Lost two feet of core 46–60; one water stained joint; no disintegration.

Hole No. 2—Elevation 552.8—Total depth 100 feet; core recovery 93 feet; 0–5 feet cased; lost core 10–12 feet.
Material—Massive amphibolite encountered two feet below surface. Lost core 24–25 feet broken by quartz veins. Lost core 52–54 feet broken and creviced, no signs of water.

Hole No. 3—Elevation 563.2—Total depth 120.5 feet; core recovery 116.6 feet; 0–4 feet cased; lost 2 feet of core.
Material—Massive amphibolite encountered two feet below surface. Creviced at 17 feet, 18½ feet, 29 feet and 30 feet, but no sign of water; probably coarser less altered rock; 24–27 feet lost two feet of core, broken and creviced.

Hole No. 4—Elevation 562.2—Total depth 120.6 feet; core recovery 116.7 feet; no core to 7½ feet, jointed rock; some disintegration.
Material—Broken and considerably water stained joints first twelve feet and somwhat jointed to 27½ foot depth, remainder massive amphibolite. This hole required 27 feet of casing. Joints reported at 90, 96, 101 and 102½ feet; some slight water stain at 101 feet, but joint walls are stable rock; no disintegration.

Hole No. 5—Elevation 569.02—Total depth 33.8 feet; core recovery 29.9 feet; lost three feet of core 0–16 feet.
Material—Massive amphibolite two feet below surface; joints to 9–15 feet all healed closed features.

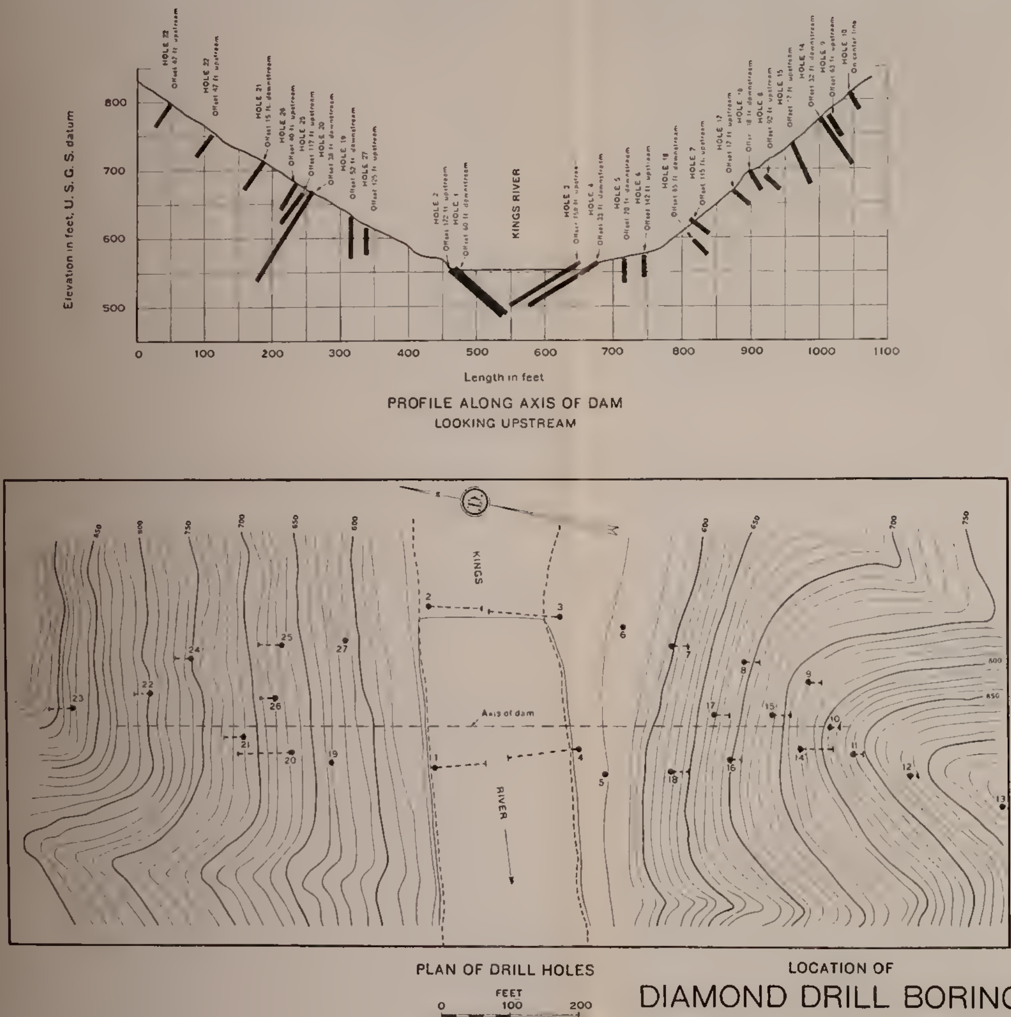
Hole No. 6—Elevation 573.4—Total depth 30.9 feet; two feet of soil at surface. Total core recovery sixteen and nine-tenths feet. Lost three feet of core 17–30 feet.
The upper fourteen feet of this hole was thoroughly broken by joints. Lost seven feet of core through which a casing was necessary. The rock below this point was hard amphibolite, but somewhat jointed, resulting in broken cores, but joints were clean, tight and probably would refuse grout.

Hole No. 7—Elevation 596.1—Total depth 30.5 feet; core recovery 26 feet; lost first three feet jointed.
Material—Massive amphibolite below 5 feet.

Hole No. 8—Elevation 688.4—Total depth 29.9 feet; two feet clay and disintegrated rock at surface. Below this two feet of broken and creviced rock requiring, in all, four feet of casing.
From 4 to 14 feet, rock somewhat jointed and at depth 5 to 6 feet the water escaped. Below at depth 14 feet to 23 feet, seven feet of core recovered. Broken and jointed between depths 16 to 17 feet. No water stains, no disintegration below 7 feet. Depth 23 feet to 29.9 feet solid rock.

Hole No. 9—Elevation 765.6—Total depth 38.2 feet; one foot soil and loose rock on surface. Total core recovery 19 feet.
From depth 1 to 17 feet the rock was more or less jointed, but the water escaped only at depth 10 to 11 feet. This section required nine feet of casing. Lost nine feet of core; 9 to 17 feet jointed with water stains. No disintegration. In the section, depth 17 to 32 feet, the rock was jointed, but no water escaped. From 32 to 38.2 feet the rock was solid.

Hole No. 10—Elevation 810.0—Total depth 30 feet overburden three feet. Lost core to 9 feet.
From depth 3 feet to 21 feet jointed rock was encountered and required sixteen feet of casing. The water escaped at depth 9 to 10 feet. The core recovery in this section was six feet. From 21 to 30 feet massive amphibolite was encountered with nine feet of core recovery.



LOCATION OF
DIAMOND DRILL BORINGS
AT
PINE FLAT DAM SITE
ON
KINGS RIVER
BORINGS MADE IN 1922

Hole No. 11—Elevation 837.7—Total depth 30.5 feet. Overburden three feet. Lost core to 12 feet.

To a depth of 22 feet the rock was somewhat jointed and the water escaped at 22 feet. From 22 feet to 30.5 feet the formation was massive amphibolite carrying dikes of granodiorite. The hole required eleven feet of casing and the core recovery was eighteen feet.

Hole No. 12—Elevation 882.2—Total depth 30.6 feet. Overburden three feet. No core to 4.5 feet.

Below 7 feet depth massive amphibolite. Core recovered sixteen and seven-tenths feet. Rock shatters along joints in drilling. Lost core 24–28 feet.

Hole No. 13—Elevation 929.0—This hole is at the extreme south end of the dam site and was drilled to a depth of 68.3 feet. First 30 feet of depth in creviced and more or less broken granitic rocks. Below 30 feet hard solid granodiorite and amphibolite.

A log of the hole shows: No core to 13 feet; 13 feet to 30 feet, granodiorite; some disintegration to 14 feet and water stained joints to 29 feet; 30 feet to 31 feet, greenstone, no veins; 31 feet to 40 feet, granite with greenstone veins; 40 feet to 47 feet, greenstone (amphibolite); 47 feet to 48½ feet, lost core; 48½ feet to 50 feet, granite; 50 feet to 50½ feet, greenstone; 50½ feet to 68.3 feet, granite, one vein of greenstone. The hole required thirteen feet of casing and core recovery was 53.3 feet. Core shows gradual merging of unaltered with altered rock.

Hole No. 14—Elevation 771.2—Total depth 80.2 feet. Lost core to 15 feet.

In this hole the drillers encountered broken and jointed rock to a depth of 58 feet. The water escaped several times and a total of 20 feet of casing was necessary. Joints were water stained and rock parted along joints 15 to 20 feet. The core recovery in this 58 foot depth was 22.5 feet. From 58 feet to 80.2 feet the formation was solid and the core recovery is seventeen feet.

Hole No. 15—Elevation 736.4—Total depth 65.8 feet. No core to 30 feet.

The first 30 feet was broken, jointed and disintegrated, with only one foot core recovery. The water escaped and 30 feet of casing was required. Between 30 and 54 feet the stone was better, the core recovery being nineteen feet. Granodiorite veins from 40 to 50 feet. From 54 to 65.8 feet the formation was solid amphibolite with eleven feet core recovery.

Hole No. 16—Elevation 697.4—Total 34.2 feet. No core to 6 feet.

Overburden four feet required four feet of casing. Balance of hole was massive amphibolite and the core recovery 28 feet.

Hole No. 17—Elevation 667.7—Total depth 30.5 feet. No core to seven feet.

The overburden in this hole was five feet and the rock was somewhat creviced to a depth of 8 feet. The water escaped at 8 foot depth, seven feet of casing was required. Below the 8 foot point massive amphibolite was encountered. The core recovery was 23.6 feet.

Hole No. 18—Elevation 626.7—Total depth 34.2 feet. No core to 10 feet.

Overburden of soil and boulders six feet. Between 6 and 15 feet depth the core recovery was five feet, the rock was broken and creviced and 15.8 feet of casing was necessary. Below this point the material was solid greenstone with a full core recovery.

Hole No. 19—Elevation 631.0—Total depth 60 feet. Drilled vertically. This hole is on the north side of the canyon just at the north side of the road.

Overburden of boulders and soil eight feet. In the first 26 feet drilled the rock was jointed, some heavy water stains with disintegration. Only twelve feet of core was recovered and sixteen feet of casing was necessary. From 26 feet to 34 feet the rock was somewhat jointed, slightly water stained, but fourteen and one-half feet of core was recovered. From 34 feet to 60 feet massive amphibolite with seventeen feet core recovery.

Hole No. 20—Elevation 668.2—Total depth 153.8 feet. No core to 13 feet.

Overburden four feet. The rock encountered in the first 25 feet of this hole was very broken and jointed, the water escaped at seventeen feet, and 24 feet of casing was necessary. Below this point and to a depth of 40 feet the rock was jointed, but held the water. From 40 feet to 153.8 massive amphibolite was encountered.

Eight and five-tenths feet of core was recovered in first 24 feet, 52.5 feet of core was recovered in the next 106 feet, and a full recovery of 23.9 feet in the remainder of the hole.

Hole No. 21—Elevation 711.2—Total depth 48.6 feet. No core to seven feet.

Overburden four feet underlaid with three feet of broken and creviced rock, all requiring seven feet of casing. From 7 feet to 20 feet solid rock was encountered with a full core recovery. From 20 feet to 25 feet the stone was jointed, but no water escaped and joints were not water stained. From 25 to 35 feet the rock was solid, and a full recovery was made.

From 35 feet to 37 feet the rock was jointed, but no water escaped. From 37 feet to 48.6 feet the material was solid. A core recovery of 9 feet was made from 35 feet to 48.6 feet.

Hole No. 22—Elevation 799.9—Total depth 41 feet. No core to 9 feet.

Overburden and loose rock seven feet. The rock encountered below 7 feet was somewhat disintegrated for two feet, thus nine feet of casing was required. Below the two feet all of the material encountered was solid, with a core recovery of 24 feet in a distance drilled of 32 feet.

Hole No. 23—Elevation 875.1—Total depth 100.2 feet. No core to 19 feet.

This hole was at the extreme north end of the dam site and was drilled to a total depth of 100 feet because of a peculiarity in the formation above the dam site in this barrier.

Overburden seven feet. Underneath the overburden a somewhat broken and jointed amphibolite was encountered and nineteen feet of casing was required. At a depth of about 20 feet the solid rock was encountered and was found to be continuous to the bottom of the hole. The total core recovery was 66.5 feet. Twenty-eight to 33 feet was granodiorite jointed and slightly water stained, with full core recovery; 33 feet to 100.2 feet was massive amphibolite.

Hole No. 24—Elevation 751.8—Total depth 40.2 feet. No core to 8 feet.

Overburden five feet. From 5 to 20 feet the rock was somewhat broken and jointed and a total of eight feet of casing was necessary. The core recovery in this section amounted to eight feet. The joints were not water stained. From 20 feet to 40.2 feet the core recovery amounted to eighteen feet, and the material encountered was massive amphibolite, throughout.

Hole No. 25—Elevation 665.3—Total depth 54.9 feet. No core to 12 feet.

Overburden six feet. From 6 to 18 feet more or less broken and jointed rock was encountered, requiring twelve feet of casing. The total core recovery in this section was two feet. From 18 to 44 feet the rock encountered was reasonably solid and the core recovery was fourteen feet. From 44 to 43.9 feet massive amphibolite was encountered and the core recovery was nine feet.

Hole No. 26—Elevation 678.2—Total depth 42.4 feet. No core to 4 feet.

Overburden three feet. From 3 to 40.2 feet solid rock was encountered. The total core recovery of 34 feet made with no parting along joints.

Hole No. 27—Elevation 613.4—Total depth 33.8 feet. No core to 14 feet.

Overburden seven feet. From 7 to 13 feet a decomposed and jointed rock was encountered which required thirteen feet of casing. From 13 to 33.8 feet massive amphibolite was encountered and a core recovery of thirteen feet made.

WARD DAM SITE ON KAWEAH RIVER
AND
PLEASANT VALLEY DAM SITE ON TULE RIVER

The Kaweah and Tule rivers drain watersheds consisting of rugged mountainous areas whose steep slopes end abruptly, with but small extent of foothill area, in a delta of alluvial materials built up in a topographic depression by the distributaries of these two streams. The accumulation of alluvium has partially or completely buried the foothill range and the preexisting gorges between foothill outcrops are known to be filled with as much as 400 feet of stream deposits at five miles distance from the present mouth of the stream canyons. The stream history of these rivers varies from that of the Sacramento and northerly lying San Joaquin tributaries in that they have been and are now aggrading streams from the mouth of their canyons, building up extensive land bodies which, merging together, form an alluvial fan of considerable extent and depth.

General Geology.

The Ward dam and reservoir sites on the Kaweah River and the Pleasant Valley dam and reservoir sites on the Tule River, lie wholly within an area comprised of granitic rock which was an extensive intrusion into the early (pre-Jurassic time) crustal rocks. This intrusion of the mass more or less changed the original rock crust so that where peridotites existed we now find serpentines; sedimentary limestones now exist as crystalline limestone; shales became slates; and a variety of rocks became "greenstone." These changed rocks make up the foothills of the region examined. They have been partially buried by stream deposits, having been attacked by the weather to produce the "red-lands" soil which borders the mountains and lies between alluvial soil areas, and are distinguished by their smooth, gently sloping surface in contrast to the rocky slopes developed in the granitic rock.

Geologic Structure.

The topographic development at the dam sites is due to differential weathering upon a massive body of crystalline rock varying widely in texture. In places the mass has developed gneissic and somewhat schistose structure, which probably indicates old crustal adjustments accompanied by shear, now long completed, and the fractures and shear zones are thoroughly healed by quartz deposition. The later jointing, which is a common structural feature of all Sierra Nevada rocks, is evidenced here by a complex series of irregular joint planes. The weathering of the rock along these joint planes has developed the "rocky" slopes characteristic of the granitic areas of the region. There are no active faults to be found in the vicinity of the dam sites, the nearest known fault being a profound structural feature passing through the eastern half of Tulare Lake bed and buried by alluvium.

Detailed Geology—Ward Dam Site.

The Ward dam site, shown on Plate C-XIII, is located at a point on the Kaweah River channel where erosion has carried the stream trench well into a massive crystalline rock—granodiorite. The rock at the dam site consists principally of quartz, feldspar and hornblende crystals, and the crystalline texture varies from fine-grained granodiorite to coarse-grained gabbro-diorite or hornblende gabbro. Mica is lacking in some phases, but small localized areas contain abundant mica. It is the massive and strong rock commonly called granite.

Granite, however, has not the durability generally conceded it. Upon the cooling of the original molten material, relatively large crystals of quartz, feldspars and ferro-magnesium minerals formed and interlocked with each other until the whole became converted into a "patchwork" of interlocking crystals, firmly knit into a strong crystalline mass. With the forces of weathering, this crystal fabric is subject to breakdown through the unequal expansion and contraction of the component crystals under temperature changes and the chemical and mechanical work of moisture penetrating into the rock through the crystal partings. The fine textured granite is more resistant to weathering, the surface rock spalling off in layers and leaving rounded outcrops. The coarse textured granite, however, is subject to disintegration to a much greater degree and far below ground-surface, leaving a residuum of so-called rotten granite over the unweathered rock. Rotten granite is a physically weak crumbly mass, subject to penetration and percolation of water and readily eroded.

The dam site is located wholly within the granite mass, with the topographic differences due to the effect of erosion and the weather upon the rock of fairly uniform hardness rather than dependent upon structural features. The granite mass has developed several systems of joints, the principal one striking north 50 to 70 degrees west and dipping nearly vertical, being intersected by one dipping south about 50 degrees, west about 40 degrees, and a complex system of minor joints.

The south abutment consists of large unweathered outcrops representing sound joint blocks, which may or may not be found to be displaced, bordered by blocks which have completely disintegrated and broken down to a sandy residuum. It contains several benches of heavy soil cover between outcrops of rock. The higher slope consists of rock in place, which has disintegrated along joint planes. Most of the outcrops are joint blocks. They have been somewhat displaced at the surface and the joint walls have parted, leaving openings along which water enters the mass to carry on chemical activity. This activity results in a decomposition of some of the mineral constituents, and mechanical action which removes the weakened or "rotted" joint walls and further enlarges the openings.

The effect of weathering along joint planes is plainly discernible in a fresh road-cut at which the firm sound rock was drilled to a depth of ten to twelve feet and shot, revealing a disintegrated zone along a joint plane from which the crumbly mass readily can be picked out.

Most of the joints in the fresh rock at stream bed were found to be closed and healed with quartz. However, it is quite possible disintegration may have extended along joint planes to considerable depths below dam foundation. Experience had in drilling exploration of similar rock leads to the conclusion that water has been in circulation through the rock along the joint planes and this circulation would be

PLATE C–XIII

GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
WARD DAM SITE
ON
KAWEAH RIVER

SCALE OF MILES

0 1 2 3 4

LEGEND

Grano-diorite

increased upon construction of a dam, allowing leakage under and around a dam and possibly uplift on it. The walls of some of the joints may be found to be sound, although water stained, indicating closed fractures, but on the whole it may be classed as seamy rock with the stable products of disintegration—the sand—left in the joint cavities which would make it difficult to seal by grouting.

The lower portion of the north abutment it made up of slabs of fairly sound rock, from which the active erosion of the stream has carried much of the residuum and left steep side slopes. These rock slabs vary from four to ten feet in thickness and are formed by the "spalling" of the rock along joint planes parallel to the slope—dipping north 60 degrees, east about 20 degrees. The upper portion of the abutment is similar to that of the south side.

The uncertainties of the results of the attack of the weather upon and the circulation of water through this type of rock make it impossible to predict with any certainty the extent of stripping and pressure grouting which would be necessary. The fresh road-cut shows twelve to fifteen feet of soil cover, three feet of completely disintegrated rock, then sound rock with disintegrated zones along joint planes. For preliminary estimate purposes only, it should be considered that the stripping will be uneven, and allowance made for at least 25 feet excavation perpendicular to the slope on the average over the entire site. If the economic features thus arrived at warrant further consideration of the site for construction of a dam, the abutments and stream bed should be drilled and tested by water under pressure in accordance with the location, inclination and extent of joints revealed upon partial stripping and test pitting and tunneling the site.

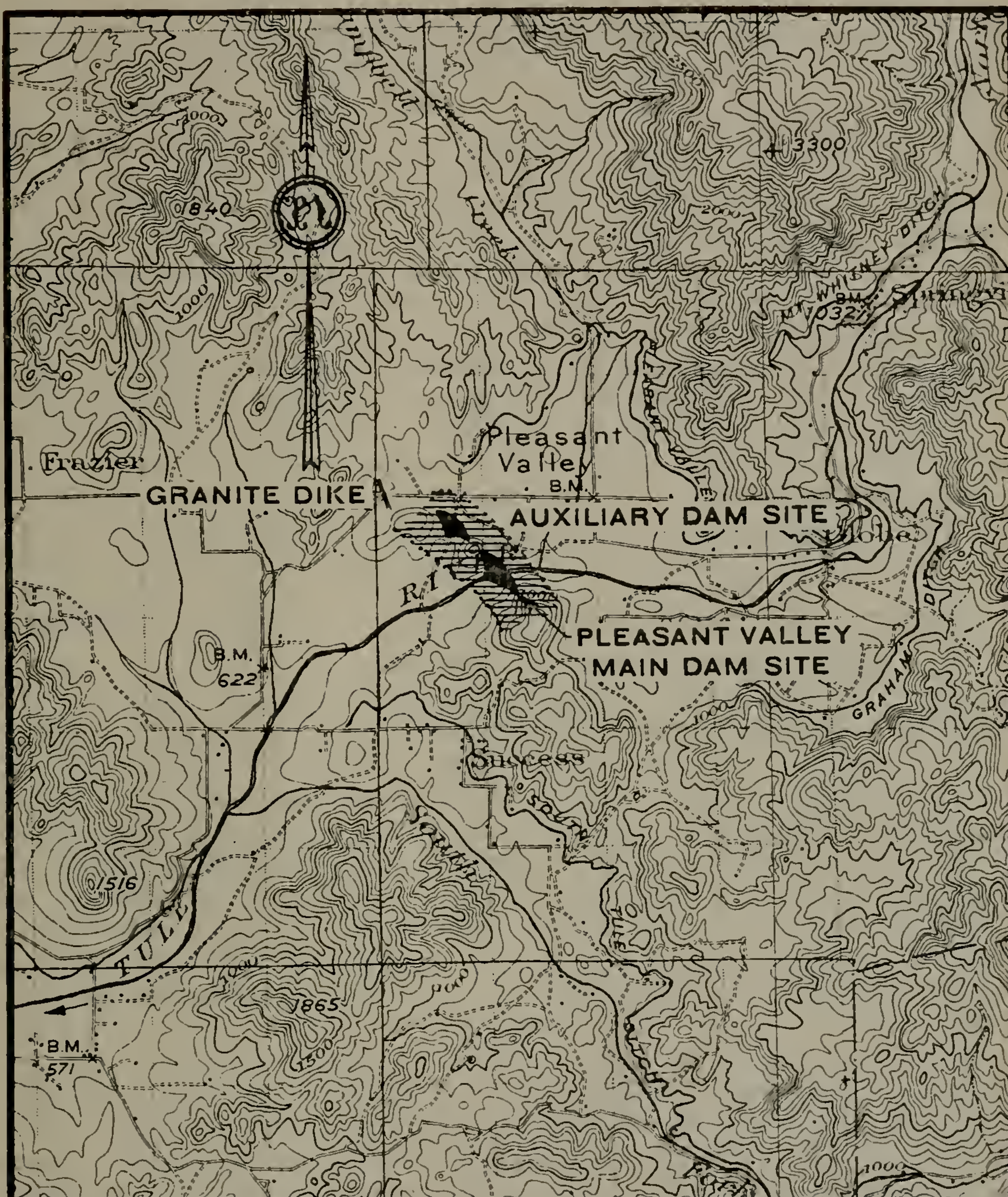
There is no question that if sound granite can be found at reasonable depth that, with reasonable preparation, a concrete arch or gravity type dam could be constructed on the site. There is no natural spillway available so the spillway should be part of the structure. Construction material is available in the stream bed above and below the site.

Detailed Geology—Pleasant Valley Reservoir.

Pleasant Valley is a fairly extensive area of flat land lying between 700 and 800 feet above sea level in Township 21 South, Range 29 East, M. D. B. and M. The surface of the area is made up largely of stream deposited sand and gravel with some coarse boulder areas. Tule River has intrenched itself in this material through the area and, at its westerly limit, has cut about 50 to 60 feet below the adjoining gravel and boulder bench lands. The area could be enclosed through construction of a main dam across the river channel at the east line of section 18 and two auxiliary dams across low areas in the north half of the same section, but the topographic development is such that little storage could be obtained for the lower section of the main dam. The site and geology of the location are shown on Plate C-XIV.

