When the work done in 1949 in the Sutter-Yuba Investigations is matched with the work done by George Curtin for his 1971 Paper is analyzed in context of the work done by Springhorn, the existence of the saline and anoxic seawater is clear. The analysis done in the 2014 USGS Paper confirms the casual relationship between both high pH and anoxic conditions. This time series and geographic specific well observations is compelling by magnitude and consistency regarding the casual relationships of the Sutter Buttes geology and the arsenic contamination.

In addition to the Paper referenced I am also attaching the EPA Violation Reports for the Grimes and Princeton water systems and a USGS Paper done on the geological history of the Sutter Buttes Volcano.

Thanks again for your time and consideration

Ben King

HYDROGEOLOGY OF THE SUTTER BASIN, SACRAMENTO VALLEY, CALIFORNIA

by

George Curtin

A Thesis Submitted to the Faculty of the

DEPARTMENT OF GEOSCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN GEOLOGY

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 7 1

Well Number	Depth ft.	Chemical constituents equivalents per million percent reactance value						parts per million		
		CA	MG	NA+K	HCO3+CO3	SO4	CL	B.	TDS	TH
10N/1E-15H2	176	1.95	2.14	1.71	4.24	0.54	1.13	1.5	270	204
		33.6	36.9	29.5	71.7	9.1	19.1			
10N/2E-17J3	243	2.05	2.14	1.71	4.24	0.40	1.07	1.5	278	207
		34.8	36.3	29.0	74.3	7.0	18.7			
11N/1E-4R1	-	1.30	4.59	5.82	9.43	1.39	1.30	4.2	695	295
		11.1	39.2	49.7	77.8	11.5	10.7			
11N/1E-16P1	172	1.85	2.06	1.83	4.74	0.23	0.93	1.3	304	195
		32.2	35.9	31.9	80.2	3.9	15.8			
11N/2E-14F4	330	1.35	1.73	2.35	4.78	0.20	0.56	0.7	277	153
		24.9	31.9	43.3	86.3	3.6	10.1			
11N/2E-32G1	-	1.45	5.85	3.75	7.26	1.00	2.31	3.3	604	366
		13.1	52.9	33.9	68.7	9.5	9.5			
11N/3E-3N2	112	0.75	0.25	0.90	1.73	0.08	0.02	0.1	131	50
		39.5	13.2	47.4	91.0	4.2	5.3			
11N/3E-14N2	-	3.59	3.40	5.49	4.30	0.18	8.10	0.3	705	351
		28.8	27.2	44.0	34.1	1.4	64.0			
11N/3E-14R1	236	1.20	0.30	10.51	4.83	0.06	7.17	0.2	718	75
		10.0	2.5	87.5	40.0	0.9	59.1			
11N/3E-24D1	145	2.18	2.88	2.05	6.92	0.15	0.31	0.2	365	253
		30.8	40.4	28.8	93.4	2.3	4.3			
11N/3E-36L1	140	0.37	0.23	3.33	3.20	0.20	0.48	0.3	246	30
		9.5	5.9	84.7	82.5	5.2	12.4			
11N/4E-3P2	305	2.30	2.38	0.99	4.49	0.11	0.87	0.0	295	234
		40.6	42.0	17.5	82.1	2.0	15.9			

Well Number	Depth ft.	Chemical constituents CA	MG	NA+K	equivalents per million / percent reactance value HCO3+CO3	SO4	CL	parts per million B.	TDS	TH
11N/4E-9D1	-	1.40 42.2	1.32 39.7	0.60 18.1	2.60 76.3	0.50 14.7	0.31 9.0	0.1	184	138
11N/4E-14D2	204	0.83 26.1	0.99 31.1	1.36 42.8	2.16 77.7	0.08 2.9	0.54 19.4	0.2	152	91
11N/4E-19E2	-	1.35 31.4	1.41 32.8	1.54 35.8	3.00 69.3	0.31 7.2	1.02 23.5	0.1	262	138
12N/1W-21A1	405	1.50 32.7	2.30 50.3	0.78 17.0	4.20 97.5	0.00 0.0	0.11 2.5	0.0	214	189
12N/2E-2J1	100	30.37 28.2	35.30 33.4	39.90 37.8	4.10 4.0	0.05 0.0	99.45 96.0	0.6	5610	205
12N/2E-9B2	-	1.35 20.6	0.03 4.0	5.17 79.0	3.89 65.2	0.33 5.5	1.75 29.3	0.5	402	69
12N/2E-11N1	-	1.55 12.5	1.15 9.3	9.70 78.2	4.30 36.0	0.00 0.0	7.61 64.0	0.9	728	135
12N/2E-14B1	-	7.58 18.3	9.21 22.2	24.65 59.5	3.12 7.9	0.00 0.0	38.63 92.1	0.8	2790	841
12N/2E-16R1	-	2.25 21.5	0.72 6.9	7.46 71.6	7.13 70.0	0.35 3.5	2.68 26.5	0.6	577	148
12N/2E-18SW	1500	19.83 19.2	7.22 7.0	76.12 73.8	2.71 2.5	0.08 0.1	99.98 97.4	10.8	5870	166
12N/2E-23Q1	-	1.15 12.1	0.55 5.8	7.82 82.1	4.50 48.4	0.01 0.0	4.79 51.6	0.7	571	85

Well Number	Depth ft.	Chemical constituents CA	MG	NA+K	equivalents per million / percent reactance value HCO3+CO3	SO4	CL	parts per million B.	TDS	TH
12N/2E-24G1	446	0.70 7.6	0.72 7.9	7.61 84.5	4.00 47.4	0.35 4.1	4.09 48.5	0.1	670	-
12N/2E-24L1	1565	19.81 19.3	7.23 7.2	75.21 73.5	2.70 2.6	0.08 0.1	100.03 97.3	10.8	5940	-
12N/2E-24L2	146	19.81 36.5	9.29 17.1	25.23 46.4	3.47 8.1	0.02 0.0	39.48 91.9	1.1	2452	-
12N/2E-26A1	-	1.40 13.3	0.72 6.8	8.41 79.9	4.64 44.8	0.00 0.0	5.72 55.2	0.6	608	107
12N/2E-35SW	44	4.09 15.3	5.84 21.7	16.88 63.0	4.20 15.4	0.01 0.0	23.41 84.6	0.4	1628	-
12N/3E-13F1	285	0.85 20.3	0.47 11.2	2.87 68.5	2.91 69.8	0.02 0.5	1.24 29.7	0.2	266	66
12N/3E-16H2	-	2.15 19.0	4.45 39.3	4.73 41.7	5.28 47.1	2.21 19.7	3.71 32.2	0.0	620	330
12N/3E-23G1	120	6.47 36.6	4.72 26.7	6.49 36.7	2.82 15.9	0.23 1.3	14.72 82.8	0.4	1060	561
12N/3E-25A1	155	2.05 41.3	1.45 29.2	1.46 29.4	4.02 79.2	0.25 5.0	0.76 15.1	0.1	286	175
12N/25C2	97	3.79 50.1	2.20 29.1	1.58 20.9	4.13 54.9	0.75 10.0	2.65 35.2	0.1	435	252
12N/3E-26R1	-	2.99 42.2	1.64 23.1	2.46 34.7	3.52 48.6	0.17 2.4	3.55 49.0	0.1	423	234

Well Number	Depth ft.	Chemical constituents CA	MG	NA+K	equivalents per million / percent reactance value HCO3+CO3	SO4	CL	parts per million B.	TDS	TH
12N/3E-30H1	232	4.64 13.9	2.96 8.9	25.71 77.2	3.18 9.7	0.19 0.6	29.34 89.7	1.5	1970	380
12N/4E-4N2	89	1.45 36.2	1.75 43.6	0.81 20.22	2.72 68.3	0.19 4.8	1.07 26.9	0.0	257	160
12N/4E-6G1	82	2.50 26.2	4.30 45.0	2.76 28.8	6.20 69.0	2.17 24.1	0.62 6.9	0.2	491	340
12N/4E-7R1	100	0.95 32.3	1.35 45.9	0.64 21.8	2.63 92.9	0.02 0.7	0.18 6.4	0.0	181	115
12N/4E-32J1	-	4.39 42.8	4.19 40.8	1.68 16.4	4.25 41.6	2.08 20.4	3.89 38.1	0.0	682	427
13N/1W-15R2	-	1.80 33.3	1.23 22.8	2.37 43.9	4.03 75.9	0.21 4.0	1.07 20.5	0.5	287	153
13N/1W-36Q2	36	1.75 38.6	1.15 24.9	1.72 36.5	3.31 74.3	0.15 3.4	0.99 22.3	0.3	276	145
13N/1E-22J1	-	2.84 52.4	1.48 27.3	1.10 20.3	3.71 69.6	0.17 3.2	1.44 27.0	0.1	327	216
13N/1E-36Q1	-	1.75 37.9	1.15 24.9	1.72 37.2	3.31 74.4	0.15 3.4	0.99 22.2	0.3	276	145
13N/2E-23B1	72	17.41 28.0	21.18 38.7	20.87 33.3	3.54 5.6	0.00 0.0	59.80 94.4	0.4	5970	2080
13N/3E-2C4	190	3.64 36.8	3.67 37.1	2.58 26.1	5.94 61.2	0.98 10.1	2.79 28.7	0.2	486	-

Well Number	Depth ft.	Chemical constituents CA	MG	NA+K	equivalents per million percent reactance value HCO3+CO3	SO4	CL	parts per million B.	TDS	TH
13N/3E-14G1	-	5.56 21.5	14.18 54.9	6.08 23.6	2.98 11.2	3.39 12.9	20.01 75.9	0.1	1994	987
13N/3E-15B1	95	6.99 31.5	9.01 40.6	6.20 27.9	2.75 12.5	0.06 0.3	19.18 87.2	0.1	1400	800
13N/3E-15C2	90	8.53 37.6	10.85 44.0	5.29 21.4	4.18 16.8	0.06 0.2	20.68 83.0	0.1	1580	970
13N/3E-23C1	105	13.40 41.9	13.00 40.6	5.60 17.5	5.92 18.7	0.10 0.3	25.60 80.8	0.2	1884	1320
13N/3E-23H1	-	5.10 30.7	7.70 46.4	3.80 22.9	3.43 20.7	0.46 2.8	12.65 76.5	0.1	900	640
13N/3E-24D1	-	7.80 26.2	11.80 39.6	10.21 34.2	1.46 4.8	0.23 0.8	28.50 94.4	0.5	2140	980
13N/4E-3D1	130	1.30 22.2	3.30 56.3	1.26 21.5	3.93 68.0	0.19 3.3	1.66 28.7	0.0	320	230
13N/4E-17J1	200	2.45 39.5	2.75 44.3	1.01 16.3	3.33 56.7	2.00 34.1	0.54 9.2	0.02	387	260
13N/4E-21A1	-	3.59 36.3	5.26 53.2	1.04 10.6	4.31 42.9	5.45 54.3	0.28 2.8	0.0	565	445
13N/4E-27M1	196	0.70 29.4	1.02 42.9	0.66 27.7	1.92 84.2	0.02 0.9	0.34 14.9	0.0	163	86
13N/4E-32N1	84	0.95 23.4	1.43 35.2	1.68 41.4	2.41 83.1	0.12 4.1	0.37 12.8	0.0	200	119

Well Number	Depth ft.	Chemical constituents equivalents per million percent reactance value: CA	MG	NA+K	HCO3+CO3	SO4	CL	parts per million: B.	TDS	TH
13N/4E-33J2	154	1.95 35.7	2.55 46.6	0.97 17.7	4.56 85.6	0.09 1.7	0.68 12.8	0.0	312	-
14N/1W-2D1	-	2.84 31.8	2.47 27.6	3.63 40.6	3.67 40.6	1.64 18.2	3.72 41.2	0.2	493	268
14N/1W-12A1	-	1.05 17.6	0.09 1.5	4.83 80.9	4.41 74.7	0.02 0.3	1.47 24.9	0.5	319	57
14N/1E-1A1	-	3.24 45.5	2.63 36.9	1.25 17.6	6.05 88.1	0.37 5.4	0.45 6.6	0.0	344	294
14N/1E-24N1	125	1.60 34.0	1.73 36.0	1.42 30.0	3.99 86.0	0.441 10.0	0.19 4.0	0.1	248	166
14N/2E-13L1	79	1.20 29.6	1.81 44.7	1.04 25.7	3.90 96.3	0.06 1.5	0.09 2.2	0.0	205	150
14N/2E-17E1	330	1.25 25.9	1.25 25.9	2.32 48.2	3.93 83.6	0.33 7.0	0.48 9.4	0.1	298	196
14N/2E-30R1	188	1.90 27.8	1.58 23.1	3.37 49.1	5.22 77.5	0.21 3.1	1.30 19.4	0.1	386	174
14N/3E-4E5	160	2.20 26.0	4.12 48.7	2.14 25.3	5.61 71.0	1.44 18.2	0.85 10.8	0.0	455	316
14N/3E-5A3	106	4.39 34.5	5.18 40.8	3.14 24.7	8.30 66.4	2.08 16.6	2.12 17.0	0.1	670	481
14N/3E-5D2	150	1.50 29.8	2.10 41.7	1.44 28.6	4.54 91.9	0.17 3.4	0.23 4.7	0.0	266	180

Well Number	Depth ft.	Chemical constituents CA	MG	NA+K	equivalents per million / percent reactance value HCO3+CO3	SO4	CL	parts per million B.	TDS	TH
14N/3E-6A1	100	2.50 32.9	3.29 43.4	1.80 27.7	6.54 89.3	0.58 7.9	0.20 2.7	0.0	363	180
14N/3E-7H1	105	1.90 23.9	4.18 52.6	1.86 23.4	6.06 77.5	0.58 7.4	1.18 15.1	0.0	401	304
14N/3E-9K1	230	2.99 33.2	3.57 39.6	2.45 27.2	3.65 41.5	0.19 2.2	4.96 56.3	0.1	628	328
14N/3E-13D1	650	1.00 37.6	0.68 25.6	0.98 36.8	2.01 76.4	0.00 0.0	0.62 23.6	0.2	198	84
14N/3E-14E2	90	1.10 44.7	1.07 43.5	0.29 11.8	2.25 91.8	0.10 4.1	0.10 4.1	0.0	118	104
14N/3E-16B2	99	4.09 29.3	7.15 51.1	2.74 19.6	4.18 29.8	1.60 11.4	8.23 58.7	0.1	895	564
14N/3E-18A2	125	2.69 35.1	3.29 42.9	1.69 22.0	6.39 81.2	0.58 7.4	0.90 11.4	0.1	396	301
14N/3E-20H3	105	2.59 34.4	3.19 42.3	1.74 23.1	5.35 73.5	0.58 8.0	1.35 18.5	0.1	385	289
14N/3E-23M2	83	0.90 37.2	1.16 47.9	0.36 14.9	2.41 97.6	0.02 0.8	0.04 1.6	0.0	385	289
14N/3E-24M1	-	1.75 34.3	2.06 40.3	1.30 25.4	3.56 71.8	0.69 13.9	0.71 14.3	0.1	280	191
14N/3E-24P1	-	1.15 41.7	0.53 19.2	1.08 39.1	1.95 72.8	0.00 0.0	0.73 27.2	0.2	184	84

Well Number	Depth ft.	Chemical constituents CA	MG	NA+K	equivalents per million / percent reactance value HCO3+CO3	SO4	CL	parts per million B.	TDS	TH
14N/3E-25D3	85	1.10 41.4	0.90 33.8	0.66 24.8	2.11 79.6	0.06 2.3	0.48 18.1	0.0	159	102
14N/3E-26D4	110	0.77 32.9	0.05 2.1	1.52 65.0	1.61 95.3	0.05 3.0	0.03 1.8	0.2	136	11
14N/3E-27K1	180	2.89 24.8	3.91 33.6	4.84 41.6	5.60 49.1	0.31 2.7	5.50 48.2	0.2	665	340
14N/3E-28E1	-	1.25 22.2	2.46 43.6	1.93 34.2	3.52 62.4	0.24 4.3	1.88 33.3	0.2	286	185
14N/3E-29Q1	-	5.12 26.9	6.52 34.2	7.40 38.9	2.92 15.6	0.10 0.5	15.67 83.8	0.4	1000	581
14N/3E-31B1	63	1.30 20.5	2.86 45.2	2.17 34.3	5.51 88.9	0.21 3.4	0.48 7.7	0.0	317	208
14N/3E-32F1	-	5.63 26.4	7.08 33.2	8.60 40.4	3.42 16.1	0.05 0.2	17.76 83.7	0.3	1135	635
14N/3E-33A1	-	3.99 30.3	6.04 45.9	3.13 23.8	2.60 19.7	0.05 0.4	10.54 79.9	0.1	682	501
14N/3E-33C1	-	3.04 21.0	7.76 53.7	3.64 25.2	3.06 21.0	0.13 0.9	11.37 78.1	0.2	806	540
14N/3E-34F1	84	3.49 28.1	4.31 34.7	4.63 37.3	4.96 40.5	0.00 0.0	7.28 59.5	0.1	750	390
14N/3E-34J1	-	1.80 18.9	5.80 60.8	1.94 20.3	3.62 38.3	1.29 13.6	4.55 48.1	0.1	481	380

Well Number	Depth ft.	Chemical constituents CA	MG	NA+K	equivalents per million percent reactance value HCO3+CO3	SO4	CL	parts per million B.	TDS	TH
14N/4E-6H1	112	1.00 44.4	0.58 25.8	0.67 29.8	1.86 81.6	0.07 3.1	0.35 15.4	0.0	116	79
14N/4E-7M1	83	2.25 35.3	2.87 45.0	1.26 19.7	3.51 56.3	2.19 35.1	0.54 8.7	0.0	528	395
14N/4E-9J1	100	1.64 33.3	2.06 41.8	1.23 25.0	3.54 73.1	0.15 3.1	1.15 23.8	0.0	242	165
14N/4E-22H1	400	0.70 31.3	0.64 28.6	0.90 40.2	1.52 70.4	0.02 0.9	0.62 28.7	0.0	191	67
14N/4E-27N1	510	0.80 36.0	0.50 22.5	0.92 41.4	1.92 86.9	0.06 2.7	0.23 10.4	0.0 0.0	148	65
15N/1E-16R1	-	1.90 27.5	3.78 54.7	1.23 17.8	5.84 85.8	0.35 5.1	0.62 9.1	0.1	355	283
15N/1E-35H1	108	2.20 35.1	2.96 47.2	1.11 17.7	5.22 85.6	0.20 3.3	0.28 4.6	0.0	225	-
15N/1E-35R1	-	3.84 47.4	3.53 43.6	0.73 9.0	5.28 66.1	0.62 7.8	2.09 26.2	0.0	466	370
15N/2E-1R1	49	2.10 36.5	2.55 44.3	1.01 17.5	4.69 88.2	0.46 8.7	0.17 3.2	0.0	310	231
15N/2E-22D1	306	1.05 36.0	0.99 33.9	0.83 28.4	2.54 89.4	0.10 3.5	0.10 7.0	0.0	184	100
15N/2E-26D2	-	3.24 40.9	2.79 35.2	1.90 24.0	5.23 74.2	0.44 6.2	1.38 19.6	0.1	447	304

Well Number	Depth ft.	CA	MG	NA+K	HCO3+CO3	SO4	CL	B.	TDS	TH
		Chemical constituents			equivalents per million percent reactance value			parts per million		
15N/3E-4C2	147	3.04 34.2	4.52 50.9	1.32 14.9	5.72 69.3	1.77 21.5	0.76 9.2	0.1	558	379
15N/3E-9C2	200	2.20 34.9	2.28 36.2	1.82 28.9	5.52 88.0	0.44 7.0	0.31 4.9	0.1	350	224
15N/3E-11H4	60	0.94 39.2	1.13 47.1	0.33 13.7	2.17 90.0	0.11 4.6	0.13 5.4	0.0	127	103
15N/3E-13F1	350	1.80 50.9	0.92 26.0	0.82 23.1	2.68 77.5	0.50 14.5	0.28 8.0	0.0	239	136
15N/3E-13J2	300	1.10 44.2	0.54 21.7	0.85 34.1	1.90 74.2	0.01 0.4	0.65 25.4	0.0	201	82
15N/3E-14N1	350	0.70 24.4	0.72 25.1	1.45 50.5	2.34 81.3	0.00 0.0	0.54 18.8	0.3	182	71
15N/3E-15C1	170	1.15 28.3	0.65 16.0	2.27 55.8	3.59 87.4	0.01 0.2	0.51 12.4	0.3	257	90
15N/3E-15E2	188	1.64 24.4	1.92 28.6	3.15 46.9	4.96 76.0	0.27 4.1	1.30 19.9	0.4	329	178
15N/3E-15H4	133	3.49 41.8	3.95 47.3	0.91 10.9	6.65 81.4	0.20 2.5	1.32 16.1	0.0	483	373
15N/3E-15J2	160	0.55 9.1	4.35 71.7	1.17 19.3	3.99 75.9	0.71 13.5	0.56 10.7	0.0	354	245
15N/3E-15Q1	-	0.70 16.8	0.86 20.6	2.61 62.6	3.61 84.6	0.04 0.9	0.62 14.5	0.3	262	-

Well Number	Depth ft.	Chemical constituents CA	MG	NA+K	equivalents per million / percent reactance value HCO3+CO3	SO4	CL	parts per million B.	TDS	TH
15N/3E-19M1	75	0.94 30.2	1.39 44.7	0.78 25.1	2.79 92.1	0.09 3.0	0.15 5.0	0.1	150	117
15N/3E-21C1	185	1.30 23.6	2.86 51.9	1.35 24.5	4.47 81.1	0.25 4.5	0.79 14.3	0.0	328	208
15N/3E-22N1	115	3.49 34.4	4.75 46.8	1.90 18.6	7.42 74.6	0.75 7.5	1.78 18.0	0.0	529	412
15N/3E-23C1	118	0.75 46.3	0.65 40.1	0.22 13.6	1.41 92.2	0.05 3.3	0.07 4.6	0.0	99	70
15N/3E-23D1	125	2.25 38.3	3.30 51.5	0.60 10.2	5.19 90.1	0.29 5.0	0.28 4.9	0.0	325	264
15N/3E-24F1	130	2.84 42.8	2.59 39.0	1.21 18.2	4.71 69.4	0.58 8.5	1.50 22.1	0.1	334	261
15N/3E-26C1	163	1.35 30.0	1.71 38.0	1.44 32.0	4.C3 90.2	0.10 2.2	0.34 7.6	0.0	262	153
15N/3E-26M1	250	1.45 32.6	1.23 27.6	1.77 39.8	3.97 89.4	0.10 2.3	0.37 8.3	0.2	241	134
15N/3E-27C1	80	3.89 32.2	6.02 49.8	2.17 18.0	8.85 77.2	0.92 8.0	1.69 14.8	0.2	557	496
15N/3E-27L1	150	2.15 31.6	3.05 51.3	1.59 17.0	4.93 86.1	0.33 6.3	1.41 7.6	0.0	370	260
15N/3E-29G1	90	3.09 34.3	4.27 47.4	1.65 18.3	7.20 85.7	0.75 8.9	0.45 5.4	0.0	488	367

Well Number	Depth ft.	Chemical constituents CA	MG	NA+K	equivalents per million / percent reactance value HCO3+CO3	SO4	CL	parts per million B.	TDS	TH
15N/3E-29G2	110	2.84 31.6	4.61 51.3	1.53 17.0	7.35 86.1	0.54 6.3	0.65 7.6	0.0	487	373
15N/3E-30D1	65	2.64 37.9	3.44 49.4	0.89 12.8	6.10 94.0	0.23 3.5	0.16 2.5	0.0	384	304
15N/3E-34N2	80	3.80 22.9	10.38 62.5	2.43 14.6	7.02 42.8	2.02 12.3	7.36 44.9	0.1	831	709
15N/4E-8D1	333	1.87 43.8	1.82 42.6	0.58 13.6	3.04 73.3	0.90 21.7	0.21 5.1	0.1	220	184
15N/4E-16P1	450	1.15 41.8	1.07 39.0	0.53 19.2	2.21 81.6	0.42 15.5	0.08 2.9	0.0	184	111
15N/4E-20J2	271	1.60 36.9	2.14 49.3	0.60 13.8	3.13 73.0	0.98 22.8	0.18 4.2	0.0	271	187
15N/4E-29H1	145	1.35 36.2	1.75 46.9	0.63 16.9	2.96 80.2	0.54 14.6	0.19 5.2	0.0	187	155
15N/4E-31A1	157	1.05 39.5	1.07 40.2	0.54 20.3	2.32 89.9	0.02 0.8	0.24 9.3	0.0	172	105
16N/1W-29J1	-	1.30 31.3	1.48 35.7	1.37 33.0	3.82 94.1	0.00 0.0	0.24 5.9	0.1	199	139
16N/3E-14G1	63	4.34 46.7	4.22 45.4	0.73 7.9	6.78 76.9	1.19 13.5	0.85 9.6	0.0	472	428
16N/3E-16B1	46	0.84 46.9	0.80 44.7	0.15 8.4	1.49 87.1	0.12 7.0	0.10 5.9	0.0	90	82

Well Number	Depth ft.	Chemical constituents equivalents per million / percent reactance value						parts per million		
		CA	MG	NA+K	HCO3+CO3	SO4	CL	B.	TDS	TH
16N/3E-23B1	160	1.13 40.1	1.08 38.3	0.61 21.6	2.38 90.5	0.10 3.8	0.15 5.7	0.0	160	110
16N/3E-26Q1	416	1.40 46.1	0.80 26.3	0.84 27.6	2.40 81.6	0.17 5.8	0.37 12.6	0.1	218	110
16N/3E-31C1	72	1.32 30.8	2.04 47.7	0.92 21.5	3.92 92.7	0.16 3.8	0.15 3.5	0.0	318	168
16N/3E-36E1	85	2.16 37.1	2.84 48.7	0.83 14.2	5.04 92.5	0.02 0.4	0.39 7.2	0.0	280	250

PWS ID	PWS Name	EPA Region	Primacy Agency	PWS Type	Primacy Type	Primary Source	Activity Status
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active

PWS ID	PWS Name	EPA Region	Primacy Agency	PWS Type	Primacy Type	Primary Source	Activity Status
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active
CA0600008	COLUSA CO. WWD #1 - GRIMES	Region 9	California	Community water system	State	Ground water	Active

Deactivation Date	Population Served Count	Rule Name	Violation Code	Violation Type
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Lead and Copper Rule	52	Follow-up Or Routine LCR Tap M/R
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Nitrates	3	Monitoring, Regular
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Lead and Copper Rule	52	Follow-up Or Routine LCR Tap M/R
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average

Deactivation Date	Population Served Count	Rule Name	Violation Code	Violation Type
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Arsenic	2	Maximum Contaminant Level Violation, Average
-	381	Radionuclides	3	Monitoring, Regular
-	381	Radionuclides	3	Monitoring, Regular

Violation Category Code	Is Health Based	Contaminant Name	Compliance Period Begin Date	Compliance Period End Date
MCL	Y	Arsenic	1-Apr-18	30-Jun-18
MCL	Y	Arsenic	1-Jan-18	31-Mar-18
MCL	Y	Arsenic	1-Oct-17	31-Dec-17
MR	N	Lead and Copper Rule	1-Oct-17	-
MCL	Y	Arsenic	1-Jul-17	30-Sep-17
MCL	Y	Arsenic	1-Apr-17	30-Jun-17
MR	N	Nitrate	1-Jan-17	31-Dec-17
MCL	Y	Arsenic	1-Jan-17	31-Mar-17
MCL	Y	Arsenic	1-Oct-16	31-Dec-16
MCL	Y	Arsenic	1-Jul-16	30-Sep-16
MCL	Y	Arsenic	1-Apr-16	30-Jun-16
MCL	Y	Arsenic	1-Jan-16	31-Mar-16
MCL	Y	Arsenic	1-Oct-15	31-Dec-15
MR	N	Lead and Copper Rule	1-Oct-15	-
MCL	Y	Arsenic	1-Apr-15	30-Jun-15
MCL	Y	Arsenic	1-Jan-15	31-Mar-15
MCL	Y	Arsenic	1-Oct-14	31-Dec-14
MCL	Y	Arsenic	1-Jul-14	30-Sep-14
MCL	Y	Arsenic	1-Jan-14	31-Mar-14
MCL	Y	Arsenic	1-Oct-13	31-Dec-13
MCL	Y	Arsenic	1-Jul-13	30-Sep-13
MCL	Y	Arsenic	1-Apr-13	30-Jun-13
MCL	Y	Arsenic	1-Jan-13	31-Mar-13
MCL	Y	Arsenic	1-Oct-12	31-Dec-12
MCL	Y	Arsenic	1-Jul-12	30-Sep-12
MCL	Y	Arsenic	1-Apr-12	30-Jun-12
MCL	Y	Arsenic	1-Jan-12	31-Mar-12
MCL	Y	Arsenic	1-Oct-11	31-Dec-11
MCL	Y	Arsenic	1-Jul-11	30-Sep-11
MCL	Y	Arsenic	1-Apr-11	30-Jun-11
MCL	Y	Arsenic	1-Jan-11	31-Mar-11
MCL	Y	Arsenic	1-Oct-10	31-Dec-10
MCL	Y	Arsenic	1-Jul-10	30-Sep-10
MCL	Y	Arsenic	1-Apr-10	30-Jun-10

Violation Category Code	Is Health Based	Contaminant Name	Compliance Period Begin Date	Compliance Period End Date
MCL	Y	Arsenic	1-Jan-10	31-Mar-10
MCL	Y	Arsenic	1-Oct-09	31-Dec-09
MCL	Y	Arsenic	1-Jul-09	30-Sep-09
MCL	Y	Arsenic	1-Apr-09	30-Jun-09
MR	N	Gross Alpha, Excl. Radon and U	1-Oct-81	30-Sep-82
MR	N	Gross Alpha, Excl. Radon and U	30-Oct-80	29-Oct-81

Compliance Status	RTC Date	Enforcement Action Type Code	Enforcement Action Description	Is Major Violation
Known	-	SFL	State Administrative/Compliance Order without penalty issued	-
Known	-	SFL	State Administrative/Compliance Order without penalty issued	-
Known	-	SFL	State Administrative/Compliance Order without penalty issued	-
Open	-	SFL	State Administrative/Compliance Order without penalty issued	-
Known	-	SFL	State Administrative/Compliance Order without penalty issued	-
Known	-	SFL	State Administrative/Compliance Order without penalty issued	-
Returned to Compliance	12-Feb-19	SOX	State Compliance achieved	Y
Known	-	SFL	State Administrative/Compliance Order without penalty issued	-
Known	-	SFL	State Administrative/Compliance Order without penalty issued	-
Known	-	SFL	State Administrative/Compliance Order without penalty issued	-
Known	-	SFL	State Administrative/Compliance Order without penalty issued	-
Known	-	SFL	State Administrative/Compliance Order without penalty issued	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	17-Jul-19	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	27-Feb-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	27-Feb-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-
Returned to Compliance	27-Feb-18	SOX	State Compliance achieved	-
Returned to Compliance	27-Feb-18	SOX	State Compliance achieved	-
Returned to Compliance	27-Feb-18	SOX	State Compliance achieved	-

Compliance Status	RTC Date	Enforcement Action Type Code	Enforcement Action Description	Is Major Violation
Returned to Compliance	27-Feb-18	SOX	State Compliance achieved	-
Returned to Compliance	27-Feb-18	SOX	State Compliance achieved	-
Returned to Compliance	27-Feb-18	SOX	State Compliance achieved	-
Returned to Compliance	27-Feb-18	SOX	State Compliance achieved	-
Known	-	-	-	Y
Known	-	-	-	Y

Severity Indicator Count	Public Notification Tier	Violation First Reported Date
-	2	23-Aug-18
-	2	23-Aug-18
-	2	23-Aug-18
-	3	17-May-18
-	2	23-Aug-18
-	2	23-Aug-18
-	3	23-Aug-18
-	2	23-Aug-18
-	2	23-Aug-18
-	2	23-Aug-18
-	2	23-Aug-18
-	2	23-Aug-18
-	2	22-Feb-16
-	3	17-May-18
-	2	2-Sep-15
-	2	22-Feb-16
-	2	16-Feb-15
-	2	16-Feb-15
-	2	16-Feb-15
-	2	16-Feb-15
-	2	16-Feb-15
-	2	16-Feb-15
-	2	16-Feb-15
-	2	16-Feb-15
-	2	26-Jun-13
-	2	22-Feb-16
-	2	22-Feb-16
-	2	22-Feb-16
-	2	26-Jun-13
-	2	22-Feb-16
-	2	22-Feb-16
-	2	22-Feb-16
-	2	26-Jun-13
-	2	26-Jun-13

Severity Indicator Count	Public Notification Tier	Violation First Reported Date
-	2	26-Jun-13
-	2	4-Jun-10
-	2	30-Nov-09
-	2	30-Nov-09
-	3	30-Sep-82
-	3	30-Sep-81

PWS ID	PWS Name	EPA Region	Primacy Agency	PWS Type	Primacy Type	Primary Source	Activity Status
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active
CA0600013	COLUSA CO. WWD #2 - PRINCETON	Region 9	California	Community water system	State	Ground water	Active

Deactivation Date	Population Served Count	Rule Name	Violation Code	Violation Type
-	356	Consumer Confidence Rule	71	Consumer Confidence Report Complete Failure to Report
-	356	Arsenic	2	Maximum Contaminant Level Violation, Average
-	356	Arsenic	2	Maximum Contaminant Level Violation, Average
-	356	Arsenic	2	Maximum Contaminant Level Violation, Average
-	356	Arsenic	2	Maximum Contaminant Level Violation, Average
-	356	Arsenic	2	Maximum Contaminant Level Violation, Average
-	356	Arsenic	2	Maximum Contaminant Level Violation, Average
-	356	Lead and Copper Rule	52	Follow-up Or Routine LCR Tap M/R
-	356	Lead and Copper Rule	51	Initial Tap Sampling for Pb and Cu
-	356	Radionuclides	3	Monitoring, Regular
-	356	Radionuclides	3	Monitoring, Regular

Violation Category Code	Is Health Based	Contaminant Name	Compliance Period Begin Date	Compliance Period End Date
Other	N	Consumer Confidence Rule	1-Jul-16	-
MCL	Y	Arsenic	1-Jul-10	30-Sep-10
MCL	Y	Arsenic	1-Apr-10	30-Jun-10
MCL	Y	Arsenic	1-Jan-10	31-Mar-10
MCL	Y	Arsenic	1-Oct-09	31-Dec-09
MCL	Y	Arsenic	1-Jul-09	30-Sep-09
MCL	Y	Arsenic	1-Apr-09	30-Jun-09
MR	N	Lead and Copper Rule	1-Oct-05	-
MR	N	Lead and Copper Rule	1-Jul-93	-
MR	N	Gross Alpha, Excl. Radon and U	1-Oct-81	30-Sep-82
MR	N	Gross Alpha, Excl. Radon and U	30-Oct-80	29-Oct-81

Compliance Status	RTC Date	Enforcement Action Type Code	Enforcement Action Description	Is Major Violation	Severity Indicator Count
Returned to Compliance	6-Feb-17	SOX	State Compliance achieved	-	-
Returned to Compliance	27-Jan-11	SOX	State Compliance achieved	-	-
Returned to Compliance	27-Jan-11	SOX	State Compliance achieved	-	-
Returned to Compliance	27-Jan-11	SOX	State Compliance achieved	-	-
Returned to Compliance	27-Jan-11	SOX	State Compliance achieved	-	-
Returned to Compliance	27-Jan-11	SOX	State Compliance achieved	-	-
Returned to Compliance	27-Jan-11	SOX	State Compliance achieved	-	-
Returned to Compliance	1-Mar-18	SOX	State Compliance achieved	-	-
Returned to Compliance	30-Sep-05	EOX	Federal Compliance achieved	-	-
Known	-	-	-	Y	-
Known	-	-	-	Y	-

Public Notification Tier	Violation First Reported Date
3	14-Feb-17
2	26-Jun-13
2	26-Jun-13
2	26-Jun-13
2	4-Jun-10
2	30-Nov-09
2	30-Nov-09
3	6-Sep-13
3	12-Dec-95
3	30-Sep-82
3	30-Sep-81

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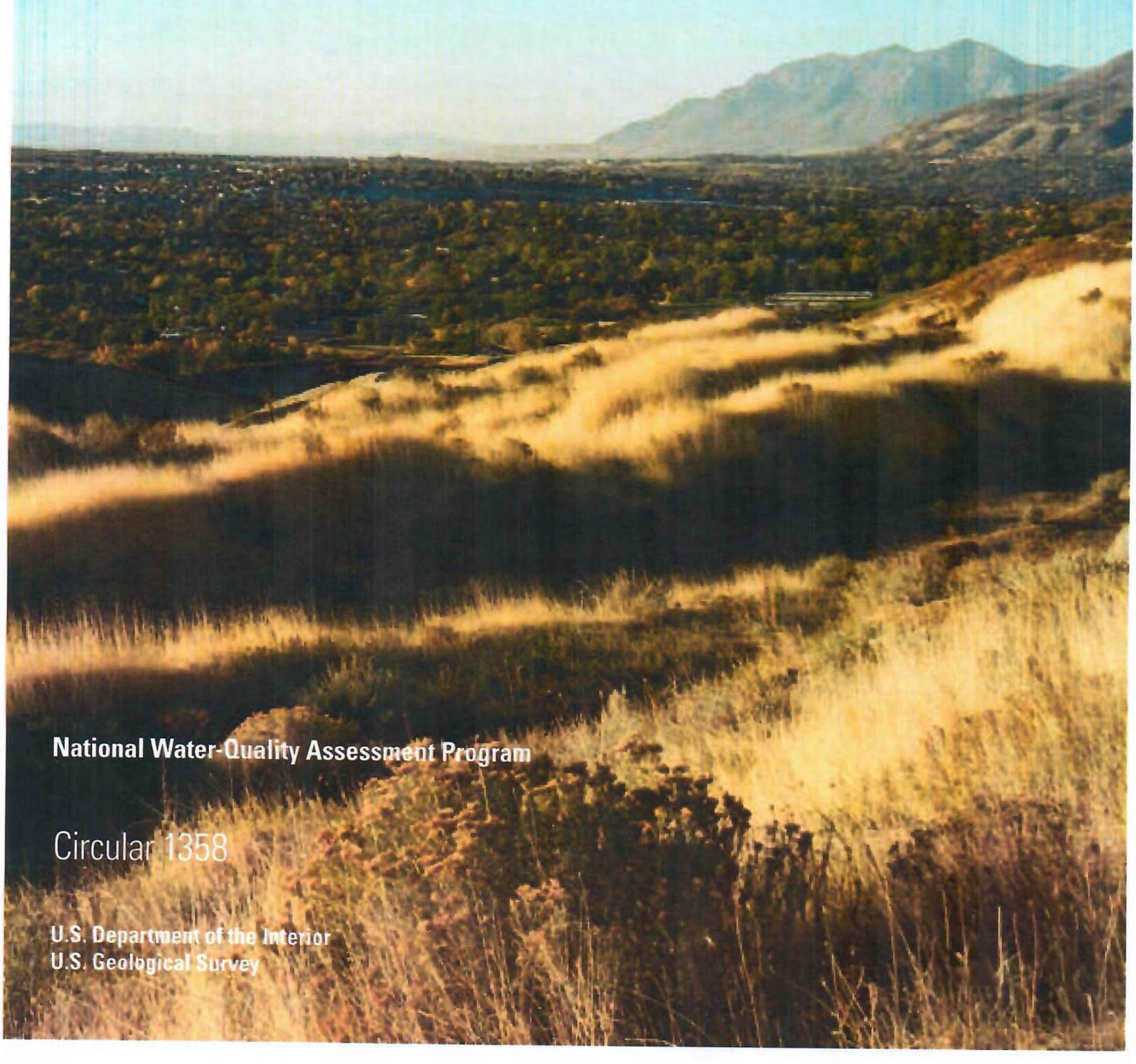
The Quality of Our Nation's Waters

Water Quality in Basin-Fill Aquifers of the Southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993–2009



National Water-Quality Assessment Program

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U.S. Department of the Interior
U.S. Geological Survey

The Quality of Our Nation's Waters

Water Quality in Basin-Fill Aquifers of the Southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993–2009

By Susan A. Thiros, Angela P. Paul, Laura M. Bexfield, and David W. Anning

National Water-Quality Assessment Program

Circular 1358

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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Chapter 6: *Understanding Where and Why Contaminants Occur in Southwest Basin-Fill Aquifers*

Arsenic, uranium, nitrate, dissolved solids, VOCs, and pesticides—these are the contaminants that are most likely to limit the use of groundwater now or in the future. Where do they occur, and what sources or processes control their concentrations? Answering these questions for selected basin-fill aquifers can help to identify areas across the Southwest that might be especially vulnerable to contamination and to estimate concentrations in areas where no data are available.

This chapter describes the sources of and factors that affect arsenic, uranium, nitrate, dissolved solids, VOCs, and pesticides in Southwest basin-fill aquifers, with focus on the intermediate to deeper parts of the aquifers that supply water for drinking and irrigation purposes.

The heavily irrigated Coachella Valley in southern California extends to the Salton Sea, a topographically low area that naturally accumulates minerals in groundwater through evapotranspiration.

Photograph by Chris Austin

Arsenic

Some geochemical conditions can cause arsenic in basin-fill sediments to dissolve into groundwater. As a result, groundwater in Southwest basin-fill aquifers commonly has arsenic concentrations that exceed the MCL of 10 µg/L. Many factors affect arsenic concentrations in groundwater—source rock type, geochemical conditions, the amount of time that groundwater is in contact with arsenic-containing rocks and sediment, the amount of groundwater moving through the aquifer, and evaporative concentration.

Almost one-half of water samples from public-supply wells and one-quarter from domestic wells sampled as part of studies in the Rio Grande aquifer system contained arsenic at a concentration that exceeded the Maximum Contaminant Level.

Arsenic is a nonmetallic trace element that commonly is present in rocks in the Southwest. Drinking water is the primary means by which people are exposed to arsenic, and long-term exposure is associated with many illnesses including skin, bladder, and lung cancers; immunological impairments; and cardiovascular disease. In 2001, the USEPA lowered the MCL for arsenic in drinking water from 50 to 10 µg/L.[25] Groundwater used for public supply in areas where the MCL is exceeded must be treated or mixed with water that contains lower arsenic concentrations to bring levels below the drinking-water standard. Many public suppliers have installed costly facilities to treat contaminated groundwater (see sidebar, The cost of arsenic contamination, p. 54).

Much of the information presented in this section is from the report "Predicted nitrate and arsenic concentrations in basin-fill aquifers of the southwestern United States" (available at http://pubs.usgs.gov/sir/2012/5065/).

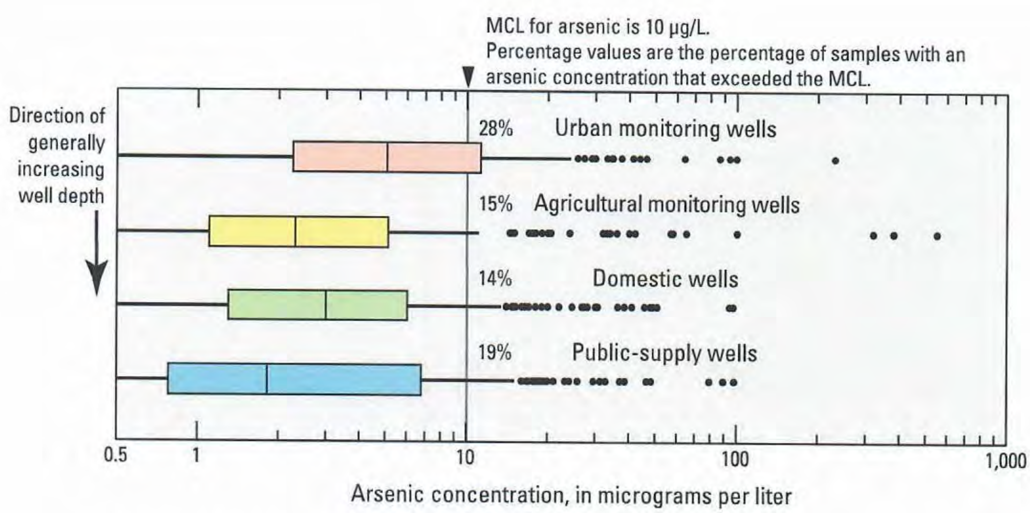
Photographs: Left, Michael Rosen; right, Doug Maurer, USGS

Arsenic occurs throughout the Southwest from geologic sources such as volcanic rocks (basalt, left) and geothermal water (discharge from a geothermal powerplant in Dixie Valley, Nevada, right).

Arsenic concentrations exceeded the MCL in about 16 percent of drinking-water wells sampled as part of studies of the Southwest Principal Aquifers (table 5–1). The MCL for arsenic was more frequently exceeded in domestic and public-supply wells in the Rio Grande aquifer system and Basin and Range basin-fill aquifers than in the Central Valley aquifer system or California Coastal Basin aquifers (table 6–1). Samples from almost one-half of the public-supply wells and one-quarter of domestic wells in the Rio Grande aquifer system exceeded the MCL for arsenic. Elevated concentrations—two or more times higher than the MCL—were measured in shallow groundwater sampled from monitoring wells, in addition to deeper groundwater sampled from drinking-water wells in the Southwest (fig. 6–2). Overall, arsenic concentrations exceeded the MCL in 19 percent of the 1,018 wells sampled as part of the NAWQA Program studies in the Southwest. This amount is consistent with a larger USGS dataset for the region (fig. 6–3) that was used to simulate arsenic concentrations.

Table 6–1. Percentage of samples with an arsenic concentration that exceeded the MCL of 10 µg/L. See appendix 2, table A2–2, for the number of wells sampled.

Type of well	All aquifers in Southwest Principal Aquifers group	Basin and Range basin-fill aquifers	Central Valley aquifer system	California Coastal Basin aquifers	Rio Grande aquifer system
Urban land-use monitoring wells	28	42	15	20	11
Agricultural land-use monitoring wells	15	51	10	Not sampled	3.3
Domestic wells	14	21	8.1	0	24
Public-supply wells	19	24	0	3.2	48
All sampled wells	19	30	8.8	6.3	17



See sidebar, Boxplots, p. 53

Figure 6–2. Arsenic concentrations in wells ranged from less than 1 to more than 100 µg/L. Although median concentrations in the monitoring, domestic, and public-supply wells were less than the Maximum Contaminant Level (MCL), many samples had concentrations up to 10 times higher than the MCL.

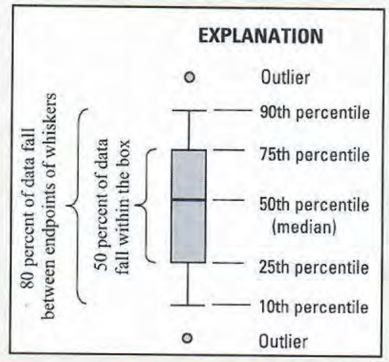
Boxplots

Boxplots are used to illustrate how results are distributed within a group. The "box" ranges from the 25th to the 75th percentile and represents 50 percent of the data. The horizontal line in the middle of the box is the median value—one-half of the values in the group are greater than the median and one-half are less.

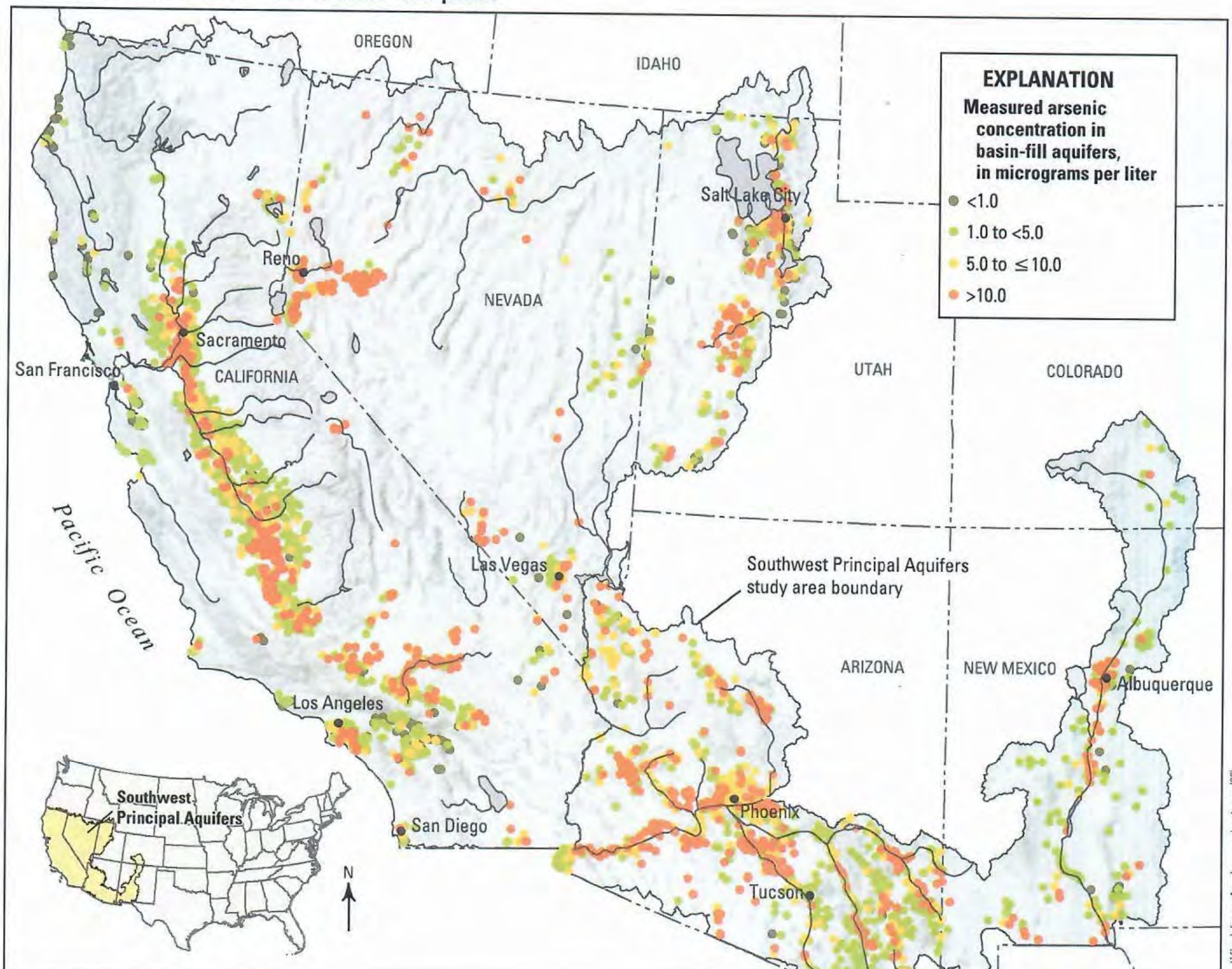
Percentiles describe the percentage of values in a group that are less than the given value: 25 percent of the values in a group are less than the 25th percentile; 75 percent of the values in a group are less than the 75th percentile. The median is also the 50th percentile.

If, for example, the 75th percentile for the measured concentration of a contaminant in a group of wells is equal to the human-health benchmark for that contaminant, then 75 percent, or three-fourths, of the wells have a concentration of that contaminant less than the benchmark, and 25 percent, or one-fourth, have a concentration greater than the benchmark.

The "whiskers" (vertical lines) in these figures extend to the 10th and 90th percentiles; box and whiskers together represent 80 percent of the data. Values greater than the 90th or less than the 10th percentile are shown as individual points (outliers).



Measured arsenic concentration in basin-fill aquifers



Modified from Anning and others (28)

Figure 6–3. During 1980–2009, USGS studies in the Southwest were conducted to measure arsenic in a total of 4,162 wells that tap basin-fill aquifers. About 19 percent of arsenic concentrations in these wells were greater than the MCL of 10 µg/L, consistent with data from this study (table 6–1). There are few or no arsenic data for groundwater in large areas in the Southwest, mostly because there are few people in these areas and, therefore, few wells.

The cost of arsenic contamination

The USEPA estimated in 2001 that the annual cost to reduce arsenic concentrations to below the MCL would range from $0.86 to $32 per household for customers of large public water systems (more than 10,000 people) to $165 to $327 per household for very small systems (25–500 people).[25] Water supplies in the Southwest are limited and often naturally contain arsenic concentrations high enough to require treatment. According to fiscal year 2010 statistics,[68] 274 public water systems in California, Nevada, Utah, Arizona, and New Mexico—mostly small systems that lack a large customer base to pay for water treatment—had a water source containing arsenic concentrations that exceeded the MCL for arsenic.

In Fallon, Nevada, groundwater supplying about 8,400 residents and a nearby Naval Air Station consistently contains arsenic concentrations exceeding the MCL. In 2004 a treatment facility was installed for arsenic removal at a cost of $19 million.[69] Upgrades to water systems throughout Nevada to remove arsenic have been estimated to cost many millions of dollars.[70]

Photograph by Jeff Ross

The arsenic treatment system for Fallon, Nevada, adds dissolved iron to the water. The iron reacts with the dissolved arsenic to form particles that then are filtered out of the water.

Rock Type, Climate, and Location Within a Basin Affect Arsenic Concentrations in Groundwater

The Southwest contains many areas with volcanic rocks, an arid to semiarid climate, and closed or constricted basins—all factors that contribute to elevated arsenic concentrations in groundwater. Arsenic commonly is found in Southwest basin-fill aquifers in areas with volcanic and crystalline rocks (see extent of volcanic rocks in figure 3–2), geothermal water, and (or) sulfide minerals associated with these geologic settings.[26] Low precipitation rates and high evapotranspiration rates result in low groundwater recharge rates to many Southwest basins. Arsenic remaining after water evaporates accumulates in aquifers in closed or constricted basins with low recharge rates. In contrast, basins with higher recharge rates have more groundwater to flush arsenic from the aquifer.

Volcanic rocks, an arid to semiarid climate, and closed or constricted basins contribute to elevated concentrations of arsenic in Southwest groundwater.

Arsenic concentrations increase as groundwater moves from recharge areas near mountain fronts through arsenic-bearing sediment in the basin toward discharge areas in the basin lowlands.[27] The long flow paths typical of Southwest aquifers contribute to elevated arsenic concentrations measured in basin lowlands because the water is in contact with the aquifer sediment for long periods of time, allowing important geochemical reactions to occur. The area where groundwater is located along a flow path in a basin can be used to infer groundwater age and geochemical conditions, which influence concentrations of dissolved arsenic and other constituents with geologic sources in an aquifer. In general, as groundwater moves along a flow path, pH increases and the concentration of dissolved oxygen decreases.

The interaction of arsenic with metal oxides, particularly iron oxide, is one of the most important processes by which groundwater can become enriched or depleted in arsenic. When geochemical conditions favor arsenic release (desorption) from oxide surfaces, groundwater concentrations are higher than when geochemical conditions favor arsenic attachment (adsorption) to oxide surfaces. Adsorption and desorption of arsenic are controlled largely by the concentration of dissolved oxygen in groundwater and by pH. Generally, if the pH of the groundwater is less than 8, arsenic adsorbs to iron oxides, removing it from groundwater (fig. 6–4). If the pH is greater than 8, arsenic tends to desorb from the iron oxides and dissolves into the groundwater. Under anoxic conditions, iron oxides dissolve and release iron and arsenic into the groundwater regardless of pH.

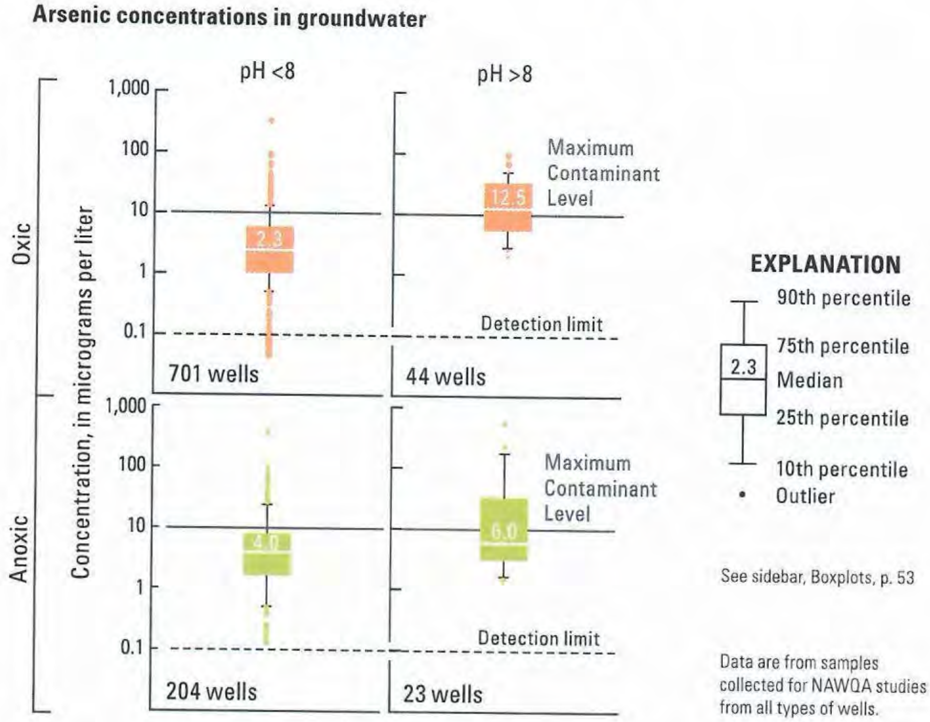


Figure 6–4. More arsenic typically is dissolved in groundwater from Southwest basin-fill aquifers under oxic conditions at a pH greater than 8 than under anoxic conditions at a pH less than 8. The pH and redox condition of the groundwater affect whether arsenic adsorbs to iron oxides on the aquifer sediment or is released into groundwater.

Photographs: Left, Michael Rosen; right, Susan Thiros, USGS

Arsenic can attach to iron oxide (reddish-brown color visible in photographs) that is present in cracks in rocks (left) and that coats basin-fill sediment (right). The pH and redox conditions in an aquifer determine if the arsenic remains attached to the iron oxide or dissolves into the groundwater. Recharged oxygenated irrigation water and groundwater pumping commonly cause the water table to fluctuate, which can release arsenic from basin-fill sediment into the groundwater.[32]

The Middle Rio Grande Basin—An example of the influence of geology, water source, and geochemical conditions on arsenic concentrations in groundwater

Arsenic concentrations greater than 20 µg/L—twice the current MCL—have been measured in groundwater throughout the Middle Rio Grande Basin, New Mexico. Groundwater is the main source of drinking water for many communities in the basin. To deliver drinking water that does not contain arsenic concentrations above the MCL, some public water suppliers use arsenic treatment systems, blend high-arsenic groundwater with low-arsenic water, or both. Groundwater was the primary source of drinking water for Albuquerque residents until late 2008 when low groundwater levels caused by pumping prompted the city to import and treat surface water; since that time, groundwater continues to be a secondary source of drinking water.

Arsenic in the Middle Rio Grande Basin originates predominately from one of two geologic sources, depending on the location within the basin:

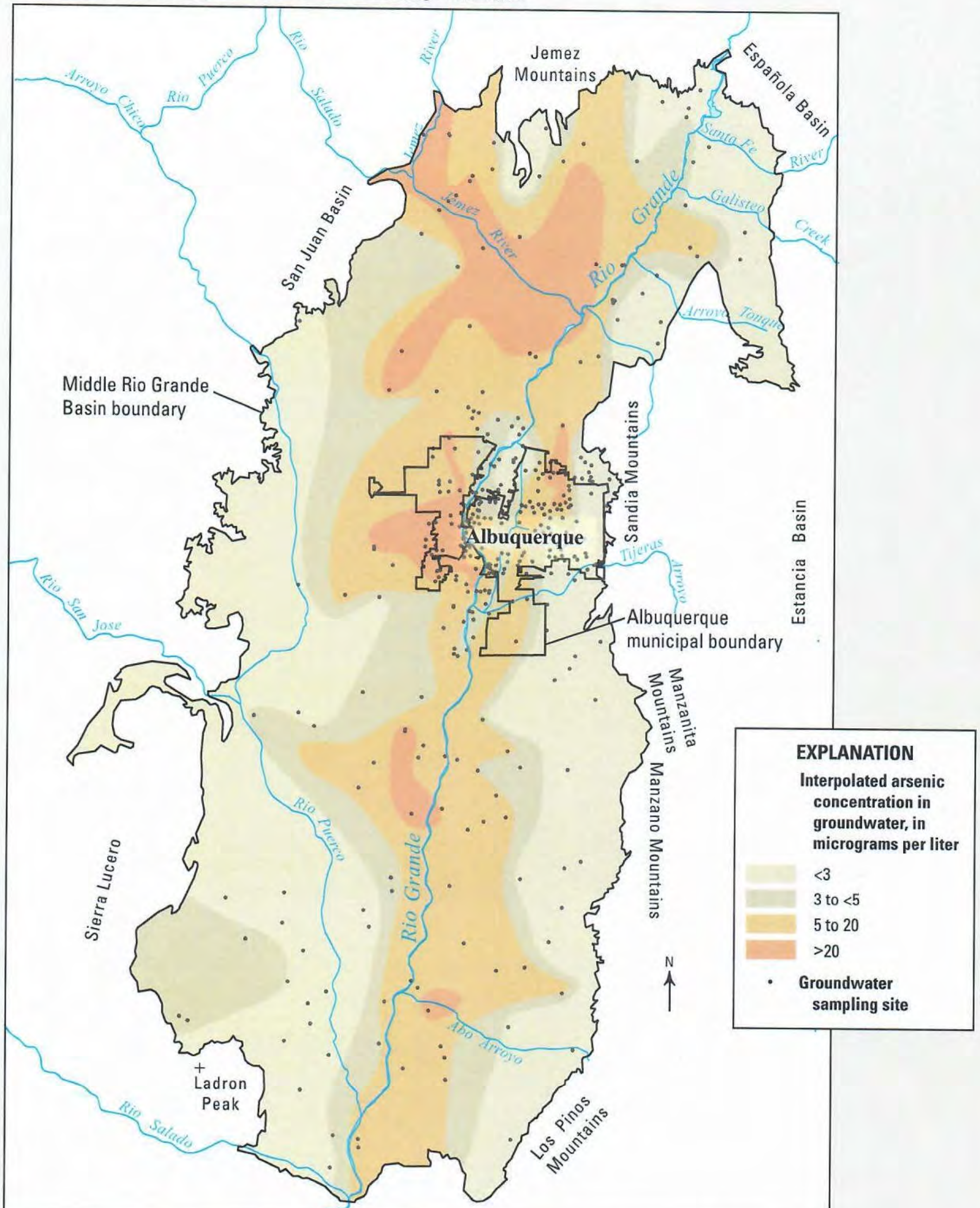
- ***Groundwater inflow from the Jemez Mountains to the north.*** High arsenic concentrations in recharge water from the Jemez Mountains result from contact between water and volcanic rocks rich in arsenic. This source of groundwater recharge affects the aquifer primarily in the northwestern part of the Middle Rio Grande Basin.
- ***Deep mineralized groundwater.*** Groundwater circulating at depth in the Middle Rio Grande Basin has high concentrations of arsenic, chloride, and other elements. This deep groundwater comes into contact with shallower groundwater where it flows upward, primarily along fault zones throughout the basin. Evidence of this mixing of shallow and deep groundwater includes locally high dissolved-solids concentrations (exceeding 5,000 mg/L), hot water temperatures (exceeding 125 degrees Fahrenheit [°F]), and the occurrence of arsenite (the reduced form of arsenic) in groundwater at relatively shallow depths.

Arsenic concentrations in groundwater from the Middle Rio Grande Basin also are affected by pH-controlled desorption from iron oxides that coat the aquifer sediment. In some areas where the groundwater was oxygenated with a pH higher than 8.5, arsenic concentrations exceeded 20 µg/L. The arsenic dissolved in this groundwater was present primarily as arsenate (the oxidized form of arsenic).

Photograph by Johanna Siegmann Photography, www.johannasiegmann.com

Residents of the Albuquerque area, New Mexico, depend on water from the Rio Grande and from the basin-fill aquifer. Groundwater west and north of the city contains elevated concentrations of arsenic.

Arsenic concentration in Middle Rio Grande Basin groundwater



Modified from Plummer and others[78]

The highest concentrations of arsenic in groundwater in the Middle Rio Grande Basin are associated with volcanic rocks in the northern part of the basin and with fault zones through which deep, mineralized groundwater rises. Arsenic concentrations in groundwater generally are lower along the eastern and western margins of the basin, where low-arsenic recharge water enters the aquifer, than near the center of the basin, where groundwater has been in contact with arsenic-bearing sediment for a long time.

Estimating Arsenic Concentrations in Areas Where No Data Are Available

The relation between arsenic concentrations in groundwater and rock type, climate, and location within a basin (for example, basin lowlands) was explored using a statistical model.(28) The model provides estimates of arsenic concentrations in areas where no measurements are available (fig. 6–3).

The statistical model found that, in a basin surrounded by volcanic and crystalline rocks, arsenic concentrations are greater in areas with less recharge to the aquifer than in areas with more recharge (fig. 6–5). Areas with relatively low groundwater recharge rates tend to have a longer groundwater residence time resulting in less flushing of arsenic and other constituents from the aquifer than areas with higher rates of recharge. As groundwater moves along the flow

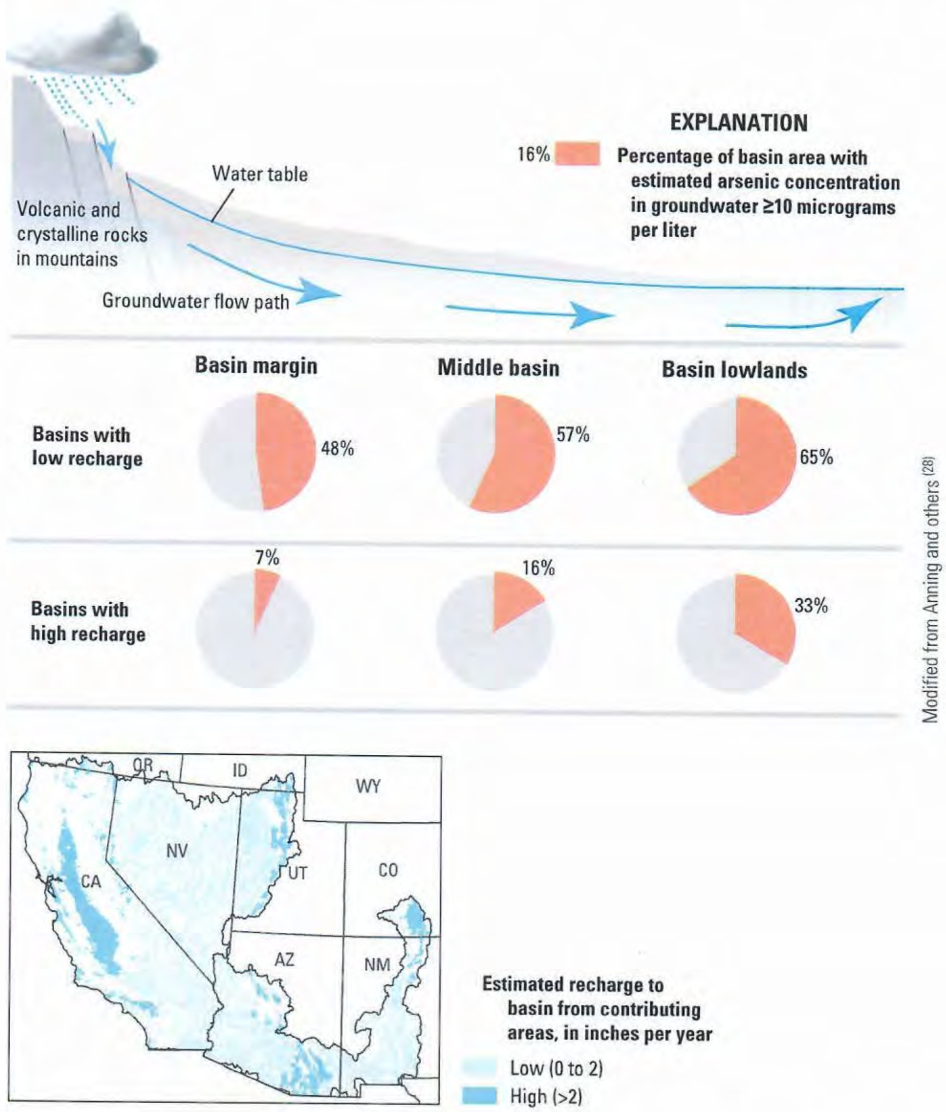


Figure 6–5. Arsenic concentrations in Southwest basins with volcanic and crystalline rocks in the adjacent mountains typically increase with distance along the groundwater flow path because of geochemical reactions between the groundwater and basin-fill sediments derived from the mountains. Aquifers in these areas that have relatively low recharge rates (less than about 2 inches per year) tend to have longer groundwater residence times and higher predicted arsenic concentrations than those that have higher rates of recharge.

path from recharge areas near basin margins to discharge areas in basin lowlands, arsenic concentrations were likely to increase. Arsenic concentrations greater than the MCL are more likely to occur in basin lowlands than in other parts of the basin because of a longer residence time in the aquifer and geochemical reactions between the groundwater and arsenic-bearing sediment.

The model estimates that 43 percent of the area with basin-fill aquifers has arsenic concentrations equal to or greater than 10 µg/L (fig. 6–6). This percentage is higher than might be expected on the basis of measured concentrations because of the inclusion of large areas with arsenic-bearing rocks and constricted groundwater flow. Many of the basins with these conditions are sparsely populated with relatively little groundwater pumping (fig. 4–5) so there are few data on concentrations, primarily because there are so few wells to sample.

Estimated arsenic concentration in basin-fill aquifers

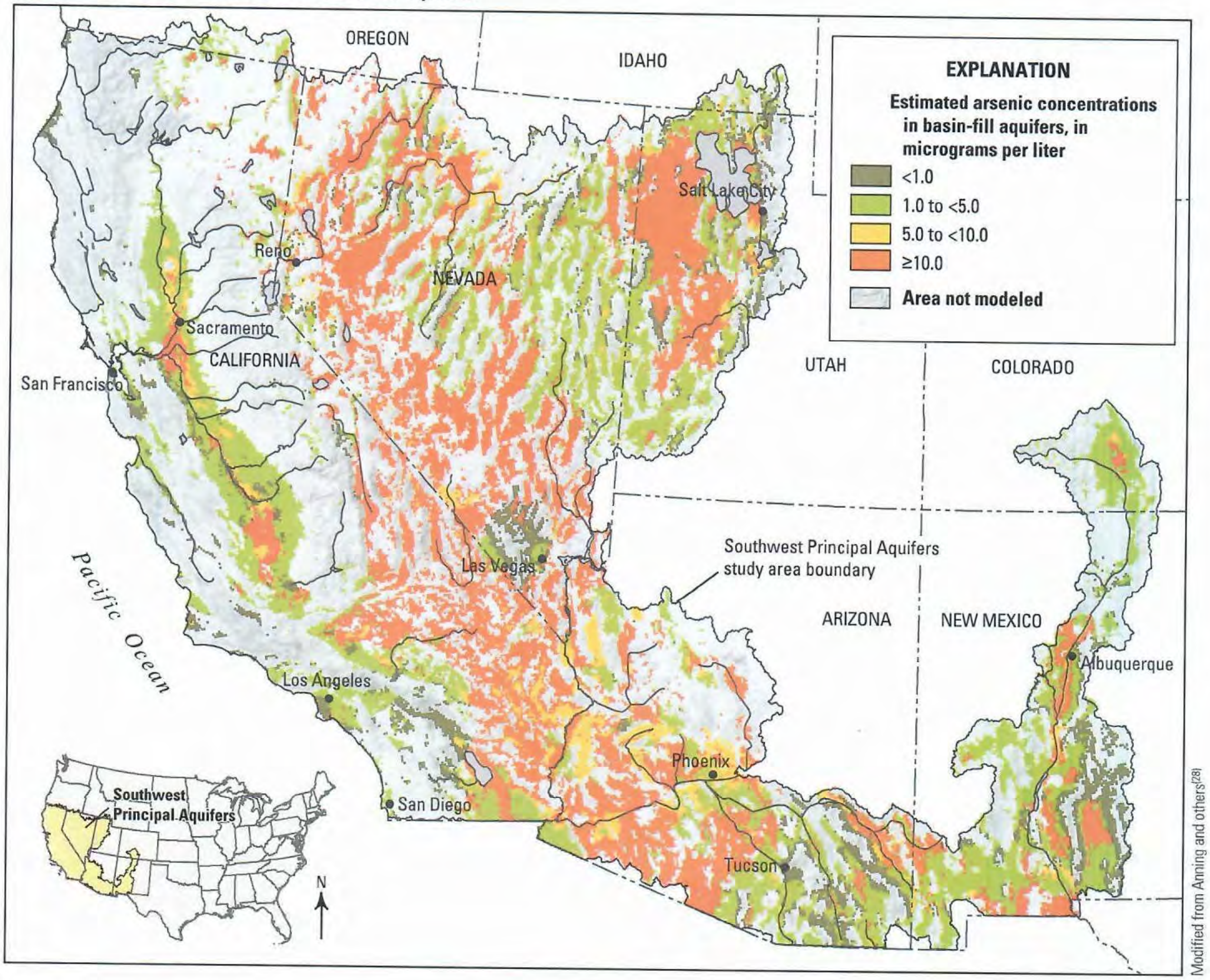


Figure 6–6. Almost half (43 percent) of the areal extent of Southwest basins likely has arsenic concentrations in groundwater that equal or exceed the MCL of 10 µg/L, on the basis of a statistical model. Proximity to volcanic rocks, an arid climate, and lack of groundwater drainage from a basin contribute to high arsenic concentrations. If used for public supply, groundwater in areas with these conditions likely would require treatment to decrease arsenic concentrations to levels acceptable for drinking.

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September, 1952

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ceeded. A discussion of the characteristics of each group follows:

Group 1. This comprised unaltered normal ground water. Four analyses were available for Group 1 water. The wells which yielded this water were located within the present zone of high chloride concentration, and the samples were taken and analyses made in 1934 and 1935 prior to recent degradation of ground water in the zone. The water had total anions ranging from 4.72 to 6.31 equivalents per million, and chlorides from 0.85 to 2.06 equivalents per million. Its mineral quality was excellent.

Group 2. This group comprised waters containing a trace of salinity. Total anions ranged from 8.95 to 10.68 equivalents per million, and chlorides from 5.45 to 6.39 equivalents per million. Four analyses repre-

TABLE 20

COMPLETE MINERAL ANALYSES OF GROUND WATERS IN AREA OF SALINE DEGRADATION IN AND ADJACENT TO SUTTER-YUBA AREA, GROUPED IN ACCORDANCE WITH TOTAL ANIONS

Ground water group	Well location or number	Date of sample	Conductance, Ec × 10⁶ at 25° C.	Boron, in ppm	Mineral constituents, in equivalents per million							Percent sodium
					Ca	Mg	Na	HCO_3 $+CO_3$	Cl	SO_4	NO_3	
1	$N\frac{1}{2}$ Sec. 9, T13N, R3E	5/31/34	483	......	1.40	1.81	1.51	3.30	1.33	0.09	......	32
	$S\frac{1}{2}$ Sec. 10, T14N, R3E	1/ 2/35	543	......	1.70	1.97	1.43	4.25	0.85	Trace	......	28
	$NE\frac{1}{4}$ Sec. 15, T14N, R3E	1/15/35	515	......	1.50	2.13	1.54	3.70	1.47	Trace	......	30
	$NW\frac{1}{4}$ Sec. 28, T14N, R3E	4/30/34	635	......	2.10	2.30	1.91	4.20	2.06	0.05	......	30
	Average	......	544	......	1.67	2.05	1.59	3.86	1.43	0.03	......	30
2	11N/3E-2B1	7/ /49	944	0.16	2.80	2.24	4.31	3.02	5.90	0.03	0.0	46
	13N/3E-3D1	7/ /49	980	0.09	3.59	5.02	2.05	4.20	6.39	0.09	0.0	19
	14N/3E-28R1	7/ /49	1,000	0.12	2.71	5.62	2.58	3.94	6.38	0.13	Trace	24
	14N/3E-33A2	7/ /49	1,037	0.0	2.98	4.29	3.32	5.09	5.45	0.03	0.0	31
	Average	......	990	0.09	3.02	4.29	3.06	4.06	6.03	0.07	Trace	30
3	13N/3E-2P3	7/ /49	1,317	0.17	3.13	3.39	6.46	3.78	9.21	0.04	0.0	50
	13N/3E-5K1	7/ /49	1,353	0.07	3.70	5.53	4.07	4.15	9.14	0.09	0.0	31
	13N/3E-10A1	7/ /49	1,190	0.05	4.40	5.83	2.13	3.91	8.06	0.22	0.0	17
	14N/3E-27E1	7/ /49	1,361	0.0	4.51	5.94	3.38	5.53	7.86	0.45	Trace	24
	14N/3E-29Q1	7/ /49	1,390	0.14	4.14	5.33	4.47	3.23	10.15	0.02	Trace	32
	14N/3E-34J1	7/ /49	1,087	0.0	4.05	5.76	2.57	6.84	3.40	2.01	0.10	21
	Average	......	1,283	0.07	3.99	5.31	3.85	4.54	7.97	0.14	0.02	29
4	13N/3E-2E1	7/ /49	1,503	0.49	2.96	3.05	8.75	3.78	11.11	0.03	0.0	59
	13N/3E-11D1	7/ /49	1,408	0.06	5.21	7.34	1.96	4.17	9.34	0.81	0.0	13
	13N/3E-14G1	7/ /49	1,307	0.06	4.43	6.85	3.44	6.20	7.49	0.71	0.06	23
	13N/3E-23H1	7/ /49	1,408	0.03	5.45	6.73	2.92	4.98	10.23	0.17	0.0	19
	13N/3E-24D1	7/ /49	1,460	1.64	3.23	2.15	9.05	3.90	11.68	0.03	0.0	63
	14N/3E-33A1	7/ /49	1,460	0.0	4.88	6.99	2.82	5.11	9.44	0.09	0.0	19
	Average	......	1,425	0.36	4.36	5.52	4.86	4.52	9.88	0.31	0.01	33
5	13N/3E-5C1	7/ /49	1,835	0.21	4.83	6.00	6.70	3.52	14.08	0.03	0.0	38
	13N/3E-11F1	7/ /49	1,710	0.85	3.29	4.51	9.40	3.26	13.04	0.28	0.0	55
	13N/3E-14J1	7/ /49	1,710	0.31	4.68	8.18	4.87	4.12	12.78	0.43	0.0	27
	14N/3E-28G2	7/ /49	1,653	0.0	5.18	6.92	4.51	5.21	10.95	0.37	0.0	27
	14N/3E-32F1	7/ /49	1,640	0.24	4.90	7.36	4.77	4.35	12.37	0.03	0.0	28
	Average	......	1,709	0.32	4.58	6.59	6.05	4.09	12.64	0.23	0.0	35
6	11N/3E-3B1	7/ /49	2,162	0.93	4.63	2.98	13.94	3.42	18.08	0.03	0.0	65
	13N/3E-2N1	7/ /49	1,802	0.07	5.71	6.31	6.02	4.63	13.61	0.15	Trace	33
	13N/3E-14R1	7/ /49	1,870	0.72	5.35	6.68	6.80	4.88	14.06	0.26	0.0	36
	13N/3E-16R1	7/ /49	2,222	0.03	5.96	8.25	7.27	4.24	17.42	0.03	0.0	34
	13N/3E-32L1	7/ /49	2,062	0.21	5.27	10.09	5.75	2.64	17.26	0.30	0.0	27
	Average	......	2,059	0.39	5.38	6.86	7.97	3.95	16.09	0.15	Trace	39
7	13N/3E-6K1	7/ /49	2,550	0.28	6.62	11.33	8.81	5.08	20.42	0.05	0.0	33
	13N/3E-23B1	7/ /49	3,390	0.0	11.83	16.80	6.71	5.50	29.01	0.34	Trace	19
	14N/3E-31J1	7/ /49	2,425	0.0	7.28	11.08	6.20	5.06	19.26	0.26	Trace	25
	14N/3E-31R1	7/ /49	2,552	0.07	7.36	11.09	6.97	4.98	20.44	0.12	0.0	27
	14N/3E-32L2	7/ /49	2,776	0.27	7.40	9.30	9.81	2.82	23.52	0.04	0.0	37
	14N/3E-21A1	8/ 3/49	2,702	1.71	10.78	4.17	12.60	1.72	22.94	2.01	Trace	46
	Average	......	2,732	0.39	8.55	10.63	8.52	4.19	22.60	0.47	Trace	31
8	$SE\frac{1}{4}$ Sec. 2, T12N, R2E	7/ 9/49	10,000	0.60	30.37	35.30	39.90	4.10	99.45	0.05	0.0	38
	$SW\frac{1}{4}$ Sec. 18, T12N, R2E	3/14/47	8,600	10.8	19.83	7.22	76.12	2.71	99.92	0.08		74
	Average	......	9,300	5.7	25.10	21.26	58.01	3.40	99.67	0.06		56

STRATIGRAPHIC ANALYSIS AND HYDROGEOLOGIC CHARACTERIZATION OF CENOZOIC STRATA IN THE SACRAMENTO VALLEY NEAR THE SUTTER BUTTES

Steven Taylor Springhorn
B.S., California State University, Chico, 2005

THESIS

Submitted in partial satisfaction of
the requirements for the degree of

MASTER OF SCIENCE

in

GEOLOGY

at

CALIFORNIA STATE UNIVERSITY, SACRAMENTO

SPRING
2008

6.0 FUTURE WORK

This study has focused on maximizing the use of existing data and integration of new data to generate a stratigraphic framework of the Valley and improve the overall understanding of the aquifer system. Based on the information collected, a number of data gaps exist and future work is needed. In this section, additional data collection needs are identified including:

- Elevated arsenic concentrations in groundwater related to the Sutter Buttes Rampart material.
- Additional subsurface information is needed in several areas within the central Sacramento Valley.
- Sequence stratigraphic analysis.

