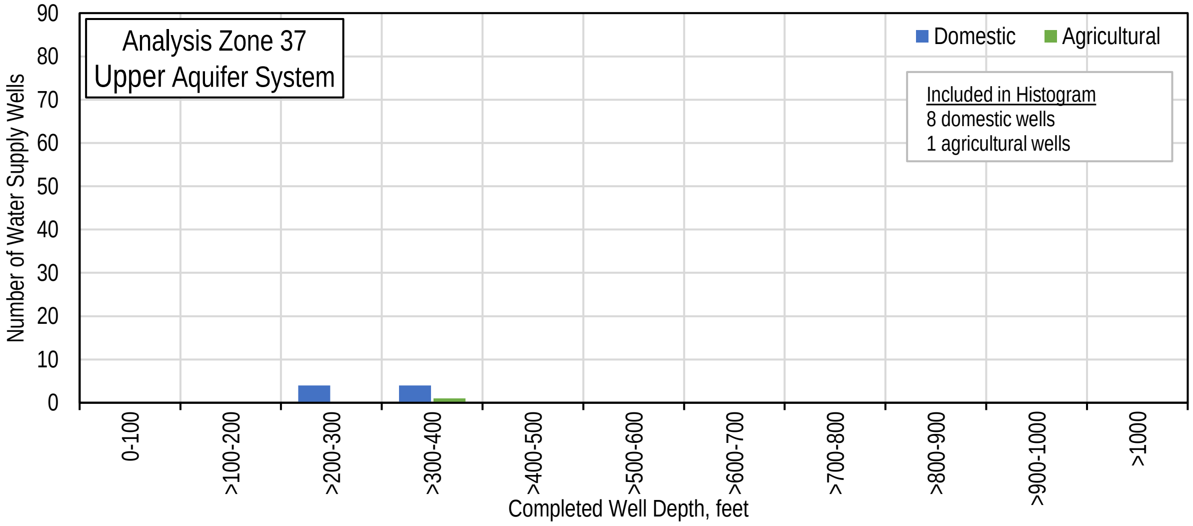
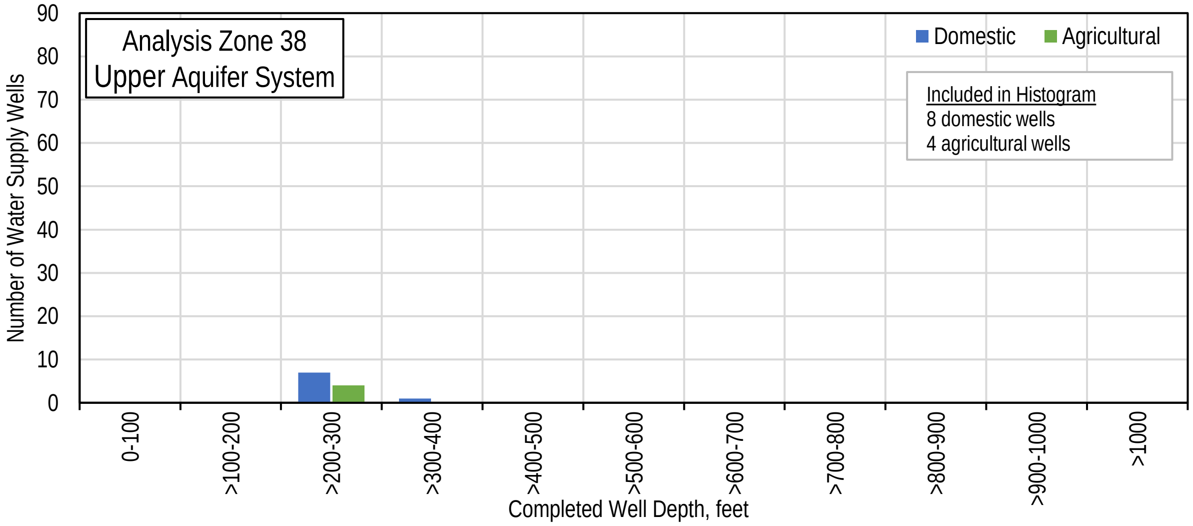
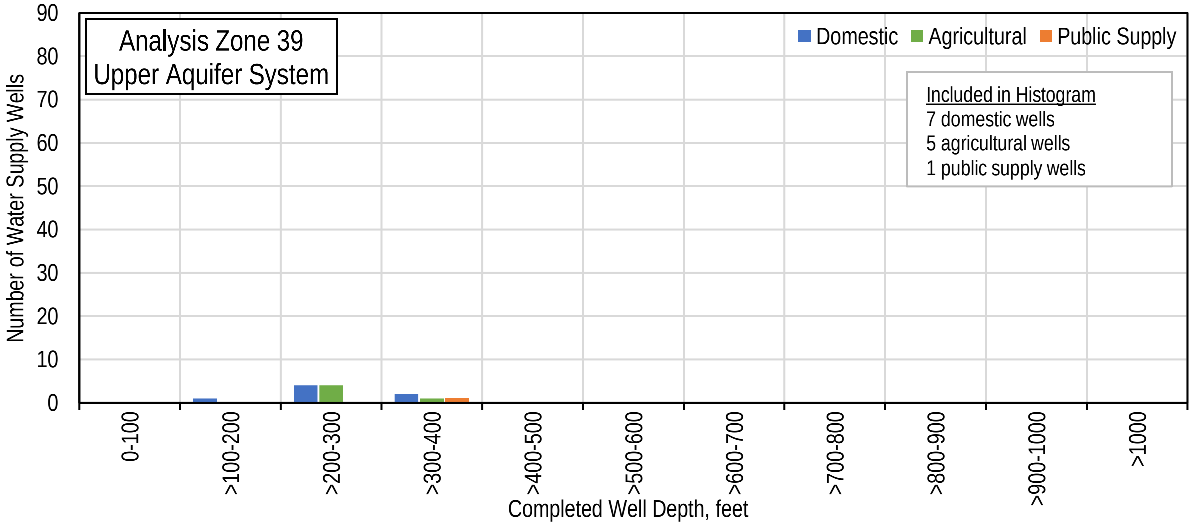
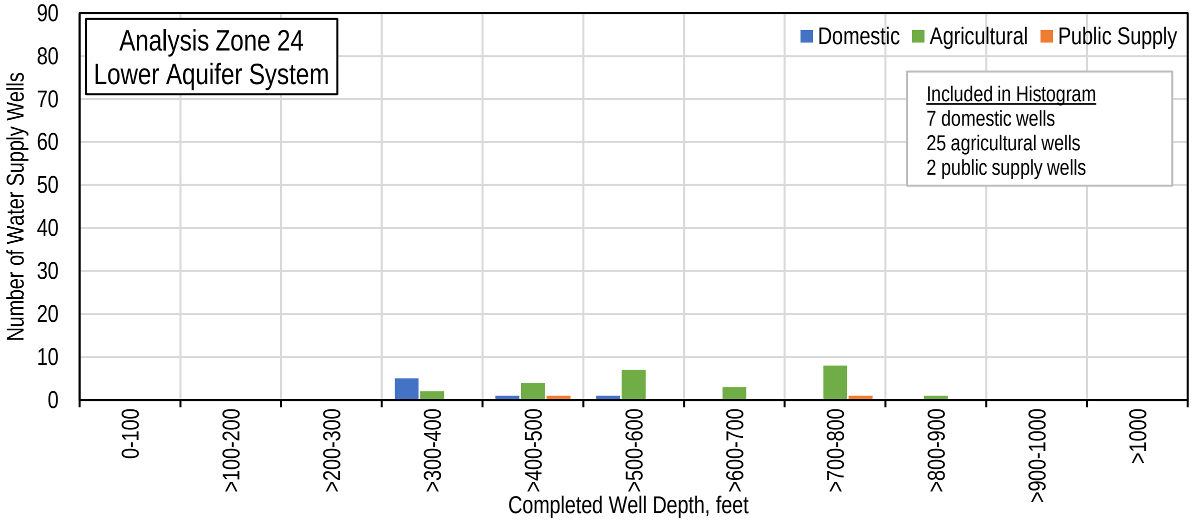
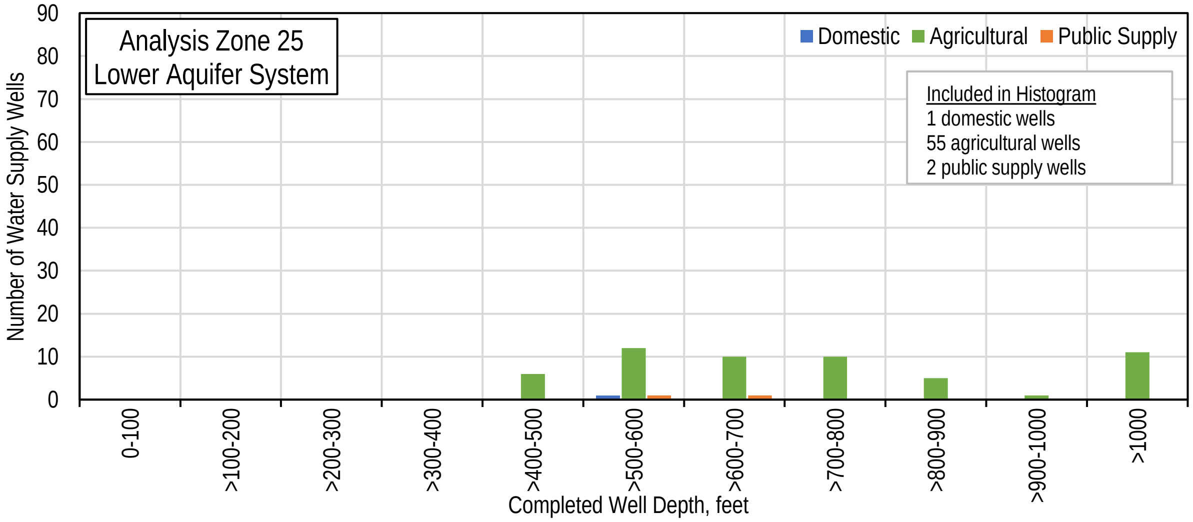
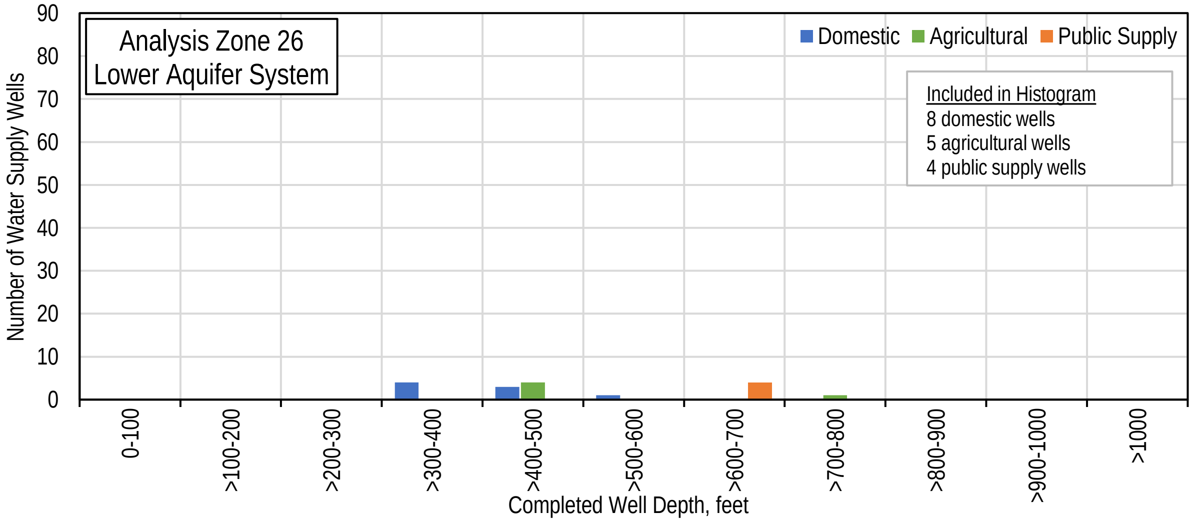