The bed rock of the region, including the dam sites, consists of granitic rock varying in texture and mineral constituents within comparatively small areas. The north abutment of the main dam site is made up of a coarse textured rock consisting principally of hornblende and feldspars, which might be designated diorite. The same rock, with some granodiorite phases, extends northwesterly through the site of

PLATE C–XIV



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
PLEASANT VALLEY DAM SITE
ON
TULE RIVER

SCALE OF MILES

0 1 2 3 4

LEGEND

Granitic bed rock covered with stream-deposited sand and gravel the required Auxiliary Dam. A dike of true granite strikes north 30 degrees west through the axis of the proposed auxiliary dam. The south abutment at the main dam site consists principally of close textured grano-diorite outcrops, but as the texture phases change over the region it is probable coarse-textured rock lies below the soil cover. This abutment carries some terrace gravels and remnants of a lava flow. The rock is massive in structure and when sound has great strength. It is considerably jointed and the mass is weakened by disintegration of joint wall rock.

Weathering has attacked the rock, producing gentle slopes at the main dam site abutments. The rock outcrops are principally dislodged jointed blocks with but little rock found in place. The rock on the north abutment, being coarsely crystalline, has disintegrated to considerable depth. An average allowance of 50 feet depth of stripping over the whole site would probably not be excessive as there are no outcrops over the stream bed, but a wide flood plain bordered by terrace gravels.

The auxiliary dam site would require a 45-foot structure. The coarsely crystalline rock found here has weathered deeply to produce gentle slopes. It is probable an earth fill structure here would require a cut-off reaching to sound rock at 50 to 60 feet below ground surface to prevent leakage through the porous residuum.

ISABELLA, BOREL AND BAKERSFIELD DAM SITES ON KERN RIVER

Kern River drains the southern end of the Sierra Nevada and is the most southerly master stream entering the San Joaquin Valley. The Kern River region presents geologic and topographic conditions which vary greatly from those obtaining over the regions examined in connection with dam sites located on the northerly lying Sierra streams. It emerges from its foothill region at Bakersfield and flows southwesterly over an alluvial fan built up in a topographic depression formed by fault displacement, terminating in a flat area formerly occupied by large fresh water bodies—Kern Lake and Buena Vista Lake.

The foothill belt, extending from Bakersfield to the mouth of Kern Canyon, is comprised of loosely cemented sandstone, conglomerate and shale beds of Tertiary age, overlaid in part by an early alluvial fan of the Kern River. The river has intrenched itself into both these formations, cutting steep rugged walls to its trench, which, in places, rise above broad mesas representing the surface of former flood plains and the Pleistocene fan of the river. Contemporary lateral erosion and weathering has carved the material originally forming the floor of the Tertiary sea into ridges and round topped hills, leaving a portion of this surface as a mesa, but slightly eroded, south of the river.

The erosive development in the foothill region has been such that it does not provide suitable dam sites with the possible exception of the Ant Hill site in the east half of Section 5, Township 29 South, Range 29 East, and the Bakersfield site about three miles downstream.

The lower Kern River Canyon, from Kernville to its mouth, is unique among Sierra stream trenches in that the grade increases down stream. This is due to uplift of the region during time so recent that the stream has not achieved a mature profile and the base leveling processes in the more resistant rock above the mouth of the canyon have not kept pace with the erosion of the sedimentaries of the foothill region. The lateral topographic development of Kern River Canyon is due principally to the attack of the weather, resisted by petrographic differences in a granitic rock mass. Where coarse textured rock prevails the slopes are moderate, with a fairly heavy cover of disintegration products, principally coarse sand, carrying loose joint blocks differing widely in size and varying in their stage of disintegration. The finer textured rock bodies are characterized by precipitous rock slopes carrying large blocks detached from the underlying mass along joint planes, but exhibiting no appreciable rock decay upon their surfaces or along joint walls.

Two areas of the latter rock occurring below Isabella were examined in detail, the upper in Section 36, Township 26 South, Range 32 East, in which the Isabella dam site is located, and the lower in Section 32, Township 27 South, Range 31 East, in which the Borel dam site is located. At these two locations the stream crosses what might be termed dykes of close textured rock at right angles to the strike and the topographic development has provided a "V" shaped stream trench well adapted to dam site purposes.

General Geology.

The greater portion of the rock through which Kern River has cut its canyon below the junction of the South Fork with the North Fork may be designated a coarse-grained, light colored granite, showing numerous large phenocrysts of feldspar (probably orthoclase). Included in this granite mass are areas of medium to close-grained grano-diorite having fairly uniform texture and consisting principally of feldspar, quartz, mica, (biotite) and hornblende. Besides these two main facies, the rock throughout its mass varies in color and texture gradations in small irregular bodies, due to local differences in feldspars and inclusions of a multitude of small hornblende crystals, and contains dykes or veins of light colored aplites varying in width from less than one to about five feet.

The granitic core of the Sierra Nevada is predominate in this region and probably represents huge batholithic intrusions in contrast to the plug or dyke from plug intrusions in the older (pre-Jurassic time) crustal rocks which characterize the occurrence of granitic rock in the northern Sierra. At the southern end of Hot Springs Valley and up South Fork Valley are limited areas of the older crustal or metamorphic rocks (including limestone) which can be distinguished by the reddish brown color and smooth surface they develop under weathering, in contrast with the light colored rocky slopes of the granite. They do not, however, reach the Kern River channel at any point below Kernville.

The batholithic intrusions probably carry as far north as the San Joaquin River, and it appeared there (in contrasting the rock at the Fort Miller dam site with that at the Temperance Flat dam site) as well as on the Kern River that the enormous intrusion was a progressive action giving rise to a series of granitic intrusive bodies of somewhat different age and having different texture characteristics. The close textured grano-diorite bodies have a "fresher" appearance, a more even crystalline texture, and are more resistant to the attack of the weather; therefore, they make the more favorable rock for dam foundation.

The Tertiary rocks comprising the foothill region are part of a belt exposed along the southern border of the San Joaquin Valley, from the Temblor Range on the west to, and flanking, the southern end of the Sierra Nevada on the east, and are geologically similar to the foothill belt north of the San Joaquin River. The Tertiary rock belt of the San Joaquin Valley is a thickness of clastic material in excess of 20,000 feet which consists largely of marine sediments, but which contains continental deposits and volcanic ash beds in its upper portions.

The Pleistocene deposits consist of continental accumulations of stream-laid detritus overlying the Tertiary rocks.

Geologic Structure.

The Kern River region may be said to be the connecting link between two major structural provinces of California—the Southern California-Coast Range province and the Great Valley-Sierra Nevada province—provinces whose geologic as well as structural characteristics are widely divergent. It lies within the area of influence of geologically recent rifting. The San Andreas rift, California's most extensive and still active fault rift, passes southeasterly from the San Francisco Bay region through the heart of the Diablo-Temblor Range and through the Carrizo Plain, to swing more easterly south of Bakersfield. A great number of complex faults along which the earth's crust has been displaced and between which the sedimentary rocks have been folded, run out from this rift.

The observed faults consist of one at the mouth of Kern River Canyon, paralleling the strike of the main granite ridge and separating it from the Tertiary sediments, and one passing through Hot Springs Valley from Kernville to Bodfish, which appears to be continuous with the profound fault line along which the North Fork of the Kern has developed and to be continuous through Walker Basin, Caliente and along the base of the El Tejon ridge. Many minor faults probably exist, though not readily discernible because of the rock on both sides of the fault having the same characteristics and because the topographic development originated before much of the displacement occurred and has progressed along the original lines in spite of the displacement. The valleys, such as Hot Springs Valley and Walker Basin, are probably features originating at the result of the major fault displacement and their erosional and depositional history has been controlled by the rift line, but the lower canyon of the Kern River is due to stream erosion established before the displacement occurred and maintained during the period of displacement and it is separated from the rift line by an intervening ridge of sound rock.

All the granitic rocks of the lower Kern River Canyon exhibit jointing. The joints are approximately horizontal and vertical and the joint blocks are more or less rectangular or slabs. The joints are more abundantly developed near the mouth of the canyon, due to compressive stresses set up in faulting along the line previously described. The same holds true between Isabella and Kernville where a major fault passes from Hot Springs Valley up the North Fork of the Kern. The east front of the ridge separating the Kern River trench from Hot Springs Valley is a fault scarp modified by erosion.

Detailed Geology—Isabella Dam Site.

Two proposed dam sites near Isabella were examined. The upper, or ''A'' site, lying in Section 19, Township 26 South, Range 33 East, is that referred to and indicated upon Map 4, in Bulletin No. 9*. The lower, or ''B'' site, (previously located) is that which the proposed Kern River Water Storage District sought to utilize. They are shown on Plate C-XV. Both sites would flood the North and South Fork Valleys and require an earth embankment across Hot Springs Valley to retain 350,000 acre-feet storage. The ''B'' site is more favorable, from both geologic and topographic standpoints, for construction of a high concrete structure.

The bedrock at both sites consists of close textured grano-diorite. The rock is jointed, but the jointing at the ''A'' site is more abundant and the rock is weakened because of its proximity (within one-half mile) to the Hot Springs Valley fault. Erosive action of the Kern River at the ''A'' site has been such as to cut into the weakened mass and remove much of the ''blocky'' material until a ''U'' shaped stream trench has been carved out. The slopes are moderate with loosened blocks and sandy residuum at lower levels and some higher benches carrying a heavy soil cover of wind-blown sand.

The ''B'' site is further removed from the rift line and exhibits less jointing, so the rock is sound and strong. The stream trench is ''V'' shaped, with fresh rock, somewhat pothollithic, making up the walls. The stream bed contains some large joint blocks around which have lodged gravel and boulders.

The joint systems consist of main vertical joints running east and west, crossed by a north and south system dipping almost vertical. The mass contains aplite veins or dykes which are continuous on both sides of the stream trench and dip about north 60 degrees west from 20 to 25 degrees. The erosive development of the left, or east, abutment has been controlled somewhat by these veins and the rock has jointed as the vein contacts. The north and south joint system has controlled the erosive development of the right, or west, abutment. Large joint blocks are displaced from the mass, but the joint walls are clean, unweathered sound rock. It is probable that few, if any, joints would be found open upon uncovering stream bed rock and there is little likelihood of leakage under a dam or uplift upon it.

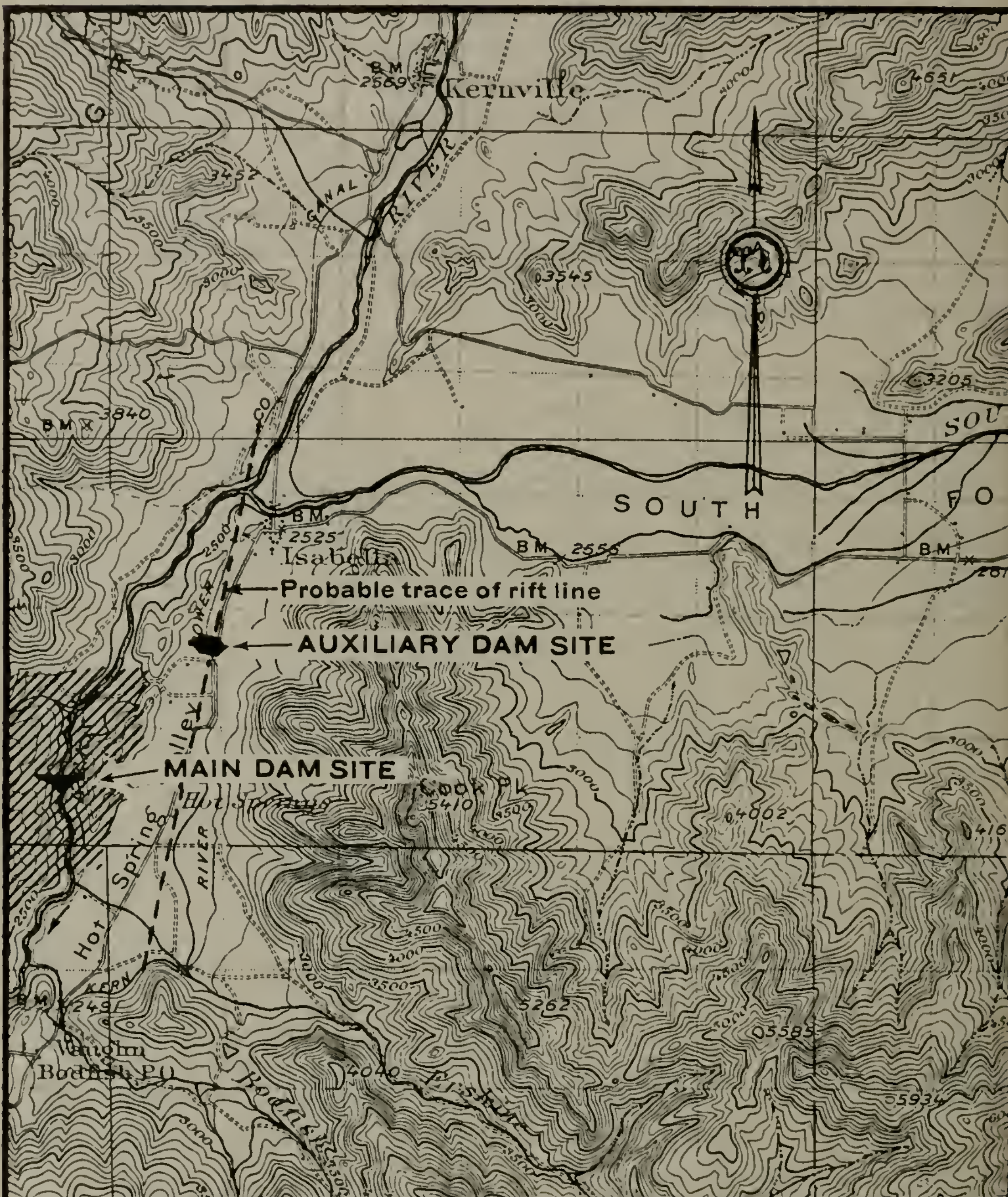
The displaced joint blocks on the abutments would necessarily be removed in stripping the site. Some joints may be found which open without appreciable displacement of the joint blocks, but the mass could be rendered sound by grouting. The upper abutments carry some disintergrated joint blocks and a light soil cover. On the average, 20 feet of stripping should provide sound rock foundation.

The site is well suited to a high concrete arch structure. No natural spillway is available, so spill must be had through overflow of dam. Construction material can be obtained by crushing at the site or from the North and South Fork Valleys upstream.

Auxiliary Dam Site, B-1. The storage requirement necessitates an embankment in Hot Springs Valley. The location B-1, shown in

* Bulletin No. 9, "Water Resources of Kern River and adjacent streams and their utilization," Department of Engineering, State of California, 1920.

PLATE C–XV



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
ISABELLA DAM SITE
ON
KERN RIVER

SCALE OF MILES

0 1 2 3 4

LEGEND

Close textured grano-diorite

Plate C-XV, is said to have been drilled and shown to have water-bearing sand to 110 feet and blue clay to 255 feet. The geologic history of the valley filling would lead to the conclusion that bedrock would not be found within reach of a cut-off wall, except possibly at Isabella. At the latter point the rock would lie within the shear zone of the rift and would probably contain open fractures which would pass water more freely than alluvium. Considering that the height of the embankment would only be 60 feet maximum and that some leakage loss is allowable, it seems more desirable to locate an earthen dam at B-1, providing a broad base so that possibility of mechanical piping through the alluvium would be reduced to a minimum.

Detailed Geology—Borel Dam Site.

Two dam sites, "A" and "B," shown on Plate C-XVI, were examined at Borel. The river takes a westerly course to about 400 feet above the present diversion dam, then swings southerly to a point about 1000 feet below the dam, thence turns westerly. This is due to the control exercised by a close textured grano-diorite dyke conspicuous in an area of coarse textured rock. The dyke rock is not so finely crystalline as at Isabella, but is sufficiently resistant to the attack of the weather and stream corrosion that the stream has taken the shortest course across it, and cliff profiles are developed in contrast to the heavy soil covered gentle slopes above and below the dyke.

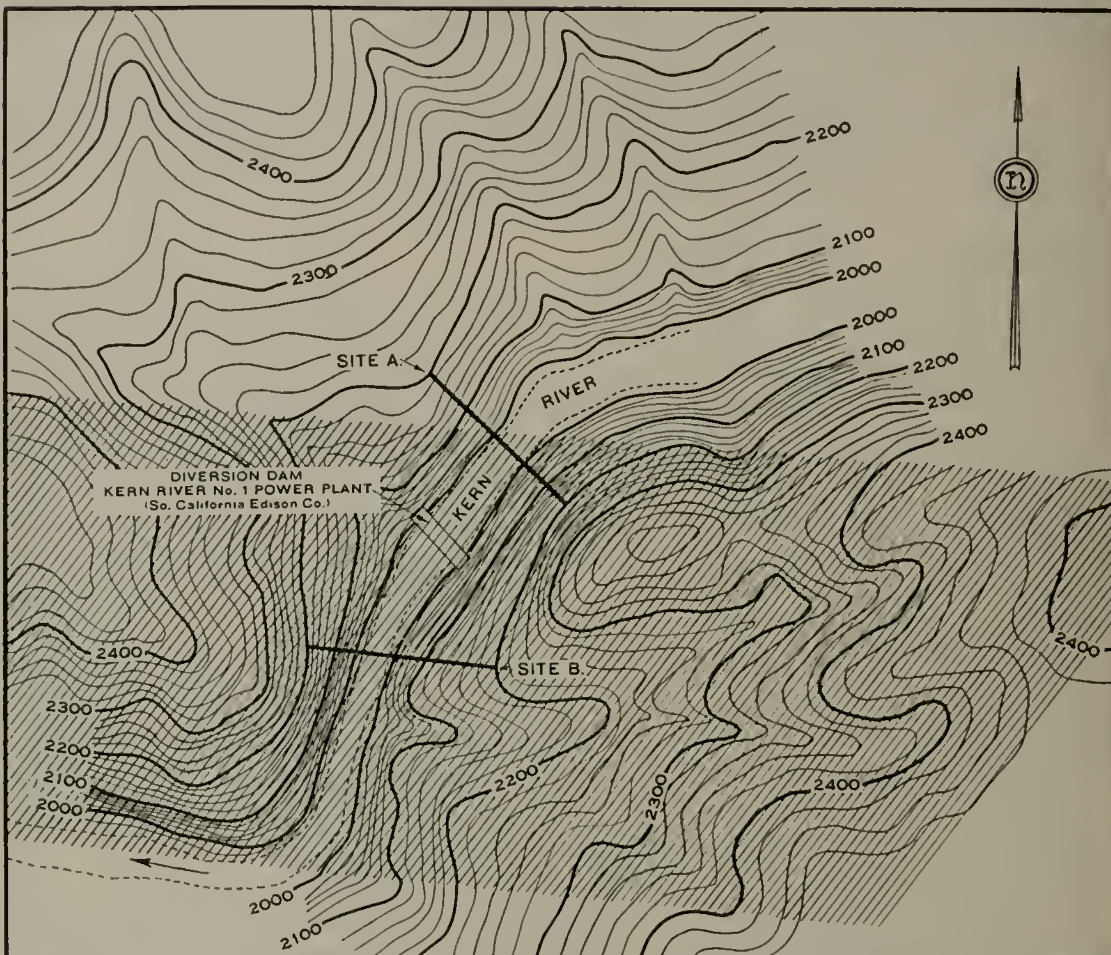
Dam site "A" crosses out of the close textured rock into coarse textured rock so that the right abutment carries a heavy soil cover. The left abutment rock is considerably jointed, moderately weathered along joint planes, and large joint blocks are displaced near stream level. The upper portion of the abutment contains rock exposures in a heavy soil cover, but these are probably all displaced blocks. The stream channel deposit is excessive in depth due to the diversion dam.

A more favorable site, "B," lies about 300 feet downstream from the diversion dam. Here the cliff profile is well developed to 100 feet above stream bed and rock outcrops more continuously to the crest of the ridge, with but shallow soil cover. The rock is moderately jointed, with the main vertical joints striking at right angles to the strike of the dyke. Some joint blocks would have to be removed, but on the average fifteen feet excavation for a 200 foot dam and 20 feet excavation for a higher dam should cover requirements. The joints in the cliff face, and at stream bed are tight closed features. Grout preparation might be required on the upper abutments to close joints there. On the whole the site is entirely satisfactory for a 200 foot or even higher concrete arch dam.

Consideration of Design to Meet Earthquake Possibilities.

The fact that the region studied is one that has, in times past, been subjected to seismic disturbances has been previously noted. The faults passings through the region near the Kern River dam sites have been considered long dead and are so indicated upon the Fault Map of the state. However, the San Andreas Rift is active and it is not beyond the range of probabilities that seismic disturbances again will affect the region in a minor way and should be amply guarded against in the design of structures.

PLATE C–XVI



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES

IN THE VICINITY OF

BOREL DAM SITE

ON

KERN RIVER

FEET

0 400 800 1200 1600

LEGEND

Close textured grano-diorite in coarse textured granitic rock

The conclusion that concrete arch dams could be safely constructed at the Isabella and Borel sites is based upon the fact that no fault line passes through them and that they would be subject to no earth movement other than tremors or shock waves. Concrete structures in the vicinity of the San Andreas fault successfully withstood the intense earthquake shock of 1906, but if there is anything which makes arch dams less resistant to earth tremors than other types of dams, a gravity type or even a rock fill type, for which there is ample material available, should be selected.

Detailed Geology—Bakersfield Dam Sites.

The Tertiary rocks which make up the foothill region and which would form the reservoir bed and dam foundation of any structure placed in Kern River between the mouth of Kern Canyon and Bakersfield, are permeable and to some extent soluble. They dip slightly downstream southwestward, and present the least favorable structure to seepage from a reservoir. Overlying these rocks are terrace gravels and portions of the eroded early fan of Kern River. Most of the ridges protruding into the river channel are composed of these continental deposits, so that, although the topographic features are most favorable to dam site purposes, they would have to be eliminated from consideration as foundation or abutments. The Ant Hill site was examined in detail but the geological data apply in general to the Bakersfield site.

The foundation rock, though soft and loosely cemented, when dry is sufficiently strong to bear the load of a 200 foot earthen dam, provided the dam be designed with a broad base, six to eight times the height, and the load per square foot on the foundation be moderate. Seepage through the foundation and abutments might saturate and rupture the structure of this material, however, so as to render it unfit for use.

Ordinarily porous and permeable materials underlying stream beds are saturated with water to within a reasonable depth below ground surface and there is a passage of water from the surface stream downward and laterally through the materials at rates controlled by the resistance to flow afforded by friction in the interstices of the materials. If the water surface be raised above the stream bed through construction of a dam, added head is applied over the water entering the materials, wider contact of water with materials is accomplished, and entirely new ground water conditions are set up.

In the present instance the inclosing rim of the reservoir consists of open textured, sandy and conglomeratic material containing beds of close textured material which absorbs moisture rapidly, resulting in the complete rupture of its structure. The close textured material contains shrinkage joints formed with the drying out of wet mud and these joints are filled with gypsum. Gypsum is soluble in water and its presence in the material suggests the formation of solution channels. It is not at all unlikely that the reservoir rim rock and dam foundation material would be subject to both mechanical and chemical piping. Just what the length of the path of percolation necessary to overcome such effect would be can not be foretold from the data at hand. It is said that the stream at present does not lose by seepage through the reservoir site. Furthermore, there is no apparent ground water contributions from the river through the south ridge to an area of heavy pumping draft in the Weed Patch area, although the ground water gradients are steep.

If the construction of an earth fill dam having a crest length of about 4000 feet, a height of 200 feet and a base width of six to eight times the height, is economically feasible, then additional tests are warranted. Such tests, with apparatus and routine used successfully in connection with similar problems, consist of the determination of the rate of percolation, measured in gallons per square foot of surface per hour, through a six inch column of material taken in its natural state under varying heads. Through such observations it also is possible to determine the physical changes undergone by the various types of materials when penetrated by water under pressure. Should it be determined by test that there would be little likelihood of mechanical or chemical piping under the ground water gradients obtaining upon completion of a dam, it is probable reservoir seepage losses at first would be excessive while the underlying material was being brought to the saturation point and the water table level was adjusting itself to the new conditions, but thereafter losses would be limited to replacement of water moving laterally through the ground and, through reservoir silting, might be further reduced.

APPENDIX D

ADEQUACY OF INITIAL AND ULTIMATE MAJOR UNITS OF STATE WATER PLAN IN SAN JOAQUIN RIVER BASIN IN THE SEASONS 1929–30 AND 1930–31

TABLE OF CONTENTS

ADEQUACY OF INITIAL AND ULTIMATE MAJOR UNITS OF STATE WATER PLAN IN SAN JOAQUIN RIVER BASIN IN THE SEASONS 1929–30 AND 1930–31

The water supply studies pertaining to the State Water Plan in the San Joaquin River Basin, as set forth in the main body of this report, are based on the estimated and measured surface run-offs which have occurred during the 40-year period extending from October 1, 1889, to October 1, 1929. This period is one of wide variability in run-off. It includes seasons of plentiful run-off and seasons of scarcity in supply. For example, in the seasons 1905–06 and 1906–07, the seasonal run-offs from the drainage basin are estimated at 23,374,000 acre-feet and 21,108,000 acre-feet, respectively, or nearly twice the estimated mean seasonal run-off for the 40-year period. In 1889–90, the seasonal run-off is estimated at 28,009,000 acre-feet, nearly two and one-half times the average for the period. On the other hand, during this period, there were seasons and consecutive seasons during which the run-off was far below the average. The season of lowest run-off for the period is 1923–24 with a run-off of 2,576,000 acre-feet. It is believed from a study of precipitation records that the latter season is one of the lowest in run-off since 1871 and probably since 1850. It should be mentioned, also, that the smallest combined run-off for periods up to five consecutive seasons, from 1871 to 1929, probably occurred during the last eight years of this 40-year period.