These data collection needs are essential to better understand the groundwater resources in the Sacramento Valley near the Sutter Buttes. These additional data will improve knowledge of the basin hydrogeology and significantly enhance the ability of water managers to cooperatively manage the shared resources in a manner that is economically and environmentally sustainable.

6.1 Elevated Arsenic Concentrations in Groundwater Related to Sutter Buttes Rampart Material

Data analyses suggest there is a connection between elevated arsenic concentrations in groundwater and the presence of the Sutter Buttes Rampart volcaniclastic material (which is derived from silicic and intermediate volcanic rocks). In stratigraphic units that occur above and below the Rampart, arsenic concentrations in groundwater are generally less than 10 μg/l (micrograms/liter). In contrast, within Rampart material, arsenic concentrations in groundwater are found in much higher concentrations (10 to 370 μg/l).

Concentrations of arsenic in 27 spatially and depth distributed samples from DWR multi-completion monitoring wells ranged from < 0.1 to 370 μg/l. Concentrations in 15 of the samples exceeded the USEPA current drinking water Maximum Contaminant Level (MCL) of 10 μg/l, and 90 percent of groundwater samples collected from monitoring wells screened in Rampart volcaniclastic material have arsenic concentrations exceeding the MCL.

A detailed geochemical analysis of the relationship between elevated arsenic concentrations and Sutter Buttes Rampart material is needed, because of the health risks associated with this constituent. If a strong link is found between arsenic in groundwater and Rampart volcaniclastic material, the subsurface distribution of the Rampart presented in this thesis can be used in future geochemical investigations to delineate areas that have a high probability of containing elevated arsenic concentrations.

6.2 Location of Data Gaps and Additional Subsurface Data Needed

A significant amount of geologic, geophysical, and hydrogeologic data has been collected to date in the study area; however, there are many areas in the central Sacramento Valley that would benefit from additional geologic, geophysical, and dedicated groundwater monitoring data. These areas include (Figure 6.1):

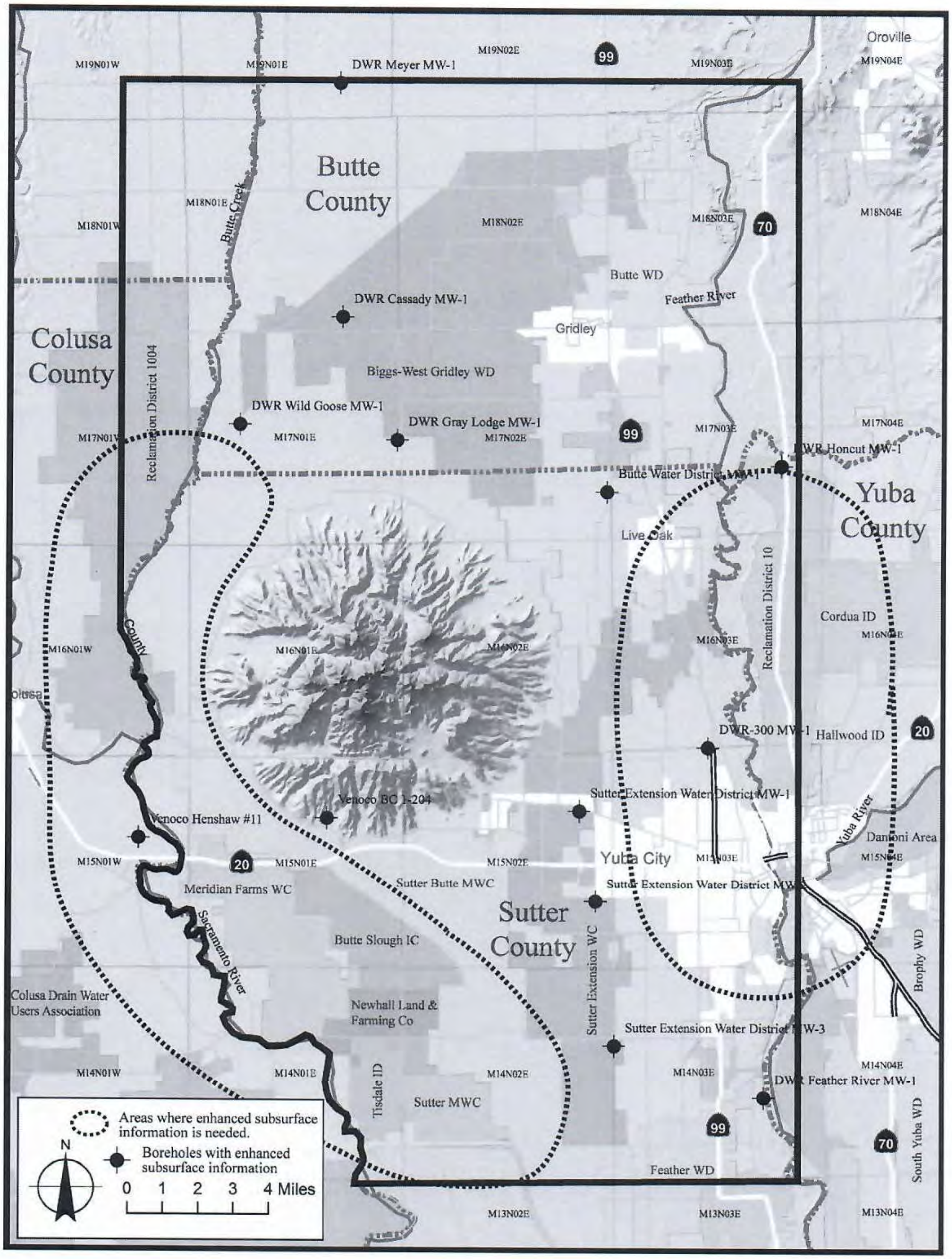
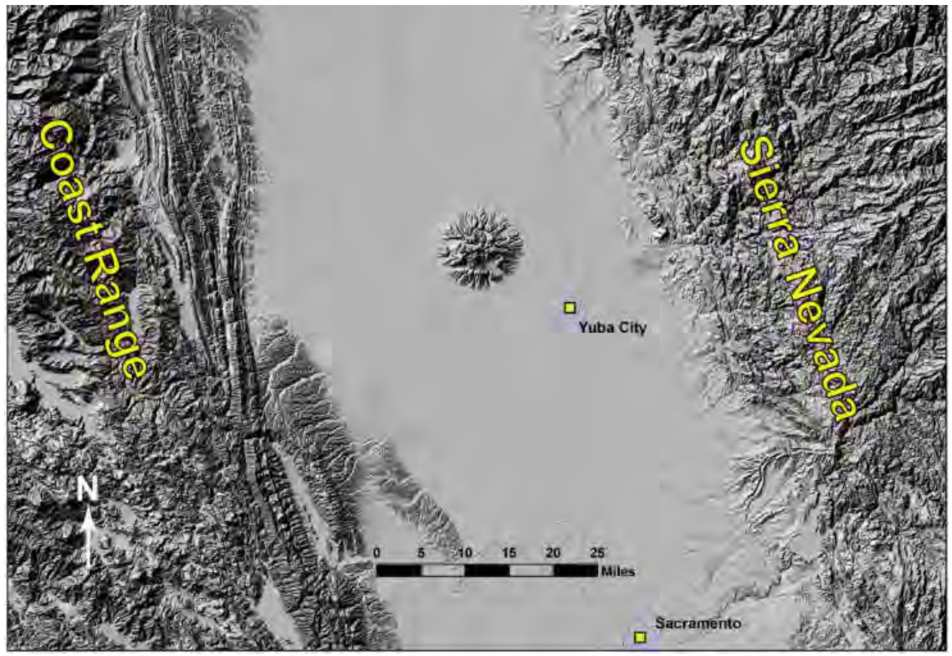


Figure 6.1: Areas where subsurface information is needed.

Sutter Buttes—The Lone Volcano in California's Great Valley

The volcanic spires of the Sutter Buttes tower 2,000 feet above the farms and fields of California's Great Valley, just 50 miles north-northwest of Sacramento and 11 miles northwest of Yuba City. The only volcano within the valley, the Buttes consist of a central core of volcanic domes surrounded by a large apron of fragmental volcanic debris. Eruptions at the Sutter Buttes occurred in early Pleistocene time, 1.6 to 1.4 million years ago. The Sutter Buttes are not part of the Cascade Range of volcanoes to the north, but instead are related to the volcanoes in the Coast Ranges to the west in the vicinity of Clear Lake, Napa Valley, and Sonoma Valley.



Rising 2,000 feet from the center of California's flat Sacramento Valley near Yuba City, the isolated Sutter Buttes were formed by volcanism more than 1 million years ago. Their dramatic isolation is well shown in this shaded-relief image. Base map from U.S. Geological Survey elevation data.

In the fall of 1841 an overland party from the United States Exploring Expedition led by Charles Wilkes traveled down the valley of the Sacramento River in central California, rejoining the expedition's ships later in San Francisco. The geologist of the expedition, James Dwight Dana, could not help noticing in the middle of that broad, flat valley an isolated cluster of hills that tower 2,000 feet above the valley floor "like an island in a vast prairie of millpond smoothness" (Dana, 1849). Dana explored the hills, now known as the Sutter Buttes, on October 16. He recognized them as the remains of an extinct volcano and described the various volcanic rocks found in them, becoming the first geologist to study this distinctive geologic and geographic feature of the valley. Dana also commented, "The whole country, we were told, was flooded during the winter freshets, and the deer and antelope of the plains then take to the Bute hills."

In 1841, an overland party from the United States Exploring Expedition led by Charles Wilkes explored the Sutter Buttes, camping southeast of South Butte, as shown in this lithograph. Engraved by J. W. Steel from a drawing by Alfred T. Agate, an artist with the expedition.

In the 170 years since the Wilkes Expedition, few other geologists have investigated the Sutter Buttes and the surrounding area. In 1929 Howel Williams, a Professor at the University of California at Berkeley, named the major landscape features and correctly outlined the basic geologic history (Williams, 1929). Nearly 50 years later, Williams and his Berkeley colleague, Garniss Curtis, revised and elaborated the volcanic history, aided greatly by radiometric dating of rocks (Williams and Curtis, 1977). In addition, the petroleum industry carried out investigations of sedimentary rocks adjacent to the Sutter Buttes and drilled many deep wells in search of natural gas. Although these investigations have determined the general history of Sutter Buttes, some aspects remain uncertain and are the subject of ongoing investigations.

Regional Geology and Anatomy of the Volcano

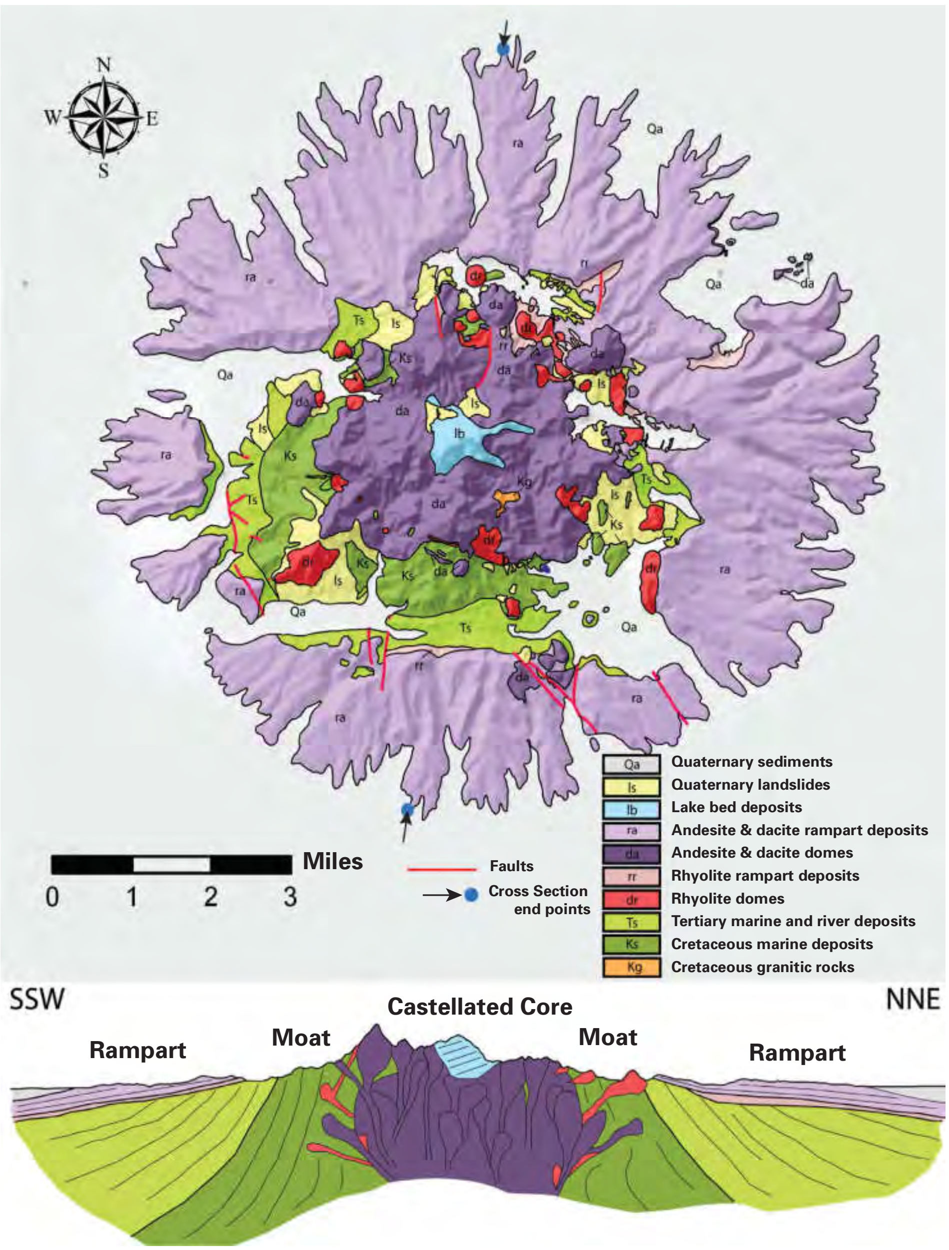
For much of the past 75 million years, the area of the Great Valley of California was a shallow sea that connected to the Pacific Ocean. Rivers carried sediments from the Sierra Nevada and Klamath Mountains and deposited them in this sea. Over time, these sediments were compacted to form an enormous thickness of marine shale and sandstone. The region eventually rose to just above sea level as an immense river valley, dominated by the Sacramento, Feather, and San Joaquin Rivers. Before the volcanic eruptions that formed the Sutter Buttes, the area was a uniform, flat plain on which rivers meandered back and forth, depositing sand, gravel, and mud on top of the earlier marine sediments.

The Sutter Buttes as we see them today consist of three major parts, termed by Professor Williams the "castellated core," the "moat," and the "rampart." The castellated core comprises the high, craggy peaks in the center of the Sutter Buttes. These were formed by batches of partly molten rock (magma) that rose to the surface as viscous plugs, forming steep-sided volcanic features known as "domes." The domes originally looked much like the Chaos Crags in Lassen Volcanic National Park. The fragmented surface materials of the Sutter Buttes domes have now been eroded away, exposing their resistant interior parts.

ACCESS TO SUTTER BUTTES

The Sutter Buttes are mostly in private ranches owned by families that have held title to the lands since the early 1900's. In order to enter these lands for hiking and other activities, nonresidents must arrange access through groups such as the Middle Mountain Foundation (http://www.middlemountain.org).

Geologic Map of the Sutter Buttes Volcano



Geologic map and diagrammatic cross section of the Sutter Buttes. Geology compiled from Williams and Curtis (1977), Thamer (1961), and new mapping by Brian Hausback. The cross section is vertically exaggerated 3X to emphasize the topography.

Immediately surrounding the castellated core is the moat. This low-lying ring of valleys is underlain by sedimentary rocks older than the Sutter Buttes volcano. These include layers of shale, sandstone, and conglomerate that range in age from late Cretaceous (~70 million years ago) to just before the Sutter Buttes first erupted about 1.6 million years ago. The sedimentary layers of the moat have been uplifted and steeply tilted by the intruding volcanic domes of the castellated core, and the soft, weak shales and sandstones have eroded away over time to form the moat valleys.

The outermost part of the Sutter Buttes is the rampart, a broad area of low, outward-sloping hills that were formed by flows of fragmental volcanic debris that moved radially outward from their source in the castellated core. Some of this material resulted from hot, explosive eruptions like most of the eruptions of Mount St. Helens, whereas other material was sloughed off the cooler outer parts of the domes and highland slopes of the castellated core and deposited as debris flows.

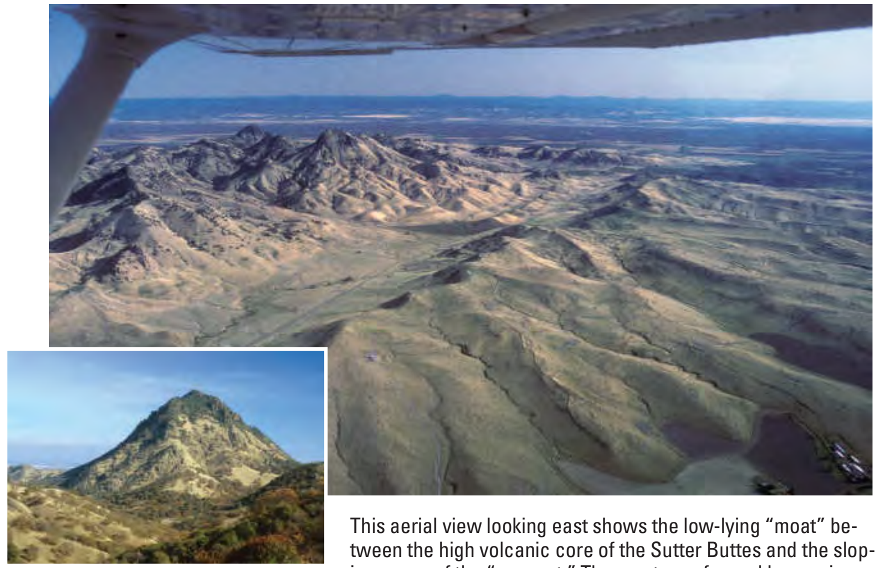
Volcanic History of the Sutter Buttes

The first eruptions at Sutter Buttes occurred about 1.6 million years ago, in the early Pleistocene, when magma pushed upward through the thick pile of Sacramento Valley sediments. Some of the magma breached the surface to form extrusive domes in the rocky core of the Buttes. Explosive eruptions pulverized the extruding magma, depositing blocky fragments and volcanic ash that hardened into pyroclastic ("fire-broken") rocks.

The first lavas to erupt were light-colored, often white, rhyolites—rocks rich in silica (SiO_2) and alkalis (potassium and sodium) but poor in magnesium and iron. The extruding lavas were so viscous that they accumulated at the surface as thick, pasty blobs, or lava domes. After about 30,000 years, these rhyolites were followed by more voluminous eruptions of andesite and dacite, lavas lower in silica and higher in magnesium and iron than the earlier rhyolites. Forming much larger domes, the andesites and dacites are darker in color than the rhyolite, typically medium to dark gray, contain abundant large crystals, and are commonly oxidized (rusted) to brick red.

The andesite-dacites erupted through numerous vents distributed throughout the castellated core. In addition to the magma that erupted at the surface, much andesite-dacite magma lodged below the ground as intrusive bodies, spreading and lifting the preexisting sedimentary layers. In this way, originally horizontal sedimentary layers around the perimeter of the volcano were bent upward to vertical and in some places overturned. This deformation is best displayed in the south moat of the volcano (see cross-section and map).

The eruption of voluminous andesite-dacite continued until about 1.4 million years ago, creating the mountainous interior of the Sutter Buttes. Eruptions of volcanic domes were at times explosive because of an abundance of gases (mostly water vapor, carbon dioxide, and sulfur gases) in the magmas. The explosive eruptions fractured the dome rocks into fragments ranging from fine ash to giant blocks. These pyroclastic materials were carried downslope from the domes as slurries of debris made fluid by either hot volcanic gases (pyroclastic flows) or liquid water (lahars). The very hot pyroclastic flows and the cooler lahars accumulated around the base of the castellated core in layer after layer of debris, forming the gently outward-sloping rampart, a continuous debris apron or "fan" all the way around the castellated core of volcanic domes and over the truncated top of the surrounding moat sediments.



This aerial view looking east shows the low-lying "moat" between the high volcanic core of the Sutter Buttes and the sloping apron of the "rampart." The moat was formed by erosion of soft sedimentary layers pushed up and tilted by the volcanic intrusions. Inset photograph at left shows North Butte, a high and well-preserved dacite dome in the central "castellated core" of the Sutter Buttes.

The sloping outer "rampart" of the Sutter Buttes was built by both volcanic mudflows (lahars) and hot flows of volcanic material (pyroclastic flows) that included large blocks, pictured here with a geologist (U.S. Geological Survey retired volcanolgist Robert L. Smith) for scale.

The lowermost, rhyolitic layers of the rampart are exposed in only a few areas on the outer part of the moat valleys. These rhyolitic pyroclastic deposits are overlain by thick deposits derived from andesitic-dacitic pyroclastic flows and lahars. The uppermost layers of the rampart contain the largest blocks (about 30 feet in diameter), derived from the youngest, tallest, and best preserved domes of the core (South, North, West, Williams, Curtis, and Twin Peaks).

Lakebeds

In the very center of the castellated core are the remnant deposits of a very deep lake that was formed during the volcanic eruptions of the Sutter Buttes. These layered deposits are mostly sands and gravels of andesite-dacite composition and are at least 1,000 feet thick. The lake may simply have filled a basin confined by volcanic domes, or the lake basin may have been excavated by powerful explosions during the andesite-dacite eruptive period. Today the lakebeds are surrounded and truncated by andesite-dacite domes that intruded into the layers and gently deformed and uplifted them to form a high central ridge in the Buttes.

Today's Topography

At the end of volcanism about 1.4 million years ago, the castellated core and the rampart looked much as they do today. The castellated core was dominated by the youngest, tallest andesite-dacite domes. The rampart was a thick accumulation of pyroclastic-flow and lahar deposits. Over the past 1.4 million years, however, the erosional effects of rain, running water, and wind have cut down into the softest and weakest of the geologic materials of the Buttes. Streams and landslides have preferentially cut into the relatively weak shale and sandstone sedimentary layers to carve the moat valleys. Outward-flowing streams have also cut down through the pyroclastic debris layers to form distinctive radial valleys in the rampart. However, the elevations of the hard volcanic domes have probably not been lowered much by erosion.

How Did the Buttes Get There?

An important question is whether the Sutter Buttes are related to the Cascade Range, which extends from the volcanoes of southern British Columbia to Lassen Peak in northern California, or to the Coast Range volcanic

NATURAL GAS IN THE SUTTER BUTTES

For thousands of years, natural gas (largely methane) has leaked to the surface within and around the Sutter Buttes. Sometimes wildfires ignited these gas seeps, causing them to produce eerie blue flames that emerged from cracks in the ground and continued to burn long after the wildfires were quenched by rain. This phenomenon undoubtedly provoked a sense of awe and reverence for these dramatic crags located in the middle of a broad, flat valley. The native Maidu people named the Buttes "Histum Yani" or Middle Mountain.

Unlike the San Joaquin Valley (the southern part of California's Great Valley), the Sacramento Valley to the north has no appreciable deposits of oil, but it does have much natural gas. This gas was generated from microscopic plankton that died and sank to the ancient sea floor to be entombed in marine mud. Gradual burial by as much as 38,000 feet of overlying sediments created high temperatures and pressures that transformed the organic remains into gas. The volcanic upheaval that formed the Sutter Buttes pushed some of these sediments upwards, creating natural traps for methane and other gases rising from depth.

Exploration for gas in the Sutter Buttes area began in 1864, when a local worker and entrepreneur, Dexter Cook, sank a shaft near South Butte. The 30-foot-deep shaft filled with gas and inevitably exploded when he lit a candle at the bottom, injuring four men. The shaft was deepened to 65 feet and then sealed, leaving a pipe extending above the surface. The gas streamed out and for years produced a 5-foot-tall, blue, smokeless flame.

This discovery well at Sutter Buttes still produces gas.

The first commercial natural-gas well in the Sacramento Valley was completed to a depth of 2,727 feet in the southwestern moat of the Sutter Buttes in early 1933. This "discovery well" flowed at 3.4 million cubic feet of gas per day and still produces today, along with many other modern wells. Gas from the wells is collected into pipelines and distributed throughout northern California.

trend, which includes the Berkeley Hills volcanics, the Sonoma Volcanics, and the Clear Lake Volcanics (the youngest of these, with eruptions from 2.1 million years to 10,000 years ago). The Sutter Buttes do not fall on the geographic trend of either the Cascades or the Coast Range. However, the composition, texture, and age of the volcanic rocks suggest that the magmas that formed the Buttes are most likely part of the magmatic system of the Coast Range volcanoes.

But why did eruptions occur at this isolated location in the middle of the Sacramento Valley, far from other volcanoes? Geophysical studies have revealed a prominent north-south linear "ridge" that has anomalously high magnetism and gravity deep beneath the Sacramento Valley and directly under the Sutter Buttes. These geophysical features may be the expression of a buried, inactive fault that separates granitic and metamorphic rocks of the Sierra Nevada to the east from oceanic rocks of the Coast Range to the west. Additional faults intersect this deep crustal fault to provide possible conduits for Sutter Buttes magmas to rise to the surface. The Sutter Buttes contain the only lavas to erupt at the surface in the Great Valley, but rhyolites similar to those at the Buttes are found in the subsurface just to the west, along the Willows Fault.

Within the castellated core, layered lake-bed deposits, more than 1,000 feet thick, attest to the former existence of a lake in the center of Sutter Buttes.

The Sutter Buttes stand as a remarkable geographic and geologic feature of California's Great Valley, and they remain a subject of scientific interest and research. One curious feature is the presence at the surface in the castellated core of a huge block, one-quarter mile across, of crystalline rock (Cretaceous granite) characteristic of the Sierran basement. How was this block carried upward to the surface? Or is it perhaps the tip of an upfaulted sliver of the basement deep below? This is one of many puzzles remaining for geologists to solve in future studies.

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Brian P. Hausback[1], *L.J. Patrick Muffler*[2], *and* *Michael A. Clynne*[2]

Edited by *Peter H. Stauffer*

Graphic design by *Judy Weathers*

[1]California State University, Sacramento

[2]U.S. Geological Survey, Menlo Park, Calif.

COOPERATING ORGANIZATION

Middle Mountain Foundation—The Sutter Buttes Regional Land Trust

For more information contact:
Middle Mountain Foundation
P.O. Box 3359
Yuba City, CA 95992-3359
(530) 755-3568
http://middlemountain.org,
middlemountain@yahoo.com
For hike reservations, contact (530) 671-6116
or
mmfhikes@yahoo.com

From: Mary Fahey <mfahey@countyofcolusa.com>
Date: Friday, March 26, 2021 at 10:51 AM
To: Ben King <bking@pacgoldag.com>, Grant Davids <grant@davidsengineering.com>
Cc: "Ceppos, David M" <dceppos@csus.edu>, Lisa Hunter <LHunter@countyofglenn.net>, "DeBow, Danaka N" <danaka.debow@csus.edu>
Subject: RE: Budget Subarea

Good Morning, Ben;

Going forward please send all inquiries to me rather than directly to the consultants and I will get the information that you need. A good place to get your questions answered directly from the consultants is at the monthly Joint TAC meetings, and other public meetings. There will also be ample opportunity to comment on the GSP chapters as they are released, and again on the final draft GSP.

Regarding your concerns about the subarea water budgets, these have been developed only as a planning tool to support quality control of the model. There are no implications to landowners resulting from these subarea delineations and your parcel is not begin divided up in the plan, or assigned to different districts. As Grant explained, we are utilizing a regional model for the Colusa Subbasin and the resolution is not to the parcel scale, so model elements will not line up perfectly with jurisdictional boundaries.

Thank you,
Mary

From: Ben King [mailto:bking@pacgoldag.com]
Sent: Thursday, March 25, 2021 4:22 PM
To: Grant Davids <grant@davidsengineering.com>; Mary Fahey <mfahey@countyofcolusa.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Lisa Hunter <LHunter@countyofglenn.net>; DeBow, Danaka N <danaka.debow@csus.edu>
Subject: RE: Budget Subarea

Hi Grant,

When you review my parcels I think you can see a good rationale to include them all in the CDMWC budget subarea. Part of them are now and it would preserve the jurisdictional integrity of my membership in the CDMWC. If you do not think that is reasonable I will need to be convinced otherwise after reviewing your model assumptions and understanding your inputs.

Thanks again,

Ben

From: Grant Davids <grant@davidsengineering.com>
Sent: Thursday, March 25, 2021 3:56 PM
To: Ben King <bking@pacgoldag.com>; Mary Fahey <mfahey@countyofcolusa.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Lisa Hunter <LHunter@countyofglenn.net>; DeBow, Danaka N <danaka.debow@csus.edu>
Subject: RE: Budget Subarea

Ben,

I understand your frustration but please recognize that the model structure is based primarily on subsurface physical conditions that affect the flow of groundwater. It's not intended to analyze land surface processes along parcel boundaries. I have not looked closely, but my guess is that most parcels in the subbasin lie completely in one subarea or another. But there are going be some, like yours, that fall on a subarea boundary.

Grant

From: Ben King <bking@pacgoldag.com>
Sent: Thursday, March 25, 2021 12:17 PM
To: Mary Fahey <mfahey@countyofcolusa.com>; Grant Davids <grant@davidsengineering.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Lisa Hunter <LHunter@countyofglenn.net>
Subject: RE: Budget Subarea

Hi Mary,

My family has farmed these parcels for 160 years and I personally have managed them since I was 12 so- about 50 years.

You have split the parcel subareas between CDMWC and COLGWS on no basis that makes sense to me. How can I see the rationale for the designation?

Thanks for the information

Best Regards,

Ben

From: Mary Fahey <mfahey@countyofcolusa.com>
Sent: Thursday, March 25, 2021 11:59 AM
To: Grant Davids <grant@davidsengineering.com>; Ben King <bking@pacgoldag.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Lisa Hunter <LHunter@countyofglenn.net>
Subject: RE: Budget Subarea

Ben, please see attached and let me know if this answers your question.
Mary

From: Grant Davids [mailto:grant@davidsengineering.com]
Sent: Thursday, March 25, 2021 9:51 AM
To: Mary Fahey <mfahey@countyofcolusa.com>; Ben King <bking@pacgoldag.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Lisa Hunter <LHunter@countyofglenn.net>
Subject: RE: Budget Subarea

Ben,

Mary is correct. The water budget subareas are defined by approximate jurisdictional boundaries. I say approximate because the boundaries of model "elements" (small areas for which water budget calculations are made) do not align perfectly with jurisdictional boundaries.

And, as Mary points out, none of this relates to Management Areas, discussion of which is ongoing, as you know.

Grant

From: Mary Fahey <mfahey@countyofcolusa.com>
Sent: Thursday, March 25, 2021 9:19 AM
To: Ben King <bking@pacgoldag.com>; Grant Davids <grant@davidsengineering.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Lisa Hunter <LHunter@countyofglenn.net>
Subject: RE: Budget Subarea

Ben – I am working on a clearer map for you, coming soon.
I just want to point out, because there has been some confusion, that the water budget subareas are completely different from Management Areas. It is not proposed that the basin will be divided up by these water budget subareas. Grant can better explain the technical reasoning behind them. The jurisdictional boundaries are counties, water suppliers and groundwater-only areas.

Hope that helps,
Mary

From: Ben King [mailto:bking@pacgoldag.com]
Sent: Thursday, March 25, 2021 9:10 AM
To: Grant Davids <grant@davidsengineering.com>; Mary Fahey <mfahey@countyofcolusa.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Lisa Hunter <LHunter@countyofglenn.net>
Subject: RE: Budget Subarea

Hi Grant,

The map is not useful to me because there is a bid CDMWC right on top of the south west portion of my property.   I can not tell is all my parcels are in the CDMWC subarea because the letters are larger on the map than the area in the portion of the Subarea under the letters.   As I see the map, there is a possibility that a portion of my property is in RD108 subarea or COLGWS Subarea.

If I could see a map of the area due west and north west of Arbuckle I could decipher the boundaries.

When you mention jurisdictional boundaries – what do you mean?

Best Regards,

Ben

From: Grant Davids <grant@davidsengineering.com>
Sent: Wednesday, March 24, 2021 6:43 PM
To: Ben King <bking@pacgoldag.com>; Mary Fahey <mfahey@countyofcolusa.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Lisa Hunter <LHunter@countyofglenn.net>
Subject: RE: Budget Subarea

Ben,

The subareas correspond approximately to jurisdictional boundaries. See attached map.

Grant

From: Ben King <bking@pacgoldag.com>
Sent: Wednesday, March 24, 2021 6:27 PM
To: Mary Fahey <mfahey@countyofcolusa.com>; Grant Davids <grant@davidsengineering.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Lisa Hunter <LHunter@countyofglenn.net>
Subject: RE: Budget Subarea

Thanks Mary

Did Davids Engineering determine the budget subareas?   What was the rationale for designation?

Best Regards,

en

From: Mary Fahey <mfahey@countyofcolusa.com>
Sent: Wednesday, March 24, 2021 2:12 PM
To: Grant Davids <grant@davidsengineering.com>; Ben King <bking@pacgoldag.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Lisa Hunter <LHunter@countyofglenn.net>
Subject: RE: Budget Subarea

Hi Ben;
Just an FYI, I have taken this off of the Consultant's plate as I have access to GIS parcel layers. I will create an overlay of your parcel with the subarea water budgets and get that over to you as soon as I can. It might be a couple of days.
Thank you,
Mary

From: Grant Davids [mailto:grant@davidsengineering.com]
Sent: Tuesday, March 23, 2021 5:07 PM
To: Ben King <bking@pacgoldag.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Mary Fahey <mfahey@countyofcolusa.com>; Lisa Hunter <LHunter@countyofglenn.net>
Subject: RE: Budget Subarea

Thanks, Ben. I'll see what I can do. Grant

From: Ben King <bking@pacgoldag.com>
Sent: Tuesday, March 23, 2021 5:03 PM
To: Grant Davids <grant@davidsengineering.com>
Cc: Ceppos, David M <dceppos@csus.edu>; Mary Fahey <mfahey@countyofcolusa.com>; Lisa Hunter <LHunter@countyofglenn.net>
Subject: Budget Subarea

Hi Grant,

Thank you again for the reply.

I have attached a parcel map and a topographical map of my property near Arbuckle for your reference

If you could send a more localized map based on my reference maps that would be appreciated
.

Best Regards,

Ben

From: Grant Davids <grant@davidsengineering.com>
Sent: Tuesday, March 23, 2021 3:01 PM
To: Ben King <bking@pacgoldag.com>
Cc: Mary Fahey <mfahey@countyofcolusa.com>; Lisa Hunter <LHunter@countyofglenn.net>; Ceppos,

David M <dceppos@csus.edu>
Subject: RE: Feb 24 TAC Follow Up

Hi Ben,

Do you need a map or can we just tell you which subarea your Arbuckle property is in?

Also, a map of your property rather than an approximate location would help on our end.

Grant

From: Ben King <bking@pacgoldag.com>
Sent: Tuesday, March 23, 2021 1:47 PM
To: Grant Davids <grant@davidsengineering.com>
Cc: Mary Fahey <mfahey@countyofcolusa.com>; Lisa Hunter <LHunter@countyofglenn.net>; Ceppos, David M <dceppos@csus.edu>
Subject: RE: Feb 24 TAC Follow Up

Hi Grant,

My apologies if you are working on this but I wanted to follow up about a more detailed map around property near Arbuckle. As I mentioned I can not determine what subarea my property near Arbuckle is located in. Can you send me a more detailed map?

Thanks again for your assistance.

Best Regards,

Ben

From: Ben King
Sent: Friday, March 19, 2021 4:40 PM
To: Grant Davids <grant@davidsengineering.com>
Cc: Mary Fahey <mfahey@countyofcolusa.com>; Lisa Hunter <LHunter@countyofglenn.net>; Ceppos, David M <dceppos@csus.edu>
Subject: RE: Feb 24 TAC Follow Up

Hi Grant,

Thanks again for the reply. I cant tell what Subarea I am in since there are 3 subareas near my property NE of Arbuckle. My property is east of Grimes Arbuckle Road and west of the Colusa Basin Drain , South of Hahn Road and North of Tule Road. Is there a more detailed map of this area. We were founding members of the Colusa Basin Drain Mutual Water Company but it is not clear all of our parcels are included in this subarea.

Best Regards,

Ben

From: Grant Davids <grant@davidsengineering.com>
Sent: Friday, March 19, 2021 3:03 PM
To: Ben King <bking@pacgoldag.com>
Cc: Mary Fahey <mfahey@countyofcolusa.com>; Lisa Hunter <LHunter@countyofglenn.net>; Ceppos, David M <dceppos@csus.edu>
Subject: RE: Feb 24 TAC Follow Up

Hello Ben,

Grant Davids here, responding for Byron who has been dealing with some health challenges. Apologies for taking so long to get back to you.

I've responded to each of your various requests and questions posed in your emails to Dave Ceppos. Please see the red text below, and let me know directly by email if you have any further questions.

Grant Davids, P.E. | President/Principal Engineer | Davids Engineering, Inc.
1772 Picasso Avenue Suite A Davis, CA 95618| office 530.757.6107 x104 | mobile 530.304.8655

From: Ben King <bking@pacgoldag.com>
Sent: Friday, March 19, 2021 8:55 AM
To: Ceppos, David M <dceppos@csus.edu>; Mary Fahey <mfahey@countyofcolusa.com>
Cc: Ben King <bking@pacgoldag.com>
Subject: RE: Feb 24 TAC Follow Up

Good Morning Dave,

I wanted to follow up again on my information request.

You should know that local farmers are telling others that the sustainable yield for the Basin is 1.9 AF. This needs clarification. The sustainable yield is much, much greater than 1.9 AF, or do you mean 1.9 AF **per acre**? Please clarify.

I just checked the CGA website and I do not see any updates. Updates of what, sustainable yield?

Am I correct that there will be a public disclosure of the Draft Basin Setting? Release of GSP Chapters 1 through 4 is scheduled for early April, including the Basin Setting (Chapter 3). If the 1.9 AF number is correct wouldn't this have to relate to a specific management area or mean that the management area boundaries have already been decided? Not 100% sure what you're asking, but sustainable yield is calculated for the entire basin, and is not tied to any particular sub-portion of the basin.

Thank you in advance for any clarifications. I am assuming that the public can request information regarding the proposed management areas before they are determined so as the public comments could be meaningfully considered. Please let me know if I am correct or not. This is a question or Mary or Dave, but I can tell you that the decision of whether or not to form MAs has not yet been made.

Best Regards,

Ben

From: Ben King
Sent: Friday, March 12, 2021 8:11 AM
To: Ceppos, David M <dceppos@csus.edu>; Mary Fahey <mfahey@countyofcolusa.com>
Cc: Ben King (bking@pacgoldag.com) <bking@pacgoldag.com>
Subject: RE: Feb 24 TAC Follow Up

Good Morning Dave,

I wanted to follow up about the information I requested.

I have orchards in both sub areas and want to understand what the impact of the Model and the potential Management Areas will have.
There are 32 subareas. When you say both, I assume you're referring to Subareas CDMWC and COLGWE? And when you say the Model, I assume you mean model results? I would say that the model results do not have direct impacts, but the results are used to establish the Minimum Thresholds (MTs) and Measurable Objectives (MOs), which could have impacts, particularly the MTs. That's why MTs have been discussed so much at TAC meetings, and will be addressed yet again at the next (4/9) TAC meeting. I don't think potential impacts of Management Areas (MAs) can be addressed until the decision whether or not to form MAs has been made. If the decision is yes, and discussion of MA boundaries begins, that would be the time to assess potential impacts. It's premature now in my opinion.

Thank you again for your time

Best Regards,

Ben
HelloFrom: Ben King <bking@pacgoldag.com>
Sent: Saturday, February 27, 2021 1:09 PM
To: Ceppos, David M <dceppos@csus.edu>; Mary Fahey <mfahey@countyofcolusa.com>
Cc: Ben King <bking@pacgoldag.com>
Subject: Feb 24 TAC Follow Up

Hi Dave,

Can I get a map of all the model subarea in the Colusa County portion of the Colusa Basin? Please see the attached map. It covers the entire subbasin, not just the Colusa County portion.

Also – Does the example on Page 24 tie into real numbers? Yes. The numbers are draft, but they are real. The numbers and graph on the left side of Page 24 seem different than the graphs on Page 20 for example? The information on Page 20 and 24 are for different subareas, so the information will not agree. Page 20 presents information for the GCID – Colusa subarea, while page 24 has information for the CDMWC subarea.

Could I get the data tables for Subareas CDMWC and COLGWE? These tables are in the attached PDF of the Subarea Water Budget technical memorandum. I believe this was provided in advance of the 2/24 Joint TAC meeting.

Thanks for your assistance

Best Regards,

Ben

From: William Vanderwaal <wvanderwaal@rd108.org>
Sent: Thursday, April 8, 2021 9:41 AM
To: Derick Strain <dstrain@strainranches.com>; Mary Fahey <mfahey@countyofcolusa.com>; Jim Wallace Colusa Drain Mutual Water Co. <jimwallace@ecolusa.com>; Lewis Bair <lbair@rd108.org>; Hilary Reinhard (rh_reinhard@yahoo.com) <rh_reinhard@yahoo.com>
Cc: Lisa Hunter <lhunter@countyofglenn.net>; Grant Davids <grant@davidsengineering.com>
Subject: Re: Colusa Subbasin Hydrographs for TAC Review

Mary,
Jim Wallace, Derrick Strain, Lewis Bair, Hilary Reinhard and I looked through these last week and we had some questions. Hopefully, they get to Grant in time so that he can answer them during the meeting tomorrow.

From the Tech Memo:
In "Initial Observations and Comments" point number "2) In general, groundwater levels are more sensitive to surface water supply reductions at wells distant from the Sacramento River as compared to wells near the river. This results in part from near-river pumping causing increased leakage from the river or capture of groundwater that would have otherwise discharged to the river."
This highlighted sentence doesn't make sense to us. Maybe you are trying to say wells near the river are more stable because of their proximity to the river, where as wells distant from the river are more sensitive because they don't have the immediate recharge available(?).

We really like and appreciate the Google Earth set up.

There are two potential controlling factors that determine the MT. Please label which controlling feature it is that controls for each well.

I see from a cursory look at the package for the upcoming meeting that you've included MO's but we noted on these there were not MO's.

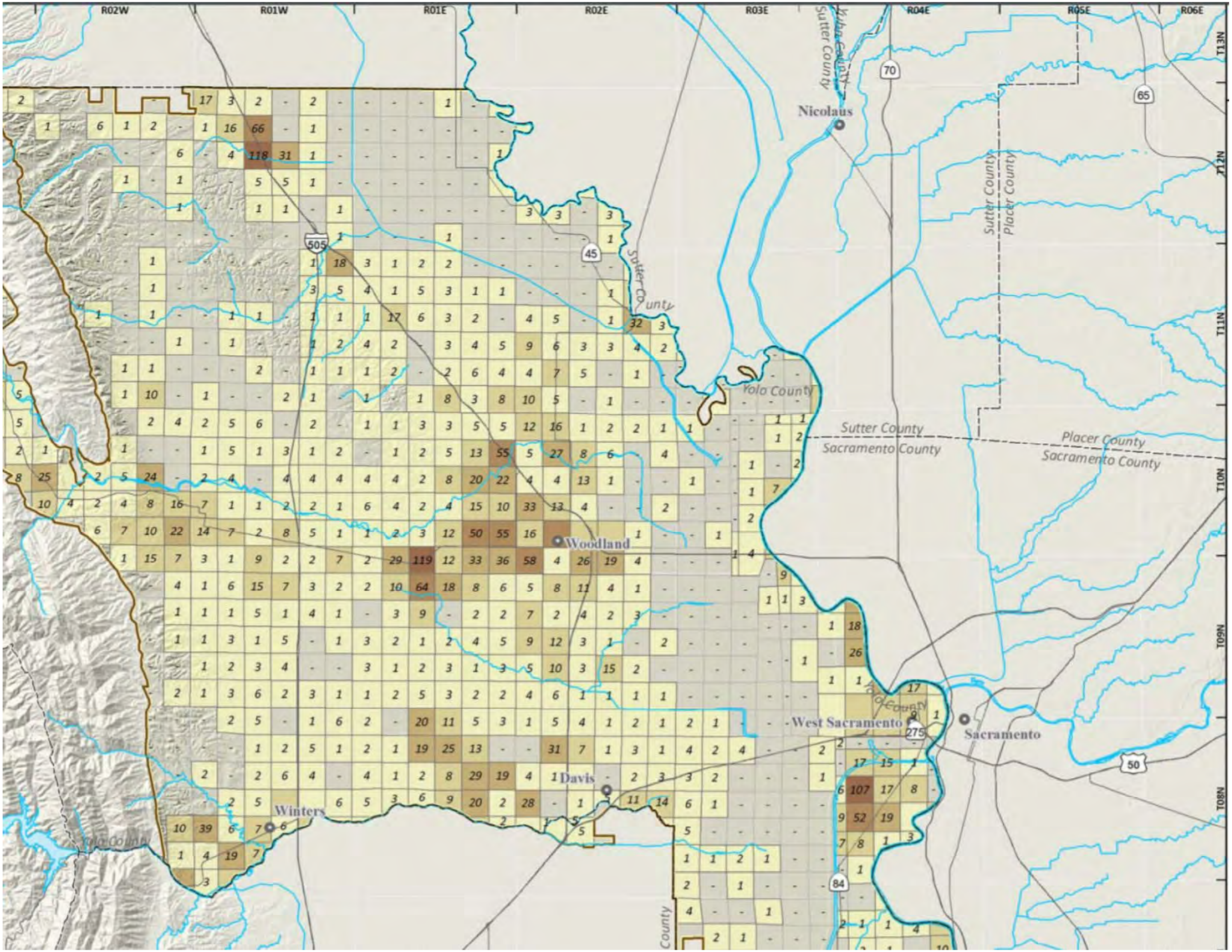
We would like to see the MT/MO compared with the historical well data. We requested and appreciate seeing these compared to the model runs but also want to see how they compare to actual historical. Some MT's seem extremely deep on the initial look.

It would be helpful to also see the number of wells per polygon for each well. That would help us understand the magnitude of wells that could be impacted if the controlling feature is the 20% of domestic wells criteria. I've attached a screen shot of what Yolo has provided in the past that shows domestic well density as an example of what could be helpful.

We have some questions about the water budgets (we were looking through those also). We noticed in CCWD, that the change in storage and the net recharge numbers don't seem to align with what we'd expect. For example, change in storage increases in 'Dry' years, but decreases in 'BN' and 'Critical' years. Also, net recharge is greater (or less extreme) in 'Dry' vs 'BN'. Is there any known explanation for that? Also, this doesn't just occur in CCWD, we're not picking on them, it's just where we noticed it first.

Thanks
Bill V

William Vanderwaal, P.E.
Deputy Manager - RD-108
Manager - Dunnigan WD
(530) 812-6276



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West Sacramento
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From: Bills, Donald J <djbills@usgs.gov>
Sent: Monday, April 12, 2021 6:14 PM
To: Lisa Hunter <LHunter@countyofglenn.net>
Cc: Bills, Donald J <djbills@usgs.gov>
Subject: Some additional questions and comments about the Land Subsidence Discussion at the 4/9 Joint TAC meeting.

Lisa,

A couple of points were made during the discussion on subsidence in the TAC meeting on Friday April 9th. I had comments to add to the discussion but was having difficulty with an unstable ZOOM connection and was unable to contribute. Please feel free to pass this on to however is most appropriate. The points I wanted to comment on are:

1.—Subsidence in the regional aquifer is mostly going to be due to dewatering of clays. Little subsidence occurs related to dewatering of sand and gravels.

2.—Subsidence is largely a surface problem.

3.—There is a significant lag time between groundwater withdrawals and subsidence.

4.—What is critical infrastructure?

5.—Surveyed subsidence monuments every 5 years is not enough.

CAUSES OF SUBSIDENCE (most relevant to Glenn-Colusa area but not discussed)

Natural Processes: Long-term climatic change, which may result in lowering of the water table, drying out of soil and sediment.

Human Causes of subsidence: Withdrawing subsurface fluids, such as water, petroleum, **natural gas, or brine.** Saturating near-surface, low-density, collapsible sediment (i.e. wetlands). Draining or reclaiming land that causes clay to dry out, peat**,** or other organic-rich sediments to decompose, etc.Manipulating certain surface-water and ground-water systems on a large scale (i.e. Stony Creek).

1.—Clays because of their small size have more pore space per volume sand or gravels. When saturated, therefore, they also contain more water that sand or clays. In addition, because of their small pore size, they take a very long time to drain and dry out completely. Once compressed in this manner it is very difficult to re-saturate them. Sand and gravel however can drain and compact quickly in response to groundwater withdrawal. This is the result of the loss of the buoyant support that the water gives the sediment and the compression weight of the overlying sediments as groundwater withdrawals increase. The volume of space occupied by the sediment (sand and gravel) decreases, as does the size of the pores (storage loss). Groundwater caused subsidence like this has been documented in unconsolidated sediments of the San Joaquin Valley as well alluvial basins in Central and Southern Arizona. Recharge, natural or artificial, can recover some of the loss in storage and slow, stop, and even reverse the subsidence. But, the loss in storage and land subsidence cannot be fully recovered.

2.—Subsidence is just one of the surface manifestations of a larger problem in the subsurface; loss in storage. In unconsolidated sediment aquifers common to the Sacramento Valley (sand, gravel, sandy gravel, silty sand, sandy silt, and silty sandy, gravel), compaction will result is a certain amount of storage loss that is not recoverable. The impact will be less groundwater available to water users in the long run. Another surface manifestation of groundwater subsidence are earth fractures and fissures caused by differential settling of dewatered portions of the aquifer.

3.—Groundwater declines resulting from natural, or human caused withdrawals are quickly apparent on local spatial and short term (seasonal and annual) temporal scales. The resultant subsidence, however, may take months, years, or decades to become apparent. Once subsidence is apparent at the surface, it can continue for years or decades after groundwater withdrawals are curtailed (irrigation conservation methods, less consumptive crops, etc.) and/or artificial recharge programs (basin spreading of treated or reclaimed water, instream flow requirements, etc.) established (demonstrated in the San Joaquin Velley and Arizona).

4.—In addition to all the critical infrastructure located at lands surface, I would argue that the aquifer itself is also critical infrastructure. There is a direct impact on ground water users as a result. Land surface around wells compacts or subsides resulting in the need to protect, move, or replace well surface infrastructure. Declining water levels and reduces storage mean less water available to wells and the need for groundwater users to re-develop or deepen existing wells or drill new and deeper ones.

5.—Surveyed subsidence monuments every 5-years is not enough. By the time you notice a change between two measurements the damage is already done and likely to continue for years. There was mention of using the CDWR annual INSAR to fill in between the 5-year monument survey. This is a good start. Another method I did not hear mentioned is gravity measurements both on the ground and via on-orbit remote-sensing. Gravity methods are very sensitive to very small changes in the Earth's local and regional gravity field. Gravity monuments are at least as easy to establish as surveyed monuments (in fact the same sites can be used), or cheaper if established topographic benchmarks are used. Surface gravity measurements can detect storage changes of as little as 0.10ft. On orbit gravity measurements (GRACE and NexGen Grace) are capable of nearly the same accuracy on regional scales. The algorithms to convert gravity measurements to +/- storage change are already available and in broad use. Use of on the ground measurements with remotely sensed data improves the accuracy of both and provide an independent check of the data. In Arizona Seasonal and longer-term trends in storage change have been detected and with groundwater level data provide an early warning of impending subsidence.

Selected References

Davis, S.N., 1983, Measurement, prediction, and hazard evaluation of earth fissuring and subsidence due to ground-water overdraft: University of Arizona, Department of Hydrology and Water Resources, Office of Wa ter Policy Project B-092-ARIZ Report, 44p

.

Ireland, RL., Poland, J.F., and Riley, F.S., 1984, Land subsidence in the San Joaquin Valley, California, as of 1980: U.S. Geological Survey Professional Paper 437-I, 193 p., scale 1:126,720.

Lofgren, B.E., and Klausing, R.L., 1969, Land subsidence due to groundwater withdrawal, Tulare-Wasco area, California: U.S. Geological Survey Professional Paper 437-B, 101 p.

Schumann, H.H., Laney, R.L., and Cripe, L.S., 1986, Land subsidence and earth fissures caused by ground-water depletion in southern Arizona, in Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States—Southwest alluvial basins of Arizona: American WaterResources Association Monograph Series 7, p. 81-91.

Donald Bills
Emeritus Scientist/Hydrologist
Flagstaff Science Campus
USGS Arizona Water Science Center, Flagstaff Programs
2255 N. Gemini Dr.
Flagstaff, AZ 86001
(928) 556-7742

djbills@usgs.gov

From: Mary Fahey
To: Ken Loy
Cc: Ceppos, David M; Choppin, Corin
Subject: FW: Arsenic Near Grimes
Date: Friday, October 29, 2021 8:39:14 AM

FYI,
Mary

From: Ben King [mailto:bking@pacgoldag.com]
Sent: Friday, October 29, 2021 7:46 AM
To: Mary Fahey <mfahey@countyofcolusa.com>
Cc: Ceppos, David M <dceppos@csus.edu>
Subject: RE: Arsenic Near Grimes

Thank you Mary,

Great explanation. The 200 ug/L typo was concerning since it would be the highest observed arsenic observation west of the Sacramento River south of the Sutter Buttes – this was my concern. I also appreciate that he identified the source as being the public supply system for Colusa County WWD#1. Unfortunately I just found out that the well for the Meridian elementary school also has arsenic contamination around the 28 ug/L also.

Best Regards,

Ben

From: Mary Fahey <mfahey@countyofcolusa.com>
Sent: Friday, October 29, 2021 7:18 AM
To: Ben King <bking@pacgoldag.com>
Subject: FW: Arsenic Near Grimes

Ben – please see below from Ken Loy.
Mary

REMINDER: This email originated from outside of the organization, only you can prevent ransomware attacks. Do not click links or open attachments unless you recognize the sender and know the content is safe. When in doubt, contact the Helpdesk at helpdesk@countyofcolusa.com.

Mary:

The 200-µg/L arsenic concentration Ben King referred to in his email below was an error in the first draft of Chapter 3 of the Colusa Subbasin Groundwater Sustainability Plan (GSP) announced for public review on April 8, 2021. This error was corrected in the complete draft of the Colusa Subbasin GSP announced for public review on September 14, 2021. This correction was also documented in the GSP comment-response summary table (Appendix 2B-1) of the September 14, 2021 public draft GSP.

The correct arsenic concentration of 28 µg/L was measured in January 2012 by Colusa County WWD #1 – Grimes in their Well 1 and reported to the State Water Resources Control Board (State Board) Division of Drinking Water. The data are available at the State Board California Drinking Water Watch website.

https://sdwis.waterboards.ca.gov/PDWW/

The specific result can be found at this link:

https://sdwis.waterboards.ca.gov/PDWW/JSP/WSamplingResultsByStoret.jsp?SystemNumber=0600008&tinwsys_is_number=142&FacilityID=001&SamplingPointID=001&SystemName=COLUSA+CO.+WWD+%231+-+GRIMES&SamplingPointName=WELL+01&Analyte=&ChemicalName=&begin_date=&end_date=&mDWW=

Thank you,

Ken

Ken Loy

Principal Hydrogeologist
We're hiring! Visit our career site, here

WEST YOST
direct 530.792.3276

From: Ben King <bking@pacgoldag.com>
Sent: Thursday, October 28, 2021 2:17 PM
To: Mary Fahey <mfahey@countyofcolusa.com>
Cc: Ken Loy <kloy@westyost.com>
Subject: RE: Arsenic Near Grimes

[This message has originated from outside of West Yost]

Hi Mary,

Do you have an answer about the 200 ug/L – where is this well? The current draft just states that it is 28 ug/L – this seems to be the public supply well for Grimes. What about the 200 ug/L well?

Thanks

Ben

From: Mary Fahey <mfahey@countyofcolusa.com>
Sent: Tuesday, July 6, 2021 4:29 PM
To: Ben King <bking@pacgoldag.com>
Subject: RE: Arsenic Near Grimes

HI Ben – this question has been forwarded to the Tech. team. This will likely take a little time to get an answer as well due to the pending release of draft Chapters 5 and 6.
Mary

From: Ben King [mailto:bking@pacgoldag.com]
Sent: Wednesday, June 30, 2021 6:51 PM
To: Mary Fahey <mfahey@countyofcolusa.com>
Subject: Arsenic Near Grimes

Hi Mary,

Here is an excerpt from Chapter 3 of the GSP.

3.2.5.2.1 Arsenic Arsenic is a naturally occurring constituent in groundwater and commonly occurs at concentrations ranging from 10 to 50 µg/L in the western United States, where it is typically associated with alluvial- lacustrine basin-fill deposits and volcanic rocks and sediments (Welch, et. al., 1988). The primary MCL for arsenic in drinking water is 10 µg/L (SWRCB, 2018a**). Arsenic has been detected near Grimes at concentrations of approximately 200 µg/L. A** federal program was initiated to install filters on water connections and reduce the arsenic concentration (Glenn County, 2005). Recent concentrations of arsenic in wells near Grimes have been less than 20 µg/L. The elevated arsenic concentrations near Grimes were determined to be due to natural conditions (Glenn County, 2005), and is potentially impacted by Sacramento River stream channel and its proximity of the Sutter Buttes and the Colusa Dome.

Can you send me the information regarding the location and measurement for the 200 ug/L measurement for Arsenic near Grimes?

Best Regards,

Ben

Choppin, Corin

From: Mary Fahey <mfahey@countyofcolusa.com>
Sent: Monday, October 25, 2021 11:53 AM
To: Choppin, Corin; Ceppos, David M
Cc: Lisa Hunter
Subject: FW: Sycamore Marsh Farm Recharge PMA Comments

Hi Corin – please add Ben King's comments below to the Admin record.
Thank you,
Mary

From: Mary Fahey
Sent: Monday, October 25, 2021 11:51 AM
To: 'Ben King' <bking@pacgoldag.com>; Grant Davids <grant@davidsengineering.com>
Subject: RE: Sycamore Marsh Farm Recharge PMA Comments

Ben;
Thank you for your comments and providing your family's background in the project area. Your comments will be added to the Admin. Record. I have also been contacted by the Dunlaps who are interested in participating in recharge projects in the area and they have submitted a PMA Solicitation Form.

As you know, projects in the Plan that the GSAs will oversee will not be implemented until they are vetted, refined and approved by the GSA boards. At that time, any coordination or integration with other project proponents can be defined.

Thank you,
Mary

From: Ben King [mailto:bking@pacgoldag.com]
Sent: Monday, October 25, 2021 11:38 AM
To: Mary Fahey <mfahey@countyofcolusa.com>; Grant Davids <grant@davidsengineering.com>
Cc: Ben King <bking@pacgoldag.com>
Subject: Sycamore Marsh Farm Recharge PMA Comments

Hi Mary and Grant,

I was able to see the PMA submission for the Sycamore Marsh Farm Recharge Project.   It seems like a great project but I wanted to point out that part of the project area is land that is owned by T&M King Farms LLC which is owned and managed by me.   I have included the map that was part of Appendix 2C and circled the portion of the parcel owned by T&M on the east side of the Colusa Basin Drain.   I also want to mention that there should be close coordination with the land owned by John and Tina Dunlap directly to the south of the Marsh project area since it is also part of the Sycamore Slough.   Since the project includes the Sycamore Slough the whole of the Slough south of Grimes Arbuckle road will have to be included in the project since it is part of the same waterway and ecosystem.   I know this area well because the Dunlap property and parts of the Marsh property because it was originally owned by my great grandparents as part of the Sherer and King pioneer farms.

We would love to be included on this project.

Best Regards,

Ben

From:	Mary Fahey
To:	Choppin, Corin
Cc:	Ceppos, David M; Lisa Hunter; Grant Davids
Subject:	FW: Public Meeting Follow Up
Date:	Thursday, November 4, 2021 9:18:45 AM

Hi Corin;
See below, questions from the October 13 virtual SGMA Series meeting (she watched the recording), for the admin record.

I also have some information to share from our legal counsel regarding what comments need to be documented in the record and in Appendix 2A. Maybe we can discuss on the call today if that is still on?

Thanks,
Mary

From: Mary Fahey
Sent: Thursday, November 4, 2021 9:12 AM
To: 'Ashley Driver' <ashley.mcarthur13@gmail.com>
Subject: RE: Public Meeting Follow Up

Hi Ashley;
To answer your questions:
Was follow-up information provided on how the groundwater pumping fees will be calculated?
There have been no decisions regarding a pumping fee. Those discussions will start happening early next year. It is still to be determined how/if fees will be instated. Those discussions and decisions will happen at public GSA Board meetings. There may be other subcommittee meetings where recommendations for the Boards will be developed.

Also, how easy is it to adjust our compliance markers (e.g. minimum thresholds)? Is there a formal process, is the public included, and does the state have to approve changes?
The GSAs are required to report annually on their progress and to update the Plans every five years. They can adjust the Sustainable Management Criteria during these updates. Any adjustments will need to be justified to DWR with data and reasoning, and DWR will have to approve any changes. It will be a public process, likely similar to what has been done the last couple years with information coming to the Technical Advisory Committees at public meetings and then to the Boards at their public meetings for final decisions.

I hope that answered your questions. Let me know if anything is not clear.
Thank you,
Mary

From: Ashley Driver [mailto:ashley.mcarthur13@gmail.com]
Sent: Wednesday, November 3, 2021 11:24 AM

To: Mary Fahey <mfahey@countyofcolusa.com>
Subject: Public Meeting Follow Up

Hi Mary!

Thank you for sharing the meeting recording. I finally had enough time to watch it this morning, and a lot of my questions were answered. I appreciate the recording and you sharing it.

I do have a couple more questions, and I am wondering if you can answer them. Was follow-up information provided on how the groundwater pumping fees will be calculated? If not, where can I find that information? Also, how easy is it to adjust our compliance markers (e.g. minimum thresholds)? Is there a formal process, is the public included, and does the state have to approve changes?

Thank you, again, and have a wonderful day!

Ashley

--
Ashley Driver, Ed.S.
(530) 665-3441
Driver Performance Improvement

From:	Ben King
To:	Mary Fahey; Gosselin, Paul
Cc:	Buck, Christina; Ben King
Subject:	Arsenic and Connate Sea Water Contamination around the Sutter Buttes
Date:	Monday, July 06, 2020 1:17:17 PM
Attachments:	Sutter_County_Final_GMP_20120319 (1).pdf Sutter County GMP Figures.pdf CA-Arsenic-Report.pdf

Hi Mary, Paul and Christina,

I wanted to follow up regarding my public comment on the last Butte Basin call. As mentioned in my call, my concern is that the connate seawater under the Sutter Buttes is contaminating groundwater and drinking water quality.

I have previously sent the SWCB Bulletin No. 6 from 1952 and the PHD Paper by George Curtin from 1971. Bulletin No. 6 reported that pumping depressions were drawing salt brines to the surface causing groundwater contamination. Curtin's paper proposes that the connate seawater is moving laterally through faults around the Buttes and researched several hundred gas well logs to express this opinion.

According to the Sutter County GMP on Page 23 "The Sutter Buttes Rampart consists largely of gravel, sand, silt and clay sediments which were deposited circumferentially around the Buttes as a geologic apron. These sediments may extend up to 15 miles north and west beyond the Sacramento River. " On Page 32 the GMP addresses the arsenic contamination issue - "… recent data analysis suggest a possible correlation between elevated arsenic concentrations and the presence of volcaniclastic material of the Sutter Buttes Rampart formation." Since the Colusa and Butter Basins are within the 15 mile circumference of the Sutter Buttes this would impact the analysis for Lower Water Quality and potentially Seawater Intrusion SGMA Sustainability metrics. I am mentioning the Seawater Intrusion metric because of the hydraulic components of pumping depressions and the physics of natural occurring contaminants moving laterally from higher elevations to lower elevations in combination of the force of pulling water to the surface by the operation of groundwater wells.

You will see the elevated EC levels and arsenic levels in the GMP Figures attachments. On Figure 19, there was an observation at T15NR3E of arsenic at 350 ppm and an EC of 1126. To the south at 14NR2E the observation of arsenic at 370 ppm and an EC of 1400. Since this study was focused on Sutter County there were not observations for Colusa County and Butter County. For Colusa County – the attached report regarding Arsenic contamination in public drinking water systems has the Grimes water district at 23.9 ppm which is the worse levels of toxicity of any public system in the Sacramento Valley. To the northwest of the Buttes there is a USGS Gamma well ESAC 21 which seems to be located in the Colusa County portion of the Butte Basic which has an arsenic reading of 80 ppm. Finally ESAC 11 which is due north of the Buttes and appears to be located in Grey Lodge has an arsenic level of 70.

I can also note that the EPA assessment of the wastewater treatment facility for Yuba City reported that the high levels of arsenic in the wastewater was apparently from the portion of the Yuba infrastructure. Since most of the source of the water for Yuba City is surface water from the Feather River the arsenic contamination is pronounced where ground water is used. Finally as I mentioned in the past you probably are aware that the EPA has entered into an mitigation agreement with Sutter County regarding the arsenic contamination at Robbins. As you know Robins is at lower elevation and due south of the Buttes which would explain the contamination so far away from the Buttes. Robbins arsenic levels are less than the levels observed at Grimes.

I will send the Yuba City EPA report and the USGS Gamma documents next.

My suggestion would be to pick up where the SWRCB left off in 1952 and examine salt water and arsenic levels within a 15 mile circumference around the Buttes and set up a monitoring network to monitor changes in ground water quality going forward. This would not only focus on the southern part of the Buttes but within the whole circumference.

Thank you for your time and consideration.

Best Regards,

Ben

From:	Ben King
To:	Mary Fahey; Gosselin, Paul; Buck, Christina
Cc:	Ben King
Subject:	Arsenic Attachments Part II
Date:	Monday, July 06, 2020 1:38:28 PM
Attachments:	USGS Water Quality.pdf EPA Arsenic yuba city 2004-05-28 inspection.pdf

Hi Mary, Paul and Christina

The 2006 USGS Study presents the observations wells on Figure 3 – Page . I have attached a photo of the link to the USGS GAMMA website sorting for Arsenic. I have also include USGS Laux Road which is ESAC 21 and USGS Gray Lodge which is ESAC 11. On the website you can see the actual locations on the satellite imagery.

The 2004 EPA assessment for the Yuba City Sewage infrastructure addresses the arsenic issue on Page 10. It ascribes more than half of the arsenic contamination to groundwater.

Thanks again for your time and consideration

Best Regards,

Ben

From: Ben King
To: Buck, Christina; Mary Fahey; Gosselin, Paul
Subject: RE: Arsenic and Connate Sea Water Contamination around the Sutter Buttes
Date: Wednesday, July 08, 2020 2:10:07 PM

Hi Christina,

Thank you very much. I appreciate the follow up.

Best Regards,

Ben

From: Buck, Christina <CBuck@buttecounty.net>
Sent: Wednesday, July 8, 2020 2:06 PM
To: Ben King <bking@pacgoldag.com>; Mary Fahey <mfahey@countyofcolusa.com>; Gosselin, Paul <PGosselin@buttecounty.net>
Subject: RE: Arsenic and Connate Sea Water Contamination around the Sutter Buttes

Hi Ben,

Thanks for the information and additional reports. I did reference some of the reports you had sent me earlier in the draft of the HCM for the Butte subbasin. That document will hit the street for public comment later this summer.

I will pass your emails and attachments along to the consultant team (Davids Engineering) for their reference and consideration as they continue supporting GSP development and completion.

I will also forward your emails to Tania Carlone, the facilitator for the Butte Advisory Board (BAB), so she can include it as correspondence in the future to the BAB since this is helpful follow up to the comment you made at their last meeting.

Best,
Christina

From: Ben King <bking@pacgoldag.com>
Sent: Monday, July 06, 2020 1:16 PM
To: Mary Fahey <mfahey@countyofcolusa.com>; Gosselin, Paul <PGosselin@buttecounty.net>
Cc: Buck, Christina <CBuck@buttecounty.net>; Ben King <bking@pacgoldag.com>
Subject: Arsenic and Connate Sea Water Contamination around the Sutter Buttes

I wanted to follow up regarding my public comment on the last Butte Basin call. As mentioned in my call, my concern is that the connate seawater under the Sutter Buttes is contaminating groundwater and drinking water quality.

I have previously sent the SWCB Bulletin No. 6 from 1952 and the PHD Paper by George Curtin from 1971. Bulletin No. 6 reported that pumping depressions were drawing salt brines to the surface causing groundwater contamination. Curtin's paper proposes that the connate seawater is moving laterally through faults around the Buttes and researched several hundred gas well logs to express this opinion.

According to the Sutter County GMP on Page 23 "The Sutter Buttes Rampart consists largely of gravel, sand, silt and clay sediments which were deposited circumferentially around the Buttes as a geologic apron. These sediments may extend up to 15 miles north and west beyond the Sacramento River. " On Page 32 the GMP addresses the arsenic contamination issue - "… recent data analysis suggest a possible correlation between elevated arsenic concentrations and the presence of volcaniclastic material of the Sutter Buttes Rampart formation." Since the Colusa and Butter Basins are within the 15 mile circumference of the Sutter Buttes this would impact the analysis for Lower Water Quality and potentially Seawater Intrusion SGMA Sustainability metrics. I am mentioning the Seawater Intrusion metric because of the hydraulic components of pumping depressions and the physics of natural occurring contaminants moving laterally from higher elevations to lower elevations in combination of the force of pulling water to the surface by the operation of groundwater wells.

You will see the elevated EC levels and arsenic levels in the GMP Figures attachments. On Figure 19, there was an observation at T15NR3E of arsenic at 350 ppm and an EC of 1126. To the south at 14NR2E the observation of arsenic at 370 ppm and an EC of 1400. Since this study was focused on Sutter County there were not observations for Colusa County and Butter County. For Colusa County – the attached report regarding Arsenic contamination in public drinking water systems has the Grimes water district at 23.9 ppm which is the worse levels of toxicity of any public system in the Sacramento Valley. To the northwest of the Buttes there is a USGS Gamma well ESAC 21 which seems to be located in the Colusa County portion of the Butte Basic which has an arsenic reading of 80 ppm. Finally ESAC 11 which is due north of the Buttes and appears to be located in Grey Lodge has an arsenic level of 70.

I can also note that the EPA assessment of the wastewater treatment facility for Yuba City reported that the high levels of arsenic in the wastewater was apparently from the portion of the Yuba infrastructure. Since most of the source of the water for Yuba City is surface water from the Feather River the arsenic contamination is pronounced where ground water is used. Finally as I mentioned in the past you probably are aware that the EPA has entered into an mitigation agreement with Sutter County regarding the arsenic contamination at Robbins. As you know Robins is at lower elevation and due south of the Buttes which would explain the contamination so far away from the Buttes.   Robbins arsenic levels are less than the levels observed at Grimes.

I will send the Yuba City EPA report and the USGS Gamma documents next.

My suggestion would be to pick up where the SWRCB left off in 1952 and examine salt water and arsenic levels within a 15 mile circumference around the Buttes and set up a monitoring network to monitor changes in ground water quality going forward. This would not only focus on the southern part of the Buttes but within the whole circumference.

Thank you for your time and consideration.

Best Regards,

Ben

2B-4. Projects and Management Actions Submittal Forms

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COLUSA SUBBASIN

Colusa Subbasin GSP Projects and Management Actions (PMAs) Submittal Form

Overview

The purpose of this form is to gather ideas for potential projects and management actions (PMAs) that could be evaluated and ultimately included in the Colusa Subbasin GSP. Once ideas are gathered, an initial screening and evaluation process will be conducted, followed by ranking of potential PMAs for more detailed evaluation and inclusion in the initial GSP.

Potential PMAs may fall under several categories, including but not limited to the following:

- Recharge projects
- Supply augmentation projects
- Water conservation projects
- Projects to reduce non-beneficial consumptive use
- Groundwater pumping allocations
- Monitoring programs (groundwater pumping, water levels, stream flows, etc.)

Please provide supporting documentation and/or links to that documentation for each question, if available. **NOTE: It is recognized that much of the requested information may not be available at this time. Please provide as much information as you can.**

Project Name and Contact

Project or Management Action Name: Boards In Program

Contact Person: Lewis Bair or Bill Vanderwaal

Organization/Affiliation (Project Proponent): RD-108

Contact Phone: 530.437.2221

Contact Email: wvanderwaal@rd108.org

Project or Management Action Description and Status

Project or Management Action Description:

Institute a voluntary or financially incentivized program to have landowners leave their spill board in place during the winter to capture rainfall and hold it on the fields for recharge.

Project or Management Action Location (please provide a map if available): Any fields with spill boards throughout the subbasin.

Which Sustainability Indicator(s) does this Project or Management Action address:

1. Groundwater levels

Project or Management Action Status (Conceptual, In Design, Ready for Implementation):

Ready for implementation

Has a feasibility assessment been conducted? If so, please list the agency and provide the documentation (or provide web link to download).
Not required for a voluntary program.

Estimated Cost:
Zero for voluntary program.

Potential Funding Sources:

Management Action or Project Yield (e.g. water contributed to the groundwater system, acre-feet per year):
Depends on rainfall and infiltration rate of field. It might be low for high clay content fields but still better than letting the precipitation runoff.

Please describe any required Permitting and Regulatory Process and status of permitting and CEQA/NEPA compliance:
N/A for voluntary program.

Does this Management Action or Project serve a disadvantaged community? If so, which one(s)?

Additional Information Sources:

Other Information:

Byron Clark

From: Emil Cavagnolo <ecavagnolo@oawd.org>
Sent: Tuesday, July 7, 2020 5:22 PM
To: Byron Clark
Cc: Lisa Hunter
Subject: OAWD Recharge Information
Attachments: SCF WIRME conceptual model 2003 r.pdf; SCF WRIME Hydro model 2003 r.pdf; Stony Creek Fan CWMP Feasibility Investigation r.pdf; MAR_Orland 02-2019.pdf; OAWD VanTol Recharge Project 2017.pdf

Follow Up Flag: Flag for follow up
Flag Status: Completed

Byron,

I attached some files on recharge projects the District has participated in. OAWD has a group of farmers who are investigating annexing over 7,000 acres into the District. They will be looking to integrate recharge projects to make the annexation more appealing. We are in the early stages but it is something to be thinking about.

Best regards,

Emil Cavagnolo, General Manager
Orland-Artois Water District
P.O. Box 218
6505 Road 27
Orland, CA 95963
O 530-865-4304
F 530-865-8497
C 530-518-5060
ecavagnolo@oawd.org **NEW**
https://www.oawd.org/

Stony Creek Fan
Conjunctive Water Management Program

Feasibility Investigation

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1. Plan Formulation
2. Existing and Baseline Conditions
3. Project Alternatives

Prepared for:

Glenn-Colusa Irrigation District
Orland-Artois Water District
Orland Unit Water Users' Association

Prepared by:

Grant Davids, Davids Engineering
Roger Putty, MWH
Susan Burke, MWH

February 2004
(DRAFT)

NOTE TO READERS:

This volume represents a major milestone in development of the Stony Creek Fan Feasibility Investigation. It contains the following three major sections:

1. **PLAN FORMULATION** is a statement of the goals and objectives of the SCF Partners and Partnership, along with a general discussion of the approach to development of conjunctive water management programs and of the physical and institutional factors that influence alternatives formulation. While additional editing needs to be done to smooth this section out, it is critical that this section be read and understood, because it explains why the alternatives take the shape that they do.