Analysis Zone 37
Upper Aquifer System
■ Domestic
■ Agricultural
Included in Histogram
8 domestic wells
1 agricultural wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

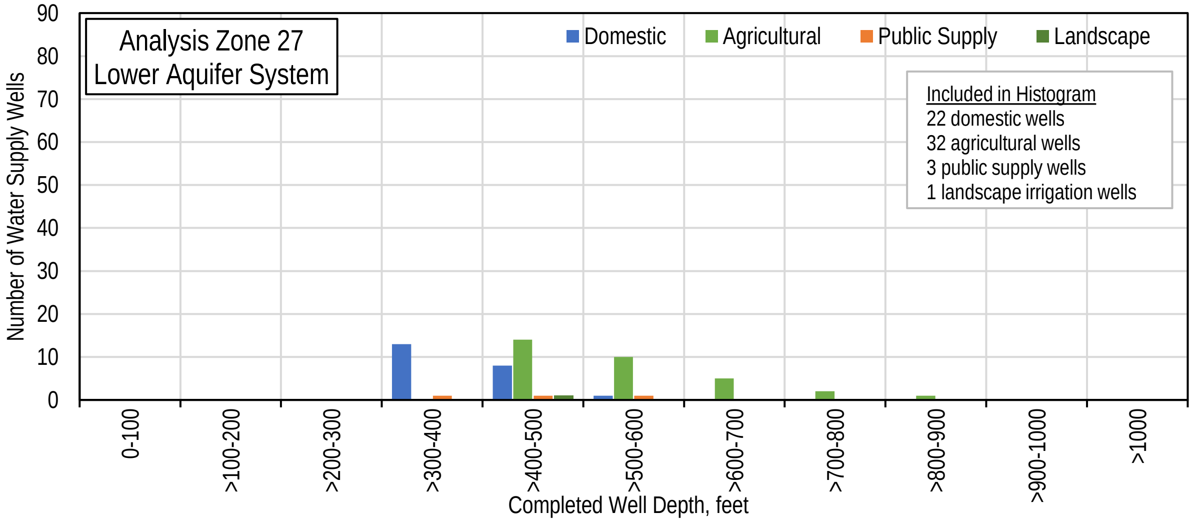

Analysis Zone 38
Upper Aquifer System
■ Domestic
■ Agricultural
Included in Histogram
8 domestic wells
4 agricultural wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