In the water supply studies which have been presented in this bulletin, the 40-year period 1889–1929 was analyzed in estimating the utilizable water supply obtainable, through the combined means of surface storage and underground storage and pumping, from the upper San Joaquin Valley streams to meet the needs of areas to be served in the upper San Joaquin Valley under the plan of ultimate development. Under the plan of initial development for the upper San Joaquin Valley, however, the 12-year period 1917–1929 of subnormal run-off was used as a basis for designing the units and estimating the utilizable supply obtainable because of the desirability of assuring an ample supply for adequate and immediate relief to the areas of serious water shortage even if a similar period of subnormal run-off were experienced immediately following the consummation of the initial project. The 40-year period also was used in the water supply analyses for the streams of the Sacramento and lower San Joaquin valleys in both the initial and ultimate plans of development. However, because of proposed regulation chiefly by surface storage, it was found that the critical period determining the safe yield and required capacity of surface storage units for the streams in the Sacramento and lower San Joaquin valleys was the 12-year period 1917–1929. With the exception of one small area in Hydrographic Division 8, no account was taken of the availability and possible utilization of underground storage in either the Sacramento Valley or lower San Joaquin Valley. All water supply analyses were made month by month for each season throughout the period studied. These foregoing criteria for water supply analyses were adopted at the beginning of the investigation in 1929. The results of the analyses made to test the adequacy of both initial and ultimate developments of the State Water Plan in the San Joaquin River Basin are set forth in Chapters VII and VIII.

Since the completion of the studies based on the available water supplies for the 40-year period 1889–1929 on which the major units of the State Water Plan for initial and ultimate development were proportioned, two seasons of low run-off have occurred, namely, 1929–30 and 1930–31. Therefore, it was deemed desirable to test further the adequacy of the plans proposed for initial and ultimate development in the San Joaquin River Basin by the inclusion of these seasons in the water supply analyses and, if either plan were found inadequate, to point out wherein, if possible, modifications could be made which would assure adequate supplies of water to all areas served by the plans. The results of these supplemental analyses and investigations are presented in this appendix.

There also is given herein an analysis for the San Joaquin River Basin, the Sacramento River Basin, and the combined basins, of the probability of the occurrence of seasonal run-offs of various magnitudes. This is presented for the purpose of indicating the probable frequency with which the low seasonal run-offs of the past few years might be expected to occur in the future and, therefore, of indicating further the adequacy of the plans.

Water Supply.

The water supplies—full natural, and ultimate net run-offs—from the San Joaquin River Basin streams for the seasons 1929–30 and 1930–31 were estimated by the methods described in Chapter II.

Indices of Seasonal Wetness—In order to estimate the run-offs from some of the unmeasured streams, and also to obtain a comparison of the precipitation in the seasons of 1929–30 and 1930–31 with that in other seasons and with the mean, indices of seasonal wetness were computed for the preciptation divisions lying wholly or partially in the San Joaquin River Basin. In calculating the values of these indices, the mean precipitation for each station or division was taken as that for the 50-year period 1871–1921. The indices for each division for the seasons 1929–30 and 1930–31 are shown in Table D-1 which is an extension of Table 3 in Chapter II.

TABLE D-1

INDICES OF SEASONAL WETNESS FOR SAN JOAQUIN RIVER BASIN

Season	Precipitation division							
	K	L	P	Q	R	S	*T	*V
1929–1930	75	76	70	67	75	81	62	73
1930–1931	60	63	69	74	65	98	75	88

*Indices for divisions T and V are computed for and apply particularly to those portions of these divisions lying within the San Joaquin River Basin.

Full Natural Run-offs—The seasonal full natural run-offs from the mountain and foothill drainage basins of the major streams and minor streams, or groups of minor streams, of the San Joaquin River Basin, for the seasons 1929–30 and 1930–31, are shown in Table D-2 which is an extension of Table 5 in Chapter II. Mean seasonal run-offs also are shown in the table for the 42-year period 1889–1931, the 22-year period 1909–1931, the 14-year period 1917–1931, the 10-year period 1921–1931, and the 5-year period 1926–1931.

TABLE D-2

SEASONAL FULL NATURAL RUN-OFF OF SAN JOAQUIN RIVER BASIN STREAMS

Stream or stream group	Drainage area, in square miles	Run-off, in acre-feet		Mean run-off for period, in acre-feet				
		1929-30	1930-31	1889-31	1909-31	1917-31	1921-31	1926-31
Upper San Joaquin Basin—								
Panoche Creek	295	3,100	9,400	25,400	22,600	14,200	13,200	10,700
Cantua Creek Group	208	2,200	3,300	12,100	10,600	6,200	5,900	4,600
Los Gatos Creek	119	1,300	3,200	9,000	7,800	4,800	4,500	3,600
Tejon Creek Group	1,341	12,600	36,800	85,600	70,100	44,000	43,200	35,400
Caliente Creek	471	12,600	25,100	36,400	28,000	21,500	22,600	20,100
Kern River	2,410	373,500	194,600	704,000	654,000	477,000	448,000	413,000
Poso Creek Group	576	13,800	9,200	43,900	36,200	27,000	27,800	23,700
Deer Creek	110	8,300	5,100	18,900	15,600	11,900	11,300	10,200
Tule River	390	48,100	20,600	130,000	106,000	76,500	73,200	62,300
Yokohl Creek Group	98	3,700	2,600	13,700	11,200	8,300	8,500	7,100
Kaweah River	514	217,600	114,200	430,000	338,000	283,000	271,000	248,000
Limekiln Creek Group	201	26,800	16,100	58,700	50,100	39,900	40,400	36,200
Kings River	1,694	862,800	465,800	1,830,000	1,497,000	1,222,000	1,161,000	1,027,000
Dry Creek	48	800	1,300	4,000	3,400	2,600	2,600	2,000
San Joaquin River	1,631	879,900	488,800	1,933,000	1,607,000	1,300,000	1,250,000	1,084,000
Cottonwood Creek	28	300	500	2,000	1,600	1,200	1,200	900
Fresno River	270	19,600	7,300	61,000	52,400	41,300	39,600	29,700
Daulton Creek Group	66	700	1,100	4,500	3,700	2,700	2,800	2,000
Chowchilla River	238	31,700	3,000	68,300	52,600	48,900	49,400	38,700
Totals, Upper San Joaquin Basin	10,708	2,519,400	1,408,000	5,470,500	4,567,900	3,633,000	3,476,200	3,059,200
Lower San Joaquin Basin—								
Orestimba Creek Group	1,340	28,600	21,400	116,000	95,200	76,600	74,300	47,100
Dutchman Creek Group	72	2,300	800	8,300	5,600	4,800	4,900	3,900
Mariposa Creek	103	4,400	2,200	12,800	8,800	7,800	7,800	6,400
Owens Creek Group	66	1,800	700	6,400	4,200	3,600	3,600	2,900
Bear Creek	71	2,300	800	7,500	5,000	4,300	4,300	3,500
Burns Creek Group	171	8,200	2,700	24,500	17,500	15,600	15,700	12,700
Merced River	1,054	512,800	262,300	1,080,000	893,000	745,000	722,000	616,000
Tuolumne River	1,543	1,148,900	607,200	2,014,000	1,691,000	1,453,000	1,416,000	1,262,000
Wildcat Creek Group	59	2,800	900	8,800	6,100	5,400	5,400	4,300
Stanislaus River	983	731,800	315,000	1,311,000	1,055,000	866,000	853,000	775,000
Totals, Lower San Joaquin Basin	5,462	2,443,900	1,214,000	4,589,300	3,781,400	3,182,100	3,107,000	2,733,800

Delta Tributaries—								
Littlejohns Creek	41	3,200	1,900	8,100	5,900	5,300	5,300	4,500
Martells Creek Group	122	5,200	2,000	14,300	10,400	9,300	9,200	7,800
Calaveras River	394	66,500	13,400	218,000	177,000	121,000	108,000	86,500
Mokelumne River	632	462,900	208,500	828,000	691,000	575,000	559,000	510,000
Sutter Creek Group	285	36,600	8,700	94,000	70,800	65,000	65,500	52,500
Cosumnes River	534	165,000	45,900	393,000	324,000	256,000	253,000	219,000
Totals, Delta tributaries	2,008	739,400	280,400	1,555,400	1,279,100	1,031,600	1,000,000	880,300
Grand totals	18,178	5,702,700	2,902,400	11,615,200	9,628,400	7,846,700	7,583,200	6,673,300

Table D-3 gives a summary of the means of the full natural run-offs of the streams of the San Joaquin River Basin tributary to the upper San Joaquin Valley, the lower San Joaquin Valley and the delta for each of the periods used in Table D-2. For purposes of comparison, the corresponding data are given in the table for various periods discussed in Chapter II, which do not include the seasons of 1929–30 and 1930–31.

TABLE D-3

SUMMARY OF MEAN SEASONAL FULL NATURAL RUN-OFF OF SAN JOAQUIN RIVER BASIN STREAMS FOR VARIOUS PERIODS

In Acre-feet

Period	Upper San Joaquin Basin	Lower San Joaquin Basin	Delta tributaries	Totals
1889–1929	5,646,200	4,725,900	1,607,900	11,980,000
1889–1931	5,470,500	4,589,300	1,555,400	11,615,200
1909–1929	4,827,300	3,976,400	1,355,900	10,159,600
1909–1931	4,567,900	3,781,400	1,279,100	9,628,400
1919–1929	3,932,400	3,475,900	1,138,600	8,546,900
1921–1931	3,476,200	3,107,000	1,000,000	7,583,200
1924–1929	3,688,700	3,345,500	1,102,800	8,137,000
1926–1931	3,059,200	2,733,800	880,300	6,673,300

Ultimate Net Run-offs—The ultimate net run-offs for the seasons 1929–30 and 1930–31 of the major streams at the reservoir sites of the State Water Plan are shown in Table D-4. These ultimate net run-offs are those that could have been expected under conditions of ultimate impairment by diversions for ultimate irrigation developments and present power developments, upstream from each reservoir site. Mean values for various periods also are set forth in the tabulation.

TABLE D-4

ULTIMATE NET SEASONAL RUN-OFF OF MAJOR STREAMS AT RESERVOIR SITES OF STATE PLAN IN SAN JOAQUIN RIVER BASIN

Stream	Run-off, in acre-feet		Mean run-off for period, in acre-feet				
	1929–1930	1930–1931	1889–1931	1909–1931	1917–1931	1921–1931	1926–1931
Kern River	346,700	184,100	692,000	642,000	465,000	435,000	399,000
Tule River[1]	46,400	17,600	126,000	102,000	73,800	70,300	60,000
Kaweah River	217,600	114,200	430,000	338,000	283,000	271,000	248,000
Kings River	862,800	465,800	1,830,000	1,497,000	1,222,000	1,161,000	1,027,000
San Joaquin River	868,600	562,800	1,932,000	1,613,000	1,308,000	1,254,000	1,083,000
Fresno River	20,600	7,100	53,200	45,100	35,800	34,500	27,600
Chowchilla River	31,700	3,000	68,300	52,600	48,900	49,400	38,700
Merced River	413,400	186,900	957,000	778,000	638,000	618,000	519,000
Tuolumne River	1,079,800	579,800	1,596,000	1,342,000	1,168,000	1,135,000	1,081,000
Stanislaus River	611,700	221,000	1,200,000	944,000	758,000	745,000	663,000
Calaveras River	45,000	13,100	182,000	144,000	91,100	79,600	61,600
Mokelumne River	383,400	216,900	795,000	660,000	547,000	532,000	481,000
Cosumnes River	84,400	25,400	279,000	219,000	159,000	161,000	131,000
Totals	5,012,100	2,597,700	10,140,500	8,376,700	6,797,600	6,545,800	5,819,900

[1] Includes South Fork of Tule River, which enters the main Tule River below the reservoir site of the State Plan.

Adequacy of Initial Units of State Water Plan.

In Chapter VIII, the operation and accomplishments of the initial units of the State Water Plan in the San Joaquin River Basin are described. The analyses on which the accomplishments for both the immediate and complete initial developments were based covered the 12-year period 1917–1929. In testing the adequacy of these units, studies were made covering the seasons of 1929–30 and 1930–31.

Immediate Initial Development—Analyses presented in Chapter VIII, based on water supply studies for the 12-year period 1917–1929 and on water supply and ground water studies for the 8-year period 1921–1929, demonstrated that sufficient water to meet the needs of present developed areas in the upper San Joaquin Valley, having a permanent deficiency in water supply, could have been most economically secured by the utilization of surplus water of the San Joaquin River and water available by purchase under rights devoted to inferior use on "grass lands" for pasture, now being served by diversions from this river above the mouth of the Merced River. The physical works of the immediate initial State Water Plan in the San Joaquin River Basin required for the utilization of these supplies are Friant Reservoir, Madera Canal and San Joaquin River-Kern County Canal. Analyses have been made, by extending the water supply and accumulative ground water studies through the seasons of 1929–30 and 1930–31, to demonstrate to what degree the plan adopted for immediate initial development would have met the needs of present developed areas of permanent deficiency in those seasons.

Table D-5 sets forth the measured monthly run-off of the major streams in upper San Joaquin Valley for the seasons of 1929–30 and 1930–31. Table D-6 sets forth by months for the seasons of 1929–30 and 1930–31 the utilization of the total impaired run-off of the San Joaquin River at Friant under conditions of immediate initial development, with the quantities and characteristics of supply for the Madera Canal and the San Joaquin River-Kern County Canal; and the corresponding average values for the 14-year period 1917–1931, 10-year period 1921–1931, and 5-year period 1926–1931. The bases of operation of the reservoir and the allocation of supplemental supplies therefrom are the same as set forth in Chapter VIII.

Table D-7 sets forth, for each season of the 10-year period 1921–1931, the water supply from Friant Reservoir, from local sources and from the combined sources that would have been available for units in the upper San Joaquin Valley receiving imported supplemental water under the plan of immediate initial development; and the net accretion to or depletion of ground water storage in the absorptive areas during this 10-year period which would have resulted from the furnishing of this water supply, after fully satisfying assumed water requirements based upon the net areas irrigated in 1929. An inspection of the tabulation reveals that the nonabsorptive areas consisting of the Alta-Foothill, Lindsay and Magunden-Edison units would have received a full surface supply in all seasons except 1930–31 when the Alta-Foothill unit would have had a deficiency of 20 per cent, the Lindsay unit, 10 per cent and the Magunden-Edison unit, 15 per cent. In both seasons 1929–30 and 1930–31, none of the absorptive areas except

TABLE D-5

MEASURED MONTHLY RUN-OFF OF MAJOR STREAMS IN UPPER SAN JOAQUIN VALLEY FOR THE SEASON OF 1929-30 AND 1930-31

Stream	Location of gaging station	Run-off, in acre-feet												
		October	November	December	January	February	March	April	May	June	July	August	September	Totals
Season 1929-30—														
Kern River	Near Bakersfield	8,800	9,000	10,000	12,200	20,100	34,600	53,500	67,800	82,800	28,400	11,800	7,700	346,700
Tule River*	Near Porterville	100	200	700	2,200	4,700	11,400	9,400	12,800	4,300	400	100	100	46,400
Kaweah River	Near Three Rivers	1,600	1,600	2,200	5,400	12,900	23,200	45,000	64,000	50,500	7,800	2,100	1,300	217,600
Kings River	At Piedra	7,200	6,700	8,300	15,000	31,600	71,900	171,000	231,000	241,000	55,000	16,500	7,600	862,800
San Joaquin River	Near Friant	29,800	24,900	31,600	30,300	39,200	70,700	121,000	138,000	155,000	96,500	79,900	51,700	868,600
Fresno River	Near Knowles	0	0	100	2,100	3,000	6,200	3,300	3,000	1,800	200	0	0	19,700
Chowchilla River**	At Buchanan	0	300	500	3,600	5,400	10,800	5,000	3,200	2,600	300	0	0	31,700
Season 1931-31—														
Kern River	Near Bakersfield	9,300	11,100	10,600	12,300	13,800	15,800	23,400	41,900	24,300	8,500	6,300	6,800	184,100
Tule River*	Near Porterville	0	1,300	1,700	3,400	3,100	3,000	2,800	2,100	200	0	0	0	17,600
Kaweah River	Near Three Rivers	1,400	3,700	3,100	5,800	7,300	11,300	23,600	40,600	12,600	2,400	1,300	1,100	114,200
Kings River	At Piedra	8,600	11,800	9,000	12,600	17,500	30,900	98,200	184,000	58,700	14,300	10,100	10,100	465,800
San Joaquin River	Near Friant	42,900	32,600	26,900	33,700	29,900	41,300	92,200	107,000	55,400	52,900	38,700	9,300	562,800
Fresno River	Near Knowles	0	600	300	800	1,200	700	1,100	1,100	300	0	0	0	6,100
Chowchilla River	At Buchanan	0	0	100	900	1,000	700	200	100	0	0	0	0	3,000

*Includes run-off of South Fork near Success.
**Estimated from index of seasonal wetness.

TABLE D-6

SEASONAL UTILIZATION OF THE IMPAIRED RUN-OFF OF THE SAN JOAQUIN RIVER AT FRIANT UNDER CONDITIONS OF IMMEDIATE INITIAL DEVELOPMENT, IN ACRE-FEET

Period	Prior crop land rights	Diversions for Upper San Joaquin Valley							Reservoir evaporation loss	Waste past reservoir	Net contribution to reservoir storage	Total impaired run-off
		Madera Canal			San Joaquin River-Kern County Canal			Totals				
		In-season	Out-of-season	Totals	In-season	Out-of-season	Totals					
1929-1930—												
October	27,900	400	0	400	4,400	0	4,400	4,800	800	0	—3,700	29,800
November	8,400	0	0	0	1,100	0	1,100	1,100	600	0	+14,800	24,900
December	6,400	0	0	0	1,100	0	1,100	1,100	0	0	+24,100	31,600
January	10,000	0	0	0	2,200	0	2,200	2,200	0	0	+18,100	30,300
February	27,900	300	0	300	3,300	0	3,300	3,600	0	0	+7,700	39,200
March	51,600	2,200	0	2,200	7,500	0	7,500	9,700	0	0	+9,400	70,700
April	114,700	5,300	0	5,300	11,500	0	11,500	16,800	1,000	0	—11,500	121,000
May	138,000	7,300	0	7,300	14,600	0	14,600	21,900	1,400	0	—23,300	138,000
June	155,000	6,700	0	6,700	16,900	0	16,900	23,600	1,500	0	—25,100	155,000
July	96,500	4,200	0	4,200	8,400	0	8,400	12,600	1,600	0	—14,200	96,500
August	79,900	0	0	0	0	0	0	0	1,400	0	—1,400	79,900
September	51,700	0	0	0	0	0	0	0	1,100	0	—1,100	51,700
Totals for season 1929–30	768,000	26,400	0	26,400	71,000	0	71,000	97,400	9,400	0	—6,200	868,600
1930-1931—												
October	27,900	400	0	400	5,500	0	5,500	5,900	800	0	+8,300	42,900
November	8,400	0	0	0	1,100	0	1,100	1,100	600	0	+22,500	32,600
December	6,400	0	0	0	1,100	0	1,100	1,100	0	0	+19,400	26,900
January	10,000	0	0	0	2,200	0	2,200	2,200	0	0	+21,500	33,700
February	27,900	300	0	300	3,300	0	3,300	3,600	0	0	—1,600	29,900
March	41,300	2,200	0	2,200	7,500	0	7,500	9,700	0	0	—9,700	41,300
April	92,200	5,300	0	5,300	11,500	0	11,500	16,800	1,000	0	—17,800	92,200
May	107,000	7,300	0	7,300	14,600	0	14,600	21,900	1,300	0	—23,200	107,000
June	55,400	6,700	0	6,700	8,800	0	8,800	15,500	1,400	0	—16,900	55,400
July	52,900	0	0	0	0	0	0	0	1,500	0	—1,500	52,900
August	38,700	0	0	0	0	0	0	0	1,400	0	—1,400	38,700
September	9,300	0	0	0	0	0	0	0	1,100	0	—1,100	9,300
Totals for season 1930–31	477,400	22,200	0	22,200	55,600	0	55,600	77,800	9,100	0	—1,500	562,800
Mean seasonal, 1917–31	769,800	87,300	8,100	95,400	337,300	95,900	433,200	528,600	10,800	2,700	—800	1,311,100
Mean seasonal, 1921–31	747,000	79,400	11,400	90,800	311,200	96,100	407,300	498,100	10,700	3,800	—1,100	1,258,500
Mean seasonal, 1926–31	726,400	60,500	0	60,500	229,400	68,200	297,600	358,100	10,300	0	—2,200	1,092,600

Madera would have received any water from Friant Reservoir. However, the total supply for all absorptive areas, for the 10-year period, would have exceeded net use requirements by 20,000 acre-feet. Although ground water storage would be depleted at the end of the 10-year period in certain units, the total accretions in other units exceed the total amounts of depletion. With minor changes in allotment, in certain seasons, all ground water reservoirs would have finished the 10-year period with slightly higher water levels at the end than at the beginning, after having furnished a full supply every season equal to the requirements for the areas irrigated in 1929.

With the water supply available during the 10-year period 1921–31 and with water requirements based upon the area irrigated in 1929 assumed to be furnished throughout the period, the weighted average pumping lifts for all absorptive areas would have been nearly as great in 1930–31 as in 1921–22. Assuming that the operation of the plan of immediate initial development were started in 1931 and the water supply for the 10-year period 1931–1941 were equal to that of the 10-year period 1921–1931, practically the same conditions of ground water depletion and excessive pumping lifts would exist at the end of 1941 as under present conditions. However, should the period following the completion of the plan of immediate initial development more closely approach the normal, the available water supply for utilization would replenish the underground reservoirs in addition to fully meeting the requirements of present areas of deficiency.

It was pointed out in Chapter VIII that, should the run-off occurring in future years result in a succession of seasons more subnormal than experienced during the period 1917–1929 upon which the water supply studies for immediate initial development are based, the utilizable water supply, from both local and supplemental sources, which would be available under the proposed plan of immediate intial development might be materially less than estimated for the period 1917–1929; and that, in this event, additional supplemental supplies might be required to adequately meet the needs of present developed areas. Adequate relief should include not only the furnishing of supplies to offset present deficiencies between supply and actual net use requirements, but also substantial ground water replenishment to reduce present excessive pumping lifts. The only dependable and practicable source of additional supplemental water supply would be the Sacramento River Basin, and the San Joaquin River Pumping System would be required to import supplies from this source to be used in the San Joaquin Valley. It was concluded in a previous report* that the construction of this unit might be deferred until experience demonstrated the need of additional water for initial development, but that provision should be made in the plan of financing for funds to construct this unit so that adequate relief would be assured for the present developed areas of deficient water supply. The foregoing studies extending the analyses of water supply under the plan of immediate initial development to include the seasons of 1929–30 and 1930–31 have further demonstrated the desirability of the inclusion of the San

*Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930. (See pages 45 and 160.)

SEASIRING AN IMPORTED SUPPLY IN UPPER SAN JOAQUIN
RRIGATED AREAS AS OF 1929

			Net area irrigated in 1929, in acres	Estimated seasonal net use requirements		Total net accretion (+) to or depletion (—) of ground water storage during 10-year period, 1921-1931, in acre-feet
	-31	Mean for period, 1921-1931		Acre-feet per acre[2]	Acre-feet	
Mader	2,500	95,880				
	2,200	90,820				
	4,700	186,700	81,000	2.5	202,500	—158,000
Lower	0	28,010	------------	------------	------------	------------
Alta-F	5,600	33,830	16,000	2.0	32,000	------------
Kawe	0,000	229,610				
	0	82,480				
	0,000	312,090	[1]122,900	2.5	307,300	+47,900
Linds	4,200	14,130				
	5,600	33,830				
	9,800	47,960	22,000	2.0	44,000	------------
Tule-	2,700	81,580				
	0	64,030				
	2,700	145,610	[4]75,200	2.2	165,400	—197,900
Earli	800	2,450				
	0	83,270				
	800	85,720	30,500	2.0	61,000	+247,200
McFa	0	31,620				
	0	76,060				
	0	107,680	49,800	2.0	99,600	+80,800
Magu	4,400	5,800	2,600	2.0	5,200	------------
T	0,200	455,270				
	7,800	498,130				
	28,000	953,400	400,000	------------	917,000	+20,000

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Madera would have received any water from Friant Reservoir. However, the total supply for all absorptive areas, for the 10-year period, would have exceeded net use requirements by 20,000 acre-feet. Although ground water storage would be depleted at the end of the 10-year period in certain units, the total accretions in other units exceed the total amounts of depletion. With minor changes in allotment, in certain seasons, all ground water reservoirs would have finished the 10-year period with slightly higher water levels at the end than at the beginning, after having furnished a full supply every season equal to the requirements for the areas irrigated in 1929.