2. **EXISTING AND BASELINE CONDITIONS** documents and expands on information presented to the Partners in both group and one-on-one meetings. Remember that the baseline condition is hypothetical…it is a reference condition used to measure and compare the benefits of project alternatives. The key things to review are the projected land uses and water demands associated with the Baseline; these are the potential future water demands that the alternatives are designed to meet. Note that the description of existing and baseline conditions for the groundwater-only areas with the SCF Project Area have not yet been prepared.

3. **PROJECT ALTERNATIVES** describes the alternative actions that could be taken under the Program to meet the Partner's goal and objectives. Emphasis is placed on the "Solo Alternative", which initially would not involve actual physical sharing of resources among the Partners, but nonetheless could (and should) be viewed as a coordinated SCF Partnership effort. The collaborative alternatives are not as beneficial to each partner as the Solo Alternative *under present basin conditions.* Bear in mind that these materials simply describe the alternatives; no effort has been made yet to compare, evaluate and "fine tune" the alternative formulation. This work comes next and will likely lead to a SCF Preferred Alternative.

SECTION 1. PLAN FORMULATION

INTRODUCTION

The Stony Creek Fan Partnership (the Partnership) was established to investigate the potential for a conjunctive water management program to mutually benefit one or all of the entities that comprise the partnership. The three individual entities that comprise the partnership are the Orland Unit Water Users' Association (OUWUA), the Orland-Artois Water District (OAWD), and the Glenn-Colusa Irrigation District (GCID). The basis for this partnership, as with any partnership, is that each individual entity is able to make better use of its resources by operating within the partnership rather than operating outside the partnership. The partners agreed, through a Phase I Agreement, dated September 6, 2001, to cooperatively pursue development of the Stony Creek Fan Conjunctive Water Management Program (Program). A map of the Study Area is attached.

To determine the feasibility and practicality of developing a conjunctive water management program and related facilities the partners began the Stony Creek Fan Feasibility Investigation. The purpose of this investigation is to evaluate the potential conjunctive water management opportunities in the Stony Creek Fan area. The planning approach to completing this investigation is the focus of Section 1 of this document. The plan formulation describes the goals and objectives of the SCF Partners and Partnership, a discussion of the general approach to developing conjunctive water management programs, and of the physical and institutional factors that influenced the plan formulation process for the Stony Creek Fan Conjunctive Water Management Program.

COMMON GOALS AND INDIVIDUAL NEEDS

From the very beginning, it was recognized that the three Partners share some common goals, but also have different individual needs that they hope to fulfill, in whole or in part, through participation in the SCF Conjunctive Water Management Program (**Table 1-1**). Common goals include the following:

- **Protect local surface water and groundwater resources consistent with Glenn County ordinances**, specifically the Glenn County Groundwater Management Plan Basin Management Objectives (BMOs) and State and federal laws. This ensures that any plan to more fully utilize available water resources to meet the Partner's needs recognizes and allows for the needs of other water users within and neighboring the SCF Project Area.
- **Pursue opportunities to maximize Program benefits through strategic, synergistic linkages with other regional water management activities and authorities**. Increasingly, water management initiatives are being approached and implemented at a regional scale. While the SCF Partnership purposely began and has been maintained thus far with only three members, the Partners recognize that linkages with other water management initiatives and parties can provide mutual benefit. Potential linkages exist with Glenn County and the independent pumpers within and neighboring the SCF project area, as well as regional initiatives such as the Sacramento Valley Water Management Program and the State Water Project and Central Valley Project.
- **Secure water supply reliability locally and provide opportunities for improved water supply reliability for water users elsewhere in the State**. Fundamentally, the SCF Partnership exists to provide reliable, affordable water supplies to local users. However, the Partners understand that a proactive stance toward addressing regional and Statewide water supply reliability ultimately yields benefits to local initiatives. Thus, the Partner's will look for opportunities to participate in regional and Statewide initiatives that are consistent with the goals of the Partnership

- **Seek ways to achieve environmental benefits that are compatible with Program operations.** The Partners recognize that water management initiatives that also yield environmental benefit are more widely supported by the public and environmental advocates, and stand a better chance of attracting public financial support. Where feasible, the Partners will look for opportunities to fold environmental purposes into project formulation.

Table 1-1. Common Goals and Individual Needs

Common Goals		
• Protect local surface water rights and contract entitlements of each individual partner. • Manage groundwater resources consistent with Glenn County ordinances, specifically the Glenn County Groundwater Management Plan Basin Management Objectives (BMOs) and State and federal laws. • Pursue opportunities to maximize benefits through strategic, synergistic linkages with other regional water management activities and authorities. • Secure water supply reliability locally and provide opportunities for improved water supply reliability for water users elsewhere in the State. • Seek ways to achieve environmental benefits that are compatible with Program operations.		
Individual Needs		
GCID	**OAWD**	**OUWUA**
Improved reliability and increased flexibility through integration of basin surface and groundwater resources.	Secure reliable, affordable water supply in all years.	Enhanced management of surface water resources. Improvements to aging and obsolete irrigation infrastructure.

The individual needs of the Partners are very different. GCID has a relatively reliable water supply, being subject to shortages of only 25% in critically dry years. Therefore, the District's water supply reliability emphasis is on improving the ability to recapture system and farm losses in years of shortage. Additionally, the District's facilities are extensive and prone to ordinary deterioration, posing a significant and growing ongoing maintenance expense as costs generally escalate.

OAWD faces dual problems of water supply adequacy and affordability. Over recent years, the District has derived about half of its total water supply from its CVP water supply contract and half from groundwater supplies pumped by private landowners. Looking to the future, however, the amount of water available under its CVP contract is expected to decrease while water demands increase. This will lead to a supply mix of about one-third surface water and two-thirds groundwater, which may or may not be sustainable or affordable. At the same time, CVP water costs are escalating much more rapidly than other costs, raising concerns about the affordability of CVP water over the long-term. Thus, OAWD's primary need is adequate, affordable water.

Finally, the OUWUA is fortunate to have an extremely reliable water supply, but its storage, conveyance and distribution facilities are approaching obsolescence. For example, the Association's distribution system is capable of operating only on a rotation schedule, which is generally adequate for forage crop production, but not for production of high value crops and modern irrigation systems. Here the need is primarily to generate financial revenues to fund system modernization.

While the individual conditions and needs of the Partners are very different, they can be expressed in terms of either *new water* that would be used directly to achieve water supply reliability, and *financial revenues* derived from water transfers. Fundamentally, the challenge to the Partnership is to generate water supplies for direct use or for transfer to generate financial revenues.

GENERAL DISCUSSION OF CONJUNCTIVE USE AND PROTECTING BASIN

Conjunctive use involves the coordinated use of groundwater and surface water to minimize the impacts of shortages and increase supply reliability. Coordinated use means using groundwater to meet demand in dry years (when surface water supplies are limited) and using surface water to meet demand in wet years (when surface water supplies are not limited). Generally, one of the goals of a conjunctive use program is to maintain and protect the health of the groundwater basin. Basin Management Objectives (BMOs) are often established for this purpose.

In some geographic areas, basin health can be maintained without a formalized program if the rate of groundwater extraction is less than or equal to the rate of natural recharge. If, on the other hand, the groundwater extraction rate is greater than the natural recharge rate, then the health of the groundwater aquifer may be compromised. In such a case a formalized conjunctive use program may be required. A formalized conjunctive use program often develops methods to artificially recharge the groundwater aquifer. Artificial recharge can occur either through in-lieu programs or through direct recharge. These artificial recharge programs, combined with natural recharge, maintain the health of the groundwater aquifer.

A year in which artificial recharge occurs is often referred to as a 'put' year. Whereas, a year in which groundwater is extracted is called a 'take' year. It is the combination of these put and take years that characterize the conjunctive use cycle.

This conjunctive use cycle is shown in **Figure 1-1**, exhibiting an idealized pattern of alternating put and take cycles, which, operating in conjunction with one another would ensure the health of the basin as measured by long-term groundwater levels (i.e. long-term basin management objectives are met).

Because groundwater basins are complex, dynamic physical systems, the pattern of put and take cycles varies considerably among basins and with time. **Figure 1-2** is an hypothetical example where basin groundwater levels start out above a hypothetical BMO and remain above that level for several cycles (years) despite continued groundwater pumping from the basin. Perhaps during these years favorable hydrologic conditions have ensured the health of the basin, or perhaps the inflow (natural recharge) to the basin is adequate under the groundwater pumping circumstances. **Figure 1-2** suggests that eventually, however, the basin groundwater levels drop below the BMO levels. At that time the basin enters a put-cycle phase and implementing artificial recharge through in-lieu or direct means, or both, ensure that BMO objectives are achieved. For example, perhaps here-to-for unutilized winter flows could be redirected and recharged into the basin. Or, available dry-year surface water supplies could be used for in-lieu recharge.

Figure 1-3 shows the same types of hypothetical conjunctive use program, however in this example the initial basin elevation is below the long-term average BMO. In this hypothetical example the program would begin with put-years in order to recharge the basin until groundwater elevations approach the long-term average BMO elevation. Once the groundwater elevation begins to approach the long-term average BMO elevations then the basin would be managed with put and take cycles as needed to maintain the average condition.

The SCF investigation was designed to explore the basin's characteristics, including the basins ability to be operated under put and take cycles. The findings from this investigation influenced the plan formulation process and subsequent alternatives. This outcome is discussed in the following section.

FACTORS INFLUENCING THE APPROACH TO FORMULATING SCF CONJUNCTIVE USE ALTERNATIVES

Over the course of the feasibility investigation, new information regarding different and very unique physical aspects of the area combined with the institutional aspects arising from the SCF Partnership arrangement served as fundamental drivers of the alternatives formulation process. In particular, a field investigation undertaken as part of the SCF study revealed new information about the Project Area's hydrogeologic and recharge characteristics. This new information improved each partner's understanding of the resources available to him or her and how best to manage those resources. And, more importantly, the fact that a conjunctive use program alternative must consider and serve the needs of three Partners, not a single entity, required an approach capable of revealing individual benefits to each partner's involvement in an integrated conjunctive use program as compared to operating independent of the partnership. Each of these factors is discussed further below.

Discussion of Physical Factors Influencing Alternatives Formulation

The basic components of a conjunctive use system are shown in **Figure 1-4**. Of paramount importance to a system of this type are, one, the basin's ability to produce groundwater without undesirable effects, and, secondly, the degree to which this ability can be enhanced by replenishing depleted groundwater supplies with artificial recharge. The Stony Creek Fan area would appear to be well suited for development of a conjunctive use system given the following characteristics[1]:

- Existing distribution and extraction facilities well positioned to support groundwater production and in-lieu recharge operations;
- The presence of the Stony Creek Fan, formerly thought of as the primary subsurface geologic feature beneath the Project Area, thought to have extensive groundwater storage and yield properties as well as highly permeable and transmissive properties capable of accepting natural and artificial recharge at relatively rapid rates;
- Viable surface water supply sources for storage and replenishment of groundwater through direct and/or in-lieu artificial recharge; and
- A strategic institutional alliance formed between GCID, OAWD, and OUWUA, bringing these key physical elements together.

As mentioned previously, "Put" and "Take" cycles govern the operation of a conjunctive water management project. The Stony Creek Fan Feasibility Investigation developed an understanding of the overall goals and needs of the districts, the water sources potentially available to the project, the various legal and institutional factors that effect the management of district resources, and an improved understanding of the groundwater basin and its response to hydrologic variations, pumping, and recharge. This analysis process is shown conceptually in **Figure 1-5a** and described in the following paragraphs.

Determine Yield Allocation: Project configurations are defined principally by the magnitude and allocation of Project yield, which shape the Project's extraction, or "Take" cycles (see **Figure 1-5a**, Determine Yield Allocation). Basic options include allocation to satisfy district unmet water demands, or to meet market demand. These options help define the primary features that drive the formulation of the project alternatives.

Assess Basin Response: The hydrogeology of the Stony Creek Fan is not well known, and a major objective of the feasibility investigation was to characterize the factors that influence groundwater behavior in the Study Area. Determining how to maximize project yield by strategic pumping or artificial recharge, thereby maintaining healthy groundwater conditions, are critical to the plan formulation process. The outcome of these evaluations will guide formulation of recharge and recovery strategies.

Determine Feasibility of Artificial Recharge: Depending on basin response to different project yield configurations, artificial recharge can be a critical component of a project configuration. The feasibility of

[1] It was recognized that the geology of the Stony Creek Fan was not well known, and a major objective of the feasibility investigation would be to characterize the factors that influence groundwater management in SCF Study Area. The outcome of these investigations changed the above thinking considerably, which is discussed further below.

artificial recharge depends largely upon the surface water supply sources and their compatibility with the recharge mechanism, in-lieu or direct recharge. Compatibility is measured both in physical terms which is governed by hydrology and also institutional terms which is governed by legal and contractual characteristics unique to each source. Also critically important are is the groundwater basins physical characteristics and hydrologic conditions, both of which govern the potential benefit of artificial recharge. For instance, a full basin may receive very limited benefit from artificial recharge in terms of long-term groundwater storage.

Figure 1-5a does not reveal the multitude of steps critical to the formulation and analysis of conjunctive use projects alternatives. These detailed steps are shown in flowchart form in **Figure 1-5b** ("Put" Cycle) and **Figure 1-5c** ("Take" Cycle). The following sections use these flowcharts to discuss the factors that influenced path followed by Stony Creek Fan Feasibility Investigation.

Assessment of Artificial Recharge Potential ("Put" Cycle)

The in-lieu leg of the flowchart (see **Figure 1-5b**) begins with the question "History of groundwater pumping per district?" If the answer is no, in-lieu recharge is not possible because there is no pumping to stop in order to achieve the in-lieu recharge. If the answer to the question is yes, then an assessment of the volume of surface water available for use as a substitute during the in-lieu recharge period is required. Finally, the assessment of surface water would be combined with the estimates of historical pumping volumes in order to estimate the size of the in-lieu potential.

The SCF investigation initially estimated the historical volume of groundwater extracted by each district to the as an initial assessment of the feasibility of in-lieu recharge. **Table 1-2** summarizes these findings.

Table 1-2
Summary of District Groundwater Pumping

District	Approximate Number of Groundwater Wells	Range of Historical Annual Groundwater Pumping (1000 AF/Yr)	Approximate In-lieu Capability (1000 AF/Yr)
GCID	200	4 to 17	17
OAWD	400	5 to 55	55
OUWUA	50	3 to 13	13
Total	**650**	**12 to 85**	**85**

The results of this initial review suggested that in-lieu recharge was possible given the amount of historical pumping. A review of surface water supplies that could be used in-lieu of pumping groundwater revealed two possible sources: unused Base Supply; and unappropriated Stony Creek water. These findings helped further shape the conjunctive use alternatives. More detailed discussion of this source identification and the characteristics of these potential in-lieu sources is provided later in this report.

The other method of artificial recharge represented on the flowchart is direct recharge. Following the "Direct Recharge" leg of the flowchart the first question asks whether or not favorable infiltration rates exist. If the answer were "No" then direct recharge would not be viable. For instance, soils consisting of fine sand to silty clay conditions are typically unsuitable for artificial recharge due to relatively low infiltration rates.

A field investigation of the Stony Creek Fan area was completed to determine infiltration characteristics within the Project Area and to help asses the feasibility of recharging the groundwater basin using constructed direct recharge basins. Candidate sites were identified throughout the area and were evaluated based on specific site selection criteria[2]. Three sites were ultimately chosen for pilot recharge testing[3]. The three sites are considered to be representative of areas favorable for groundwater recharge throughout the Project Area.

The pilot recharge tests were conducted over a several week period under varied conditions. Infiltration rates varied from several feet per day to ten's of feet per day. The range of infiltration rates are summarized in **Table 1-3**. These infiltration rates are considered highly favorable for direct recharge operations.

Table 1-3
Pilot Recharge Test Infiltration Rates

Site	Long Term Infiltration Rate (ft/d)	
	Spreading Basin	Flooded Field
Van Tol	22	2
Jasper	45	6
Olivarez	10	0.5

1 Spreading basins are shallow ponds excavated to relatively shallow depths (2 to 6 feet) through low permeability soils and/or through shallow hardpan.
2 A flooded field refers to the groundwater recharge technique of applying shallow water to a bermed field (approximate berm height, 2 feet).

With the finding that favorable infiltration rates exist in the Project Area, the next logical question along the "Direct Recharge" path is "Does recharge water reach the target aquifer?" If the answer is "yes' then proceed to the next step. If the answer is "No", then direct recharge may not be effective. The SCF investigation found that the recharge water, under the existing state of the basin, might not be reaching the target aquifer, the Tehama formation.[4] Instead the recharge water appears to enter the Stony Creek Fan alluvium, where it may only reside in storage for a relatively short period - weeks or months as opposed to several months to several years – before being discharged from the area. It is postulated that the high conductivities associated with the alluvial materials result in lateral movement and lateral spreading of the recharge water, and little downward migration. This is evident by the shallow, mid, and deep groundwater level hydrographs shown for the Van Tol site. The groundwater levels associated with the shallow monitoring well show evidence of the recharge water reaching the surface of the water table, however, the mid and deep monitoring wells are not effected. This observation is typical of the monitored groundwater levels at all three pilot recharge testing sites. Furthermore, recent field work completed by the Northern District of the California Department of Water Resources suggests that the hydrogeology of the Stony Creek Fan alluvium is a relatively thin water-bearing zone of layered sands and gravels 50 to 80 feet thick (see **Figure 1-6**). This relatively thin "veneer" is layered on top of relatively impermeable clays comprising the Tehama formation; there is believed to be little interconnection between the alluvium and this formation.[5] This proposed distinction is in stark contrast to the previously accepted theory that the Stony Creek Fan aquifer consisted of sand and gravel layers associated with the younger alluvial

[2] The Pilot Recharge Test Site Selection Criteria are: soils and geologic conditions; groundwater conditions; land availability; water availability; site access; environmental issues; geographic variability. For a complete description refer to Stony Creek Pilot Test Site Selection Criteria Memorandum, MWH, October 2001.

[3] See Technical Memorandum 2:Pilot Recharge Test Designs and Monitoring Program, MWH, August 2002

[4] The Tehama Formation typically includes confined (or semi-confined) water-bearing layers occurring at multiple depths, which are believed to be the source of groundwater pumped by most irrigation wells in the Study Area.

[5] This is partly corroborated by results of well interference tests that suggest there is little interaction between the unconfined surface layer (Stony Creek Fan Alluvium) and the deeper confined aquifers (the Tehama formation) (personal communication with Toccoy Dudley, DWR-ND).

materials interbedded and interconnected with the silts and clays that are characteristic of the older alluvium, or Tehama formation.

The results of the field work described above suggests that in-lieu recharge may be more effective than direct recharge in managing the long-term health of groundwater resources in the Project Area. Assuming the artificial recharge water reaches the target aquifer, the next question on the flowchart is "Does the recharge water appear to positively impact the storage of the basin?" In other words, does the recharge water improve basin conditions (e.g. groundwater elevations) or does the recharge water appear to run-off? If the answer to this question is "Yes" then artificial recharge appears viable. If the answer to the question is "No" then recharge water is being rejected possibly because the basin is already "full."

The term "full", as used here, is referring to groundwater conditions that are relatively stable, or in balance. Under these conditions water leaving the basin is approximately equal to water entering the basin on a long-term average annual basis. For instance, groundwater storage conditions in the Project Area have varied over the course of the last 30 years due to varied hydrologic and water supply conditions, however, the cumulative change in storage conditions has been minimal. This is supported by the following information:

- A water balance completed for the Project Area shows a net recharge on average of approximately 1.1 acre-feet per acre per year; and
- Review of groundwater level hydrographs throughout the region indicate groundwater levels typically return to pre-pumping conditions the following spring.

Based on the above findings, it was concluded that average annual natural recharge to the basin has generally exceeded average annual extractions from the basin, and artificial recharge at this time would not provide any additional direct benefit. However, as described previously, operating the basin in a "take" mode could require additional artificial recharge at some point in the future. For this reason, consideration of artificial recharge using in-lieu methods is pursued as part of the conjunctive use alternatives formulation effort.

Assessment of Additional Groundwater Yield Potential

[This section needs further discussion of the need to transfer water for the purposes of revenue generation to help each District achieve their goals/needs as discussed at the beginning of Section 1.]

The 'take' cycle, shown n **Figure 1-5c**, begins by asking "Transfer dry-year water?" If the answer to the question is no then the pumped groundwater would be used to meet local demand. Note that both legs of the flow chart could be followed and some water could be used to meet local demand while some could be reserved for transfer. If the answer to the transfer question is 'Yes' then a series of questions must be answered.

The first question is, does the groundwater pumping entity have access to dry year surface water supply to transfer. If there is no dry-year supply then a transfer is not possible. If the answer to the question is yes then the question is, "Is there conveyance for the transfer?" For example, both GCID and OAWD have relatively efficient conveyance for transfer water. Both districts would leave water in the Sacramento River. OUWUA is relatively more challenged for conveyance. The Stony Creek is believed to be a losing creek for much of the stretch between OUWUA and the Sacramento River.[6] Therefore transfers down Stony Creek are jeopardized by high losses. Potential transfers of OUWUA water may require involving exchanges with TC contractors.

If there is both dry-year surface water and conveyance ability the next question to answer is "is the transfer possible per the water code?" In general, groundwater substitution transfers have little trouble

[6] Personal conversations with Toccoy Dudley of DWR.

with a legal review. The legal 'transfer-ability' of source water available to the SCF partners, other than groundwater substitution water, is not as clear.

The components necessary to a groundwater substitution transfer are summarized in **Table 1-4.** The three components are 1) dry year water supply 2) groundwater pumping capacity and 3) conveyance. The OAWD is limited in their dry-year surface supply but possess the other two attributes. The OUWUA has limited groundwater pumping capacity but possess the other two components. GCID posses all three components. In addition, field investigations have confirmed the presence of a potentially high-producing confined aquifer, the Lower Tuscan formation: Hydrogeologic investigations underway by DWR-Northern District have documented the presence of this formation in the vicinity of the Project Area. Evaluation of well logs supported by recently developed wells support the notion that this groundwater source could potentially provide new supplies to the Partners.[7]

Table 1-4
Components of a Dry-year Groundwater Substitution Transfer

Partner	Groundwater Substitution Transfer Component		
	Dry Year Surface Supply	Groundwater Pumping Capacity	Conveyance of dry-year surface water
OAWD	Limited *(Junior CVP entitlement)*	Not limited	Not limited *(Forebear diversion into TC canal from Sacramento River)*
OUWUA	Not limited *(Adjudicated Pre-1914 storage and direct diversion rights)*	Limited	Limited *(Forbear diversions from Stony Creek – either travel down Stony Creek (high loss factor, or move water from South Canal to TC canal and ultimately Sac River at the drain).*
GCID	Not limited *(Base supply and supplemental CVP supply)*	Not Limited	Not limited *(Forbear diversions into the GCID from the Sacramento River)*

Summary of Physical Factors Influencing Alternatives Formulation

In summary, the field investigations and modeling analysis narrowed the set of alternative components. Initially the set of alternative components was believed to include variations of artificial direct recharge, in-lieu recharge, supply sources, extraction volumes, and yield destinations. However, as a result of the field investigations and subsequent modeling, artificial direct recharge was determined to offer less opportunity than originally thought. Furthermore, examination of historical water level data supported by modeling analysis indicates that the basin is more resilient than previously thought and is capable supporting additional production. In addition, greater understanding of the hydrogeology has revealed new sources of potential groundwater supplies. These findings combined have lead too more focused alternative formulation as discussed below.

Discussion of Institutional Factors Influencing Alternatives Formulation

An alternative that combines the resources of two or more partners is successful only if it provides each partner benefits that exceed those that each could achieve on their own. The most important implication

[7] It is noted that development of the Lower Tuscan formation as a source of new supply poses risks not yet fully identified or understood. For example, there remains limited understanding of the potential range of well's yields, the potential physical effects of long-term pumping, and the potential political ramifications of landowners predisposed to using private landowner wells rather than district-owned wells. These unquantified risks will be addressed through future efforts to compare and analyze SCF project alternatives.

this had to the alternatives formulation process was that each Partner needed to have a good sense of the individual water management options that they could pursue alone, so that they could weigh the benefits of collaboration versus individual actions. This resulted in organizing alternatives into two primary groupings, "Solo" Alternatives and Collaborative Alternatives, defined accordingly:

- *Solo Alternatives*: A solo alternative consists of individual action(s) identified for each Partner.
- *Collaborative Alternatives*: A collaborative alternative involves the joint operation of two or more district resources through either physical or institutional means, or both.

A series of focused meetings were held with each Partner individually to identify the water management options available to them, and to combine those options into a strategic plan of action. The individual strategic plans, or solo alternative, for each Partner serve the essential purpose of providing each Partner a means of judging the value of a collaborative approach relative to an individual (or solo) course. The approach to developing these two primary groups of alternatives is discussed further below under *Approach to Formulating the Project Baseline and Alternatives.*

[An expanded discussion will be added to address other institutional factors such as BMOs, air quality, SVWMP, CVPIA, etc]

APPROACH TO FORMULATING THE PROJECT BASELINE & ALTERNATIVES

Focused Alternatives Formulation Approach

The formulation process for developing conjunctive water management alternatives can involve a systematic identification and extensive evaluation of all potential sources of recharge water, all means and locations of groundwater recharge and production, and various combinations of these components. However, the fundamental implications stemming from the factors discussed above are that (1) Solo Alternatives are essential to the plan formulation process, and (2) the benefit of artificial recharge may be relatively small, effectively narrowing the field of potential collaborative alternatives. Thus, attention was concentrated on formulation of the Solo Alternatives and on identifying and formulating the types of collaborative alternatives most likely to succeed; i.e., those involving in-lieu recharge and offering opportunity to derive value or benefit from resources that otherwise would go unutilized.

Baseline Condition

As noted earlier, the Project Baseline is used as a reference condition for measuring the benefit or value of the various Solo and Collaborative alternatives. It is a hypothetical future condition that is assumed to exist if none of the alternatives was implemented; it is therefore sometimes also referred to as the "future without the project" or "without-project" condition.

The traditional standard for identifying possible future actions to include in a project baseline is the standard of "reasonably foreseeable", which is intended to exclude highly speculative actions. The Partners agreed that the project baseline should be comprised of non-speculative actions that clearly could be accomplished by each Partner. The parameters and actions ultimately included in the Project Baseline are described in Section 2.

"Solo" Alternatives

The purpose in developing the Solo Alternatives is to identify the combination of water management initiatives that each Partner would most likely pursue in the absence of participation in potentially more beneficial, collaborative alternatives. The Solo Alternatives serve as "yardsticks" for each Partner to gauge the advisability of entering into an alternative which involves some level of joint operation of partner resources, as compared to an alternative which involves one partner proceeding alone. The approach used to identify each district's "Solo" Alternative is described below.

Collaborative Alternatives

Collaborative alternatives involve some degree of joint operation of district resources. This could involve the actual physical exchange of resources among the districts, and institutional mechanism that enables each district to modify their own resource utilization under a joint program, or a combination of the two. As noted previously, the realm of viable collaborative alternatives is narrowed as a result of the limited benefit of artificial recharge. In particular, it appears that the most fruitful opportunities for partnership are ones involving in-lieu recharge and where presently unutilized resources can be put to use.

Identification of "Solo" and Collaborative Alternatives

The project team worked closely with each district to define and refine their "Solo" Alternatives and to identify potential Collaborative Alternatives. The GW Model was used to evaluate the effect of each District's actions on the basin and the effect these actions would have if implemented together. An economic analysis was also conducted to compare the present value of project costs to the present value of project benefits, to determine economic feasibility. This analysis explored and improved the understanding of how each Partner's water supplies could best be managed in terms of quantity, distribution, and timing. The primary objective of developing this information was to educate the Partners and the Project Team so that the "Solo" Alternatives and Collaborative Alternatives could be refined as needed. The Project Team worked with each Partner to identify specific questions and/or planned actions.

SECTION 2. DESCRIPTION OF EXISTING AND BASELINE CONDITIONS

INTRODUCTION

This section describes the existing and baseline conditions in the Project Area. Both conditions are described in sections dedicated respectively to the Orland Unit (Subunit 1), Orland-Artois Water District (Subunit 2), Glenn-Colusa Irrigation District (Subunit 3) and the independent pumper areas (Subunits 4-7). The descriptions of existing conditions are based on observations and interpretations derived from the historical (1970 through 2000) water balances prepared for the various subunits (see **Map 1**)and in aggregate for the Project Area. The project baseline represents conditions that are predicted to occur in the future, if one of the project alternatives is not implemented. It is a hypothetical condition developed primarily to serve as a yardstick for measuring the relative merits of the various alternatives.

Discussion begins with examination of the assumptions that are common and applied uniformly to all three Partners to establish the project baseline. This is followed by sections describing each Partner's pertinent background information, water resources setting, and existing and individual baseline condition.

The information presented here is derived primarily from the prior tasks completed for the Feasibility Investigation:

- Initial Field Investigations (Task 3)
- Collect and Review Existing Data (Task 4)
- Characterize Existing and Future Hydrologic Conditions (Task 5)

COMMON BASELINE ASSUMPTIONS

The Baseline Condition is a hypothetical future condition that would exist if Solo or Collaborative project alternatives are not pursued. Development of Baseline conditions requires making certain assumptions about future conditions, some of which are unique to the individual Partners, and others of which are common among the Partners. This section describes the baseline assumptions that are common among the Partners.

Planning Horizon

The planning horizon refers to the point in time for which Baseline Conditions are developed. Factors that influence selection of the time horizon includes the presence of trends in historical land use and cropping, the time that would likely be required to implement the project alternatives, the horizons used for other related planning efforts, and other factors. Based upon review by, and discussion with, the SCF Partners a time horizon of 2025 was assumed for planning purposes. This is consistent with other planning efforts recently completed, such as the USBR water needs analysis completed for contract renewals, regional planning ongoing for CALFED, and the California State Water Plan Update (DWR Bulletin 160).

Hydrologic Conditions

The hydrologic period over which the alternatives are analyzed and evaluated must include enough variability to reveal how the alternatives would function under conditions of prolonged water shortages and surpluses. The historical water balances prepared for the Project Area cover the period of 1970 through 2000. This period probably includes sufficient hydrologic variability, but does not match the longer and even more variable period of 1922 through 1994, which is used by DWR, the USBR and

CALFED for planning purposes. Therefore, the historical hydrologic record spanning the period of 1922 to 1994 is used to develop Baseline Conditions, and for formulation and comparison of alternatives.

Future Land Use & Cropping Patterns

With minor exception, projections of future irrigated area and cropping patterns within each subunit were based on trends observed during recent years. The basic assumption is that recent trends are acceptable indicators of change that will occur between 2000 and 2025. The methodology described here was developed in consultation with staff of DWR's Northern District, to ensure comparable results with DWR land use projections. The first step was to assign the total land area within each subunit to the broad classifications of "cropped", "non-cropped" and "idle". The cropped area in 2025 was assumed to be the same as the maximum cropped area observed anytime between 1991 and 2000. (An exception was made for OAWD where land is still being developed for irrigation. In that case, 1,352 acres was added to the maximum observed cropped area, to account for land connected to the OAWD distribution system and paying assessments, but which has not yet been developed.) The non-cropped area in each subunit was then increased at a constant annual rate to account for urbanization, based on the growth in urban lands observed between 1993 and 1998 (the two years for which DWR land use data are available). Finally, lands not accounted for as cropped or non-cropped were assigned to an "idle" classification as a closure calculation.

Land within the cropped category was assigned to specific crops based on the percentage observed in 2000, plus the percentage change observed between 1996 and 2000, with a dampening factor allied to moderate the compounding effect.

The results of the cropping projections are presented in the appropriate following sections.

Irrigation Management Practices

Irrigation management practices, including irrigation methods and existing technologies, are assumed to be the same as those currently in place in the Project Area. The only exception to this assumption is for alternatives that may have as a key feature some change in the irrigation scheme within a district or districts.

ORLAND UNIT WATER USERS' ASSOCIATION (SUBUNIT 1)

Background

The Orland Unit Water Users' Association (OUWUA) is located in north central Glenn County (see **Map 1**). The OUWUA is a Non-Profit California Corporation. Founded in 1906, the Association petitioned the Secretary of the Interior to encourage the USBR (then the Untied States Reclamation Service) to develop an irrigation project near the town of Orland. As a result, the USBR began construction of the Orland Project in 1909. The facilities of the Orland Project deliver water from the Stony Creek watershed to the shareholders of the OUWUA.

There are 1,099 shareholders within the OUWUA. The average farm size in the OUWAU is relatively small, and some shareholders maintain hobby farms (33 percent of the shareholders having 5 acres or less). The average farm size is 18 acres. Approximately 25 percent of the farms are greater than 20 acres.

The OUWUA service area enjoys favorable growing conditions for agriculture. A thermal belt, with very few frosts, warms the Orland area. The soil is considered some of the richest and most productive in the nation (USBR). The textures of the soils in the OUWUA are predominately loam, gravelly loam and gravelly sandy loam. Average rainfall is 18 inches, most of which is measured between the first of November and the first of April.

The primary facilities of the Orland Project include East Park reservoir and Stony Gorge reservoir. The Project was constructed between 1909 and 1928. In 1954 the OUWAU took over operation and maintenance of the Project from the USBR. These reservoirs are upstream of the US Army Corps of Engineers (USACE) Black Butte Dam, constructed in 1962 for flood control.

Flows from Black Butte Reservoir are controlled by the USACE and are released to meet the total demands required by OUWUA. After calculating the total delivery demands for the day and adding 10 percent for losses, OUWUA calls the USACE at 7:00AM to give its daily order. At 1:00PM in the afternoon OUWUA has the opportunity to change their order if needed. Surface water is distributed in open channels to approximately 17,600 of the 20,200 acres of the OUWUA through 17 miles of canals; and 139 miles of laterals (CALFED 2003 [1]).

The project is divided into six geographic areas called 'beats'. Surface water deliveries are made to the six beats on a rotational basis. Regardless of the crop being grown, the soil texture, or the evapotranspiration rate, water is delivered every 12 days during the peak demand period from June through September and every 14 days at the beginning and end of the season when crop demand is lower. During the months of peak demand, it is not possible to shorten the rotation period because of capacity constraints mostly in the main laterals. Some growers augment surface water supplies with groundwater were the physical constraint of these rotational periods result in surface water delivery patterns that do not meet crop demands for producing maximum yield. Some growers use groundwater exclusively where surface water is not available. Of the 20,200 acres of the OUWUA, 17,600 are receiving surface water. Of the 2,600 acres that are not supplied surface water, approximately 500 acres are irrigated with groundwater and the rest are fallow.

Six fulltime ditchriders, one for each beat, control flows by manually adjusting turnout gates and checks. Irrigators are informed in advance of the time they will be provided water and it is their responsibility to open and close their farm turnout(s) at the right time. Water deliveries are not measured at farm turnouts, except for several piped turnouts with meters, but are typically estimated from experience and measurement at upstream flumes and weirs.

Due to the nature of the open channel distribution system an the limited use of meters within the OUWUA estimates of conveyance losses and operational spills are 20 percent of total diverted water.

The OUWUA has investigated modernizing its existing distribution system in order to enhance conservation (CALFED 2003 [1]). Three estimates of the volume of water that could be conserved were 40,100, acre-feet (AF) per year 25,400 AF per year and 14,400 AF per year depending on the size of the investment in infrastructure. The range of capital investments for the three alternatives are $221,640,000, $53,499,000 and 18,489,000, respectively. The OUWUA is currently deciding which, if any, of the conservation measures to adopt and is examining various financing scenarios. This topic is discussed in the section of this Technical Memorandum that describes SCF Partner Alternatives.

OUWUA employs a total of fifteen fulltime staff; six ditchriders, two dam-tenders, four maintenance workers, one foreman, one office manager and on manager. The current overall O&M cost for OUWUA is $869,000. Shareholders pay $29.50 per acre per year that entitles them to 3.0 AF per acre. For additional water, it costs $9.83 per AF for up to 2 AF and $10.90 per AF thereafter.

Water Resources Setting

Surface Water

With very little snow, winter runoff from the Stony Creek watershed occurs almost immediately after precipitation. The Stony Creek watershed had an average annual runoff of 410,000 AF for the period 1921 to 2001. The low of 17,000 AF occurred in 1977. The high of 1,435,000 AF occurred in 1983.

The reservoir capacity on the Stony Creek watershed is as follows: East Park Reservoir is 50,900 AF, Stony Gorge Reservoir is 50,000 AF and Black Butte Reservoir is 136,000AF (DWR). Approximately 90 percent of the time precipitation is sufficient to fill the OUWUA reservoirs, East Park and Stony Gorge. The total reservoir capacity in the upper watershed is not adequate to provide regular planned inter-annual carryover storage.

Black Butte Reservoir, while originally built for flood control was financially and operationally integrated with the CVP, authorizing use of conservation storage for irrigation and recreation.[8] Operations of the three reservoirs were coordinated under a 1964 agreement to increase the net benefits of the system.

The rights to water available to the Orland Project as summarized in **Table 2-1**. Many of the rights to the water delivered by the Orland Project's facilities were adjudicated in the terms of the Decree in the case of The United States of America vs. H. C. Angle, et al, 1930. Water rights from the Angle Decree provide for both storage of water and direct diversion of water. The Angle Decree provides a total of 85,050 af (not to exceed 279 cfs) of direct diversion rights for irrigation and reclamation. The Angle Decree provides rights for storing water in East Park Reservoir (51,000 af of Little Stony Creek water) and a maximum of 250 cfs of water on Big Stony Creek for irrigation and reclamation. In addition to the water rights adjudicated in the Angle Decree, the USBR holds 50,200 af of rights to storage of Stony Creek water. This storage water is contained in Stony Gorge Reservoir. [Need to comment on the USBR storage and diversion right of S006354.

Table 2-1
Summary of the Water Rights Available to the Lands of the Orland Project

Quantity	Type of Right	Date of Right	Time	Source
85,050 af not to exceed 279 cfs	Direct Diversion on Stony Creek	10//10/1906	Irrigation season as available	Angle Decree, Article VIII (1)
51,000 af	Storage of Little Stony Creek water	10/11/1906	Year round as available	Angle Decree, Article VIII (3)
250 cfs	Storage and conveyance of water from Big Stony Creek	3/25/1913	Year round as available	Angle Decree, Article VIII (4)
50,200 af	Storage, water of Stony Creek	Permit issued on 12/2/1925 License on 5/15/1944	November 1 to May 1	SWRCB Application number A002212 held by USBR for Orland Project

Groundwater

The lands of the Orland Project overlie the Stony Creek Fan (alluvium). Historically, surface water supplies are sufficient to meet irrigation demands, however some of the lands within the Project use groundwater for irrigation due to conveyance constraints of the Project. The quantity of ground water pumped in any year is estimated to average 3,000 af. A detailed description of the hydrogeology of the basin will be provided in TM 3.

Historical Water Demands & Supplies (1970 – 2000)

A water balance analysis was prepared for the Orland Unit for the period 1970 through 2000 as a means of understanding historical water demands and supplies, irrigation efficiency, and the relationship

[8] In addition to the USBR, USACE and OUWUA the City of Santa Clara operates a 6.2 MW hydroplant on Black Butte dam. The hydroplant is operated under a cooperative agreement between the City of Santa Clara, USACE and OUWUA.

between Unit operations and regional hydrology (see Technical Memorandum #3 for more information). The primary purpose in developing the historical water balances is to provide a factual basis for forecasting future cropping patterns and water demands under the Baseline Condition and project alternatives. Pertinent aspects of the water balance analysis are described below.

Cropping Patterns (Historical)

The total land area within the Orland Unit is 24,130 gross acres, of which approximately 15,000 to 17,000 acres were cropped and irrigated over the period of analysis. Exceptions to this were the critically dry years of 1977 and 1996, when water supply shortages resulted in reductions in irrigated area. The cropping pattern is dominated by pasture and forage, which accounts for roughly 60% to 70 % of the total cropped area. The dominance of pasture and forage is believed to be associated with the large number of small parcels in the Orland Unit that are not commercially farmed, and a rotational water delivery pattern that is conducive to forage production, and less so to production of other crops. Permanent crops, although a minor percentage of the total, have steadily expanded in acreage, from about 2,700 acres in 1970 to 3,500 acres in 2000. Field crops have at times been planted to more than 4,000 acres; however, field crops have seen a steady decline in recent years, falling to less than 2,000 acres in 2000. The maximum total irrigated area observed during the period of analysis was about 17,500 acres in 1982.

Water Diversions and Demands

The total measured historical water diversions in the Orland Project between 1970 and 2000 have ranged between 126,308 af/yr and 26,299 af/yr. The average diversion for that period has been 95,372 af/yr. Approximately 20 percent of that diversion is estimated to be conveyance losses (see **Figure 2-1**). The remainder of diversions after conveyance losses is available to meet applied water demand. Applied water demand is the sum of (ETaw) and the irrigation efficiency requirement. [9]

Figure 2-2 represents the various uses of surface water and groundwater to meet ETaw. The surface water diversions are categorized by conveyance losses, irrigation efficiency losses and ETaw. The average estimate of historical ETaw (given conveyance and irrigation efficiency losses) is 49,593 af/yr. On average, water demand is comprised 40% of ET of applied water, 40% on-farm losses and 20% system losses, indicating significant potential for demand reduction through reduction of losses. Private Pumping is negligible in most years, except in water-short years like 1976, 1977 and 1998. The maximum volume of private pumping ever to occur in the Orland Unit was about 13,000 af in 1976.

Baseline Condition (2025)

As noted earlier, the Project Baseline (or Baseline Condition) is used as a reference condition for measuring the benefit or value of the various Solo and partnership-based alternatives. It is a hypothetical future condition that is assumed to exist if none of the alternatives was implemented; it is therefore sometimes also referred to as the "future without the project" or "without-project" condition.

Assumptions

Common to all of the partner's baseline, or without project condition, is the assumption that the planning horizon looks out to 2020. Therefore estimates of future water demand and available water supply of the OUWUA were developed.

[9] To maintain the water balance, changes from year to year in water stored in the root zone must also be accounted for. A decrease in stored water across years is counted as a component of supply, while an increase in storage is represented as a component demand. The volumes of water associated with storage changes are generally small both year to year and cumulatively over the period of analysis, and can generally be neglected.

Cropping Patterns

The cropping pattern in the OUWUA is expected to shift slightly to more pasture and forage than what was historically grown, reflecting the expected increase in the already large number of small parcels that are not commercially farmed. Although the management of the OUWUA is anticipating that, either through the implementation of a solo alternative or a collaborative alternative, the existing rotational water delivery system can be replaced through system modernization it is not anticipated that the cropping patterns over the next 15 years will reflect this change

Water Supply and Demand

Water supply is not expected to change from historical. The OUWUA has relatively senior water rights (as discussed above) and the availability of water under those rights is not expected to change. The challenge before the OUWUA is to make certain that those rights are not reduced through environmental actions.

The demand for water in OUWUA is not expected to change significantly from historical. See **Figure 2-3** for a comparison of the historical and baseline demand. The average historical demand is 79,780 af. The average of the estimated baseline demand is 85,270 af. The difference of approximately 5,000 af per year represents the change to more water intensive pasture and forage crops.

ORLAND-ARTOIS WATER DISTRICT (SUBUNIT 2)

Background

The Orland-Artois Water District (Subunit 2) is located between the Orland Unit (Subunit 1) to the north and GCID (Subunit 3) to the south and east (**Map 1**) The District was formed in 1954 for the purpose of contracting with the United States (Bureau of Reclamation) for a supplemental surface water supply from the Central Valley Project (CVP). The parties originally entered into Contract No. 14-06-200-467-A on April 19, 1963; that contract was amended on September 15, 1964. The original contract, as amended, provided for supplemental surface water to be delivered to OAWD via the Tehama-Colusa Canal (TCC), a feature of the CVP construction of which had not yet begun when the contract was executed.

The original contract was superceded by Contract No. 14-06-200-8283A, entered into by the parties on February 26, 1976. The 1976 contract superceded the original contract with respect to provision of supplemental surface, and provided for the design, construction and repayment of a distribution system to deliver the contract water supply to District lands. According to the agreement, the Bureau provided design and construction management services. Since the expiration of the 1976 contract in 1995, the District has continued to receive Central Valley Project (CVP) water under a series of two-year interim contracts with the United States, each with the same maximum contract amount (53,000 acre-feet) as the 1976 contract. Along with other CVP water contractors, the District is currently negotiating long-term renewal of its water supply contract with the United States.

The District is comprised of 30,290[10] (gross[11]) acres of land interspersed with non-District lands in a checkerboard-like pattern. This pattern reflects the decisions made by individual landowners to join the District or not. The District's assessed area is 28,988 (gross) acres.

[10] According to District records, there are 30,290 gross acres within the District's boundaries. The area digitized to represent OAWD in the water balance analysis was comprised of 31,264 acres because it included some adjoining acreage as well as OAWD lands. This difference is not considered be significant for purposes of the Feasibility Investigation.

[11] Unless otherwise indicated, all references to irrigated areas are to net acreages actually planted to crops and receiving water for irrigation. In general, net acreages are about 6% less that assessed or gross acreages, and

Construction of the distribution system under the District's contract with the United States began in 197? and was completed in 198?. Delivery of CVP water began in 1976 and expanded gradually, year by year, as construction proceeded. The system consists of approximately 100 miles of buried asbestos-cement pipeline with diameters ranging from 8 to 96 inches (Figure ____) *(Note: OAWD distribution system map to be included in subsequent draft documen.)*. The combined delivery capacity through the 5 permanent and 3 temporary turnouts from the TCC is 427 cubic feet per second (cfs). The TCC bisects the District, running east to west across the northern portion of the District, then from north to south across the west side of the District. About 16,767 assessed acres lie down-gradient (generally south and east) of the TCC and are served by gravity, without the need for pumping. The remaining 12,221 assessed acres lie up-gradient (generally north and west) of the TCC and are served by canal side pumping plants that were constructed as components of the distribution system. The maximum elevation difference between the TCC and highest farm delivery is about ____ feet.

Water users are required to place water orders with the District, specifying the volume of water to be used at each turnout on each day. User's orders are compiled for each lateral pipeline system and associated TCC turnout, and submitted to the Bureau of Reclamation daily to enable coordinated operation of the TCC. The District pipelines are closed systems; they operate in response to grower demands, allowing growers to take delivery of their ordered volumes at the rates and durations that are most efficient or convenient for farm operations. There is no spillage from the system, and the District maintains a leak detection program to prevent appreciable leakage. Thus, system losses are negligible. Water deliveries are made to farms through individual farm turnouts with totalizing flow meters. District staff read meters monthly, with meter readings and water bills sent monthly to water users.

Water Resources Setting

Water demands within OAWD are satisfied by a combination of surface water and groundwater sources; both sources are described in the following sections.

Surface Water Sources

OAWD is traversed by several small, ephemeral creeks that originate in the foothills west of the District. The largest among these is Walker Creek, which at times poses a flood hazard. Some irrigation diversions are made from the creeks to District lands in the spring; however, these diversions are unrecorded and are generally believed to be insignificant from a District water supply perspective[12]. Thus, the District's main sources of surface water are imported, including CVP supplies provided under Contract No. 14-06-200-8283A (described above) and occasional, temporary (year to year) water transfers from other CVP water contractors. The maximum water quantity available under the District's CVP contract is 53,000 acre-feet annually (March 1 through February 28); however, this maximum is subject to limitation, depending on overall CVP water supply conditions and Bureau water allocation policy.

Because OAWD is generally water-short, each year the District seeks to augment its CVP contract supplies with short-term water transfers, primarily from CVP contractors that have temporary CVP contract surpluses. Throughout the mid- to late-1980s, due to favorable water supply conditions and prior to enactment of the Central Valley Project Improvement Act (CVPIA) in 1992, the District was successful in transferring significant quantities of water into the District. Since enactment of the CVPIA, and due to poor water supply conditions, water transfer opportunities have been limited.

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therefore generally do not agree with acreage records maintained by Districts. The difference between net and gross acreage is the land area occupied by roads, farmsteads, canals, ditches, etc.

[12] Based on discussions with District staff, average annual diversions from local surface water sources were estimated to be 200 acre-feet annually, during March and April. For purposes of this Feasibility Investigation, this supply source is considered to be insignificant.

In addition to the surface supply source described above, OAWD filed an Application to Appropriate Water with the State Water Resources Control Board on May 15, 2002 (Application #31324). The State Board issued a Notice of Application on May 12, 2003, drawing protests from several interested parties; resolution of those protests is currently pending. If permitted as applied for, OAWD would be allowed to divert water from the Sacramento River at a rate of up to 400 cfs between the dates of October 1 and May 31, not to exceed 30,000 acre-feet for direct diversion for irrigation and frost control purposes, and not to exceed 80,000 acre-feet for diversion for underground storage. The total volume of direct diversion plus diversion to storage would not exceed 80,000 acre-feet during the permitted diversion period. At this time, it is uncertain whether a water right permit will be granted by the State Board or whether the application will be modified in response to protests or State Board concerns.

Groundwater Sources

While surface water is used in OAWD exclusively for agricultural purposes, groundwater serves both agricultural and rural domestic purposes. Groundwater production wells are owned and operated by individual landowners; OAWD does not own or operate any groundwater production wells. Customers having private wells use them to supplement their CVP water supply, particularly during drought conditions when deliveries are curtailed. It is not known how many privately owned and operated groundwater wells exist in OAWD, nor is amount of groundwater pumping known since wells are typically not metered. A description of the regional hydrogeology of the area is provided in Technical Memorandum No. 3 [*to be provided*].

Water Source Preferences

Because groundwater is generally available throughout the District, and because District surface water supplies are not sufficient to meet the total demands of each farm, most growers rely on a combination of surface water and groundwater to meet irrigation demands. The notable exception is certain locales on the west side of the District, where groundwater is not readily available in adequate quantities. In those areas, growers are strongly dependent on District surface water supplies. The District estimates that about 5,000 acre-feet of surface water is needed annually to serve lands that have limited groundwater.

The primary factors that growers consider in selecting water source are discussed below.

- Cost – Cost is widely regarded as the strongest single factor affecting water source decisions. In comparing costs between District surface water and private groundwater, most growers neglect capital recovery associated with private wells costs. Thus, private groundwater production tends to be favored whenever the variable costs of groundwater pumping (energy and pump O&M) are lower that the costs of purchasing surface water from the District. As noted above, however, there are areas on the District's west side where groundwater production is not feasible; in these areas, surface water is the only viable option.
  Moss/Algae – Due to a number of factors, District surface water at times contains high concentrations of moss and algae. Primary contributors are low velocities, long resident times and warm water temperatures in the TCC, which create conditions favorable for algae growth. Moss and algae do not significantly affect surface irrigation systems, but do pose serious problems to operation and maintenance of filtration systems used with drip and micro-spray systems. Thus, drip irrigators tend to favor groundwater as the preferred water source.

- Temperature – The temperature of District surface water varies seasonally, being cold in the winter and spring and warmer in the summer. In contrast, groundwater temperature is relatively stable year-round. Thus, compared to surface water, groundwater is very warm in the winter and warmer in the summer, depending on the depth from which groundwater is pumped. During the frost control season, growers definitely prefer to use groundwater, because it is more effective in preventing frost damage to the crop. To the extent that groundwater is warmer in the summer, it is preferred by rice growers.

- Pathogens/Disease – Some crops are sensitive to water-born pathogens that may at times be present in surface water sources. Farmers concerned about such pathogens prefer to use groundwater.

Historical Water Demands and Supplies (1970 – 2000)

A water balance analysis was prepared for OAWD for the period 1970 through 2000 as a means of understanding historical water demands and supplies, irrigation efficiency, and the relationship between District operations and regional hydrology (see Technical Memorandum #3 for more information). The primary purpose in developing the historical water balances is to provide a factual basis for forecasting future cropping patterns and water demands under the Baseline Condition and project alternatives.

Cropping Patterns (Historical)

Prior to the start of surface water deliveries in 1976, roughly 10,000 acres within OAWD were identified as being irrigated with groundwater; the remaining District acreage was dry-farmed or idle. Since 1976, the irrigated area has expanded to between 22,000 and 23,000 acres (**Figure 2-4**). The dominant crop type initially was pasture and forage with relatively minor acreages of field crops and permanent trees and vines. It appears that there was no rice irrigated with groundwater prior to CVP deliveries. The area planted to field crops increased sharply in 1976 with the introduction of supplemental CVP water. This increase in field crop acreage, together with increases in rice and permanent crop acreage, resulted in a gradual increase in total irrigated area between 1976 and 1983, corresponding more or less to the period of construction of the distribution system. Since 1983, the areas planted to permanent crops and rice have continued to expand, while pasture and forage acreage have gradually declined. The maximum area irrigated was about 24,000 acres in 1997.

Water Demands and Supplies (Historical)

Irrigation demands in Orland-Artois are comprised of two components: (crop) ET of Applied Water and Farm Losses. Conveyance Losses from the pipe District distribution system are considered insignificant[13]. Irrigation demands have ranged from roughly 33 taf in 1975 before the introduction of surface water, to a high of 92 taf in 1988. The median demand is roughly 64 taf and occurred in 1991 (**Figure 2-5a; Table 2-2**). After the introduction of surface water, demand has consistently been comprised of 70% ET of Applied Water and 30% Farm Losses, reflecting a District-wide average on-farm efficiency of 70% since 1977.

Water supply sources include District Surface Water, including water received under the District's CVP water contract and occasional, one-year water purchases from other CVP contractors, and Private Pumping[14] (**Figure 2-5b**). The total utilized[15] supplies have met the demands described above, ranging from 33 taf to 92 taf with a median of 64 taf over the period of record. The supply source varies significantly from year to year depending on the availability of surface water under the District's CVP contract and through CVP water purchases. In 1992, during the drought, the water supply was comprised

[13] To maintain the water balance, change in storage across years is also accounted for. This results in a typically small, artificial component of demand in years when storage increases from year to year. This is called Storage Demand.

[14] To maintain the water balance, change in storage across years is also accounted for. This results in a typically small, artificial component of supply in years when storage decreases from year to year. This is called Storage Supply.

[15] The utilized supply is the quantity actually diverted from available sources to meet water demands; thus, the total utilized supply is equal to total demand. Additional water supplies may have been available, but were not used.

of only 23% District Surface Water and 77% Private Pumping while in 1988 the corresponding fractions were 93% District Surface Water and only 7% Private Pumping. On average, the water supply is comprised of 66% District Surface Water and 34% Private Pumping, reflecting a District-wide average efficiency of 66% over the 1970 to 2000 period.

Since the start of surface water deliveries in 1977, the District has transferred in an addition 6,400 af annually. However, over the period 1990 to 2000, transfers have amounted to less than 2,000 of annually, due to the effects of drought and CVPIA.

Table 2-2. Subunit 2 (OAWD) –Minimum, Maximum, and Average Values of Water Demand and Supply Components (1970-2000)

	Demand				Supply				
	ET of Applied Water	Farm Losses	Conveyance Losses	Storage Demand	District Surface Water	District Pumping	Private Pumping	Private Diversion	Storage Supply
Minimum	27,010	5,151	-	-	-	-	4,152	-	-
Maximum	54,030	42,687	-	3,016	84,127	-	54,361	-	2,828
Average	38,576	22,985	-	361	36,566	-	24,678	-	678

Regional Perspective

Prior to the import of surface water in 1976, activities on OAWD lands resulted in a positive net extraction of groundwater in all but one year (1973), meaning that groundwater pumping exceeded deep percolation from the combination of applied water and precipitation (**Figure 2-6**). Net extraction averaged about 15 taf during the 1970 to 1976 period. With the gradually increasing import of surface water between 1976 and 1983, the area transitioned from an area of net extraction to an area of net recharge. Even during years when CVP supplies were constrained and private pumping reached new highs (e.g., 1992 and 1994), net extraction was essentially zero, meaning that groundwater pumping was offset by an equal volume of groundwater recharge.

Baseline Condition (2025)

As previously described, the Partners agreed to use a modest forecast of Baseline Conditions featuring non-speculative assumptions and actions that clearly could be accomplished by each Partner. The assumptions used to shape the Baseline Condition for OAWD are discussed below, followed by discussion of the implication of the assumed conditions to future OAWD water demands and supplies.

Baseline Assumptions

The assumptions common to all Partners' baseline condition were discussed earlier. Following are the assumptions that are unique to OAWD's Baseline Condition.

1. **CVP Water Supplies:** OAWD's contract with the United States will be renewed at its current maximum amount of 53,000 afa. Pursuant to the Central Valley Project Improvement Act, tiered pricing provisions will be included that have the effect of making the top two 10-percent tiers unaffordable, thereby reducing the maximum useable quantity to 42,400 afa. Additionally, water availability will be constrained by federal water allocation policy and CVP water supply conditions. The assumed availability of water under OAWD's contract, by hydrologic year type, is tabulated below, reflecting the factors noted above as they would apply over long-term hydrologic cycles.

2. **CVP Water Cost:** Despite recent increases in CVP contract rates, it is assumed that the 80 percent of the contract supply not subject to tiered pricing will remain affordable to growers, including the District's operating charges. Thus, it is assumed that all water available under the District's CVP contract below the tiered pricing threshold would be purchased and used by OAWD growers.

Hydrologic Year Type	Assumed Contract Yield (% of 53,000 af Contract max.)	TAF
W	80	42.4
AN	80	42.4
BN	50	26.5
D	25	13.3
CD	10	5.3

3. **Water Transfers:** Opportunities to supplement surface water supplies through short-term purchases will not exist, nor will OAWD sell water out of the District to generate revenues.
4. **Pending Water Rights Application:** It is highly speculative whether OAWD will be granted a permit to divert winter water from the Sacramento River and, if a permit is granted, whether the necessary arrangements can be made with the Bureau of Reclamation under a Warren Act contract for conveyance of the water from the Red Bluff Diversion Dam to the District. Thus, it is assumed that no water will be available to the District under the pending application.
5. **Participation in the Sacramento Valley Water Management Agreement (Phase 8):** Reflecting current OAWD Board policy, it is assumed that the District will not participate in this Agreement.

Cropping Patterns (Baseline)

By 2025, it is anticipated that the total (*net*) irrigated area within OAWD will be 25,312 acres (**Figure 2-7**). The major cropping difference compared to existing conditions would be a significant expansion of permanent crop acreage, reflecting continuation of the expansion in almond plantings observed in recent years. The expansion in permanent cropped area would be accompanied by minor expansions of rice and pasture/forage acreage and a modest reduction in field crop acreage. The non-cropped land area within the District would decrease to accommodate the overall growth in irrigated land area.

Water Demands & Supplies (Baseline)

Under the 2025 cropping pattern discussed above, and based on simulations using 1922 to 1994 hydrologic conditions (precipitation and runoff/water supply), the average on-farm ET of applied water (ETaw) demand would be 63 taf annually, ranging between 52 and 71 taf annually (**Figure 2-8**), depending on hydrologic conditions. The total applied water demand, based on 70% on-farm efficiency, would range between 75 and 101 taf annually, averaging 90 taf annually over the long term (**Figure 2-8**). Because water losses from the District distribution system are negligible, the total District water demand is the same as the applied water demand at the farm level, including on-farm losses.

Subject to the previously discussed assumptions, it is estimated that OAWD's CVP contract would yield an average of 27 taf annually, satisfying less than one-third of the long-term average applied water demand. The supply would range between 5 taf and 42 taf annually, depending on hydrologic conditions (**Figure 2-9**). Water demands in excess of available CVP supplies would be met entirely by groundwater supplies pumped by OAWD landowners. Average pumping would be 63 taf annually, ranging between 35 taf and 95 taf annually, as needed to fill shortages in surface water supplies (**Figure 2-10**). All pumping would be by private landowners, primarily from the Tehama Formation.

Discussion

Relative to existing conditions, the main consequence under the assumed Baseline Condition would be a significant increase in groundwater pumping needed to offset the anticipated reduction in CVP supplies and expansion of applied water demands. From a regional hydrology perspective, OAWD would change from being a net groundwater recharge area under existing conditions to being a net groundwater discharge area under the Baseline Condition.

(Note: need a graph or table to illustrate this change.)

GLENN-COLUSA IRRIGATION DISTRICT (SUBUNIT 3)

Background

GCID is located in the central portion of the Sacramento Valley on the west side of the Sacramento River, as illustrated on **Map 1** (Glenn County portion only). The District's service area extends from northeastern Glenn County near Hamilton City to south of Williams in Colusa County. The east side of the District stretches toward the Coastal Range and Tehama-Colusa (TC) Canal. GCID's main facilities include a 3,000 cfs pumping plant and fish screen structure located on the Sacramento River at the northern end of the District, just north of Hamilton City, a 65-mile Main Canal, and approximately 900 miles of laterals and drains.

With 175,000 acres, GCID is the largest irrigation district in the Sacramento Valley. The soils within this area generally consist of clay-like and loam characteristics. The low infiltration rates of the tight soils within much of the District are conducive to furrow and border irrigation. To that end, rice is the predominant cultivated crop. Other crops include, but are not limited to, tomatoes, vine crops, sunflowers, prunes, almonds, and walnuts.

GCID uses an arranged schedule to deliver irrigation water to District customers. The main canal is situated along the west side of the District and supplies various laterals that supply individual farms and refuges. GCID does not supply municipal or industrial water.

In 1990 the District's Sacramento River diversion was identified as a significant impediment to the downstream migration of juvenile salmon. Following the state and federal listing of the winter-run Chinook salmon as endangered through the Endangered Species Act, pumping restrictions were imposed on GCID by a court-ordered injunction, preventing the District from diverting its full water entitlement. A long-term solution was developed to provide both safe fish passage past the GCID diversion facilities and to ensure a reliable water supply to GCID by allowing the District to divert their maximum capacity of 3,000 cfs. Key components of the solution included enlargement and improvement of the fish screen structure and the construction of a gradient facility in the main stem of the Sacramento River to stabilize the river channel. These facilities were complete in 2002.

In response to the reduced diversions described above, and three years in the last decade classified as "critically dry years," resulting in contract supplies being reduced to 75% of entitlement, the District developed a number of programs to supplement these reduced supplies, including an aggressive drainwater recapture program, an emergency water conservation program, a voluntary groundwater conjunctive water management program, and an in-basin water transfer program.

Water Resources Setting

Lands within GCID rely primarily on surface water and only a small fraction of landowners also pump groundwater. These sources are discussed further below.

Surface Water Sources

The Sacramento River serves as the principal water source for GCID. Its diversion is the largest surface water diversion on the river. The District holds both pre- and post-1914 appropriative water rights to divert water from the natural flow of the Sacramento. GCID also has adjudicated pre-1914 water rights under the Angle Decree, issued in 1930 by the Federal District Court, Northern District of California, to divert water from the natural flow of Stony Creek. In addition, as the successor in interest to Central Canal and Irrigation Company, GCID has, under a May 9, 1906 Act of Congress the right to divert up to 900 cfs from the Sacramento River (Pub. L. No. 151, Ch. 2439).

GCID entered into a negotiated agreement with the USBR in 1964, quantifying the amount of water GCID could divert from the Sacramento River (Contract No. 14-06-200-0855A (Contract No. 0855A)). The resulting negotiated agreement recognized GCID's annual entitlement of a Base Supply of 720,000 ac-ft/yr of flows from the Sacramento River and also provided for a 105,000 ac-ft/yr allocation of Project Water, resulting in a total contract entitlement of 825,000 ac-ft/yr. The 825,000 ac-ft/yr entitlement recognized under contract for GCID is inclusive of their entitlement recognized under their Angle Decree rights, which, on average, yield about 15,000 to 18,000 ac-ft/yr. This negotiated agreement will remain in effect until March 31, 2004. Under the terms of a separate wheeling agreement with USBR, GCID can request to receive a portion of its entitlement water through the Tehama-Colusa Canal via two points on interconnections with the Tehama-Colusa Canal. The use of the Tehama-Colusa Canal for delivery of entitlement water is subject to available capacity as determined by USBR.

Contract No. 0855A does not limit GCID from diverting water for beneficial use during the months of November through March, to the extent authorized under California law. GCID has recently obtained a water right permit for non-contract period diversions in the amount of 182,900 ac-ft (up to 1,200 cfs). Although some pre-irrigation occurs within the District, non-contract period diversions are predominantly used for rice straw decomposition and waterfowl habitat. GCID also holds water rights to divert from a number of small tributaries to the Sacramento River, including Hunters Creek (2 cfs), an unnamed stream tributary to Funks Creek (2 cfs), Stone Corral Creek (11 cfs), and Colusa Basin Drain (134 cfs).

Reuse and Recirculation

As mentioned above, an aggressive drainwater recapture program, which includes both groundwater seepage and tailwater runoff from cultivated fields from within GCID's service area, is a part of GCID's overall water management program. GCID recaptures this water with both gravity and pump systems. Recaptured water is delivered to either laterals or the main canal for reuse by both in-District and out-of-District users. It is estimated that GCID currently recycles approximately 155,000 ac-ft annually.

Much of GCID's drainwater is captured for use by downstream districts such as the Provident Irrigation District (PID), Princeton-Codora-Glenn Irrigation District (PCGID), and Maxwell Irrigation District (MID). GCID is one of the irrigation districts that signed the Five Party agreement of June 2, 1956. This agreement represents a cooperative effort by GCID, PID, PCGID, MID, and two entities that have since dissolved (Compton-Delevan Irrigation District and Jaciento Irrigation District) to share operation and maintenance of the drains within their respective service areas and to share the right to recirculate the water in those drains. In addition, Colusa Basin Drain Mutual Water Company members (57,000 acres, gross) rely on tailwater from GCID and other upstream water users.

Groundwater

Approximately 200 privately owned wells are located within the District's boundaries. GCID operates one well with an approximate capacity of 10 cfs. Groundwater has been placed to greater use since Endangered Species Act (ESA) restrictions on GCID in the early 1990's. While historical records of groundwater pumping are not available district-wide, the California Department of Water Resources estimated that in 1993 approximately 4,200 acres were irrigated with 17,000 acre-feet of groundwater. This is believed to be representative of total independent private pumping throughout GCID in any given year aside from district-sponsored programs such as the voluntary groundwater conjunctive water management program discussed below. A description of the regional hydrogeology of the area is provided in Technical Memorandum #3 *(to be provided).*

In recent years, the District has supplemented its surface water supplies with groundwater from local production wells. It has accomplished this with a voluntary conjunctive water management program. This District-managed program involved more than 100 private landowners that were reimbursed by the District per acre-foot contributed to GCID's supply. The program has contributed up to an estimated 72,000 ac-ft in a single year (1992) in response to reductions in surface water supply.

Water Source Preferences

The circumstances associated with the Districts' Sacramento River entitlement, particularly the seniority and size of the water right, make it the preferred and primary source. Rather than developing and depending upon alternative supplemental sources, the District has emphasized the development of programs designed to make the best use of this source, programs such as those described previously.

Drainwater recovery and reuse is an important source of water to farmers within and outside GCID. Although not a new source of water, reuse of drainwater allows water users to manage the timing and quantity of water delivered, providing flexibility and maximizing water use efficiency in the area. The District has, and continues to, augment its drainage system to enable recovery of tailwater for reuse. In terms of relative costs, it tends to be the cheapest alternative to the Sacramento River entitlement. Continued expansion of drainwater recovery capabilities within the District may occur at the expense of impacting downstream users and must be carefully considered to avoid conflict. There is also a potential for salinity buildup on fields due to drainwater reuse, and the potential impacts on crop yields must be assessed.

The production of groundwater for local use by privately owned wells, either independent or in coordination with District operations, is the next most cost-effective option. Independently produced groundwater tends to be very small, less than 3% of total supply, and the pattern of this use has not changed significantly in recent years. The reasons for a farmer's preference to augment their surface water supply with groundwater vary. The most common reason is to accommodate crops susceptible to temperature and water quality changes. Supplies originating from the Sacramento River would tend to exhibit wider ranges seasonally as compared to groundwater. Groundwater produced as part of the District-managed conjunctive water management program has been a cost-effective tool in terms of offsetting reduced surface water supplies, as discussed previously. In more recent years the District-managed program has been used to help meet water needs outside of the District. The compensation for this water made to the District and its growers has enhanced the affordability and reliability of the District's supplies.

Water conservation measures such as canal lining, conveyance system automation, district-level water measurement, farm-level metering, precision farming techniques, and other irrigation technology improvements have been used effectively within GCID in last decade to improve water use efficiency and reduce diversions in times of shortage. Within the last decade, District diversions have been reduced as much as 25 percent (increased drainwater recovery and reuse also contributed to this savings). However, water conservation measures are typically the most expensive options and can be in conflict with the regional water management characteristics of the area. The hydrologic characteristics of the region GCID lies within, the Colusa Basin, can be described as a "flow-through" system, in that the vast majority of the water not consumptively used returns to drains and is rediverted by others, percolates into the ground and potentially pumped by others, or returns to the river and is reused downstream. Therefore, the actions of an upstream district such as GCID can have a considerable effect on downstream areas. Currently, GCID is participating, along with other Sacramento River Settlement Contractors and the U.S. Bureau of Reclamation, in a study to assess the potential for improved water measurement. The primary objective of this study is to identify the potential benefits of improved district-level and sub-basin-level water measurement and the potential issues and impacts that might arise.

Historical Water Demands and Supplies (1970 – 2000)

A water balance analysis was prepared for GCID for the period 1970 through 2000 as a means of understanding historical water demands and supplies, irrigation efficiency, and the relationship between District operations and regional hydrology (*Technical Memorandum #3 discusses the water balance in detail and will be provided later*). The primary purpose in developing the historical water balances is to provide a factual basis for forecasting future cropping patterns and water demands under the Baseline Condition and project alternatives. The water balance was developed for the Glenn County-portion of GCID only because of its close linkage to the proposed SCF Conjunctive Water Management Program area.

Cropping Pattern (Historical)

The total land area within GCID-Glenn County (Subunit 3) is 72,643 acres, with the cropped area ranging between roughly 32,000 acres and 60,000 acres over the 1970 to 2000 period (**Figure 2-11**). Rice is the predominant crop, accounting for approximately 85 percent of the District's irrigated acreage. Other important crops include tomatoes, orchards, vineseeds, cotton, alfalfa, and irrigated pasture.

Although the irrigated area varies considerably from year to year, there appears to have been an overall expansion in irrigated area over the period, with the irrigated area holding more or less constant at about 55,000 acres over recent years. The expansion in irrigated acreage is explained almost entirely by an increase in the dominance of rice, which increased in acreage from about 24,000 acres initially to 48,000 acres throughout most on the 1990s. Over the same period, the combined area of non-rice crops has remained essentially constant at 10,000 to 12,000 acres, while other non-cropped land uses declined in area by about 20,000 acres.

Water Demands and Supplies (Historical)

The GCID annual diversions are bimodal, a reflection of the cultural practices of growing rice. Near the beginning of the irrigation season when farmers are flooding their rice fields, beginning in the spring months, the District typically relies upon their entire allotted monthly contractual amounts. This need for water typically peaks during the hot, dry summer month of July, during which time maximum monthly diversions usually occur. This pattern is followed by a gradual decrease in diversions until later in the year when a much smaller peak occurs in the fall. This last peak is again a result of farmers flooding their rice fields, this time post-harvest for straw decomposition.

Historically, GCID has used all of its Base Supply and diverted a majority of their Project Supply. In 1981 and 1984, GCID purchased additional CVP water above the 105,000 ac-ft amount provided for in the contract. During the critical months, GCID diverted CVP water every year from 1964 to 1997, as shown on **Figure 2-12**.

The water demands were met primarily through District surface water with small supplemental amounts of private pumping (**Figure 2-13**). The water supplies are consistently composed of 97% District surface water and 3% private pumping throughout the period of record. Historical surface water supplies estimate for the Glenn County portion of GCID ranged from 292 taf to 507 taf per year, averaging 416 taf per year. Estimated private pumping ranged from 0 to 31 taf per year, with an average of 10 taf per year.

Regional Perspective

The water balance analysis indicates GCID is an area of recharge over the period of record from 1970 to 2000, meaning deep percolation from the combination of applied water and precipitation exceeded groundwater pumping. Net extractions ranged from roughly -111 taf to -277 taf per year and averaged roughly -188 taf or -2.6 AF/acre per year. Variability in net extractions can be mainly attributed to variability in annual rainfall (**Figure 2-14**). It is not surprising to see such large net recharge given the large proportion of surface water supply available to the District. Even during critically dry years when the District surface water supply is reduced 25%, such a 1992, net recharge remains significant.

Baseline Condition (2025)

The assumptions used to shape the Baseline Condition for GCID are discussed below, followed by discussion of the implication of the assumed conditions to future GCID water demands and supplies.

Baseline Assumptions

1. Ongoing contract renewal efforts associated with GCID's Sacramento River supplies will likely result in similar contract entitlements. The renewed contract is also expected to include better provisions with regards to water transfers allowing for more flexibility. For the purposes of the feasibility investigation it is assumed that the renewed contract in its current form will be renegotiated and in place. For the purposes of defining GCID's baseline conditions, it is assumed GCID renews its settlement contract for 720,000 acre-feet of Base Supply and 105,000 acre-feet of Project Water Supply, totaling 825,000 acre-feet annually.
2. It is also assumed that GCID will continue to recover drainwater from district drains to generate supplies for local water supply reliability, especially in 75% supply years. Drainwater recapture is assumed to occur at levels similar to recent historical conditions. For the purposes of this investigation, the range of drainwater recapture is assumed to be between 25,000 acre-feet and 200,000 acre-feet per year.
3. Groundwater production for local use is expected to occur similar to recent historical conditions, and is assumed to meet all remaining unmet demands.
4. Outside of a potential SCF partnership, GCID will take measures to ensure local water supply reliability and to generate financial revenues to ensure affordability of surface water supplies to District water users, and to finance system modernization. The underlying strategy is to protect the District's water rights by maintaining a substantial base of surface water users. Groundwater substitution programs to support potential water transfers outside of the district are expected to continue and possibly expand in the future. This is the subject of further discussion under the Solo Alternatives section below.
5. GCID has one district-specific action that is included in the Baseline Condition. As part of the Sacramento Valley Water Management Agreement (i.e. Phase 8 settlement agreement) GCID has agreed to implement a groundwater substitution program. Environmental documentation and related efforts are underway to implement this and other related programs for other parties to the SWVMA. For this reason, the Baseline Condition for the SCF Feasibility Investigation assumes GCID's SVWMP project will be in place.

   As part of the SVWMP, GCID plans to transfer up to 30,000 acre-feet of water in below normal, dry, and critically dry years. The transfer water would be made available through the substitution of surface water, under the District's pre-1914 water right, for groundwater pumped within the District. It is assumed the transfer water would be regulated in and released from the Bureau of Reclamation's Shasta Lake, and would flow through the Sacramento River and then to the Delta. Transfer water reaching the Delta would be available for salinity and water quality control within the Delta, or for export to users within the SWP or CVP service areas.

   GCID will implement similar management and operational schemes used successfully in recent years to support similar groundwater substitution programs. For example, in June and July 2001, private well pumpers participated in producing 33,000 ac-ft of supply as part of the 2001 Water Forbearance Program executed between GCID, Bureau of Reclamation, and Westland's Water District. Facility operations are assumed to include full utilization of the network of existing private landowner wells that have contracted with the District in past conjunctive use programs. The project components are summarized in **Table 2-3**.

Table 2-3: GCID Groundwater Substitution Program Components for 30,000 ac-ft SVWMP (Phase 8)

COMPONENT	DESCRIPTION/ASSUMPTION
Yield (ac-ft/yr)	30,000
Frequency	Below Normal, Dry and Critically Dry Year types (a)
Pumping Zone	Tehama Formation
Potential Recipients	Water users participating in DWR's Dry Year Water Purchase Program Environmental needs. CVP water users.
Surface Water Source	GCID's pre-1914 appropriative water rights on the Sacramento River.
Delivery Pattern	Irrigation pattern, June through October.
Pumping Location	Pumping will occur within the 175,000 acreage of GCID with approximately 80% in Glenn County and 20% in Colusa County. The precise location of wells would depend upon landowner participation. GCID estimates 100 to 115 wells would participate, approximately 85% diesel and 15% electric.
(a) Water year classification based on the Sacramento Valley Index.	

Cropping Pattern (Baseline)

By 2025, it is anticipated that the total (*net*) irrigated area within GCID (Subunit 3) will be 57,593 acres (**Figure 2-15**). Review of trends in recent historical crop acreage distributions in GCID suggest rice will continue to be the predominant crop in the future with small shifts towards higher value, more permanent crops and small reductions in lower valued crops, such as field and pasture crops. The non-cropped land area would remain virtually unchanged relative to recent observed conditions, suggesting negligible overall change in the total irrigated area within GCID (Subunit 3).

Water Demands & Supplies (Baseline)

For the feasibility investigation it is assumed that GCID's settlement contract will be renewed according to the conditions discussed above. For this reason it is not expected that the availability of GCID's Sacramento River water supply will change significantly.

Projected water demands for GCID are anticipated to remain relatively the same as current conditions (Sacramento River Basinwide Water Management Plan, Sep. 2002). The average historical demand for GCID-Glenn County based on the water balance analysis was estimated at 427 taf annually. The average of the estimated projected baseline demand is 450 taf over the same period of record. This is an estimated increase of approximately 5% on average. The difference is primarily attributable to a small assumed increase in rice and permanent crop acreage represented under the baseline condition as compared to recent historical conditions.

Discussion

Relative to existing conditions, the main change under the assumed Baseline Condition would be an increase in groundwater pumping in conjunction with the Phase 8 30 TAF per annum groundwater substitution program. From a regional hydrology perspective, under the Baseline Condition GCID's contribution as a net groundwater recharge area would be diminished as a result of this activity.

(Note: need a graph or table to illustrate this change.)

GROUNDWATER ONLY AREAS (SUBUNITS 4-7)

Background

[to be completed after review of this initial draft document]

Cropping Pattern (Historical)

The Ground Water only areas, Subunits 4-7 encompass 74,965 acres. The irrigated area has remained more or less constant from 1970 to 2000 ranging from 40,000 acres during the drought years of 1976 and 1977 to 55,000 acres with and average of 49,000 acres (**Figure 2-16**). A major trend displays steady increases in permanent crops offset by decreases in pasture and idle lands throughout the areas. Permanent crops have increased from 6,000 acres in 1970 to 20,000 acres in 2000. Pasture has decrease from 22,500 acres in 1970 to 13,000 acres in 2000. Other non-cropped land uses including idle lands have declined by roughly 5,000 acres. Field crop acreage has varied considerable from year to year ranging from 15,000 to 28,000 acres and averaging 20,000 acres; however there appears to be no increasing or decreasing trends. Rice acreages have remained relatively constant averaging roughly 900 acres.

Water Demands and Supplies (Historical)

The Ground Water only areas water demand components are (crop) ET of applied water and farm losses (**Figure 2-17a**). They have ranged from a low of 105 taf in 1998 to a high of 182 taf in 1994, the median year occurring in 1999 at 152 taf. The variation is directly related to variation in spring rain, 1998 had large quantities of spring rain while 1994 had relatively low quantities of spring rain. ET of Applied Water on average comprises approximately 70% of the water demand, while Farm Losses are 30% of the water demand. The only source of water supply is Private Pumping (**Figure 2-17b**).