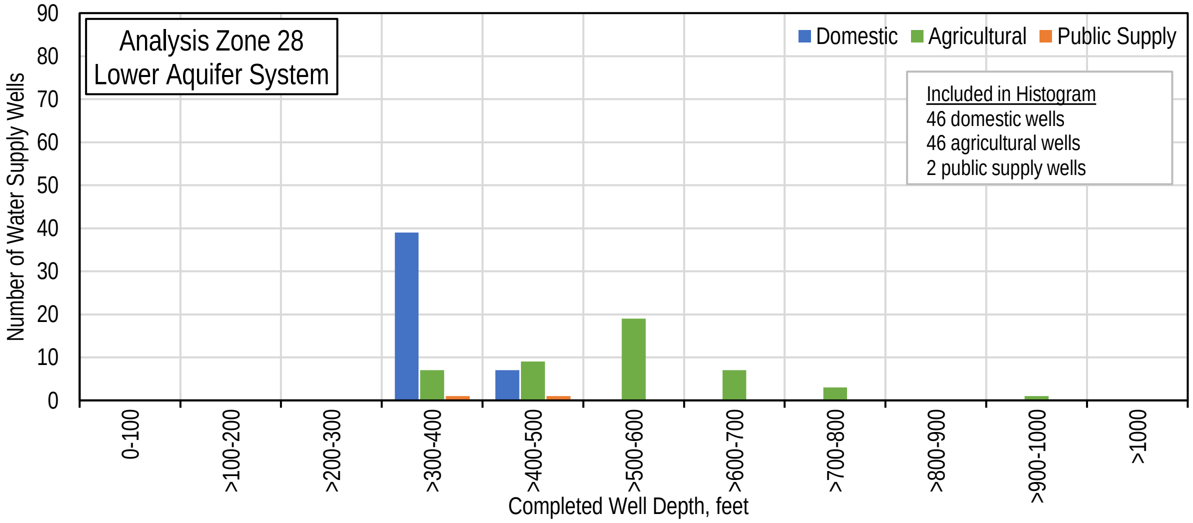

Analysis Zone 39
Upper Aquifer System
■ Domestic
■ Agricultural
■ Public Supply
Included in Histogram
7 domestic wells
5 agricultural wells
1 public supply wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

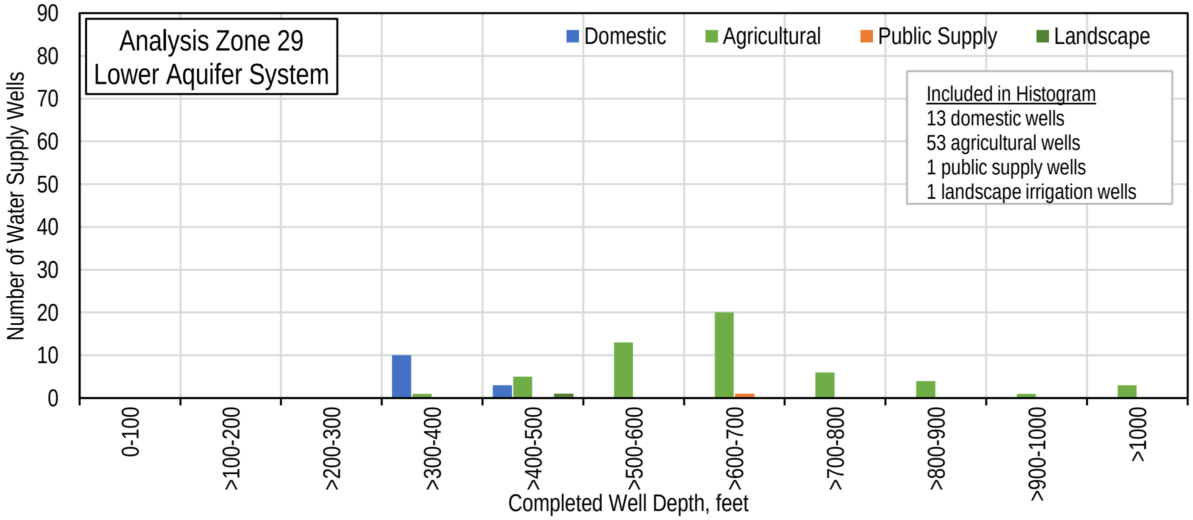

Analysis Zone 24
Lower Aquifer System
🟦 Domestic 🟩 Agricultural 🟧 Public Supply
Included in Histogram
7 domestic wells
25 agricultural wells
2 public supply wells
Number of Water Supply Wells
90
80
70
60
50
40
30
20
10
0
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

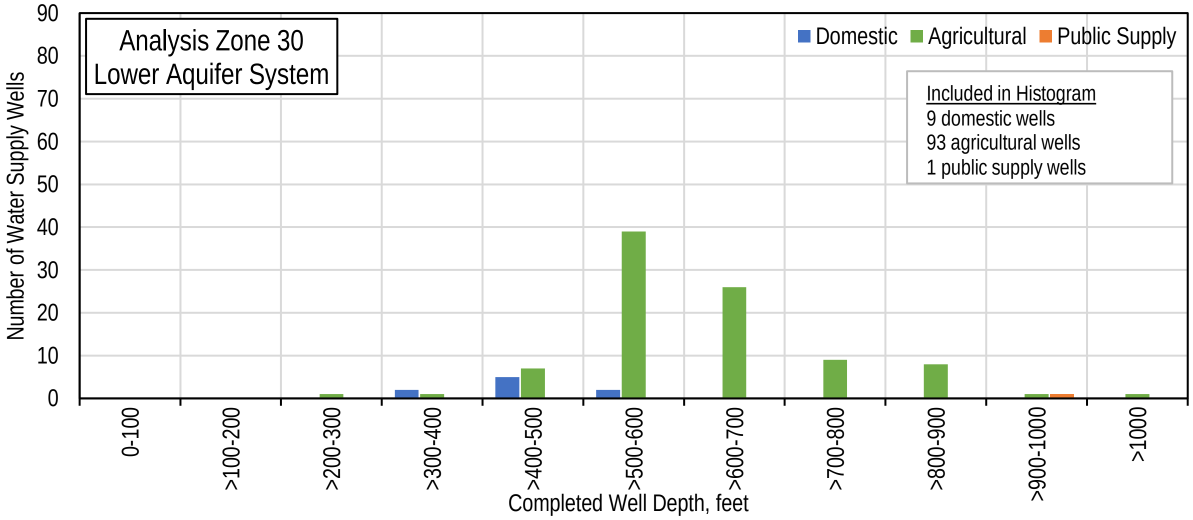

Analysis Zone 25
Lower Aquifer System
🟦 Domestic 🟩 Agricultural 🟧 Public Supply
Included in Histogram
1 domestic wells
55 agricultural wells
2 public supply wells
Number of Water Supply Wells
90
80
70
60
50
40
30
20
10
0
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