With the water supply available during the 10-year period 1921–31 and with water requirements based upon the area irrigated in 1929 assumed to be furnished throughout the period, the weighted average pumping lifts for all absorptive areas would have been nearly as great in 1930–31 as in 1921–22. Assuming that the operation of the plan of immediate initial development were started in 1931 and the water supply for the 10-year period 1931–1941 were equal to that of the 10-year period 1921–1931, practically the same conditions of ground water depletion and excessive pumping lifts would exist at the end of 1941 as under present conditions. However, should the period following the completion of the plan of immediate initial development more closely approach the normal, the available water supply for utilization would replenish the underground reservoirs in addition to fully meeting the requirements of present areas of deficiency.

It was pointed out in Chapter VIII that, should the run-off occurring in future years result in a succession of seasons more subnormal than experienced during the period 1917–1929 upon which the water supply studies for immediate initial development are based, the utilizable water supply, from both local and supplemental sources, which would be available under the proposed plan of immediate intial development might be materially less than estimated for the period 1917–1929; and that, in this event, additional supplemental supplies might be required to adequately meet the needs of present developed areas. Adequate relief should include not only the furnishing of supplies to offset present deficiencies between supply and actual net use requirements, but also substantial ground water replenishment to reduce present excessive pumping lifts. The only dependable and practicable source of additional supplemental water supply would be the Sacramento River Basin, and the San Joaquin River Pumping System would be required to import supplies from this source to be used in the San Joaquin Valley. It was concluded in a previous report* that the construction of this unit might be deferred until experience demonstrated the need of additional water for initial development, but that provision should be made in the plan of financing for funds to construct this unit so that adequate relief would be assured for the present developed areas of deficient water supply. The foregoing studies extending the analyses of water supply under the plan of immediate initial development to include the seasons of 1929–30 and 1930–31 have further demonstrated the desirability of the inclusion of the San

*Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930. (See pages 45 and 160.)

TABLE D-7

SEASONAL WATER SUPPLY AND NET ACCRETION TO OR DEPLETION OF GROUND WATER STORAGE DURING PERIOD 1921-1931 FOR AREAS REQUIRING AN IMPORTED SUPPLY IN UPPER SAN JOAQUIN VALLEY UNDER CONDITIONS OF IMMEDIATE INITIAL DEVELOPMENT, WITH WATER REQUIREMENTS BASED UPON IRRIGATED AREAS AS OF 1929

Unit or area	Source of water supply	Seasonal surface water supply, in acre-feet											Net area irrigated in 1929, in acres	Estimated seasonal net use requirements		Total net accretion (+) to or depletion (—) of ground water storage during 10-year period, 1921-1931, in acre-feet
		1921-22	1922-23	1923-24	1924-25	1925-26	1926-27	1927-28	1928-29	1929-30	1930-31	Mean for period, 1921-1931		Acre-feet per acre[2]	Acre-feet	
Madera	Local	205,100	154,800	24,000	134,800	66,700	143,600	100,300	62,100	55,100	12,500	95,880				
	Friant Reservoir	245,800	132,100	32,700	104,900	90,500	130,400	90,500	32,700	26,400	22,200	90,820				
	Totals	450,900	286,900	56,700	230,500	157,200	274,000	190,800	94,800	81,500	34,700	188,700	81,000	2.5	202,600	—158,000
Lower Kings River	Friant Reservoir	85,200	48,400	6,200	18,500	26,700	66,200	26,200	2,700	0	0	28,010	....	....	....	....
Alta-Foothill	Friant Reservoir	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	32,700	25,600	33,830	16,000	2.0	32,000	....
Kaweah	Local	377,300	299,700	88,000	274,200	185,000	405,200	182,100	194,800	189,800	100,000	229,610				
	Friant Reservoir	250,900	142,700	18,200	54,500	78,500	194,900	77,200	7,900	0	0	82,480				
	Totals	628,200	442,400	106,200	328,700	263,500	600,100	259,300	202,700	189,800	100,000	312,090	[1]122,900	2.5	307,300	+47,900
Lindsay	Local[3]	13,400	14,100	13,700	12,700	14,100	13,300	14,300	15,500	16,000	14,200	14,130				
	Friant Reservoir	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	32,700	25,600	33,830				
	Totals	48,400	49,100	48,700	47,700	49,100	48,300	49,300	50,500	48,700	39,800	47,960	22,000	2.0	44,000	....
Tule-Deer Creek	Local	158,600	116,400	29,600	107,400	56,500	146,600	57,100	88,200	54,700	22,700	81,580				
	Friant Reservoir	194,800	110,800	14,100	42,300	60,900	151,300	60,000	6,100	0	0	64,030				
	Totals	351,400	227,200	43,700	149,700	117,400	297,900	117,100	74,300	54,700	22,700	145,610	[4]75,200	2.2	165,400	—197,900
Earlimart-Delano	Local	3,700	4,800	0	3,600	1,400	4,700	2,300	1,900	1,300	800	2,450				
	Friant Reservoir	253,300	144,100	18,300	55,000	79,200	196,800	78,000	8,000	0	0	83,270				
	Totals	257,000	148,900	18,300	58,600	80,600	201,500	80,300	9,900	1,300	800	85,720	30,500	2.0	61,000	+247,200
McFarland-Shafter	Local	123,100	52,500	0	23,400	13,600	82,000	11,800	4,800	6,000	0	31,620				
	Friant Reservoir	231,300	131,600	16,800	50,300	72,400	179,700	71,200	7,300	0	0	76,060				
	Totals	354,400	184,100	16,800	73,700	86,000	261,700	83,000	12,100	6,000	0	107,680	49,800	2.0	99,800	+80,800
Magunden-Edison	Friant Reservoir	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	5,600	4,400	5,800	2,600	2.0	5,200	....
Totals	Local	879,200	642,300	155,300	555,900	337,300	795,400	367,900	347,300	321,900	150,200	455,270				
	Friant Reservoir	1,337,300	785,700	182,300	401,500	484,200	995,300	479,100	140,700	97,400	77,800	498,130				
	Totals	2,216,500	1,428,000	337,600	957,400	821,500	1,790,700	847,000	488,000	419,300	228,000	953,400	400,000	....	917,000	+20,000

[1] Excludes 5,600 acres of irrigated pasture.
[2] On basis of per acre values determined in Chapter IV.
[3] Importation from Kaweah River in accord with diversions of Lindsay-Strathmore Irrigation District. Amounts diverted to Lindsay Unit deducted from local supply of Kaweah Unit.
[4] Includes 5,000 acres east of ground water unit.

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Joaquin River Pumping System as an initial unit in the financing of the plan.

Complete Initial Development—With the units of the plan of complete initial development constructed and in operation, practically the entire flow of the San Joaquin River at Friant would be available for diversion into the upper San Joaquin Valley. The average seasonal yield from the Friant Reservoir for the 14-year period 1917–1931 would have been 1,272,000 acre-feet. The average seasonal utilizable yield from the Chowchilla, Fresno, Kings, Kaweah, Tule and Kern rivers, for this period, was about 2,058,000 acre-feet. The average combined total yield of 3,330,000 acre-feet would have satisfied the requirements of 1,665,000 acres or about one and one-half times the irrigated area now receiving a supply from these streams.

The San Joaquin River Pumping System would make available water supplies from the delta and the lower San Joaquin River tributaries, for "crop lands" now being served from the San Joaquin River. These crop lands would have received a full supply in all seasons except 1930–31. In that season there would have been a deficiency of 35 per cent through the months of May to September, inclusive. The deficiency for the entire season would have been 25 per cent. Even with this deficiency, the amount received would have exceeded the amount actually available to these lands during the season 1930–31 by 191,000 acre-feet or 40 per cent more water. The monthly contributions of surplus and return waters from the lower San Joaquin Valley for the seasons 1929–30 and 1930–31 are set forth in Table D-8. The means for the 14-year period 1917–31 are also shown. This table is an extension of Table 183 in Chapter VIII, and the bases of compilation and explanation of the quantities are the same as set forth in that chapter. The deficiencies shown would be supplied by pumping Sacramento River water from the delta and would have been fully met from this source except during the months of May to September, inclusive, in 1931 when there would have been a deficiency of 35 per cent.

Adequacy of Major Units of Ultimate State Water Plan.

The operation and accomplishments of the major units of the ultimate State Water Plan in the San Joaquin River Basin and in the entire Great Central Valley, based upon the 40-year period of run-off 1889–1929, are presented in Chapter VII. In the analyses shown therein of the water supply that would have been made available by the proposed units of the ultimate plan during the 40-year period 1889–1929, it was demonstrated that the irrigable areas to be served under ultimate development in practically all of the lower San Joaquin Valley and along the west side of the upper San Joaquin Valley would have received an adequate surface supply of water obtained through surface storage regulation on local streams and from importations from the Sacramento River Basin, with a maximum deficiency of not to exceed 35 per cent in any season during that period; and that the eastern and southern slopes of the upper San Joaquin Valley would have received a full supply without deficiency through the combined utilization of surface and underground storage. No utilization was

TABLE D-8

UTILIZATION OF RETURN FLOW AND UNREGULATED SURPLUS WATERS IN LOWER SAN JOAQUIN RIVER UNDER EXISTING IRRIGATION AND STORAGE CONDITIONS AND MUNICIPAL DIVERSIONS AS OF 1940 TO SUPPLY LOWER SAN JOAQUIN VALLEY CROP LANDS

Season	Item	Quantities, in acre-feet												
		October	November	December	January	February	March	April	May	June	July	August	September	Totals
	Demand of Lower San Joaquin Valley crop lands	27,900	8,400	6,400	10,000	27,900	51,600	114,700	158,700	163,000	142,000	108,300	76,800	895,700
1929-30	Inflow to delta[1]	31,500	34,200	42,000	92,600	95,300	136,100	192,800	178,500	160,900	33,100	29,500	34,200	1,060,700
	Excess	3,600	25,800	35,600	82,600	67,400	84,500	78,100	19,800					397,400
	Deficiency									2,100	108,900	78,800	42,600	232,400
1930-31	Inflow to delta[1]	33,200	51,100	66,500	68,700	67,800	37,200	19,700	1,500	14,200	16,000	13,000	17,700	406,600
	Excess	5,300	42,700	60,100	58,700	39,900								206,700
	Deficiency						14,400	95,000	101,600	91,700	76,300	57,400	32,100	468,500
Mean, 1917-1931	Inflow to delta[1]	65,600	80,100	97,800	121,100	170,100	215,200	318,300	499,900	374,000	88,900	40,700	44,900	2,116,600
	Excess	37,700	71,700	91,400	111,100	142,200	165,000	216,200	360,500	246,300	19,300			1,461,400
	Deficiency						1,500	12,600	15,300	31,200	68,900	64,900	30,000	224,400

[1] Quantities shown for inflow to the delta are the estimated amounts of surplus and return flow waters as measured immediately above Dam No. 1 of the San Joaquin River Pumping System. They comprise the estimated flow of the San Joaquin River above Merced River, adjusted for the operation of Friant Reservoir and diversions through the Madera and San Joaquin River-Kern County canals and for greater return flow due to increased supply to the lower San Joaquin Valley "crop lands" under the plan of complete initial development; and the estimated flow of the Merced, Tuolumne, and Stanislaus rivers at their junction with the San Joaquin River under existing irrigation and storage conditions and municipal diversions as of 1940, with deductions for west-side pumping diversions from Patterson Colony to Banta-Carbona Irrigation District, inclusive.

made of the available capacity of underground reservoirs in the lower San Joaquin Valley for storage regulation and subsequent extraction by pumping, except to a minor extent in Hydrographic Division No. 8. In order to test the adequacy of the proposed ultimate plan of development through the dry seasons of 1929–30 and 1930–31, the analyses of water supply and the studies of the operation of the major surface storage and conveyance units and the underground reservoirs were extended through these two additional seasons. In making this test the same methods were employed for estimating the available surface water supplies as were used and described in Chapter VII, with studies of water supply made on a month by month basis.

Utilizable Yield of Surface Water Supplies in the Seasons 1929–30 and 1930–31—The utilizable yields of surface water supplies which would have been available in the seasons of 1929–30 and 1930–31 under the ultimate State Water Plan in the San Joaquin River Basin are set forth in Table D-9. The table shows for each season the yield from the major streams in the San Joaquin River Basin, the contributions from minor streams in the upper San Joaquin Valley, the return flow and unregulated surplus water from the lower San Joaquin Valley and the water supply that would be imported from the Sacramento River Basin.

TABLE D-9

UTILIZABLE YIELD OF SURFACE WATER SUPPLIES FOR ULTIMATE STATE WATER PLAN IN SAN JOAQUIN RIVER BASIN IN SEASONS 1929-30 AND 1930-31

Source	Surface reservoir	Capacity of reservoir in acre-feet	Total seasonal yield in acre-feet	
			1929-1930	1930-1931
Kern River	Isabella	338,000	346,700	184,100
Tule River	Pleasant Valley	39,000	44,700	17,600
Kaweah River			217,600	114,200
Kings River	Pine Flat	400,000	862,800	465,800
San Joaquin River	Friant	(Net)270,000	860,000	554,200
Fresno River	Windy Gap	62,000	20,300	7,100
Chowchilla River	Buchanan	84,000	30,900	3,000
Merced River	Exchequer	279,000	409,000	185,900
Tuolumne River	Don Pedro	1,000,000	1,072,500	577,800
Stanislaus River	Melones	1,090,000	607,400	220,700
Calaveras River	Valley Springs	325,000	43,000	12,200
Mokelumne River	Pardee	222,000	156,800	78,000
Dry Creek	Ione	610,000	23,500	7,800
Cosumnes River	Nashville	281,000	137,400	24,200
Return flow and unregulated surplus water from lower San Joaquin Valley			1,042,000	777,000
Minor streams, upper San Joaquin Valley			57,400	54,400
From Sacramento River Basin			2,791,000	1,728,000
Totals			8,723,000	5,012,000

The total seasonal yields available from surface supplies to meet the needs of the San Joaquin Valley and adjacent foothill areas below the major reservoirs, under the plan of ultimate development, as shown by the foregoing tabulation, would have been 8,723,000 acre-feet in 1929–1930 and 5,012,000 acre-feet in 1930–1931 for a total area of 4,945,000 acres having a total seasonal water requirement (gross allowance) of 11,612,000 acre-feet. The available surface supply for the season of 1930–1931 would have been but 43 per cent of the gross requirement.

Under the plan of operation set forth in Chapter VII for ultimate development, the utilizable yield of surface water supplies in the seasons 1929–30 and 1930–31, with these two dry seasons following a period of generally subnormal supply extending from 1917 to 1929, are so small in amount that there would have been insufficient water in certain areas to meet the requirements. Carry over storage in the surface reservoirs and ground water supplies in certain of the underground reservoirs of the upper San Joaquin Valley south of the San Joaquin River would have been exhausted to such an extent that large deficiencies would have occurred in the season 1930–31.

Modified Plan of Operation for Ultimate State Water Plan in San Joaquin River Basin—In order to provide adequate supplies in the season 1930–31 for all areas in the San Joaquin River Basin, it was found necessary to modify the plan of operation as set forth in Chapter VII so as to make greater utilization of the underground reservoirs not only in the upper San Joaquin Valley but also in certain areas of the lower San Joaquin Valley.

An equal degree of utilization of all ground water reservoirs in the upper San Joaquin Valley would be required to eliminate the deficiencies which would have occurred in Hydrographic Divisions 1, 2 and 3 in 1930–31 under the plan of operation set forth in Chapter VII. Under the modified plan of operation, greater utilization would be made of the underground reservoir in Hydrographic Division No. 6 and a smaller amount of surface irrigation supply from Friant Reservoir would be allocated to this area in order to make more water available from this reservoir to the areas south of the San Joaquin River.

In the lower San Joaquin Valley, under the modified plan of operation, the underground reservoirs would be utilized for obtaining ground water supplies to supplement the available surface water supplies in the seasons of 1929–30 and 1930–31 in Hydrographic Divisions 8, 9 and 11, and in the season of 1930–31 in Hydrographic Division No. 12. In addition to utilization of ground water supplies to meet the water requirements in these hydrographic divisions in these seasons, it was found that additional water would be required in the season 1930–31 for Hydrographic Division No. 11 in order to meet a large deficiency which would have occurred in that season in this division. The additional supply required could have been furnished by importation from the American River. Hence, the modified plan of operation would provide for serving a portion of the water requirements in Hydrographic Division No. 11 with American River water. In any normal or greater than normal season there would be a surplus of 68,000 acre-feet over and above the requirements for Hydrographic Divisions 12 and 13, in the supply available from the American River which could be allocated to Hydrographic Division No. 11. This would reduce the drafts required from Melones Reservoir by an equal amount and would permit the accumulation of storage in the reservoir to hold over for use during periods of subnormal supply. A monthly analysis under this modified plan of operation for Hydrographic Division No. 11 under conditions of ultimate development showed that there would be only a small deficiency in 1930–31. The supplies from the American River for Hydrographic Divisions 12 and 13 would not be reduced under this modified plan of operation except in the season 1930–31 when the studies showed that it would have been necessary to allocate all available American River water to Hydrographic Divisions 11 and 13 with none allocated to Hydrographic Division No. 12 in that season. This would have necessitated the utilization of ground water in Hydrographic Division No. 12 in order to obtain an adequate supply for this area during the season 1930–31.

Results of Modified Plan of Operation in Upper San Joaquin Valley—Under the plan of operation set forth in Chapter VII, the underground reservoirs in Hydrographic divisions 1, 2, 3, 4 and 6 would have been full in 1917. Therefore, in the consideration of a modified plan of operation as regards particularly the allocation of the supplies made available from Friant Reservoir to the hydrographic divisions in the upper San Joaquin Valley, the 14-year period 1917–1931 was analyzed. Numerous trial studies were required to determine the proper allocation of San Joaquin River water from Friant Reservoir in order to provide adequate supplies for all hydrographic divisions on the east side of the upper San Joaquin Valley and prevent depletion of the underground reservoirs in Hydrographic Divisions 1, 2 and 3 which would have occurred under the plan of operation set forth in Chapter VII.

Under the modified plan of operation that was found to meet the requirements during the 14-year period including the season 1930–31, Hydrographic Division No. 6 would receive through the Madera Canal 10 per cent of the water available for diversion at Friant Reservoir, except during May and June in seasons of greater than normal run-off and during periods when Friant Reservoir would be spilling when it would be served additional water for ground water recharge limited by the 1500 second-feet diversion capacity of the Madera Canal. Division 1 would receive 29 per cent; Division 2, 56 per cent; and Division 3, 5 per cent of the total water available for diversion at Friant Reservoir limited by the 3000 second-feet diversion capacity of the San Joaquin River-Kern County Canal. Local supplies in Hydrographic Division No. 4 were found to be sufficient through 1930–31 and hence no allocation of San Joaquin River water was made for that area. Table D-10 sets forth the allocation of the yield from the Friant Reservoir during the 14-year period 1917–1931, by hydrographic divisions, without and with modification of the plan of operation under ultimate development.

Under the modified plan of operation with the change in allocation of water supplies from Friant Reservoir, seasonal analyses were made of the accumulative ground water storage in the absorptive areas of each of these hydrographic divisions for the 14-year period 1917–31, using methods and limiting factors of utilizable yield similar to those presented in Chapter VII in the original accumulative ground water analyses. Studies show that the maximum capacity of water supply utilization in Hydrographic Division No. 6 is materially in excess of the water supplies made available under the modified plan of operation during the 14-year period considered. During periods when the underground reservoirs would have been nearly full or the surface supplies would have closely approached the maximum capacity of utilization, the analyses were made month by month. The results of these analyses are presented in Table D-11 which sets forth by seasons, for each hydrographic division, the utilizable local and imported water supplies, net use requirement, seasonal net contributions to or extractions from ground water and the water supply remaining in ground water storage at the end of each season for the 14-year period 1917–1931.

TABLE D-10

ALLOCATION OF TOTAL YIELD FROM FRIANT RESERVOIR UNDER CONDITIONS OF ULTIMATE DEVELOPMENT

For 14-year Period 1917-1931

Hydrographic division	Allocation of yield, without modification of plan		Allocation of yield, with modification of plan	
	Acre-feet	Per cent of total	Acre-feet	Per cent of total
1	4,098,000	23.0	5,064,200	28.5
2	8,460,400	47.5	*9,779,400	54.9
3	661,000	3.7	873,300	4.9
6	4,586,400	25.8	**2,088,500	11.7
Totals	17,805,800	100.0	17,805,400	100.0

* 7,900 acre-feet occurring in season 1917-18 not utilizable.
** 4,500 acre-feet occurring in season 1917-18 not utilizable.

TABLE D-11

SEASONAL WATER SUPPLY, WATER REQUIREMENTS, CONTRIBUTIONS TO GROUND WATER AND WATER SUPPLY REMAINING IN STORAGE AT END OF EACH SEASON IN UNDERGROUND RESERVOIRS, IN ABSORPTIVE AREAS OF UPPER SAN JOAQUIN VALLEY UNDER MODIFIED PLAN OF OPERATION FOR ULTIMATE DEVELOPMENT DURING PERIOD 1917-1931

(Quantities, in Acre-feet)

Season	Utilizable local water supply	Utilizable imported water supply	Total utilizable water supply	Net use	Seasonal net contribution (+) to or extraction (—) from ground water	Water supply remaining in ground water storage
Hydrographic Division 1						
1916-17	----------	----------	----------	----------	----------	3,750,000
1917-18	606,000	445,000	1,051,000	1,058,000	—7,000	3,743,000
1918-19	606,000	389,500	995,500	1,058,000	—62,500	3,680,500
1919-20	606,000	376,800	982,800	1,058,000	—75,200	3,605,300
1920-21	531,300	449,200	980,500	1,058,000	—77,500	3,527,800
1921-22	583,700	482,200	1,065,900	1,058,000	+7,900	3,535,700
1922-23	606,000	497,400	1,103,400	1,058,000	+45,400	3,581,100
1923-24	323,600	184,600	508,200	1,058,000	—549,800	3,031,300
1924-25	463,600	368,600	832,200	1,058,000	—225,800	2,805,500
1925-26	340,100	355,300	695,400	1,058,000	—362,600	2,442,900
1926-27	584,100	502,000	1,086,100	1,058,000	+28,100	2,471,000
1927-28	521,400	351,200	872,600	1,058,000	—185,400	2,285,600
1928-29	328,500	252,300	580,800	1,058,000	—477,200	1,808,400
1929-30	346,700	249,400	596,100	1,058,000	—461,900	1,346,500
1930-31	184,100	160,700	344,800	1,058,000	—713,200	633,300
Totals	6,631,100	5,064,200	11,695,300	14,812,000	—3,116,700	
Average	473,700	361,700	835,400	1,058,000	—222,600	
Hydrographic Division 2						
1916-17	----------	----------	----------	----------	----------	3,650,000
1917-18	54,500	851,400	905,900	970,000	—64,100	3,585,900
1918-19	74,300	752,100	826,400	970,000	—143,600	3,442,300
1919-20	108,100	727,700	835,800	970,000	—134,200	3,308,100
1920-21	88,600	867,400	956,000	970,000	—14,000	3,294,100
1921-22	134,700	931,200	1,065,900	970,000	+95,900	3,390,000
1922-23	100,300	960,600	1,060,900	970,000	+90,900	3,480,900
1923-24	25,000	356,400	381,400	970,000	—588,600	2,892,300
1924-25	87,300	711,700	799,000	970,000	—171,000	2,721,300
1925-26	47,700	686,200	733,900	970,000	—236,100	2,485,200
1926-27	127,900	969,400	1,097,300	970,000	+127,300	2,612,500
1927-28	47,200	678,100	725,300	970,000	—244,700	2,367,800
1928-29	53,400	487,300	540,700	970,000	—429,300	1,938,500
1929-30	44,700	481,600	526,300	970,000	—443,700	1,494,800
1930-31	17,600	310,400	328,000	970,000	—642,000	852,800
Totals	1,011,300	9,771,500	10,782,800	13,580,000	—2,797,200	
Average	72,200	698,000	770,200	970,000	—199,800	
Hydrographic Division 3						
1916-17	----------	----------	----------	----------	----------	2,182,900
1917-18	229,700	76,700	306,400	498,000	—191,600	1,991,300
1918-19	289,200	67,200	356,400	498,000	—141,600	1,849,700
1919-20	372,100	65,000	437,100	498,000	—60,900	1,788,800
1920-21	360,800	77,500	438,300	498,000	—59,700	1,720,100
1921-22	461,100	83,200	544,300	498,000	+46,300	1,775,400
1922-23	363,500	85,800	449,300	498,000	—48,700	1,726,700
1923-24	101,700	31,800	133,500	498,000	—364,500	1,362,200
1924-25	325,500	63,500	389,000	498,000	—109,000	1,253,200
1925-26	218,800	61,300	280,100	498,000	—217,900	1,035,300
1926-27	483,200	86,600	569,800	498,000	+71,800	1,107,100
1927-28	203,000	60,500	263,500	498,000	—234,500	872,600
1928-29	222,800	43,500	266,300	498,000	—231,700	640,900
1929-30	217,600	43,000	260,600	498,000	—237,400	403,500
1930-31	114,200	27,700	141,900	498,000	—356,100	47,400
Totals	3,963,200	873,300	4,836,500	6,972,000	—2,135,500	
Average	283,100	62,400	345,500	498,000	—152,500	