Regional Perspective

The Groundwater only areas are net extractors averaging 49 taf or 0.62 AF per acre per year for the 1970 to 2000 period (**Figure 2-18**). Over this period there were four years (1973, 1983, 1995, and 1998) when these areas had net annual recharge to the Groundwater System cause by record high annual rainfalls leading to high levels of Deep Percolation of Precipitation.

Baseline Water Supplies and Demands (2025)

[to be completed after review of this initial draft document]

[see Figure 2-19 and 2-20]

SECTION 3. DESCRIPTION OF PROJECT ALTERNATIVES

INTRODUCTION

At the outset of this Feasibility Investigation, the expectation was that the project alternatives would involve some degree of actual sharing of physical resources between or among the Partners to implement the groundwater recharge and recovery cycles of a conjunctive water management program. However, as the hydrogeology of the Project Area became better defined, primarily by virtue of the efforts of the DWR Northern District, it became evident that the opportunities for conjunctive water management were more likely to involve independent actions pursued by each Partner and not actual, physical sharing of resources. The factors contributing to this outcome were discussed previously; briefly restated, the two primary contributing factors are:

The fact that groundwater system is essentially full, meaning that additional groundwater recharge is not needed or effective for implementing conjunctive water management *at this time.* The new source of water represented by the Lower Tuscan aquifer, which is believed to be substantial in quantity and developable at low cost, supplants the value of cooperative action, at least in the context of achieving local water supply reliability objectives.

In view of these conditions, primary emphasis was placed on developing a Solo Alternative comprised of the physical actions that the individual Partners were most likely to take to meet their respective objectives, but planned and conducted in a coordinated manner, with certain administrative and institutional functions served by the Partnership. Collaborative alternatives based on actual physical sharing of resources were also investigated. Both the Solo Alternative and the collaborative alternatives are described in the section.

SOLO ALTERNATIVE

As mentioned above, the Solo Alternative is comprised of the physical actions that each Partner would most likely take to pursue its individual objectives, combined with certain common administrative and institutional functions served by the Partnership. The physical actions that would be undertaken by each Partner represent the conjunctive water management program that best achieves that Partner's respective individual objectives with its available resources. Although the Partners would operate independently, the individual conjunctive water management programs comprising the Solo Alternative were formulated in a coordinated, integrated manner, particularly concerning potential effects on the groundwater system.

The administrative and institutional functions that would be performed by the Partnership include *monitoring* of groundwater conditions to ensure compliance with County BMO's and possibly other standards, *marketing* of water generated by the individual Partners and *environmental compliance*.

The individual conjunctive water management programs and the Partnership's administrative functions comprising the Solo Alternative are described below.

Orland Unit Water Users Association

Background

The goals of the OUWUA are to protect the Association's water rights by maintaining a substantial base of surface water users and to manage the water resource for local and state benefit. Maintaining a substantial base of surface water users could be achieved by transitioning from the Association's existing rotation delivery service to a more flexible, responsive water delivery service. Such an improvement in water delivery would allow the Association to better provide for the irrigation needs of its members, particularly to those with relatively smaller parcels of land. A portion of the capital required for such an investment could be generated by contributing to the state's water shortages via voluntary transfers of water.

The SCF pursued two types of solo alternatives for the OUWUA. In addition to analyzing groundwater substitution transfers, as was done for the other two partners, the SCF investigation also analyzed the potential for the OUWUA to generate new yield via reservoir re-operation. Each of these two types of alternatives is discussed below in more detail.

Solo Alternative 1: Groundwater Substitution Transfers

The analysis of groundwater substitution transfers in OUWUA focused on two topics.

- Considerations for the production of the groundwater given the legal status of the Association as a California corporation.
- Conveyance of the forgone surface water down Stony Creek

Each of these two topics is discussed below in turn.

Production of Groundwater

Given the legal status of the OUWUA as a California corporation the ability of the Association to own wells and pump groundwater for distribution throughout its system should undergo a legal review. If the Association can legally own and operate wells for use in a groundwater substitution transfer then the Association needs to determine if it would choose to develop its own wells and/or whether it would rely on members to produce the groundwater.

If the Association is legally precluded from operating wells it owns for a groundwater substitution transfer then production of the groundwater falls to its members. In which case the volume of water available for transfer could depend on the existing capacity of pumping in the basin, and/or the incentives that could be offered members to construct new wells.

The water balance analysis described in the 'Baseline' section of this report estimates that the historical maximum amount of groundwater pumping in OUWUA is 13,000 acre-feet. Assuming this represents the existing groundwater pumping capacity, OUWUA could participate in annual groundwater substitution transfers of up to 13,000 acre feet annually. The capacity of a proposed program could be limited by two factors, namely:

- Not all growers who own the wells would choose to participate in the proposed program.
- Some of the existing pumps, used to produce the water, may not be allowed in the program if there are restrictions placed on the use of diesel pumps due to air quality constraints.

For purposes of evaluating this alternative it is assumed that 10,000 af could be transferred in any one year. The volume of a potential transfer will be more clearer understood during the development of the Groundwater Production Element Study.

The revenue generated by the proposed transfer would be used to compensate the members participating in the program that normally use surface water, for pumping groundwater. The remainder of the revenue, net of costs is, available for distribution to the Association and the members. The distribution of the net revenue would be based on a negotiation between participating members and the Association. **Table 3-1** shows per af net revenue available from a transfer. The transfer prices shown in **Table 3-1** reflect those used in the Sacramento Valley Water Management Plan, Short-Term Agreement. Pumping costs are an estimate, and could vary.

Table 3-1
Per Acre Foot Revenue and Costs of Groundwater Substitution by Year Type

Transfer Component	Year Type			
	Wet to Above Normal	Below Normal	Dry	Critical
Price	$50	$75	$100	$125
Pumping Cost	$20	$20	$20	$20
Net Revenue	$30	$55	$80	$105

Figure 3-1 shows the exceedance probability of the present value of the net revenue of a groundwater substitution transfer over 25 years. The figure shows the value of transferring 10,000 af in dry years and critical years and the value of transferring 10,000 af in below normal, dry and critical years. The dry year and critical year transfer has a 50 percent exceedance value of approximately $5.5 million. The average annual transfer volume over the 25 year project is 4,000 af. The transfer that occurs in above normal, dry and critical years has a 50 percent exceedance value of just over $9.0 million over 25 years. The average annual transfer volume when water is transferred in below normal, dry and critical years is 5,900 af.

Figure 3-2 shows the *annual* net revenue for the same information presented in **Figure 3-1**. The annual net revenue generated by a transfer is $550 thousand, $800 thousand and $1,050 thousand in below normal, dry and critical years, respectively. The frequency of the transfers is based on the Sacramento Valley River Year-type Index for the period from 1922 to 1994.

Facts to help generalize the information presented in **Figure 3-1** and **Figure 3-2**:

- The net revenue may not be available only to the Association. In the past some local districts that have participated in groundwater substitution transfers have paid members who pump between approximately 60 percent and 90 percent of the transfer price.
- The information presented in **Figure 3-1** and **Figure 3-2** is scalable, e.g. to estimate a transfer of 20,000 af in each specified year type multiple the estimates of net revenue and net present value times 2. To estimate the value to distributing the net revenue between the pumping-members and the Association multiple the estimates of net revenue by an appropriate factor.

Figure 3-3 provides a conceptual view of how to estimate the change in storage in the aquifer as a result of a groundwater substitution transfer of 10,000 af in dry and critical years. The natural recharge rate for the aquifer is not known with certainty. **Figure 3-3** shows three different estimates of the change in storage volume under three different estimates of natural recharge rates; 10,000 af per year, 7,500 af per year and 5,000 af per year. If the natural recharge rate were 5,000 af an the estimated change is storage over the hydrologic trace ranges from negative 70,000 acre feet to positive 15,000 acre feet. Likewise, the change in storage when recharge rates are estimated to be 7,500 af per year and 10,000 af per year show similar reductions in storage and relatively higher increases. In all likelihood the increases in storage volume represented by the conceptual drawing would not be as high as they are shown because at some storage level the basin rejects recharge because it is full when the transfers began. **Figure 3-3** is intended to provide an intuitive understanding of how modest groundwater substitution transfers that occur in only the two most dry year types can have minimal impact on the storage of the basin.

Conveyance of Transfer Water

The last issue to be discussed under this alternative is the potential challenge faced by conveying transferred water down Stony Creek. Recent work by the DWR suggests that Stony Creek is a loosing stream for most of the area between OUWUA Eastern boundary and the Sacramento River. The rate of loss may be a factor in a transfer if the potential buyer of the water believes that the loss rate is too high. One possible solution to this challenge would be to adjust the price (or quantity) of the transfer to reflect the loss. Another possible solution to the challenge that is more advantageous, is to time the transfer to occur when there is already water in Stony Creek. Thus, avoiding or reducing the loss. There may be a limit to how much timing can be used to avoid the challenge based on the potential buyers needs. The solution would have to be found once more particulars of a potential transfer were know.

Solo Alternative 2: Reservoir Re-operation

The combined storage of East Park and Stony Gorge reservoirs is approximately 100,000 af. To the extent that the reservoirs could be re-operated to put new water in the system OUWUA may have the opportunity to transfer that water. In order to prove-up the availability of new water under a re-operation alternative OUWUA would have to show that it can lower the end of year storage of the reservoirs below the historical levels. Using this method to 'prove-up' the existence of new yield would prove to the potential buyer and participating agencies that the re-operation is 'pushing' water out of the reservoir, essentially spilling water, that would not have otherwise been there but for the transfer.

The steps to proving-up this sort of transfer start by analyzing the historical end of season storage to see if the current operations of the reservoir creates a predictable end of season storage that is nearly always the same. **Figure 3-4** shows the end of month storage for the sum of East Park and Stony Gorge Reservoirs over the hydrologic trace from 1956 through 2003. What can be seen by examining **Figure 3-4** is that there is a wide variance in end of season storage. This variance may prove an obstacle to prove-up that a change in the end of season storage, that would result from a transfer, would not have occurred anyway. It may still be possible to affect a re-operation transfer however much more work would have to go into understanding how the end of season storage for the reservoirs is planned. Since the Stony Creek Fan was an investigation of conjunctive use and how best to utilize the groundwater aquifer, further work on re-operation alternative was determine to be outside the current scope of work. However, OUWUA may benefit from continued investigation of a re-operation.

Solo Alternative 3: Reservoir Reoperation Combined with Conservation

As part of a CALFED study OUWUA examined the possibility of providing new water by investing in system modernization. One of the alternatives of the report entitled, *OUWUA Distribution System Modernization and Water Conservation Project* proposed an investment of $53,499,000 in 'Canal Rehabilitation' thereby conserving 25,400 af annually. One of the stated purposes in the study was examine the ability of OUWUA to transfer this conserved water.

California Water Code §1011 authorizes the transfer of water made available because of "water conservation efforts". However, the State Water Resources Control Board (SWRCB) has clarified the State's position in its 1999 Order WR 99-012 on the petition by Natomas Mutual Water Company to transfer conserved water. The Order states:

> *The SWRCB concludes that, pursuant to Water Code section 1725, Natomas may transfer the right to use the amount of water that Natomas would have consumptively used but for Natomas's conservation efforts. A reduction in diversions that does not reduce consumptive use cannot be transferred pursuant to section 1725.*

For this reason the SCF Investigation feasibility study team recommends that OUWUA does not pursue a transfer of conserved water.

At the same time as the aforementioned report was being completed there was an additionally, CALFED investigated underway that investigated the possibility of increasing yield to the Tehama Colusa Canal via water use efficiency. The document entitled *OUWUA and TCCA Regional Water Use Efficiency Project* describes the findings. The document suggests that re-operating the existing reservoirs on Stony Creek in conjunction with a well field new yield may be available to the region. The document was intended to examine the physical nature of a program and not the legal aspects of water rights.

The SCF study team followed the direction of the CALFED study by examining the potential for OUWUA to create new yield by combining conservation efforts with re-operation. So that rather than transferring conserved water the OUWUA would be offering to change the pattern of water deliveries to a potential buyer through re-operation. This alternative would face the same challenges in a potential transfer as the challenges faced in Solo Alternative 2, none the less the study team attempted to estimate the volume of water that could be made available by combining conservation with re-operation.

A CALSIM model of the Stony Creek system was obtained from the Bureau and estimates where made of changes to end of year storage from a 25,400 af reduction in irrigation demand. **Table 3-2** shows the results of this modeling effort. The estimated change in end of September storage for the three reservoirs is 15,600 af. The range of changes is from a maximum of 47,200 af to a negative 14,300. The extent to which that OUWUA can transfer any or all of this water is met with the same challenges as described in Solo Alternative 2. It may still be possible to affect a transfer under Solo Alternative 3 however much more work would have to go into understanding how the end of season storage for the reservoirs is planned and how the revenue necessary to generate the conservation could be raised.

Table 3-2
Change in End of September Storage Statistics

	East Park	Stony Gorge	Black Butte	Total
Average	4.9	4.1	6.7	15.6
Maximum	17.6	11.1	18.5	47.2
Minimum	-5.5	-3.0	-5.9	-14.3

In summary, it appears that the OUWUA has multiple alternatives available to them both for re-operation and groundwater substitution transfers. The conclusion of this analysis is that the alternative that presents the fewest challenges for 'proving-up' a transfer, and the least cost is the groundwater substitution transfer.

General Issues for OUWUA Alternatives

As a nonprofit corporation OUWUA is limited in the amount of revenue that can be generated from other than their specified non-profit purpose. For example, if a nonprofit corporation engages in profit-making activities unrelated to its recognized nonprofit purpose, it must set up a separate corporation to engage in that activity or risk losing its nonprofit, or tax exempt, status, or pay tax on the revenue. The OUWUA is limited to only earn 15% of total revenue from activities such as water transfers without facing taxation. The OUWUA may want to consider what legal structure serve, it best under future operations.

Orland-Artois Water District

Under Baseline Conditions, it was shown that OAWD's 2025-level water demands would increase relative to existing demands, while the availability of surface water supplies under its CVP contract and through short-term water would decrease. The effect would be that OAWD landowners would need to pump substantially more groundwater from the Tehama Formation than has ever been pumped historically, which may not be sustainable. These conditions compel the District to take positive measures to fulfill its fundamental mission of providing reliable, affordable water supplies to its landowners. These measures, discussed below, comprise the District's Solo Alternative.

- District Development of Lower Tuscan Groundwater – District-sponsored development of groundwater drawn from the Lower Tuscan Formation. The Lower Tuscan is generally regarded as being separate from the overlying Tehama and Stony Creek formations, thus representing a new, essentially undeveloped water supply source. The District's plan would be to develop sufficient capacity from the Lower Tuscan so that, combined with available surface water supplies, the resulting magnitude of private pumping from the Tehama Formation would be sustainable.

- Pricing Incentives – Provision of pricing incentives that encourage growers to use District CVP surface water supplies and District-produced groundwater in favor of privately produced groundwater. This means that the blended cost of District water supplies (CVP surface water and District-produced groundwater) must be maintained below the cost of private groundwater production. With this incentive, landowners would use District water supplies to exhaustion before relying on their own wells, thereby limiting extractions from the Tehama to sustainable levels.
- Strategic Marketing of CVP Supplies – Marketing of modest portions of the District's CVP contract supply, when market conditions are favorable, to generate revenues as needed to implement the pricing incentives described above.

District Development of Lower Tuscan Groundwater

As described under the Baseline Condition, the expected long-term yield of the District's CVP supply is about 27 taf annually. In addition, based on historical observations and experience, the District believes that the safe yield from the Tehama formation, the source of most private pumping, is about 30 taf annually. Thus, currently available supplies total to just 57 taf annually on average, or about 33 taf short of OAWD's projected long-term average water demand of 90 taf. To fill this shortage, the District has embarked on a program to develop additional groundwater supplies from the Lower Tuscan Formation.

The District completed a 1,520-foot test hole into the Lower Tuscan in late 2003. The e-log results were promising, so the District is proceeding with construction of a 1,320-foot production well, which reportedly will be the deepest groundwater well yet to be constructed in the Sacramento Valley. Interpretation of the e-log by DWR Northern District staff indicates that the well should produce at the rate of approximately 3,000 gpm (6.7 cfs). The well will be located strategically to tie into the existing Lateral 35.2 at a point where relatively large downstream demands will allow maximum production opportunity each year. Additionally, the selected site has electrical power available nearby, so the pump can be electrically driven. (Cost estimates reveal that at current rates diesel is marginally less expensive than electricity for powering groundwater wells, neglecting powerline extension costs. However, concerns about emerging air quality regulations that could apply to diesel engines lead to an overall preference for electrical energy.) Operations studies conducted by the District indicate that the well should be able to produce up to 3,300 af annually, depending on the magnitude and distribution of demand.

The cost of the Lower Tuscan well is estimated to be $230,000 *(need to confirm this with OAWD staff)*, complete with pump, motor, controls, inter-tie to the existing distribution system, and SCADA improvements to enable automatic operation and remote monitoring and control override. The annual cost of the well is estimated to be $48,000, including $13,600 in capital recovery, $3,300 in annual O&M and $31,100 in annual energy charges. Thus, the cost of water produced by the well will be about $15/af, which is lower than the cost of the District's CVP supply and privately-produced groundwater. The District is planning to monitor groundwater conditions as the first well is operated, and to construct additional wells to the extent that the Lower Tuscan system can accommodate additional development. Ultimately, the District would install about 10 wells to achieve the targeted 33 taf of annual production capacity. Studies conducted by the District indicate that the unit water cost should not change appreciably as additional wells are constructed and production capacity is scaled up.

The quality of the Lower Tuscan water is reportedly very good. Coming from deep aquifers, it is anticipated to have a year-round temperature of 70 to 74 degrees F. This relatively high temperature will provide benefits to rice farmers and growers who apply water for frost control purposes.

Pricing Incentives

To achieve sustainable conjunctive water management, OAWD needs to ensure that use of available District surface water and groundwater supplies is maximized, so that GW extractions from the Tehama Formation by landowners are minimized. (This strategy also benefits other pumpers drawing from the Tehama Formation, which includes nearly all neighboring independent pumpers.) However, this priority of use will not occur naturally, because District supplies are generally more costly than privately-produced groundwater. To achieve the desired use priority, the District intends to use pricing incentives. Neglecting intangible factors that influence landowners' water source preference, the blended per acre-foot cost of surface water and groundwater delivered by the District must be less than the per acre-foot cost of privately produced groundwater. Under projected average water supplies and present pricing conditions, the total subsidy would be $282,000 on average, or $4.70 per acre-foot for the 30,000 acre-feet pumped by landowners on long-term average (Table ___) *(table not yet developed).* This amount would vary between $66,000 and $402,000 annually, depending on the amount of CVP water available each year. Because CVP is the most expensive of the three available sources, the maximum subsidy would be needed in full CVP water supply years and the minimum in years of zero CVP supply.

The effect of the subsidy would be to maintain the effective price of District water equal to the price of groundwater, or about $16 per af under existing conditions. In practice, the subsidy would require occasional "tuning" to achieve the intended result, because of changes in relative water costs and to account for intangible factors that are also reflected in landowners water source preferences. In particular, the subsidy would have to be increased if CVP water costs increase as expected.

The revenues needed to implement the price subsidies would be derived from the sale of modest proportions of available District CVP water supplies, as described in the following section.

Strategic Marketing of CVP Supplies

As a water-short district, the District Board is philosophically opposed to transfers of water out of the basin before in-basin needs are first satisfied. However, the Board has taken the position that marketing a portion of its CVP supply is justified if it enables a net expansion or ensures affordability of its total water supply. In this context, the District plans to market CVP water in selected years, when water prices are high and significant revenue can be generated from the sale of modest volumes of water. The anticipated sales of CVP water would be conducted pursuant to the water transfer provisions of the CVPIA. Key provisions of the CVPIA as they relate to the planned transfer/sale of CVP contract supplies by OAWD are listed below.

1. Transfers are effectively limited to other CVP contractors, because water transferred to non-CVP contractors must be repaid at the greater of the full cost or cost of service rates.
2. The water available for transfer is limited to the water that would have been consumptively used or irretrievably lost to beneficial use during the year or years of the transfer (*unless* the transfer is to another CVP contractor located within the county or area of origin, in which case the full unused volume may be transferred).

Considering these factors, and given the objective to seek out high prices, logical transfer partners north of the Delta would be the federal wildlife refuges and south would be water-short CVP contractors, such as Westlands, San Benito County and Santa Clara County Water Districts.

A number of water marketing strategies were tested using a monthly operations model developed specifically for OAWD. The model operates with the long-term demands presented earlier, and allows the user to input certain parameters, priorities and constraints. The following parameters were input for a series of runs aimed at testing various market strategies:

1. The District's CVP contract would yield the annual percentages discussed previously under the Baseline Condition.
2. The District must reserve a minimum of 5,300 af annually of its CVP supply to meet water demands an lands that do not have access to groundwater, located primarily on the west side of the District.
3. The District's groundwater pumping capacity from the Lower Tuscan Formation is 33 taf annually.

The water marketing strategies tested are distinguished primarily by the different percentages of CVP contract supply that would be marketed in different year types, ranging from marketing modest amounts of water in dry years only to marketing appreciable amounts of water in D, BN and AN years. This progression generally maintains the highest possible price per acre-foot of water sold as the marketed volume increases (**Table 3-3**). Despite the fact that the highest price occurs in CD years, OAWD does not contemplate marketing water in those years, to ensure that the small amount of CVP water available under contract to the District is available to landowners in areas without groundwater.

Table 3-3. OAWD Water Marketing Scenarios

Scenario	Volume Marketed (AF)			Remaining CVP Water Available (AF)	Revenue Generated ($)	
	Min	Max	Average		Average Total	Average $/AF)
Base Case (No Marketing)	0	0	0	26,863	$0	$0
1: (25%D)	0	3,313	726	26,137	$72,603	$100
2:(50%D)	0	6,625	1,452	25,411	$145,205	$100
3: (20%D; 20%BN)	0	5,300	1,597	25,266	$134,315	$84
4: (50%D; 50%BN)	0	13,250	3,993	22,870	$335,788	$84
5: (50%D; 50%BN; 50%AN)	0	21,200	6,897	19,966	$480,993	$70

<u>Scenario 1</u> looks at marketing 25% of available CVP supplies in D years only. The volume marketed in any particular year would range between 0 and 3,313 af, averaging 726 afy and preserving 26,137 afy of CVP supply for in-District uses. All water would be sold at the assumed D year price of $100 per af, generating revenues of about $73,000.

<u>Scenario 2</u> is identical to Scenario 1, except that the D year percentage is increased from 25% to 50%, doubling the maximum and average marketed volumes as well as the average transfer revenue. The amount of CVP water retained for in-District uses would decrease slightly to 25,411 afy.

<u>Scenario 3</u> involves marketing 20% of available CVP supplies in D and BN years. The volume marketed in any particular year would range between 0 and 5,300 afy, averaging 1,597 afy. The volume of CVP water remaining available for in-District uses would be 25,266 afy on average. The average price received for marketed water would be $84 per af.

<u>Scenario 4</u> is identical to Scenario 3, except that the D and BN year percentages are increased from 20% to 50%, increasing the maximum year marketed volume to 13,250 af and the average marketed volume to

nearly 4,000 afy. The average market revenue increases to nearly $336,000, while the price per af remains at $84. The average volume of CVP supply retained for in-District uses falls to 22,870 afy.

<u>**Scenario 5**</u> is the most aggressive strategy evaluated; it looks at marketing 50% in D, BN and AN years. The maximum marketed volume would be 21,200 afy in AN year types, and the average marketed volume would be nearly 6,900 afy. The average price received would be $70 per af, earning the District an average of just over $480,000. About 20,000 afy would be retained for in-District uses.

A summary of these results is shown in **Figure 3-5**, which shows a plot of market revenues in relation to market volume. It can be seen that the District would need to market roughly 3,200 afy on average to generate the $282,000 of revenue needed to subsidize District water supplies. The average price received at this level of market participation, subject to the strategies laid out above, would be roughly $88 per af. It should be noted that this analysis neglects water transfer transaction costs, such as would be needed for environmental documentation, monitoring and meeting other possible requirements.

Glenn-Colusa Irrigation District

Outside of a potential SCF partnership, GCID will take measures to ensure local water supply reliability and to generate financial revenues to ensure affordability of surface water supplies to District water users, and to finance system modernization. As an example of the measures being taken to support this strategy, GCID is developing a water transfer project in support of the Sacramento Valley Water Management Program (SVWMP). (This measure is include in GCID's Baseline Condition and is described above.) GCID may also pursue strategic water transfers above those dedicated to the SVWMP. These additional transfers are what define GCID's Solo Alternative. The features of GCID's Solo Alternative are summarized below, and discussed in the following sections.

Solo Alternative: Groundwater Substitution Transfers

As described under the Plan Formulation, a greater understanding of the physical behavior of the basin indicates that the basin is more resilient than originally thought and that direct recharge through artificial spreading facilities does not significantly enhance basin yield. In consideration of these findings, GCID's Solo Alternative is designed to explore the District's ability to implement transfers of Base Supply water made available through groundwater substitution.

The groundwater substitution-based strategies initially tested for the GCID Solo Alternative were distinguished by the frequency of the annual water transfer, and by the groundwater production scheme. Each of these topics is discussed below.

<u>Source and Frequency of Transfer Water</u>

The source of the transfer water made available under the groundwater substitution program would be GCID's pre-1914 appropriative water rights on the Sacramento River, referred to as Base Supply under GCID's Sacramento River Settlement Contract with the United States Bureau of Reclamation (Reclamation) (Contract No. 14-06-200-855A). The transfer water would be delivered on a pattern similar to that which GCID would have required for irrigation. The water will stay in the river for export to potential customers downstream. For the purposes of this analysis it is assumed that upstream reservoirs (i.e. Oroville or Shasta) will account for this transfer water and will manage these reservoirs to assure releases occur at times when exports south of the Delta could be made.

The transfer water will be made available in below normal (BN), Dry (D), and critically dry (CD) year types. For purposes of exploring the differences, economically and hydrologically, of reducing the frequency of the water transfer, a variation of the groundwater substitution program is to make transfer water available in D and CD years only.

<u>Production of Groundwater</u>

As described in the Existing and Baseline Condition discussions, GCID has pumped groundwater in conjunction with groundwater substitution-based programs with no long-term changes to the groundwater basin. For the purposes of developing GCID's Solo Alternative, similar management and operational schemes used successfully in recent years are also assumed for this evaluation.

Based on review of past pumping programs, GCID's Solo Alternative assumes that 90,000 af could be produced in a given water transfer year. The initial analysis assumes that the entire 90,000 af will be produced by private well pumpers. The location of groundwater wells is assumed to be the 200 approximate privately owned wells, of which roughly 80% are located in Glenn County and 20% are located in Colusa County. The degree of certainty to which these well owners would all participate is unknown. In addition, analysis of past programs indicates that average production of participating wells is approximately 500 af per year per well; 200 wells would produce, then, 100,000 af/yr which is 20,000 af/yr short of the assumed 90,000 af/yr (Solo Alternative) plus 30,000 af/yr (GCID SVWMP included in the Baseline Condition). For the feasibility investigation, it is assumed that 240 privately-owned wells would participate. The level of actual participation and potential production capacity per well will be the subject of detailed examination as part of the Groundwater Production Element investigation. During this investigation emerging air quality regulations that could apply to diesel engines used to drive agricultural wells will also be given additional consideration, given that approximately 85% of the privately owned wells within GCID are diesel driven.

Recognizing the above concerns and in light of the developments regarding the potential viability of utilizing the Lower Tuscan Formation as a "new" supply source, a variation of the GCID Solo Alternative is to utilize District-developed wells in this formation. Recent explorations of this formation by others in the region, including OAWD, indicate the cost of water produced by wells tapping this resource can be as low as $15/af (see OAWD Solo Alternative discussion). Selecting sites strategically to tie into existing conveyance facilities is critical to allow for proper distribution of water produced. Furthermore, sites located where electric power is nearby could provide advantages in terms of emerging air quality regulations mentioned previously. However, stand-by charges associated with PG&E power supplies can also be cost-prohibitive. These issues will be further addressed as part of the subsequent alternatives evaluation (to be completed following review of this document) and also as part of the Groundwater Production Element investigation.

Groundwater Substitution Transfer Scenarios

The groundwater substitution scenarios considered for GCID are summarized in **Table 3-4**, and described briefly below.

Scenario 1 considers transferring 90,000 af/yr in BN, D, and CD years. Groundwater pumped in substitution of this transfer would occur from existing private owned wells. **Scenario 2** is identical to Scenario 1, except that transfers only occur in D and CD years. **Scenario 3** is identical to Scenario 1, except that groundwater pumped in substitution of the transfer water would occur from new District-owned wells developed in the Lower Tuscan formation. **Scenario 4** is identical to Scenario 1, except that half of the groundwater pumped in substitution of the transfer water would occur from existing private owned wells and half from new District-owned wells developed in the Lower Tuscan formation.

Table 3-4:
GCID Groundwater Substitution Program Components for Solo Alternative

COMPONENT	DESCRIPTION/ASSUMPTION			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Yield (ac-ft/yr) (a)	90,000	90,000	90,000	90,000
Frequency (b)	BN/D/CD	D/CD	BN/D/CD	BN/D/CD
Pumping Zone	Tehama	Tehama	Lower Tuscan	Tehama and Lower Tuscan
Private or District Owned Wells	Private	Private	District	Both
Well Locations	Depends upon landowner participation. Assume uniform distribution similar to the 200+ wells known to exist.		Adjacent to the Main Canal AND where the Lower Tuscan is present.	Combination of uniform distribution of known wells and District wells along Main Canal.
No. of Wells	240 (c)		40 (d)	120 Private and 20 District
Potential Recipients	• Water users participating in DWR's Dry Year Water Purchase Program • Environmental needs. • CVP water users.			
Surface Water Source	GCID's pre-1914 appropriative water rights on the Sacramento River.			
Delivery Pattern	Irrigation pattern, June through October.			

a) The yield shown for each scenario is the amount above the Phase 8 30,000 ac-ft already include in the GCID Baseline Condition. For each scenario it is assumed the Phase 8 yield is produced in the same manner (same Frequency, Pumping Zone, Wells, etc.) as the 90,000 ac-ft, unless otherwise specified.
b) Water year classification based on the Sacramento Valley Index (Year-type abbreviations: BN=Below Normal; D=Dry; CD=Critically Dry).
c) Assumes 500 AF/Y per privately owned well, based on analysis of past pumping programs which have averaged as high as 581 AF/Y per well (1994). Thus, total capacity of 240 wells equals 120,000 ac-ft.
d) Assumes 3000 AF/Y per District-owned well, based on operations studies conducted by OAWD. Thus, total capacity of 40 wells equals 120,000 ac-ft.

Groundwater modeling analysis (using the GW Model) was conducted to evaluate the effect of the additional groundwater pumping as a result of the 90,000 af/yr transfer program. Locations throughout the study area were identified for review of simulated groundwater levels under Baseline Conditions and the Solo Alternative. Review of simulated well hydrographs indicate the following:

- Under Scenario 1, groundwater levels in and adjacent to the groundwater pumping region within GCID consistently showed declines in groundwater levels relative to Baseline Conditions of between 5 and 10 feet, with a maximum difference of approximately 18 feet in the middle of the pumping area. Simulated groundwater levels showed no long-term decline in groundwater storage.
- Under Scenario 2, groundwater levels responded favorably to the pumping in only D and CD years. Simulated groundwater levels were between 3 and 5 feet less than those under Scenarios 1. Also of particular note is that in areas adjacent to the pumping region, simulated groundwater levels under Scenario 2 returned to near Baseline Condition levels following periods of wetter than normal conditions, before declining below Baseline Condition levels in subsequent D and CD year combinations. This is indicative of a basin that is being replenished by natural recharge under the circumstances.

- Under Scenario 3 and 4, groundwater modeling results were somewhat inconclusive because of the poor hydrogeologic understanding of the Lower Tuscan formation, particularly the understanding of its influence on the groundwater aquifer layers, that compromised the GW Models ability to accurately simulate these conditions. It is expected, however, that groundwater levels in the Tehama formation would decline very little, if at all, because of the information suggesting that the Lower Tuscan formation which is relatively isolated from the Tehama formation due to the presence of the overlying confining layer known as the Upper Tuscan formation.

It should be noted that details of this hydrologic analysis will be presented as part of documentation summarizing the groundwater modeling efforts *(to be provided following review of this document)*. In addition, further economic and financial analysis of GCID's Solo Alternative will be completed for the purposes of completing the alternative evaluation effort for the feasibility investigation final report.

COLLABORATIVE ALTERNATIVES

[to be completed]

Overview of this section

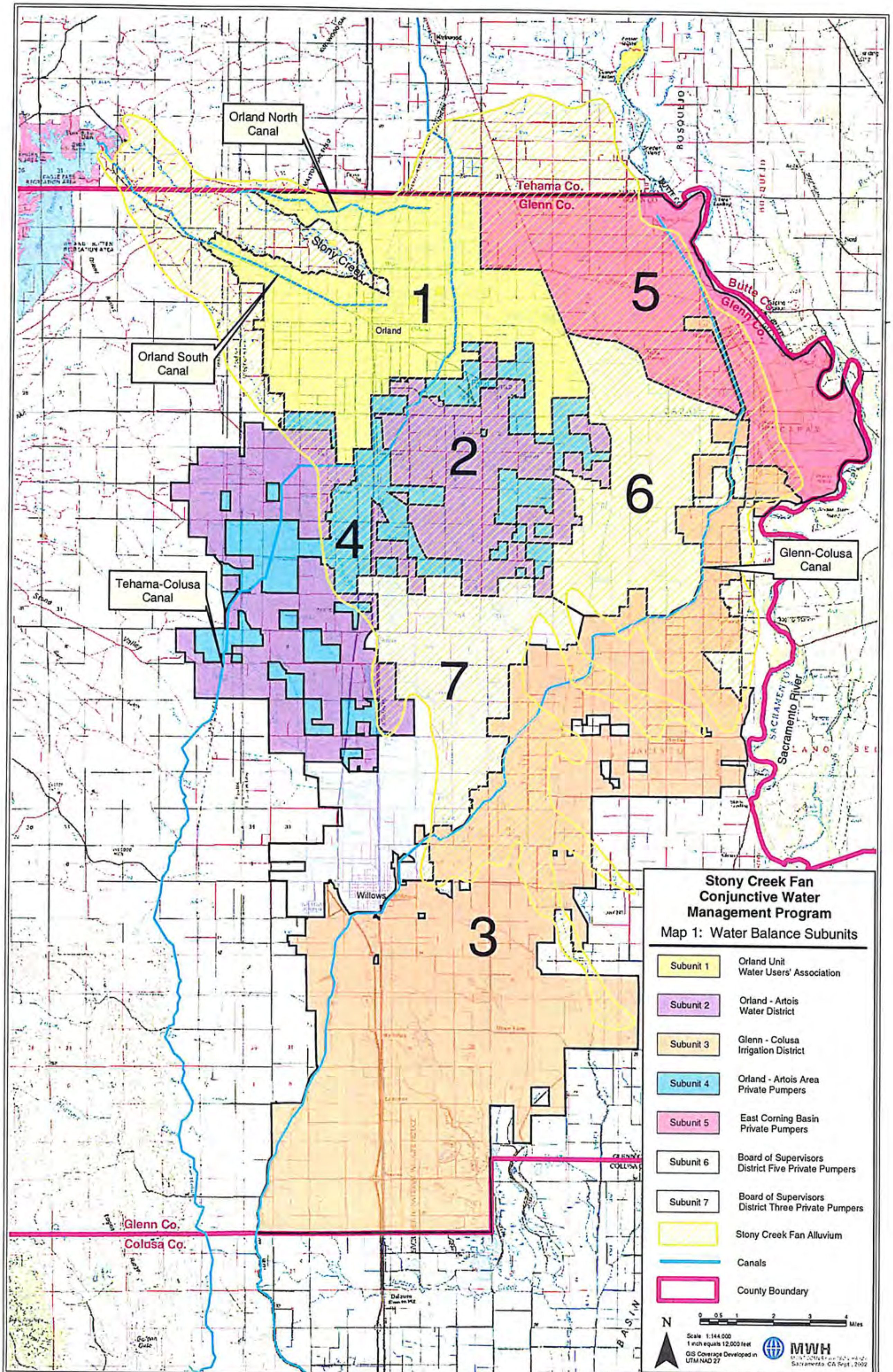
- *Review the partner's objectives. Describe the need to examine how to use available resources more effectively.*
- *Summarize the partner resources, surface water and groundwater supplies and potential relationships.*
- *Describe how various collaborative alternatives were screened.*
- *Introduce the collaborative alternatives and describe them below.*

Alternative C1

- *Collaborative Alternatives that examine using OUWUA dry-year supplies with OAWD's conveyance system.*

Alternative C2

- *Collaborative Alternatives that examine using GCID Unused Base Supplies for In-lieu Recharge in OAWD*


Orland North Canal
Orland South Canal
Tehama-Colusa Canal
Glenn-Colusa Canal
Stony Creek
Orland
Willows
Tehama Co.
Glenn Co.
Butte Co.
Glenn Co.
Colusa Co.
Sacramento River
1
2
3
4
5
6
7
Stony Creek Fan Conjunctive Water Management Program
Map 1: Water Balance Subunits
Subunit 1 Orland Unit Water Users' Association
Subunit 2 Orland - Artois Water District
Subunit 3 Glenn - Colusa Irrigation District
Subunit 4 Orland - Artois Area Private Pumpers
Subunit 5 East Corning Basin Private Pumpers
Subunit 6 Board of Supervisors District Five Private Pumpers
Subunit 7 Board of Supervisors District Three Private Pumpers
Stony Creek Fan Alluvium
Canals
County Boundary
N
0 0.5 1 2 3 4 Miles
Scale 1:144,000
1 inch equals 12,000 feet
GIS Coverage Developed in UTM NAD 27
MWH

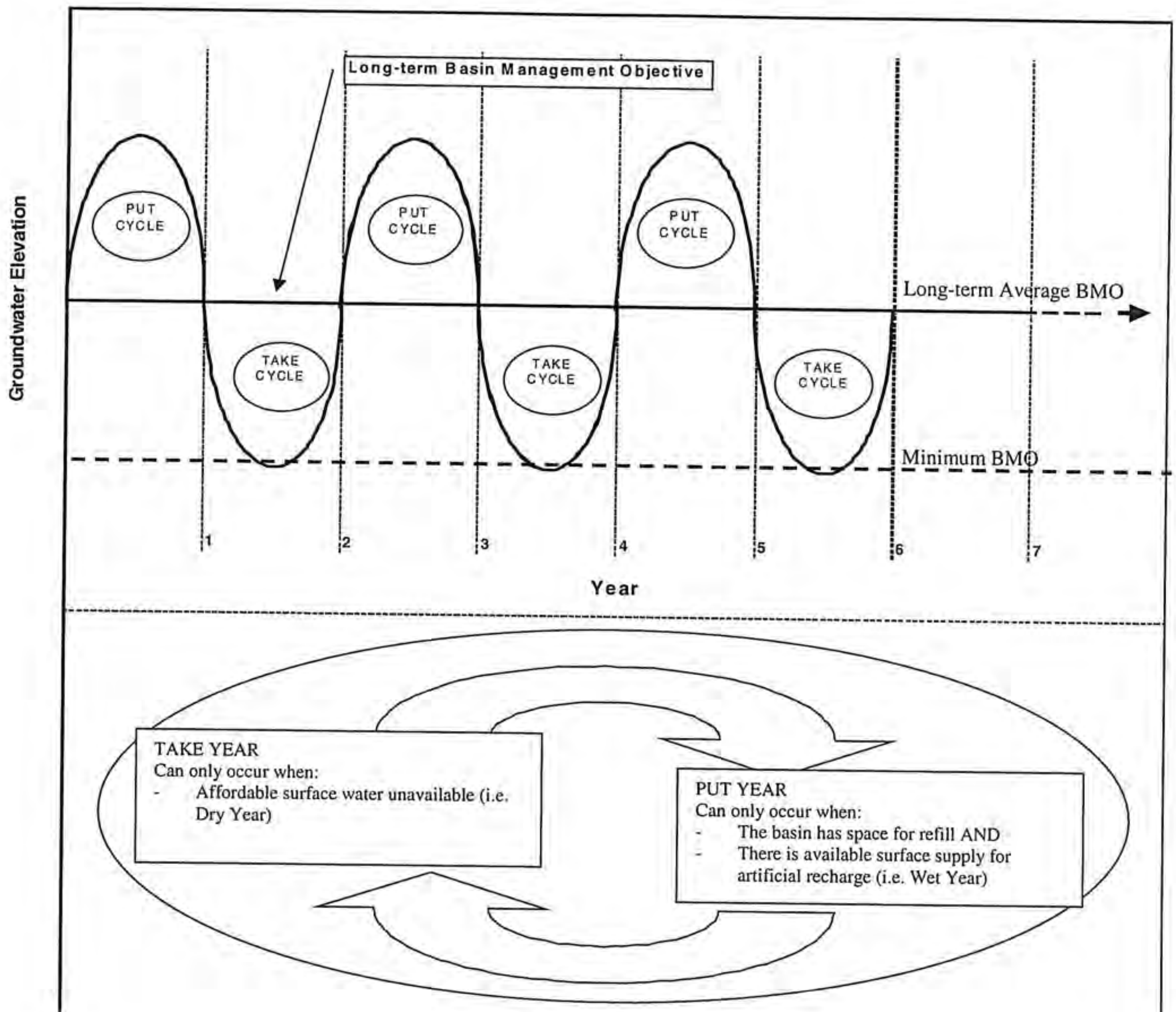


Figure 1-1

The Conjunctive Use Cycle

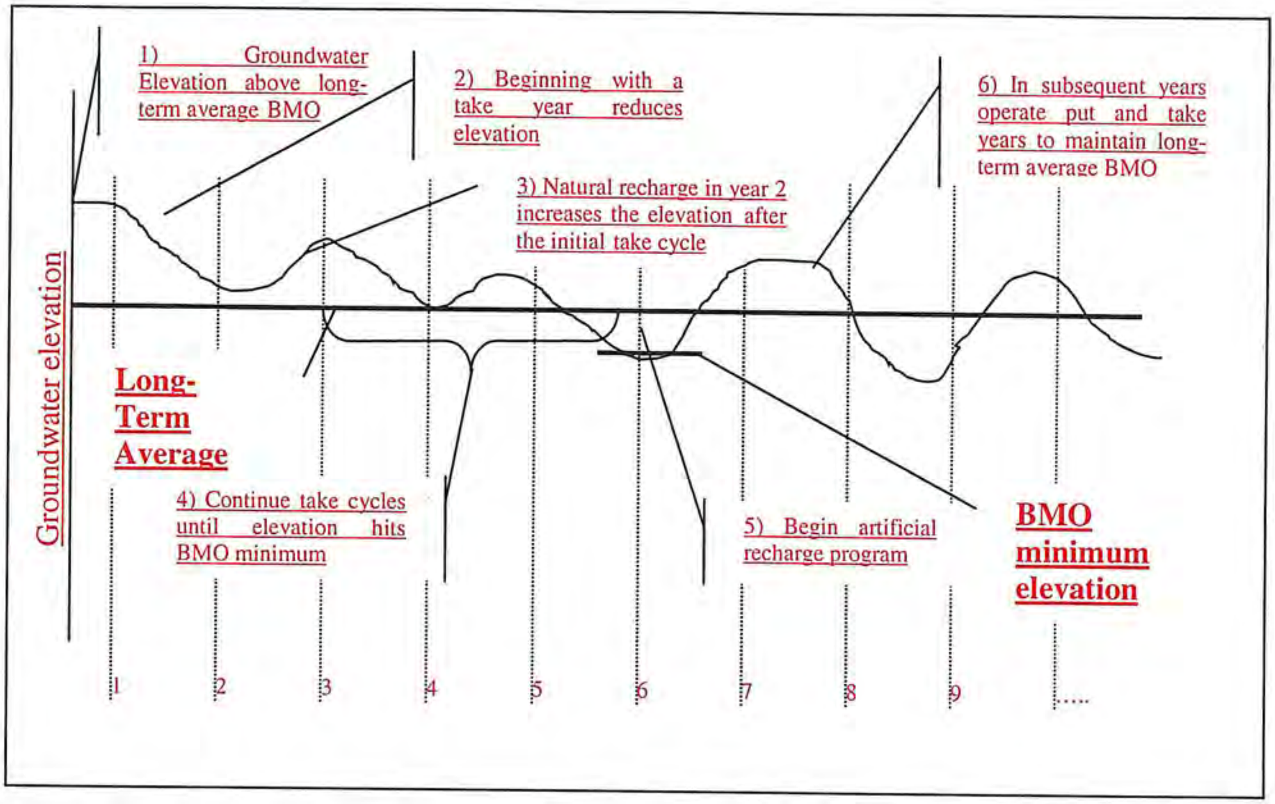


Figure 1-2

Hypothetical Conjunctive Use Program

Beginning with a Put year

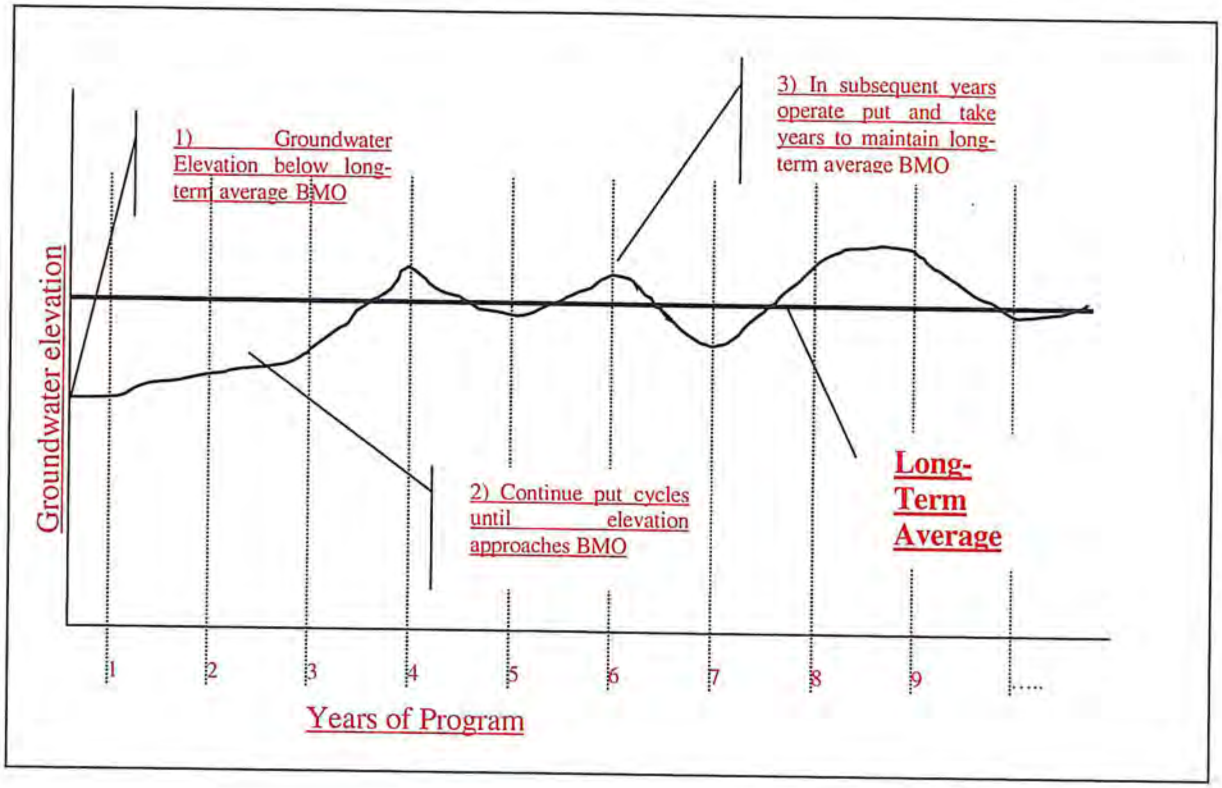


Figure 1-3

Hypothetical Conjunctive Use Program

Beginning with a Take year

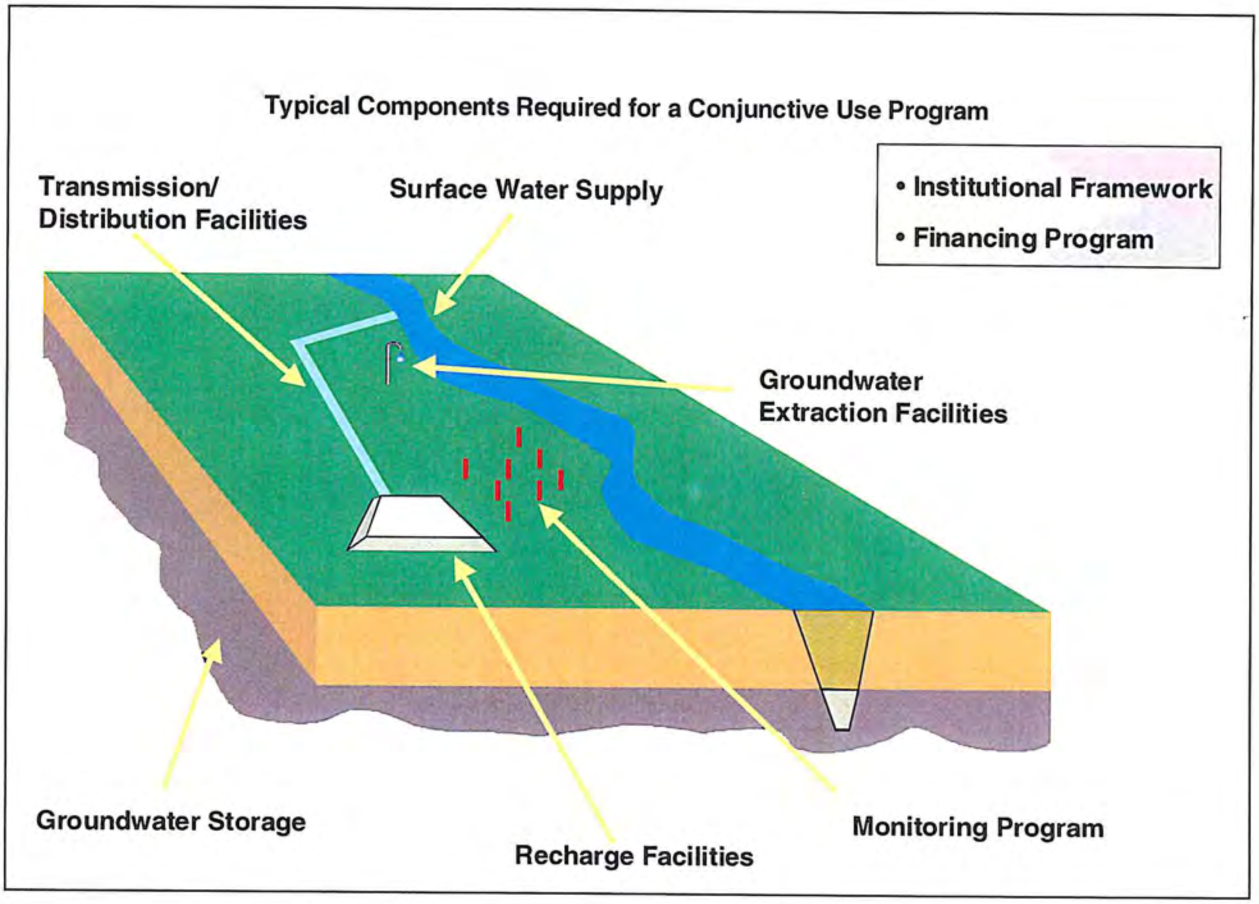


Figure 1-4
Typical Components Required for a Conjunctive Use Program

Figure . 5a
Formulation and Analysis of Conjunctive Use Projects

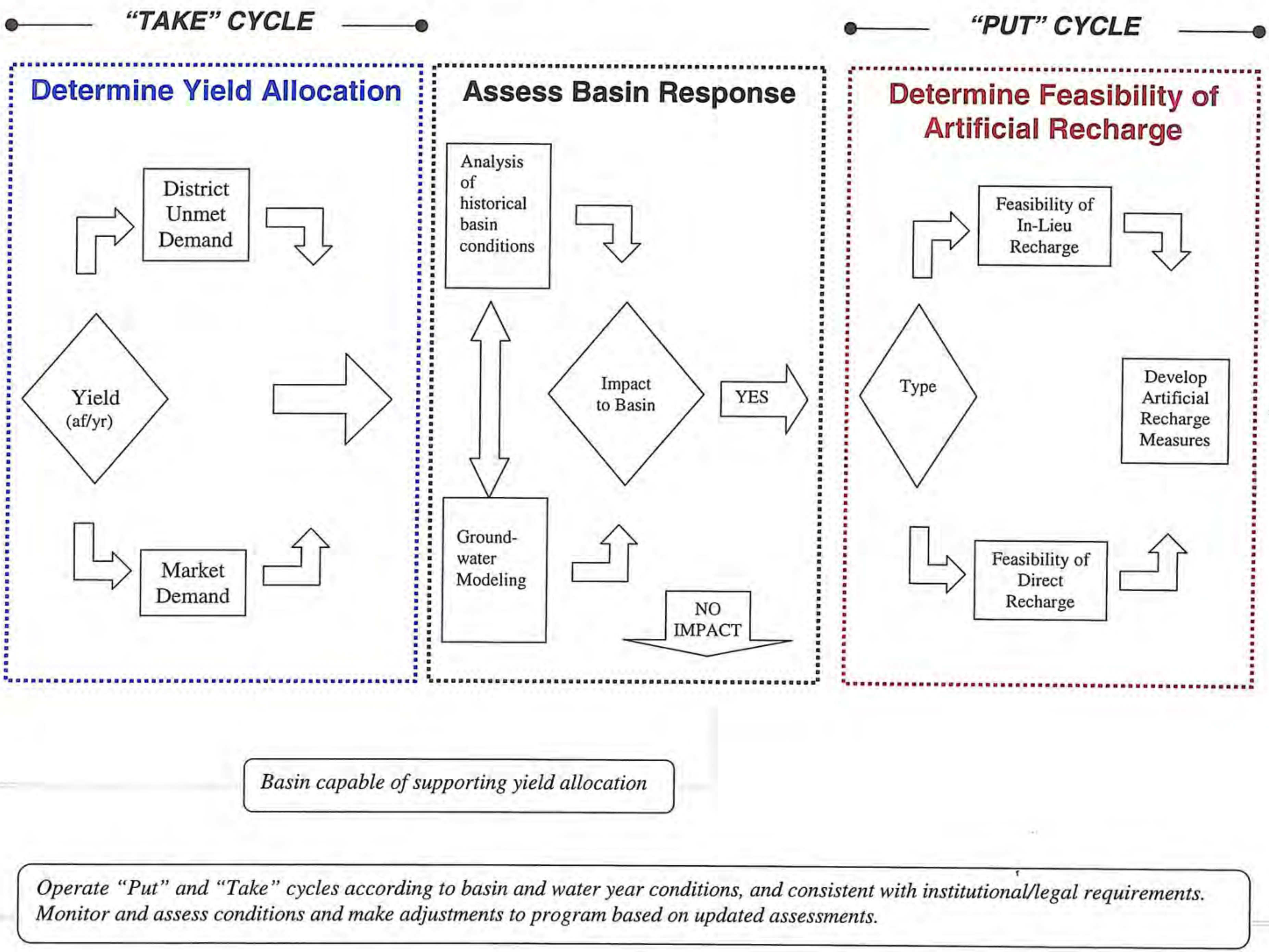


Figure 1-5b
Decision Tree for Conjunctive Use Operation to Increase System Yield - "PUT" Cycle

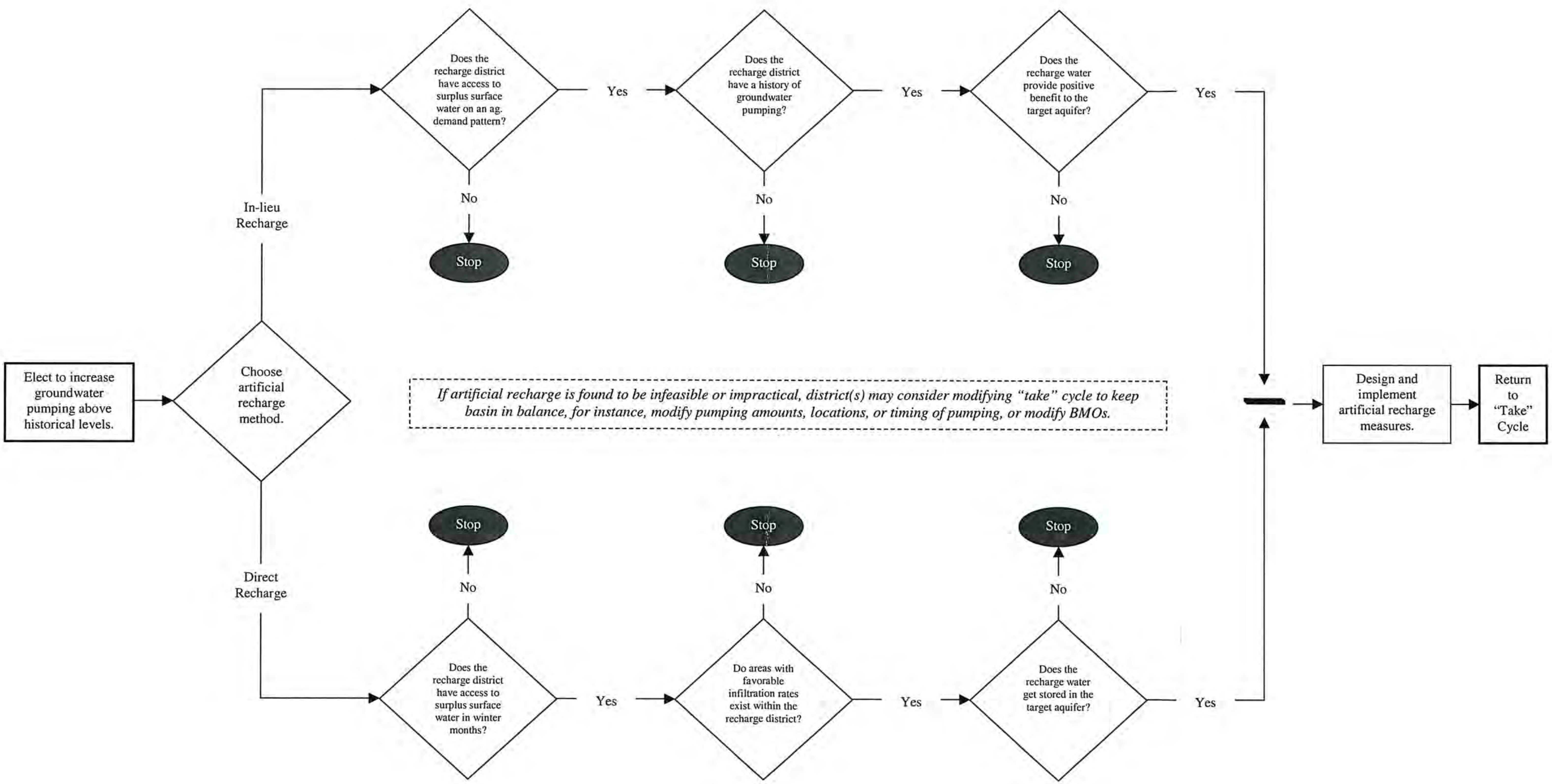
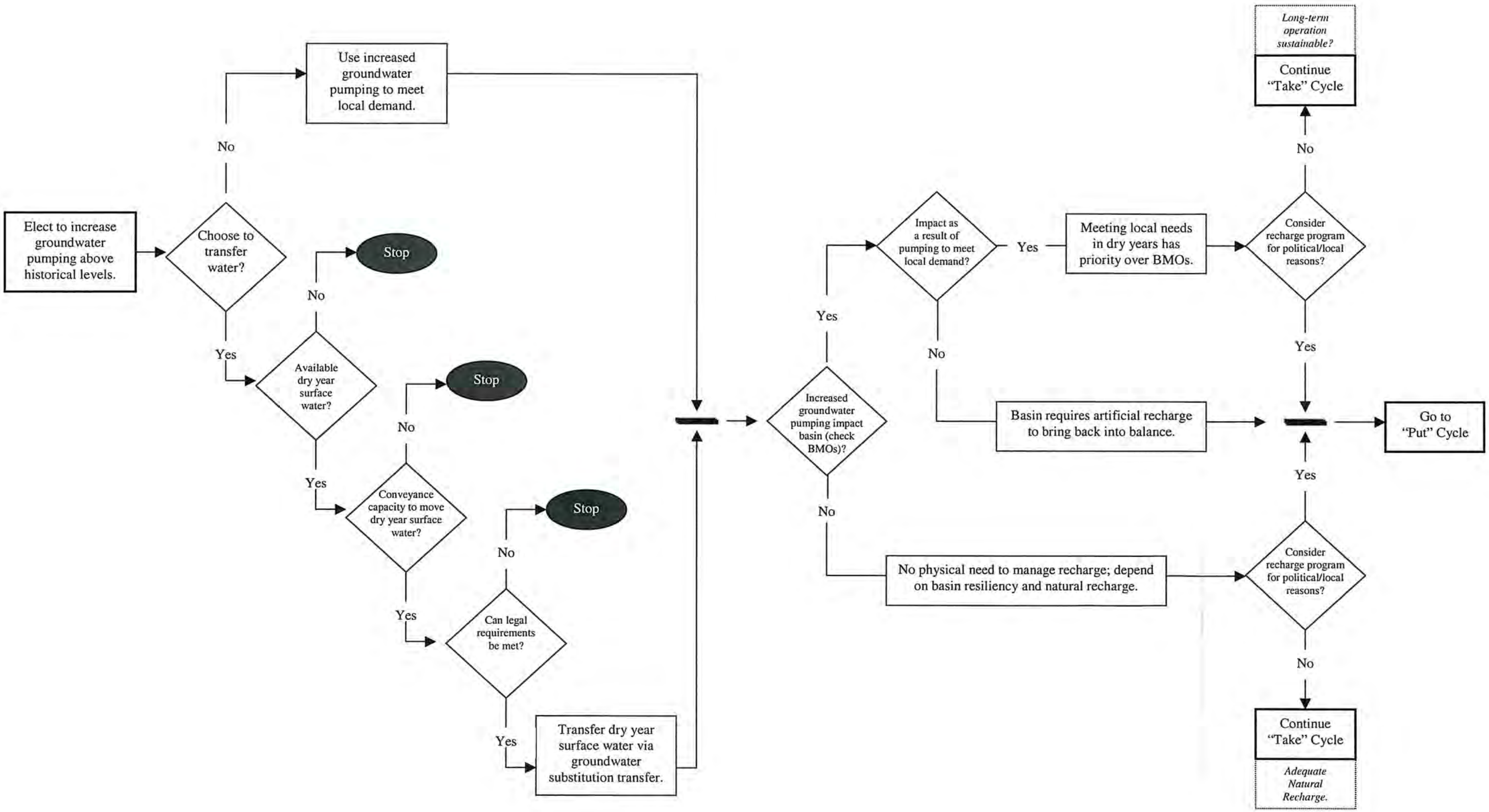
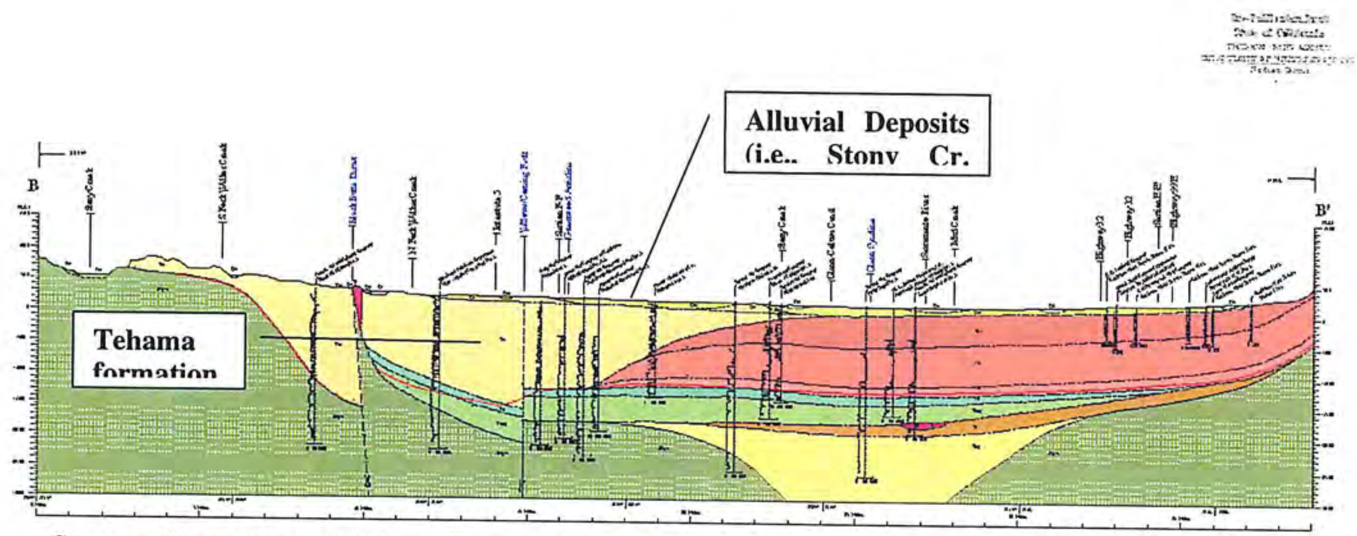


Figure 1-5c
Decision Tree for Conjunctive Use Operation to Increase System Yield - "TAKE" Cycle





Source: Department of Water Resources

Figure 1-6
Geology of the Stony Creek Fan Area, Glenn County, California

Figure 2-1

Orland Unit Historical District Diversions
(includes system losses)

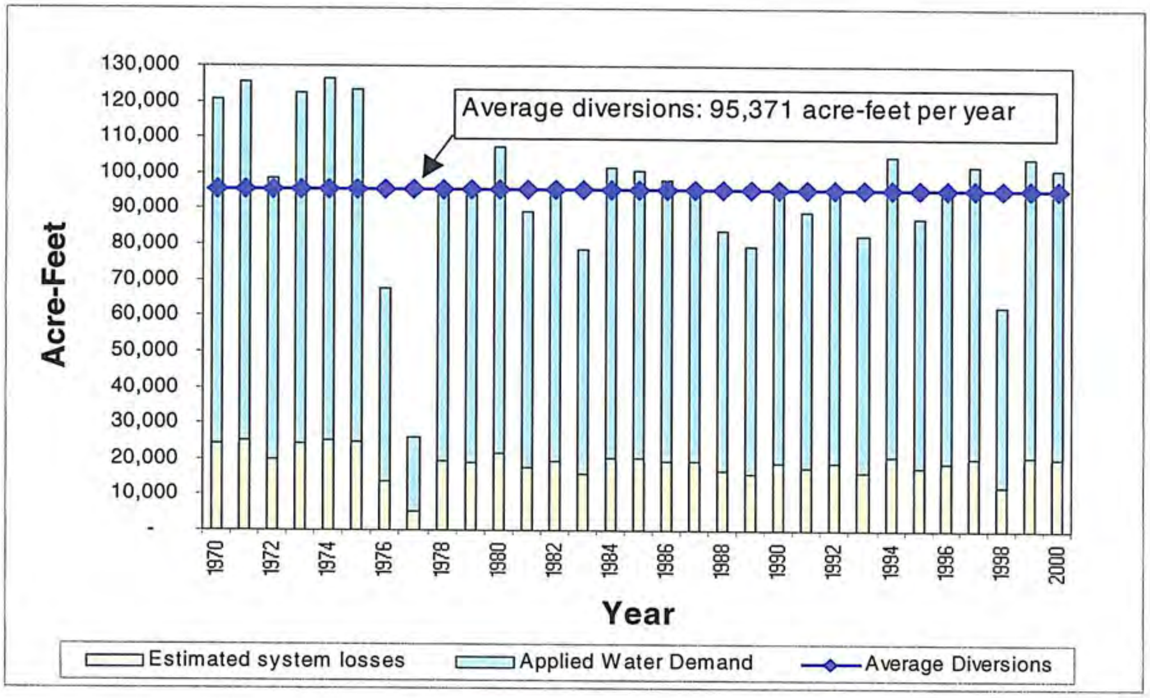


Figure 2-2
Surface and Ground Water Necessary to Meet ETaw

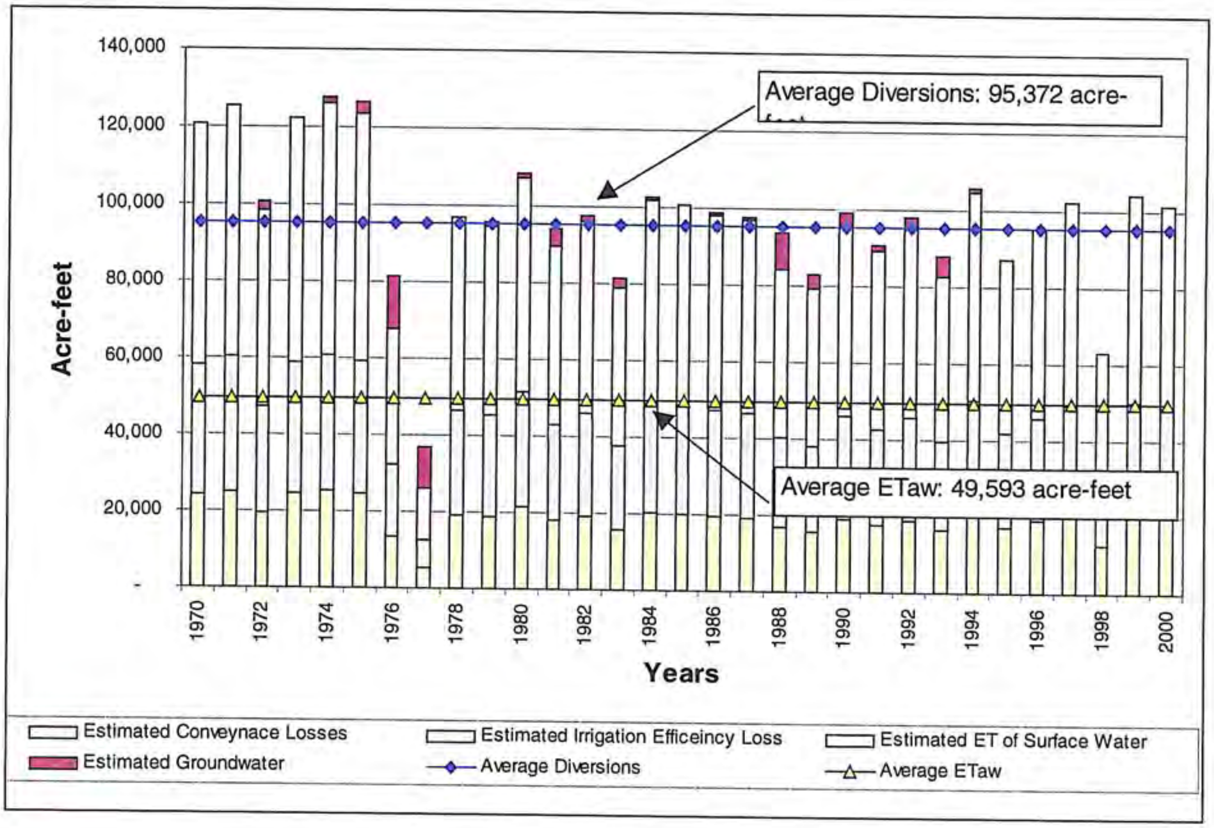


Figure 2-3

Historical and Baseline ETaw for the OUWUA

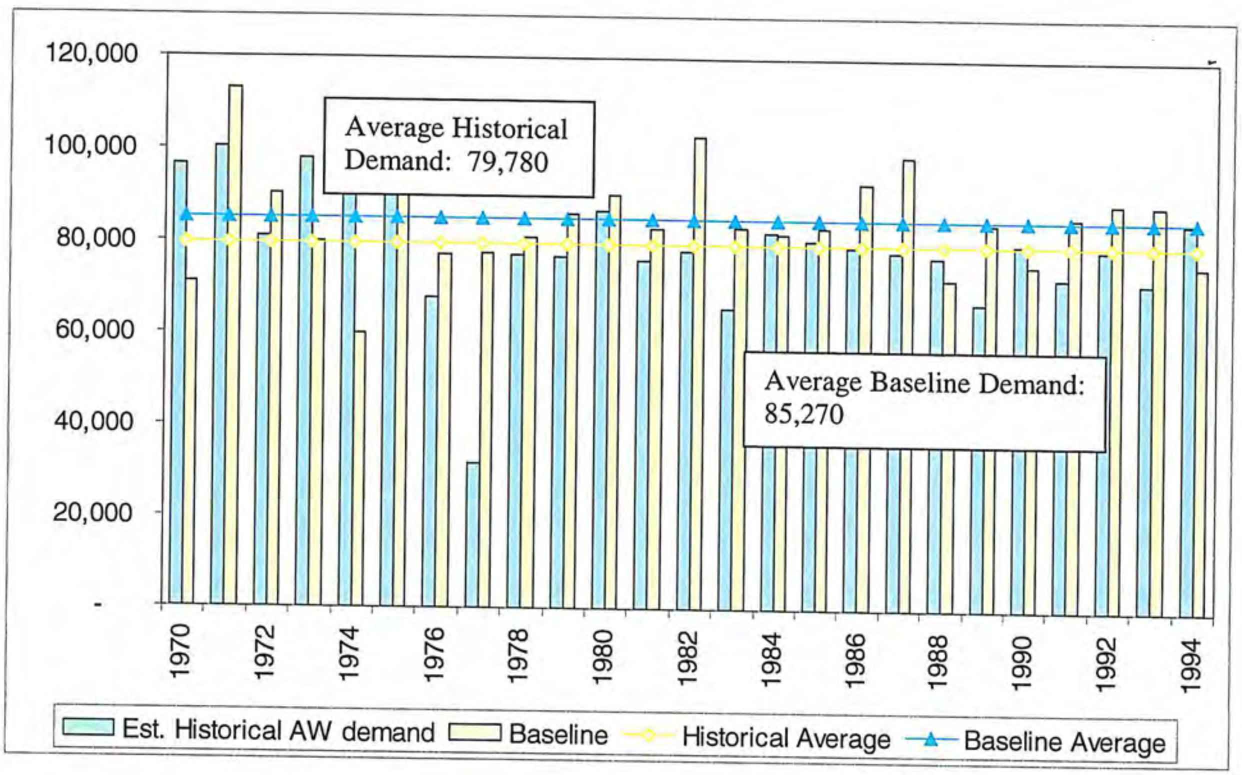


Figure 2-4. Historical Cropping Pattern for Subunit 2 (OAWD) 1970-2000

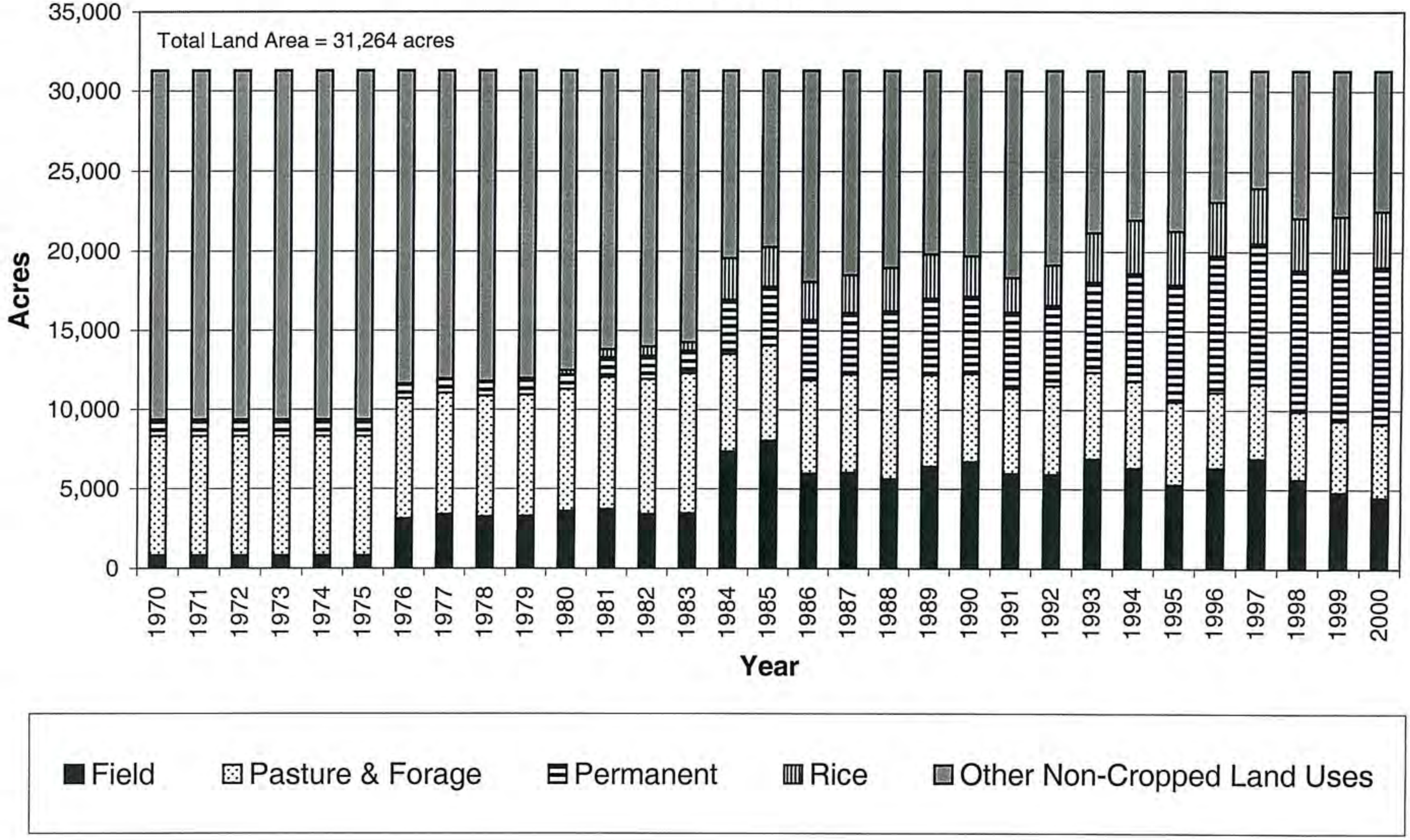


Figure 2-5a. Subunit 2 (OAWD) Historical Water Demands

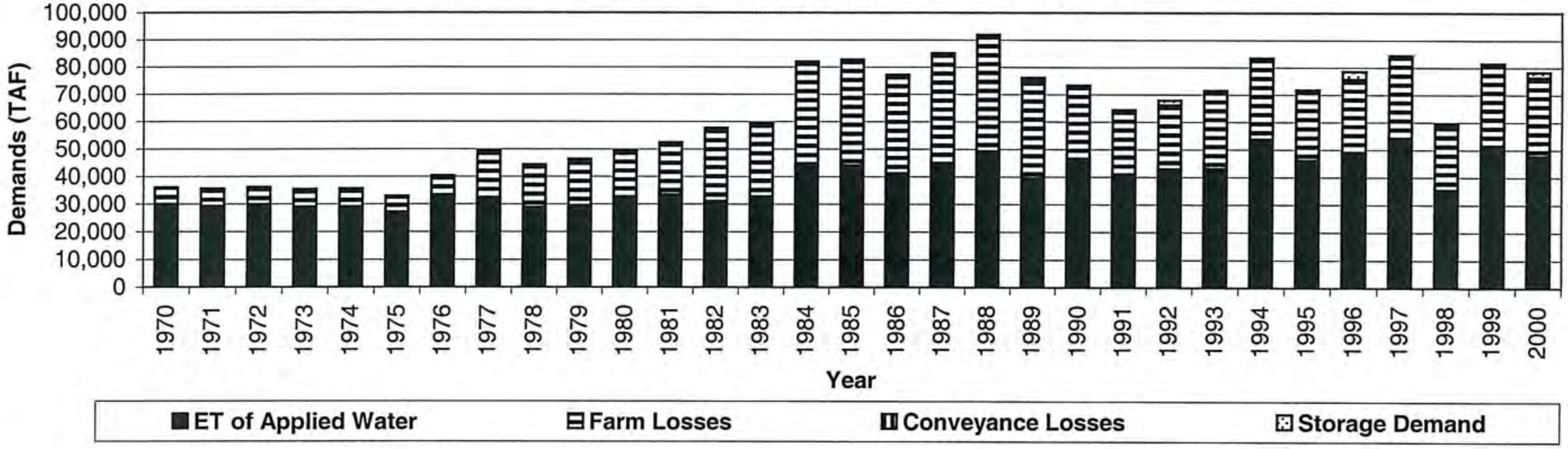


Figure 2-5b. Subunit 2 (OAWD) Historical Water Supplies

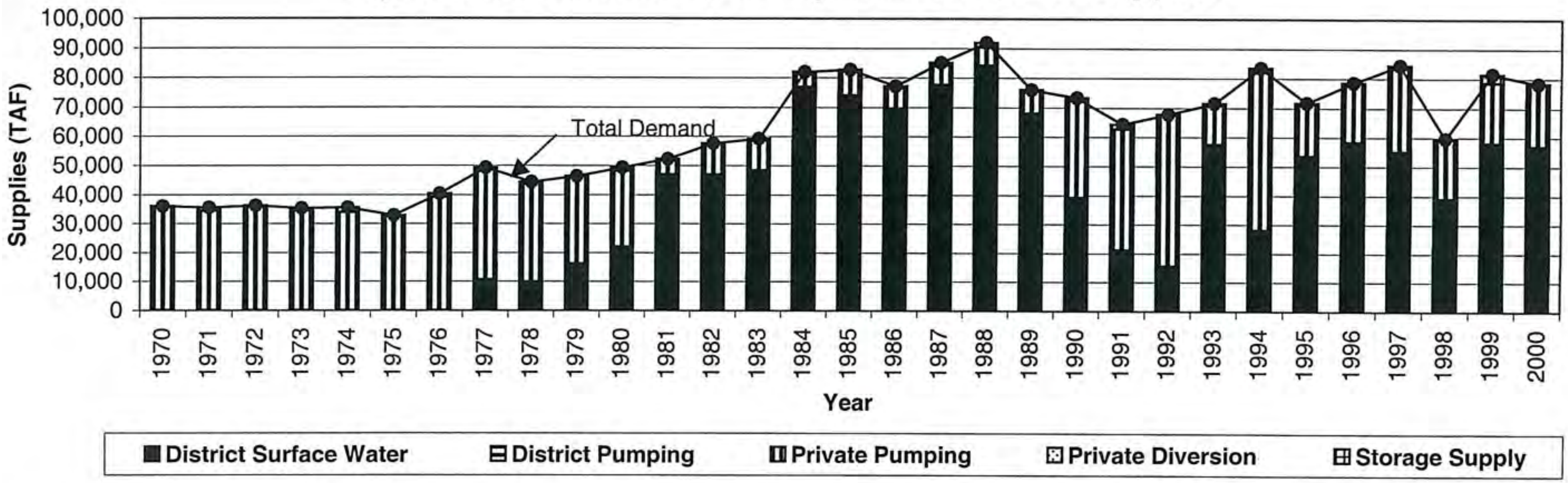


Figure 2-6. Net Extraction for Subunit 2 (OAWD) from 1970-2000 (Total Area = 31,264)