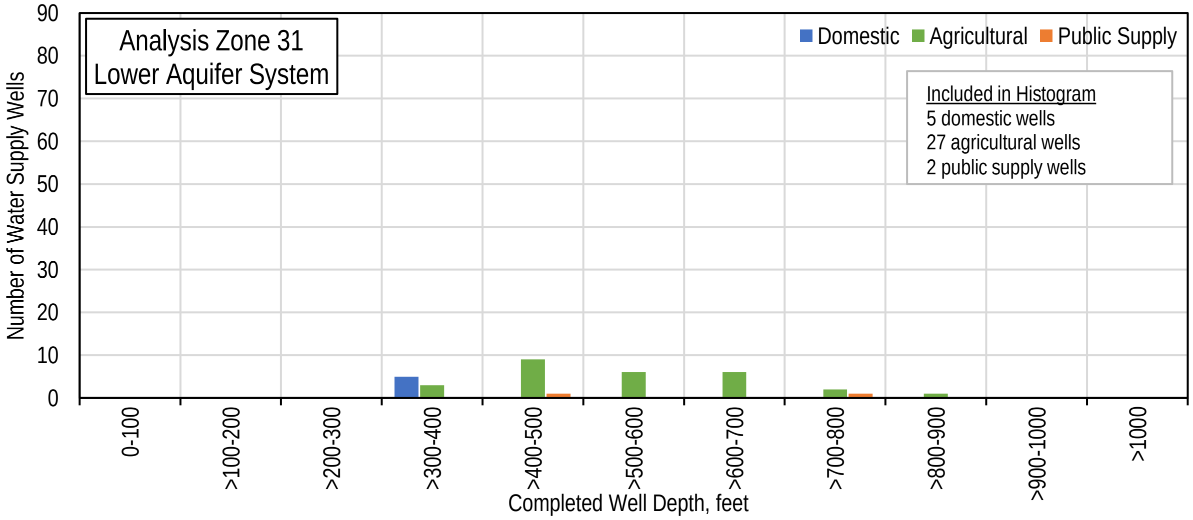

Analysis Zone 26
Lower Aquifer System
🟦 Domestic 🟩 Agricultural 🟧 Public Supply
Included in Histogram
8 domestic wells
5 agricultural wells
4 public supply wells
Number of Water Supply Wells
90
80
70
60
50
40
30
20
10
0
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

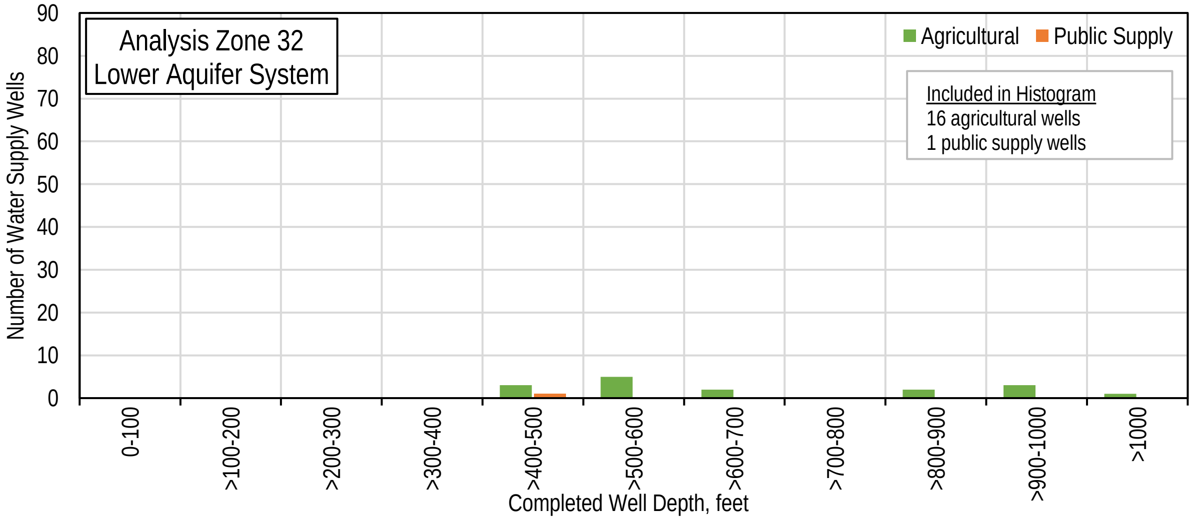

Analysis Zone 27
Lower Aquifer System
Domestic
Agricultural
Public Supply
Landscape
Included in Histogram
22 domestic wells
32 agricultural wells
3 public supply wells
1 landscape irrigation wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

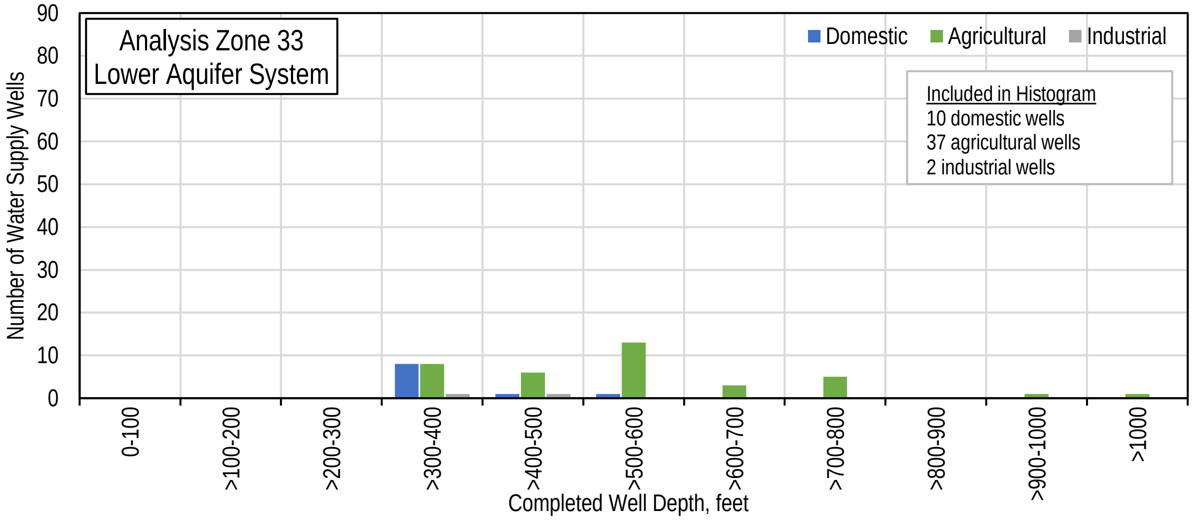

Analysis Zone 28
Lower Aquifer System
Domestic
Agricultural
Public Supply
Included in Histogram
46 domestic wells
46 agricultural wells
2 public supply wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