TABLE D-11—Continued

SEASONAL WATER SUPPLY, WATER REQUIREMENTS, CONTRIBUTIONS TO GROUND WATER AND WATER SUPPLY REMAINING IN STORAGE AT END OF EACH SEASON IN UNDERGROUND RESERVOIRS, IN ABSORPTIVE AREAS OF UPPER SAN JOAQUIN VALLEY UNDER MODIFIED PLAN OF OPERATION FOR ULTIMATE DEVELOPMENT DURING PERIOD 1917-1931

(Quantities, in Acre-feet)

Season	Utilizable local water supply	Utilizable imported water supply	Total utilizable water supply	Net use	Seasonal net contribution (+) to or extraction (—) from ground water	Water supply remaining in ground water storage
Hydrographic Division 4						
1916-17						8,517,100
1917-18	1,361,900		1,361,900	1,658,900	—297,000	8,220,100
1918-19	1,199,700		1,199,700	1,658,900	—459,200	7,760,900
1919-20	1,398,100		1,398,100	1,658,900	—260,800	7,500,100
1920-21	1,523,800		1,523,800	1,658,900	—135,100	7,365,000
1921-22	2,010,000		2,010,000	1,658,900	+351,100	7,716,100
1922-23	1,599,800		1,599,800	1,658,900	—59,100	7,657,000
1923-24	392,000		392,000	1,658,900	—1,266,900	6,390,100
1924-25	1,285,900		1,285,900	1,658,900	—373,000	6,017,100
1925-26	1,032,900		1,032,900	1,658,900	—626,000	5,391,100
1926-27	1,973,500		1,973,500	1,658,900	+314,600	5,705,700
1927-28	969,500		969,500	1,658,900	—689,400	5,016,300
1928-29	847,600		847,600	1,658,900	—811,300	4,205,000
1929-30	862,800		862,800	1,658,900	—796,100	3,408,900
1930-31	465,800		465,800	1,658,900	—1,193,100	2,215,800
Totals	16,923,300		16,923,300	23,224,600	—6,301,300	
Average	1,208,800		1,208,800	1,658,900	—450,100	
Hydrographic Division 6						
1916-17						2,284,100
1917-18	99,700	149,000	248,700	368,000	—119,300	2,164,800
1918-19	99,700	134,300	234,000	368,000	—134,000	2,030,800
1919-20	81,000	130,000	211,000	368,000	—157,000	1,873,800
1920-21	99,700	154,900	254,600	368,000	—113,400	1,760,400
1921-22	99,700	366,800	466,500	368,000	+98,500	1,858,900
1922-23	99,700	171,500	271,200	368,000	—96,800	1,762,100
1923-24	99,700	63,600	163,300	368,000	—204,700	1,557,400
1924-25	99,700	127,100	226,800	368,000	—141,200	1,416,200
1925-26	86,800	122,500	209,300	368,000	—158,700	1,257,500
1926-27	97,900	314,800	412,700	368,000	+44,700	1,302,200
1927-28	99,700	121,100	220,800	368,000	—147,200	1,155,000
1928-29	82,500	87,000	169,500	368,000	—198,500	956,500
1929-30	51,200	86,000	137,200	368,000	—230,800	725,700
1930-31	10,100	55,400	65,500	368,000	—302,500	423,200
Totals	1,207,100	2,084,000	3,291,100	5,152,000	—1,860,900	
Average	86,200	148,900	235,100	368,000	—132,900	

With the modified plan of operation there would have been some water remaining in ground water storage at the end of the season 1930–31 in each hydrographic division, after furnishing the full ultimate net use requirements in each season during the period 1917–31 analyzed. Therefore, the studies demonstrate that, with the modified plan of operation involving a change in allocation of supplemental supplies from Friant Reservoir and an equal degree of utilization of all underground reservoirs in the upper San Joaquin Valley, the proposed ultimate plan of development for the upper San Joaquin Valley is adequate to meet the ultimate requirements.

Hydrographic Division	De[illegible]	Water requirements			Deficiency	
		[illegible] served by [illegible] supply [illegible]lowance) Acre-feet	For areas served by pumping from ground water at 2.0 acre-feet per acre, in acre-feet	Totals in acre-feet	In acre-feet	In per cent of requirements
1a	North of Poso Cre[illegible] San Joaquin Ri[illegible]	34,000	------------	34,000	0	0
1b	Between Kern Ri[illegible] 200 feet above [illegible]	72,000	------------	72,000	0	0
1d	South of Kern Ri[illegible] Kern River Ca[illegible]	116,000	------------	116,000	0	0
1f	West side rim lan[illegible] Mendota-West	434,000	------------	434,000	134,000	31
1	Valley lands, incl[illegible] in 1a, 1b, 1d an[illegible]	153,000	773,000	926,000	0	0
	Totals, Hydr[illegible]	809,000	773,000	1,582,000	------------	------------
2a	East side rim land Joaquin River-[illegible]	156,000	------------	156,000	0	0
2b	East side rim land San Joaquin Ri[illegible] sions from Tule	62,000	------------	62,000	0	0
2c	Land served entir[illegible]	20,000	------------	20,000	10,000	50
2d	Lands served by conduits	26,000	------------	26,000	13,000	50
2e	West side rim lan[illegible] Mendota-West [illegible]	148,000	------------	148,000	46,000	31
2	Valley lands, excl[illegible]	92,000	628,000	720,000	0	0
	Totals, Hydr[illegible]	504,000	628,000	1,132,000	------------	------------
3	Valley lands, inclu[illegible]	161,000	379,000	540,000	0	0
4	Valley lands, inclu[illegible]	466,000	1,194,000	1,660,000	0	0
5	Kettleman Hills t[illegible]	520,000	------------	520,000	160,000	31
5B	Kettleman Hills t[illegible]	442,000	------------	442,000	136,000	31
6	Valley lands, exclu[illegible]	65,000	303,000	368,000	0	0
6	Columbia Canal a[illegible]	26,000	------------	26,000	8,000	31
	Totals, Hydr[illegible]	91,000	303,000	394,000	------------	------------

TABLE D-12

SUMMARY OF WATER REQUIREMENTS AND WATER SUPPLY FOR ULTIMATE STATE WATER PLAN IN SAN JOAQUIN RIVER BASIN BY HYDROGRAPHIC DIVISIONS, FOR SEASON 1930-1931

Hydro-graphic Divi-sion	Description of area t obe served	Net irrigable area to be served, in acres	Sources of water supply: Local	Sources of water supply: Return flow and unregulated surplus	Sources of water supply: Imported	Utilizable water supply in acre-feet: Surface supply: From San Joaquin River Basin: San Joaquin River at Friant	Local streams	Return flow and unregulated surplus	Totals	From Sacramento River Basin	Totals	Supply available in underground reservoir at beginning of season	Total utilizable supply	Areas served by surface supply in acres	Areas served by ground water supply in acres	Water requirements: For areas served by surface supply (gross allowance): Acre-feet per acre	Acre-feet	For areas served by pumping from ground water at 2.0 acre-feet per acre, in acre-feet	Totals in acre-feet	Deficiency: In acre-feet	In per cent of require-ments
1a	North of Poso Creek, to be served by pumpinglifts above the San Joaquin River-Kern County Canal	17,000			San Joaquin River	34,000			34,000		34,000		34,000	17,000		2.0	34,000		34,000	0	0
1b	Between Kern River and Poso Creek, within pumping lifts of 200 feet above Beardsley and Lerdo canals	36,000	Kern River and Poso Creek				72,000		72,000		72,000		72,000	36,000		2.0	72,000		72,000	0	0
1d	South of Kern River within pumping lifts of 350 feet above Kern River Canal	58,000	Kern River and minor streams				116,000		116,000		116,000		116,000	58,000		2.0	116,000		116,000	0	0
1f	West side rim lands above elevation 250 feet, to be served by Mendota-West Side Pumping System	217,000		Lower San Joaquin Valley	Sacramento River			54,000	54,000	246,000	300,000		300,000	217,000		2.0	434,000		434,000	134,000	31
1	Valley lands, including municipal areas, and excluding areas in 1a, 1b, 1d and 1f	463,000	Kern River and minor streams		San Joaquin River	127,000	26,000		153,000		153,000	1,346,000	1,499,000	76,500	386,500	2.0	153,000	773,000	926,000	0	0
	Totals, Hydrographic Division 1	791,000				161,000	214,000	54,000	429,000	246,000	675,000	1,346,000	2,021,000	404,500	386,500	2.0	809,000	773,000	1,582,000		
2a	East side rim lands within pumping lifts of 250 feet above San Joaquin River-Kern County Canal	78,000			San Joaquin River	156,000			156,000		156,000		156,000	78,000		2.0	156,000		156,000	0	0
2b	East side rim lands to be served jointly by pumping lifts from San Joaquin River-Kern County Canal and gravity diversions from Tule River	31,000			San Joaquin River	62,000			62,000		62,000		62,000	31,000		2.0	62,000		62,000	0	0
2c	Land served entirely by gravity diversions from Tule River	10,000	Tule River and Deer Creek				10,000		10,000		10,000		10,000	10,000		2.0	20,000		20,000	10,000	50
2d	Lands served by pumping lifts from Tule River diversion conduits	13,000	Tule River and Deer Creek				13,000		13,000		13,000		13,000	13,000		2.0	26,000		26,000	13,000	50
2e	West side rim lands above elevation 250 feet, to be served by Mendota-West Side Pumping System	74,000		Lower San Joaquin Valley	Sacramento River			19,000	19,000	83,000	102,000		102,000	74,000		2.0	148,000		148,000	46,000	31
2	Valley lands, excluding areas in 2a, 2b, 2c, 2d and 2e	360,000			San Joaquin River	92,000			92,000		92,000	1,495,000	1,587,000	46,000	314,000	2.0	92,000	628,000	720,000	0	0
	Totals, Hydrographic Division 2	566,000				310,000	23,000	19,000	352,000	83,000	435,000	1,495,000	1,930,000	252,000	314,000	2.0	504,000	628,000	1,132,000		
3	Valley lands, including municipal areas	270,000	Kaweah River and minor streams		San Joaquin River	28,000	133,000		161,000		161,000	404,000	565,000	80,500	189,500	2.0	161,000	379,000	540,000	0	0
4	Valley lands, including municipal areas	830,000	Kings River				466,000		466,000		466,000	3,408,000	3,874,000	233,000	597,000	2.0	466,000	1,194,000	1,660,000	0	0
5	Kettleman Hills to Mendota, below elevation 350 feet	260,000		Lower San Joaquin Valley	Sacramento River			65,000	65,000	295,000	360,000		360,000	260,000		2.0	520,000		520,000	160,000	31
5B	Kettleman Hills to Mendota, above elevation 350 feet	221,000		Lower San Joaquin Valley	Sacramento River			56,000	56,000	250,000	306,000		306,000	221,000		2.0	442,000		442,000	136,000	31
6	Valley lands, exclusive of Columbia Canal area	184,000	Chowchilla, Fresno and San Joaquin rivers			55,000	10,000		65,000		65,000	726,000	791,000	32,500	151,500	2.0	65,000	303,000	368,000	0	0
6	Columbia Canal area	13,000		Lower San Joaquin Valley	Sacramento River			9,000	9,000	9,000	18,000		18,000	13,000		2.0	26,000		26,000	8,000	31
	Totals, Hydrographic Division 6	197,000				55,000	10,000	9,000	74,000	9,000	83,000	726,000	809,000	45,500	151,500	2.0	91,000	303,000	394,000		

TABLE D-12—Continued

SUMMARY OF WATER REQUIREMENTS AND WATER SUPPLY FOR ULTIMATE STATE WATER PLAN IN SAN JOAQUIN RIVER BASIN BY HYDROGRAPHIC DIVISIONS, FOR SEASON 1930-1931

Hydrographic Division	Description of area to be served	Net irrigable area to be served, in acres	Sources of water supply: Local	Sources of water supply: Return flow and unregulated surplus	Sources of water supply: Imported	Utilizable water supply in acre-feet: Surface supply: From San Joaquin River Basin: San Joaquin River at Friant	Local streams	Return flow and unregulated surplus	Totals	From Sacramento River Basin	Totals	Supply available in underground reservoir at beginning of season	Total utilizable supply	Areas served by surface supply in acres	Areas served by ground water supply in acres	Water requirements: For areas served by surface supply (gross allowance): Acre-feet per acre	Acre-feet	For areas served by pumping from ground water at 2.0 acre-feet per acre, in acre-feet	Totals in acre-feet	Deficiency: In acre-feet	In per cent of requirements
7	West side area, south of Merced River, exclusive of rim lands	203,000		Lower San Joaquin Valley	Sacramento River			227,000	227,000	242,000	469,000		469,000	203,000		3.3	670,000		670,000	201,000	30
7	West side area, north of Merced River, exclusive of rim lands	62,000		Lower San Joaquin Valley				85,000	85,000		85,000		85,000	62,000		2.0	124,000		124,000	39,000	3[illegible]
7a	Rim lands, above present irrigated areas	143,000		Lower San Joaquin Valley	Sacramento River			54,000	54,000	141,000	195,000		195,000	143,000		2.0	286,000		286,000	91,000	[illegible]2
	Totals, Hydrographic Division 7	408,000						366,000	366,000	383,000	749,000		749,000	408,000		2.6	1,080,000		1,080,000		
8A	Foothills, below Exchequer Reservoir	28,000	Merced River				84,000		84,000		84,000		84,000	28,000		3.0	84,000		84,000	0	0
8	Valley lands, exclusive of area served from San Joaquin River	213,000	Merced River	Merced River			102,000	60,000	162,000		162,000	556,000	718,000	49,000	164,000	3.3	162,000	328,000	490,000	0	0
8	Area served from San Joaquin River	69,000		Lower San Joaquin Valley	Sacramento River			76,000	76,000	83,000	159,000		159,000	69,000		3.3	226,000		226,000	67,000	30
	Totals, below Exchequer Reservoir, hydrographic divisions 8 and 8A	310,000					186,000	136,000	322,000	83,000	405,000	556,000	961,000	146,000	164,000	3.2	472,000	328,000	800,000		
9A	Foothills, below Don Pedro Reservoir	47,000	Tuolumne River				141,000		141,000		141,000		141,000	47,000		3.0	141,000		141,000	0	0
9	Valley lands	312,000	Tuolumne River				437,000		437,000		437,000	1,163,000	1,600,000	132,000	180,000	3.3	437,000	360,000	797,000	0	0
	Totals, below Don Pedro Reservoir, hydrographic divisions 9 and 9A	359,000					578,000		578,000		578,000	1,163,000	1,741,000	179,000	180,000	3.2	578,000	360,000	938,000		
10	West delta uplands	69,000			Sacramento River					94,000	94,000		94,000	69,000		2.0	138,000		138,000	44,000	32
11A	Foothills, below Melones Reservoir	30,000	Stanislaus River				77,000		77,000		77,000		77,000	30,000		2.6	77,000		77,000	0	0
11	Valley lands	260,000	Stanislaus River	Stanislaus River	American River		144,000	72,000	216,000	81,000	297,000	335,000	632,000	90,000	170,000	3.3	297,000	340,000	637,000	5,000	1
	Totals, below Melones Reservoir, hydrographic divisions 11 and 11A	290,000					221,000	72,000	293,000	81,000	374,000	335,000	709,000	120,000	170,000	3.1	374,000	340,000	714,000		
12A	Foothills, below Valley Springs Reservoir	7,000	Calaveras River				12,000		12,000		12,000		12,000	7,000		2.5	17,000		17,000	5,000	29
12	Valley lands, below Valley Springs Reservoir	53,000	Calaveras River									138,000	138,000		53,000			106,000	106,000	0	0
12A	Foothills, below Pardee and Ione reservoirs	22,000	Mokelumne River and Dry Creek				41,000		41,000		41,000		41,000	22,000		2.5	55,000		55,000	14,000	25
12	Valley lands, below Pardee and Ione reservoirs	165,000	Mokelumne River and Dry Creek				45,000		45,000		45,000	382,000	427,000	17,000	148,000	2.7	45,000	296,000	341,000	0	0
	Totals, below reservoirs, hydrographic divisions 12 and 12A	247,000					98,000		98,000		98,000	520,000	618,000	46,000	201,000	2.5	117,000	402,000	519,000		
13	Valley lands	127,000	Cosumnes River		American River		24,000		24,000	204,000	228,000		228,000	127,000		2.7	343,000		343,000	115,000	34

Water Supply for Season 1930–31 by Hydrographic Divisions—The supplemental analyses of water supply extended through the seasons 1929–30 and 1930–31 under the ultimate State Water Plan in the San Joaquin River Basin show that the critical season testing the adequacy of the proposed physical units would be that of 1930–31. Accordingly, a final demonstration of the adequacy of the plan may be obtained by comparing the utilizable water supplies that would have been available in the season 1930–31 under the modified plan of operation previously described with the water requirements. This final demonstration is set forth in Table D-12 which shows by hydrographic divisions and zones of service the available utilizable water supply for the season 1930–31 from all sources including surface water supplies in the San Joaquin River Basin, ground water supplies, return flow and unregulated surplus waters and imported supplies from the Sacramento River Basin. The table also shows by hydrographic divisions and zones of service the irrigable areas to be served, the areas and water requirements served by surface water supplies, the areas and water requirements served by ground water supplies, the total water requirements and finally the deficiency, if any, between supply and requirements.

The data in Table D-12 show that the water supply obtainable in the season 1930–31, the critical season of the entire period, would have been generally adequate for all areas in the San Joaquin River Basin. The deficiency would not have exceeded 35 per cent in any hydrographic division or zone of service with the exception of zones (c) and (d) in Hydrographic Division No. 2 wherein the deficiency on 23,000 acres would have reached 50 per cent. The greater deficiency in these two zones might be met by additional minor modifications in the plan of operation, as for example an increase in the area of service in zone 2(b) and a corresponding decrease in zone 2(c). Other minor modifications might be made which would improve the plan of operation, after more detailed study and with longer records of run-off. However, it is believed that the detailed analyses presented demonstrate that the proposed ultimate State Water Plan in the San Joaquin River Basin would be adequate and dependable for providing the ultimate water requirements in the San Joaquin River Basin even over an extended dry period such as the one experienced from 1917 to 1931, inclusive.

Performance of Ultimate State Water Plan in Great Central Valley—The performance of the ultimate State Water Plan in the entire Great Central Valley for the 14-year period 1918–1931 is set forth in Table D-13. For comparison, the accomplishments based upon the study for the 11-year period 1918–1929, as previously set forth in Chapter VII, also are shown.

For the period 1918–1931, there would have been some deficiencies in 1924 and 1931. It should be noted, however, that in only one relatively small area would the deficiency have exceeded 35 per cent in any month and that in most instances the seasonal or yearly supply would have been much less than 35 per cent deficient. Occasional deficiencies of such magnitude in water supplies are not serious and can be endured.

However, if it should be desirable to have perfect supplies in years of deficient precipitation, or supplies with only small and infrequent shortages, the necessary additional water supplies could be obtained in several ways, namely by increasing the storage capacity in the Sacramento River Basin, by the use of ground water in that basin, by the importation of water from the upper Klamath and Eel rivers, or by a combination of any or all of these methods.

TABLE D-13

PERFORMANCE OF ULTIMATE STATE WATER PLAN IN GREAT CENTRAL VALLEY IN CRITICAL PERIODS 1918-1929 AND 1918-1932 OF FORTY TWO-YEAR PERIOD 1890-1932

Item	Accomplishments in period	
	1918-1929	1918-1932
1. A supply of 9,033,000 acre-feet per season, gross allowance, available in the principal streams, for the irrigation of the net area of 2, 640,000 acres of irrigable lands of all classes on the Sacramento Valley floor.	Full supply in all years	Full supply in all years except 1931. Deficiencies in that year—seasonal, 32 per cent; maximum in any area, 35 per cent.
2. A supply of 1,200,000 acre-feet per season for the irrigation of all the net area of 392,000 acres of irrigable lands, and for unavoidable losses, in the Sacramento-San Joaquin Delta.	Full supply in all years	Full supply in all years except 1931. Deficiencies in that year—seasonal and maximum monthly, 32 per cent.
3. A fresh water flow of 3,300 second-feet past Antioch into Suisun Bay for the control of salinity to the lower end of the delta.	Full supply in all years	Full supply in all years except 1931. Deficiencies in that year—seasonal, 19 per cent; maximum monthly, 32 per cent.
4. A supply of 5,342,000 acre-feet per season, gross allowance, for the irrigation of the net area of 1,810,000 acres of irrigable lands of all classes in the lower San Joaquin Valley, including 134,000 acres of foothills on the eastern side of the valley below the major reservoir units.	Full supply in all years except 1924. Seasonal deficiency of 35 per cent in supply of 896,000 acre-feet for "crop lands" in 1924.	Full supply in all years except 1924 and 1931. Deficiency in 1924 same as shown in preceding column. Deficiencies in 1931—seasonal, 26 per cent; maximum in any area, 35 per cent.
5. A supply of 4,700,000 acre-feet per season for the irrigation of a net area of 2,350,000 acres of class 1 and 2 lands on the eastern and southern slopes of the Upper San Joaquin Valley.	Full supply in all years	Full supply in all years except 1931. Deficiency in that year of 50 per cent in supply for an area of 23,000 acres dependent upon Tule River.
6. A supply of 1,570,000 acre-feet per season for the irrigation of the net irrigable area of 785,000 acres of class 1 and 2 lands lying on the western slope of the Upper San Joaquin Valley.	Full supplies in all years except 1924. Seasonal deficiency of 35 per cent in that year.	Full supply in all years except 1924 and 1931. Seasonal deficiencies in those years, 35 per cent.
7. A water supply and channel depth in the San Joaquin River sufficient to provide a navigable depth of six feet as far upstream as Salt Slough, nine miles above the Merced River.	Fully maintained in all years	Fully maintained in all years.
8. A supply of 403,000 acre-feet per year, in the Sacramento-San Joaquin Delta, for use in the San Francisco Bay Basin. Of this, 80,000 acre-feet are allotted to industrial use and 323,000 acre-feet to irrigation.	Full supply in all years except 1924. Annual deficiency of 35 per cent in 1924 in the irrigation supply.	Full supply in all years except 1924 and 1931. Deficiency in 1924 same as shown in preceding column. Maximum monthly deficiency in 1931—32 per cent in both industrial and irrigation supplies. Annual deficiency in industrial supply, 19 per cent, and in irrigation supply, 30 per cent.

Probable Frequency of Occurrence of Seasons and Consecutive Seasons of Subnormal Run-off.

The adequacy of the units for the initial and ultimate developments of the State Water Plan for the Great Central Valley has been tested through the period 1917–1931 having the lowest run-off of record. Considering the entire period 1889–1931, it is found that the units proposed would have furnished adequate and dependable supplies for all purposes and to all areas in accord with the objectives sought to be obtained in each plan of development. In the Sacramento River Basin, it has been determined from the records of run-off and precipitation from 1889 to 1931 that a surplus of water exists, over and above the ultimate water requirements in that basin, which would be adequate in amount to provide the supplemental supplies required in the San Joaquin River Basin for its ultimate requirements. Under the ultimate State Water Plan, a maximum deficiency in some instances of not to exceed 35 per cent would have occurred in only two seasons during the entire 42-year period, namely the seasons 1923–1924 and 1930–1931. Such a deficiency occurring only at infrequent intervals is not serious and it is doubtful if it would be economic to provide a perfect supply in such abnormally dry seasons.