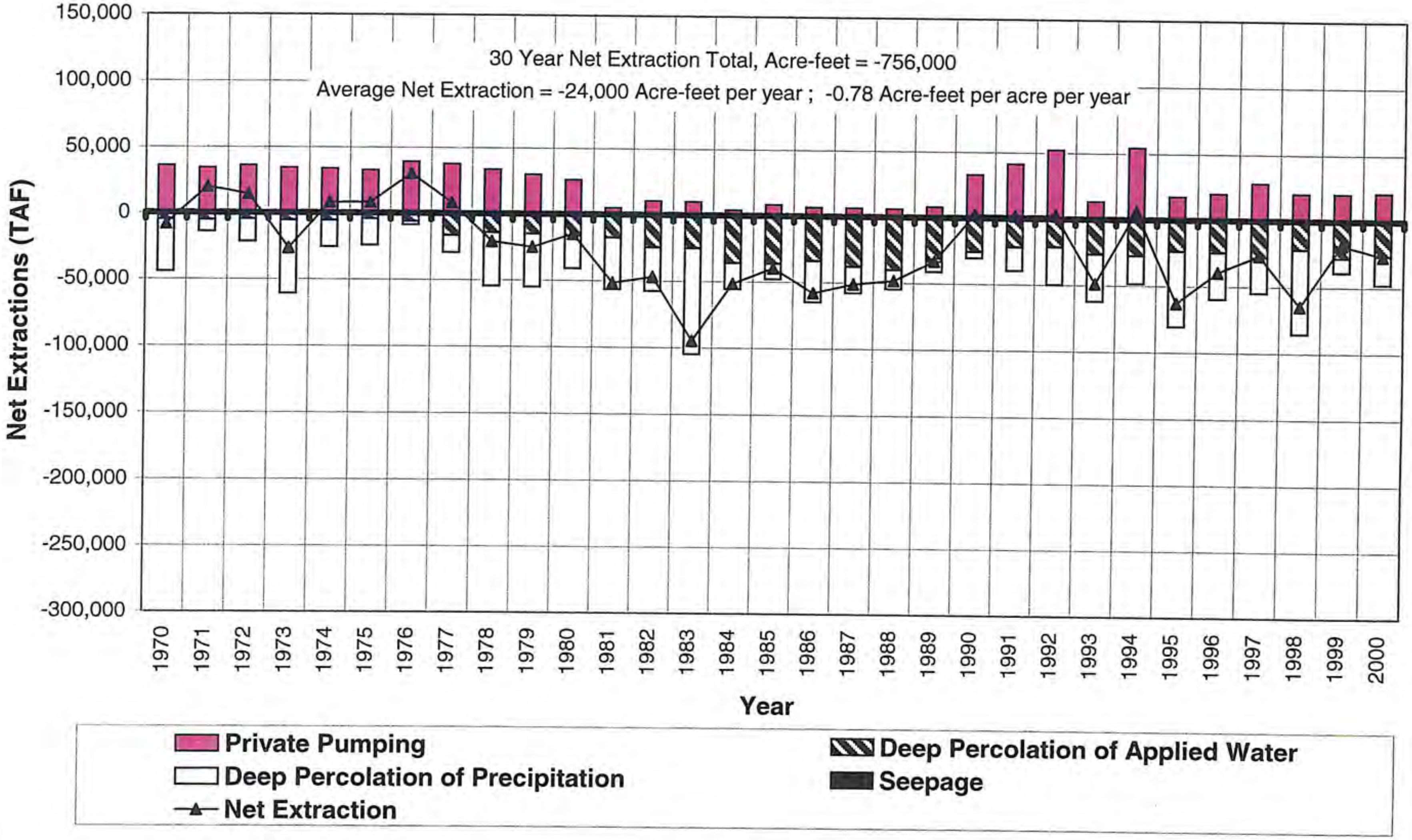


Figure 2-7. Historical and Baseline Cropping Patterns for Subunit 2 (OAWD)

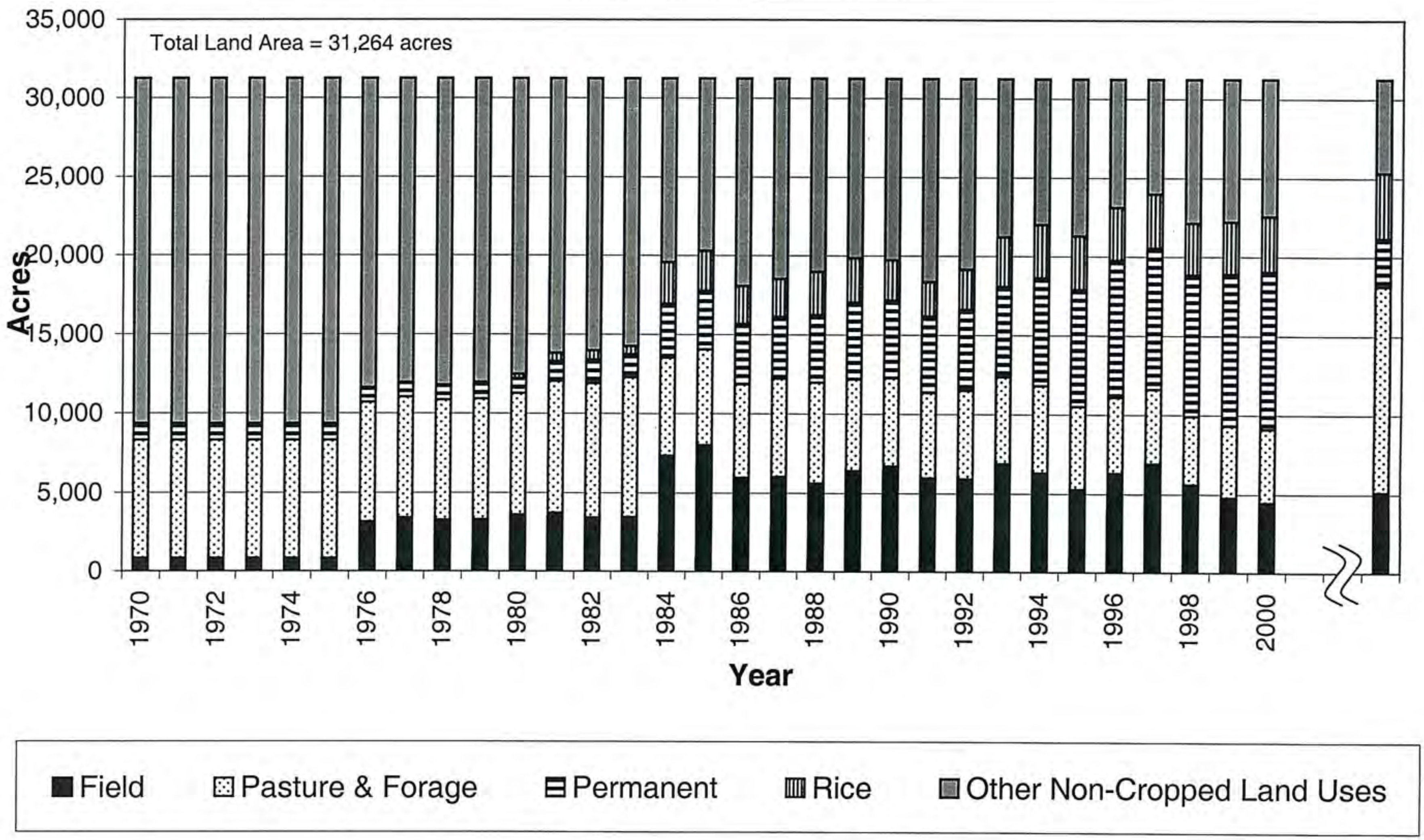


Figure 2-8. OAWD Baseline ETaw and Applied Water Demands (1922 to 1994 Hydrology; Projected 2025 Land Use; 70% On-farm Irrigation Efficiency)

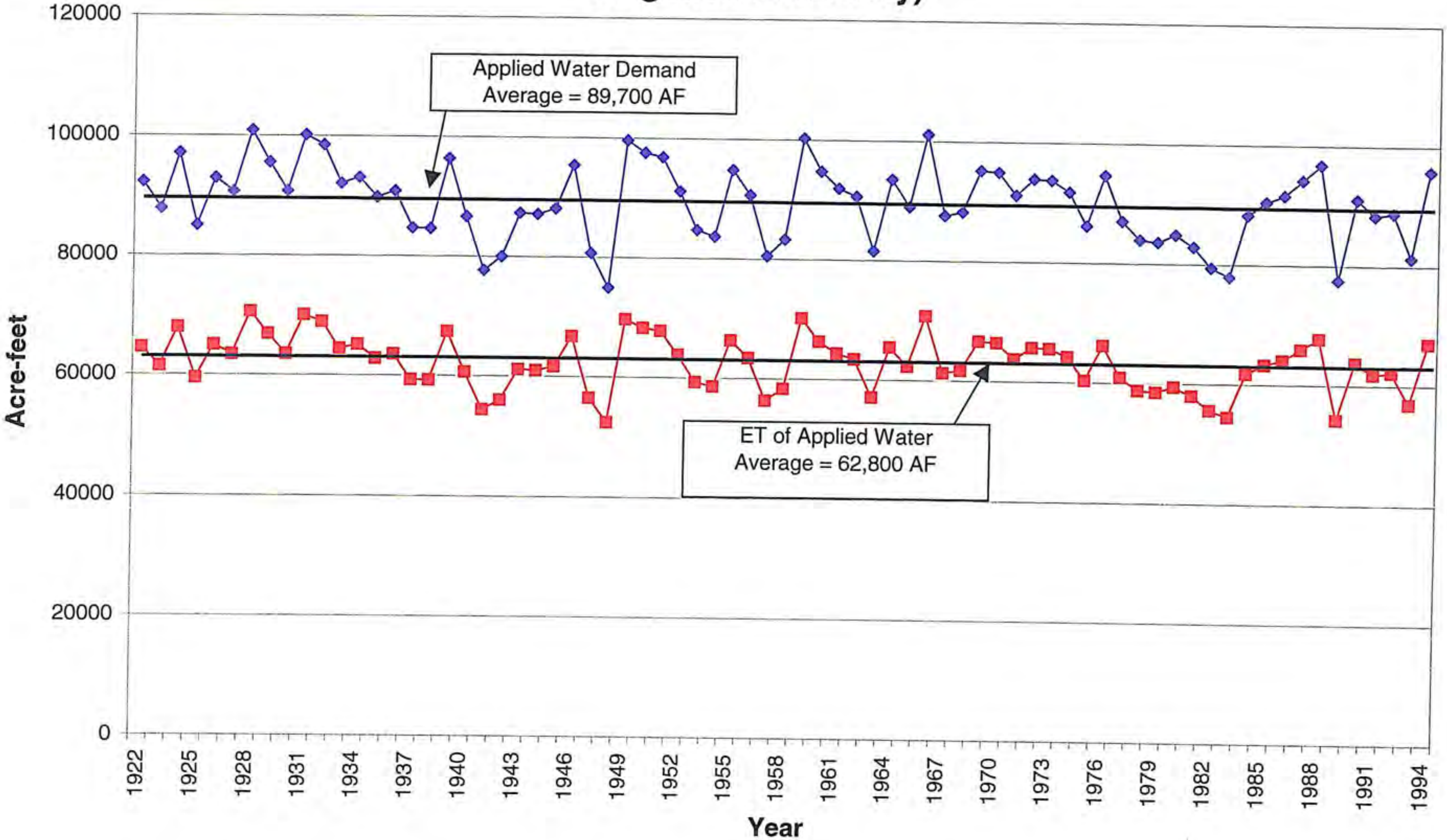


Figure 2-9. OAWD Baseline CVP Water Supply (1922-1994 Hydrology; Projected 2025 Land Use; Future (80%) CVP Contract; No Purchases; No Marketing)

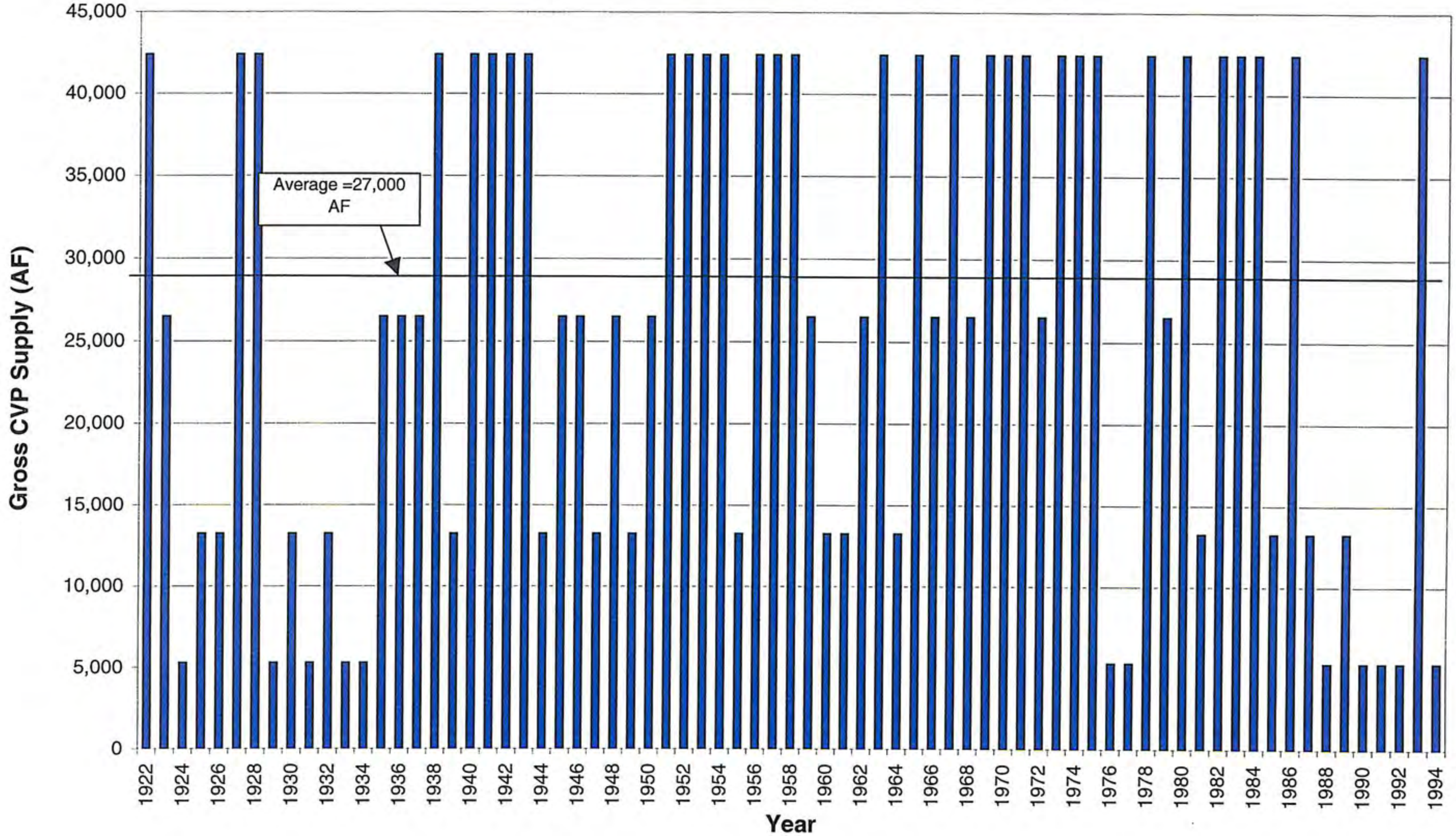


Figure 2-10__. OAWD Baseline Private Pumping (1922-1994 Hydrology; Projected 2025 Land Use; Future (80%) CVP Contract; No Purchases; No Marketing)

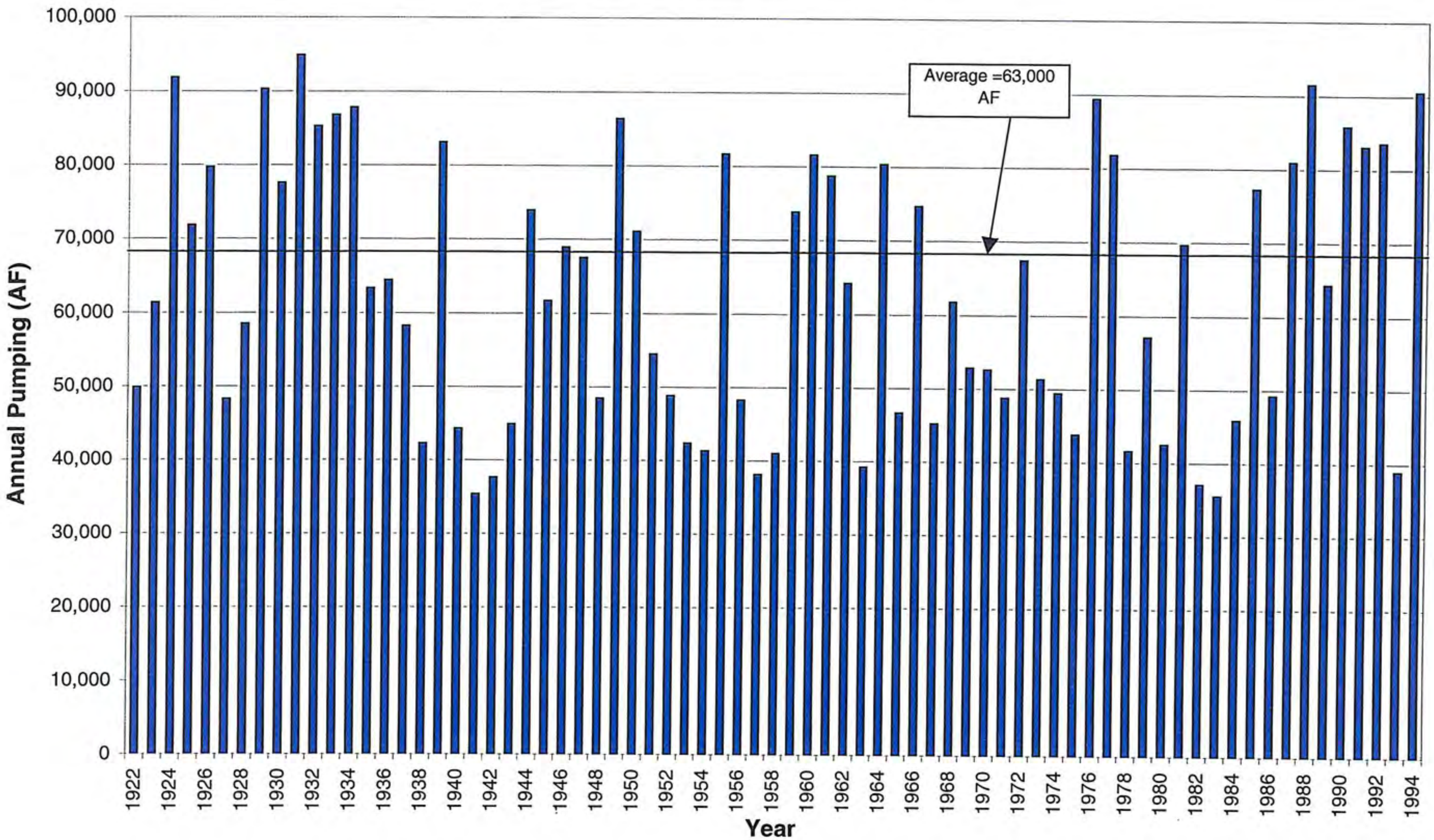


Figure 2-11. Historical Cropping Pattern for Subunit 3 (GCID) 1970-2000

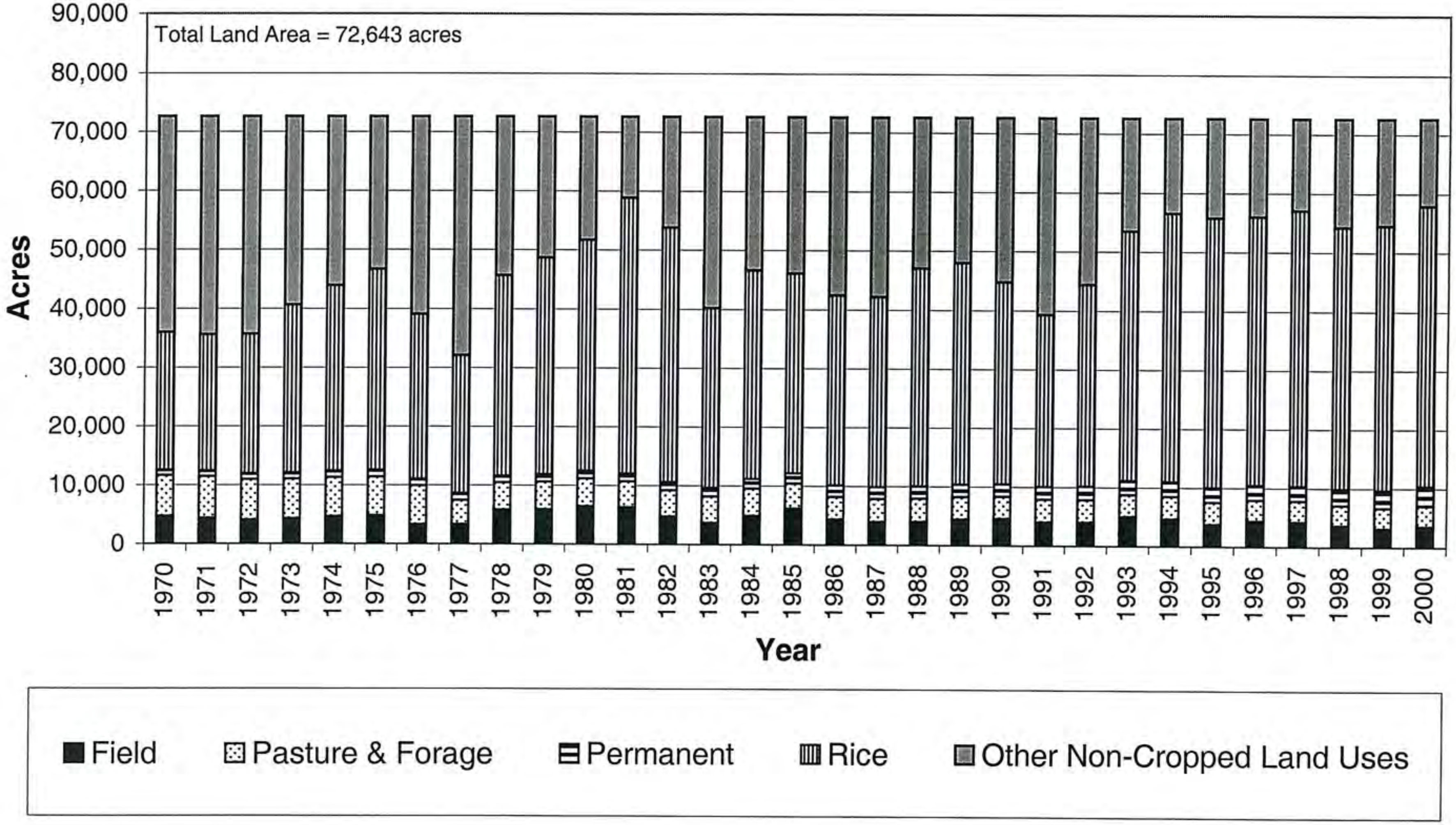
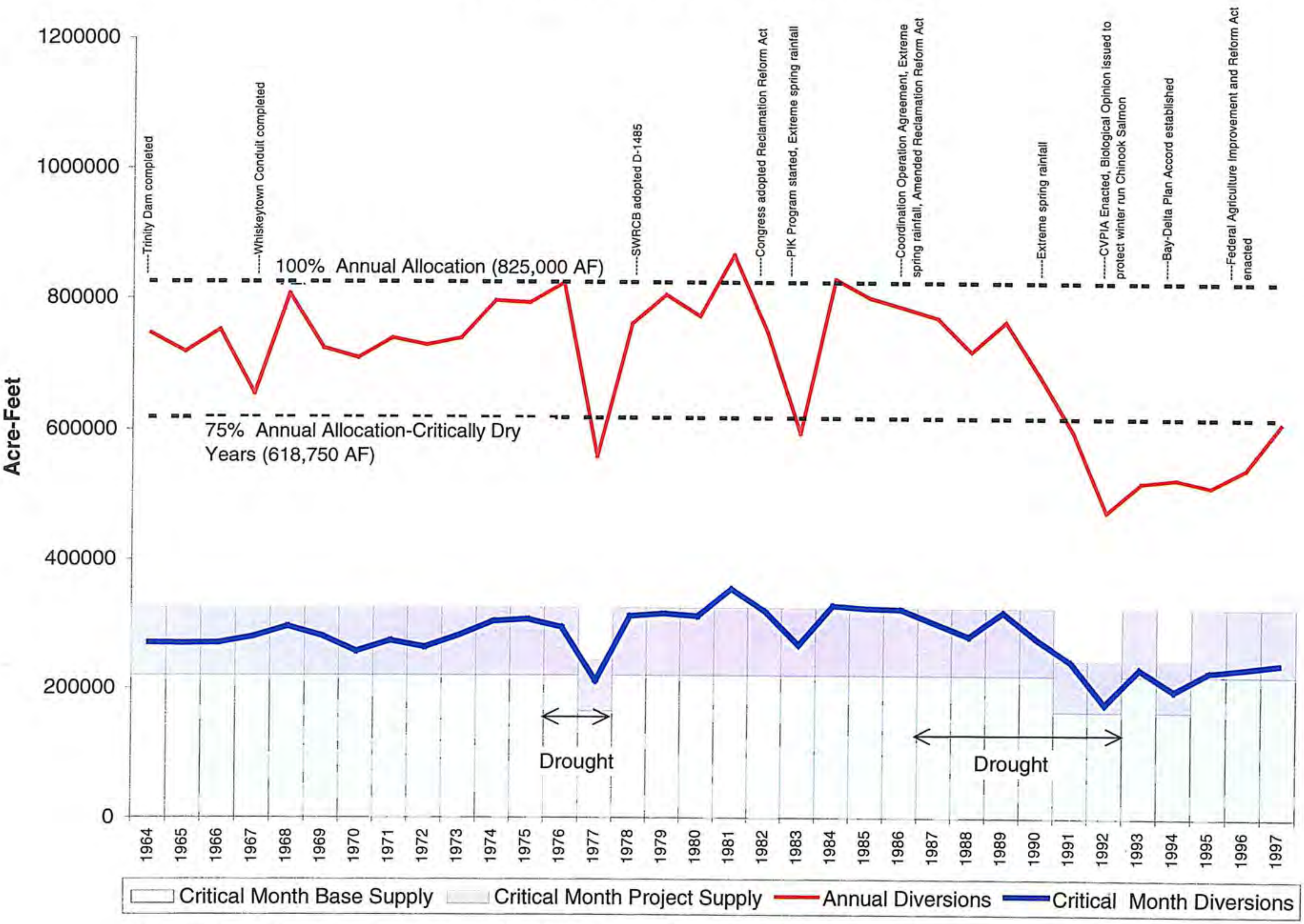


Figure 2-12

Glenn-Colusa Irrigation District
Project Supply and Base Supply Diversions



Note: Annual quantities are based on contract period from April to October; Critical Months include July and August

Figure 2-13. Subunit 3 (GCID) Historical Water Supplies

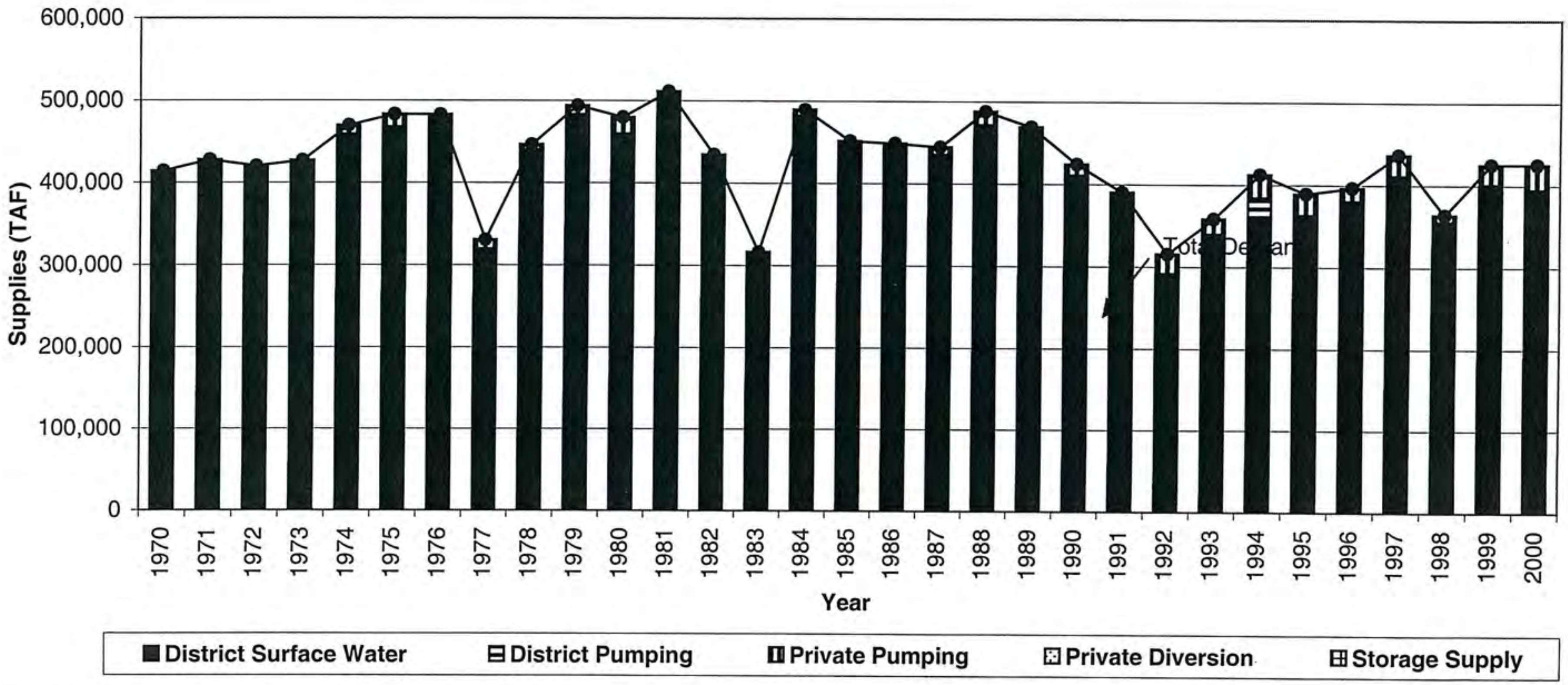


Figure 2-14. Net Extraction for Subunit 3 (GCID) from 1970-2000
(Total Area = 72,643)

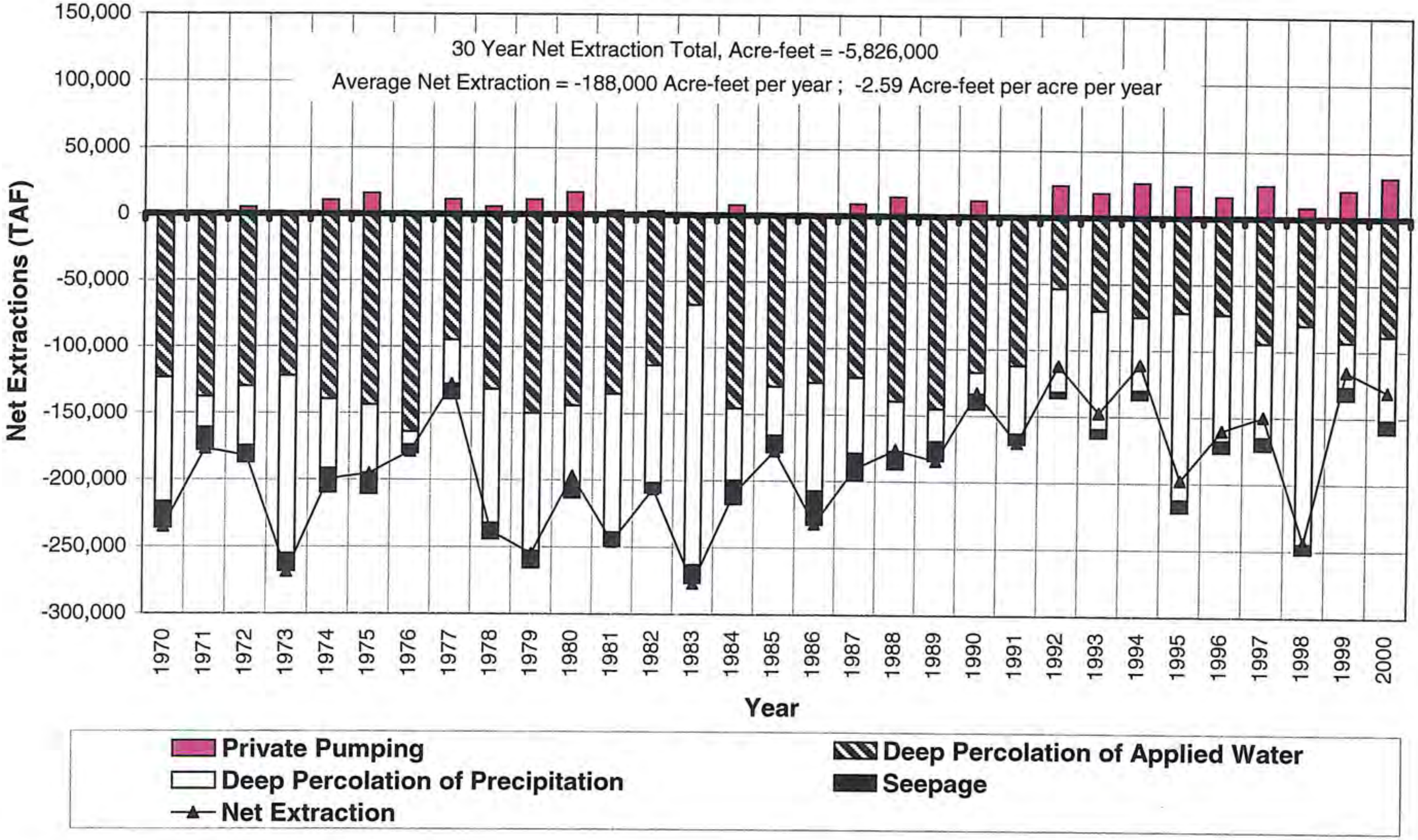


Figure 2-15. Historical and Baseline Cropping Patterns for Subunit 3 (GCID)

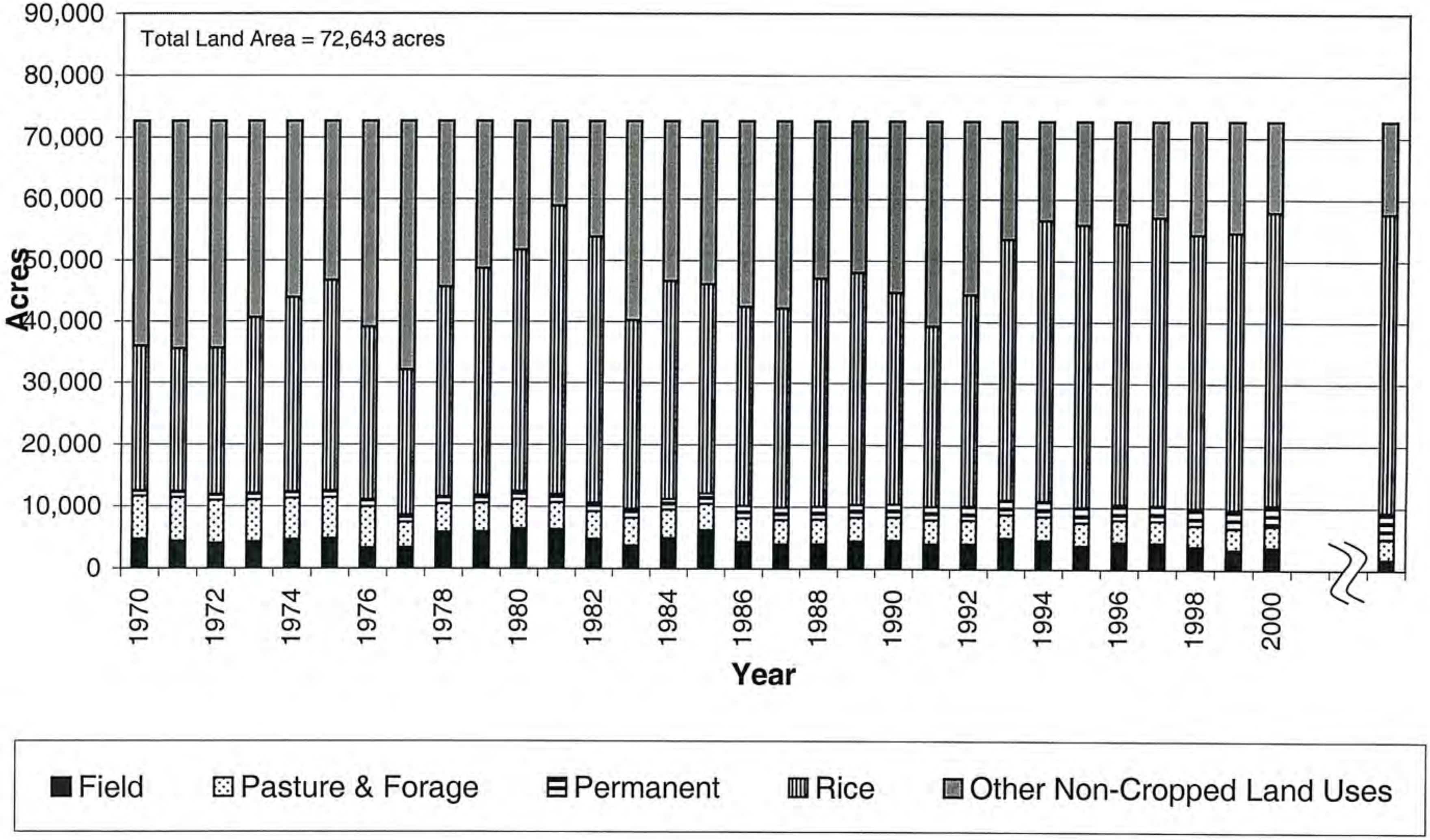


Figure 2-16. Historical Cropping Pattern for Subunit 4-7 (GW only) 1970-2000

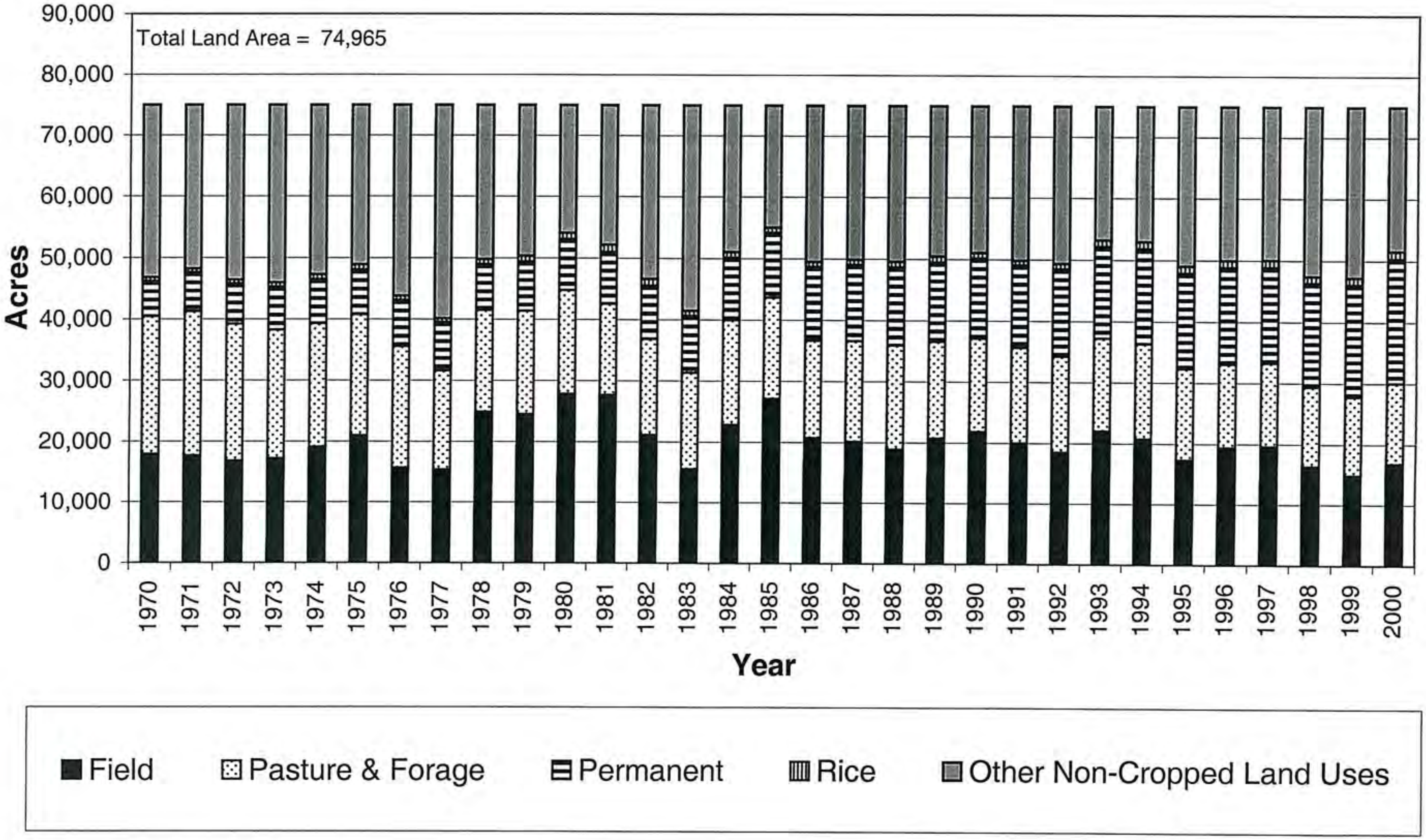


Figure 2-17a. Subunit 4-7 (GW only) Historical Water Demands

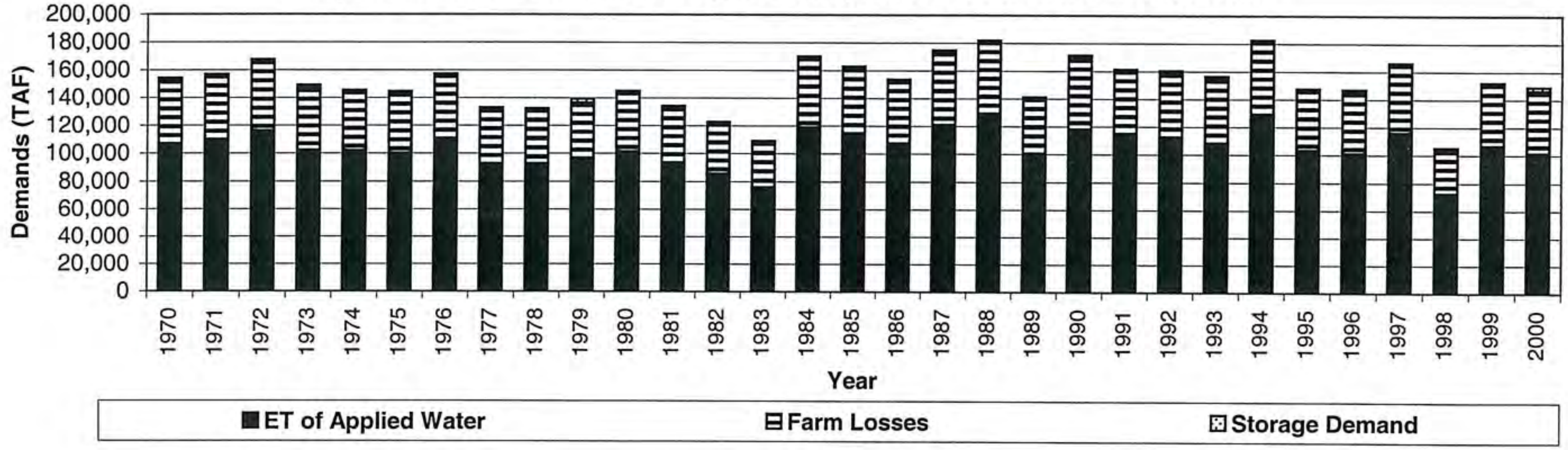


Figure 2-17b. Subunit 4-7 (GW only) Historical Water Supplies

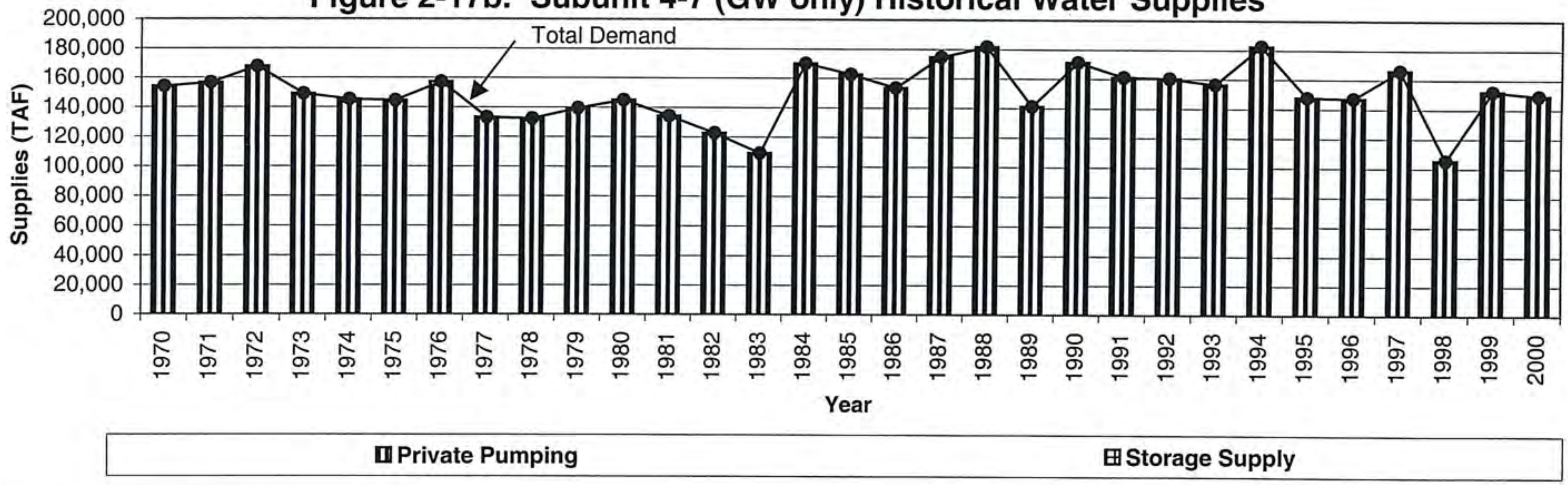


Figure 2-18. Net Extraction for Subunits 4-7 (GW only) from 1970-2000 (Total Area = 74,965)

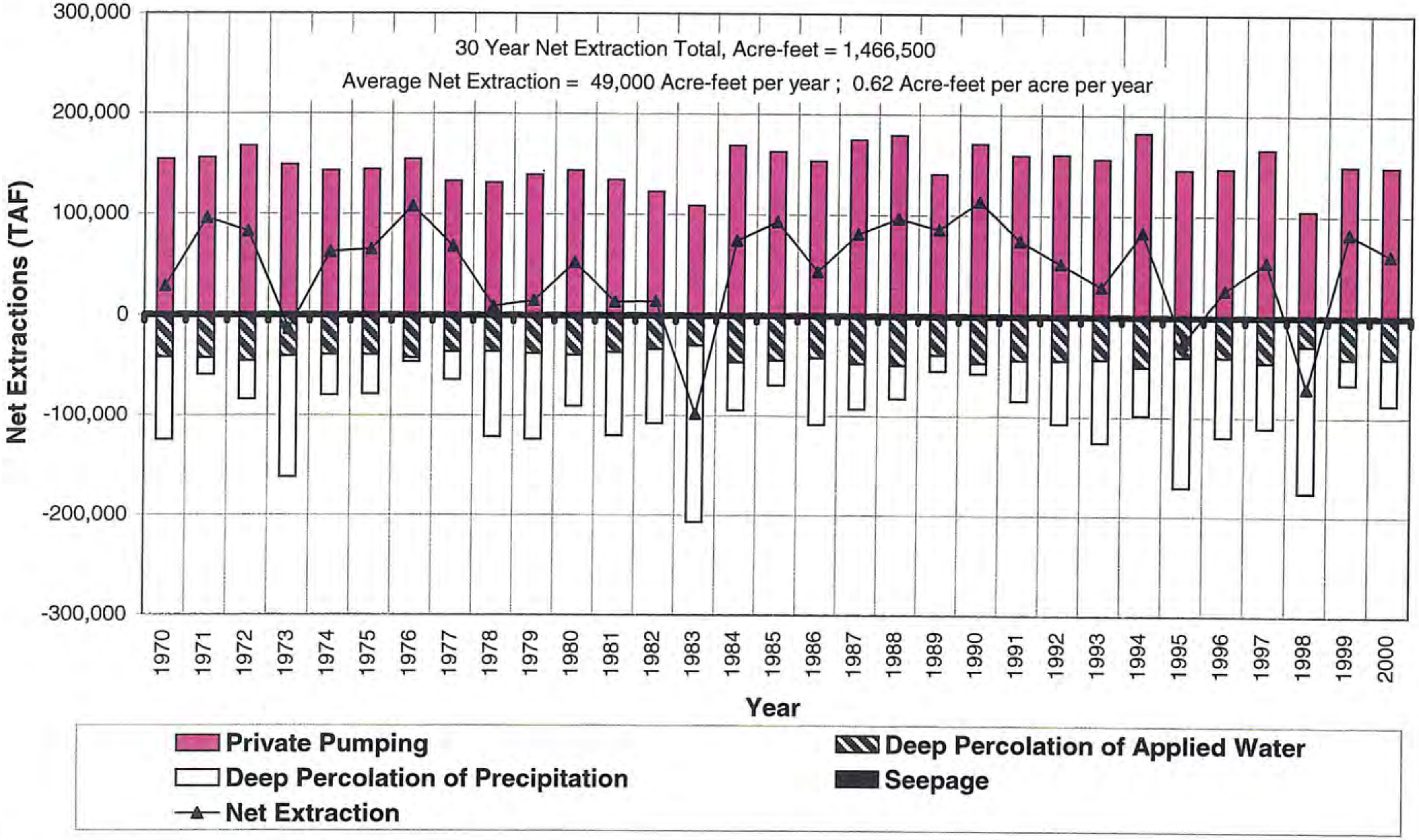


Figure 2-19. Historical and Baseline Cropping Patterns for Subunit 4-7 (GW only)

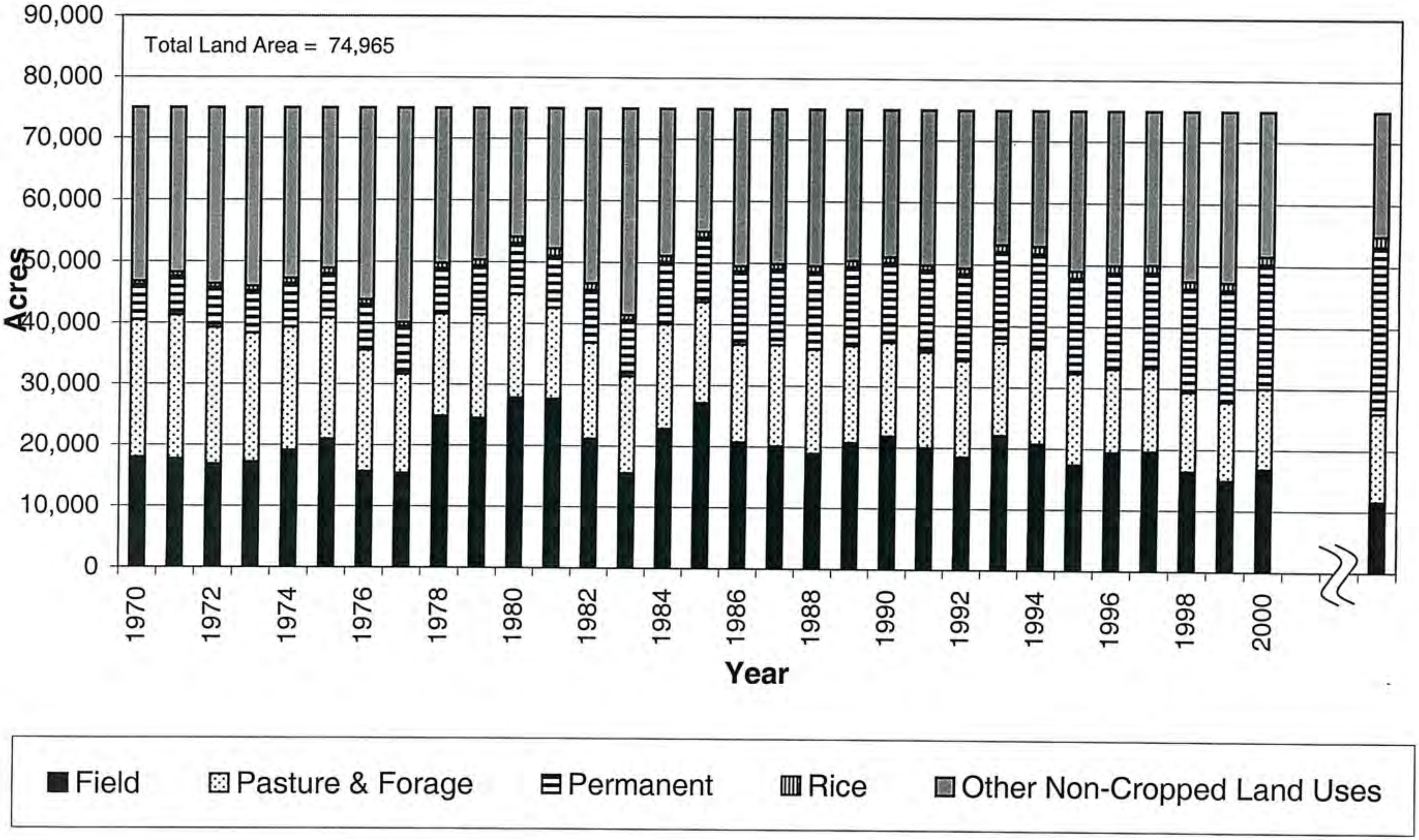


Figure 2-20. Subunits 4-7 (GW-only) Baseline ETaw and Applied Water Demands

(1922 to 1994 Hydrology; Projected 2025 Land Use; 75% On-farm Irrigation Efficiency)

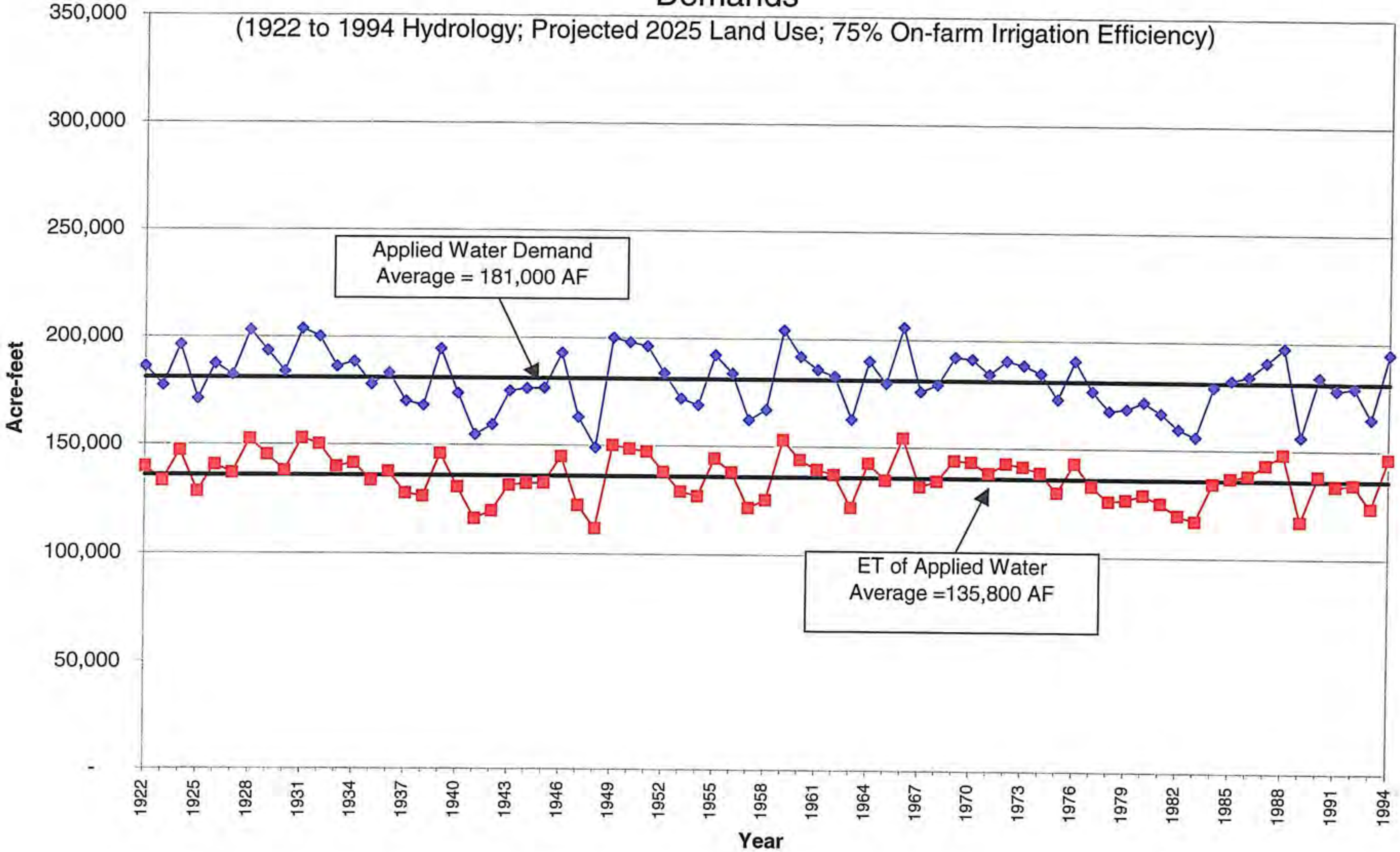


Figure 3-1
Percent Exceedance of the Value of Net Revenue for a 10,000 af Groundwater Substitution Transfer over 25 Years in Specified Year Types

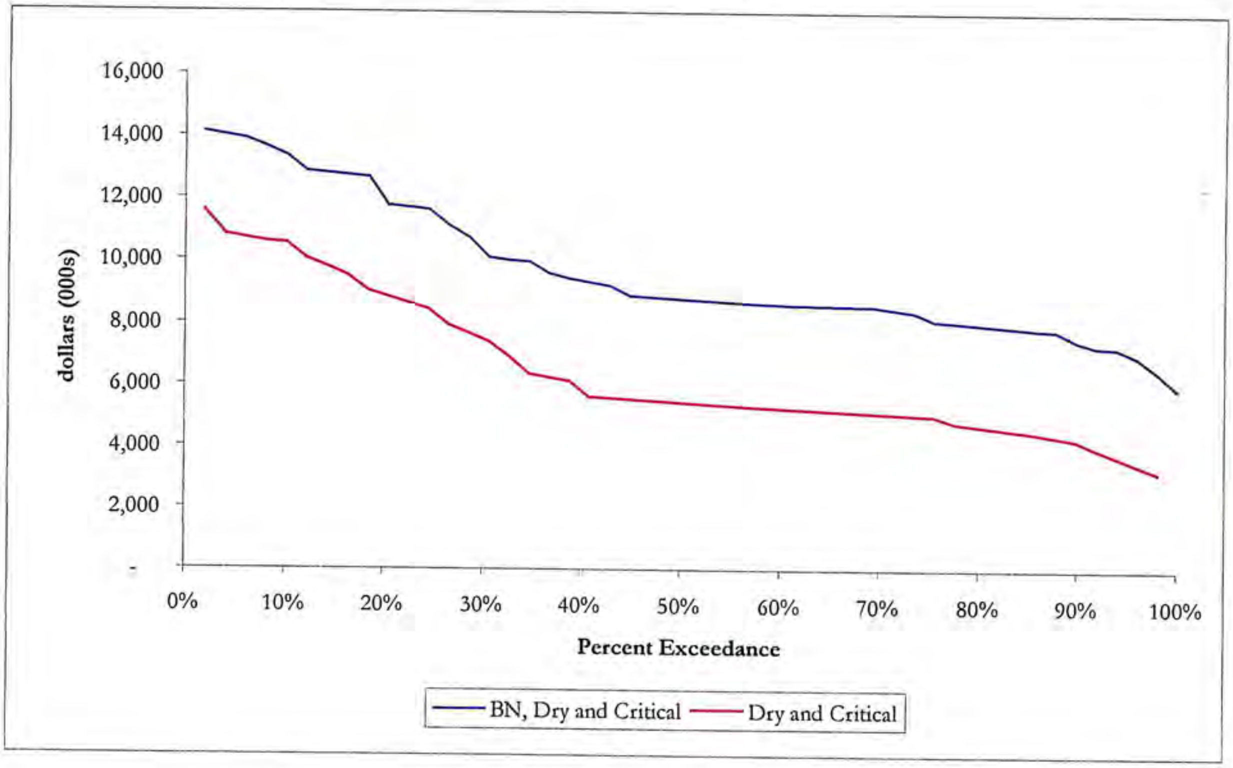


Figure 3-2
Total Annual Net Revenue of 10,000 af Groundwater Substitution in Specified Year Types

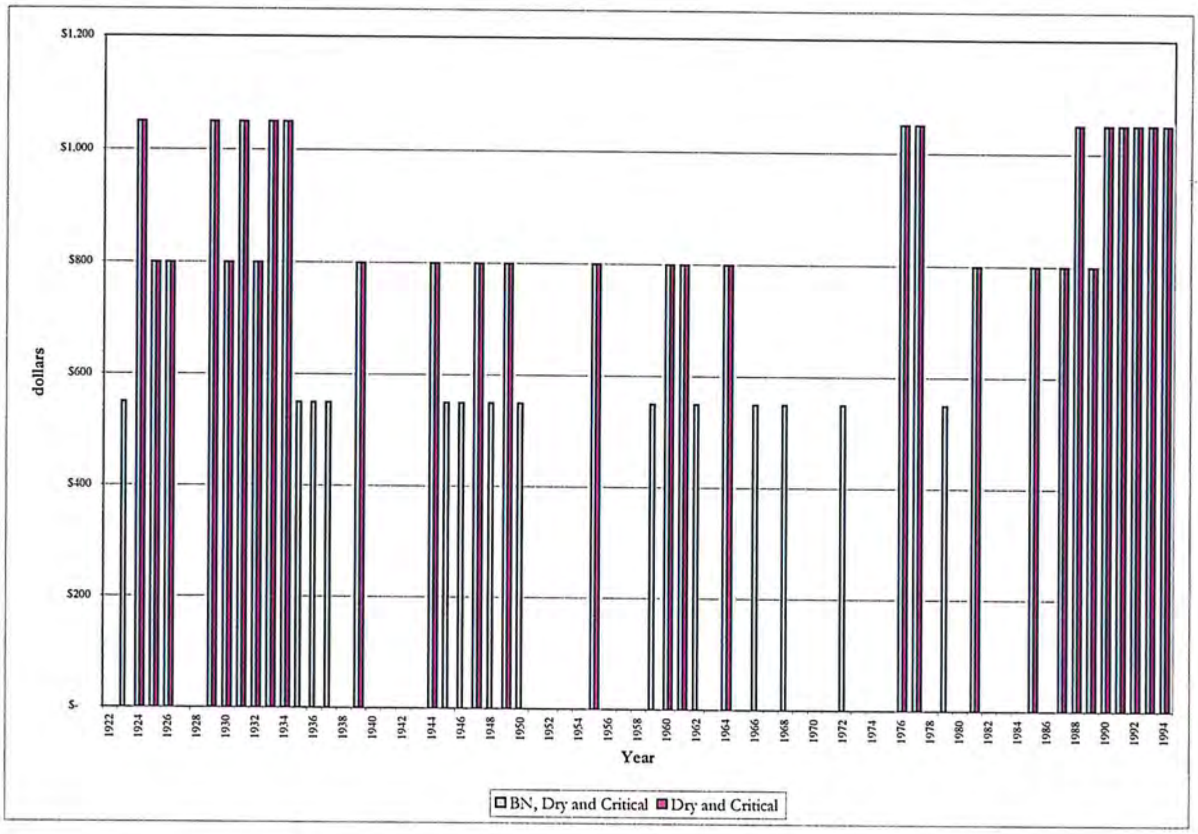


Figure 3-3
Estimated Change in the Volume of Storage in the Aquifer as a Result of a Groundwater Substitution Transfer in Dry and Critical Years under Varying Estimates of Average Annual Recharge

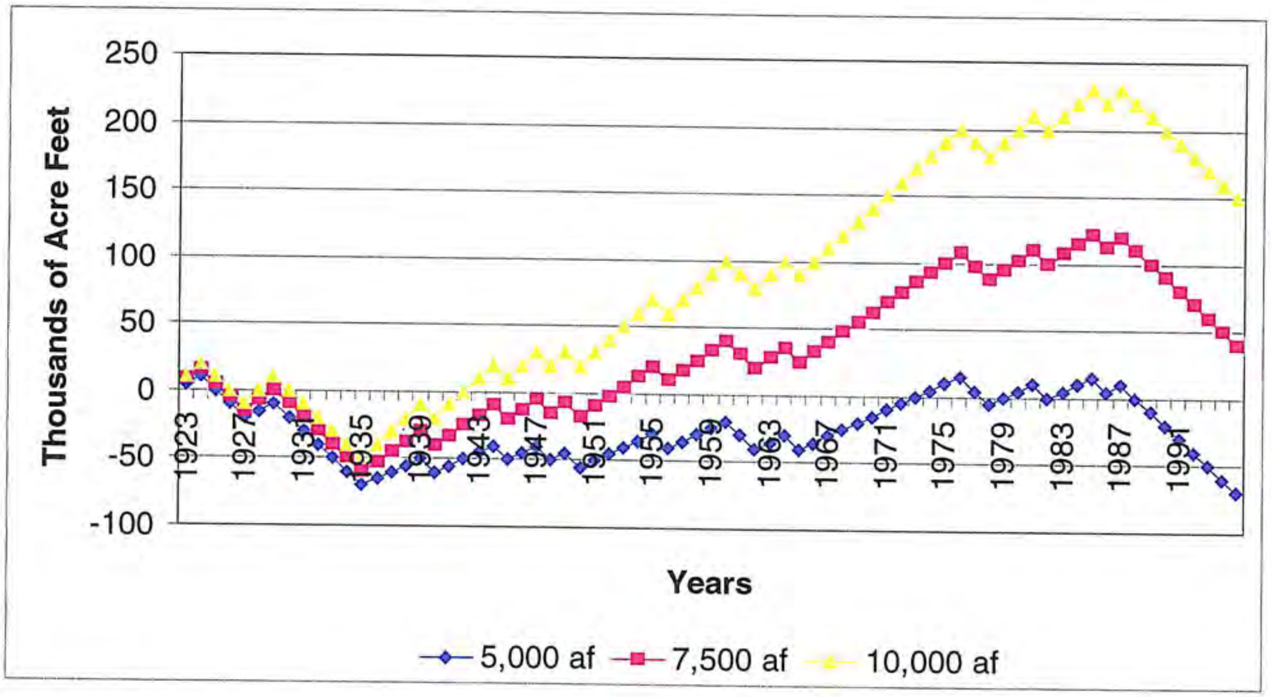


Figure 3-4
Actual Cummulative End of Month Storage for East Park Reservoir and Stony Gorge Reservoir Annually from 1922 to 2003

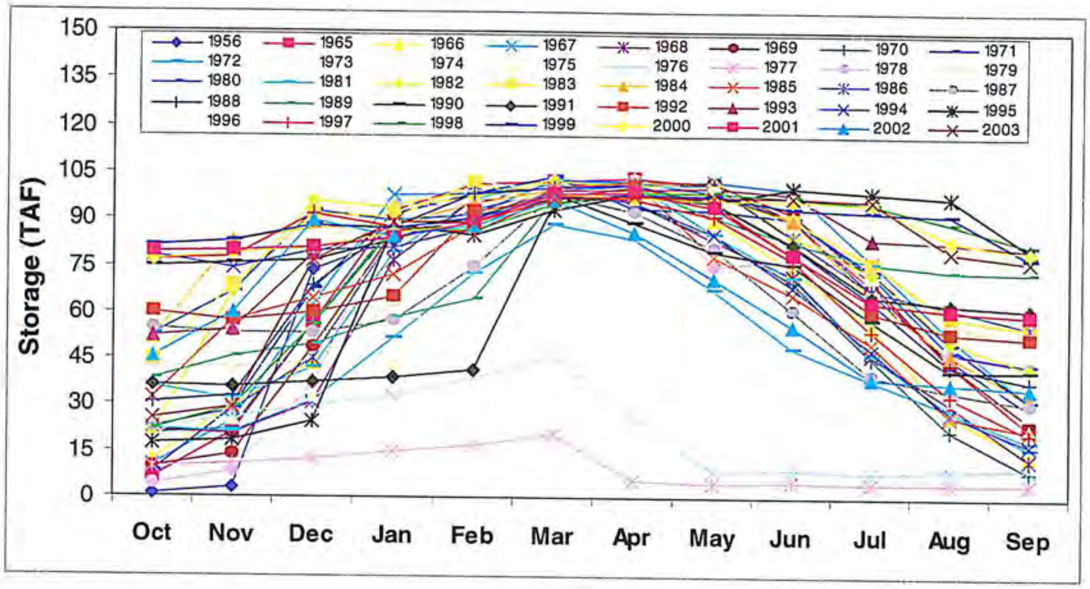
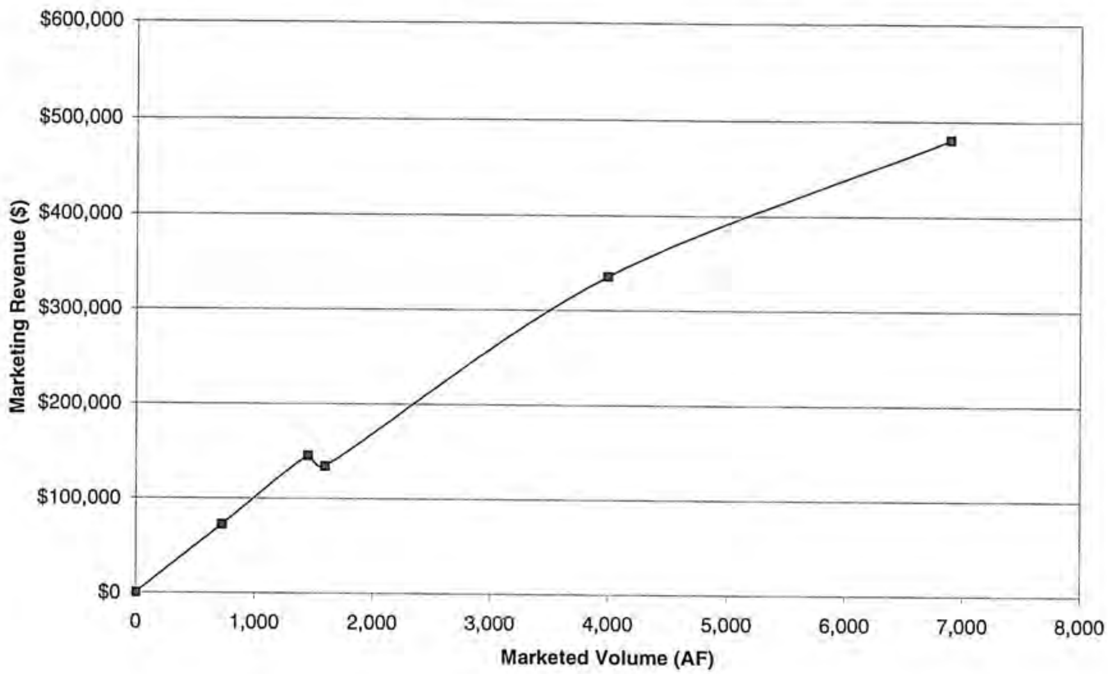
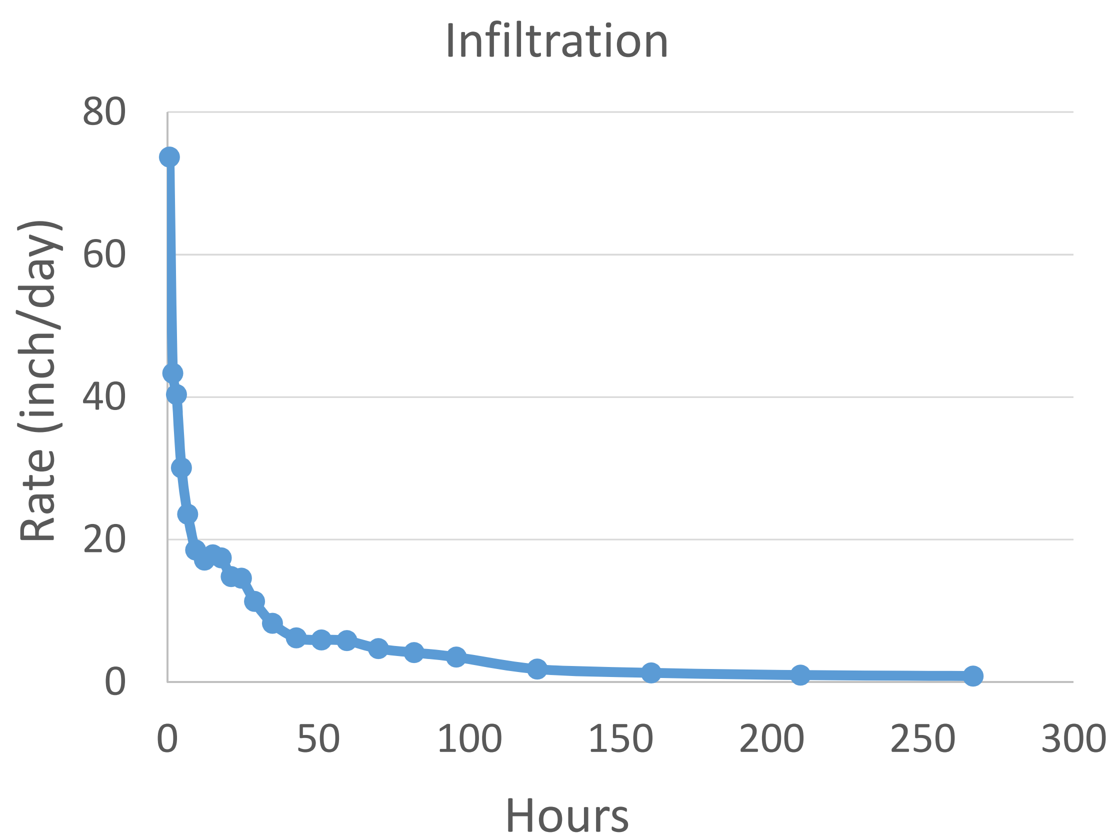


Figure 3-5

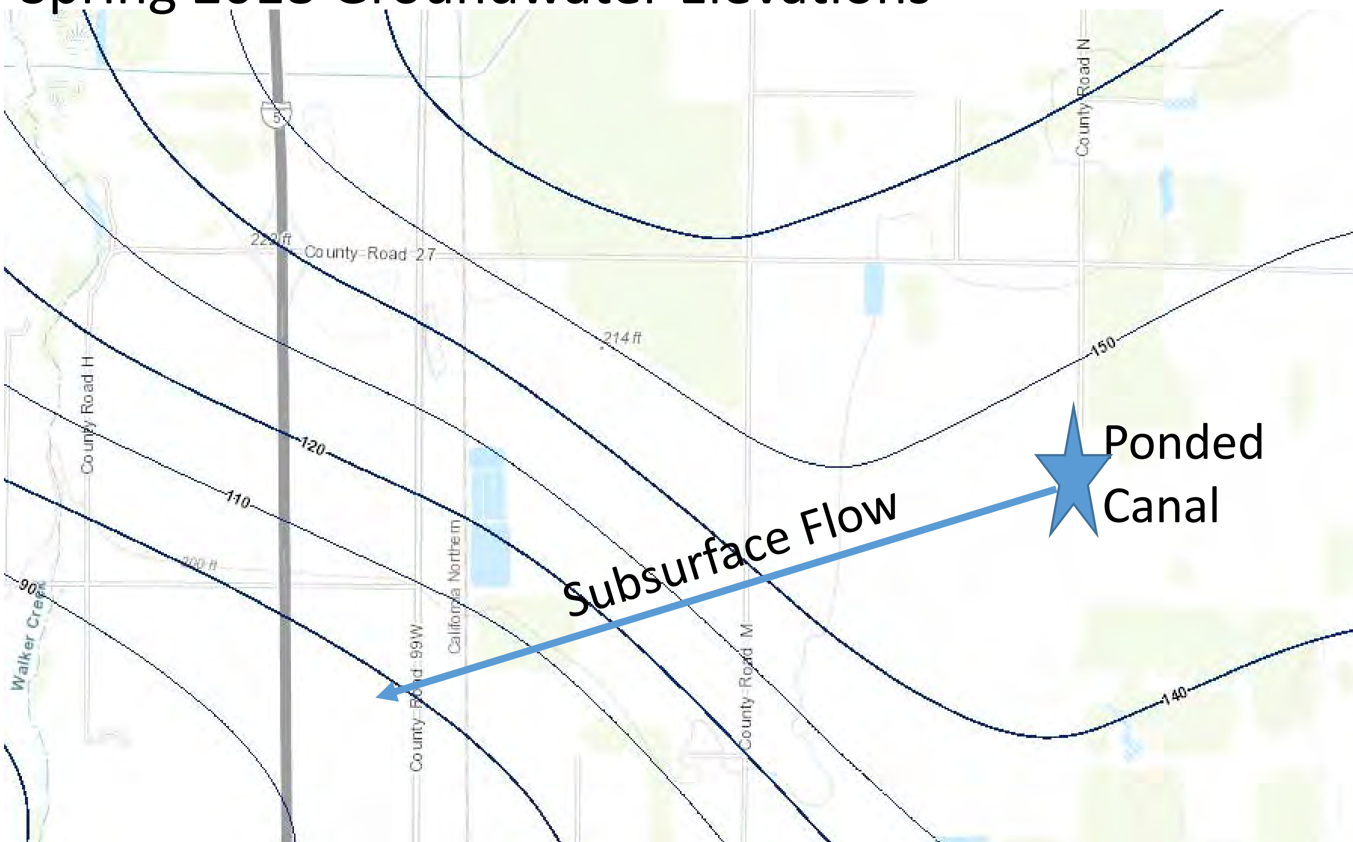
Water Marketing Revenue vs Volume for OAWD



- Infiltration is a function of soil structure and hydraulic gradient
- With 0.8 foot of head saturated infiltration occurs in approximately 125 hours yielding a value of 1.1 inches per day
- There is a linear relationship between infiltration and the hydraulic gradient



Spring 2018 Groundwater Elevations



Project Area: County Road N and 27

WRIME Water Resources & Information Management Engineering, Inc.
tel. 916.564.2236 1451 River Park Drive Suite 142, Sacramento, CA 95815
fax 916.564.1633 http://www.wrime.com • info@wrime.com

TECHNICAL MEMORANDUM

DRAFT

Stony Creek Fan Conjunctive Water Management Program

SCFIGSM Conceptual Model

To:	Eric Hong, DWR	**CC:**	Sue King Rick Massa Van Tenney Toccoy Dudley Derrick Louie Ron Milligan Roger Putty Grant Davids
From:	Saquib Najmus Mike Cornelius	**Date:**	March 31, 2003
Subject:	**Stony Creek Fan Integrated Groundwater and Surface Water Model (SCFIGSM) Conceptual Model**		
Project Reference:	Contract No.: 4600000734 Task Order: WRIME-Glenn-0901-001		

LIST OF FIGURES

LIST OF TABLES

The purpose of this report is to present the conceptual model developed for the Stony Creek Fan Integrated Groundwater and Surface water Model (SCFIGSM).