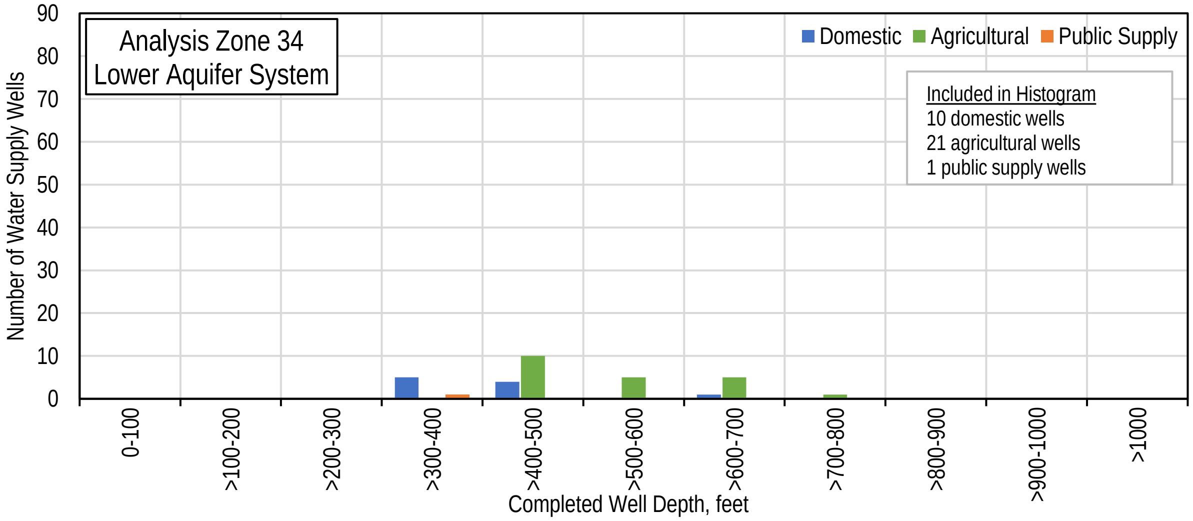

Analysis Zone 29
Lower Aquifer System
Domestic
Agricultural
Public Supply
Landscape
Included in Histogram
13 domestic wells
53 agricultural wells
1 public supply wells
1 landscape irrigation wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

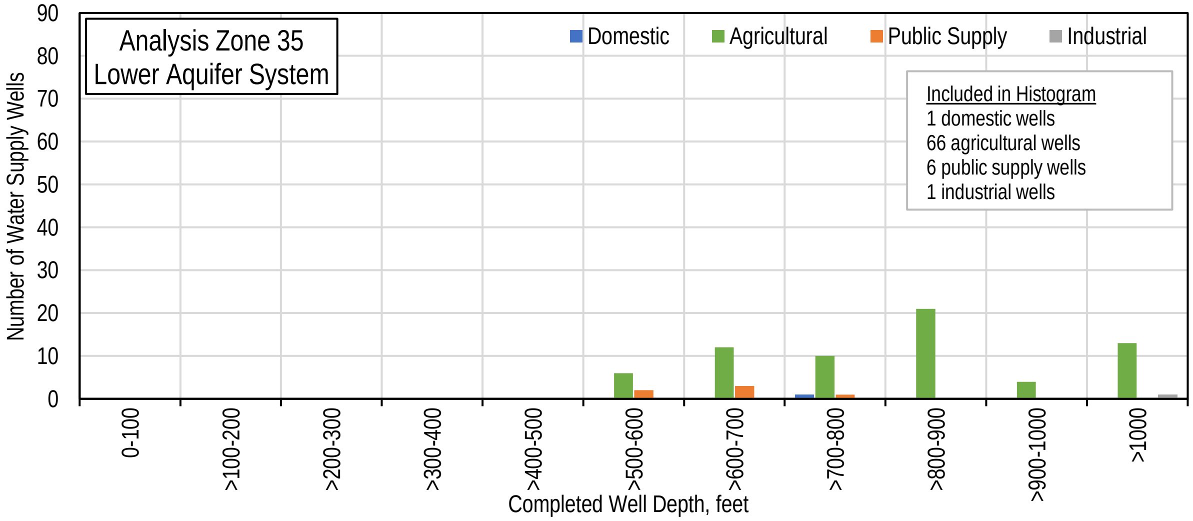

Analysis Zone 30
Lower Aquifer System
Domestic
Agricultural
Public Supply
Included in Histogram
9 domestic wells
93 agricultural wells
1 public supply wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

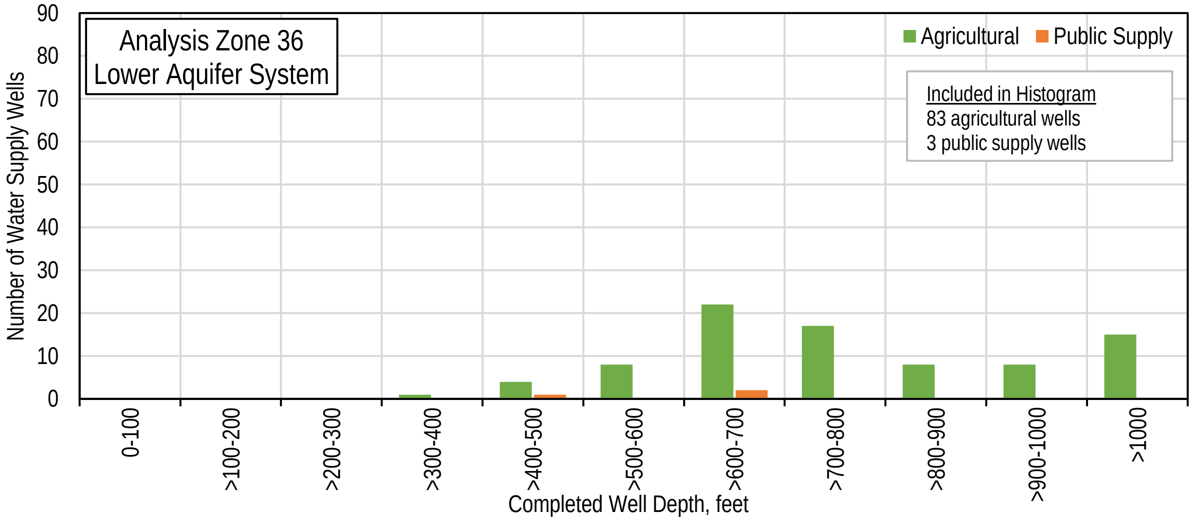

Analysis Zone 31
Lower Aquifer System
Domestic
Agricultural
Public Supply
Included in Histogram
5 domestic wells
27 agricultural wells
2 public supply wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