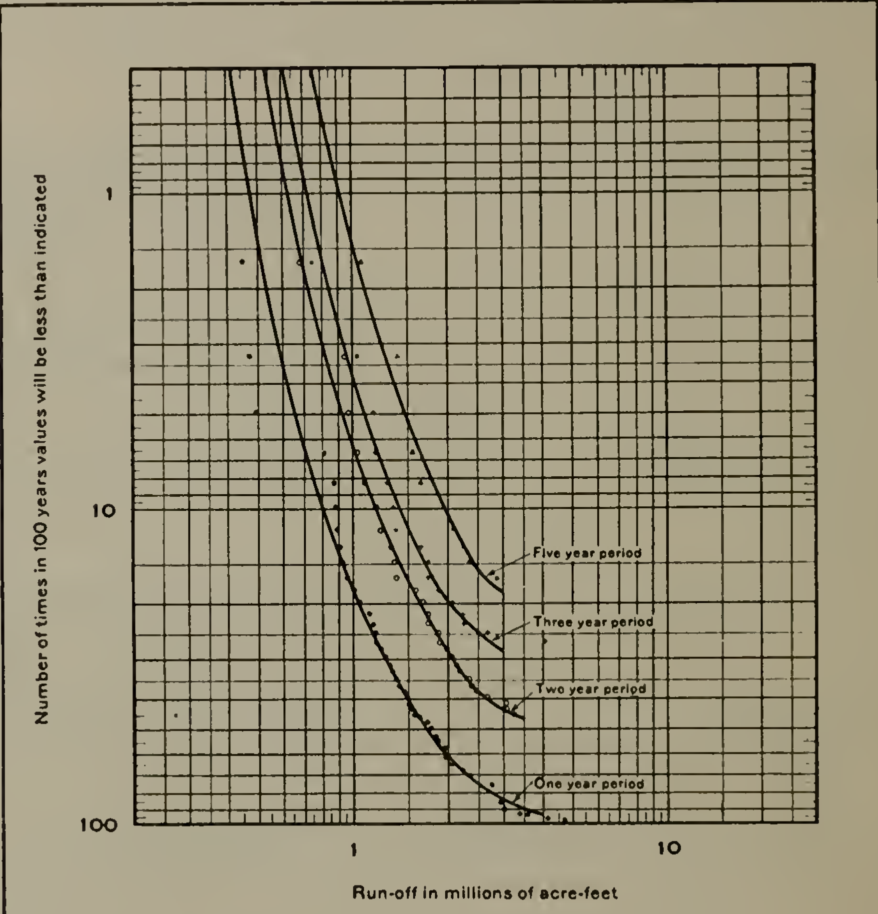
However, it is important to determine as accurately as practicable the probable frequency of occurrence of seasons and consecutive seasons of low run-off because it is such periods which determine the dependable amounts of water supply for any particular project. In order that some idea may be obtained of the magnitude and probable frequency of occurrence of low run-offs in the San Joaquin River Basin and also in the Sacramento River Basin, a study was made utilizing all available information on run-off and precipitation in the two basins. The study was divided into two parts. The first part pertains to the upper San Joaquin River on which Friant Reservoir, the initial unit in the San Joaquin River Basin, is located; and the second to the entire Great Central Valley.

Upper San Joaquin River—The data used in the analyses comprise the seasonal run-offs from October 1, 1871, to October 1, 1932, or a period of 61 years. The values used are the full natural run-offs unimpaired by upstream storage for power regulation. Values are based on actual measurements of the run-off of the San Joaquin River at Herndon from 1894 to 1901 and from measurements at Friant from 1907 to 1932. Prior to 1894, the values have been estimated by means of curves developed to show the relation between precipitation and run-off for periods of stream flow record. The estimated seasonal run-offs for the period 1889–1931 are shown in Table 5 of Chapter II and Table D-2 of this appendix; and those from 1871 to 1889 are given in Table 77, Bulletin No. 5, "Flow in California Streams," Division of Engineering and Irrigation, State Department of Public Works.

Analyses were made to estimate the probable frequency of occurrence of single seasons, and also two, three and five consecutive seasons, of low run-off. In making the analysis for the single season, or one-year periods, the seasonal values of run-off were arranged and numbered in order of increasing magnitude. The number assigned to any particular seasonal run-off value gave the frequency with which seasonal run-offs equal to or less than that particular value had occurred during the period analyzed. These numbers were then converted to values representing frequencies in 100 years. Each frequency value represented the number of times in 100 years for which the seasonal run-off would be equal to or less than the corresponding seasonal run-off. These values of seasonal run-offs were plotted on logarithmic scale paper in accord with their respective frequencies. A smooth curve interpreting the trend of the data was drawn and extended to a frequency of 0.4

in 100 years. Analyses of the mean seasonal run-offs for consecutive two, three and five-season periods were made in a similar manner. These analyses, delineated on Plate D-1, "Probable Frequencies of Mean Seasonal Run-offs from Upper San Joaquin River above Friant," are an empirical interpretation of all the available data and are believed to be indicative, at least, of the frequency of occurrence of various magnitudes of seasonal run-offs in single seasons and mean seasonal run-offs during consecutive two, three and five-season periods.

PLATE D-I



PROBABLE FREQUENCIES
OF MEAN SEASONAL RUN-OFFS
FROM
UPPER SAN JOAQUIN RIVER BASIN ABOVE FRIANT

The average frequencies with which the low run-offs of several recent seasons, and periods of consecutive seasons are likely to occur, are set forth in Table D-14.

It may be noted that a seasonal run-off of less than the 446,000 acre-feet for the season 1923–1924 would be expected to occur once in 147 years and that for the season 1930–1931, once in 80 years.

Great Central Valley—Analyses similar to those for the upper San Joaquin River above Friant were made for the entire San Joaquin River Basin, for the Sacramento River Basin and for the combined basins to estimate the probable frequencies of occurrence of seasonal run-offs of varying magnitudes. As in the case of the upper San Joaquin River, the values used in the analyses are the full natural run-offs. For these analyses, the run-offs from mountainous areas of the major streams, only, were used. Those for the minor streams and unmeasured areas were not included. They represent less than 10 per cent of the total run-off from the basins. Graphs similar to those for the upper San Joaquin River were prepared and are presented herewith as Plate D-II, "Probable Frequencies of Mean Seasonal Run-offs from Major Streams of Sacramento and San Joaquin River Basins."

TABLE D-14

FREQUENCIES OF OCCURRENCE OF SEASONAL RUN-OFFS OF PERIOD 1915-1931 FROM UPPER SAN JOAQUIN RIVER ABOVE FRIANT

Based on seasonal run-offs for 61-year period 1871-1932.
Mean seasonal run-off, 1,981,000 acre-feet.

Period (Season October 1 through September 30th)	Mean seasonal run-off for period		Average frequency of occurrence (from curves on Plate D-1)
	In acre-feet	In per cent of mean seasonal run-off for period 1871-1932	
One-year periods—			
1919-1920	1,320,000	67	Once in 3 years
1923-1924	446,000	23	Once in 147 years
1928-1929	873,000	44	Once in 8 years
1930-1931	489,000	25	Once in 80 years
Two-year periods—			
1922-1924	1,053,000	53	Once in 13 years
1929-1931	684,000	35	Once in 64 years
Three-year periods—			
1917-1920	1,365,000	69	Once in 11 years
1921-1924	1,488,000	75	Once in 9 years
1928-1931	747,000	38	Once in 83 years
Five-year periods—			
1915-1920	1,765,000	89	Once in 13 years
1919-1924	1,477,000	75	Once in 20 years
1921-1926	1,416,000	71	Once in 22 years
1926-1931	1,084,000	55	Once in 53 years

Values of frequency of occurrence of mean seasonal run-offs during several recent seasons and periods of two, three and five consecutive seasons have been taken from the developed curves on Plate D-II and are tabulated in Table D-15. These values are presented for the San Joaquin River Basin alone, the Sacramento River Basin alone, and for the combined basins.

An inspection of the figures in the table reveals that the run-off may be expected to be less than that of the season 1923–1924, the season of lowest run-off, once in 128 years for the San Joaquin River Basin, once in 130 years for the Sacramento River Basin and once in 147 years for the combined basins. The corresponding figures for the smallest mean seasonal run-off for two consecutive seasons are once in 43 years for the San Joaquin River Basin in 1929–1931, once in 26 years for the Sacramento River Basin in 1922–1924, and once in 33 years for the combined basins in 1929–1931. Similarly, the corresponding figures for the three run-off seasons 1928–1931, the driest three consecutive seasons during the period 1918–1931, are once in 62 years for San Joaquin River Basin, once in 62 years for the Sacramento River Basin, and once in 77 years for the combined basins.

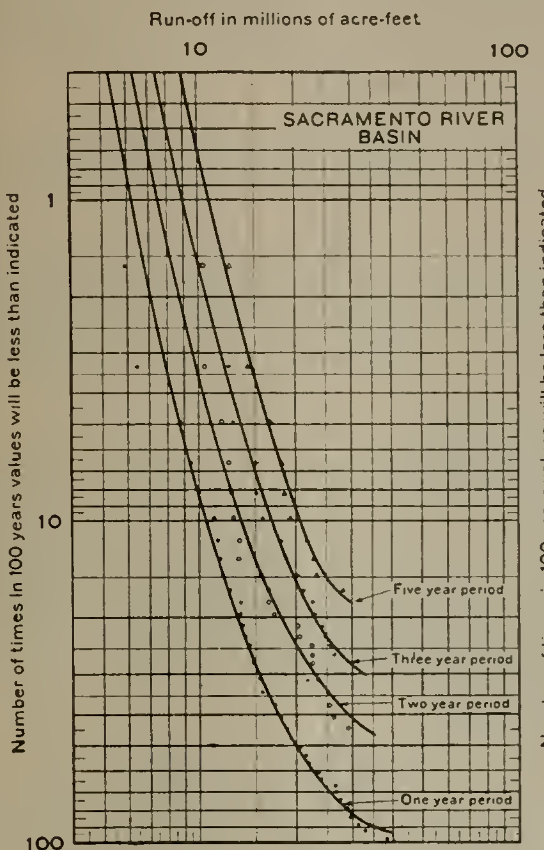
TABLE D-15

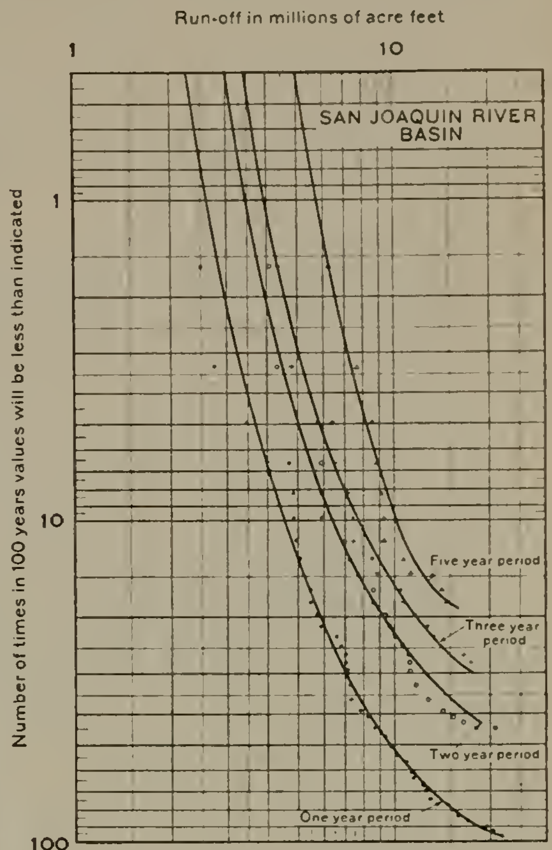
FREQUENCIES OF OCCURRENCE OF SEASONAL RUN-OFFS OF PERIOD 1916-1931 IN GREAT CENTRAL VALLEY OF CALIFORNIA

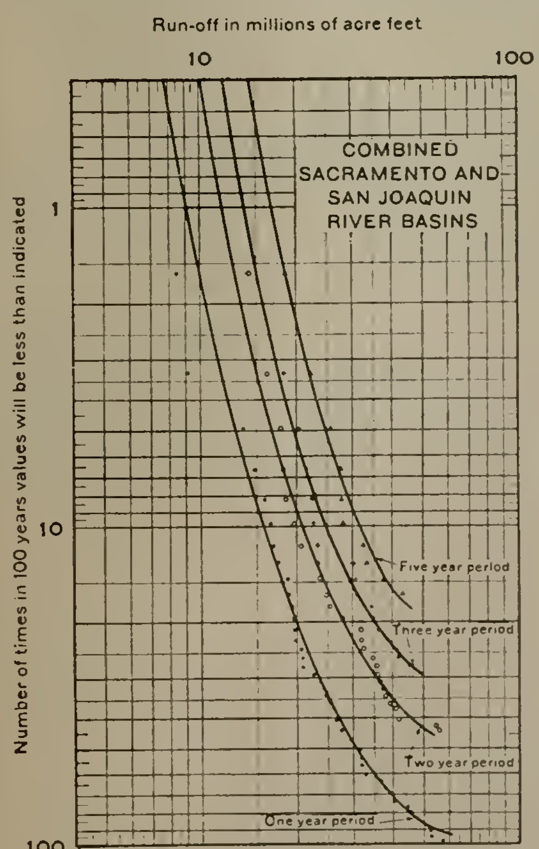
Based on Seasonal Run-offs of Major Streams for 61-year Period, 1871-1932

Period (Season October 1st through September 30th)	San Joaquin River Basin			Sacramento River Basin			Combined Sacramento and San Joaquin River basins		
	Mean seasonal run-off, 1871-1932, 10,880,000 acre-feet			Mean seasonal run-off, 1871-1932, 21,570,000 acre-feet			Mean seasonal run-off, 1871-1932, 32,450,000 acre-feet		
	Mean seasonal run-off for period		Average frequency of occurrence (from curves on Plate D-II)	Mean seasonal run-off for period		Average frequency of occurrence (from curves on Plate D-II)	Mean seasonal run-off for period		Average frequency of occurrence (from curves on Plate D-II)
	In acre-feet	In per cent of mean seasonal run-off for period 1871-1932		In acre-feet	In per cent of mean seasonal run-off for period 1871-1932		In acre-feet	In per cent of mean seasonal run-off for period 1871-1932	
One year periods—									
1919-1920	7,340,000	67	Once in 3 years	9,540,000	44	Once in 14 years	16,880,000	52	Once in 8 years
1923-1924	2,500,000	23	Once in 128 years	5,960,000	28	Once in 130 years	8,460,000	26	Once in 147 years
1928-1929	4,840,000	44	Once in 8 years	8,870,000	41	Once in 18 years	13,710,000	42	Once in 16 years
1930-1931	2,740,000	25	Once in 75 years	6,440,000	30	Once in 85 years	9,180,000	28	Once in 96 years
Two-year periods—									
1918-1920	7,280,000	67	Once in 8 years	13,320,000	62	Once in 10 years	20,600,000	63	Once in 10 years
1922-1924	5,990,000	55	Once in 12 years	10,300,000	48	Once in 26 years	16,280,000	50	Once in 21 years
1927-1929	5,960,000	55	Once in 12 years	13,680,000	63	Once in 10 years	19,640,000	61	Once in 12 years
1928-1930	5,160,000	47	Once in 18 years	11,840,000	55	Once in 16 years	17,000,000	52	Once in 18 years
1929-1931	4,120,000	38	Once in 43 years	10,630,000	49	Once in 23 years	14,750,000	45	Once in 33 years
Three-year periods—									
1917-1920	7,440,000	68	Once in 11 years	12,760,000	59	Once in 25 years	20,200,000	62	Once in 18 years
1923-1926	5,800,000	53	Once in 20 years	12,450,000	58	Once in 27 years	18,250,000	56	Once in 26 years
1928-1931	4,360,000	40	Once in 62 years	10,040,000	47	Once in 62 years	14,400,000	44	Once in 77 years
Five-year periods—									
1916-1921	8,820,000	81	Once in 16 years	16,760,000	78	Once in 19 years	25,580,000	79	Once in 18 years
1921-1926	7,980,000	73	Once in 22 years	14,280,000	66	Once in 32 years	22,260,000	69	Once in 29 years
1922-1927	7,680,000	71	Once in 26 years	15,720,000	73	Once in 23 years	23,400,000	72	Once in 24 years
1926-1931	6,330,000	58	Once in 61 years	15,050,000	70	Once in 27 years	21,380,000	66	Once in 33 years

PLATE D–II







PROBABLE FREQUENCIES

OF

MEAN SEASONAL RUN-OFFS

FROM

MAJOR STREAMS

OF

SACRAMENTO AND

SAN JOAQUIN RIVER BASINS

Summary.

The studies made to test the adequacy of the initial and ultimate major units of the State Water Plan and to estimate the probable frequency of occurrence of single and consecutive seasons of subnormal run-off such as those used in these tests, show that:

(1) The objectives sought to be accomplished by the units for the immediate initial development would have been fully met throughout the 42-year period 1889–1931.

(2) The objectives sought to be accomplished by the units for complete initial development would have been fully met throughout the 42-year period 1889–1931, except in the season of 1930–31. In that season there would have been bearable deficiencies in the irrigation supply much less than those obtained under existing conditions, for the lower San Joaquin Valley "crop lands."

(3) The objectives sought to be accomplished by the major units of the ultimate State Water Plan for the Great Central Valley would have been fully met throughout the 42-year period 1889 to 1931, except in the seasons 1923–24 and 1930–31. In these two seasons, the deficiencies occurring would be bearable, except for a limited area of foothill lands in the San Joaquin River Basin in the season 1930–31. Minor modifications in the plan of operation would reduce the deficiency to bearable amounts for these lands.

(4) Low seasonal run-offs such as those which occurred in the seasons 1923–24 and 1930–31, and in the three consecutive seasons 1928–1931, in the upper San Joaquin River watershed, and which were used in the tests of the adequacy of the Friant Reservoir unit in the initial development, may be expected to occur with average frequencies of once in 147 years, once in 80 years and once in 83 years, respectively.

(5) Low seasonal run-offs such as those which occurred in the seasons 1923–1924 and 1930–1931, and in the three consecutive seasons 1928–1931, in the Great Central Valley, and which were used in the tests of the adequacy of the ultimate State Water Plan for this valley, may be expected to occur with the following average frequencies:

Period	*San Joaquin River Basin*	*Sacramento River Basin*	*Combined Sacramento and San Joaquin River Basins*
1923–1924	Once in 128 years	Once in 130 years	Once in 147 years
1930–1931	Once in 75 years	Once in 85 years	Once in 96 years
1928–1931	Once in 62 years	Once in 62 years	Once in 77 years

APPENDIX E

THE CHEMICAL CHARACTER OF SOME SURFACE WATERS OF CALIFORNIA, 1930–1932

by

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TABLE OF CONTENTS

THE CHEMICAL CHARACTER OF SOME SURFACE WATERS OF CALIFORNIA, 1930–1932

Introduction.

A comprehensive study of the chemical character of surface waters in California was made by Van Winkle and Eaton in 1906–8 and reported in United States Geological Survey Water-Supply Paper 237, published in 1910. The major part of this work consisted of complete mineral analyses of 10-day composites of daily samples collected over a period of a year at 33 points on 30 streams, with a few analyses of single samples.

The extensive development of irrigation since 1908, including the building of dams for storage reservoirs, has made a decided change in the character of some of the waters. In some of the drainage basins, however, comparatively little change has taken place.

In order to obtain some indication of the present value of the older analyses, a brief preliminary survey was made in 1930 as part of the cooperative work on waters being conducted by the United States Geological Survey and the State Department of Public Works. In this survey 145 samples were collected at 69 points on 56 streams. During the period from July 20, 1931, to January 1, 1932, samples were collected about twice a week from the Sacramento River at the M Street Bridge in Sacramento, and from January 1 to July 13, 1932, samples were collected on the average once a week. Altogether 71 samples were taken at this point. All samples were sent to Washington for analysis.

The samples collected in 1930 were collected by or under the direction of H. D. McGlashan, district engineer of the Geological Survey, at San Francisco, for the northern part of the State, and by F. C. Ebert, of the Los Angeles office of the Geological Survey, for the southern part of the State. The samples from the Sacramento River in 1931–32 were collected under the direction of Edward Hyatt, State engineer of California. Mr. Hyatt and Mr. McGlashan furnished discharge data, information as to the general conditions at the sampling points, and explanations of some of the results shown by examination of the samples.

The examination of the single small samples collected in 1930 was little more than is covered by the so-called "preliminary examination"[1] made to determine the approximate composition of samples received in the laboratory. This included regular determinations of carbonate, bicarbonate, chloride, nitrate, and hardness by the soap method, turbidimetric determinations of calcium and sulphate, and approximate determination of boron. Calcium, magnesium, and sulphate were determined in the regular way in several samples that contained large enough quantities to be determined in the small volume of water available. These partial analyses are almost as valuable as complete analyses for single samples of surface waters. Such occasional samples can not show the character of a water throughout the year, but they give

[1] Collins, W. D., Notes on practical water analysis: U. S. Geol. Survey Water-Supply Paper 596-H, p. 238, 1927.

reasonably clear indications of changes or lack of changes in composition of the water since the earlier work was done.

The samples from the Sacramento River at Sacramento were analyzed according to the methods regularly used by the Geological Survey for the complete analysis of the mineral content of waters.[2] All the usual constituents present in determinable amounts were recorded, and in addition approximate determinations of boron were made. The results are of the same degree of reliability as those reported in Water-Supply Paper 237, with possibly some slightly greater accuracy on account of developments in analytical methods since the earlier work. In the analyses made in 1931–32 potassium was determined and several of the other determinations were made more carefully. Although the results do not cover the composition of the river water completely throughout the year, they do indicate the probable range in composition of the water. The earlier results had the advantage of including a small sample of water for each day in the year. When these small samples were made into composites covering 10 days the analysis gave an average composition of the water for the period covered.

The results obtained in 1930 are given in Table E-2. Those obtained for the complete analyses of samples from the Sacramento River in 1931–32 are given in Table E-3. Some comparisons between the earlier and later results at a few points are given in Table E-1.

Rainfall and discharge in 1906–8 and 1930–32.

Climatic records show that, in general, years of maximum precipitation have been accompanied or closely followed by years of high discharge. The investigation of 1906–8 was made at a time when the rainfall was for the most part considerably above the normal. The discharge of the Sacramento and Tuolumne Rivers was much above the normal, and records for other rivers in the State show the same trend. The samples taken in 1930 were collected during the period of low rainfall. In the two years prior to 1930 there had been a deficiency of 17 inches of rain, and during 1930 the rainfall was 7 inches below the normal, making a total deficiency of 24 inches for the 3-year dry period. With few exceptions the rivers of the State had discharges decidedly below normal during most of 1930.

The average rainfall in 1931 was only 1.15 inches below the normal. A deficiency occurred between January and July, but for the remainder of the year it was mostly above the normal, particularly in December, when it was two to three times the monthly normal at many weather stations. During the first 7 months in 1932 there was a total deficiency of slightly over 4 inches. The analyses of the Sacramento River in 1931–32 were, therefore, made during a period of nearly normal precipitation. The discharge at Sacramento, however, was considerably below normal during the summer of 1931, owing to the heavy draft for irrigation.

Because of changing conditions with reference to the importance of different streams and the need for information concerning their discharges, there is a considerable difference between the sampling points in 1930 and those for which analyses were made in 1906–8. Strict comparisons between the two periods are possible only for the stations

[2] Collins, W. D., *op. cit.*

that are identical. For some of the others reasonably accurate comparisons can be made, but for some stations the only value of the new figures lies in their own worth as indicating roughly what kind of water is now available.

Identical sampling points, 1906–8 and 1930.

Of the 145 samples collected for analysis in 1930 only 24, taken at 12 places on 10 rivers, came from points identical with the sampling places of the earlier survey. From the analyses of the samples from identical sampling points the composition of the waters of the Yuba River at Smartsville, the Kern River near Bakersfield, Arroyo Seco near Soledad, and the San Gabriel River at Asusa seemed to be about the same as found by Van Winkle and Eaton.

The Feather River at Oroville, the American River at Fairoaks, the Stanislaus River at Knights Ferry, and the Santa Ana River near Mentone showed appreciable changes. They appeared to contain less chloride and sulphate in 1930, even though the discharge at several stations was but one-fourth to one-half that at corresponding periods in 1906–8. The sulphate, chloride, total hardness, and discharge of these rivers for the two periods are shown in Table E-1. The results for 1930 represent single samples on the dates shown. Those for 1906 and 1908 represent 8 to 23 day composites. The difference for the Stanislaus River may be accounted for in part by the passage of the water through the Melones Reservoir, which was constructed in 1926.

TABLE E-1

PARTIAL ANALYSES OF SOME CALIFORNIA SURFACE WATERS AT DIFFERENT PERIODS

	Sulphate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$	Discharge in second-feet
Feather River at Oroville:				
May 8, 1930	4	.3	33	6,520
April 18-May 10, 1906	6.9	7.8	40	18,871
August 27, 1930	3	2.0	44	1,960
September 5-10, 1906	22	6.1	38	1,978
American River at Fair Oaks:				
May 8, 1930	1	.4	16	4,000
May 1-10, 1906	8.6	3.9	34	16,865
August 26, 1930	6	4.0	27	173
August 21-30, 1906	15	4.9	53	648
Stanislaus River at Knights Ferry:				
May 7, 1930	3	.4	20	1,420
May 2-10, 1906	17	3.9	30	9,264
Santa Ana River near Mentone:				
June 9, 1930	7	3.0	62	52
June 1-10, 1906	16	7.6	81	129
June 8-17, 1908	30	4.0	108	61.4

NOTE.—(Analyses in 1930 by S. K. Love; in 1906 and 1908 by Walton Van Winkle and F. M. Eaton. Analytical results in parts per million).

A sample from the Tuolumne River at La Grange, collected in May 1930, contained about the same quantity of mineral matter as was found in 1906; but a single sample in September was much lower in dissolved solids and particularly in calcium, sulphate, and chloride.

The discharge in May 1930 was about one-fifth that of 1906, but in September 1930 it was nearly 30 times greater, this being one of the few exceptions to the general condition of low flow in 1930. The greater discharge was probably due to releases from the Don Pedro Reservoir, constructed about 1923.

A single sample from the Ventura River near Ventura in May 1930 had much more calcium, magnesium, sulphate, and chloride and slightly less bicarbonate than were found by Van Winkle and Eaton. The quality of total solids was about 720 parts per million, which is higher than was reported for any composite sample during 1908.

Nearly identical sampling points in 1906–8 and 1930.