The purpose of developing a conceptual model is to simplify the modeling problem and organize the relevant field data and information so that the hydrogeologic system can be analyzed (Anderson and Woessner, 1992). The actual hydrogeologic system is too complicated to model; therefore, it needs to be simplified as much as possible. However, a conceptual model should retain enough complexity and level of detail in the representation of the actual field conditions so that the numerical model can reproduce the physical system responses with reasonable accuracy. It has been found that the long-term regional groundwater response projections require the following:

1. assessment of the hydrologic components of the physical system being modeled;
2. delineation of hydrogeology;
3. specification of associated land and water use processes that affect groundwater levels;
4. description of boundary conditions; and
5. definition of horizontal and vertical flow regimes within the system.

Development of a sound conceptual model is essential to understanding how the groundwater basins in a study area may respond to different water management strategies. The conceptual model serves as the basis for the development of a numerical simulation model.

PROJECT BACKGROUND

The Stony Creek Fan is a geologic feature located in Glenn and Tehama counties, near Orland. The coarse grained nature of the Stony Creek alluvial fan provides potential opportunities for direct recharge of the surface water during years of excess surface water supply. However, additional exploration and studies are needed to help determine the optimum approach to conjunctive use operations and methods of groundwater recharge (direct and in-lieu) and recovery of stored groundwater. In addition, studies are needed to assure compliance with the local groundwater management plans, ordinances, and Basin Management Objectives (BMO).

Three Sacramento Valley water purveyors, Orland-Artois Water District (OAWD), Orland Unit Water Users' Association (OUWUA), and Glenn-Colusa Irrigation District (GCID), hereinafter referred to as "Program Sponsors", agreed through a Memorandum of Understanding (MOU) earlier this year to cooperatively pursue development of the Stony Creek Fan Conjunctive Water Management Program (Program).

The SCFIGSM is being developed in coordination with the California Department of Water Resources (DWR) and the three Project Sponsors to serve as an analytical tool that can provide quantitative information on a comparative basis to help answer different questions on the groundwater and surface water system characteristics and to evaluate alternative conjunctive water management strategies.

STUDY AREA

The general study area, shown in Figure 1.1, extends about 30 miles from west to east and about 70 miles from north to south. The study area includes three reservoirs (the East Park Reservoir, the Stony Gorge Reservoir, and the Black Butte Lake), three major streams (the Thomes Creek, the Stony Creek, and the Sacramento River), five major water distribution canals (the Tehama-Colusa Canal, the Glenn-Colusa Canal, the Colusa Basin Drain, the Orland North Canal, and the Orland South Canal), and several small creeks.

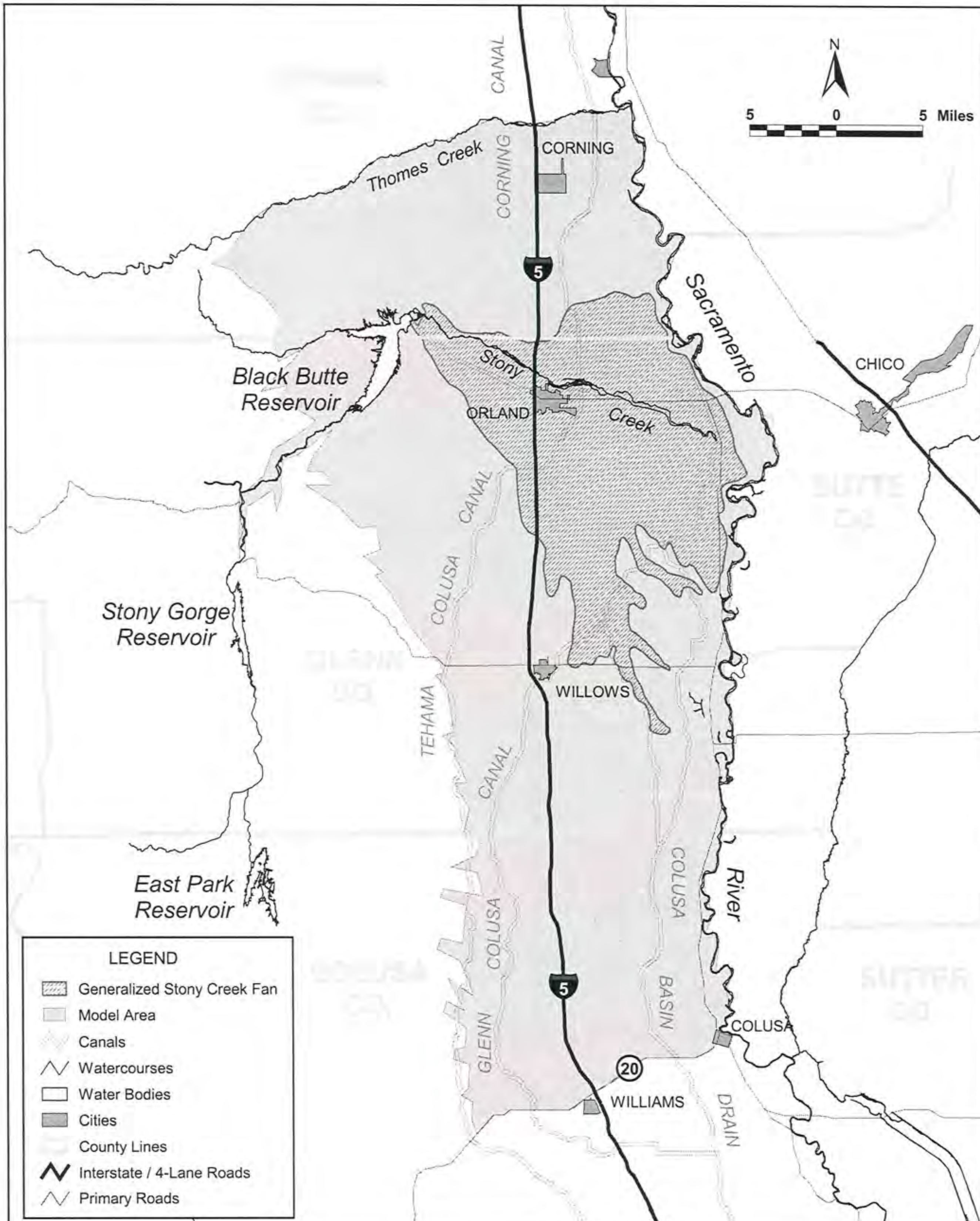
The Stony Creek Fan, shown as a hatched area in Figure 1.1, is a highly permeable near surface formation that extends southeast from the Black Butte Reservoir in the Glenn County. The study area for this project includes the Stony Creek Fan and the areas surrounding the Fan that are included in the model.

The SCFIGSM model area is smaller than the general study area because it follows the hydrogeologic boundaries and features of the underlying groundwater aquifer that is being modeled. The model area is bounded on the north by Thomes Creek and on the south by Highway 20. The model area extends east from the geologic contact with the Coast Ranges Foothills to the Sacramento River.

ORGANIZATION OF THE TECHNICAL MEMORANDUM

The SCFIGSM Conceptual Model Technical Memorandum is organized into the following sections:

- **Section 1: Introduction** describes the purpose, project background, study area and organization of this technical memorandum.
- **Section 2: Hydrogeology** describes the hydrogeology of the Stony Creek Fan Model Area.



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STONY CREEK FAN CONJUNCTIVE WATER MANAGEMENT PROGRAM

Model Study Area

DRAFT

MARCH 2003

FIGURE 1.1

- **Section 3: Hydrology** describes the general hydrology of the study area.
- **Section 4: Modeling Goals and Objective** describes the goals and objectives of the modeling, which guides the model formulation and development
- **Section 5: Conceptual Model** describes the conceptual model for the study area.
- **Section 6: Summary** presents a summary of conceptual model development and potential model uses.

The description of the study area geology provided in this technical memorandum builds on DWR's recent geologic mapping of the area, well log data analysis, and previous investigations by various agencies and authors.

The DWR Northern District is currently in the process of completing comprehensive geologic mapping of the Stony Creek Fan. Several geologic cross sections were developed based on analysis and interpretation of recent and E-logs, and oil and gas logs. These geologic cross-sections are not yet published but were provided as preliminary data to the project study team solely for the purpose of use in the development of conceptual model for SCFIGSM.

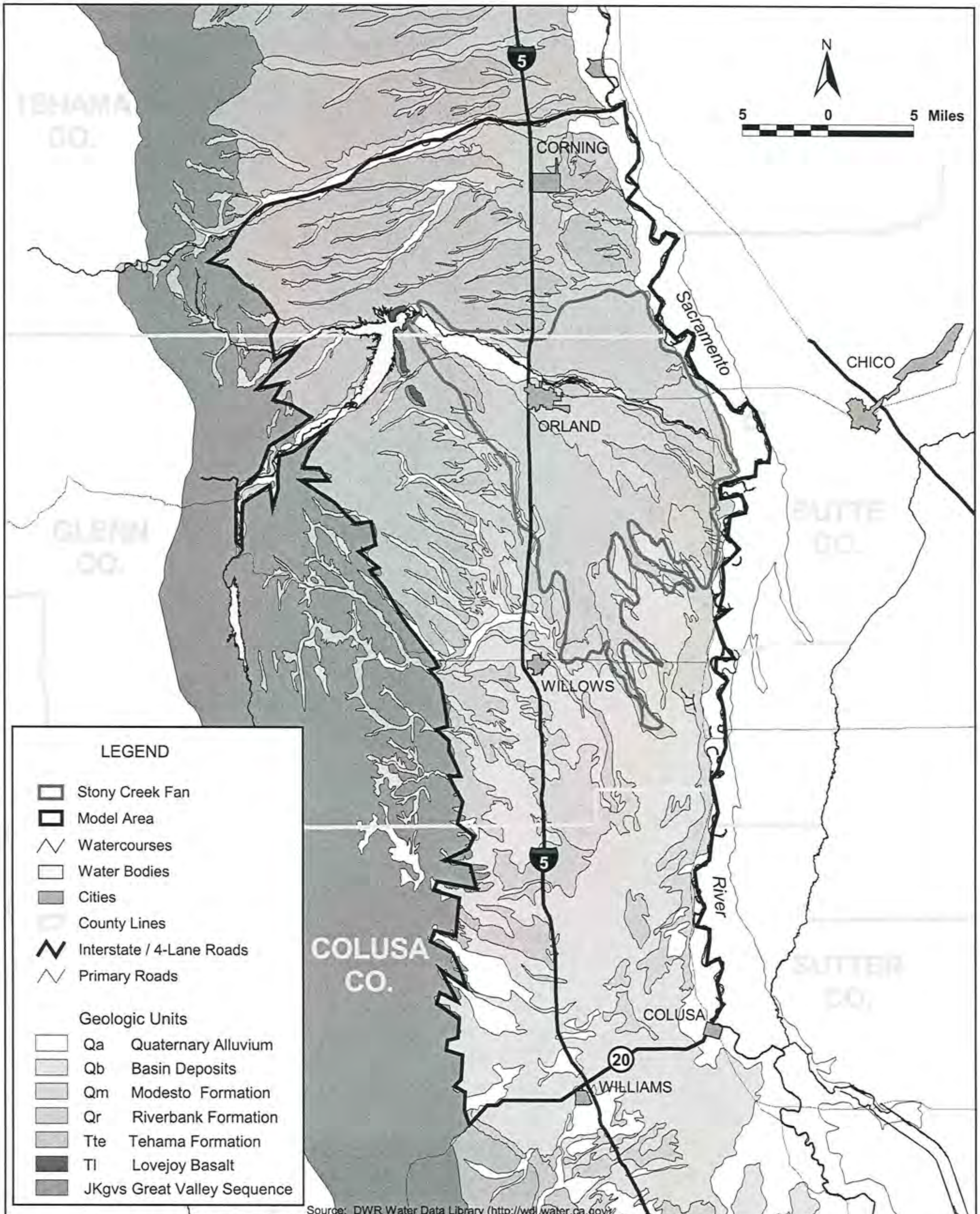
This geologic mapping effort of DWR has resulted in the redefinition of the hydrogeologic setting of Sacramento Valley north of the Sutter Buttes. Until recently, it was believed that the northern Sacramento Valley alluvial aquifer system consisted primarily of a thick layer of interbedded sands and clays. The recent aquifer mapping by the DWR Northern District provides more detailed information about the different aquifer layers that are present in the northern Sacramento Valley.

Monitoring and production well logs for the Counties of Glenn, Tehama, and Colusa are also available as hardcopy data at the DWR Northern District office in Red Bluff. About 400–500 driller's logs were reviewed and screened for the geographic coverage and the level of detail reported in the well log. About 154 driller's logs were further analyzed, interpreted, and used to supplement the existing geologic cross-section data to develop an understanding of the hydrogeology.

DEPOSITIONAL ENVIRONMENT

The geology of the Stony Creek Fan area consists of both marine deposits and continental deposits. The older marine deposits contain saline water and underlie the younger continental deposits. The freshwater bearing continental deposits are the geologic units of interest in the Stony Creek Fan Conjunctive Water Management Program. The geologic units present in the study area are shown in Figure 2.1 and a brief description of the characteristics of these units is provided in Table 2.1.

During the Cretaceous Period to early Miocene Epoch, the present Sacramento Valley trough was inundated by an inland sea, which deposited thousands of feet of marine sediments above the pre-Cretaceous granitic basement rocks. After withdrawal of the marine waters in the



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STONY CREEK FAN CONJUNCTIVE WATER MANAGEMENT PROGRAM

MARCH 2003

Surficial Geology

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FIGURE 2.1

Table 2.1
Description of Geologic Units in Study Area

System and Series		Geologic Unit	Lithologic Character	Maximum Thickness[1] (ft)	Water-bearing Character
QUATERNARY	Holocene	Alluvium Qa	Unconsolidated unweathered gravel, sand, silt, and clay[1].	80	Deposits are moderately to highly permeable with high permeability gravelly zones yielding large quantities to shallow wells[2]. Although deposits along Stony, Chico, and Thomes Creeks are important recharge areas[2], extensive water bearing capacity is restricted by thickness and areal extent[1].
QUATERNARY	Holocene	Basin Deposits Qb	Unconsolidated[5] fine-grained silts and clays, locally interbedded with stream and channel deposits along the Sacramento River[1].	150	Deposits are typically saturated nearly to the ground surface[2]. The low to moderate permeability results in yields of small quantity and poor groundwater quality to domestic wells[1,2].
QUATERNARY	Pleistocene	Modesto Formation Qm	Poorly sorted[5] unconsolidated weathered and unweathered gravel, sand, silt, and clay[3].	200	Moderately to highly permeable[1].
QUATERNARY	Pleistocene	Riverbank Deposits Qr	Poorly sorted[5] unconsolidated to semi-consolidated[3] pebble and small cobble gravels interlensed with reddish clay, sand, and silt[1].	200	Water-bearing capability is limited by thickness. These poorly to highly permeable deposits supply moderate groundwater amounts to domestic and shallow irrigation wells. Deeper irrigation wells may be supplied if the wells contain multiple perforation zones[1].
TERTIARY AND QUATERNARY	Pliocene and Pleistocene	Tehama Formation Tte	Fluviatile moderately consolidated pale green, gray, and tan sandstone and siltstone enclosing lenses of sand and gravel; silt and gravel; and cemented conglomerate derived from the Coast Ranges[1,3].	2,000	Local high permeability zones within this characteristically low to moderate permeability unit, widespread distribution, and deep thickness cause this formation to be the principle water bearing unit in the area. Deep well yields are typically moderate, but are highly variable[2].
TERTIARY	Pliocene	Tuscan Formation Tt	This series of volcanic flows, consolidated tuff breccia, tuffaceous sandstone, and volcanic ash derived from the Cascade Range interfingers with the Tehama Formation as it westerly grades into volcanic sands, gravels, and clays[1,2]. The formation is divided by layers of thin tuff or ash units into four lithologically similar units A-D[1].	1,500	Within this formation, moderately to highly permeable volcanic sediments are hyraulically confined by layers of tuff breccias and clays[2]. Units A and B are the primary water-bearing zones and are composed of volcanic conglomerate, sandstone, and siltstone layers interbedded with lahars. Stragraphically higher, the massive lahar deposits of unit C confine groundwater in the permeable beds of units A and B[1].
TERTIARY	Pliocene	Nomlaki Tuff Member	Tuff breccias and white tuffs of dacitic composition. This member of the Tehama and Tuscan Formations serves as an important stratagraphical marker bed in northern Sacramento Valley[5].	60 [5]	Poorly permeable.
TERTIARY	Miocene	Neroly Formation Tn	Marine to non-marine tuffaceous andesitic sandstone interbedded with tuffaceous shales and tuff layers. Contains local conglomerate lenses[4].	500	This formation of variable permeability contains interstitial fresh water under confined conditions[4], however, deposits of the Neroly Formation are typically located below the base of fresh water.
TERTIARY	Miocene	Lovejoy Basalt Tl	Black, dense, hard microcystalline basalt[3].	65	Largely non-water bearing.
TERTIARY	Miocene and Oligocene	Upper Princeton Valley Fill Tupg	Non-marine sandstone containing mudstone, conglomerate, and sandstone conglomerate interbeds[3].	1,400	Largely non-water bearing or contains saline water.
TERTIARY	Eocene	Lower Princeton Submarine Valley Fill Tlpg	Marine conglomerate and sandstone interbedded with silty shale[3].	2,400	Largely non-water bearing or contains saline water.
CRETACEOUS		Great Valley Sequence JKgvs	Marine siltstone, shale, sandstone, and conglomerate[3].	15,000	Largely non-water bearing or contains saline water[2].
PRE-CRETACEOUS		Basement Complex pTb	Metamorphic and igneous rocks.	n/a	May contain groundwater, mainly saline, in fractures and joints.

Notes:

[1] Department of Water Resources web page (www.wq.water.ca.gov).
[2] Department of Water Resources, Bulletin 118-6, 1978.
[3] Department of Water Resources, Bulletin 118-7 (Draft, not published).
[4] Department of Water Resources, Sacramento River Basin-Wide Water Management Plan-Draft, 2000.
[5] Department of Water Resources, Groundwater Levels in the Sacramento Valley Groundwater Basin, Glenn County, 1997.

Miocene Epoch, there was a period of erosion dominated by the deposition of continental deposits.

During the Pliocene Epoch, the northern Coast Range uplift was initiated and the Sacramento Valley began to assume its current form. Coast Range uplift and related erosion of the uplifted block resulted in deposition of the Tehama Formation onto the heavily eroded, subsiding valley floor. In late Pliocene period, volcanic activity on the southern Cascade Range caused the widespread deposition of the Nomlaki tuff across the northern Sacramento Valley. This extensive ash layer is found near basal deposits of the Tehama and Tuscan Formations. Continuous volcanism in the southern Cascade Range produced consecutive mudflows of basaltic and andesitic composition. These igneous deposits were reworked coincident with volcanic activity resulting in the Tuscan Formation on the east side of the Sacramento Valley.

The deposition of the Tehama and Tuscan Formations occurred simultaneously during the Pliocene Epoch. These thick, widespread deposits overwhelmed the previous topography, creating a relatively flat plain that was repeatedly dissected by meandering and braided streams.

Fluviatile sedimentation of the Tehama Formation was continuous on the west side of the Sacramento Valley throughout the Pliocene and possibly into the Pleistocene period. During the middle part of the Pleistocene period, mountain-building activity brought the Coast Ranges to their current structure and shape. The Tehama Formation deposits, along with older deposits, were involved in this folding and faulting event, and formed low hills and dissected uplands. Intense erosion concurrent and following this orogenic activity reworked the Tehama Formation and redeposited the sediments near the center of the Valley. Much of these sediments were carried away by the Sacramento River.

Quaternary sedimentation is represented in the deposition of broad alluvial fans and flood plains. In the vicinity of the Stony Creek Fan, the newly eroded surface of the Tehama Formation was covered with poorly sorted gravel deposits of the Pleistocene Modesto and Riverbank Formations. Gravels of these terrace deposits were partially supplied by continued erosion of the Coast Ranges. The northwest Sacramento Valley cycle of valley deposition continues to the present day.

The low hills and dissected uplands appear between the Coast Ranges and the alluvial fans of the valley. An abrupt increase in the land slope marks the transition between the alluvial fans and the uplands. These hills are topographic expressions of subsurface folding and faulting of the Tehama Formation and older underlying sediments.

As streams draining east from the Coast Ranges leave the low hills and dissected uplands, they flow out into the relatively flat valley floor. This change in slope causes them to deposit their bed load, forming broad alluvial fans. Alluvial fan deposits are an intricate system of buried channels formed by a dynamic fluviatile depositional environment. An example of an alluvial fan is the Stony Creek Fan (Figure 1.1 in Section 1), the focus of the current study. This fan is the largest and most complex alluvial fan in the northwest portion of the Sacramento Valley and was deposited by Stony Creek. The apex of the Stony Creek Fan is approximately five miles northwest of the town of Orland, where Stony Creek flows out of the low hills. The Stony Creek Fan extends east to the Sacramento River flood plain, and south to the Colusa basin deposits near the town of Willows. The surface of the fan is not smooth, but rather cut by many abandoned channels. Smaller and less impressive fans have been deposited by intermittent streams south of the Stony Creek Fan. In general, these deposits are much finer grained than the deposits of the Stony Creek Fan.

In flat, low-lying basins between the alluvial fans and the Sacramento River, distal alluvial fan sediments merge with the fine-grained basin deposits. During flooding events along the Sacramento River, water spills over the natural river levee and accumulates in these basins. The trapped water creates temporary lakes, and the quiescent environment allows for deposition of fine-grained suspended material. The Colusa Basin, which extends 60 miles south of the Stony Creek Fan, is an example of this depositional phenomenon.

The Sacramento River and Stony Creek have deposited a large quantity of coarse material in the northwest Sacramento Valley over thousands of years. These deposits form the alluvial aquifer in the study area. The Sacramento River and Stony Creek are also the primary sources of surface water to the study area.

GEOLOGIC FAULTS

The Sacramento Valley is an asymmetrical northward-trending syncline partially filled with sedimentary deposits. Several faulting, folding, and uplift events tilted the Sierra Nevada block relative to the Coast Ranges. Latter orogenic events are expressed in folding and faulting of Pre-Middle Pleistocene basal deposits. Faults related to this geologic activity include the Paskenta, Willows, Corning, and Black Butte Faults.

WATER BEARING FORMATIONS

The key characteristics of the water-bearing geologic formations of the study area are summarized in Table 2.1, presented previously. These units include the Pliocene Tuscan

Formation; Pliocene and Pleistocene Tehama Formation; Pleistocene Modesto and Riverbank Formations; and the Holocene alluvial, basin, and flood plain deposits.

Marine sediments in the study area include the Miocene Neroly Formation, the Miocene and Oligocene Upper Princeton Valley Fill, the Eocene Lower Princeton Submarine Valley Fill, and the Cretaceous Great Valley Sequence. These deposits define the subsurface freshwater aquifer boundary. In general, these largely non–water bearing deposits occur below the base of fresh water; thus they may contain small amounts of saline water.

PLIOCENE TUSCAN FORMATION

Tuscan deposits are characterized by their Cascade Range origin and volcanic signature. This extensive series of basaltic and andesitic volcanic flows, consolidated tuff breccia, tuffaceous sandstone, and volcanic ash is primarily located on the northeastern portion of the Sacramento Valley. The Tuscan Formation underlies much of the Valley floor and extends from the Cascades to the center of the Valley where it grades into volcanic sands, gravels, clays, and interfingers with the Tehama Formation. Thin tuff or ash units separate the Tuscan Formation into four distinct, yet lithologically similar Units A, B, C, and D (D being the youngest). Only A, B, and C are found in the project study area. Unit C is composed of massive lahar (mudflow) deposits with volcanic sandstone and conglomerate interbeds. Tuscan Formation Unit C is referred to as the Upper Tuscan Formation. Tuscan Units A and B are largely composed of layered, inter-bedded lahars, siltstone, and volcanic sandstone and conglomerate; they are referred to as the Lower Tuscan Formation. Unit A is distinguished from Unit B by the presence of metamorphic rock fragments in siltstone layers. This formation contains fresh water.

PLIOCENE-TO-PLEISTOCENE TEHAMA FORMATION

Deposits of the Tehama Formation are characterized by their fluviatile nature and origin from the Klamath Mountains and Coast Ranges. This assemblage of moderately consolidated sandstone and siltstone with local coarse lenses is located in the northwest portion of the Sacramento Valley. These yellowish to greenish grey deposits are separated from the underlying Eocene Epoch and Cretaceous Period marine sediments by an unconformity. The Tehama Formation was deposited under floodplain conditions by rivers and streams flowing from nearby mountains in a subsiding, low relief valley. Several properties of the Tehama Formation indicate a western and northwestern origin. Mineral composition and rock type of Tehama deposits are identical to those in the Coast Ranges and Klamath Mountains. Additionally, the grain size of Tehama Formation sediments decreases to the south and east, suggesting a western and northwestern origin. This formation contains fresh water.

PLIOCENE NOMLAKI MEMBER

This deposit is recognized as a member of both the Tehama and Tuscan Formations indicating simultaneous deposition. The Nomlaki Member is composed of coarse tuff breccias and white tuffs of dacitic composition and has an eastern source. This widespread deposit serves as an important stratigraphical marker in the northern part of Sacramento Valley. This formation contains fresh water.

PLEISTOCENE DEPOSITS

Terrace deposits of the Pleistocene Modesto and Riverbank Formations are composed of poorly sorted clay, silt, sand, and gravel, and form a thin veneer at the ground surface. The Riverbank Formation is distinguished from the Modesto deposits by interbedded clay layers. In the Stony Creek Fan area, these terraces are well defined, but they are absent or poorly defined along other minor streams in the study area. This formation contains fresh water.

HOLOCENE DEPOSITS

Quaternary alluvium, the most recent deposit, is found along major rivers and is composed of unconsolidated unweathered clay, silt, sand, and gravel. Fine-grained flood plain deposits include silt with minor amounts of sand. The basin deposits are composed of fine-grained sediments and are found in flood basins and near streams. The coarse-grained sediments of the alluvial fan include sand and gravel. This formation contains fresh water.

HYDROGEOLOGY

The Stony Creek Fan deposits include Pleistocene and Holocene upper, unconfined aquifer deposits. As Stony Creek meandered across the fan, channels were created, abandoned, and then buried, creating a complex system of coarse- and fine-grained sediments. The variable nature of this fluviatile, depositional environment causes difficulty in defining groundwater aquifers within the fan.

The Stony Creek alluvial fan sediments form a thin veneer over the Tehama Formation. During the Pleistocene, the surface of the Tehama Formation was intensely eroded, then backfilled with both coarse- and fine-grained deposits of the Stony Creek Fan. The resulting uneven contact between the geologic units makes it difficult to determine the contact between the Stony Creek Fan deposits and the underlying Tehama Formation. The nature and extent of groundwater interaction between these deposits is uncertain due to the channelized nature of both formations.

Typical Tuscan deposits are coarser than those of the Tehama Formation. Simultaneous deposition of these extensive formations onto a broad valley surface resulted in the interfingering of Tuscan and Tehama sediments near the center of the valley. In general, the grain size of the Tehama Formation becomes finer to the east, and the Tuscan Formation grades into volcanic gravels, sands, and clays where the deposits overlap. The nature of groundwater interaction where these formations merge is uncertain.

The aquifer system of the Stony Creek Fan Area includes a freshwater aquifer overlying a saline aquifer. The freshwater alluvial aquifer system in the study area is composed of late Tertiary to Quaternary continental deposits. The aquifer system includes an upper unconfined alluvial aquifer consisting of Quaternary deposits overlying a confined aquifer system composed of Quaternary and Tertiary continental deposits of fluvial and volcanic origin. The saline aquifer system composed primarily of Tertiary and older marine deposits.

FRESHWATER AQUIFER SYSTEM

The freshwater aquifer system is composed of an unconfined aquifer overlying a confined aquifer as described below.

Unconfined Aquifer

The upper unconfined aquifer consists of Quaternary deposits, including Holocene alluvium, flood plain, alluvial fan, and basin deposits, and the Pleistocene Riverbank and Modesto Formations. The unconfined aquifer system is important to local groundwater users, but the potential for significant groundwater storage is limited due to insufficient thickness.

Recharge Areas

The unconsolidated, highly permeable Quaternary alluvium deposits are important recharge areas. These deposits are generally located along major rivers and facilitate groundwater recharge from rivers. Highly permeable alluvial fan deposits, specifically of the Stony Creek Fan, are also important recharge areas. The moderately permeable basin deposits and floodplain deposits are less important recharge areas.

In addition to the Holocene deposits, the highly permeable terrace deposits of the Pleistocene Modesto and Riverbank Formations are significant recharge areas. Water bearing capabilities of these formations are limited by their thickness.

Confined Aquifer

The confined aquifer is composed of Tertiary Deposits, including the Pliocene and Pleistocene Tehama Formation and the Pliocene Tuscan Formation. These widespread and thick formations are important in aquifer storage and well water supply.

Tehama Formation

The Tehama Formation is the primary water source of the study area. Groundwater in this formation occurs under semi-confined to confined conditions. The widespread occurrence and relatively higher thickness allow this formation to supply water to most of the wells in the study area. Moderately compacted, thickly bedded sandstone and siltstone layers derived from the Coast Ranges result in characteristically low to moderate permeability. However, thinner lenses of sand and gravel result in local, high permeability zones.

Potential for groundwater recharge and storage is limited by the geographic irregularity of these permeable lenses. Well yields are typically moderate for deeper wells. However, well yields vary from high to low due to variable permeability zones. Generally, wells located near the Stony Creek Fan have higher yields than those located to the south. The Tehama Formation has a higher concentration of more permeable coarse material in the vicinity of the alluvial fan deposits. Variations in well yields indicate the north to south decrease in grain size.

Tuscan Formation

The Tuscan Formation serves as the primary source of groundwater on the east side of the Sacramento River. In the study area, these deposits occur at depths in excess of the depths of the most of the existing domestic and irrigation wells.

Moderately permeable to highly permeable volcanic sediments are hydraulically confined by layers of tuff breccias and clays within the Tuscan formation. The low permeability lahar deposits of Unit C serve as confining beds for the underlying older Tuscan Units A and B. Although Unit C contains permeable volcanic sandstone and conglomerate interbeds, this unit is characterized by an overall low yield of water to wells. Units A and B are much more coarse-grained than the overlying Unit C, causing them to be the primary water-bearing zones of eastern Sacramento Valley.

SALINE AQUIFER SYSTEM

The saline aquifer system lies beneath the fresh water aquifer. The base of the fresh water aquifer is defined by the contact between continental deposits and pre-Pliocene marine deposits. The marine deposits present in the study area subsurface include the Miocene Neroly Formation, the Miocene and Oligocene Upper Princeton Valley Fill, the Eocene Lower Princeton Submarine Valley Fill, and the Cretaceous Great Valley Sequence.

HISTORIC GROUNDWATER CONDITIONS

DWR Bulletin 118-6 provided historic water level contours for 1912 and 1961 in the Sacramento Valley. The 1912 pre-development conditions water level in the study area varied from 80 feet to 300 feet above mean sea level. The direction of groundwater flow was generally in southeast direction. Bulletin 118-6 also provided a water level difference map between the years 1961 and 1912, which showed no difference in almost the entire study area except a 10 feet rise in groundwater level near the town of Orland.

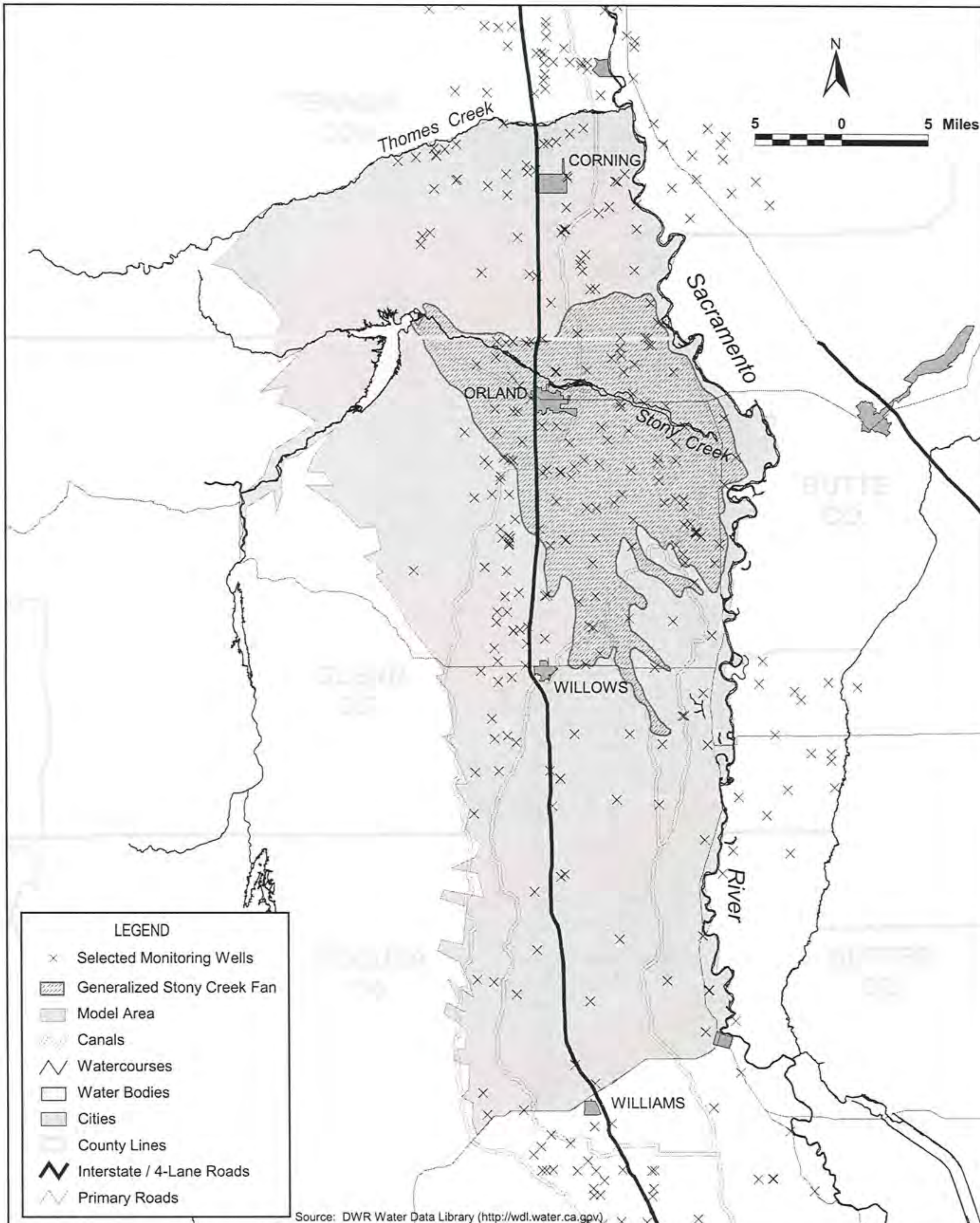
DWR has been collecting water level data at different monitoring wells in the study area for a number of years. The locations of selected past and current monitoring wells in the study area are shown in Figure 2.2. There are about 191 wells (18N–22N) in the Glenn County, 40 wells (15N–18N) in the Colusa County, and 203 wells (23N–25N) in the Tehama County that are monitored intermittently. The period of record spans from 1921 to current. Table 2.2 shows the frequency of water level measurements at wells for the 3 counties in the study area. This data is used to develop historic groundwater level contours for different periods and are presented in Figures 2.3 to 2.12. It should be noted that there are few monitored wells in the area northwest of Willows.

The fall of 1969 water surface elevation is shown in Figure 2.3. The recorded data for October 1969 were used to develop this contour map. During the month of October, the water surface elevations are at their lowest following high groundwater pumping in summer months and prior to aquifer recharge during rainy winter months.

The contour map for March 1974 (Figure 2.4) shows water level conditions prior to 1976-77 drought and prior to Tehama-Colusa Canal deliveries. In general, there is little change from the October 1969 groundwater levels, except small decreases in groundwater levels in some areas.

The contour map for March 1977 (Figure 2.5) map shows water level conditions during a historical dry period. Water levels show a decrease in elevations across the study area in response to the drought conditions. The October 1977 water level contour map (Figure 2.6) shows the impact of dry conditions compounded by increased groundwater pumping during the summer months.

Following the 1976 to 1977 drought conditions, additional surface water was delivered to the model area via the Tehama-Colusa Canal. This, along with a historical wet period, enabled



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Monitoring Well Locations

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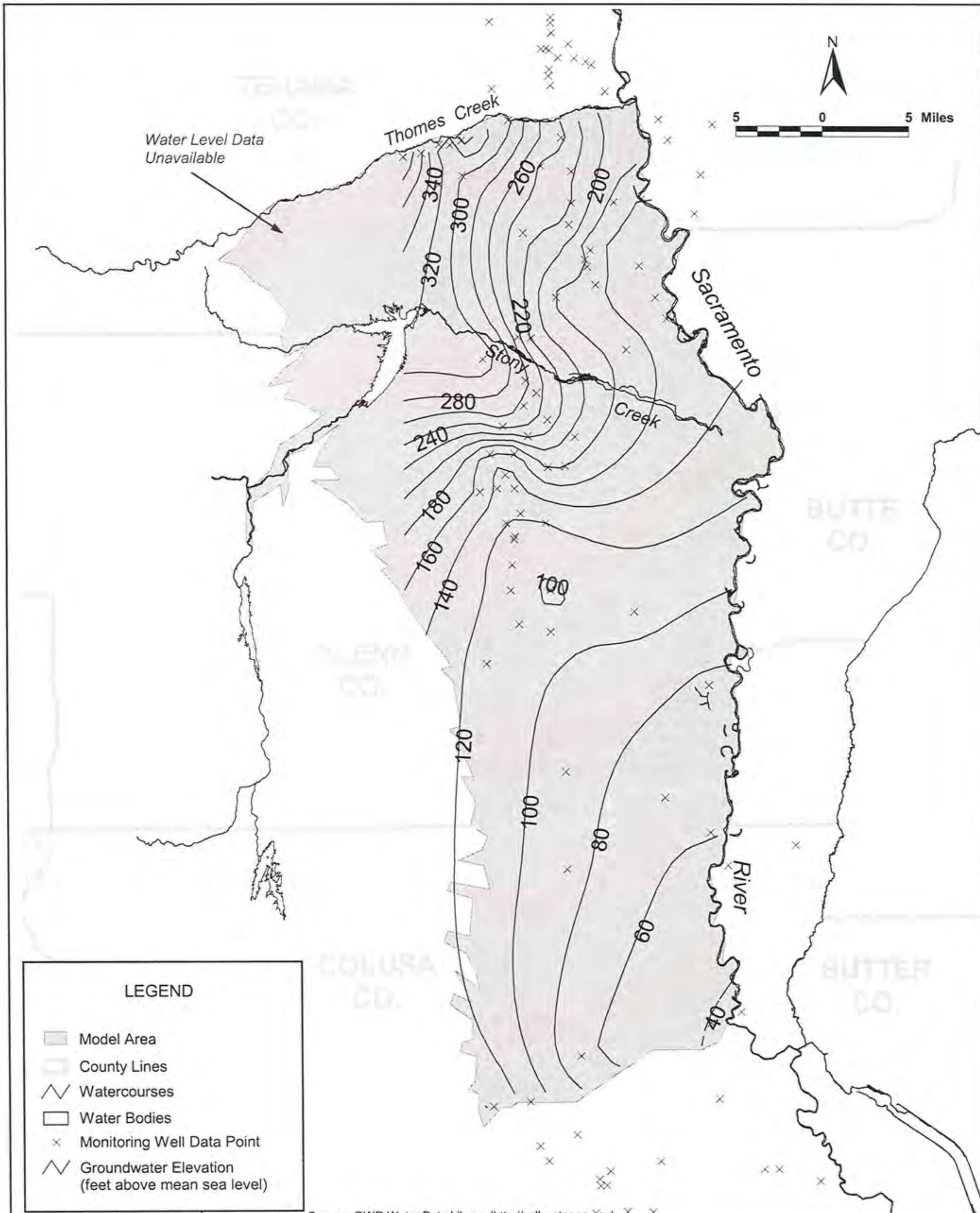
FIGURE 2.2

Table 2.2
Monitoring Well Measurements per Year

Year	Number of Wells Measured	Number of Measurements
1921	2	2
1922	1	1
1923	9	127
1924	7	134
1925	7	165
1926	10	159
1927	10	163
1928	12	167
1929	42	200
1930	43	200
1931	42	201
1932	37	177
1933	39	183
1934	35	35
1935	0	0
1936	33	33
1937	31	31
1938	1	1
1939	32	32
1940	27	27
1941	31	79
1942	29	347
1943	30	253
1944	30	269
1945	30	118
1946	44	512
1947	99	399
1948	121	476
1949	100	295
1950	115	247
1951	142	267
1952	159	430
1953	176	714
1954	158	457
1955	114	365
1956	115	333
1957	140	249
1958	174	536
1959	191	611
1960	191	620
1961	197	624
1962	204	765

Table 2.2
Monitoring Well Measurements per Year

Year	Number of Wells Measured	Number of Measurements
1963	220	832
1964	223	918
1965	254	948
1966	256	1069
1967	268	1129
1968	261	1149
1969	257	1154
1970	255	1138
1971	252	1169
1972	249	976
1973	278	1019
1974	246	869
1975	268	953
1976	279	1028
1977	279	1072
1978	281	1060
1979	284	816
1980	281	789
1981	276	802
1982	270	784
1983	265	766
1984	261	695
1985	260	821
1986	260	814
1987	262	775
1988	274	785
1989	272	853
1990	281	943
1991	281	1320
1992	286	897
1993	288	983
1994	286	989
1995	274	953
1996	290	766
1997	259	541
1998	250	505
1999	249	640
2000	277	527



Source: DWR Water Data Library (http://wdl.water.ca.gov)

RIME Water Resources & Information Management Engineering, Inc.	STONY CREEK FAN CONJUNCTIVE WATER MANAGEMENT PROGRAM	MARCH 2003
	Fall 1969 Groundwater Elevation Contour Map	FIGURE 2.3
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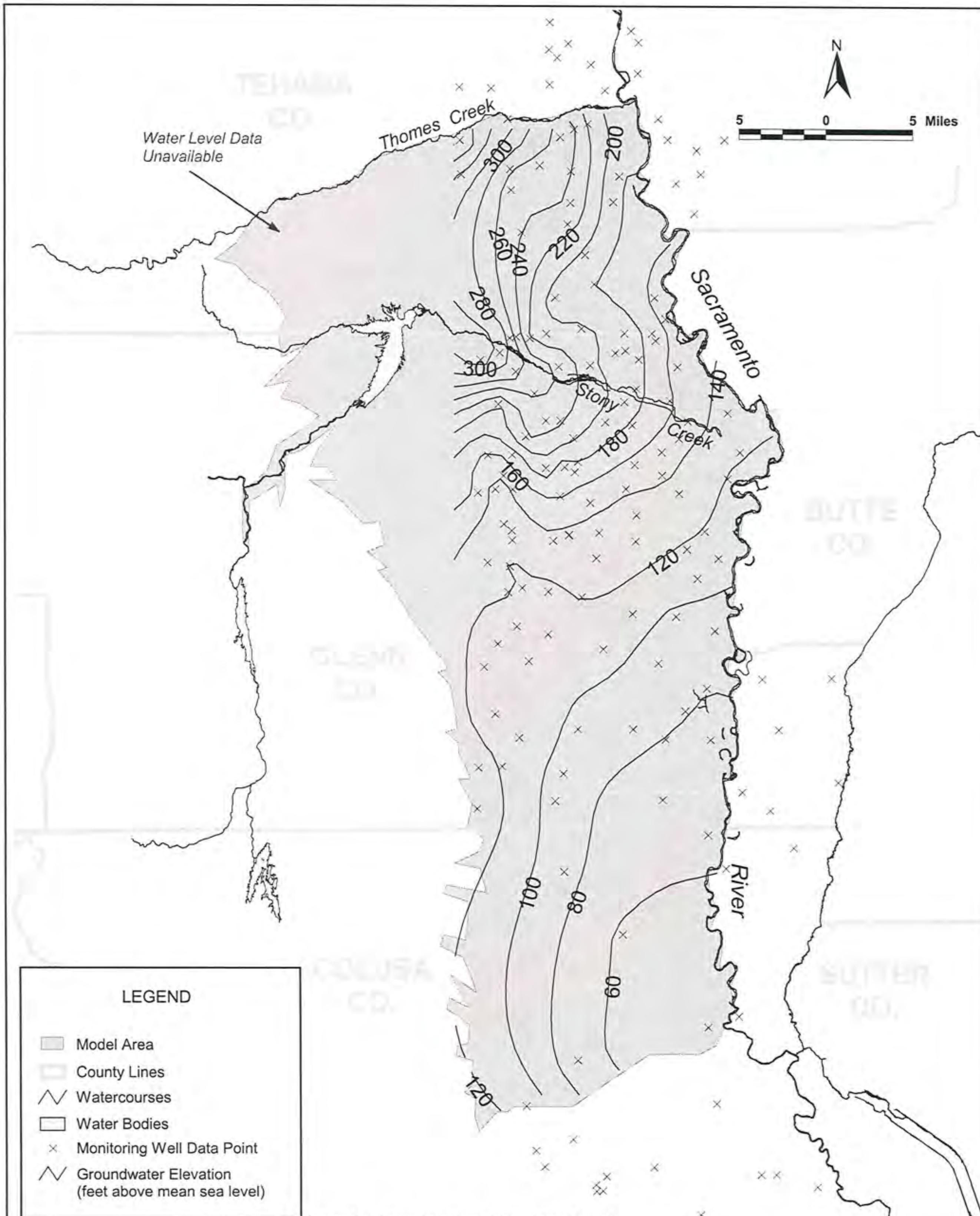

Source: DWR Water Data Library (http://wdl.water.ca.gov)

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Spring 1974 Groundwater Elevation Contour Map

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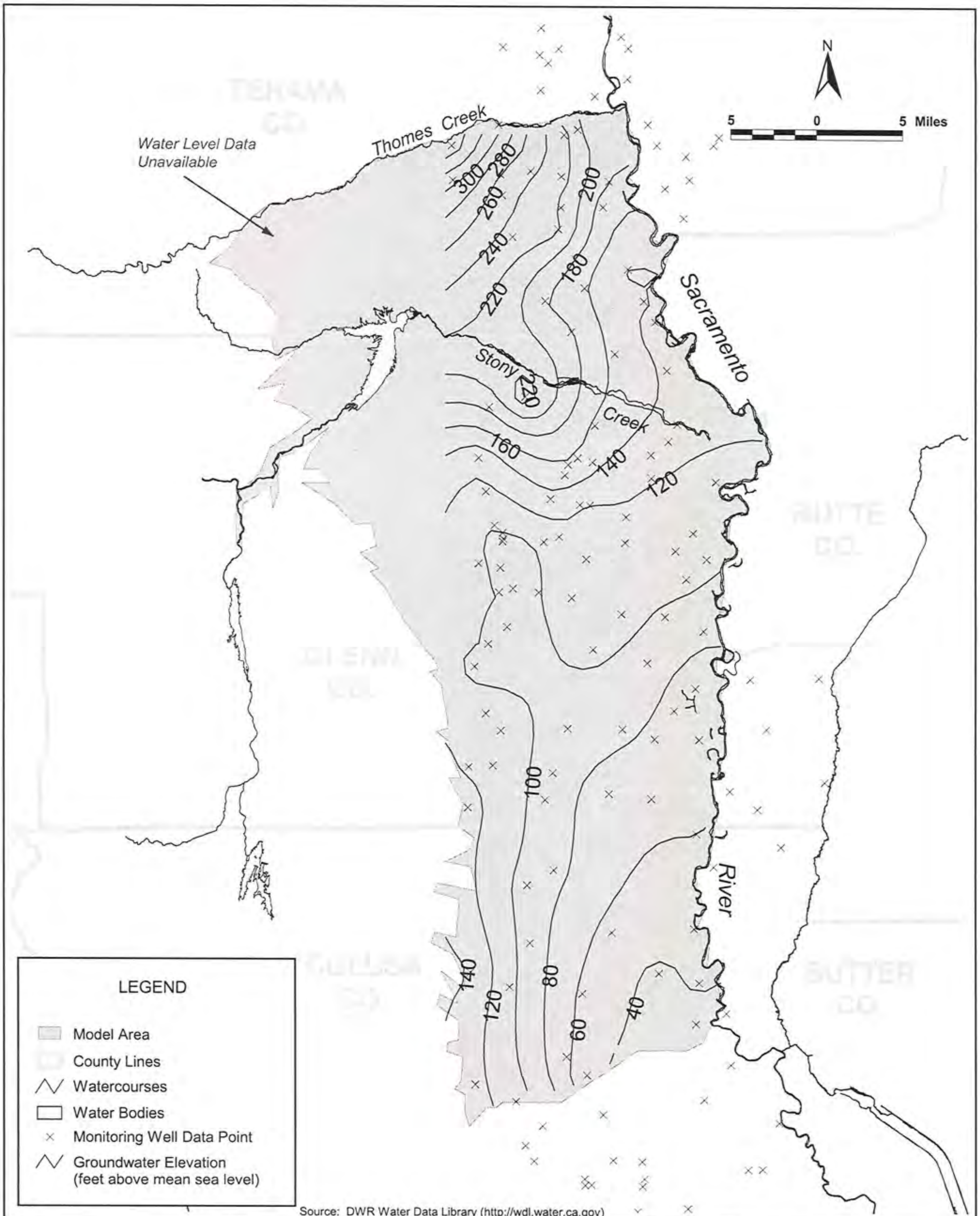
FIGURE 2.4



Source: DWR Water Data Library (http://wdl.water.ca.gov)

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Spring 1977 Groundwater Elevation Contour Map

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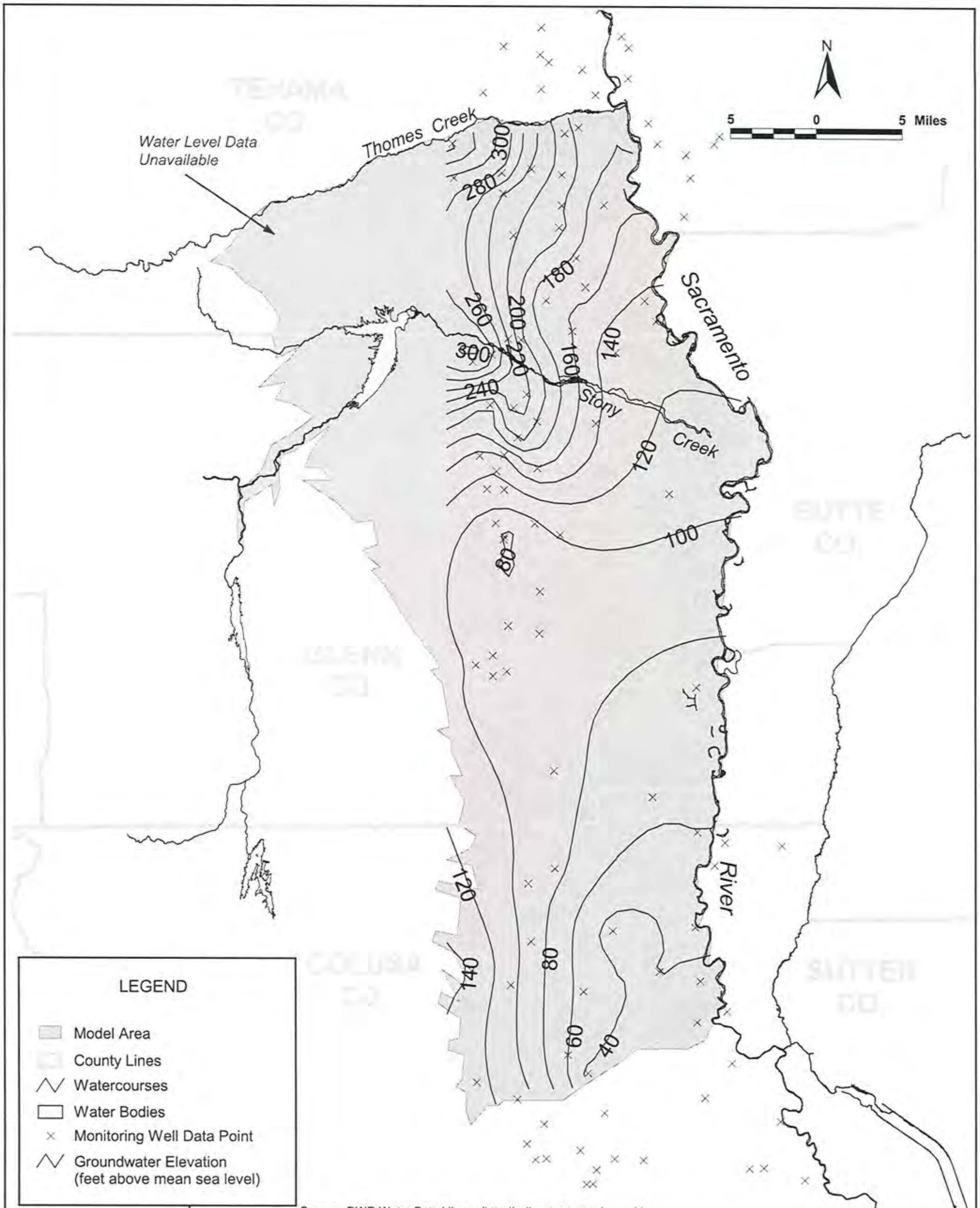
FIGURE 2.5



Source: DWR Water Data Library (http://wdl.water.ca.gov)

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Fall 1977 Groundwater Elevation Contour Map

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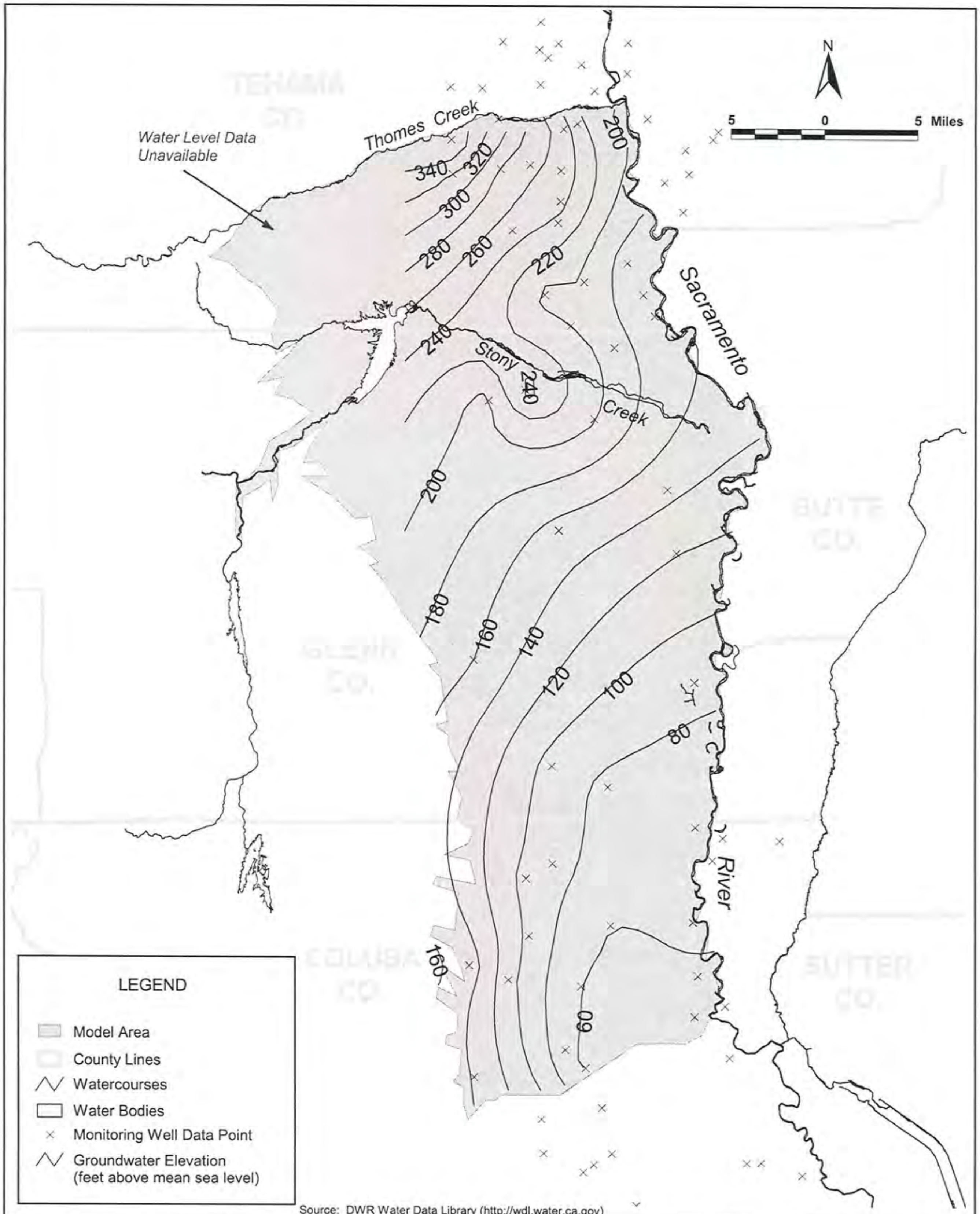
FIGURE 2.6



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Spring 1983 Groundwater Elevation Contour Map

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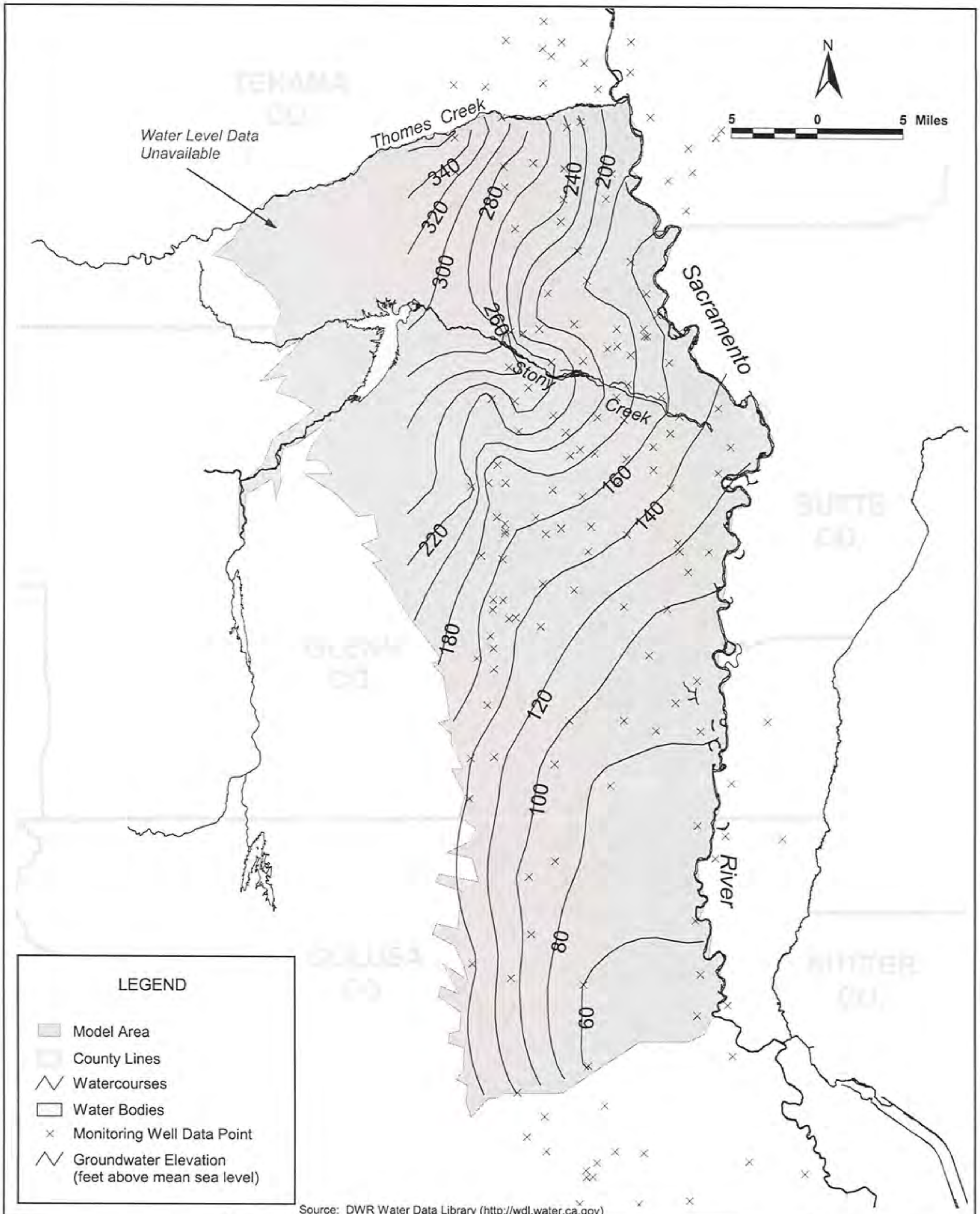
FIGURE 2.7



Source: DWR Water Data Library (http://wdl.water.ca.gov)

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Spring 1986 Groundwater Elevation Contour Map

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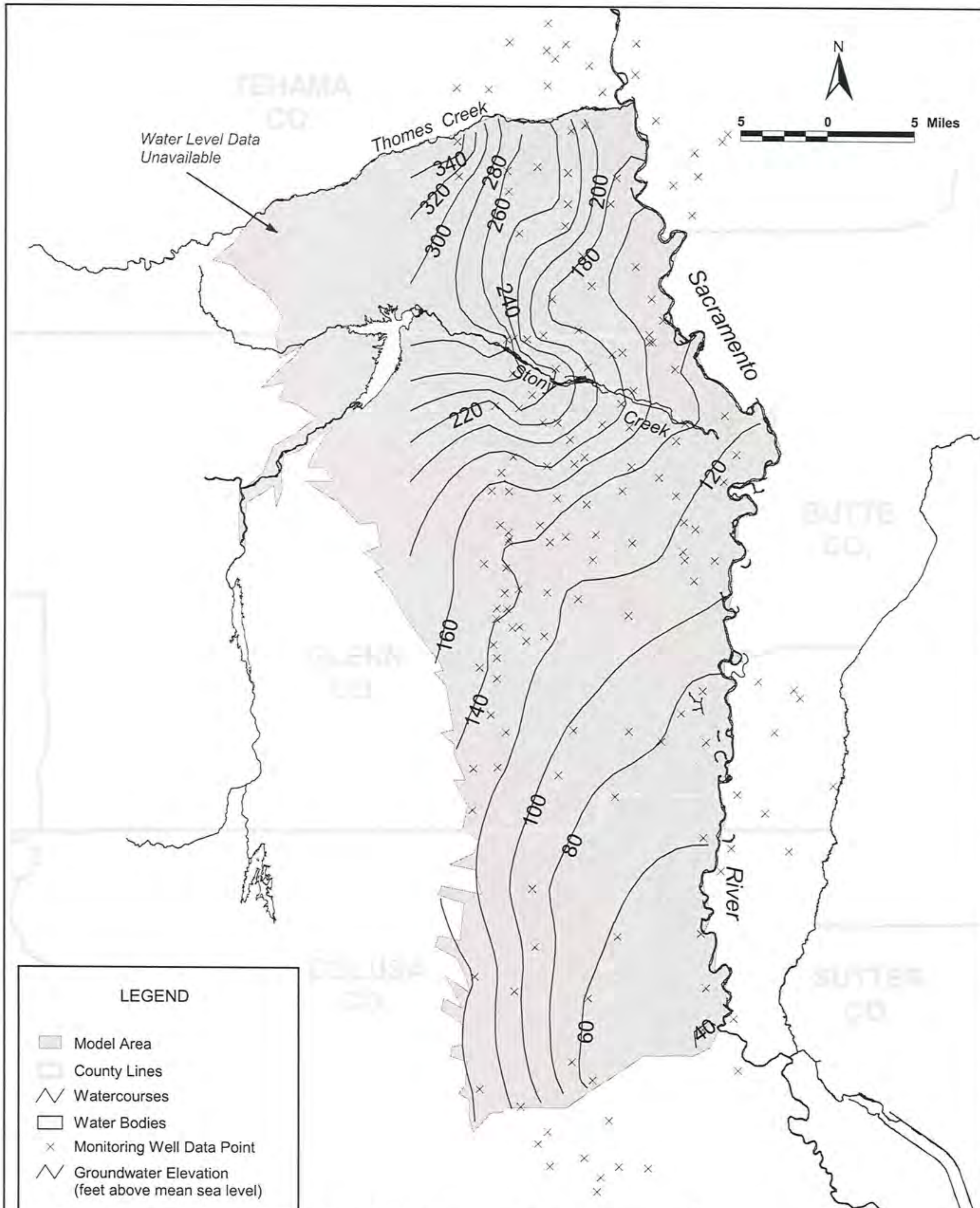
FIGURE 2.8



Source: DWR Water Data Library (http://wdl.water.ca.gov)

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Spring 1992 Groundwater Elevation Contour Map

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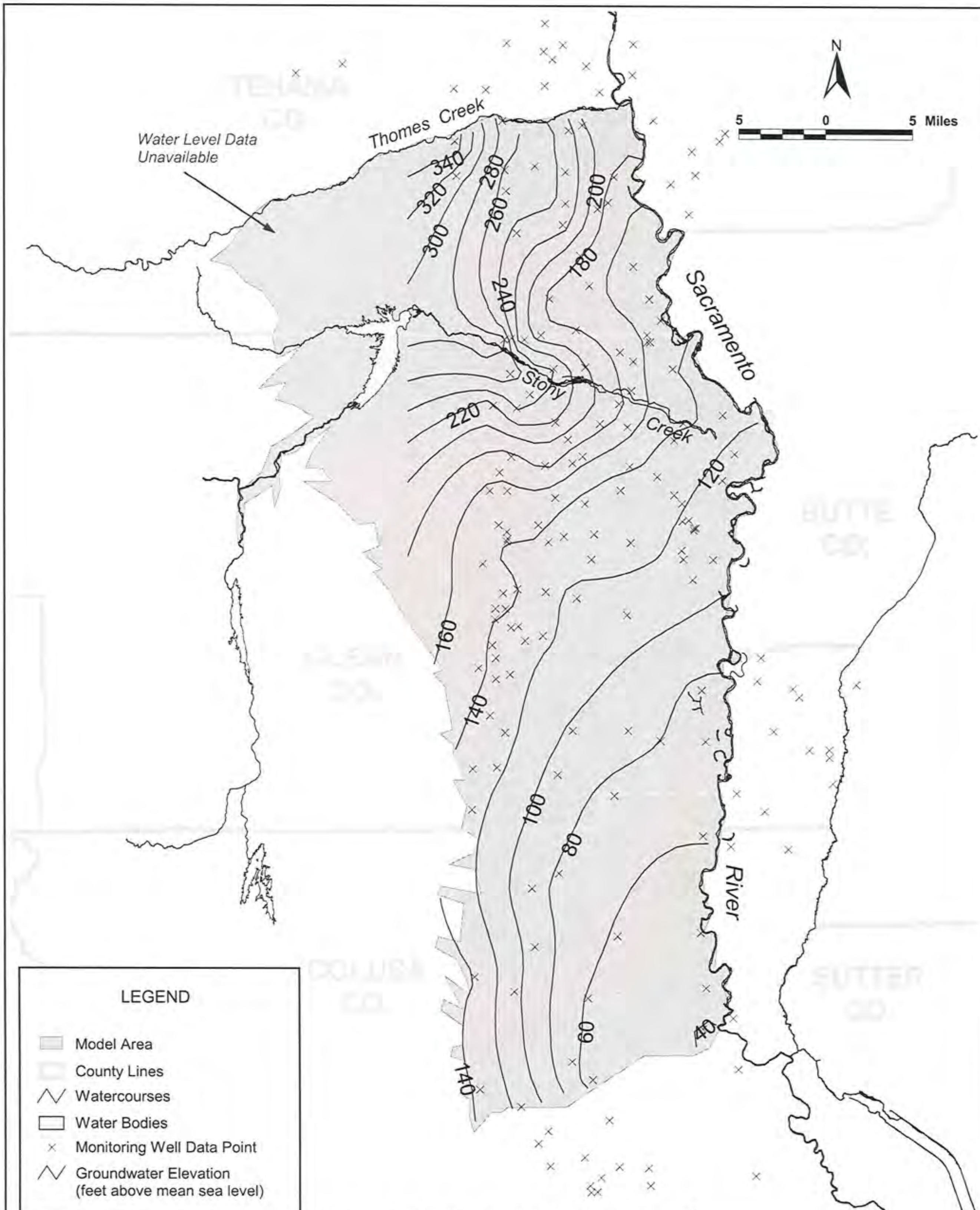
FIGURE 2.9



Source: DWR Water Data Library (http://wdl.water.ca.gov)

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MARCH 2003

Fall 1992 Groundwater Elevation Contour Map

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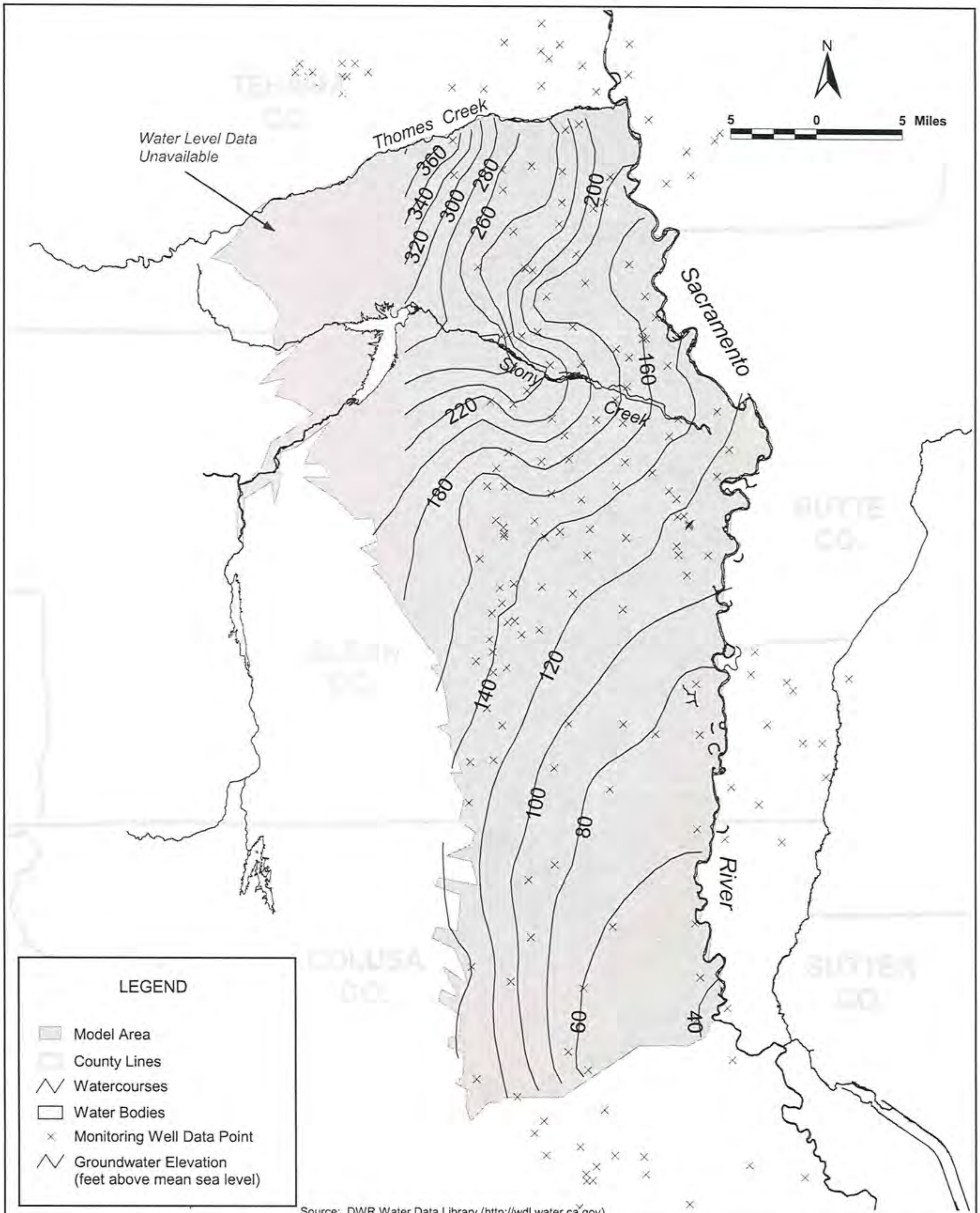
FIGURE 2.10



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Spring 1994 Groundwater Elevation Contour Map

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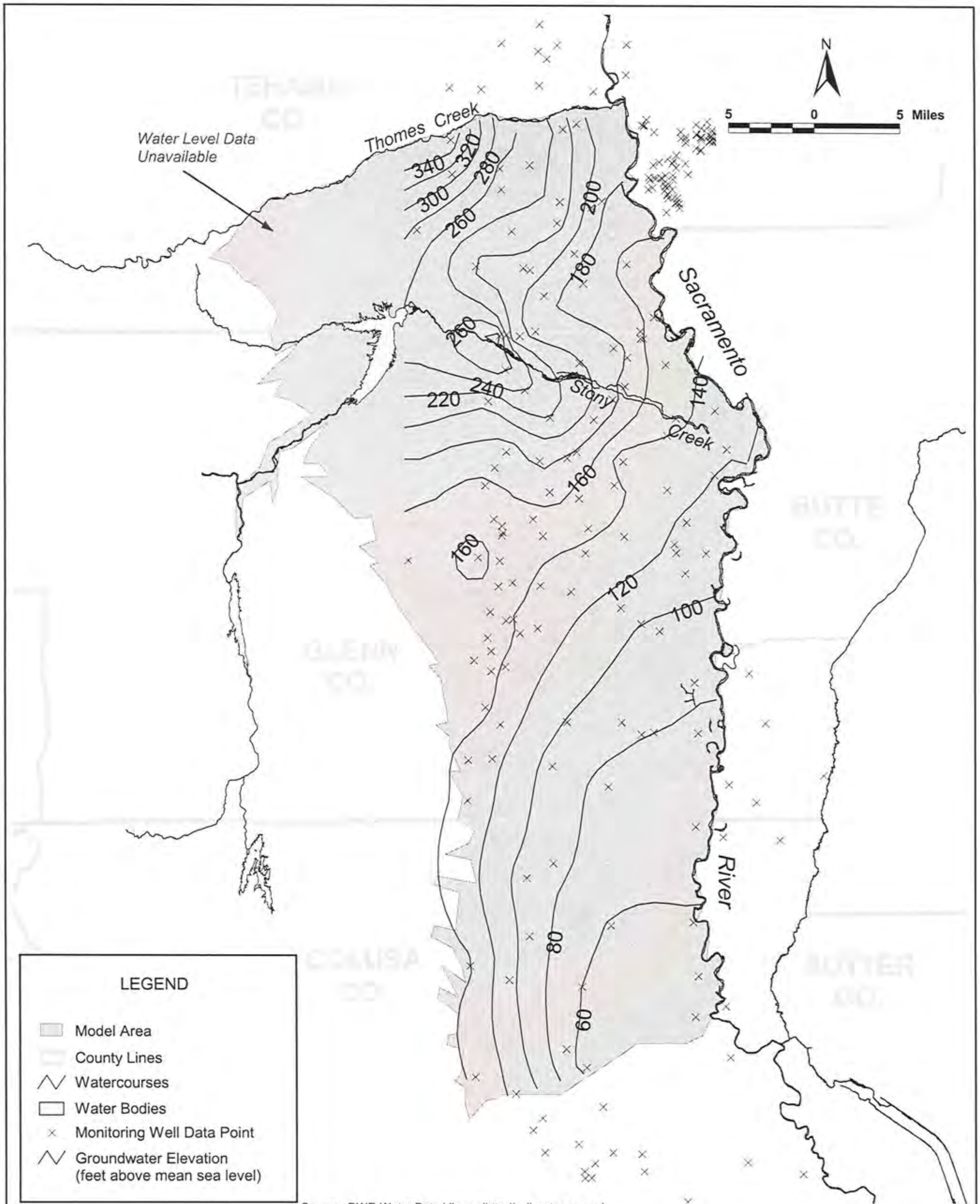
FIGURE 2.11



Source: DWR Water Data Library (http://wdl.water.ca.gov)

RIME Water Resources & Information Management Engineering, Inc.	STONY CREEK FAN CONJUNCTIVE WATER MANAGEMENT PROGRAM **Spring 2000 Groundwater Elevation Contour Map** **DRAFT**	MARCH 2003 FIGURE 2.12

groundwater surface elevations to increase substantially. The March 1983 water level contour map (Figure 2.7) shows significant increases in elevations as compared to the 1977 maps. The 1983 map also shows increases in elevations as compared to the October 1969 contour map indicating full recovery of the aquifer to pre-drought conditions.