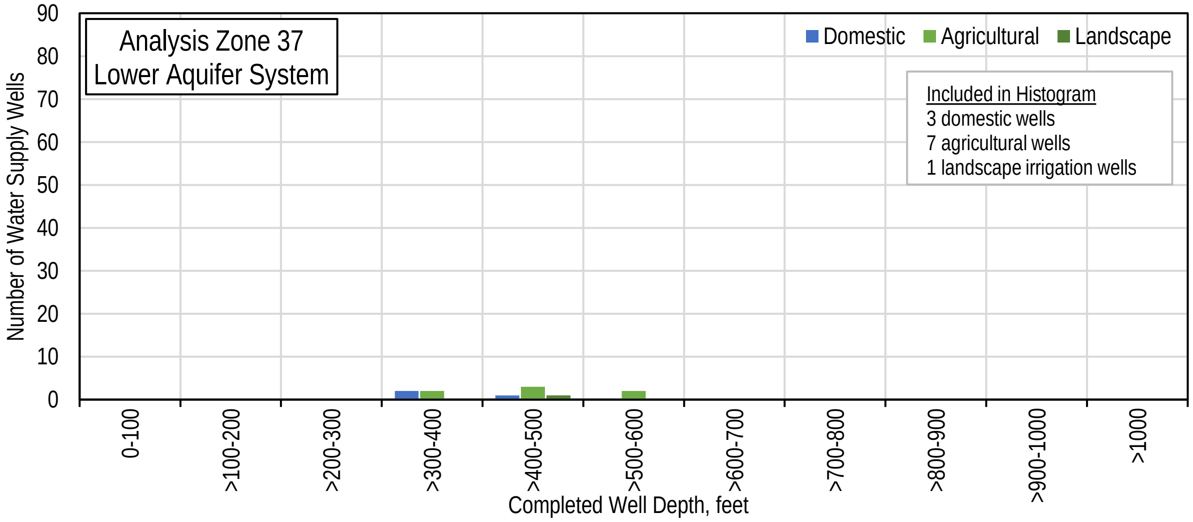

Analysis Zone 32
Lower Aquifer System
Agricultural
Public Supply
Included in Histogram
16 agricultural wells
1 public supply wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

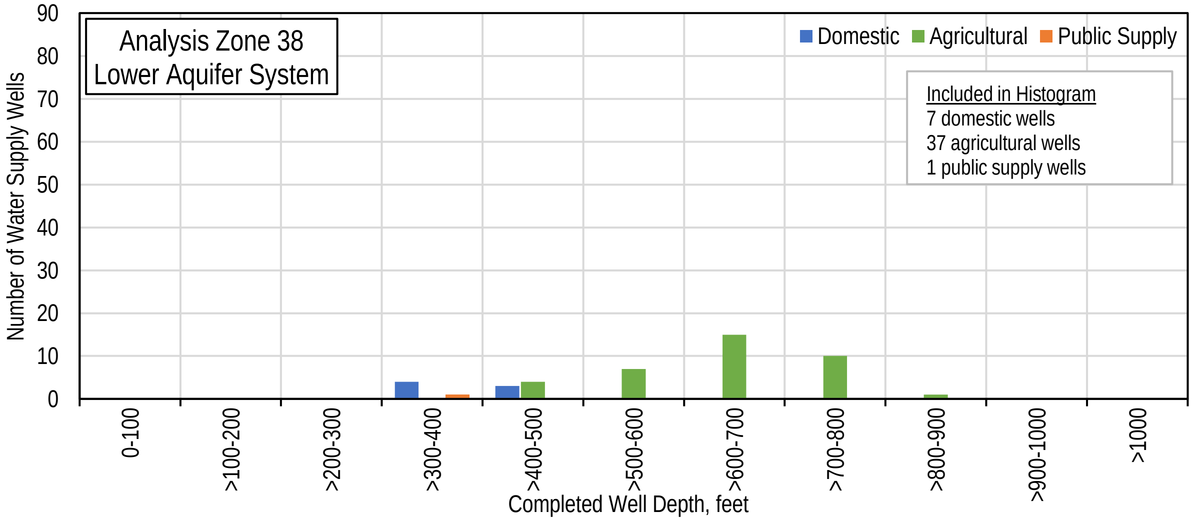

Analysis Zone 33
Lower Aquifer System
Domestic
Agricultural
Industrial
Included in Histogram
10 domestic wells
37 agricultural wells
2 industrial wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

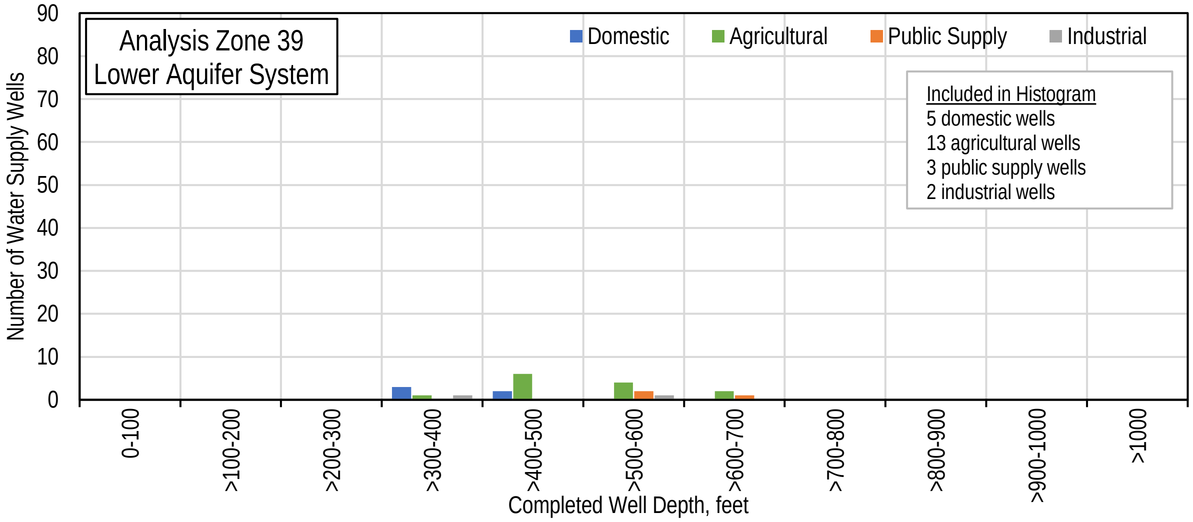

Analysis Zone 34
Lower Aquifer System
Domestic
Agricultural
Public Supply
Included in Histogram
10 domestic wells
21 agricultural wells
1 public supply wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet


Analysis Zone 35
Lower Aquifer System
Domestic
Agricultural
Public Supply
Industrial
Included in Histogram
1 domestic wells
66 agricultural wells
6 public supply wells
1 industrial wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet


Analysis Zone 36
Lower Aquifer System
Agricultural
Public Supply
Included in Histogram
83 agricultural wells
3 public supply wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet


Analysis Zone 37
Lower Aquifer System
Domestic
Agricultural
Landscape
Included in Histogram
3 domestic wells
7 agricultural wells
1 landscape irrigation wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet


Analysis Zone 38
Lower Aquifer System
Domestic
Agricultural
Public Supply
Included in Histogram
7 domestic wells
37 agricultural wells
1 public supply wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet


Analysis Zone 39
Lower Aquifer System
Domestic
Agricultural
Public Supply
Industrial
Included in Histogram
5 domestic wells
13 agricultural wells
3 public supply wells
2 industrial wells
Number of Water Supply Wells
0
10
20
30
40
50
60
70
80
90
0-100
>100-200
>200-300
>300-400
>400-500
>500-600
>600-700
>700-800
>800-900
>900-1000
>1000
Completed Well Depth, feet