Fourteen samples were collected in 1930 from four rivers at points only short distances from the sampling points in 1906–8, and it seems safe to compare directly the results of the analyses. Five samples were taken between June and October from the Sacramento River at Verona, about 20 miles upstream from Sacramento, the sampling point during the earlier survey. The concentration seems to have been slightly less on days in June, September, and October but considerably more in July and August than at corresponding periods in 1906–8. No discharge figures are available for the Sacramento River at Sacramento or Verona during 1906–8, but the records obtained at Red Bluff, about 200 miles upstream from Sacramento, show that the discharge at that point was approximately twice as great in 1906–8 as at similar periods in 1930. The flow at Verona during the summer is reported to be made up largely of return water from rice irrigation.

Six samples were taken over a period of 6 months from the San Joaquin River near Vernalis, a short distance upstream from Lathrop. The difference in concentration was much greater between May and July 1930 than during a similar period in 1906. The analyses made in 1908 showed greater variation than those of 1906, but none made in May of either year showed as much dissolved matter as the sample collected May 16, 1930. There are no discharge records available for the San Joaquin River at Lathrop during 1906–8. The amount of irrigation, and consequently the amount of return water, above Vernalis was much greater in 1930 than in 1906–8.

The Merced River at Exchequer appeared to contain in 1930 less calcium, sulphate, and chloride than at Merced Falls, a short distance downstream, in 1906. The discharge was about one-fifth as great at Exchequer in 1930 as at Merced Falls in 1906. The water collected from the river at Exchequer in 1930 had passed through the Exchequer Reservoir, constructed about 1926.

One sample from the Owens River at Zurich in 1930 indicates little or no change. Calcium and magnesium were slightly higher than in 1908, but bicarbonate, sulphate, and chloride were a little lower. The discharge was about the same at both times.

Rivers sampled at different points in 1906–8 and 1930.

Among the 51 samples collected from 17 stations on 10 rivers at points other than those selected for the survey made by Van Winkle and Eaton, 18 came from 5 stations on the Sacramento River and 12 from 3 stations on the San Joaquin River. Both rivers showed a considerable range in amount of dissolved matter, but the range was greater for the San Joaquin. The hardness ranged from 50 to 132 parts per million in the Sacramento and from 3 to 169 parts per million in the San Joaquin. The total solids ranged from about 70 to 200 parts per million in the Sacramento and from about 20 to 450 parts per million in the San Joaquin. No discharge figures are available for any of the stations on the Sacramento River in 1906–8 except at Red Bluff; but records for three tributaries, the Feather, American, and Yuba Rivers, show that the discharge of these streams was about three times as great in 1906–8 as at corresponding periods in 1930. Records are similarly lacking for the San Joaquin River, but records for the main tributaries show that their discharge was three to five times as great in 1906 and about one-half as great in 1908 as at similar periods in 1930.

Two samples collected in 1930 from the Mokelumne River at Mokelumne Hill were less concentrated than those taken in 1906 at Clements, about 25 miles downstream. The discharge was about four times as great at Clements in 1906 as at Mokelumne Hill in 1930.

A single sample collected in 1930 from the San Benito River at Hernandez contained about five times as much magnesium as calcium, whereas in 1906 the concentrations of magnesium and calcium at Hollister, about 50 miles downstream, were nearly the same. No analyses of this or other tributaries are available, however, to indicate the character of the water that flows into the San Benito between Hernandez and Hollister. No discharge figures are available for either period.

The concentration of the Salinas River near San Miguel was very much greater than at Paso Robles, a few miles above San Miguel, at a similar period in 1908. The greatest increase was in sodium, sulphate, and chloride. The change was probably brought about by the Estrella River, which flows into the Salinas between the two sampling points. Analyses of the Estrella River by Van Winkle and Eaton show that it was higher in all mineral constituents except bicarbonate than the Salinas at Paso Robles, which might account for the increased concentration near San Miguel.

The San Antonio River at Pleyto contained in 1930 less dissolved matter, particularly calcium, bicarbonate, and sulphate, than near Bradley at a corresponding period in 1908. The discharge and concentration of the San Antonio River fluctuate so greatly, however, that no attempt should be made to predict the present character of the water from a single sample.

Six samples taken in 1930 from the Santa Ana River near Prado and two at Riverside Narrows, near Arlington, indicate that the concentration at these points was considerably greater than near Corona, a short distance away, in 1908. Because of numerous diversions for irrigation and the subsequent return of the water to the river, comparisons of analyses are not trustworthy except when made from samples collected at the same point.

Analyses of samples from other rivers studied in 1906–8—the Santa Ynez, the San Luis Rey, and the Mojave—are not comparable because of change of sampling points.

Samples from rivers not studied in 1906–8.

The remaining 86 samples were collected at 35 stations on 35 streams none of which were studied by Van Winkle and Eaton. Some of these streams are worthy of mention because of their size, location, and unusual composition.

A single sample from the Calaveras River and two from the Tule River indicate that they are more concentrated than the other tributaries of the San Joaquin River.

Piru and Sespe Creeks, the chief tributaries of the Santa Clara River, carry large and variable quantities of dissolved matter. Piru Creek was especially high in sulphate, its content ranging from 508 parts per million in May 1930 to 1508 parts per million in September. Sespe Creek, although less concentrated than Piru Creek, doubled in dissolved matter between May 20 and June 18 and again between September 20 and October 27, with a rapid lowering of concentration between June 18 and July 23. Both Piru and Sespe Creeks contain large amounts of boron, which is characteristic of both surface and ground waters in this region.[3]

Analyses of single samples from several small streams in the southern part of the State indicate that they contain chiefly calcium and bicarbonate, with relatively large amounts of sulphate. Although the discharge is ordinarily small, many of these streams are important because of diversions for irrigation, power, and other uses. They include Mill, Lytle, and Warm Creeks and the San Jacinto River, in the Santa Ana Basin; Tujunga Creek and Arroyo Seco, in the Los Angeles Basin; San Dimas Creek, in the San Gabriel Basin; and the San Diego and Santa Margarita Rivers. Dissolved solids ranged from about 120 parts per million in Mill Creek near Craftonville to 640 parts per million in the Santa Margarita River at Fall Brook.

Single analyses for several streams in the northern part of the State indicate they are higher in dissolved mineral matter than most of the rivers in the Sacramento Basin. These include Conn Creek and the Napa and Coyote Rivers, flowing into San Francisco Bay; the Pit River and Putah Creek, in the Sacramento Basin; and the Trinity River, which flows into the Klamath River, in the north Pacific slope area. The magnesium content of the Trinity River and of Conn and Putah Creeks is greater than the calcium content. This condition is frequently found in rivers along the coast. Total dissolved solids ranged from about 100 parts per million in the Trinity River at Lewiston to about 400 parts per million in Putah Creek near Winters.

Sacramento River in 1931–32.

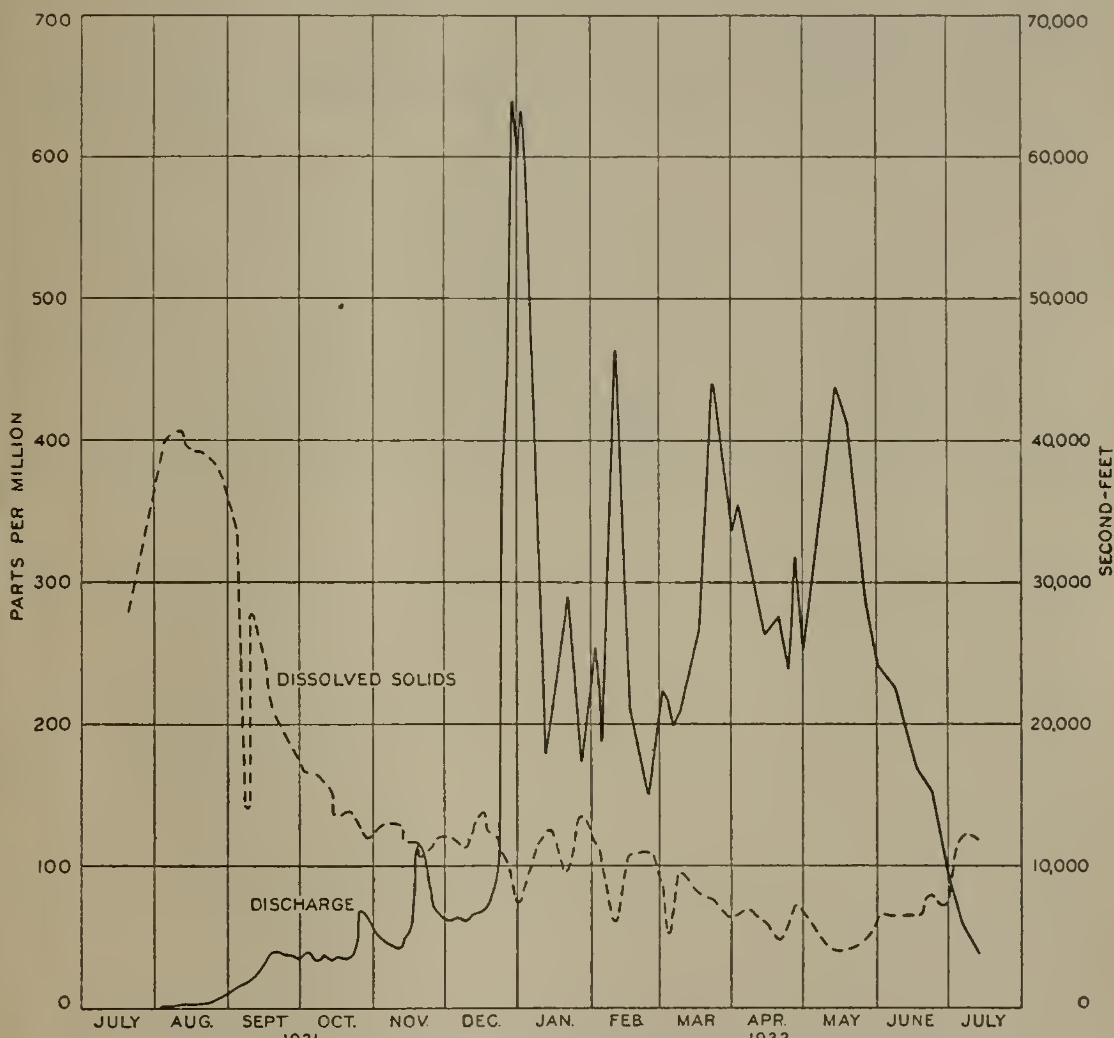
The Sacramento River at Sacramento in 1931–32 carried appreciably more dissolved mineral matter than was found by Van Winkle and Eaton in 1906 or in 1908. The average quantities for the three periods were 153, 124, and 113 parts per million, respectively. The range in concentration of the single samples in 1931–32 was greater than the range for the composite samples in either 1906 or 1908.

The quantities of dissolved solids in the samples for 1931–32 are plotted on Plate E-I, together with the mean daily discharge of the

[3] Scofield, C. S., and Wilcox, L. V., Boron in irrigation waters: U. S. Dept. Agr. Tech. Bull. 264, November 1931.

river at Sacramento. Actual discharge measurements are not made at Sacramento because of tidal influence at low stages. The plotted discharge figures have been computed[4] by using the record at Verona, 20 miles upstream, and making allowance for the measured inflow and draft between that station and Sacramento. The plotted results show that in general the concentration was lower at times of high discharge.

PLATE E–I



Dissolved solids and discharge of Sacramento River at Sacramento, California, 1931–32.

Between September 3 and 8, 1931, the concentration of dissolved solids dropped from 322 to 141 parts per million, with an increase in discharge from 1530 to 1840 second-feet. The discharge on September 10 was 2300 second-feet, but the concentration of dissolved solids increased to 284 parts per million. This was presumably caused by irrigation return water. After September 23 the concentration of dissolved solids remained below 200 parts per million until the end of the collection of samples, in July 1932. The minimum concentration found was 42 parts per million, May 18, 1932.

[4] Stafford, H. M., Sacramento-San Joaquin Water Supervisor's Report, 1931, p. 25, California Dept. Public Works, Div. Water Resources.

The chloride content changed in a general way with the total dissolved solids. After September 23, 1931, it was from 3 to 30 parts per million. The maximum chloride was found in the sample collected August 27, 1931, which had 86 parts per million. None of these results suggested any contamination from encroachment of sea water. This agrees with the figures for chloride content of the Sacramento River at Sacramento as determined by the California Department of Public Works in the salinity investigations[5] in the Sacramento-San Joaquin Delta region during 1931.

[5] Variation and control of salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay, 1931: California Dept. Public Works, Div. Water Resources, Bull. 27, pp. 365–375, 1932.

Summary.

The analyses made in 1930 indicate that the concentration of dissolved matter in certain rivers in the Sacramento, San Joaquin and Santa Ana Basins, particularly the Feather, American, Stanislaus and Santa Ana rivers, was considerably less than found by Van Winkle and Eaton, notwithstanding the fact that the discharge of these rivers was much less than in 1906–8.

The Yuba, San Gabriel, and Owens rivers and Arroyo Seco near Soledad appeared to have changed very little in concentration, but the Ventura River contained more dissolved matter than at any time in 1908.

The brief study of 1930, though it covered more streams than the earlier survey and included several stations on some of the large rivers, is wholly inadequate for estimating the average mineral content of any of the streams. The results indicate, however, that for some of the streams the older analyses may still be accepted with confidence. They also show the probability of sudden and large changes in the mineral content of some surface waters in the southern part of the State.

The complete analyses of 71 samples from the Sacramento River at Sacramento in 1931–32 show higher concentration of dissolved solids than in 1906–8 but do not indicate the salt-water encroachment.

TABLE E-2

*PARTIAL ANALYSES OF SOME SURFACE WATERS OF CALIFORNIA, 1930

(Analytical Results in Parts per Million)

Location	Date	Discharge in second-feet	Total dissolved solids (calculated)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K) (calculated)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4) (by turbidity)	Chloride (Cl)	Nitrate (NO_3)	Borate (BO_3)	Total hardness as $CaCO_3$ (calculated)
	1930												
San Diego River near Santee	June 8	1.2	440	44	24	86	9.8	153	a40	150	0.15	0.1	208
San Dieguito River at Lake Hodges	June 8	----------	298	36	19	49	0	212	34	46	.10	(b)	168
San Luis Rey River at Bonsall	June 7	7	527	68	27	89	14	253	a74	118	.20	.2	281
Santa Margarita River at Fall Brook	June 7	5.5	634	74	23	127	14	275	a145	111	.20	.5	279
San Juan Creek at San Juan Capistrano	June 8	0	316	61	17	25	0	174	a92	26	.53	.1	222
Santa Ana River near Mentone	June 9	52	96	c21	----------	14	0	98	7	3.0	.10	(b)	a62
	July 10	43	109	c15	----------	16	0	106	10	4.0	.20	(b)	a69
Santa Ana River at Riverside Narrows near Arlington	July 10	32	446	88	19	51	0	313	a28	81	12	.1	298
	Nov. 12	33	471	85	19	62	0	310	a58	71	13	.5	290
Santa Ana River at Auburndale Bridge	July 10	40	453	76	24	54	8.9	234	a68	88	5.0	.4	288
Santa Ana River near Prado	June 8	70	485	76	19	75	6.9	251	a93	80	4.2	.3	268
	July 10	50	344	62	17	40	6.9	207	a39	62	4.2	.3	225
	Aug. 7	35	507	77	23	77	0	272	a77	107	1.0	.3	287
	Sept. 11	49	484	74	22	71	5.9	232	a74	105	6.4	.3	275
	Oct. 8	60	488	80	22	66	6.9	233	a74	103	10	.3	290
	Nov. 12	80	479	80	20	67	0	271	a71	88	9.0	.6	282
Mill Creek (tailrace No. 1, power house) near Craftonville	June 18	5.8	122	32	6.8	2.3	3.0	105	18	2.0	.36	(b)	108
	July 10	3.1	154	35	7.8	10	0	135	28	c1.5	.10	(b)	119
Warm Creek near Colton	July 10	19	262	52	10	29	0	186	25	26	22	.1	171
Lytle Creek at Fontana	June 7	27	184	50	8.5	5.6	0	173	24	3.0	1.0	(b)	160
San Jacinto River near San Jacinto	June 16	0	96	22	3.5	10	0	96	3	7.0	.10	(b)	69
Gage Canal at Tippecanoe Avenue, near San Bernardino	July 10	----------	186	43	8.3	13	0	151	28	10	3.5	(b)	142
San Gabriel River at Azusa	June 6	95	190	48	12	4.1	6.9	168	25	2.0	.10	.2	169
San Gabriel River at Paso de Bartolo	June 6	16	218	56	14	3.1	0	205	26	6.0	.57	.2	197
	July 9	45	226	54	11	15	0	212	28	6.0	.64	.1	180
	Aug. 6	24	269	68	14	10	0	244	a33	8.0	4.7	.3	227
	Sept. 5	14.6	260	64	13	14	0	247	a26	9.0	2.3	.1	213
	Oct. 6	22	266	67	14	11	5.9	234	30	8.0	4.7	.2	225
	Nov. 12	22	273	67	15	11	0	243	a35	9.0	5.1	.2	229
San Dimas Creek near San Dimas	June 10	2.4	335	59	26	26	9.8	271	a51	13	.20	.2	254
Los Angeles River, Riverside Drive and North Figueroa St., Los Angeles	June 18	----------	815	120	37	118	0	359	a185	150	12	.6	452
	July 8	----------	414	58	17	66	3.9	209	a128	32	2.3	.8	215
	Nov. 12	----------	349	71	15	30	0	236	a73	13	21	.2	239

Los Angeles River, Riverside Drive and Catalina St., Los Angeles	Aug. 9	....	349	52	13	55	0	194	[a]101	27	1.8	2.5	183
	Sept. 10	....	371	55	16	54	0	199	[a]114	26	2.8	1.0	203
	Oct. 6	....	550	80	24	77	0	249	[a]193	39	7.2	2.0	298
Tujunga Creek near Sunland	June 17	1.5	301	54	17	33	4.9	243	[a]53	10	.20	.6	205
Arroyo Seco near Pasadena	June 18	1.3	251	52	17	16	12	206	[a]33	8.0	.10	.4	200
Piru Creek at Piru	May 20	....	976	116	60	113	19	190	[a]508	46	.10	10	536
	June 17	....	1,283	144	75	164	0	282	[a]675	64	.10	10	668
	July 23	....	2,418	218	149	334	0	308	[a]1,418	110	.10	40	1,156
	Aug. 22	....	2,491	238	150	338	0	347	[a]1,443	113	.25	35	1,210
	Sept. 20	....	2,590	237	161	352	0	335	[a]1,508	123	.05	40	1,253
	Oct. 27	....	1,851	183	114	243	0	284	[a]1,049	91	.05	15	925
Sespe Creek at Sespe	May 20	....	616	82	32	74	0	145	[a]295	51	.20	5.0	336
	June 18	....	1,194	198	49	115	0	219	[a]653	61	.10	6.0	696
	July 23	....	521	73	21	82	8.9	167	[a]151	97	.30	15	269
	Aug. 22	....	584	72	19	113	0	196	[a]144	136	.70	20	258
	Sept. 20	....	610	74	21	116	7.9	170	[a]160	144	.10	30	271
	Oct. 27	....	1,192	174	48	151	0	206	[a]556	151	.05	15	632
Ventura River at Foster Memorial Park dam, near Ventura	May 20	....	719	127	38	59	0	279	[a]294	47	.10	1.5	473
Santa Ynez River near Lompoc	May 20	3.3	908	106	73	91	5.9	320	[a]337	99	.50	1.2	564
Sisquoc River near Sisquoc	May 20	3.7	745	104	63	46	6.9	288	[a]328	21	.05	.3	518
Cuyama River near Santa Maria	May 19	2.2	3,050	412	202	220	9.8	170	[a]1,893	150	.38	2.0	1,858
Guadalupe Creek at Guadalupe	May 7	4.2	291	48	30	12	9.8	232	44	12	([b])	.5	243
Salinas River at State highway bridge just above Nacimiento Creek, near San Miguel	May 1	....	798	85	44	135	18	304	[a]236	114	.58	1.3	393
San Antonio River at Pleyto	May 19	2.2	270	[c]36	....	3.8	15	150	[a]67	16	([b])	.1	[a]232
Arroyo Seco near Soledad	May 1	43	223	52	14	6.3	4.9	158	50	8.0	([b])	([b])	187
San Benito River just below Hernandez Valley, at Hernandez	May 2	0	589	23	121	5.3	41	531	25	26	.20	4.0	554
Coyote River near Madrone	May 7	6	327	56	27	22	9.8	236	55	23	.15	.4	251
Whitewater River Canal at Whitewater	June 16	....	248	53	14	17	3.9	197	[a]46	7.0	1.0	([b])	190
West Fork of Mojave River at Hesperia	June 10	....	143	30	7.0	14	0	130	14	9.0	.20	([b])	104
Big Rock Creek at Valyermo	June 16	....	212	48	14	9.4	3.0	193	[a]29	3.0	.36	.4	177
Owens River at Zurich, near Big Pine	Aug. 2	232	228	36	7.3	40	7.9	157	40	17	.20	.9	120
Bishop Creek at tailrace, plant No. 5, near Bishop	Aug. 2	....	25	....	....	....	0	20	4	[c]1.5	.05	([b])	[a]7.5
Rush Creek at State highway bridge near Mono Lake	Aug. 3	....	40	[c]10	....	5.5	0	36	4	3.0	.05	.1	[a]26
West Walker River near Coleville	Aug. 3	....	53	[c]11	....	10	0	53	4	2.0	.10	.2	[a]28
Kern River near Bakersfield	May 8	946	103	[c]12	....	20	11	64	14	7.0	.10	.2	[a]51
	Aug. 2	206	83	[c]14	....	22	0	66	12	7.0	.05	.2	[a]28
Tule River near Porterville	May 11	153	106	[c]13	....	9.6	0	110	3	6.0	.10	([b])	[a]81
	Aug. 1	.4	218	48	8.7	25	0	223	8	13	.10	.1	156
Kaweah River near Three Rivers	May 11	592	40	[c]10	....	8.7	12	20	1	[c]1	.05	([b])	[a]20
	Aug. 1	46	53	[c]14	....	8.3	0	49	4	4.0	.10	([b])	[a]32
Kings River at Piedra	May 12	2,330	18	[c]5	....	2.1	0	16	2	[c]1	([b])	([b])	[a]12
	Sept. 6	136	40	[c]6	....	9.8	0	28	3	8.0	.05	.1	[a]16
San Joaquin River near Friant	May 12	1,280	25	[c]3	....	7.0	0	20	1	4.0	.10	([b])	[a]8
	Sept. 6	1,050	25	[c]3	....	8.0	0	19	2	4.0	.10	([b])	[a]6.0

TABLE E-2—Continued

*PARTIAL ANALYSES OF SOME SURFACE WATERS OF CALIFORNIA, 1930

(Analytical Results in Parts per Million)

Location	Date	Discharge in second-feet	Total dissolved solids (calculated)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K) (calculated)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulphate (SO_4) (by turbidity)	Chloride (Cl)	Nitrate (NO_3)	Borate (BO_3)	Total hardness as $CaCO_3$ (calculated)
	1930												
San Joaquin River near Mendota	July 23	....	20	[c]1	....	7.2	0	16	1	3.0	.20	([b])	[a]3
	Aug. 22	....	25	[c]3	....	8.3	0	17	2	4.0	1.1	.1	[a]4.5
	Sept. 26	....	26	[c]2	....	2.0	0	20	2	4.0	.30	([b])	[a]20
	Oct. 24	....	24	[c]2	....	2.7	0	19	2	3.0	.10	([b])	[a]16
San Joaquin River near Newman	May 14	370	135	[c]14	....	25	0	85	14	27	.88	.1	[a]69
	June 14	210	189	[c]17	....	44	3.9	110	18	40	.80	.1	[a]76
	July 18	180	153	[c]20	....	63	0	97	12	34	.67	.1	[a]63
	Aug. 22	200	139	[c]15	....	36	0	96	12	26	.58	.1	[a]51
	Sept. 26	200	146	[c]14	....	36	0	107	12	24	.87	.1	[a]57
	Oct. 24	160	461	38	18	107	0	139	[a]78	145	2.5	.3	169
San Joaquin River near Vernalis	May 16	1,390	205	[c]19	....	37	0	102	23	55	.20	.1	[a]106
	June 14	3,430	39	[c]5	....	6.9	0	35	4	[c]2	.55	.1	[a]21
	July 18	1,210	162	[c]14	....	31	0	79	20	42	.60	.1	[a]78
	Aug. 15	955	168	[c]28	....	28	0	96	10	45	1.7	.1	[a]93
	Sept. 26	1,540	179	[c]18	....	34	0	84	22	48	1.1	.1	[a]86
	Oct. 23	1,570	222	26	12	38	0	92	28	65	1.6	.2	114
Fresno River near Knowles	May 13	50	51	[c]7	....	13	0	39	2	10	.10	([b])	[a]21
	July 31	.1	144	[c]20	....	35	0	76	5	46	.20	.1	[a]57
Merced River at Exchequer	May 14	1,400	19	[c]4	....	1.9	0	19	1	[c]1	.05	([b])	[a]14
	Sept. 7	1,260	36	[c]6	....	6.0	0	32	3	3.0	.55	([b])	[a]21
Tuolumne River above La Grange Dam, near La Grange	May 7	1,780	31	[c]7	....	4.9	0	29	4	[c].5	.15	([b])	[a]18
	Sept. 7	1,840	38	[c]3	....	12	5.9	25	4	1.0	.10	([b])	[a]9
Stanislaus River near Knights Ferry	May 7	1,420	32	[c]7	....	4.6	1.0	30	3	[c].4	.10	([b])	[a]20
	Sept. 7	781	55	[c]9	....	6.5	0	55	4	2.0	.05	([b])	[a]38
Calaveras River at Jenny Lind	May 8	46	125	28	10	2.7	0	110	12	10	.20	.1	111
Mokelumne River near Mokelumne Hill	May 8	1,090	21	[c]5	....	5.1	0	13	5	2.0	([b])	([b])	[a]7.5
	Oct. 11	60	50	[c]9	....	7.8	0	38	3	9.0	.05	([b])	[a]30
Cosumnes River at Michigan Bar	May 8	370	35	[c]11	....	5.9	4.9	27	2	1.0	([b])	([b])	[a]21
	Aug. 26	1.6	61	[c]10	....	9.3	0	61	5	2.0	.20	([b])	[a]38
Sacramento River at Kennett	Aug. 29	2,820	86	[c]12	....	12	0	90	3	4.0	.45	.2	[a]56
Sacramento River near Red Bluff	July 15	3,320	95	[c]14	....	17	0	85	7	8.0	.92	.1	[a]51
	Aug. 12	3,060	90	[c]16	....	1.0	0	90	5	5.0	.15	.1	[a]84
	Sept. 16	3,400	84	[c]12	....	11	0	83	5	5.0	.10	.3	[a]57
	Oct. 14	3,490	86	[c]12	....	14	0	81	6	6.0	.10	.2	[a]51