The March 1986 water level contour map (Figure 2.8) shows a slight decrease from the 1983 conditions. This map was constructed to evaluate water level conditions previous to the 1987-1992 drought.

The March 1992 water level contour map (Figure 2.9) shows water level conditions at the end of the 1987-1992 drought. Groundwater surface elevations decreased in response to the drought conditions. The October 1992 water level contour map (Figure 2.10) shows additional decreases resulting from increased summer groundwater pumping.

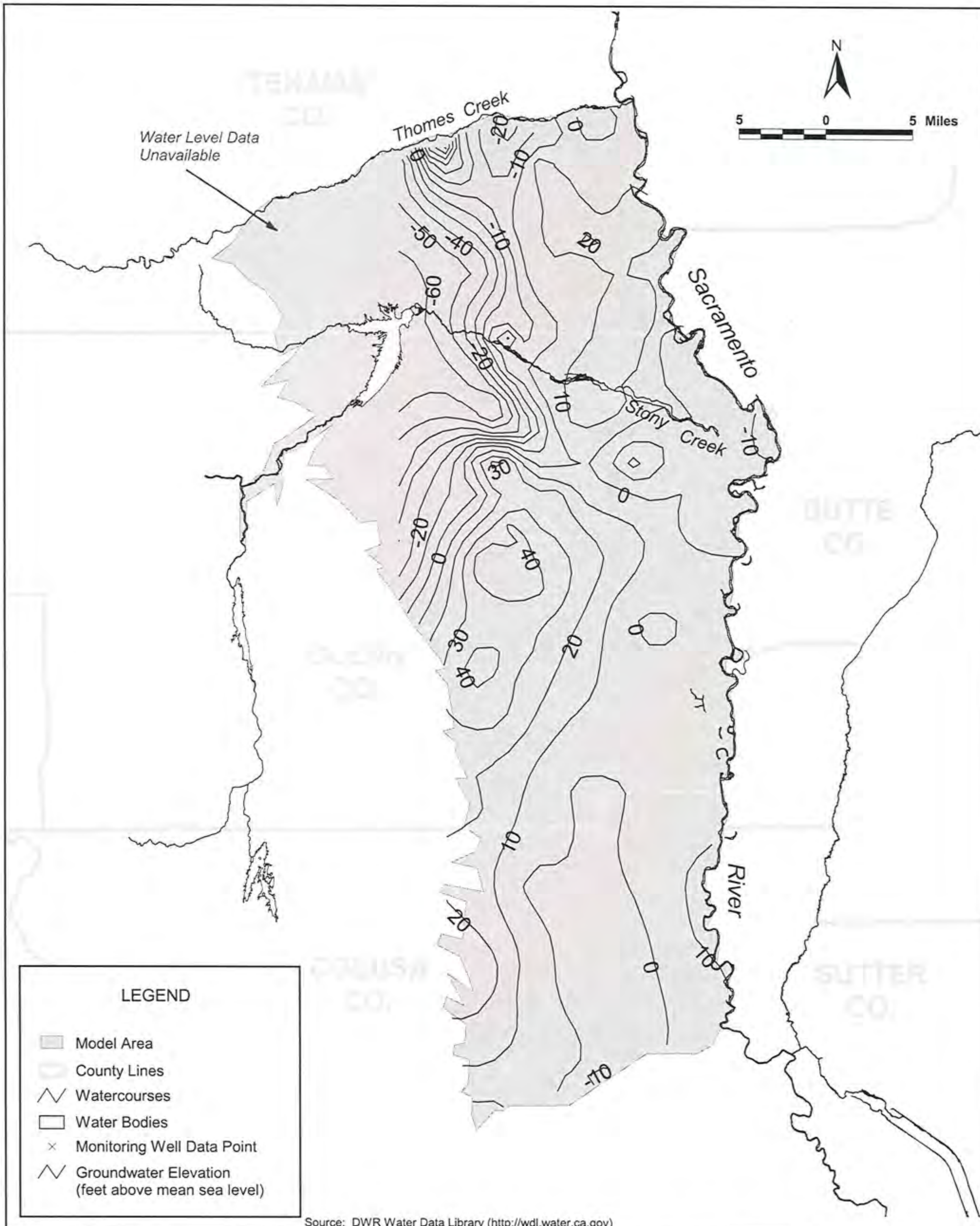
The March 1994 water level contour map (Figure 2.11) shows recovery of the aquifer with increasing groundwater surface elevations.

The March 2000 water level contour map (Figure 2.12) shows current groundwater surface elevation conditions. This map shows a slight increase in elevations compared to the March 1994 conditions.

The overall trend of the groundwater conditions is relatively stable. Although the groundwater surface elevation maps show declines in response to drought conditions, the contour maps demonstrate full aquifer recovery. This general trend is demonstrated by the groundwater surface elevation difference contour map (Figure 2.13) showing the change in elevations from the October 1969 conditions to the March 2000 conditions. In many of the areas of the basin, there is little or no change, while other portions, specifically in the area of the Stony Creek fan, groundwater levels increased by as much as 30 feet. This trend also holds true when comparing the 1969 map with the March 2000 map.

Well Hydrograph Analysis

In addition to evaluating contour maps, individual well hydrographs were analyzed for groundwater level trends. Specific well information was obtained from the Department of Water Resources, Northern District, Sacramento Valley Groundwater Basin groundwater level monitoring program. Historical water surface elevations are available in published county reports and DWR website postings. Data contained in this database is current through water level measurements made in the Fall of 2002. Six wells, as shown in Figure 2.14, are chosen to illustrate historical groundwater level trends in the model area. These trends are discussed in the following section.



Source: DWR Water Data Library (http://wdl.water.ca.gov)

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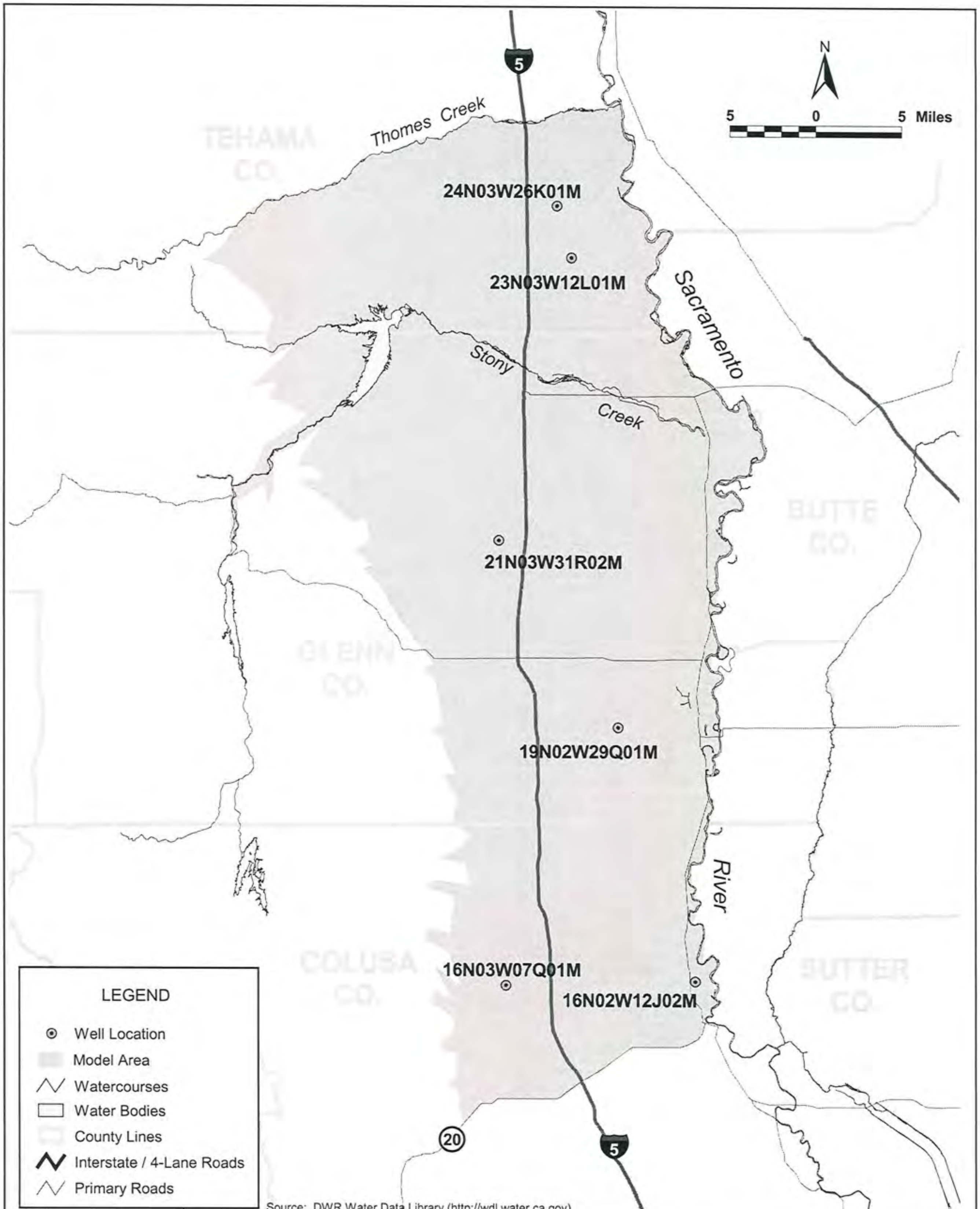
STONY CREEK FAN CONJUNCTIVE WATER MANAGEMENT PROGRAM

Groundwater Elevation Difference Contour Map
Spring 2000 Minus Fall 1969
DRAFT

MARCH 2003

FIGURE 2.13



Source: DWR Water Data Library (http://wdl.water.ca.gov)

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Well Locations of Selected Hydrographs

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FIGURE 2.14

Tehama County

DWR and USBR have been collecting groundwater level data on 138 wells beginning in the late 1920's through the Tehama groundwater monitoring program. The information collected previous to 1993 is summarized in *Groundwater Levels in the Sacramento Groundwater Basin, Tehama County*. Of the 138 wells in the Tehama County monitoring program, 43 wells are located within the model area

In general, the historical groundwater level in Tehama County is constant. This is depicted in hydrographs for wells 23N03W12L01M and 24N03W26K01M, shown respectively in Figure 2.15 and Figure 2.16. Some wells in the area may show groundwater level declines reflecting the 1976-77 and 1987-92 drought periods. However, all water levels in Tehama County recovered from these droughts.

Glenn County

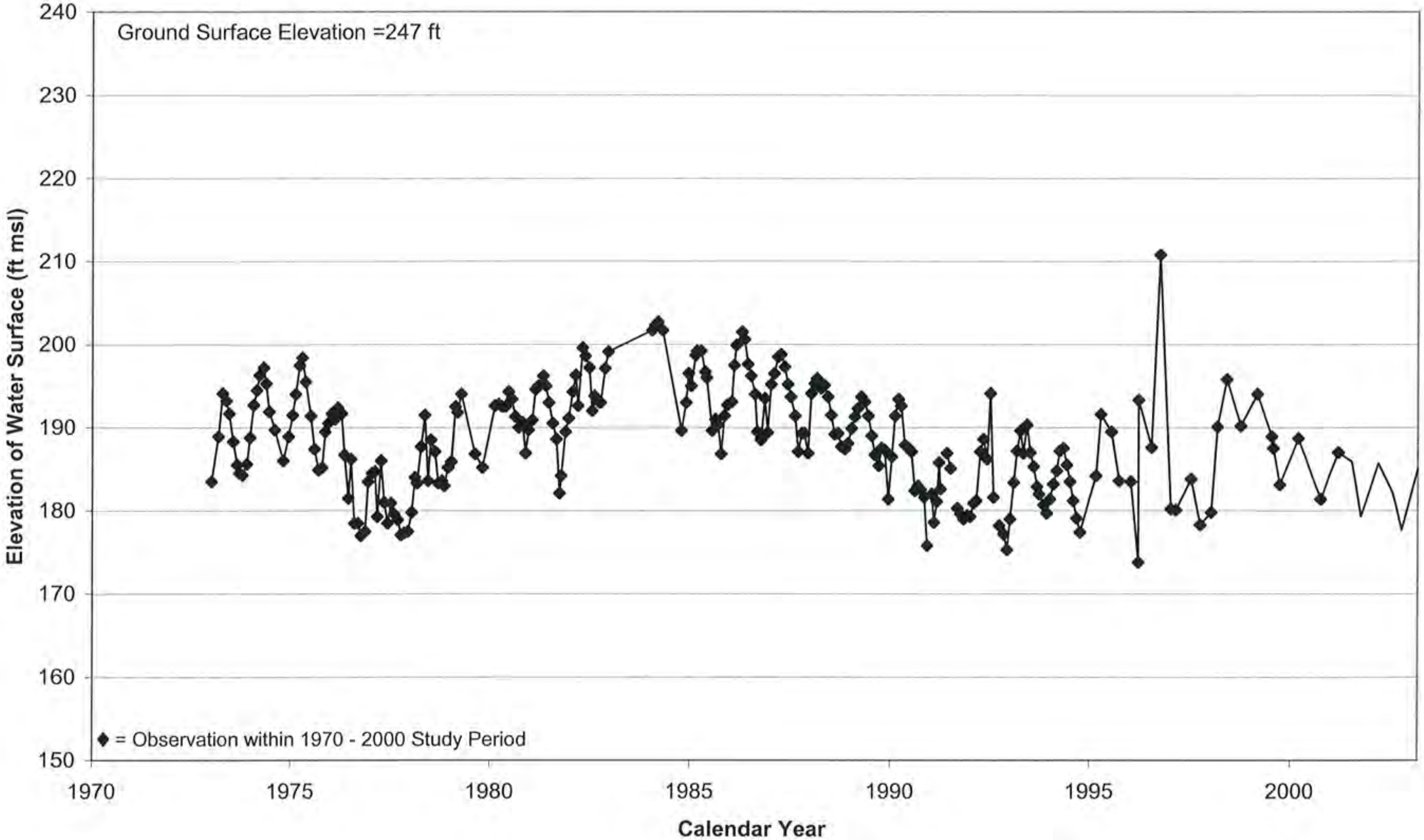
There are two groundwater monitoring programs in Glenn County. The first is similar to the groundwater monitoring program in Tehama County. Under this program, groundwater levels in Glenn County have been collected by DWR and USBR since the mid 1920's and continuing to 1997 and are summarized in *Groundwater Levels in the Sacramento Valley Groundwater Basin, Glenn County*. This study monitors 174 wells in Glenn County. The second groundwater monitoring program is the Basin Management Objective program. The information collected in this study is summarized in *Basin Management Objective (BMO) For Groundwater Surface Elevations in Glenn County, California*. There are 50 wells in this program, 42 monitored by DWR and 8 monitored by independent water districts.

In general, the current groundwater level for Glenn County is unchanged from historical groundwater levels, depicted in the well hydrograph for 19N02W29Q01M shown in Figure 2.17. The 1976-777 and 1987-92 droughts are reflected in many hydrographs in the area, both droughts followed by a recovery of the aquifer to pre-drought conditions. Surface water supplied by the Tehama-Colusa Canal was introduced to many parts of Glenn County near the end of the 1976-77 drought. This reduced the need for groundwater pumping as reflected in the rise in groundwater level around this time at well 21N03W31R02M (Figure 2-18).

Colusa County

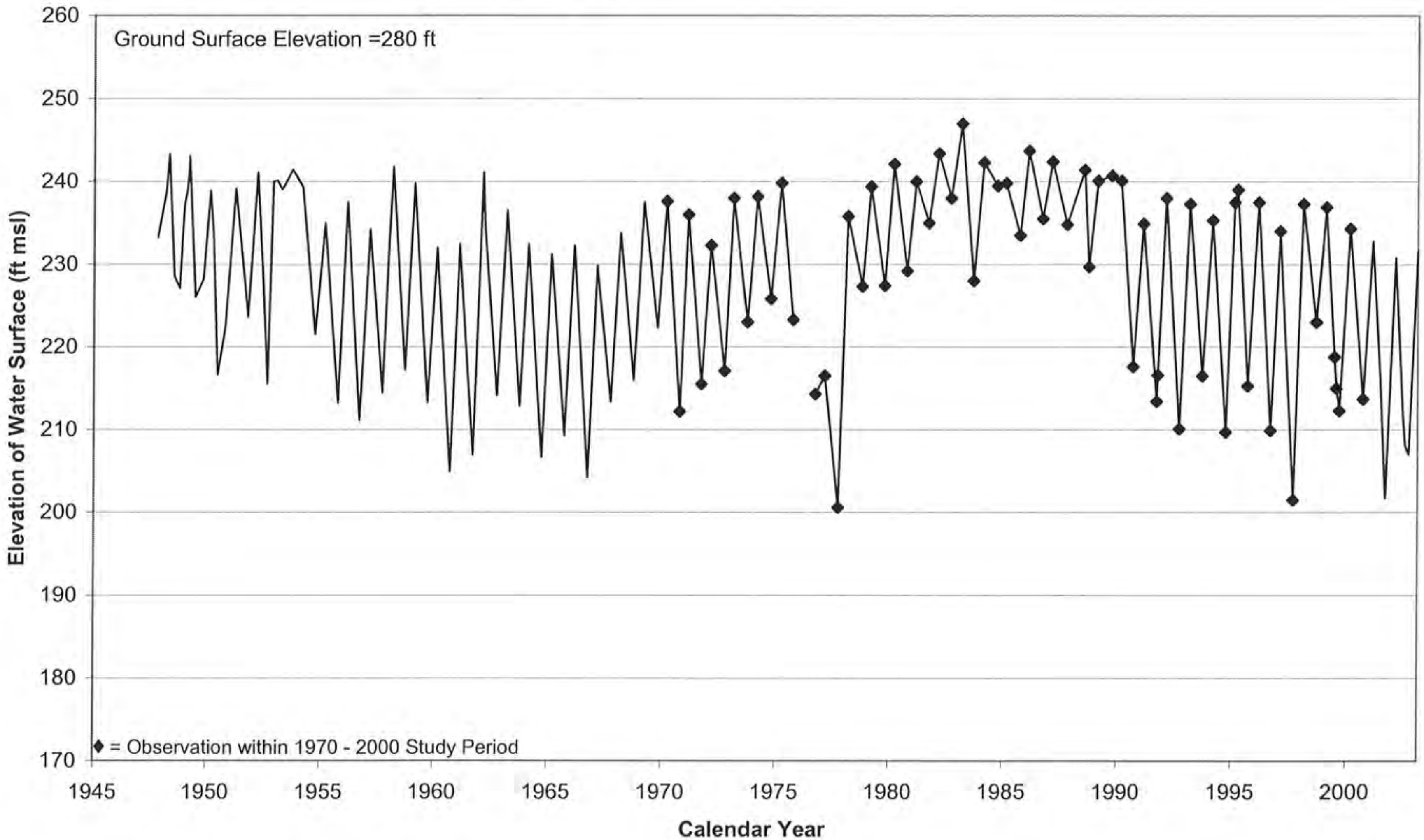
The report *Groundwater Levels in the Sacramento Valley Groundwater Basin, Colusa County*, summarizes the data collected by DWR and USBR in Colusa County from the late 1920's to

Figure 2.15
Hydrograph for Well 23N03W12L01M



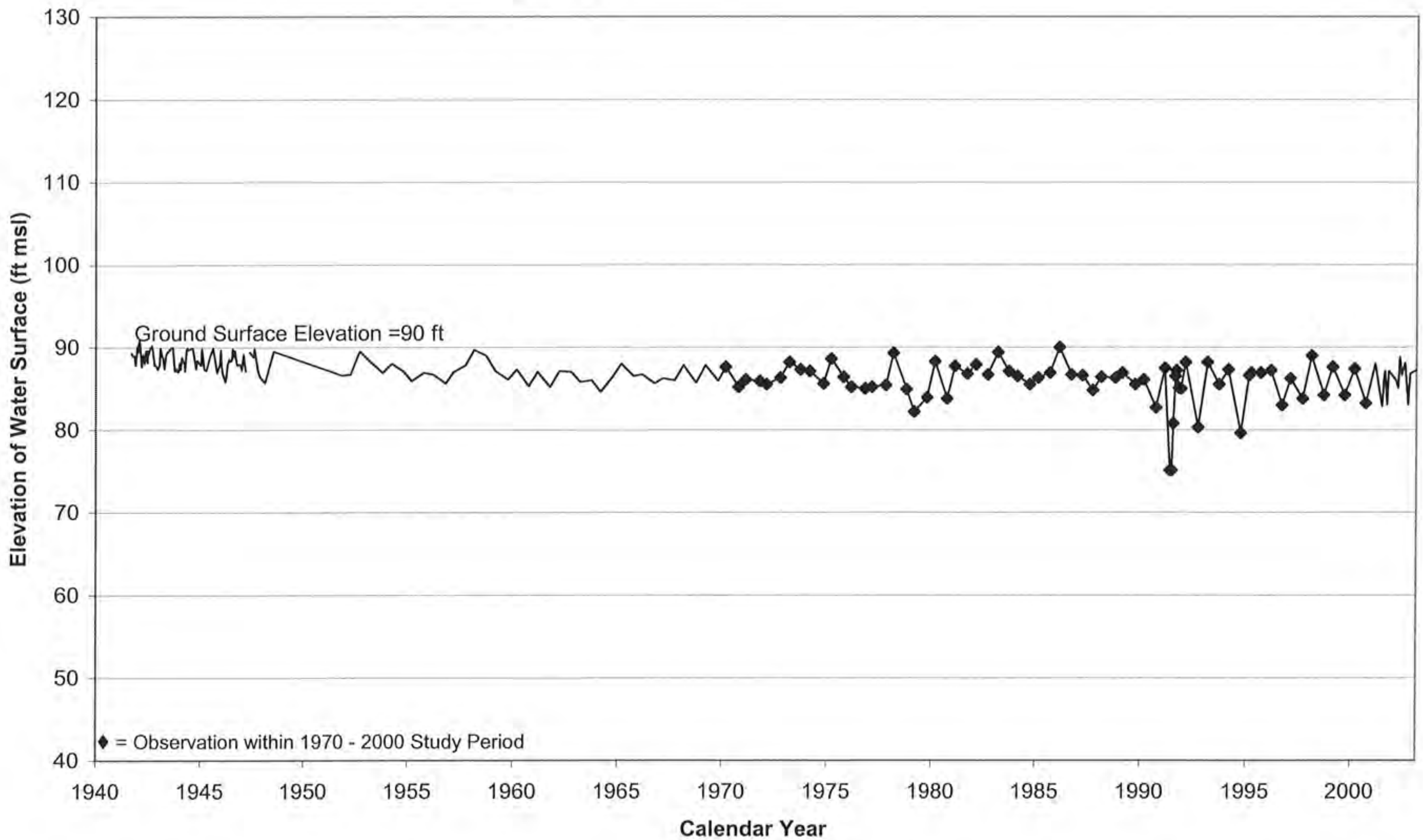
Source: DWR Water Data Library

Figure 2.16
Hydrograph for Well 24N03W26K01M



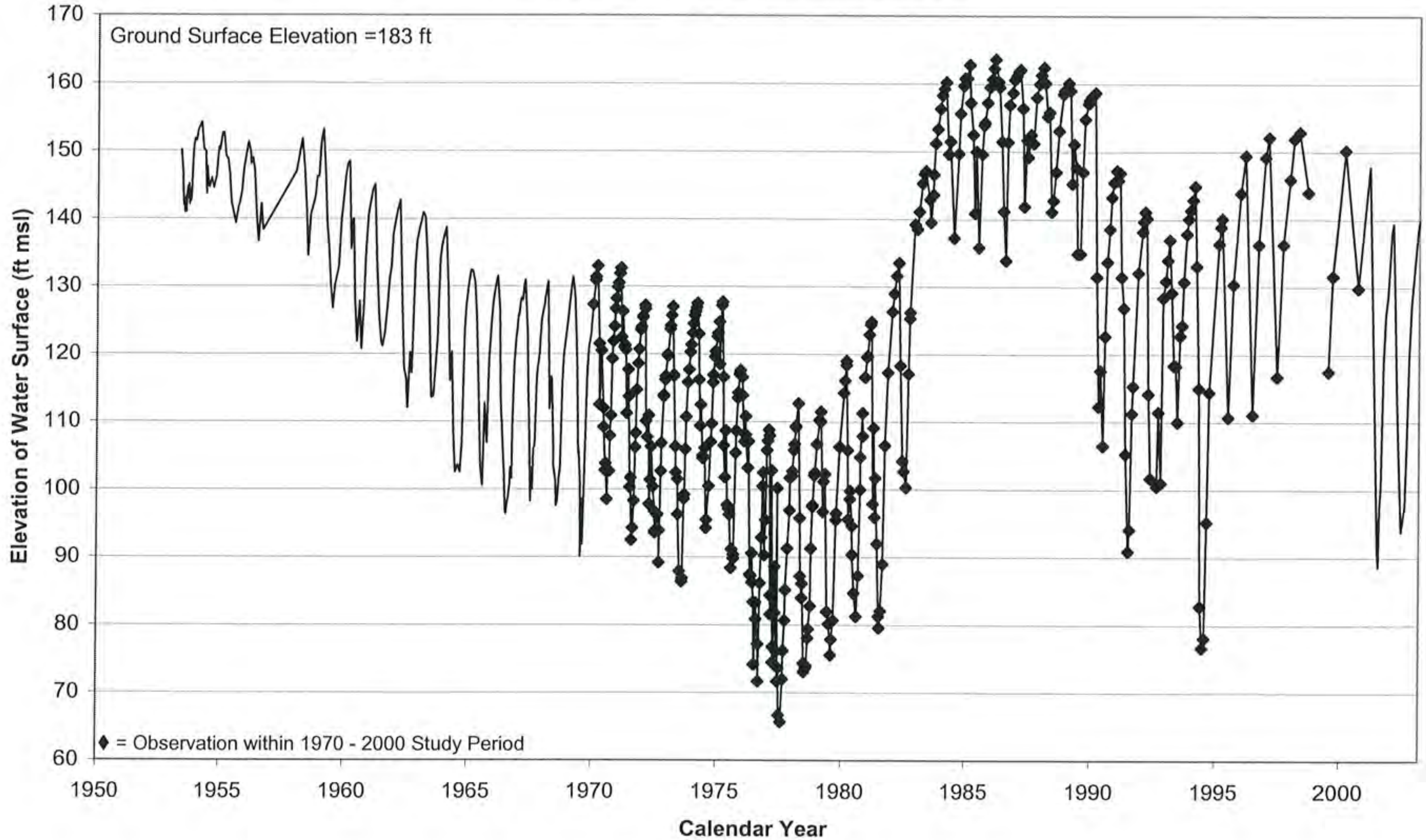
Source: DWR Water Data Library

Figure 2.17
Hydrograph for Well 19N02W29Q01M



Source: DWR Water Data Library

Figure 2.18
Hydrograph for Well 21N03W31R02M



Source: DWR Water Data Library

1995. There are 114 wells in this groundwater monitoring program, 23 of which are located within the model area.

The historical groundwater level trend in Colusa County is constant, as depicted in the hydrographs for wells 16N02W12J02M and 16N03W07Q01M, shown respectively in Figure 2.19 and Figure 2.20. Some wells in the county may reflect the 1976-77 and 1987-92 drought periods demonstrated by declines in water level, followed by full recovery.

SOILS

The processes that control the percolation of precipitation, runoff, and applied water are tied to soil properties. Published soil surveys for Glenn County, Colusa County, and Tehama County by the NRCS were reviewed for the Stony Creek Fan model area. The information contained in these surveys provides data necessary to classify the model elements based on hydrologic soil type. Inclusion of this information into the SCFIGSM enables the model to capture the influence of the ground surface and the soil horizon on aquifer recharge.

The National Resource Conservation Service (NRCS), formerly the Soil Conservation Service, has published three soil surveys in the study area for Colusa County (1907), Glenn County (1965), and Tehama County (1967). These soil surveys are compilations of a series of aerial photographs containing soil type boundaries, and tables and text detailing the soil types.

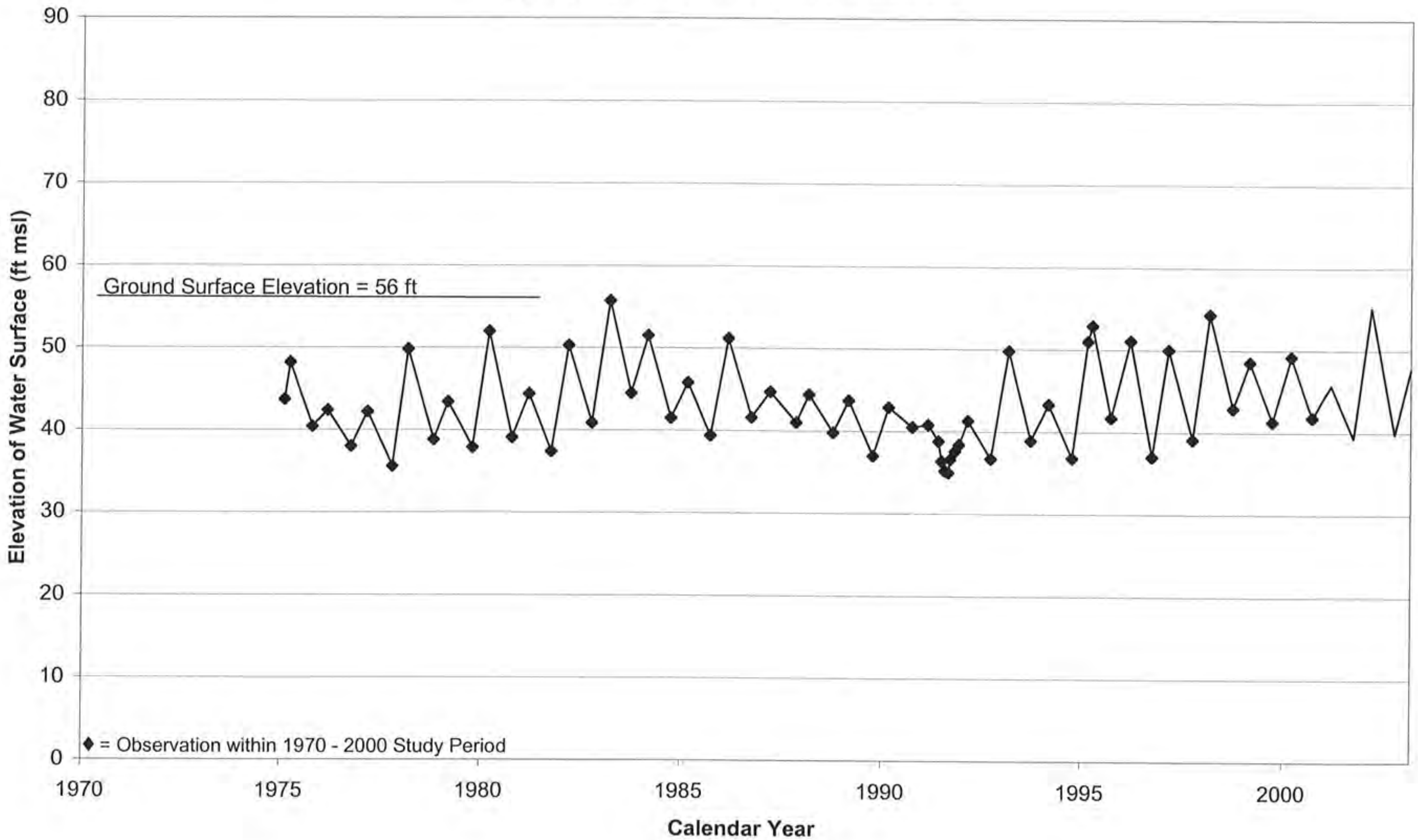
The NRCS is developing a Soil Survey Geographic Database (SSURGO) containing digital copies of original soils survey maps. The SSURGO mapping scales generally range from 1:12,000 to 1:63,000. A SSURGO database for Colusa County is available. Tehama County and Glenn County do not have a SSURGO database at this time.

HYDROLOGIC SOIL GROUPS

For the purposes of hydrologic analysis, soil types can be classified into four hydrologic soil groups, Groups A-D. This categorization system is based on estimates of runoff potential, infiltration rates, water intake, and water transmission of a saturated soil profile, with Group A having the lowest runoff potential and D having the highest.

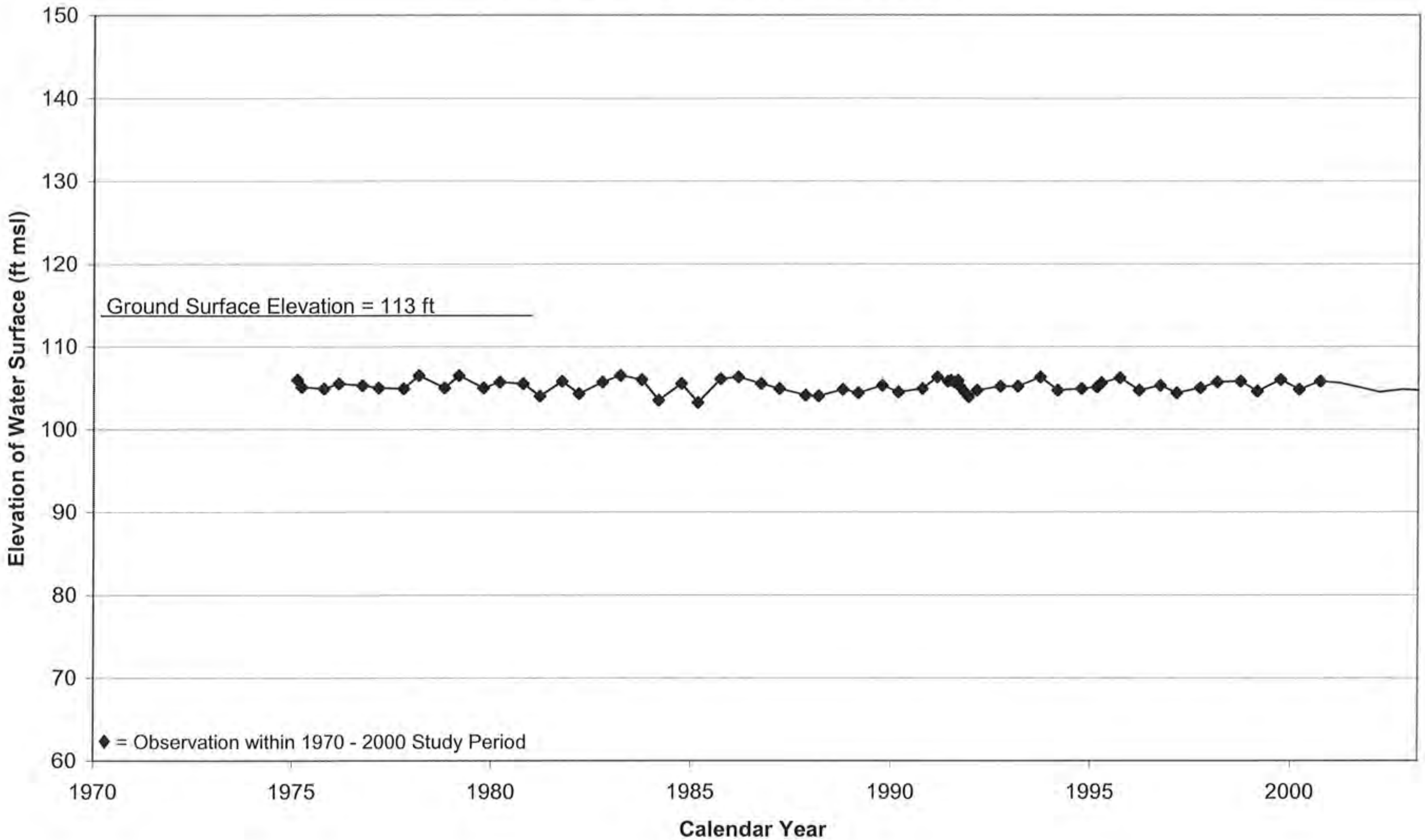
Predominant soil group and geomorphic feature associations of the study area are summarized in Table 2.3 along with the corresponding hydrologic soil groups. Typical hydrologic soil groups are discussed for the following geomorphic features: foothills, low terraces and older alluvial fans, more recent alluvial fans and flood plains, and basin deposits. These associations are demonstrated in Figure 2.21, which shows the hydrologic soil type distribution by element.

Figure 2.19
Hydrograph for Well 16N02W12J02M



Source: DWR Water Data Library

Figure 2.20
Hydrograph for Well16N03W07Q01M



Source: DWR Water Data Library

Table 2.3
Predominant Soil Types

Soil Location	Soil Name	Hydrologic Soil Group
Soils of the Foothills		
	Millsholm	C
	Altamont	D
	Newville	C
Soils of Older Alluvial Fans and Low Terraces		
	Arbuckle	B
	Kimball	C
	Hillgate	D
Soils of the More Recent Alluvial Fans and Flood Plains		
	Cortina	A
	Orland	B&C
	Columbia	B
Soils of the Basins		
	Landlow	D
	Stockton	D

Source: NRCS
Soil Survey, Tehama County, California (1967)
Soil Survey, Glenn County, California (1965)
2001 Colusa County SSURGO Dataset (http://soils.usda.gov/soil_survey/main.htm)

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Hydrologic Soil Types

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FIGURE 2.21

Soil groups C and D are the predominant soil groups of the study area and are associated with foothills, low terraces and basin deposits. More permeable soil groups A and B are associated with major hydrologic features such as the Sacramento River and the more recent alluvial fans and flood plains, such as the area of the Stony Creek alluvial fan deposits.

This section summarizes the general hydrology of the Stony Creek Fan study area based on the information compiled during the Data Collection and Assessment Task of this project. The hydrology of a groundwater basin is the primary driving force for groundwater flow and quality. Therefore, it is essential to understand the hydrologic characteristics of the model area in order to develop a sound conceptual model.

SURFACE WATER SUPPLIES

RAINFALL

The hydrology of the Stony Creek Fan model area is typical of a California inland basin characterized by dry summers and moist winters. Annually, the area receives an average of 24 inches of rainfall. The typical rainfall pattern is that of little to no rainfall in the summers with most of the precipitation occurring during the winter months. Figure 3.1 shows the monthly distribution of rainfall at a gaging station near the town of Orland. Figure 3.2 shows the accumulative departure from the mean precipitation for the same gauging station. This graph represents the climatic trends in the study area for the period from 1951 to 2000.

The long-term annual average rainfall distribution in the study areas is presented in Figure 3.3. This isohyetal map is developed by DWR using one hundred years of precipitation data from various raingages in the study area.

STREAMFLOWS

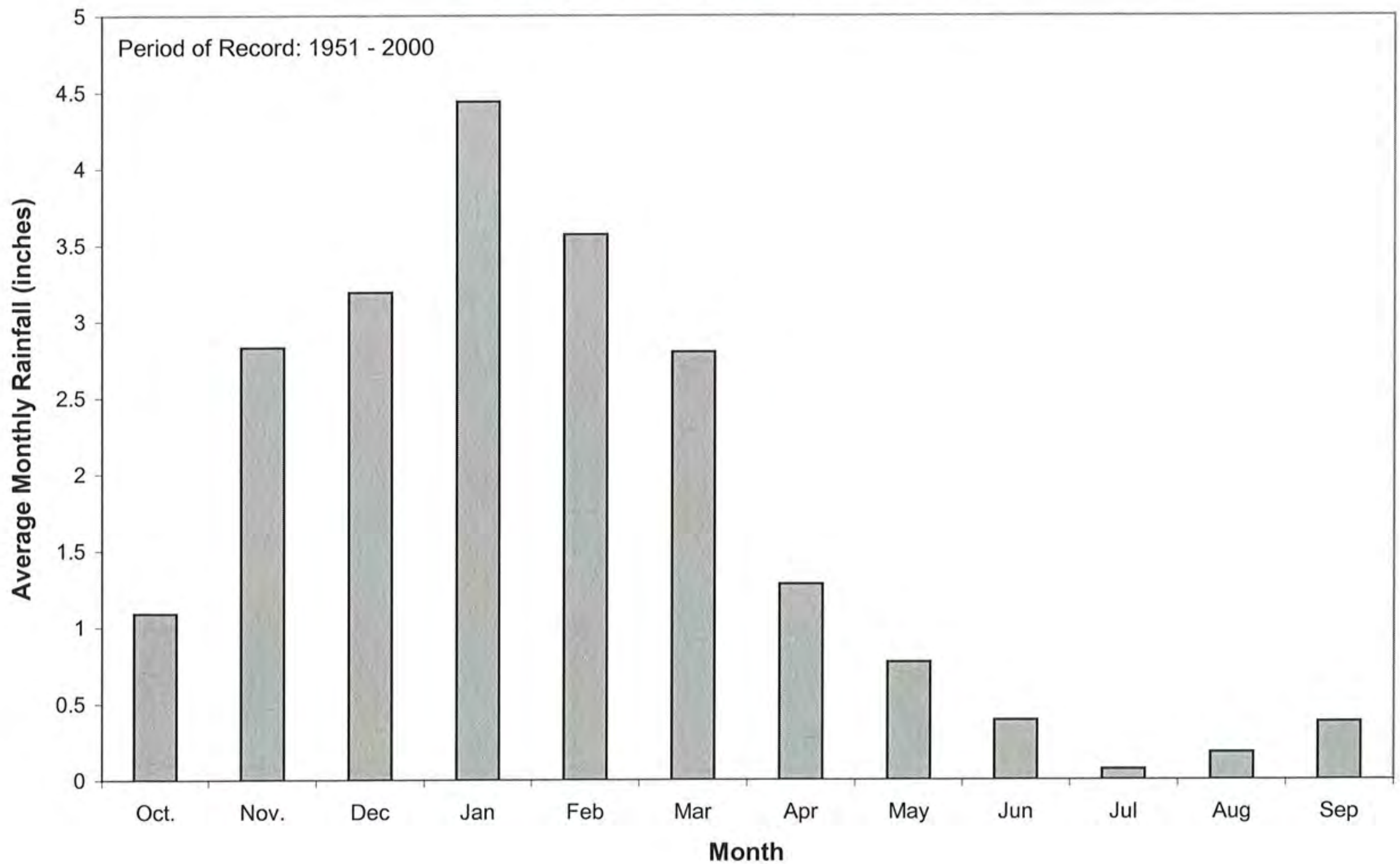
There are three major streams in the model area:

- **Thomes Creek** that coincides with the northern boundary of the model area
- **The Sacramento River** that coincides with the eastern boundary of the model area, and
- **Stony Creek** that is located within the model area.

The average annual inflows from these streams are presented in Figure 3.4 to 3.6.

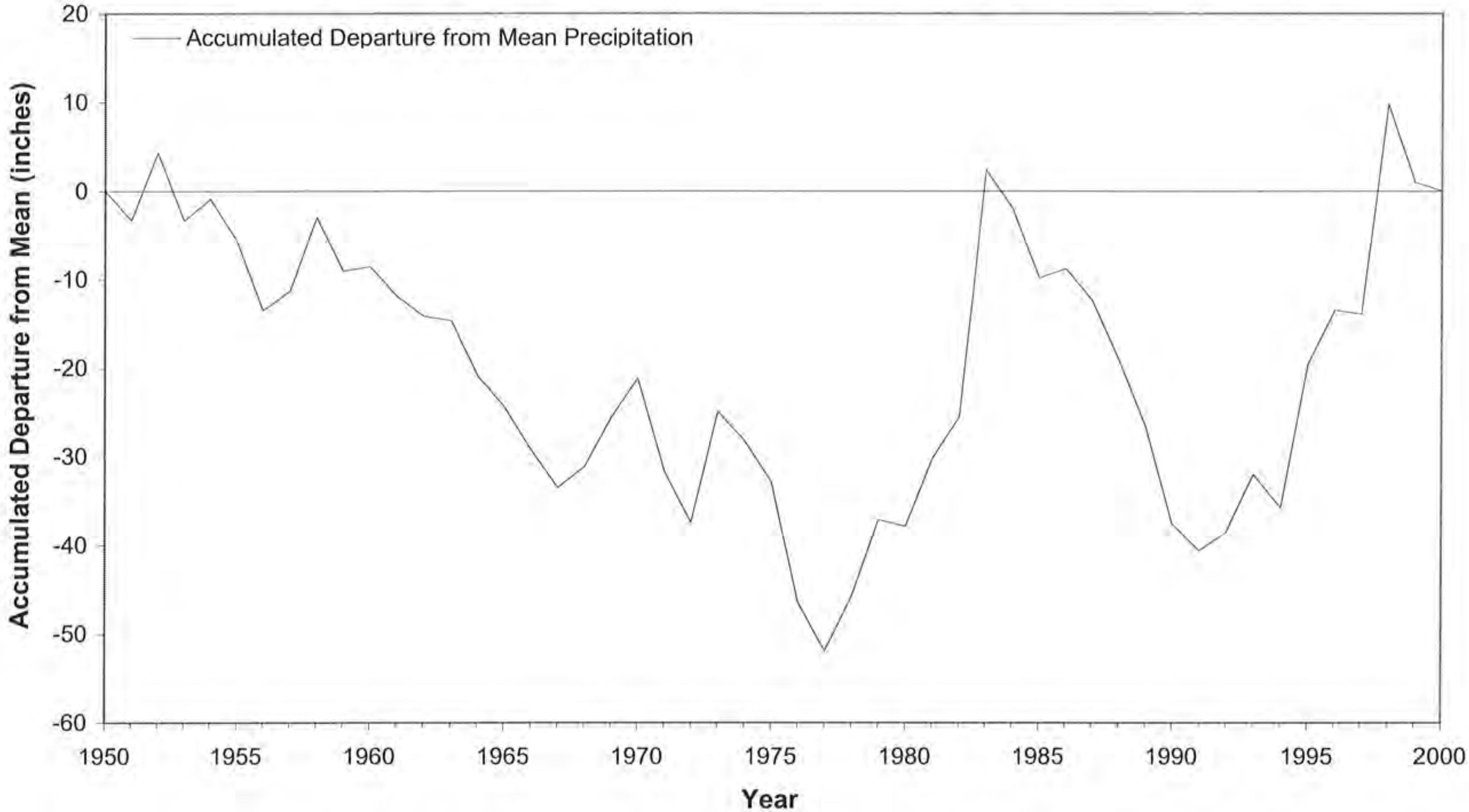
There are other tributaries of the Sacramento River on the east; these eastside streams are outside the model area, but they contribute inflows at the model boundary.

Figure 3.1
Average Monthly Rainfall (Orland)

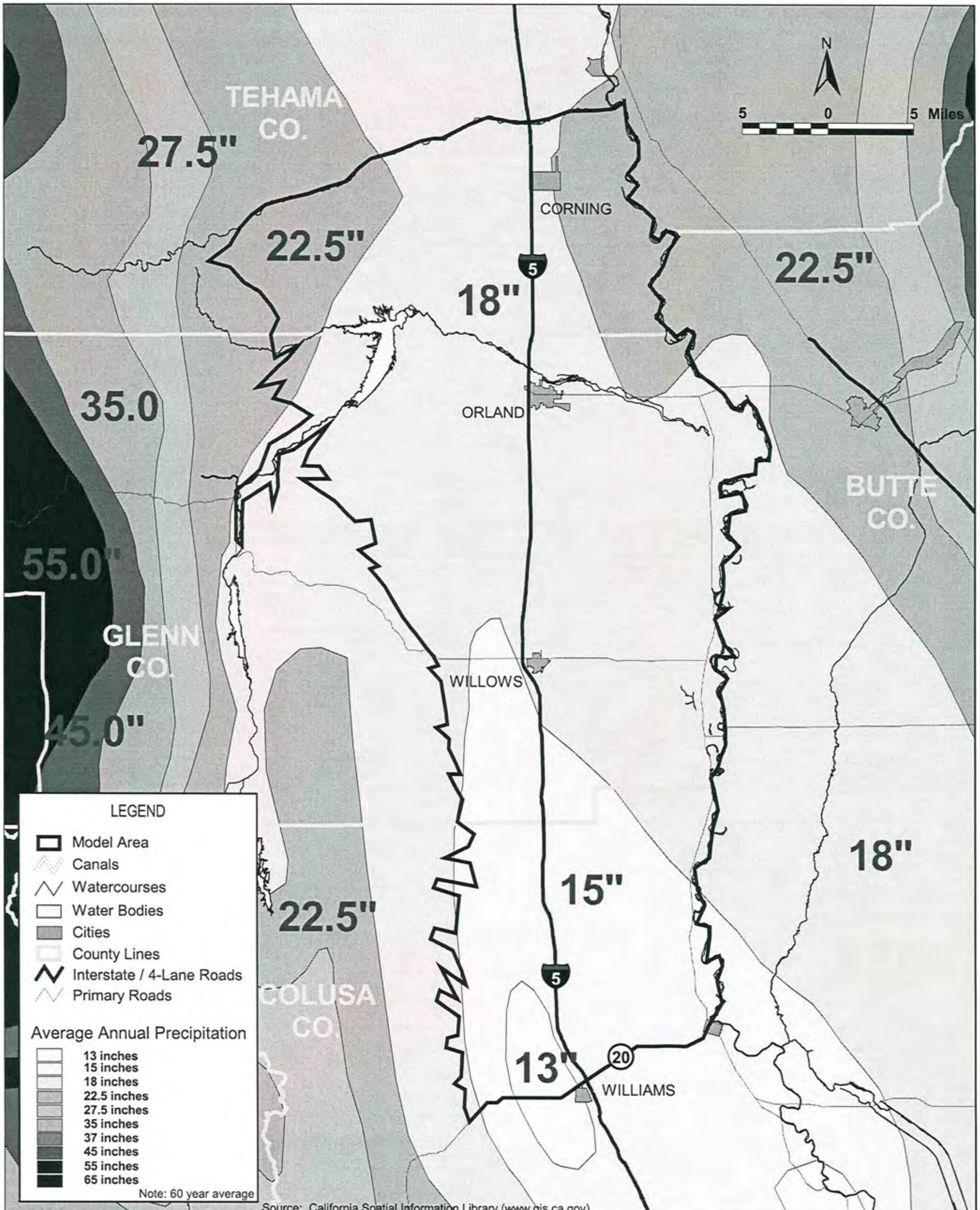


Source: National Climate Data Center (Station 6506)

Figure 3.2
Orland Accumulated Departure from Mean Precipitation (1951-2000)



Source: National Climate Data Center (Station 6506)



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Isoheytal Map

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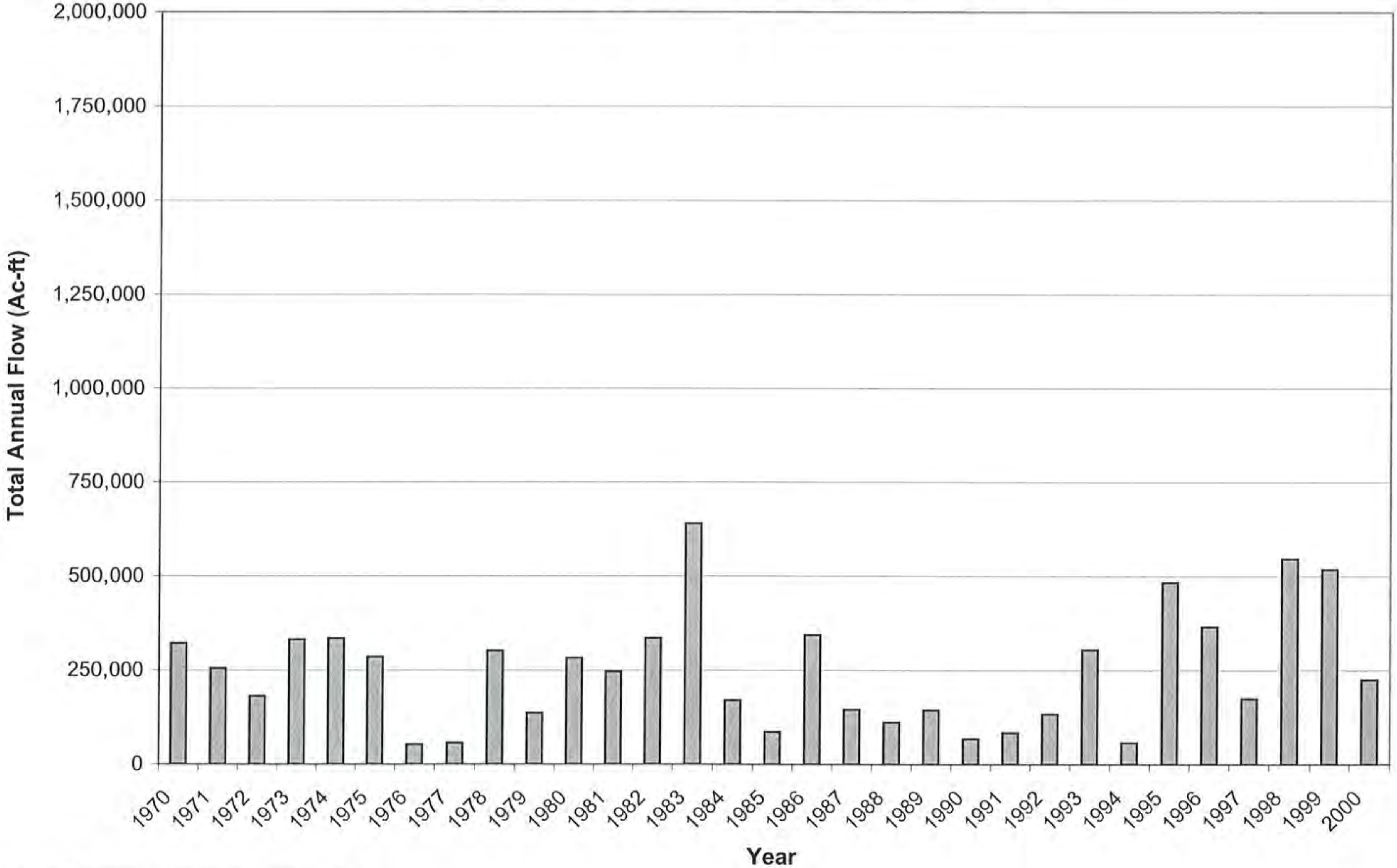
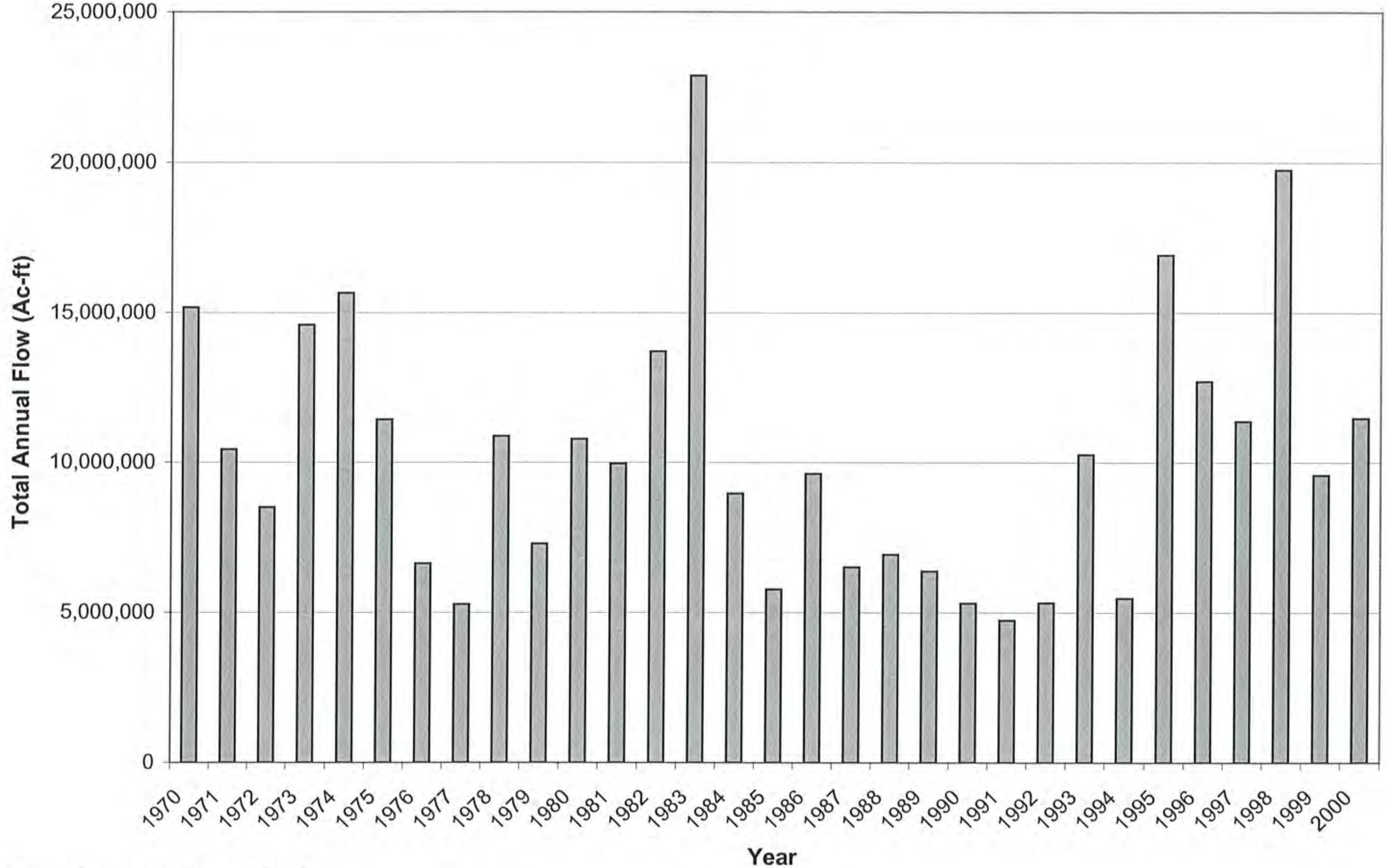
FIGURE 3.3

Figure 3.4
Stream Inflow to SCFIGSM from Thomes Creek



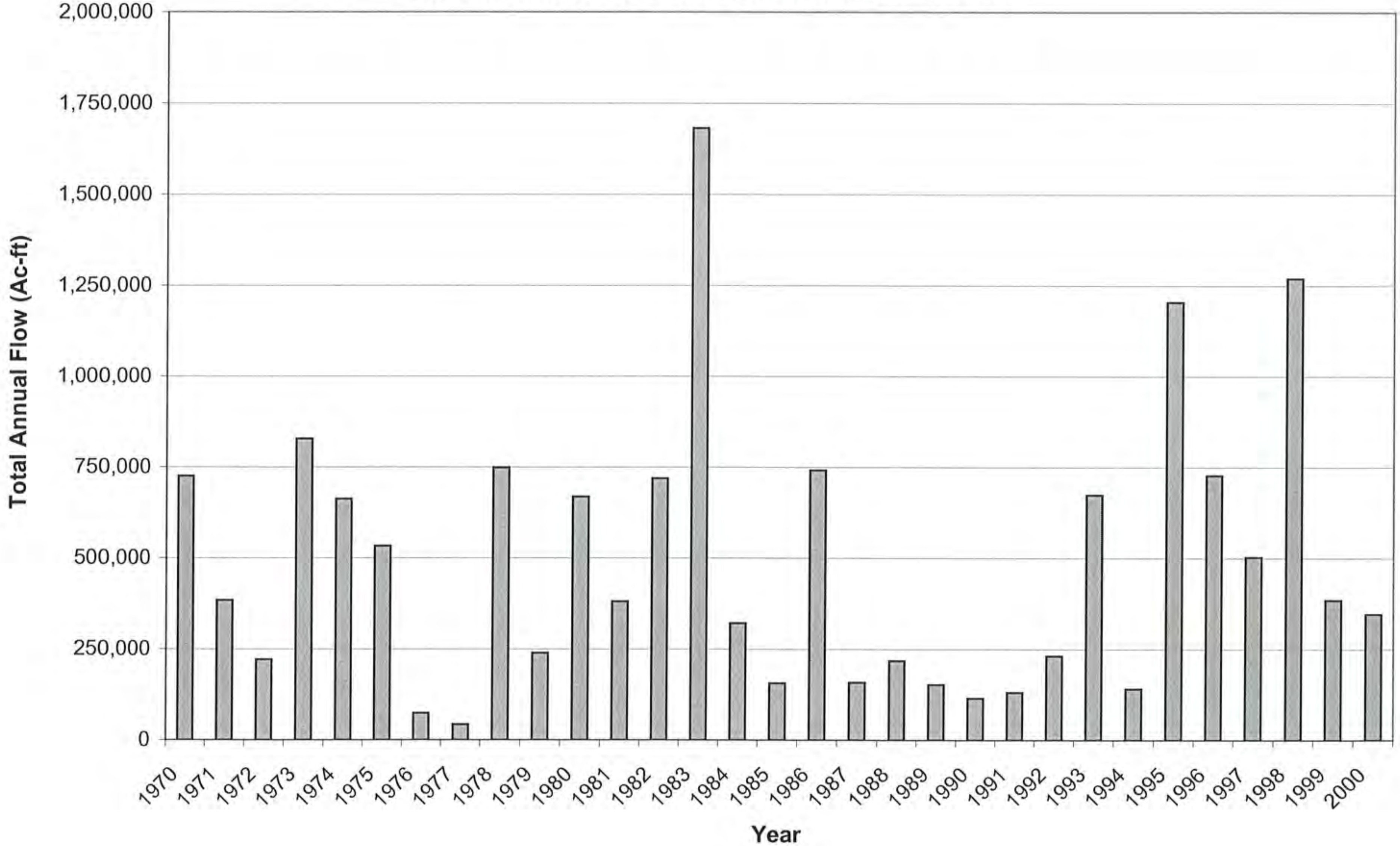
Source: Thomes Creek at Paskenta Gage
Monitored by USGS (gage 11382000) from 1970 - 1996
Monitored by DWR (gage A03500) from 1920 - 1999
Data for 1997 and 2000 and partial data from 1998 and 1999 was estimated using the monthly flow correlation between the Thomes Creek at Paskenta gage and the Elder Creek near Paskenta gage (USGS 11379500)

Figure 3.5
Stream Inflow to SCFIGSM from Sacramento River



Source: Sacramento River at Vina Gage
Monitored by USGS (gage 11383730) from 1945 - 1978
Monitored by DWR (gage A02700) from 1978 - 2001
Partial missing data from 1983-1989 was estimated using the daily flow correlation between the Sacramento River at Vina gage and the Sacramento River at Old Ferry gage (USGS 11383730).

Figure 3.6
Stream Inflow to SCFIGSM from Stony Creek



Source: Stony Creek at Black Butte Reservoir (Operations Data)
Monitored by US Corps of Engineers from 1963 - 2001 (Water Control Data System Report, US Corps of Engineers, www.spk/wc.usace.army.mil)

Two primary sources of stream flow data are the USGS and the DWR. The USGS data is obtained from the web site (http://water.usgs.gov/usa/nwis/sw) and the DWR data is obtained from the Northern District. There are several stream gauging stations in the study area, some of which are now discontinued.

SMALL WATERSHEDS

There are several small ungauged intermittent streams along the western boundary of the model area. Flow along these streams are not significant to be modeled as streams; however, the surface run off associated with these streams is a source of aquifer recharge. Estimation of inflow along these streams can be conducted by specifying the small watershed drainage areas and precipitation rates. Inflows can be set as an input to the groundwater node at which the streams enter the model area.

SURFACE WATER DIVERSIONS AND DELIVERY

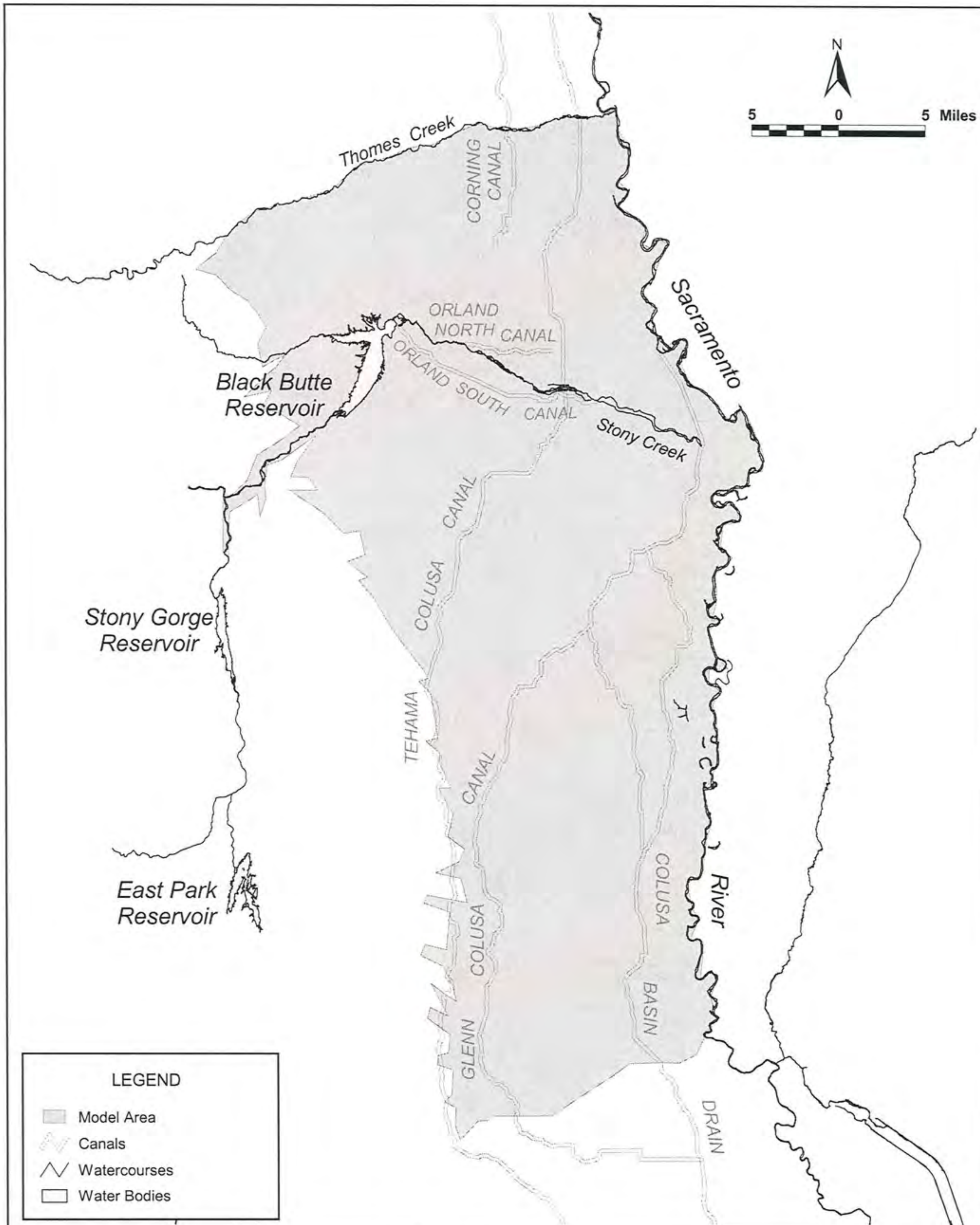
The agricultural land in the model area is irrigated by surface water from adjacent rivers and reservoirs and by groundwater pumping.

The Stony Creek system includes East Park, Stony Gorge, and Black Butte Reservoirs. Water is primarily supplied from Black Butte Reservoirs to Orland Unit Water Users Association (OUWUA). During spring, some water is diverted from Stony Creek to the Glenn-Colusa Canal.

The Sacramento River does not include any storage facilities within the model area. There are five major diversion locations along the river. These diversion locations are for the following water districts:

- Glenn-Colusa Irrigation District,
- Provident Irrigation District,
- M&T Chico Ranch, (outside model area)
- Princeton-Corado-Glenn Irrigation District, and
- Maxwell Irrigation District.

The irrigation water is brought into the model area using a network of lined and unlined canals and pipelines. There are six major canals and drains within the model area; these are shown in Figure 3.7 and listed below:



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Locations of Major Canals and Drains

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FIGURE 3.7

- **Corning Canal** - the southern extent of this canal extends about 5 miles into the northern boundary of the model area.
- **Orland North and South Canals** are entirely within model area; they deliver water from Black Butte reservoir to Orland Unit Water User Association (OUWUA).
- **Tehama Colusa Canal** is a concrete lined canal that traverses the model area from north to south along the western edge; it diverts water from Sacramento river outside of the model area .
- **Glenn-Colusa Irrigation District Main Canal** is an unlined canal, which diverts water from Sacramento river inside the model area.
- **Colusa Basin Drain** is an unlined canal that is used as a major irrigation drain in the Glenn Colusa Irrigation District.

The Corning Canal provides water to districts within the Tehama County. There are two water districts within the model boundary that receive water from the Corning Canal. These districts are Thomes Creek Water District and Corning Water District.

The Tehama-Colusa Canal provides water to over fifteen districts within Tehama, Glenn, and Colusa counties. Within in the model area, the Glenn-Colusa Irrigation District is largest recipient of water supplied by the Tehama-Colusa Canal.

The Glenn-Colusa Canal provides water to the Glenn-Colusa Irrigation District. It should be noted that the national wildlife refuges located in the GCID also receive water from the Glenn-Colusa Canal.

Water in the Colusa Basin Drain consists of return flow from GCID and other water districts that divert directly from the Sacramento River. GCID and Colusa Basin Water Users Association divert water from the Colusa Basin Drain.

The surface water diversion data is obtained from three different sources: DWR Northern District (*Sacramento Valley Westside Data*, 1970-1992), USBR, and GCID.

Table 3.1 shows the average annual surface water diversions from these sources into the model area.

Table 3.1
Summary of 1970 to 2000 Average Annual Diversions

District	Total Diversion by District	Diversion Amount Applied within SCFIGSM
North Canal		
1 - Orland Unit Water Users Association deliveries from Black Butte Reservoir via North Canal	32100[1,2]	32,100
South Canal		
2 - Orland Unit Water Users Association deliveries from Black Butte Reservoir via South Canal	63800[1,2]	63,800
Corning Canal		
3 - Corning WD delivery from Corning Canal	15900[1,2]	18,500
4 - Thomes Creek WD delivery from Corning Canal	4700[1,2]	1,800
Tehama-Colusa Canal		
5 - Ritchfield WD delivery from Tehama-Colusa Canal	100[1,2]	100
6 - Tehama W.D. delivery from Tehama-Colusa Canal	100[1,2]	100
7 - Kirkwood W.D. delivery from Tehama-Colusa Canal	400[1,2]	400
8 - O'Connel Mutual M.W.C. delivery from Tehama-Colusa Canal	20[1,2]	20
9 - Orland Water Users delivery from Tehama-Colusa Canal	2800[1,2]	2,800
10 - Orland-Artois delivery from Tehama-Colusa Canal	36400[1,2]	36,400
11 - Glide W.D. delivery from Tehama-Colusa Canal	8700[1,2]	8,700
12 - Kanawha W.D. delivery from Tehama-Colusa Canal	21300[1,2]	19,300
13 - Glenn-Colusa I.D. delivery from Tehama-Colusa Canal	87800[1,2]	87,800
14 - Holthouse W.D. delivery from Tehama-Colusa Canal	900[1,2]	800
15 - 4-M W.D. delivery from Tehama-Colusa Canal	1600[1,2]	100
16 - Glenn Valley W.D. delivery from Tehama-Colusa Canal	3500[1,2]	800
17 - La Grange W.D. delivery from Tehama-Colusa Canal	600[1,2]	600
18 - Davis W.D. delivery from Tehama-Colusa Canal	2500[1,2]	2,500
19 - Westside W.D. delivery from Tehama-Colusa Canal	20000[1,2]	5,800
Sacramento River		
20 - Glenn-Colusa ID Diversion from Sacramento River	719500[3]	649,600
21 - Glenn-Colusa ID Diversion from Glenn-Colusa Canal - Glenn County	337400[4]	337,400
21 - Glenn-Colusa ID Diversion from Glenn-ColusaID Canal - Colusa County	312200[5]	312,200
22 - Provident ID diversion from Sacramento River to Subregion 13	42000[1,2]	33,600
22 - Provident ID diversion from Sacramento River to Subregion 16		9,500
23 - Princeton-Codora-Glenn ID diversion from Sacramento River to Subregion 13	54600[1,2]	29,500
23 - Princeton-Codora-Glenn ID diversion from Sacramento River to Subregion 16		25,100
24 - Fred Cannell diversion from Sacramento River at RM 106 to Subregion 16	700[1,2]	700
25 - Maxwell ID diversion from Sacramento River to Subregion 16	5900[1,2]	5,900
26 - Odysseus Farms diversion from Sacramento River at RM 93.15 to Subregion 17	400[1,2]	400
27 - Roberts Ditch Company diversion from Sacramento River at RM 90.7 to Subregion 16	2300[1,2]	2,300
28 - M&T Chico Ranch left bank diversion from Sacramento River	23700[1,2]	23,700

[1] DWR Northern District Westside Data Report 77, 2000
[2] USBR Central Valley Operations Annual Report, 1976 - 2000
[3] Glenn-Colusa Irrigation District Annual Report, 1970 - 2000
[4] Davids Engineering Water Balance Model
[5] Estimated based on data provided by Source 3 and following equation: Diversion from Sacramento River + Tehama-Colusa Canal Delivery - GCID (Supply to Glenn County) - GCID (Delivery to outside model area) = GCID (Deliveries to Colusa County within model area

GROUNDWATER

SOURCES OF RECHARGE

Groundwater elevation in the Stony Creek Fan area are directly affected by the volumes of water that recharges the underlying groundwater basin. Recharge of the model area consists of the following hydrologic components:

- Deep percolation of precipitation and applied water
- Stormflow recharge
- Recharge from unlined agricultural drains
- Recharge from ponded rice fields
- Steam aquifer interactions
- Subsurface inflow from adjacent groundwater basins;

Estimates of these hydrologic components will be developed using the SCFIGSM.

GROUNDWATER OUTFLOW

Groundwater pumping data in the study area is not generally recorded except for special pumping program undertaken by a water purveyor. Annual pumping data from 1994 to 1999 and 2001 were collected from GCID for 107 wells. These wells are located in the areas between the Glenn-Colusa Canal and the Sacramento River. No other records of historic groundwater pumping could be found. It appears that historic groundwater pumping will need to be estimated using applied water demand, surface water deliveries and irrigation efficiencies. Groundwater pumping has varied over time due to variations in climate, land use, and the availability of alternative sources of water.