MONTGOMERY
& ASSOCIATES

Appendix C

90% Protective Elevations (Methodology 1), Groundwater Level Trend Elevations (Methodology 2), and Interpolated Minimum Threshold (Methodology 3) for Representative Monitoring Site Minimum Thresholds

MONTGOMERY & ASSOCIATES

90% Protective, Groundwater Level Trend, and Interpolated Minimum Threshold Elevations for Kaweah Subbasin Representative Monitoring Sites

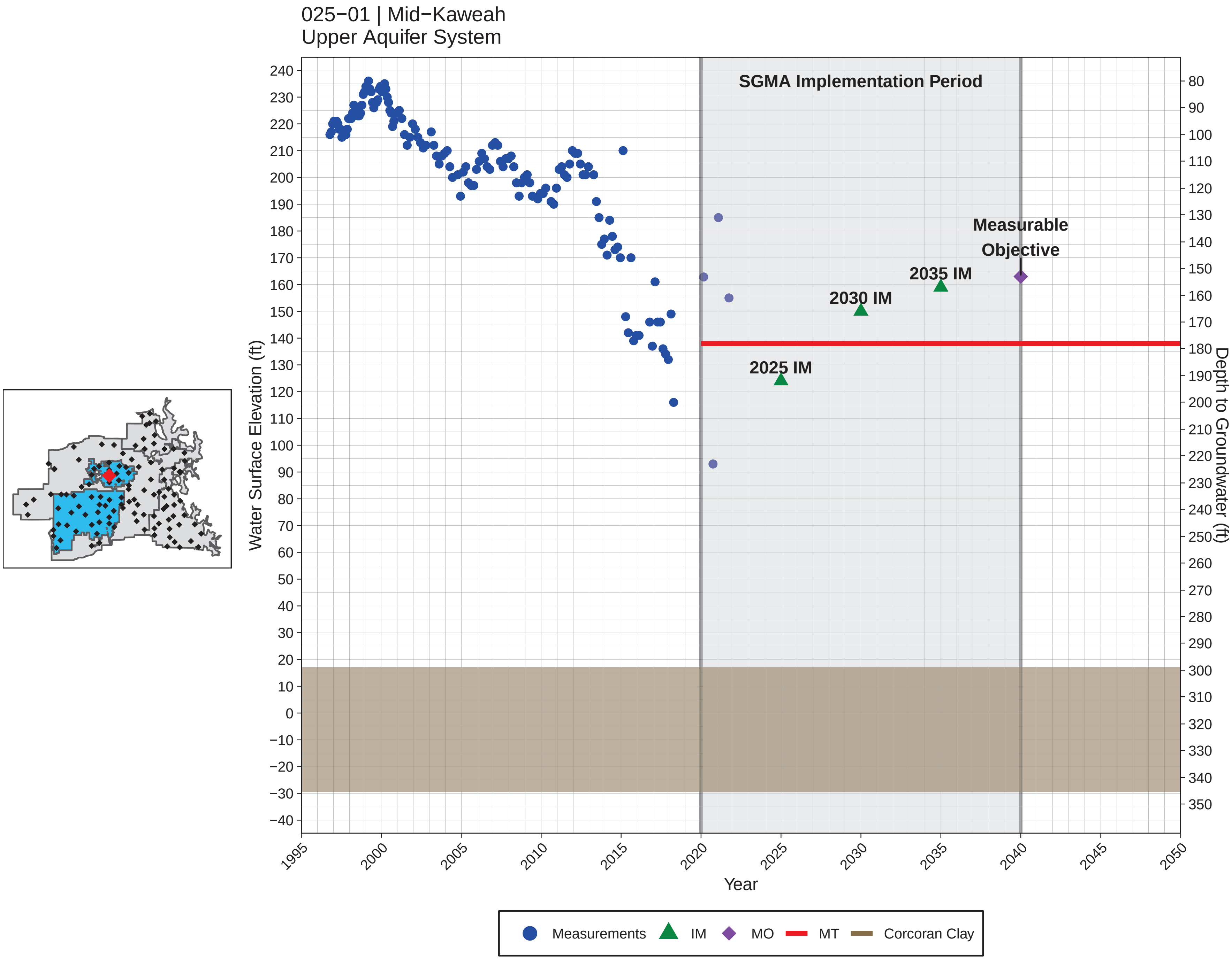
Unique Well ID	Local Well ID	GSA	Aquifer System	Analysis Zone	Methodology 1 90% Protective Elevation (feet)	Methodology 2 Groundwater Level Trend Projection Elevation (feet)	Methodology 3 Interpolated Minimum Threshold (feet)
16S25E36M002M	16S25E36M002M	East Kaweah	Single	2	260	292	-
16S26E30Q001M	16S26E30Q001M	East Kaweah	Single	2	285	292	-
17S25E25A001M	17S25E25A001M	East Kaweah	Single	1	124	185	-
17S25E35E001M	KSB-2107	East Kaweah	Single	1	110	185	-
17S26E04F002M	KSB-2369	East Kaweah	Single	2	276	292	-
17S26E07C001M	17S26E07C001M	East Kaweah	Single	2	233	292	-
17S26E21E001M	KSB-2354	East Kaweah	Single	2	266	292	-
17S26E29R001M	17S26E29R001M	East Kaweah	Single	2	269	292	-
18S26E02D002M	18S26E02D002M	East Kaweah	Single	2	295	292	-
18S26E06D001M	18S26E06D001M	East Kaweah	Single	1	130	185	-
18S26E24J003M	18S26E24J003M	East Kaweah	Single	4	306	365	-
18S27E17H002M	18S27E17H002M	East Kaweah	Single	4	327	365	-
18S27E29E001M	18S27E29E001M	East Kaweah	Single	4	330	365	-
18S27E30H001M	18S27E30H001M	East Kaweah	Single	4	327	365	-
19S26E03A001M	19S26E03A001M	East Kaweah	Single	5	207	244	-
19S26E11R001M	19S26E11R001M	East Kaweah	Single	5	198	244	-
19S26E13R001M	19S26E13R001M	East Kaweah	Single	9	123	145	-
19S26E23E001M	Lindsay Well 15	East Kaweah	Single	9	103	145	-
19S26E25R001M	19S26E25R001M	East Kaweah	Single	9	98	145	-
19S26E34R006M	Lindsay Well 14	East Kaweah	Single	10	43	75	-
19S26E35C001M	19S26E35C001M	East Kaweah	Single	9	88	145	-
19S27E29D001M	19S27E29D001M	East Kaweah	Single	7	197	312	-
20S26E08H001M	KSB-2333	East Kaweah	Single	10	30	75	-
20S26E11R001M	20S26E11R001M	East Kaweah	Single	9	100	145	-
20S26E12H001M	Lindsay Well 11	East Kaweah	Single	9	112	145	-
20S26E16R001M	20S26E16R001M	East Kaweah	Single	10	39	75	-
20S26E20J001M	20S26E20J001M	East Kaweah	Single	10	32	75	-
20S26E23R001M	20S26E23R001M	East Kaweah	Single	9	98	145	-
20S26E32A001M	KSB-2344	East Kaweah	Single	10	35	75	-
20S26E35H001M	20S26E35H001M	East Kaweah	Single	9	104	145	-
20S27E08A001M	20S27E08A001M	East Kaweah	Single	7	211	312	-
20S27E15R001M	20S27E15R001M	East Kaweah	Single	6	354	429	-
20S27E18R001M	20S27E18R001M	East Kaweah	Single	8	194	235	-
20S27E25N001M	20S27E25N001M	East Kaweah	Single	6	363	429	-
21S26E11H001M	21S26E11H001M	East Kaweah	Single	9	110	145	-
21S27E03B001M	21S27E03B001M	East Kaweah	Single	8	237	235	-
21S27E06F001M	21S27E06F001M	East Kaweah	Single	9	119	145	-
21S27E08F001M	21S27E08F001M	East Kaweah	Single	8	199	235	-
21S27E12F001M	21S27E12F001M	East Kaweah	Single	7	287	312	-
SCID Office	SCID Office	East Kaweah	Single	2	243	292	-