Sacramento River at Colusa	June 10	3,470	95	c15		9.9	0	89	9	5.0	.20	.1	*68
	July 15	1,980	105	c10		13	0	98	10	6.0	.10	.1	a72
	Aug. 12	1,680	129	c24		22	3.9	102	6	18	.15	.1	a74
	Sept. 16	2,950	95	c16		9.3	0	85	11	5.0	.20	.2	a68
	Oct. 14	3,570	94	c14		12	0	91	7	5.0	.10	.2	a62
Sacramento River at Knights Landing	June 10	3,580	127	c14		15	0	101	18	11	.15	.2	a84
	July 14	1,820	145	c20		19	0	119	15	15	.48	.2	a93
	Aug. 11	1,540	204	c24		37	0	137	a25	34	.25	.3	a105
	Sept. 15	3,300	131	c16		18	0	101	22	10	.10	.2	a81
	Oct. 13	3,620	108	c12		12	0	91	14	8.0	.10	.2	a75
Sacramento River at Verona	June 11	8,400	67	c13		6.0	0	61	7	4.0	.10	.1	a50
	July 18	2,640	167	c24		23	0	118	13	31	.69	.1	a104
	Aug. 13	2,640	148	c32		9.0	0	132	20	6.0	.25	.2	a118
	Sept. 17	5,780	96	c12		13	0	81	10	9.0	.30	.1	a62
	Oct. 15	6,520	79	c14		11	0	78	4	5.0	.55	.1	a52
Sacramento River at Courtland	Aug. 7		214	c30		29	0	133	20	46	.77	.4	a132
	Sept. 18		170	c18		25	0	115	20	28	.87	.2	a100
	Oct. 16		105	c12		15	0	88	6	14	.42	.1	a66
Pit River at Bieber	Aug. 28		294	c20		70	3.0	263	30	16	1.2	.8	a123
Feather River at Oroville	May 8	6,520	44	c10		3.9	0	45	4	c.3	.10	(b)	a33
	Aug. 27	1,960	63	c12		7.0	0	63	3	2.0	1.9	.1	a44
Feather River at Nicolaus	June 11	3,610	59	c7		7.5	0	55	7	2.0	.20	(b)	a39
	July 16	718	83	c14		8.5	0	79	7	4.0	1.0	(b)	a60
	Aug. 13	814	84	c20		7.7	4.9	74	6	3.0	.51	.1	a63
	Sept. 17	1,990	74	c10		7.3	0	74	6	2.0	.30	.1	a54
	Oct. 15	2,600	70	c10		9.4	0	69	5	3.0	.50	.1	a46
Yuba River at Smartsville	May 8	2,960	54	c8		10	0	36	15	c2	.05	(b)	a26
	Aug. 27	280	80	c18		9.1	0	67	14	3.0	.10	(b)	*54
American River at Fair Oaks	May 8	4,000	21	c5		1.7	0	22	1	c.4	.15	(b)	a16
	Aug. 26	173	46	c9		7.4	0	38	6	4.0	.20	(b)	a27
Putah Creek at Winters	Aug. 7	0	404	36	58	25	17	354	28	25	.56	3.0	328
Napa River near Napa	May 10	26	166	22	19	11	0	158	4	16	2.1	1.0	133
Conn Creek near St. Helena	May 10	3.2	290	36	43	3.5	4.9	275	25	10	.78	.7	266
Trinity River at Lewiston	Aug. 29	80	92	10	15	.5	0	94	6	3.0	.30	.1	86

a Determined by usual analytical methods.
b Less than 0.1 part per million.
c Determined by turbidity.
* Analyzed by S. K. Love.

TABLE E-3

*ANALYSES OF WATER FROM THE SACRAMENTO RIVER AT THE M STREET BRIDGE, SACRAMENTO, CALIFORNIA, 1931-32

(Analytical Results in Parts per Million)

Date and time of collection	Approximate stage of tide	Discharge in second-feet	Total dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Borate (BO_3)	Total hardness as $CaCO_3$ (calculated)
1931—															
July 20— 5.40 p.m.	Low low	91	280	22	0.02	31	21	38	2.6	160	25	62	(a)	--------	164
Aug. 6— 9.45 a.m.	Low low	206	403	26	.03	40	30	63	2.1	237	43	83	(a)	--------	223
Aug. 12— 3.00 p.m.	Low low	345	406	26	.03	39	31	61	2.4	237	49	81	(a)	--------	225
Aug. 14— 8.22 a.m.	High high	369	395	26	.09	38	29	61	2.9	225	47	80	(a)	--------	214
Aug. 20— 1.26 a.m.	High high	480	394	28	.04	36	28	62	3.6	224	50	80	0.40	0.4	205
10.04 a.m.	Low low	--------	389	29	.03	35	28	61	3.0	224	48	75	.40	.4	202
Aug. 27— 8.00 a.m.	High high	737	387	27	.03	37	28	62	2.7	217	44	86	.40	.4	207
4.50 p.m.	Low low	--------	373	29	.04	34	27	55	3.0	202	40	81	.40	.4	196
Sept. 3—12.50 a.m.	High high	1,530	349	28	.03	33	25	51	3.0	194	38	72	.40	.4	185
8.25 a.m.	Low low	--------	322	27	.03	30	23	50	2.0	186	36	61	.40	.4	169
Sept. 8— 5.17 a.m.	High high	1,840	141	26	.17	16	10	16	2.6	100	12	14	.10	.2	81
Sept. 10— 6.30 a.m.	High high	2,300	271	26	.11	27	20	42	2.6	166	29	50	.25	.3	150
2.45 p.m.	Low low	--------	284	25	.11	28	21	44	3.0	173	32	54	.25	.3	156
Sept. 16—11.50 p.m.	High high	3,520	236	27	.11	23	17	34	2.9	147	22	42	.21	.2	127
Sept. 17— 9.26 a.m.	Low low	3,750	223	29	.21	22	15	31	2.6	140	25	33	.28	.2	116
Sept. 23— 3.28 p.m.	Low low	3,780	198	27	.15	20	14	27	2.4	128	19	30	.25	.2	107
Sept. 25— 7.45 a.m.	High high	3,800	188	28	.15	19	13	25	2.4	121	16	28	.25	.2	101
Sept. 30—10.17 p.m.	High high	3,490	179	28	.12	19	13	23	1.8	117	15	29	.25	.2	101
Oct. 1— 8.00 a.m.	Low low	3,670	169	28	.13	18	12	20	2.4	113	15	23	.23	.2	94
Oct. 8— 2.35 p.m.	Low low	3,420	165	28	.14	18	11	19	2.1	110	13	22	.10	.2	90
Oct. 14— 6.22 p.m.	Low low	3,450	145	28	.04	17	10	15	1.3	97	9.5	14	.14	.2	84
10.20 p.m.	High high	--------	160	26	.12	17	11	20	1.8	104	12	24	.10	.2	88
Oct. 15— 8.05 a.m.	High high	3,580	135	26	.16	15	9.6	15	1.9	97	10	14	.10	.2	77
Oct. 21— 2.02 p.m.	Low low	3,560	144	30	.04	17	10	16	.8	103	9.1	18	.12	.2	84
Oct. 29— 6.54 a.m.	Low low	6,360	120	24	.04	17	9.2	10	.9	84	11	12	.14	.2	80
Nov. 4—12.13 p.m.	Low low	4,940	131	26	.04	15	7.6	13	.8	84	12	14	.11	.2	69
5.03 p.m.	High high	--------	128	24	.03	18	8.3	14	.7	87	12	13	.15	.2	79
Nov. 11— 9.04 p.m.	High high	4,300	129	28	.04	15	8.4	14	.7	91	9.7	10	.12	.2	72
Nov. 12— 6.52 a.m.	Low low	4,580	120	24	.04	16	8.1	12	.5	87	9.5	9.0	.07	.2	73
Nov. 18— 5.00 p.m.	High high	11,300	117	20	.07	14	8.4	13	.5	71	16	10	.13	.2	69
Nov. 19— 1.00 p.m.	Low low	11,500	107	21	.06	18	6.5	9.1	.5	72	12	8.0	.12	.1	72
Nov. 25— 8.00 p.m.	High high	7,060	114	23	.05	15	7.6	9.0	.6	74	13	8.0	.12	.2	69
Nov. 26— 6.00 a.m.	Low low	7,060	120	23	.09	14	7.4	9.3	1.8	74	13	8.0	.3	.3	65
Dec. 2— 4.05 p.m.	High high	6,160	120	25	.02	14	7.9	11	1.6	79	12	11	.2	.2	67
Dec. 3—11.35 a.m.	Low low	6,350	120	24	.02	14	8.0	11	1.8	82	12	11	.15	.2	68
Dec. 9— 8.00 p.m.	High high	6,220	114	24	.02	14	7.8	10	1.7	79	11	8.0	.2	.3	67
Dec. 10— 6.00 a.m.	Low low	6,460	119	25	.02	14	8.1	9.9	1.6	82	11	9.0	.15	.3	68

Dec. 16— 3.20 p.m.	High high	6,910	139	24	.02	16	9.6	13	1.8	85	13	16	.2	.3	79
Dec. 17—11.20 a.m.	Low low	6,810	126	24	.02	14	8.2	11	1.6	84	12	11	.15	.3	69
Dec. 23— 7.00 p.m.	High high	12,100	121	20	.04	15	8.2	12	1.7	74	14	13	.3	.2	71
Dec. 24— 5.00 a.m.	Low low	24,500	112	21	.02	14	7.5	9.5	1.4	71	13	8.0	.3	.2	66
Dec. 30— 2.00 p.m.	(b)	61,000	74	14	.04	8.6	4.8	4.7	1.5	39	9.1	4.0	2.0	.1	41
Dec. 31—10.00 a.m.	(b)	60,000	74	14	.03	8.1	5.1	5.0	1.9	40	10	5.0	2.0	.1	41
1932—															
Jan. 7	(b)	36,200	114	19	.05	14	7.3	11	1.5	63	15	14	1.2	.2	65
Jan. 13	(c)	19,800	125	21	.04	15	7.9	13	1.3	72	16	16	.74	.2	70
Jan. 20	(b)	27,500	97	18	.04	12	6.3	8.3	1.4	60	12	10	.80	.1	56
Jan. 27	(c)	17,400	135	19	.06	17	8.8	16	1.8	81	20	16	.80	.2	79
Feb. 3	(c)	22,600	111	27	.04	13	6.7	11	1.4	64	13	10	.45	.1	60
Feb. 10	(b)	46,200	61	13	.04	7.5	3.6	4.1	.6	37	7.8	3.0	.60	.1	34
Feb. 16— 6.05 p.m.	(c)	21,200	109	18	.03	13	6.7	11	1.9	63	14	12	.30	.1	60
Feb. 24—10.45 a.m.	High high	15,000	110	21	.02	14	6.8	11	1.5	69	13	11	.20	.2	63
Mar. 2— 5.20 p.m.	High high	22,900	85	19	.02	12	5.0	7.5		56	8.3	5.0	.15	.2	50
Mar. 4— 1.30 p.m.	(b)	21,300	52	12	.06	6.5	2.8	5.4	.9	35	4.7	3.0	.10	.1	28
Mar. 9— 6.45 p.m.	Low low	20,600	96	20	.03	13	5.5	8.9	1.5	59	8.6	10	.10	.2	55
Mar. 17— 1.03 a.m.	(c)	27,500	82	18	.05	11	4.7	6.6	1.6	53	6.3	6.0	.15	.2	47
Mar. 24—11.00 a.m.	(b)	41,900	75	16	.05	10	4.4	6.2	2.2	49	5.8	5.0	.20	.1	43
Mar. 30— 3.20 p.m.	(b)	34,000	64	16	.06	8.6	3.4	5.3	.8	45	5.5	3.0	.20	.1	35
April 6— 3.15 p.m.	(b)	32,100	70	16	.06	9.4	4.0	6.5	1.0	46	5.7	6.0	.20	.1	40
April 14— 3.05 p.m.	(c)	26,300	60	14	.05	7.7	3.1	5.7	.8	38	5.5	4.0	.15	.1	32
April 20— 2.00 p.m.	(c)	28,300	49	12	.05	6.2	2.4	4.8	.7	28	4.7	3.0	.15	.1	25
April 27— 3.03 p.m.	(b)	30,600	72	16	.06	8.4	3.8	7.1	1.0	42	6.6	6.0	.30	.1	37
May 11— 4.30 p.m.	(b)	41,400	43	12	.06	6.0	2.5	3.8	.5	27	3.5	3.0	.40	.1	25
May 18— 3.20 p.m.	(b)	42,600	42	12	.06	5.7	2.4	3.4	.6	27	3.0	4.0	.25	.1	24
May 26— 9.45 a.m.	(b)	30,000	49	12	.06	6.1	2.8	4.3	1.0	29	4.2	5.0	.25	.1	27
June 1— 5.05 p.m.	(c)	24,000	65	16	.06	8.2	3.9	6.3	1.0	43	5.2	6.0	.20	.1	36
June 8—12.30 p.m.	(c)	22,500	65	17	.06	8.0	3.7	5.6	.9	40	4.9	7.0	.20	.1	35
June 18—10.35 a.m.	(c)	16,400	66	14	.06	8.3	4.1	7.6	.7	41	5.7	8.0	.20	.1	38
June 23— 3.30 p.m.	Low low	15,200	79	17	.06	9.6	4.9	7.8	1.3	50	6.8	9.0	.15	.1	44
June 29— 5.15 a.m.	High high	10,700	73	16	.05	8.3	4.1	7.0	1.0	42	5.8	9.0	.15	.1	38
July 7—11.15 a.m.	High high	5,460	122	19	.05	15	8.3	14	1.6	80	10	18	.20	.2	72
July 13— 1.20 p.m.	High high	3,930	119	21	.05	15	7.9	13	1.8	77	10	18	.10	.2	70

* Analyzed by S. K. Love except samples July 20 to Sept. 3 and Oct. 21 to Nov. 25, 1931, which were analyzed by C. S. Howard.
[a] Less than 0.2 parts per million.
[b] No tide.
[c] Small tidal effect.

PUBLICATIONS

DIVISION OF WATER RESOURCES

PUBLICATIONS OF THE

DIVISION OF WATER RESOURCES

DEPARTMENT OF PUBLIC WORKS

STATE OF CALIFORNIA

When the Department of Public Works was created in July, 1921, the State Water Commission was succeeded by the Division of Water Rights, and the Department of Engineering was succeeded by the Division of Engineering and Irrigation in all duties except those pertaining to State Architect. Both the Division of Water Rights and the Division of Engineering and Irrigation functioned until August, 1929, when they were consolidated to form the Division of Water Resources.

STATE WATER COMMISSION

First report, State Water Commission, March 24 to November 1, 1912.
Second Report, State Water Commission, November 1, 1912, to April 1, 1914.
*Biennial Report, State Water Commission, March 1, 1915, to December 1, 1916.
Biennial Report, State Water Commission, December 1, 1916, to September 1, 1918.
Biennial Report, State Water Commission, September 1, 1918, to September 1, 1920.

DIVISION OF WATER RIGHTS

*Bulletin No. 1—Hydrographic Investigation of San Joaquin River, 1920–1923.
*Bulletin No. 2—Kings River Investigation, Water Master's Reports, 1918–1923.
*Bulletin No. 3—Proceedings First Sacramento-San Joaquin River Problems Conference, 1924.
*Bulletin No. 4—Proceedings Second Sacramento-San Joaquin River Problems Conference, and Water Supervisors' Report, 1924.
*Bulletin No. 5—San Gabriel Investigation—Basic Data—1923–1926.
Bulletin No. 6—San Gabriel Investigation—Basic Data, 1926–1928.
Bulletin No. 7—San Gabriel Investigation—Analysis and Conclusions, 1929.
*Biennial Report, Division of Water Rights, 1920–1922.
*Biennial Report, Division of Water Rights, 1922–1924.
Biennial Report, Division of Water Rights, 1924–1926.
Biennial Report, Division of Water Rights, 1926–1928.

DEPARTMENT OF ENGINEERING

*Bulletin No. 1—Cooperative Irrigation Investigations in California, 1912–1914.
*Bulletin No. 2—Irrigation Districts in California, 1887–1915.
Bulletin No. 3—Investigations of Economic Duty of Water for Alfalfa in Sacramento Valley, California, 1915.
*Bulletin No. 4—Preliminary Report on Conservation and Control of Flood Waters in Coachella Valley, California, 1917.
*Bulletin No. 5—Report on the Utilization of Mohave River for Irrigation in Victor Valley, California, 1918.
*Bulletin No. 6—California Irrigation District Laws, 1919 (now obsolete).
Bulletin No. 7—Use of water from Kings River, California, 1918.
*Bulletin No. 8—Flood Problems of the Calaveras River, 1919.
Bulletin No. 9—Water Resources of Kern River and Adjacent Streams and Their Utilization, 1920.
*Biennial Report, Department of Engineering, 1907–1908.
*Biennial Report, Department of Engineering, 1908–1910.
*Biennial Report, Department of Engineering, 1910–1912.
*Biennial Report, Department of Engineering, 1912–1914.
*Biennial Report, Department of Engineering, 1914–1916.
*Biennial Report, Department of Engineering, 1916–1918.
*Biennial Report, Department of Engineering, 1918–1920.

* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

DIVISION OF WATER RESOURCES

Including Reports of the Former Division of Engineering and Irrigation

*Bulletin No. 1.—California Irrigation District Laws, 1921 (now obsolete).
*Bulletin No. 2—Formation of Irrigation Districts, Issuance of Bonds, etc., 1922.
Bulletin No. 3—Water Resources of Tulare County and Their Utilization, 1922.
Bulletin No. 4—Water Resources of California, 1923.
Bulletin No. 5—Flow in California Streams, 1923.
Bulletin No. 6—Irrigation Requirements of California Lands, 1923.
*Bulletin No. 7—California Irrigation District Laws, 1923 (now obsolete).
*Bulletin No. 8—Cost of Water to Irrigators in California, 1925.
Bulletin No. 9—Supplemental Report on Water Resources of California, 1925.
*Bulletin No. 10—California Irrigation District Laws, 1925 (now obsolete).
Bulletin No. 11—Ground Water Resources of Southern San Joaquin Valley, 1927.
Bulletin No. 12—Summary Report on the Water Resources of California and a Coordinated Plan for Their Development, 1927.
Bulletin No. 13—The Development of the Upper Sacramento River, containing U. S. R. S. Cooperative Report on Iron Canyon Project, 1927.
Bulletin No. 14—The Control of Floods by Reservoirs, 1928.
*Bulletin No. 18—California Irrigation District Laws, 1927 (now obsolete).
*Bulletin No. 18—California Irrigation District Laws, 1929, Revision (now obsolete).
Bulletin No. 18-B—California Irrigation District Laws, 1931, Revision.
Bulletin No. 19—Santa Ana Investigation, Flood Control and Conservation (with packet of maps), 1928.
Bulletin No. 20—Kennett Reservoir Development, an Anaylsis of Methods and Extent of Financing by Electric Power Revenue, 1929.
Bulletin No. 21—Irrigation Districts in California, 1929.
Bulletin No. 21-A—Report on Irrigation Districts in California for the year 1929.
Bulletin No. 21-B—Report on Irrigation Districts in California for the year 1930.
Bulletin No. 21-C—Report on Irrigation Districts in California for the year 1931. (Mimeographed.)
Bulletin No. 21-D—Report on Irrigation Districts in California for the year 1932. (Mimeographed.)
Bulletin No. 22—Report on Salt Water Barrier (two volumes), 1929.
Bulletin No. 23—Report of Sacramento-San Joaquin Water Supervisor, 1924–1928.
Bulletin No. 24—A Proposed Major Development on American River, 1929.
Bulletin No. 25—Report to Legislature of 1931 on State Water Plan, 1930.
Bulletin No. 26—Sacramento River Basin, 1931.
Bulletin No. 27—Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay, 1931.
Bulletin No. 28—Economic Aspects of a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers, 1931.
Bulletin No. 28A—Industrial Survey of Upper San Francisco Bay Area, 1930.
Bulletin No. 29—San Joaquin River Basin, 1931.
Bulletin No. 31—Santa Ana River Basin, 1930.
Bulletin No. 32.—South Coastal Basin, a Cooperative Symposium, 1930.
Bulletin No. 33—Rainfall Penetration and Consumptive Use of Water in Santa Ana River Valley and Coastal Plain, 1930.
Bulletin No. 34—Permissible Annual Charges for Irrigation Water in Upper San Joaquin Valley, 1930.
Bulletin No. 35—Permissible Economic Rate of Irrigation Development in California, 1930.
Bulletin No. 36—Cost of Irrigation Water in California, 1930.
Bulletin No. 37—Financial and General Data Pertaining to Irrigation, Reclamation and Other Public Districts in California, 1930.
Bulletin No. 38—Report of Kings River Water Master for the Period 1918–1930.
Bulletin No. 39—South Coastal Basin Investigation, Records of Ground Water Levels at Wells, 1932.
Bulletin No. 40—South Coastal Basin Investigation, Quality of Irrigation Waters, 1933.
Bulletin No. 41—Pit River Investigation, 1933.
Bulletin No. 42—Santa Clara Investigation, 1933.

* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

Bulletin No. 43—Value and Cost of Water for Irrigation in Coastal Plain of Southern California, 1933.

Bulletin No. 44—Water Losses Under Natural Conditions from Wet Areas in Southern California, 1933.

Biennial Report, Division of Engineering and Irrigation, 1920–1922.

Biennial Report, Division of Engineering and Irrigation, 1922–1924.

Biennial Report, Division of Engineering and Irrigation, 1924–1926.

Biennial Report, Division of Engineering and Irrigation, 1926–1928.

PAMPHLETS

Act Governing Supervision of Dams in California, with Revised Rules and Regulations, 1933.

Water Commission Act with Amendments Thereto, 1933.

Rules, Regulations and Information Pertaining to Appropriation of Water in California, 1933.

Rules and Regulations Governing the Determination of Rights to Use of Water in Accordance with the Water Commission Act, 1925.

Tables of Discharge for Parshall Measuring Flumes, 1928.

General Plans, Specifications and Bills of Material for Six and Nine Inch Parshall Measuring Flumes, 1930.

COOPERATIVE AND MISCELLANEOUS REPORTS

*Report of the Conservation Commission of California, 1912.

*Irrigation Resources of California and Their Utilization (Bul. 254, Office of Exp. U. S. D. A.) 1913.

*Report, State Water Problems Conference, November 25, 1916.

*Report on Pit River Basin, April, 1915.

*Report on Lower Pit River Project, July, 1915.

*Report on Iron Canyon Project, 1914.

*Report on Iron Canyon Project, California, May, 1920.

*Sacramento Flood Control Project (Revised Plans), 1925.

Report of Commission Appointed to Investigate Causes Leading to the Failure of St. Francis Dam, 1928.

Report of the California Joint Federal-State Water Resources Commission, 1930.

Conclusions and Recommendations of the Report of the California Irrigation and Reclamation Financing and Refinancing Commission, 1930.

*Report of California Water Resources Commission to the Governor of California on State Water Plan, 1932.

*Booklet of Information on California and the State Water Plan prepared for United States House of Representatives' Subcommittee on Appropriations, 1931.

*Bulletin on Great Central Valley Project of State Water Plan of California Prepared for United States Senate Committee on Irrigation and Reclamation, 1932.

* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

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