Urban water supplies in the study area are entirely from the groundwater source. A water duty of 2 acre-feet per acre is used to estimate the groundwater pumping for urban use. This amounts to an average of 19,000 ac-ft. This amount of pumping is insignificant when compared to the groundwater pumping for agricultural use. Agricultural pumping can be estimated as the difference between agricultural water demand and surface water supply. The surface water supply data are measured data. The agricultural water demand is estimated using Consumptive Use of Applied Water (CUAW) methodology. This methodology uses antecedent soil moisture conditions, crop evapotranspiration requirements, rooting depths, crop acreages, and irrigation efficiency. Preliminary estimates of groundwater pumping using this land-use based methodology and areally averaged rainfall show that the groundwater pumping in the model area are in the vicinity of 400,000 ac-ft to 500,000 ac-ft. These preliminary estimates will be revised as more data analysis is conducted during model development process

The historic knowledge of the groundwater conditions in the study area indicates that there are two groundwater divides (no flow boundary) in the study area: one in the north along Thomes Creek and one in the south along Highway 20. This knowledge has resulted in choosing the model boundary to be Thomes Creek and Highway 20. On the west, the geologic contact provides a no flow boundary. On the east of the model area, it is thought that groundwater flows into the model area from the east.

LAND AND WATER USE

LAND USE

Land use data for Glenn, Tehama, and Colusa counties were obtained from DWR in two formats: (a) electronic Arc View shape files for recent years; and (b) hardcopy summary tables by USGS quad sheet. The survey years for each county differ from one another. A composite map of the most recent land use patterns in the study area is developed using the most recent land use surveys and is presented in Figure 3.8.

IRRIGATED CROP ACREAGE DATA

Irrigated crop acreage data for the Glenn, Tehama, and Colusa counties are obtained from several sources, as listed below:

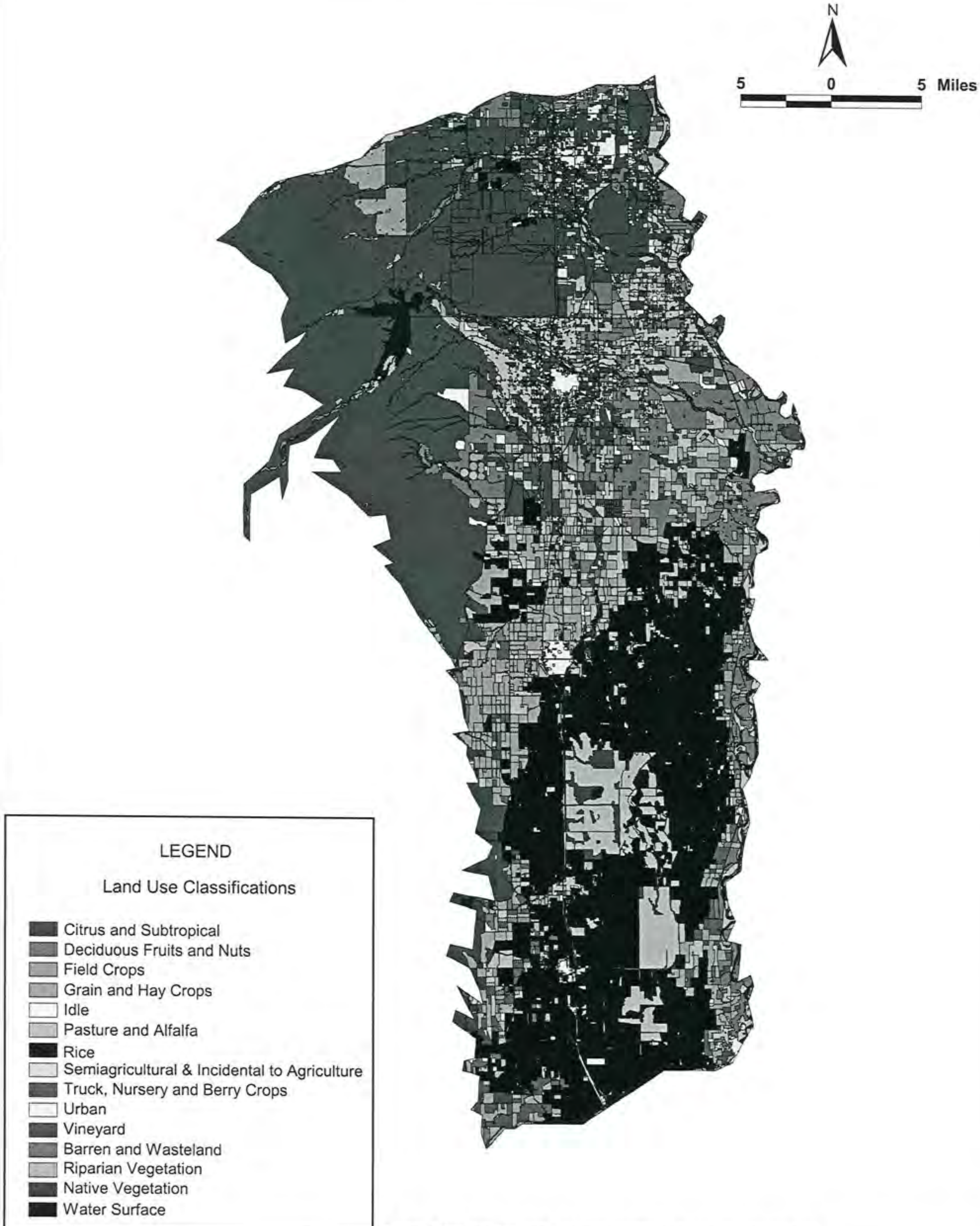
1. U.S. Bureau of Reclamation – CVP Contractors Crop Report;
2. Agricultural Commissioner – Countywide data reported annually;
3. Web Site http://www.nass.usda.gov/ca/bul/agcom/indexcac.htm for Glenn County

The historic land use trends for agricultural, urban, and rice acreage is shown in Figure 3.9.

WATER USE

The primary water use in the model area is for agriculture. Surface water comprises the major source of agricultural water supply. Groundwater is used to (a) supplement additional needs for water; and (b) to irrigate lands that do not receive surface water.

A preliminary data analysis indicates that the total amount of surface water use in the model is in the vicinity of about 1,000,000 ac-ft. It should be noted that these numbers are preliminary and provides general idea about the water use to be utilized in the development of the conceptual model.



Source: DWR (http://www.water.ca.gov/landwateruse/landuse/ludataindex.htm)

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Land Use (1998 and 1999 Surveys)

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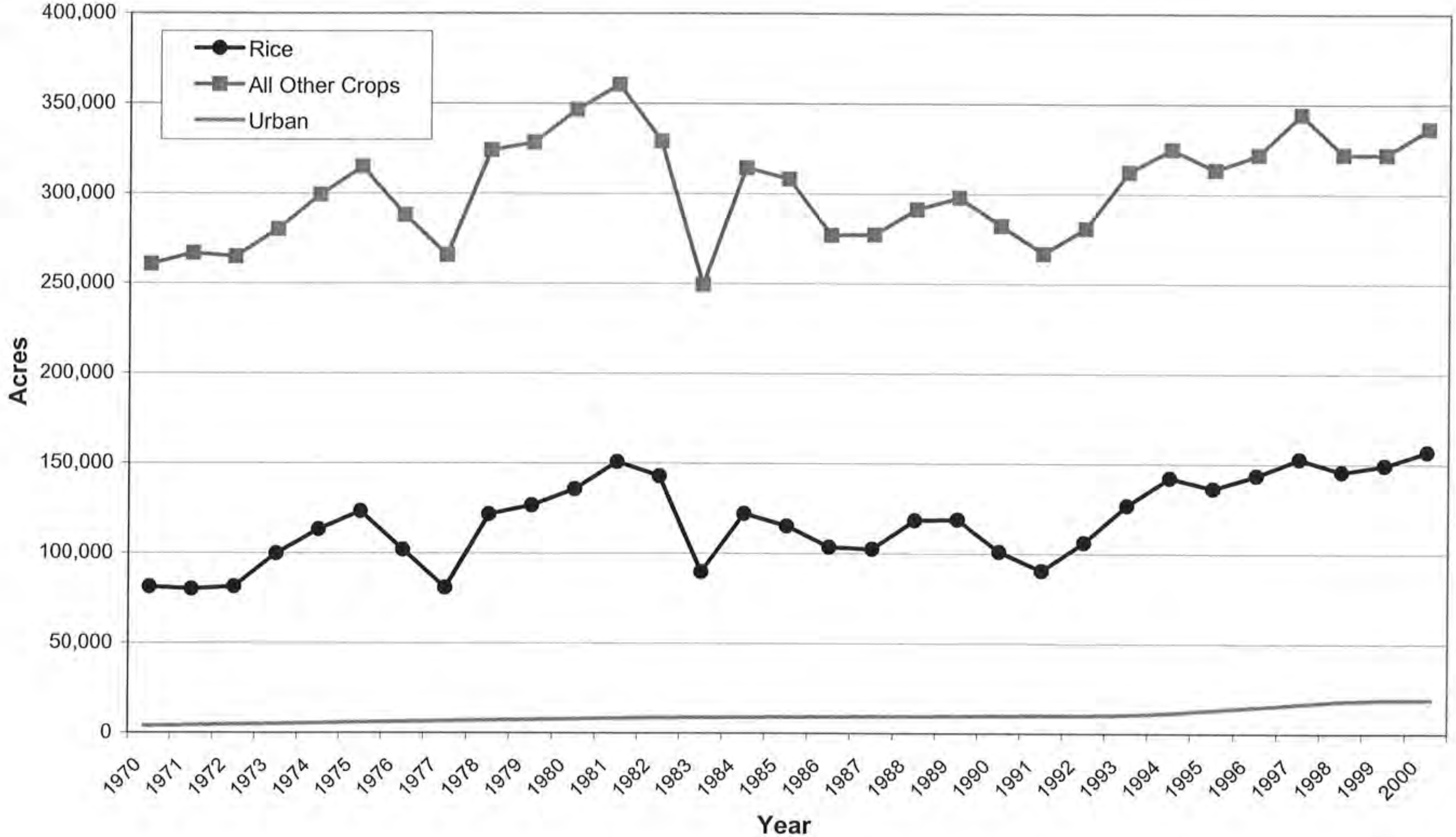
FIGURE 3.8

Figure 3.9
Land Use Trends in the SCFIGSM Area



Source: DWR (http://www.water.ca.gov/landwateruse/landuse/ludataindex.htm)

It is important to consider the modeling goals and objectives during the development of the conceptual model. The choice of the features and capabilities of a model and the level of detail depends on the goals and objectives of the development of the numerical simulation model. In addition, modeling goals and objectives guides the decision regarding the inclusion, exclusion, and simplification of hydrologic processes to be considered in the conceptual model.

MODELING GOALS

The Program Sponsors have identified both common and specific goals for the Stony Creek Fan Conjunctive Water Management Program.

COMMON GOALS OF THE SPONSORS

1. Protect local surface water and groundwater resources consistent with Glenn County ordinances, specifically the Glenn County Groundwater Management Plan BMOs, and State and Federal laws;
2. Pursue opportunities to maximize Program benefits through strategic, synergistic linkages with other regional water management activities and authorities;
3. Secure water supply reliability locally and provide opportunities for improved water supply reliability for water users' elsewhere in the state; and
4. Seek ways to achieve environmental benefits that are compatible with Program operations.

INDIVIDUAL GOALS OF THE SPONSORS

Individual Goals – Orland Unit Water Users' Association

- Enhanced management of surface water resources; and
- Infrastructure improvements

Individual Goals – Orland-Artois Water District

- Secure affordable water supply reliability in all years.

Individual Goals – Glenn-Colusa Irrigation District

- Improved reliability and increased flexibility through integration of basin surface water and groundwater resources.

MODELING OBJECTIVES

In order to meet the above Program goals, it is necessary to develop a thorough understanding of:

- the groundwater basin behavior in the Program area;
- the surface water systems behavior and its interaction with underlying aquifers; and
- the interrelationships among the various operational parameters of the river/reservoir/aquifer systems.

An integrated groundwater and surface water model can be used as an analytical tool to meet the above-mentioned needs. It can also be used to determine the optimal combination of physical and operational parameters that best meet the goals of the Program Sponsors. The model will also be used to assess potential environmental and third party impacts resulting from the proposed conjunctive use Program.

In order to ensure the success of the modeling efforts in meeting the Program goals, it was decided to establish modeling objectives through discussion with key technical and managerial people involved with the Program. Several interviews and meetings were conducted in that regard and objectives, issues, concerns, and questions related to modeling were identified.

The project team members selected three modeling objectives for the Stony Creek Fan Conjunctive Water Management Program. These are:

- To develop for the Stony Creek Fan and the surrounding Glenn County area an analytical tool that can represent the groundwater and surface water flow systems and their interactions.
- To develop a planning level analytical tool that can provide quantitative information on a comparative basis to help answer different questions on the groundwater and surface water system characteristics and to evaluate alternative conjunctive water management strategies.
- To develop a tool that can be used in assessing management strategies consistent with the Program goals and objectives.

The process of selection of these objectives included interviews with the Program sponsors, assessment of the modeling needs through careful analysis of the Program goals and objectives, evaluation of the criteria for meeting the Program goals, and technical sessions among the project team members.

An effort was also made to prioritize the model capabilities and features. However, it was found that almost all of the identified model capabilities and features are needed for the evaluation and analysis of the Program. As a result, no priorities were assigned to any particular model feature.

On the basis of the required model features, Integrated Groundwater Surface water Model (IGSM) was selected as the model to be used for the Stony Creek Conjunctive Water Management Program. Several criteria were used in the model selection process, as listed below:

- A model that can meet the three modeling objectives identified by the Program Sponsors;
- An integrated hydrologic model that can simulate both the surface water and groundwater systems and their interactions;
- A model that has reservoir operations simulation capabilities;
- A model that has the built-in capability to evaluate conjunctive water management programs without development of additional elaborate program modules;
- A model that has most of the required features identified by the Program Sponsors;
- A model that can be easily modified to accommodate relevant features that may be needed for a Conjunctive Water Management Program;
- A non-proprietary model;
- A model that has a history of successful applications in California;
- A model that has the capability to share/exchange data with the regional groundwater model of the Central Valley (e.g. CVGSM - Central Valley Groundwater Surface Water Model) for boundary conditions generation;
- A model that has the capability to share/exchange data with the regional/statewide reservoir operations model, such as CALSIM, DWRSIM, and PROSIM; and

- A model that can be developed for the Program in a timely and cost effective manner.

The IGSM meets all of the above selection criteria. In addition, both the DWR staff and the project team members are familiar with the IGSM, which will ensure successful model application in a timely and cost effective manner.

The purpose of building a conceptual model is to simplify the modeling problem and organize the relevant field data and information so that the hydrogeologic system can be analyzed (Anderson and Woessner, 1992).

There are three key steps in developing a conceptual model, such as:

- Conceptual description of modeling of hydrologic processes;
- Delineation of hydrostratigraphic units and model grid; and
- Definition of flow systems and boundary conditions.

The conceptual model for the Stony Creek Fan Integrated Groundwater Surface water Model (SCFIGSM) is described below.

CONCEPTUAL DESCRIPTION OF MODELING OF HYDROLOGIC PROCESSES

In IGSM, the hydrologic system is divided into four major subsystems as shown in Figure 5.1. These are:

- Soil Zone;
- Stream System
- Unsaturated Zone;
- Groundwater Zone.

The hydrologic components of these physical subsystems that are considered in IGSM are shown in Figure 5.2.

SOIL ZONE

The SCFIGSM will simulate soil zone processes including evapotranspiration, direct runoff, infiltration, and deep percolation from rainfall and applied water. The computations will be performed at a finer geographical scale represented by finite element discretization. Evapotranspiration from the soil surface is computed on the basis of crop consumptive use requirement and available soil moisture. Direct runoff from rainfall and applied water is computed by using a modified Soil Conservation Service (SCS) runoff curve number method.

Figure 5.1
Hydrologic System Interactions

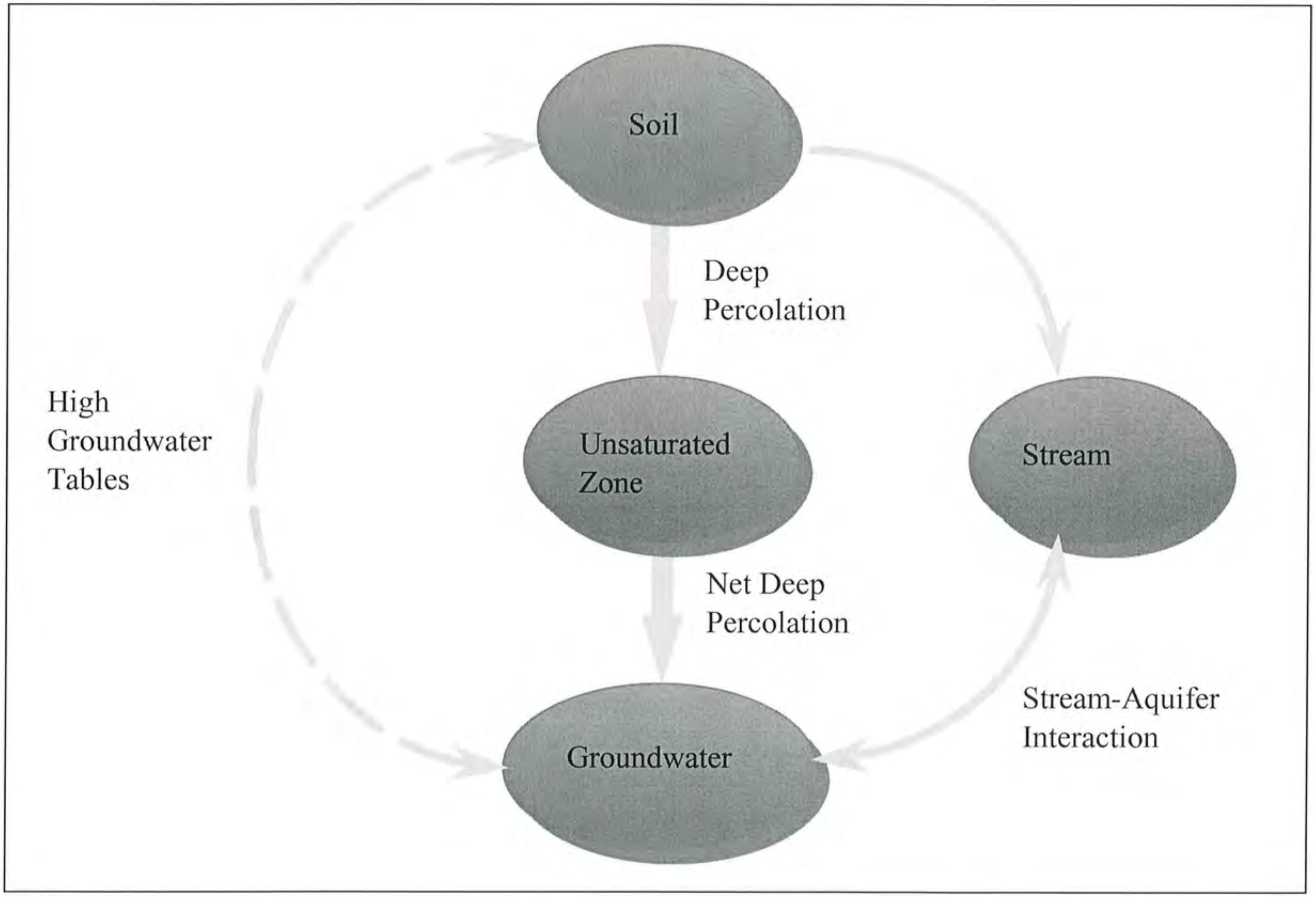
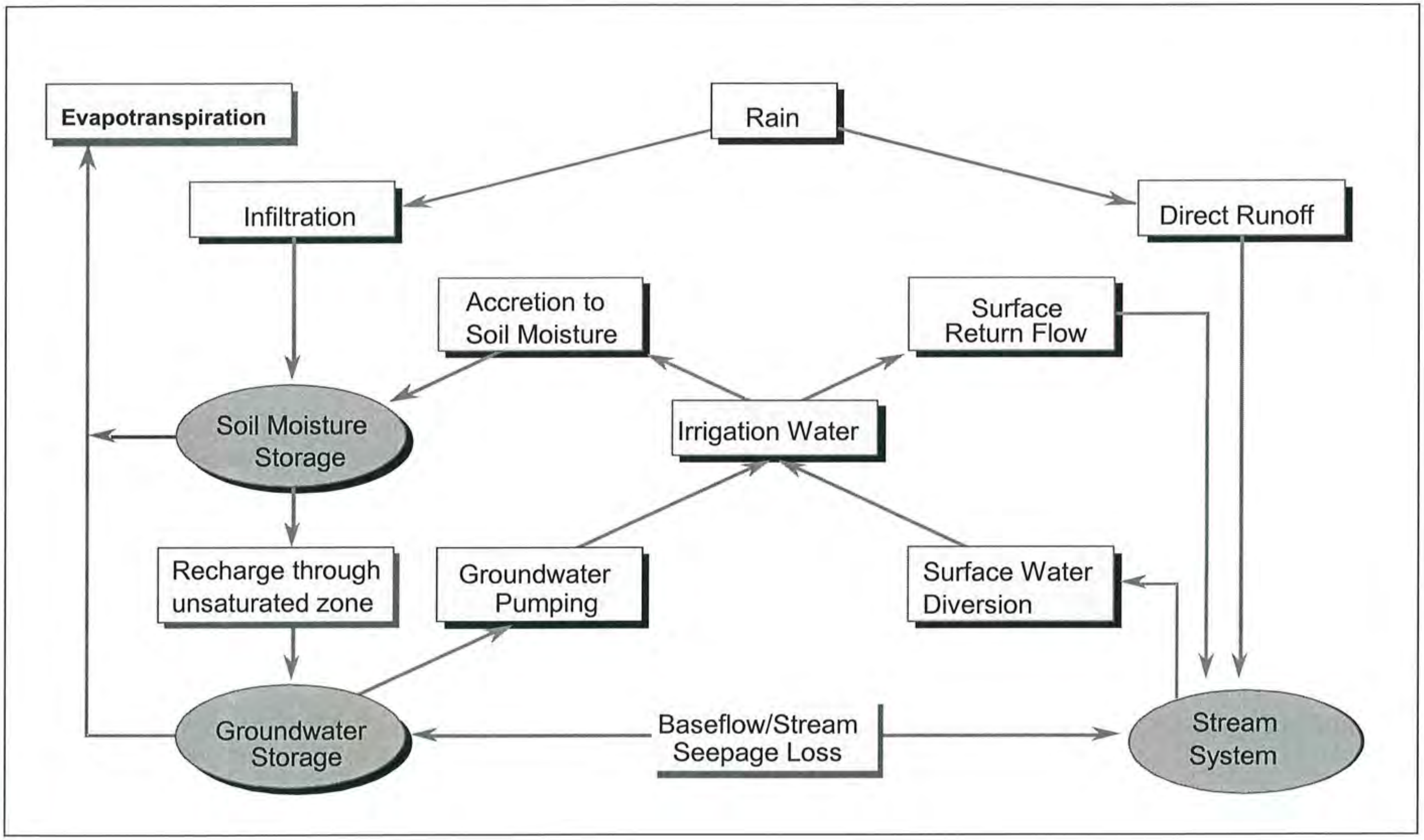


Figure 5.2
Hydrologic Components



The computed runoff from each finite element is routed to the appropriate stream node. Percolation of precipitation and applied water is added to the unsaturated zone that underlies the soil zone.

Input data for soil zone simulation includes initial soil moisture; rainfall; land use history; SCS hydrologic soil group and; minimum soil moisture requirements for:

- crop growth;
- crop consumptive use;
- root zone depth for each crop;
- surface drainage pattern; etc.

Parameter data for this submodel includes:

- SCS curve number;
- field capacity; and
- soil infiltration rate.

STREAM SYSTEM

The water balance equation is solved for each stream element to simulate streamflow in SCFIGSM. The stream elements are a series of 1-dimensional line elements that are used to describe the stream system within the model area. Each stream element is defined by two consecutive stream nodes that are coincident with the aquifer nodes. Components of water balance in a stream element of SCFIGSM are:

- inflow at upstream node of the stream element;
- direct runoff (lateral inflow);
- surface water diversions;
- wastewater discharge;
- agricultural return flow; and
- gain or loss due to interaction with the underlying aquifer.

The gain or loss due to stream aquifer interaction is computed by using mathematical equations that are based on water levels in the stream and underlying aquifer. The depth of water in the stream is computed using stage-discharge relationships at the corresponding stream node. The solution of the water balance equation in this manner provides the downstream outflow for a stream element. This outflow is used as the upstream inflow for the stream element that is downstream of the current stream element.

The input data for the stream system simulation includes:

- stream configuration;
- stream node elevation;
- cross-section;
- stage-discharge relationship;
- stream inflows at boundary;
- tributary inflows;
- wastewater discharges to streams; and
- streamflow diversions.

The parameter data for this submodel includes hydraulic conductivity and thickness of the streambed.

VADOSE ZONE SIMULATION

Water that percolates down from the soil zone travels through the vadose zone as unsaturated flow and eventually reaches the saturated groundwater zone. The mathematical equation of unsaturated flow is solved numerically at every time step. The vadose zone is divided into a number of discrete layers of specified thickness. The one-dimensional vertical flow equation is solved layer by layer on a nodal basis. The number of vadose zone layers at any node at any time is determined by the depth to groundwater at the corresponding node. The deep percolation of applied water and precipitation that passes through the soil zone becomes the inflow to the uppermost vadose zone layer. Outflow from the overlying layer becomes inflow to the layer beneath, and so on. The outflow from the last vadose zone layer becomes inflow to the saturated groundwater zone. The effect of the rise and fall of the water table is incorporated into this submodel by keeping track of depth to groundwater and vadose zone moisture content. SCFIGSM vadose zone simulation is capable of simulating perched water table conditions resulting from the presence of low permeability zones.

The input data for vadose zone simulation includes thickness of vadose zone layers, vertical hydraulic conductivity and effective porosity.

GROUNDWATER ZONE

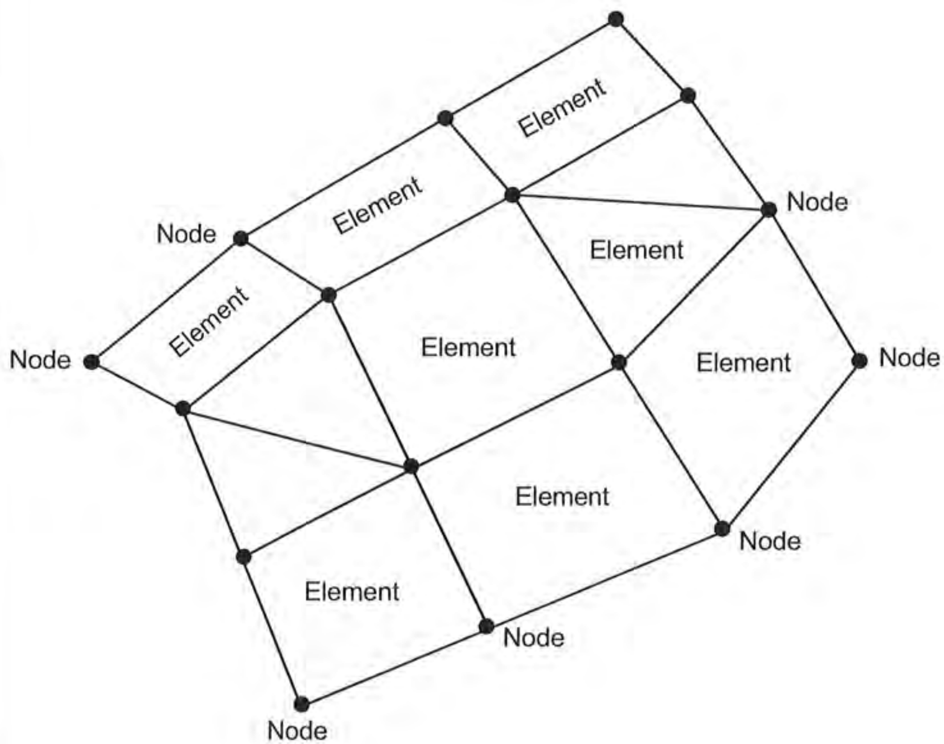
Saturated groundwater flow is simulated in SCFIGSM by solving the governing groundwater flow equation by the Galerkin finite element technique. The model flow domain has been broken down horizontally into a collection of small polygonal areas. These areas are called finite elements and they can be either three-sided or four-sided polygons. The vertices of these elements are called nodes. The network of finite elements and nodes is called a model grid. The groundwater flow domain has been broken down vertically into three discrete layers that represent the underlying groundwater aquifers. These aquifers are separated by aquicludes. A conceptual representation of horizontal and vertical discretization of the flow domain is presented in Figure 5.3.

Aquicludes limit the vertical movement of water, and are generally composed of low hydraulic conductivity materials such as silt and clay; or interbedded sequences where the hydraulic conductivity is governed by silt and clay. The aquifers are primarily composed of materials with relatively high conductivity. The predominant flow paths in groundwater aquifers are horizontal. The horizontal flow system is simulated by solving a two-dimensional groundwater flow equation. The governing differential equation is converted into a set of algebraic equations defined at the finite element nodes. This set of algebraic equations is then solved by using a matrix iterative technique until a specified convergence criterion is satisfied. The vertical flow system is simulated by solving a leakage equation based on the groundwater elevations in two adjacent aquifers.

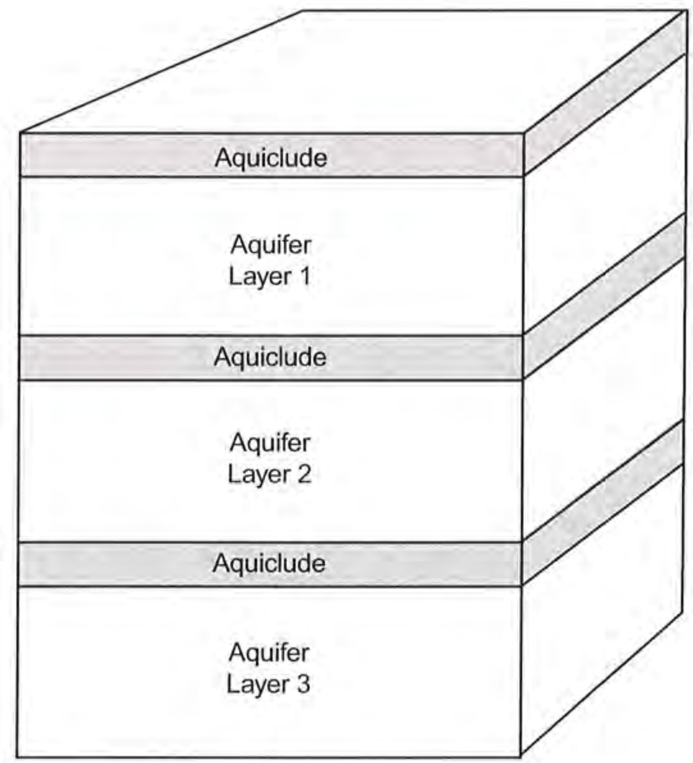
The input data for groundwater flow simulation includes:

- well location;
- well diameter and perforation interval of wells;
- monthly pumping;
- boundary conditions at boundary nodes;
- initial groundwater elevations;
- aquifer and aquiclude thickness at each node;
- hydraulic conductivity of aquifer and aquiclude material;
- specific yield;

Figure 5.3
Horizontal and Vertical Discretization of Groundwater Flow



Horizontal Discretization



Vertical Discretization

- specific storage; and
- leakance.

Hydrologic Water Balance

The primary purpose of all hydrologic modeling is to solve the water balance equation of the selected model area or watershed. The model area can be hydrologically defined, such as a watershed or drainage basin; it can also be politically or arbitrarily defined, such as water district, county, or a plot of land. Regardless of the geographic scale or time period of simulation, water balance equation should be developed as the first step of modeling to identify the appropriate components of the hydrologic cycle for a specific model area. The defining criterion for a model's reliability is how well it incorporates water balance equation for the modeled hydrologic subsystem. A model that does not explicitly generate output showing water budget at appropriate temporal and spatial scale should be used with extreme caution.

The IGSM is a unique hydrologic model that places significant emphasis on hydrologic water balance. An estimate of the net inflow of the Stony Creek Fan IGSM area can be made by summing up the appropriate hydrologic components of the physical system being modeled. This estimate is intended to ensure that the model is properly representing the key hydrologic components of the groundwater basin. As discussed above, SCFIGSM tracks the movement of all of the primary sources of water coming into and leaving the basin, including rainfall, streamflows, applied water, consumptive use, and subsurface inflows and outflows.

The model outputs are reviewed and refined during the model calibration to ensure that the primary sources of inflows and outflows in the different physical subsystems (e.g. soil zone, groundwater subsystem, stream subsystem) of the model are represented properly. This includes annual and monthly water budgets for groundwater, streamflow, soil moisture, and land and water use for the entire model area and for selected model subareas. The key components for each of these water budgets are listed in the Table 5.1 below.

Table 5.1 Water Budget Components

Budget	Components					
Groundwater	Deep Percolation	Stream Recharge	Boundary Flows	Pumping	Overdraft	
Streamflow	Upstream Flow	Rainfall Runoff	Gain from Groundwater	Diversions	Return Flows	Downstream Flow
Soil Moisture	Rainfall	Irrigation	Evapo-transpiration	Direct Runoff	Percolation	Return Flow
Water Use	Agricultural Use	Urban Use	Pumping	Diversions	Imports	Shortages

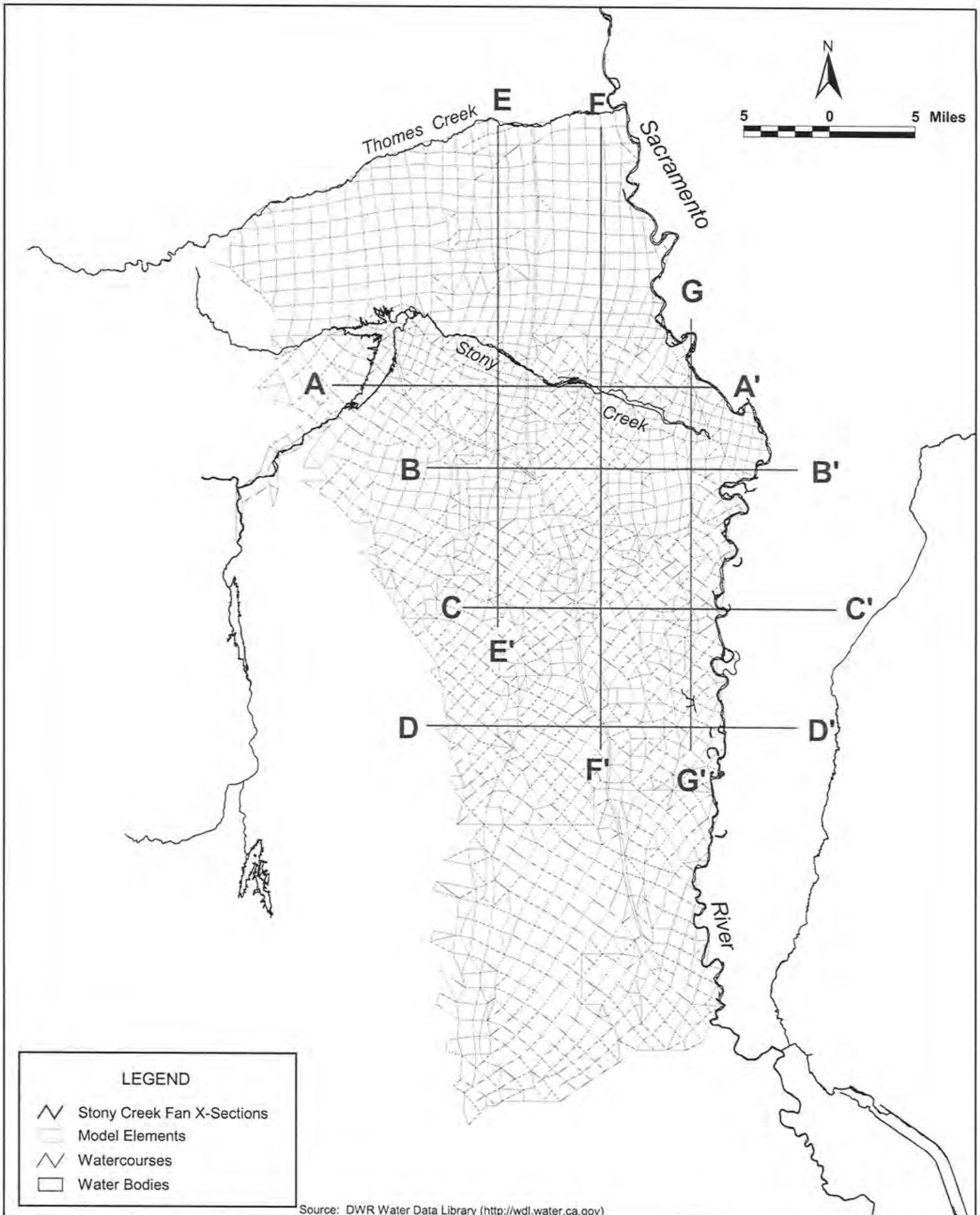
Model Simulation Period

The study period for the SCFIGSM is the 31-year period representing water years 1970 to 2000 (October 1969 to September 2000). This recent period was chosen in part because there is a relatively good set of land and water use data as well as hydrologic data such as rainfall, streamflow, and groundwater levels. This period also includes two historic drought events, 1976-1977 and 1989-1992, and two historic flood events, 1983 and 1986. This time period also includes the introduction of significant quantities of surface water to the area. This simulation period is assumed to be adequate for developing and calibrating a hydrologic model like IGSM.

The SCFIGSM will analyze the hydrologic water balance on an annual basis for this 31 years of model simulation period.

DELINEATION OF HYDROSTRATIGRAPHY

The geologic information described in Section 2 was used in conjunction with the recent geologic mapping by the DWR and well construction logs to define the hydrostratigraphic units of the SCFIGSM. Hydrostratigraphic units comprise geologic units of similar hydrogeologic characteristics and properties. Several geologic formations may be combined into one hydrostratigraphic unit or a geologic formation may be subdivided into aquifer and confining units. Seven hydrostratigraphic cross-sections from the DWR's unpublished recent geologic mapping effort were used as anchor points for developing the detail stratigraphic definition of the entire model area. These sections are shown in Figure 5.4. The number and location of these sections were selected based on the location of lithologic and geophysical data, and for stratigraphic coverage of the entire model area.



Source: DWR Water Data Library (http://wdl.water.ca.gov)

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DWR Geologic Cross Sections Used in Stratigraphic Analysis

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FIGURE 5.4

In developing hydrostratigraphic sections, ground surface elevations were obtained from the U.S. Geologic Survey Digital Elevation Model (DEM) database. The base of the aquifer system is considered to be the base of the freshwater-bearing deposits obtained from recent geologic mapping by the DWR and the past reports published by USGS.

The conceptual model is developed with four hydrostratigraphic units as presented in Figure 5.5, and summarized on Table 5.2.

SCFIGSM Layer 1

The conceptual model for SCFIGSM Layer 1 includes Pleistocene and Holocene deposits consisting of Holocene alluvium, alluvial fan, flood plain, and basin deposits, and the Pleistocene Modesto and Riverbank Formations. The highly permeable sands and gravels of Pleistocene Modesto and Riverbank Formations are only present on the Stony Creek Fan. Where Layer 1 is present throughout the model area it is exposed at the ground surface, and represents the unconfined groundwater system. Wells perforated in this layer are likely used for domestic and some agricultural water supplies.

The highly permeable sands and gravels are 50 to 80 feet thick within the Stony Creek Fan. They are not present outside the Stony Creek Fan. On the Fan, some of the highly permeable deposits are underlain by up to 50 feet of finer-grained alluvial or basin deposits. Outside the Fan, alluvial and basin deposits can reach a total thickness of 200 feet. The conceptual model stratigraphy was developed to reflect the significant difference in the characteristics of the Fan material and the other alluvial deposits present within the model area.

Inside the Fan Area

Inside the Stony Creek Fan Area, SCFIGSM Layer 1 represents the 50 to 80 foot thick highly permeable sand and gravel deposits. Any alluvial or basin deposits that may be present beneath the sands and gravels are included in Layer 2.

Outside the Fan Area

Outside the Stony Creek Fan Area, SCFIGSM Layer 1 represents the upper 80-foot thickness of the basin and alluvial deposits. Any remaining basin or alluvial deposits are considered part of SCFIGSM Layer 2.

Figure 5.5
Conceptual Model Stratigraphy

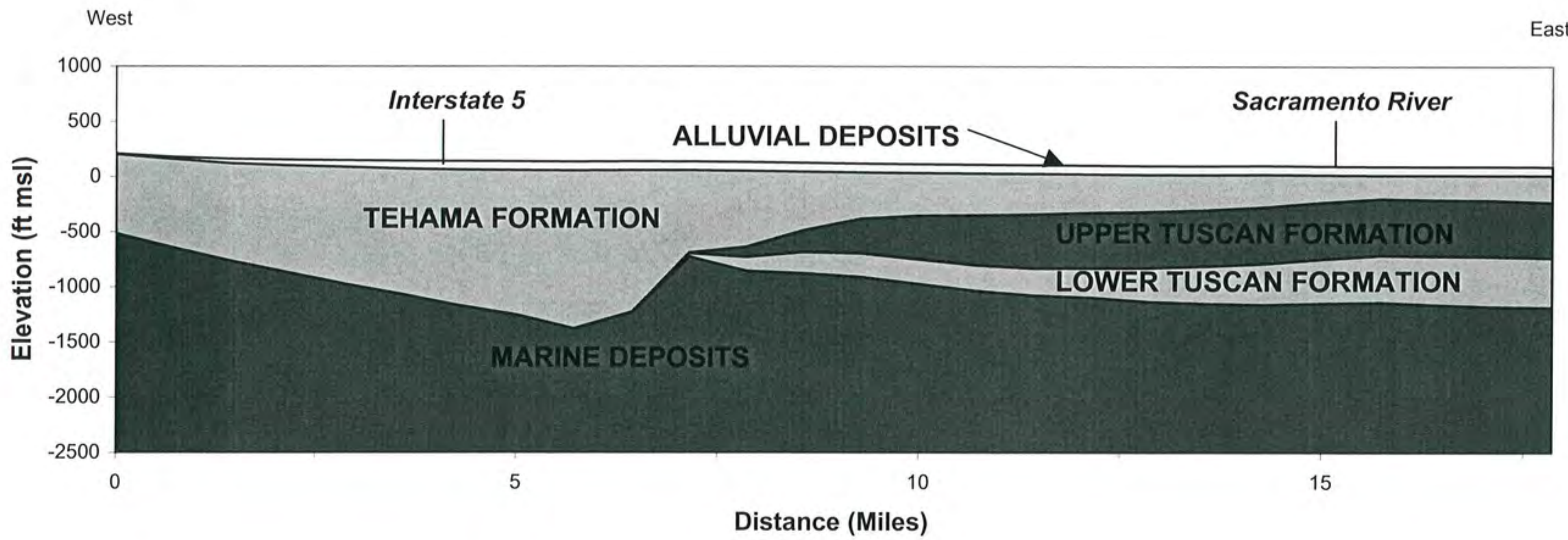


Table 5.2
Definition of SCFIGSM Stratigraphy Layers

Location within Model	Fan Material	Alluvium, Basin and Flood Plain Deposits	Tehama Formation	Upper Tuscan Formation	Lower Tuscan Formation
	Predominantly gravel and sand with minor amounts of silt and clay.	Characterized by fine-grained silts and clays.	Moderately compacted sandstone and siltstone enclosing lenses of sand and gravel; silt and gravel; and cemented conglomerate.	Characterized by massive lahar deposits.	Composed of volcanic conglomerate, sandstone, and siltstone layers interbedded with lahars.
Inside Fan Area					
Layer 1	■1 ●1	●1			
Layer 2		■2	■2 ●2		
Layer 3				■3 ●3	
Layer 4					■4 ●4
Outside Fan Area					
Layer 1	Not Present	up to 80 feet ■1 ●1			
Layer 2		greater than 80 feet ■2	■2 ●2		
Layer 3				■3 ●3	
Layer 4					■4 ●4

■ Designates the composition of each layer in the current model using Layer 1 = 50-80 feet thick where Layer 1 is defined by the hydrogeologic properties of the material.

● Designates the composition of each layer in the alternate model which would follow the geologic cross sections exactly and classifly Layer 1 as all Quaternary alluvial deposits.

SCFIGSM LAYER 2

The conceptual model for SCFIGSM Layer 2 consists primarily of the Tehama Formation (described in Section 3). The widespread distribution and thickness allow this formation to supply water to many of the agricultural wells in the study area. The Tehama Formation is present throughout the model area ranging in thickness from about 200 feet to over 2,000 feet. Model Layer 2 thickens from west to east about halfway across the model area. Model Layer 2 thins rapidly where Model Layer 3 is present (Table 5.2). As mentioned above, for modeling purposes, Layer 2 does include some basin and alluvial deposits.

Model Layer 2 generally represents groundwater systems ranging from semi-confined to confined conditions. Confinement generally increases with depth, but the actual level of confinement may vary locally due to other conditions, such as continuously perforated wells connecting different aquifer layers. Model Layer 2 is exposed at the ground surface in the northwestern portion of the model area.

SCFIGSM LAYER 3

The conceptual model for SCFIGSM Layer 3 consists of the Upper Tuscan Formation (described in Section 3). Model Layer 3 is present throughout the eastern portion of the model area (Figure 5.5). Although this layer contains coarse grained sandstone and conglomerate lenses within the study area, this layer predominantly consists of fine-grained lahar deposits, so groundwater within Layer 3 represents confined aquifer conditions. Because of its overall low permeability, few wells in the model area rely on Layer 3 for groundwater supply.

SCFIGSM LAYER 4

The conceptual model for SCGIGSM Layer 4 consists of the Lower Tuscan (described in Section 3). Model Layer 4 is present throughout the eastern portion of the model area (Figure 5.5). In contrast to Layer 3, it is composed of more permeable volcanic conglomerate, sandstone, and siltstone layers interbedded with lahars. It is overlain by the Upper Tuscan Formation (Layer 3), which acts as a confining layer; as a result, groundwater within Layer 4 represents confined aquifer conditions. At this time, few production wells in the model area reach Layer 4, so it currently has little groundwater production and water level data.

Base Of The Aquifer System

The base of the aquifer system is considered to be the base of the freshwater-bearing deposits (Figure 5.5). The base of the aquifer system is represented by the base of Model Layer 2 (base of the Tehama Formation) in the western half of the model area. The base of the aquifer system is represented by the base of Model Layer 4 (base of the Lower Tuscan Formation) in the eastern half of the model area.

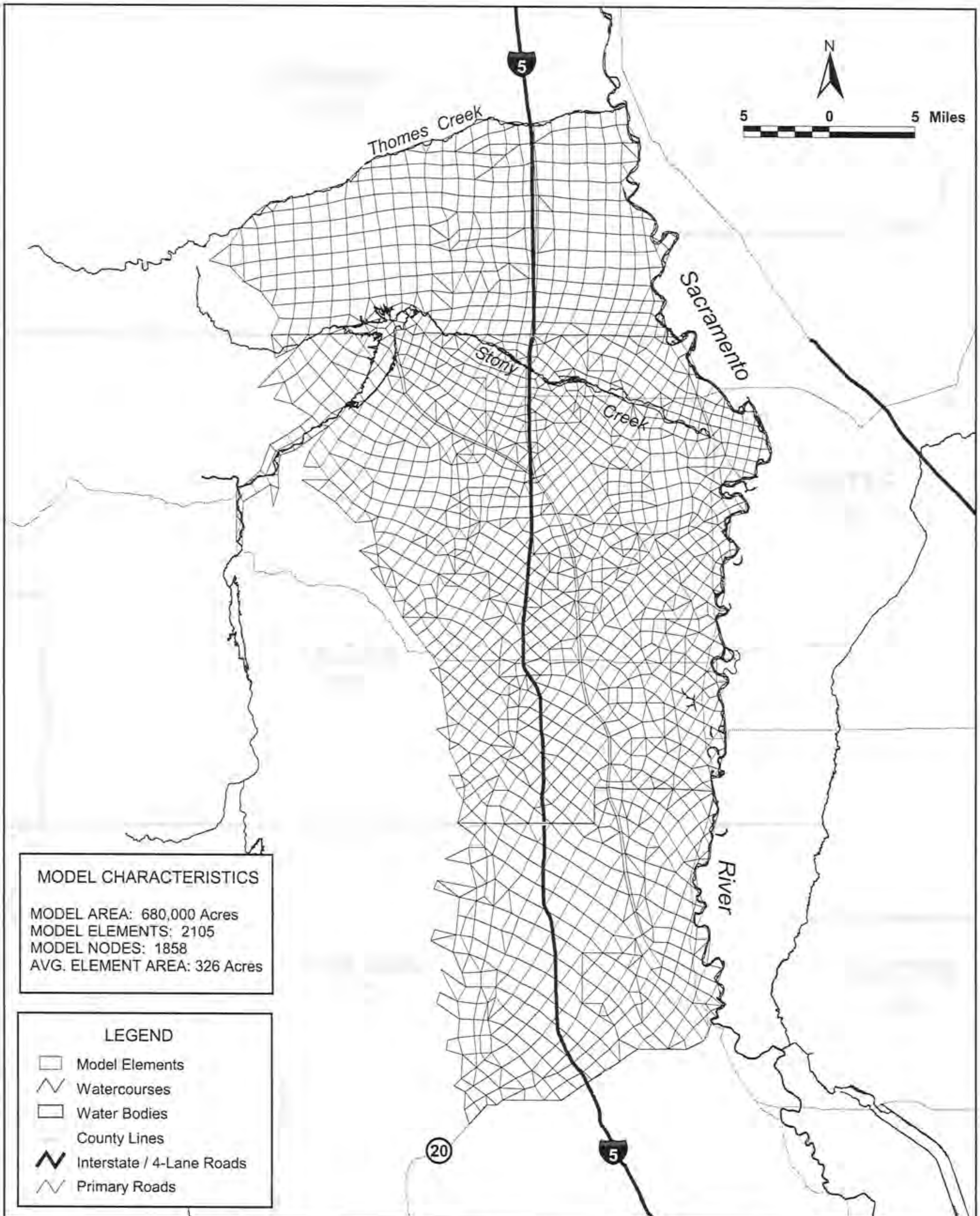
The base of freshwater is mapped in the model area on the basis of available electronic log data. In some locations the base of freshwater is identified to exist within the lower portions of the Tehama Formation or Tuscan Formation (Figure 5.5**Error! Bookmark not defined.**). The base of freshwater is not considered as a boundary between model layers because it is not a fixed location (such as the base of a formation).

SCFIGSM GRID

A two-dimensional finite element grid network was developed to model the groundwater flow in the Stony Creek Fan Area. The entire model area consists of about 1,060 square miles. The SCFIGSM model grid (shown in Figure 5.6) was divided into 2,105 elements and 1,858 model nodes. The average size of single element is about one-half square mile (316 acres). Notable features of the model grid are:

- Model boundary matches the hydrologic and hydrogeologic boundaries of the Stony Creek Fan Area;
- Grid orientation follows the regional groundwater streamlines;
- Elements are smaller in the vicinity of steep groundwater gradients; and
- Thin strips of elements are used to incorporate the discontinuities in the groundwater levels across major geologic faults and barriers.

The model grid is defined by Universal Transverse Mercator (UTM) coordinates at each model node and be the list of connecting nodes for each model element. The x-y coordinates for each model node were obtained from Geographic Information System (GIS) coverage of the model area in UTM Zone 10.5. The list of connecting nodes for each element was developed after numbering the model nodes and model elements. Two independent sets of sequential numbers were used for nodes and elements. These node and element numbers are used in specifying model input data.



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Model Grid

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FIGURE 5.6

The SCFIGSM grid was developed to reflect local conditions including:

- Geologic and Hydrogeologic Considerations,
- Hydrologic Considerations, and
- Potential Water Management Project Areas.

Each of these considerations is described below.

Geologic And Hydrogeologic Considerations

The geologic and hydrogeologic information presented in Section 3 was considered during the SCFIGSM model grid development. These include:

- Geologic Contacts,
- Faults, and
- Groundwater Flow Direction.

Geologic Contacts

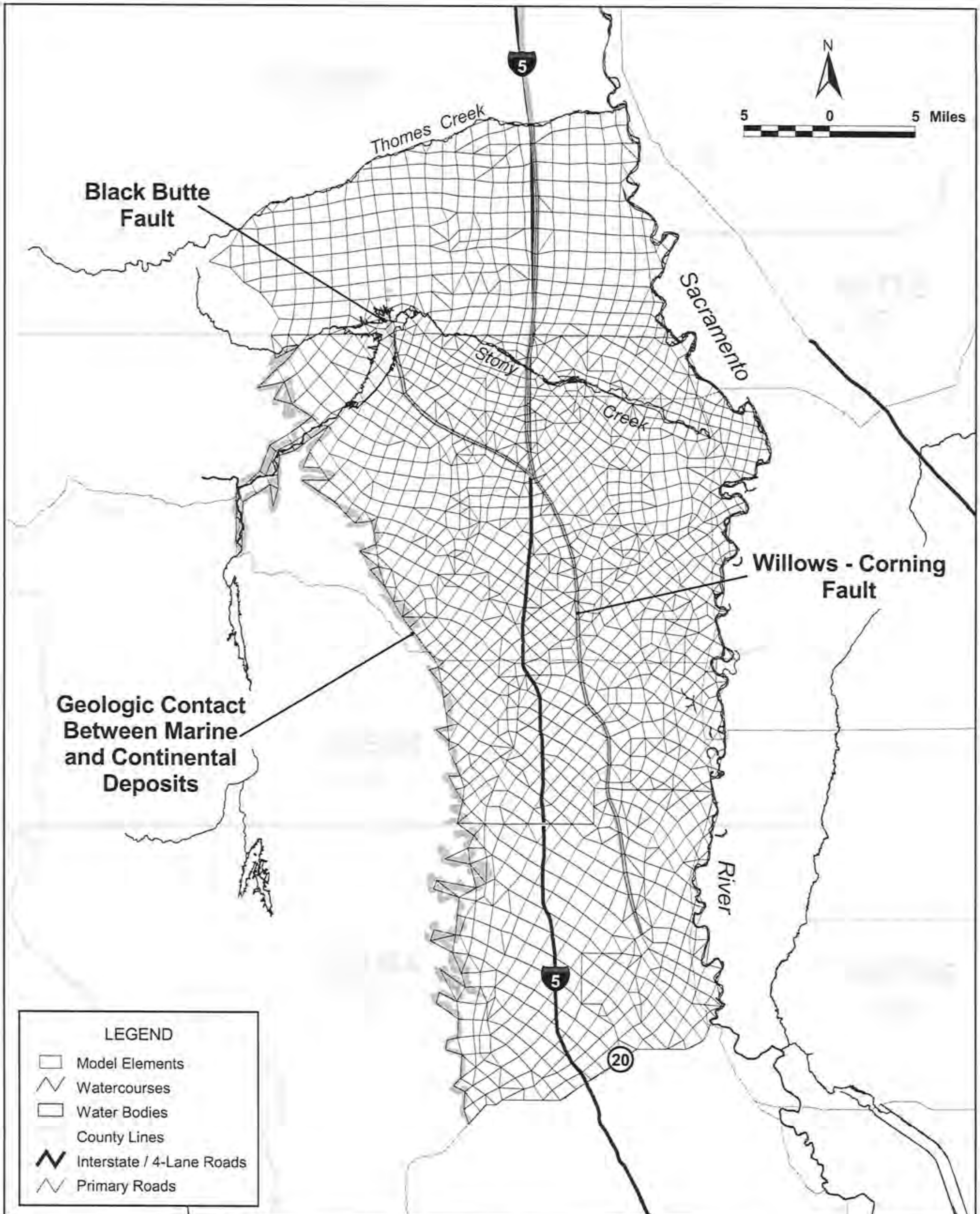
The western boundary of the SCFIGSM grid was defined as the contact between the marine basement rocks of the Coast Range and the continental and alluvial deposits of the Central Valley.

Faults

The SCFIGSM model grid was developed to reflect those faults that either may affect the flow of groundwater, or result in an abrupt change in the aquifer thickness. The SCFIGSM model grid reflects existence of faults by a narrow band of elements along the trace of the fault. After several discussions with DWR, the two faults incorporated into the model grid include the Black Butte Fault and the Willows-Corning Fault. The locations of these faults are shown in Figure 5.7.

Groundwater Flow Direction

The long-term regional groundwater flow directions were considered in the SCFIGSM grid development. Near the Stony Creek Fan, the regional groundwater flow direction is from the fan's apex to the distal portions of the fan generally in the northwest to southeast direction.



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Geologic and Hydrogeologic Considerations

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FIGURE 5.7

North and South of the Stony Creek Fan groundwater generally flows from the upland areas in the west towards the Sacramento River near the center of the Valley.

HYDROLOGIC CONSIDERATIONS

The surface water flow system is modeled by using 1-dimensional line elements along the stream courses. These line elements are defined by stream nodes that are coincident with the aquifer nodes. An independent numbering system is used to number the stream nodes. There are 266 stream nodes representing the surface water flow system in the SCFIGSM. This includes rivers, creeks, and lakes as well as major leaky water delivery canals and drains. Figure 5.8**Error! Bookmark not defined.** shows the locations of the hydrologic features simulated in the SCFIGSM model area, such as:

- Rivers and Creeks,
- Lakes, and
- Canals and Drains.

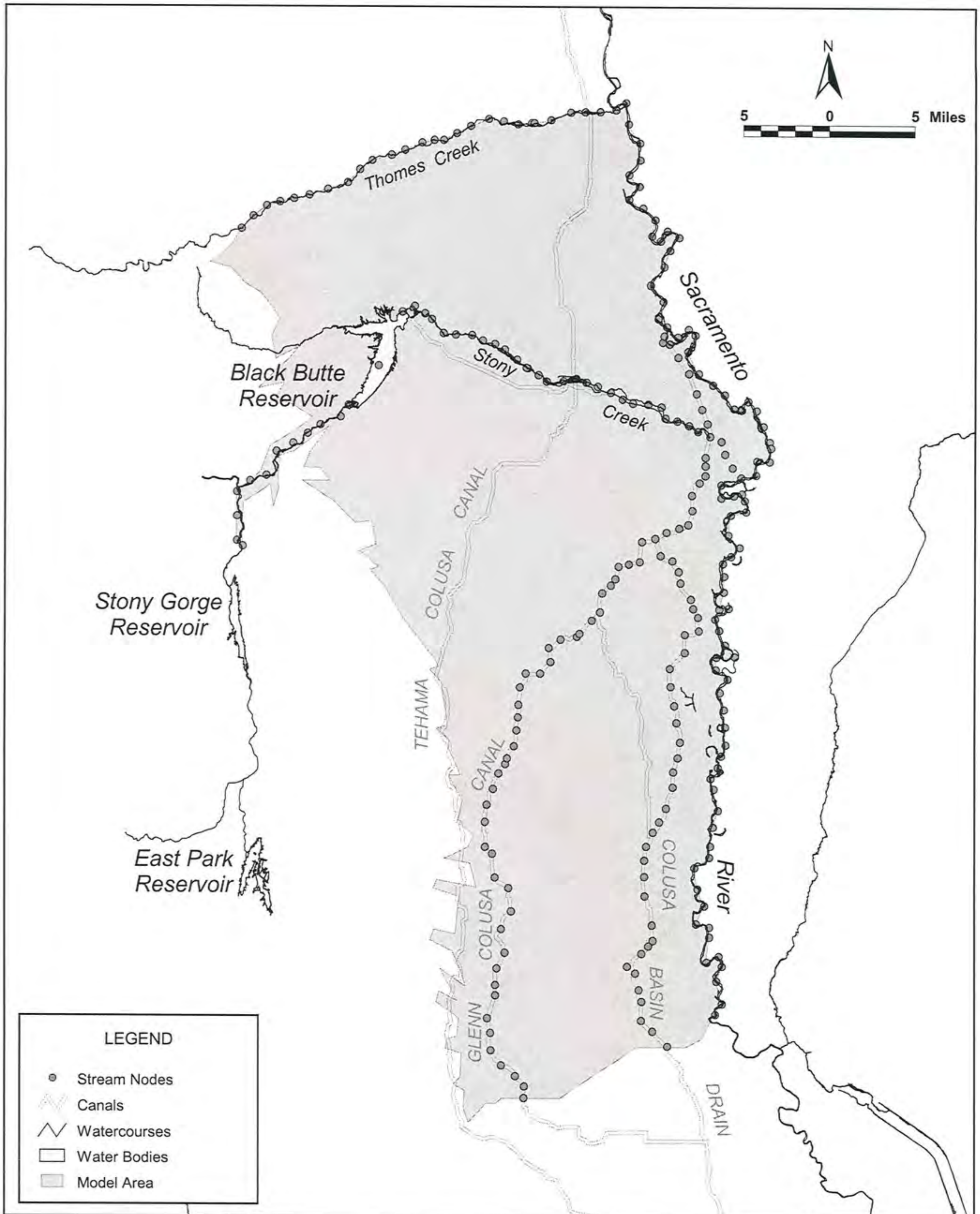
Rivers and Creeks

There are three rivers and creeks simulated in the SCFIGSM: Thomes Creek, Sacramento River, and Stony Creek.

- **Thomes Creek** coincides with the northern boundary of the SCFIGSM, and is simulated along the stream nodes shown in Figure 5.8**Error! Bookmark not defined.**.
- **The Sacramento River** coincides with the eastern boundary of the SCFIGSM, and is simulated along the stream nodes shown in Figure 5.8.
- **Stony Creek** is located within the SCFIGSM model area. It is simulated both above and below Black Butte Reservoir along the stream nodes shown in Figure 5.8.

Lakes

Black Butte Lake is located entirely within the SCFIGSM model area. The model grid was developed to represent the maximum inundation area of Black Butte Lake. The extent of the Black Butte Lake is shown in Figure 5.8.



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Location of Hydrologic Features

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FIGURE 5.8

Canals and Drains

There are two ways to model canals and drains in SCFIGSM: (1) by explicitly defining canals and drains as 1-dimensional stream elements, similar to river and streams; and (2) by specifying a series of recharge elements along the canal which recharges a portion of diverted water to the aquifer during conveyance of irrigation. The explicit definition of canals and drains require specification of canal cross section data and flow-stage rating curve at every stream node.

Two major canals and drains are modeled in the SCFIGSM by using 1-dimensional line elements; these are:

- The **Glenn-Colusa Irrigation District Main Canal** is unlined. It is simulated in the SCFIGSM along the stream nodes shown on Figure 5.8.
- The **Colusa Basin Drain** is unlined. It is simulated in the SCFIGSM along the stream nodes shown on Figure 5.8.

These canals are considered to be major water conveyance facilities that interact with the groundwater aquifer.

There are other leaky irrigation canals in the model area; such as Orland North and South Canals and Corning Canal. They will be simulated by specifying recharge elements along the canal.

The Tehama Colusa canal is concrete lined and leaks only a small amount of water. It can also be modeled by specifying recharge elements if canal seepage is determined to be of importance during the model calibration.

POTENTIAL WATER MANAGEMENT PROJECT AREAS

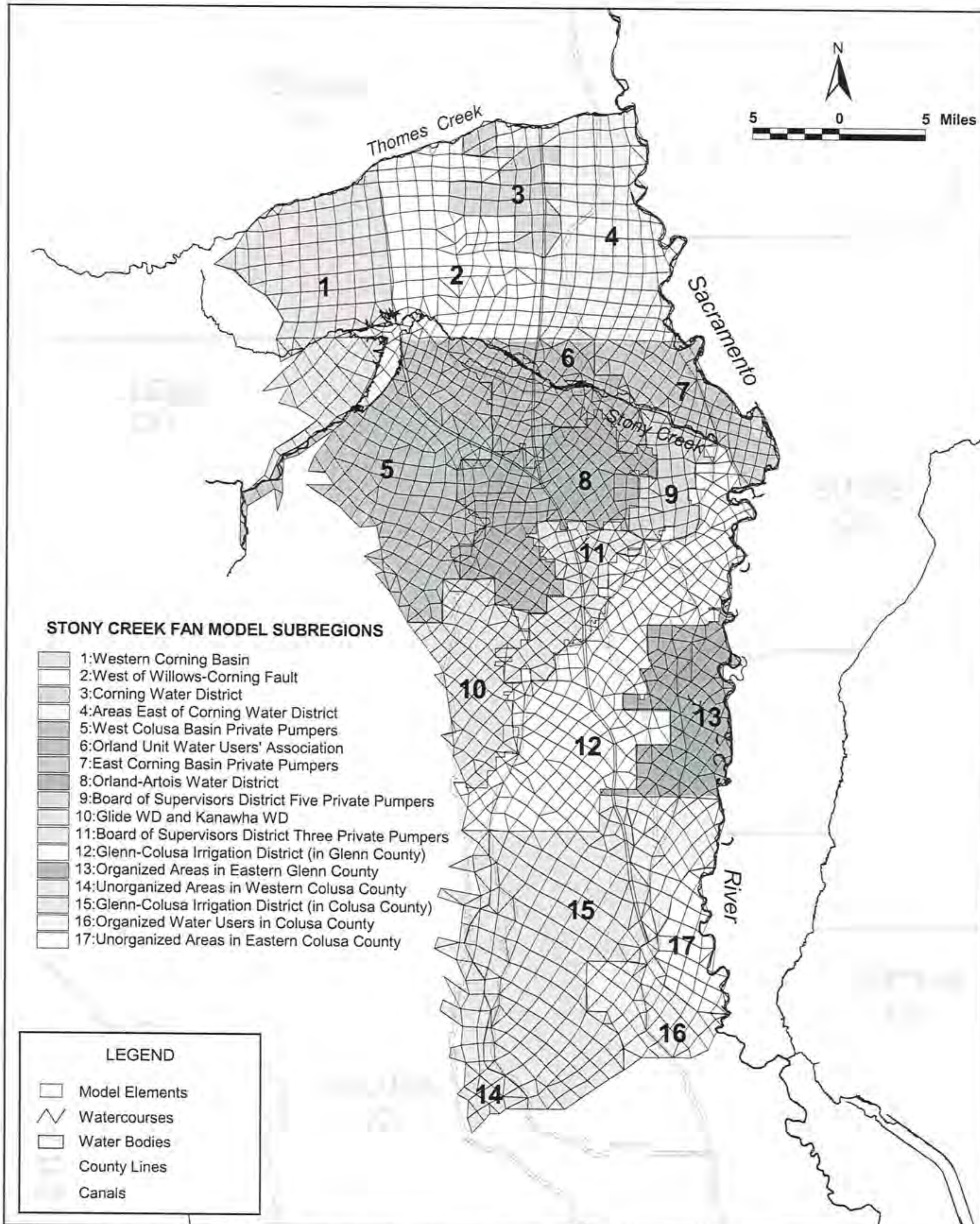
Water and land use management in the model area is represented in the SCFIGSM by subdividing the model area into 17 management areas called subregions. The criteria for the subregion delineation is described below and presented in Table 5.2. The SCFIGSM model subregions are shown on Figure 5.9.

Stony Creek Feasibility Study Subunits

Model subregions were developed to provide geographic coverage similar to the water balance subunits used in the Stony Creek Fan Feasibility Study. This criterion was utilized to define six subregions on or adjacent to the Stony Creek Fan as presented in Table 5.2 and shown in Figure 5.9. SCFIGSM Subregions 6, 7, 8, 9, 11, and 12 were defined based on this criterion.

Table 5.2
SCFIGSM Model Subregions

Stony Creek Fan Conjunctive Use Project		*Primary Criteria*	*Optional Criteria*	
Subregion Number	**Model Subregion Name**	**Stony Creek Fan Feasibility Study Water Balance Subunits**	**Glenn County BMO Basin Management Sub-Area**	**Comments**
1	Western Corning Basin	NA	1 (West Corning Basin Private Pumpers)	Includes unorganized areas in western Tehama County.
2	West of Willows Corning Fault	NA	NA	Includes the area between the northern extension of the Black Butte Fault and the Willows-Corning Fault.
3	Corning Water District	NA	NA	
4	Areas east of Corning Water District	NA	NA	
5	West Colusa Basin Private Pumpers	NA	3 (West Colusa Basin Private Pumpers)	
6	Orland Unit Water Users' Association	1 (Orland Unit Water Users' Association)		
7	East Corning Basin Private Pumpers	5 (East Corning Basin Private Pumpers)		
8	Orland-Artois Water District	2 (Orland-Artois Water District) and 4(Unorganized Pumpers embedded in OAWD)		
9	Board of Supervisors District Five Private Pumpers	6 (Board of Supervisors District Five Private Pumpers)		
10	Glide WD and Kanawha WD	NA	6 (Glide WD) and 7 (Kanawha WD) (and small portion of Sub-Area 11 west of GCID)	
11	Board of Supervisors District Three Private Pumpers	7 (Board of Supervisors District Three Private Pumpers)		
12	Glenn-Colusa Irrigation District (in Glenn County)	3 (Glenn-Colusa Irrigation District)		
13	Organized Areas in Eastern Glenn County	NA	12 (Provident ID), 13 (Willow Creek MWC), 14 (Princeton-Codora- Glenn ID)	Includes portion of Willow Creek MWC in Glenn County.
14	Unorganized Areas in western Colusa County	NA	NA	
15	Glenn Colusa Irrigation District (in Colusa County)	NA	NA	Includes portion of GCID in Colusa County north of Highway 20.
16	Organized Water Users in Colusa County	NA	NA	Includes Maxwell ID, Colusa Drain Water Users' Association
17	Unorganized Areas in Eastern Colusa County	NA	NA	



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Model Subregions

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FIGURE 5.9

Glenn County Basin Management Objectives Basin Management Sub-Areas

Additional model subregions were developed to provide geographic coverage similar to the basin management subareas used in the Glenn County Basin Management Objectives. This criterion was utilized to define four subregions within the model area in Glenn County as presented in Table 5.2 and shown in Figure 5.9**Error! Bookmark not defined.**. SCFIGSM Subregions 1 (portion in Glenn County), 5, 10, and 13 were defined based on this criterion.

Tehama County

Four subregions were defined in Tehama County based on the hydrogeologic conditions and water supply source (access to surface water). Subregions 1 (portion in Tehama County), 2, 3, and 4 were defined based on this criterion.

Colusa County

Four subregions were defined in Colusa County, primarily based on the water supply source (access to surface water). Subregions 14, 15, 16, and 17 were defined based on this criterion.

DESCRIPTION OF FLOW SYSTEMS AND BOUNDARY CONDITIONS

The groundwater flow system in the SCFIGSM area is part of the larger Central Valley groundwater basin of California. The Central Valley groundwater basin encompasses about 20,000 square miles of area. It is an almost flat alluvial plain extending more than 400 miles from near Redding in the north to near Bakersfield in the south. The width of the valley ranges from 20 to 70 miles with an average of 50 miles in most places. The Central Valley is a closed groundwater basin with an outlet into the Sacramento-San Francisco Delta where two major rivers of the Valley, the Sacramento River and the San Joaquin River, drain their outflows. The Valley is surrounded by the Klamath mountains on the north, by a volcanic plateau of the Cascade Range on the northeast, by the Coastal Ranges on the west, by the Sierra Nevada on the east, and by the Coast Ranges and the Tehachapi mountains on the south. The SCFIGSM groundwater basin is part of this larger Central Valley groundwater basin.

The underlying groundwater aquifer in the SCFIGSM model area is replenished by precipitation recharge, streams/canal seepage, and recharge of applied water over vast lands of irrigated acreage. Recent geologic investigations indicate that the SCFIGSM model area also receives groundwater from areas east of Sacramento River through relatively transmissive lower Tuscan formation which has surface outcrops in Butte County, east of the Sacramento

River. The underlying aquifer is also pumped to meet irrigation demands that cannot be met by surface water supplies. Almost all of the urban water demands in the area is also met by groundwater pumping.

The groundwater flow system in SCFIGSM model area can be defined by specifying the boundaries of the model area. IGSM requires specification of boundary conditions such as groundwater elevation or flux along the boundary of the model. The types of boundary conditions that can be handled by the SCFIGSM include:

- Prescribed flux
- Specified head
- Mixed head (rating table between heads and flows)
- General head
- Small watershed inflow

The small watershed inflow boundary condition accounts for groundwater baseflow or streamflow generated from the watershed areas adjacent to the model area. The model can simulate subsurface or surface outflows from these areas and route them as groundwater recharge or to nearby streams within the model area.

The specific boundary conditions of SCFIGSM are described below.

EXTERNAL BOUNDARIES

North Boundary

The model area is bounded on the north by the Thomes Creek. A no flux boundary condition is assumed along that boundary because of historical evidence of water level measurements and groundwater contour maps;

East Boundary

The model area is bounded on the east by the Sacramento River. A specified flux boundary condition is assumed along this boundary because of anectdotal evidence of water flowing underneath the Sacramento River through the lower Tuscan Formation. The amount of specified flux will be determined during model calibration.

South Boundary

The model area is bounded on the south by the Highway 20, which acts as a groundwater divide on the basis of historical evidence of water level measurements and groundwater contour maps.

West Boundary

The model area is bounded on the west by the geologic contact. A no flux boundary condition is assumed along this boundary.

INTERNAL BOUNDARIES

The internal boundaries are the geologic faults within the model area; they are:

A. Willows Corning Fault; and

B. Black Butte Fault.

Provisions for these internal boundaries require that the model be constructed such that barrier effects and rapid groundwater level changes across faults can be simulated. In order to simulate these internal boundaries, the model grid are kept finer spacing along these boundaries and then allowed to gradually transition to a coarser spacing away from the boundaries. These boundaries may not be vertically continuous.

A conceptual model for the Stony Creek Fan Integrated Groundwater and Surfacewater Model (SCFIGSMM) was presented in this report. The conceptual model was developed on the basis of hydrogeology of the model area, hydrology, land use, water use, and other relevant information and data as well as goals and objectives of the modeling.

This conceptual model will guide the development of the numerical simulation model for the Stony Creek Fan. The following section provides additional information on the potential uses and limitations of the numerical model.

MODEL USES AND LIMITATIONS

The primary intent of the Project Sponsor is to use the SCFIGSM in the formulation and development conjunctive water management strategies in the study area. This is generally a three-step process:

1. development of an calibrated model;
2. development of a baseline model; and
3. use of model in the alternatives analysis.

The definition of these model types is provided below:

Calibrated (or Historic) Model: A model that simulates the historic conditions (generally 20 to 30 years period) and is calibrated with recorded observations of groundwater levels (or other relevant variables of interest); the process of calibration (or history matching) ensures that the model is representative of the physical system being modeled.

Baseline Model: This is a revised version of the Calibrated Model with the following changes in input data: (a) the future land and water use conditions (such as 2030 build out conditions) replace the historic land and water use data; and (b) the surrogate for the future hydrology is a long sequence of historic observed hydrology. This baseline model provides the reference frame for comparison of all alternatives.

Alternatives Models: These are the versions of Baseline model with different alternative scenarios of land and water use conditions and/or conjunctive water management programs. The results of these models are used to determine the comparative impacts of different alternatives with reference to the Baseline Model results.

USE OF MODELS FOR DEVELOPMENT AND/OR REFINEMENT OF BMOS

Basin Management Objectives (BMO) are basin operational criteria developed on the basis of historic measurements of well water levels, understanding and observations of groundwater basin behavior, and other field observations. A baseline model (with existing or 2030 conditions and historic hydrologic sequence as a surrogate for future hydrology) cannot be used to evaluate/ revise/implement BMOs, because the purpose of a baseline model is to give reference frame for analyses of alternative management plans, while BMOs are real-time operational guidelines. Furthermore, a model cannot tell whether BMOs are met or not met; the compliance with BMOs can be evaluated only through monitoring of the water levels in the area. Therefore, model should not be used for implementing the Glenn County Groundwater Management Ordinance.

However, a calibrated model can be used to (a) possibly re-examine the assumptions made during the development of the BMOs; (b) enhance the information background of an existing decision or a revised decision related to the Groundwater Management Ordinance or BMOs; (c) identify sensitive areas where additional monitoring may be required to check compliance with BMOs; (d) develop general response characteristics and/or sensitivity ranges among different physical and operational elements; and (e) enhance understanding of the groundwater system behaviors, characteristics, and constraints.

The use of the calibrated model for the above purposes is contingent upon how well the model matches the historical groundwater level observations and how well the model represents physical systems to provide insights (not exact answer) into the groundwater basin response characteristics and into the inter-relationships among different physical and operational elements

USES AND LIMITATIONS OF MODELS IN MEETING THE COMMON GOALS OF THE PROGRAM SPONSORS

One of the common goals of the Program Sponsors is to pursue opportunities to maximize Program benefits through strategic, synergistic linkages with other regional water management activities and authorities. The model can help identify some opportunities or give some quantitative information to help formulate, understand, evaluate, and rank opportunities that can be specified in terms of model input data.

Another common goal of the Program Sponsors is to secure water supply reliability locally and provide opportunities for improved water supply reliability for water users' elsewhere in the state; the model can be used in a statistical mode to develop probabilistic measures of water supply reliability in the face of hydrologic uncertainties and different demand levels.

Another common goal is to seek ways to achieve environmental benefits that are compatible with project operations. A groundwater and surface water model cannot seek ways to achieve environmental benefits; also, a hydrologic model cannot determine whether environmental benefits are achieved or not. But the model can provide information on the water levels and stream flows that can be used as an indicator or measure for evaluating environmental benefits of different alternative plans.

USES AND LIMITATIONS OF MODELS IN MEETING THE INDIVIDUAL GOALS OF THE PROGRAM SPONSORS

The Orland Unit Water Users' Association has two individual goals: (1) enhanced management of surface water resources; and (2) infrastructure improvements. A model will be able to assess on a comparative basis different alternative ways to manage surface water resources (e.g. reservoir reoperations, conjunctive use, water exchanges etc.). In addition, a calibrated model can provide general estimates of canal seepage loss ranges and help compare different alternatives of canal lining; a calibrated model also can help screen pumping well field sites or recharge sites on a preliminary basis. Both model input data and output data will be helpful in this regard.

The Orland-Artois Water District's individual goal is to secure affordable water supply reliability in all years. The hydrologic model database will have the historic water needs and water supply data and it can be used in a statistical mode to help evaluate the water supply reliability, once the quantitative measure for affordable water supply reliability is determined by the district through its planning process.

The Glenn-Colusa Irrigation District's individual goal is to improve reliability and increase flexibility through integration of basin surface and groundwater resources. As mentioned before, a calibrated model can be used in the statistical mode to help evaluate the water supply reliability, once a quantitative measure of reliability in terms of hydrology is established by the district through its planning process. In addition, an integrated surface water and groundwater model will provide insights into the interrelationships among surface water and groundwater resources to help evaluate management strategies consistent with this individual goal.

GENERAL LIMITATIONS OF A MODEL

"Models are simplified mathematical representations of physical processes. Constructing a model that accounts for all the finest details of a process is not possible, nor is it useful or necessary." (Saquib Najmus, Water Resources Planning, AWWA Manual M50, AWWA, 2001, p.144). Thus no hydrologic model is an exact representation of the physical world. Therefore, the simulated or predicted groundwater levels from a groundwater model should never be