Unique Well ID	Local Well ID	GSA	Aquifer System	Analysis Zone	Methodology 1 90% Protective Elevation (feet)	Methodology 2 Groundwater Level Trend Projection Elevation (feet)	Methodology 3 Interpolated Minimum Threshold (feet)
17S23E34J001M	KSB-1161	Greater Kaweah	Upper	32	-5	67	-
17S24E34B001M	KSB-1580	Greater Kaweah	Single	11	5	78	-
17S24E36H003M	KSB-1775	Greater Kaweah	Single	12	55	73	-
17S26E36R001M	KSB-2690	Greater Kaweah	Single	4	299	288	-
18S22E24D001M	KSB-0818	Greater Kaweah	Upper	37	-38	59	-
18S23E14A001M	KSB-1222	Greater Kaweah	Upper	32	5	73	-
18S23E30D001M	KSB-0905	Greater Kaweah	Lower	36	-311	-207	-
18S23E30D901M	KSB-0903	Greater Kaweah	Upper	36	-26	71	-
18S25E05Q001M	KSB-1936	Greater Kaweah	Single	13	93	81	-
18S25E15C001M	KSB-2058	Greater Kaweah	Single	13	109	110	-
18S25E23J001M	KSB-2147	Greater Kaweah	Single	14	164	169	-
18S26E17L001M	KSB-2297	Greater Kaweah	Single	15	250	313	-
18S26E27B001M	KSB-2466	Greater Kaweah	Single	5	199	349	-
18S27E05J001M	KSB-2822	Greater Kaweah	Single	16	328	415	-
19S22E24B001M	KSB-0856	Greater Kaweah	Upper	36	-36	25	-
19S22E28D001M	KSB-0616	Greater Kaweah	Upper	35	33	19	-
19S22E31B002M	KSB-0531	Greater Kaweah	Upper	35	27	57	-
19S23E12L001M	KSB-1259	Greater Kaweah	Lower	38	-129	56	-
19S23E21C001M	KSB-1055	Greater Kaweah	Upper	29	-9	51	-
19S25E09H001M	KSB-2017	Greater Kaweah	Single	14	142	92	-
19S25E13A002M	KSB-2200	Greater Kaweah	Single	19	151	114	-
19S25E16A002M	KSB-2015	Greater Kaweah	Single	18	75	91	-
19S25E27A001M	KSB-2089	Greater Kaweah	Single	18	72	57	-
19S25E28H001M	KSB-2021	Greater Kaweah	Single	20	23	56	-
19S25E32J001M	KSB-1937	Greater Kaweah	Upper	24	82	49	-
19S25E35B002M	KSB-2139	Greater Kaweah	Single	18	66	47	-
19S26E05C001M	KSB-2291	Greater Kaweah	Single	14	171	229	-
19S26E16J002M	KSB-2411	Greater Kaweah	Single	18	106	124	-
19S26E20A001M	KSB-2322	Greater Kaweah	Single	18	92	106	-
20S22E07A003M	KSB-0550	Greater Kaweah	Upper	35	20	-28	-
20S22E24R001M	KSB-0889	Greater Kaweah	Upper	30	-73	-17	-
20S22E36A001M	KSB-0890	Greater Kaweah	Upper	30	-79	-10	-
20S24E24H001M	KSB-1783	Greater Kaweah	Upper	24	51	56	-
20S25E03R001M	KSB-2095	Greater Kaweah	Single	20	8	17	55
20S25E12A001M	KSB-2197	Greater Kaweah	Single	20	17	18	65
20S25E14F004M	KSB-2114	Greater Kaweah	Single	21	-72	2	60
20S25E24R001M	KSB-2203	Greater Kaweah	Single	21	-63	-2	65
21S24E03L001M	KSB-1535	Greater Kaweah	Upper	25	89	-24	**
21S24E08A001M	KSB-1425	Greater Kaweah	Lower	25	-262	10	-

Unique Well ID	Local Well ID	GSA	Aquifer System	Analysis Zone	Methodology 1 90% Protective Elevation (feet)	Methodology 2 Groundwater Level Trend Projection Elevation (feet)	Methodology 3 Interpolated Minimum Threshold (feet)
025-01	KSB-1696	Mid-Kaweah	Upper	39	112	13	138
036-01	KSB-1884	Mid-Kaweah	Single	22	79	27	-
047-01	KSB-1699	Mid-Kaweah	Upper	39	107	157	-
053-01	KSB-1977	Mid-Kaweah	Single	23	52	56	-
075-01	KSB-1447	Mid-Kaweah	Upper	39	81	60	-
077-01	KSB-1427	Mid-Kaweah	Upper	39	81	33	-
18S24E13N001M	KSB-1689	Mid-Kaweah	Single	22	69	75	-
18S24E22E001M	KSB-1526	Mid-Kaweah	Upper	39	103	-139	85
18S24E25D001M	KSB-1690	Mid-Kaweah	Upper	39	114	161	-
18S25E28R001M	KSB-2014	Mid-Kaweah	Single	23	54	69	-
18S25E30Q001M	KSB-1819	Mid-Kaweah	Single	22	75	34	-
19S23E20C001M	KSB-0994	Mid-Kaweah	Lower	29	-12	71	-
19S23E22H001M	KSB-1168	Mid-Kaweah	Upper	29	3	30	-
19S23E31R001M	KSB-0946	Mid-Kaweah	Upper	29	-27	-72	-
19S23E35H001M	KSB-1226	Mid-Kaweah	Upper	29	3	-101	-
19S24E08D002M	KSB-1384	Mid-Kaweah	Upper	38	47	38	-
19S24E20F001M	KSB-1408	Mid-Kaweah	Upper	28	75	Drilled after 2016	-
19S24E22E001M	KSB-1545	Mid-Kaweah	Upper	28	86	Drilled after 2016	-
19S24E25D001M	KSB-1709	Mid-Kaweah	Upper	27	2	-6	88
19S24E34D001M	KSB-1536	Mid-Kaweah	Upper	28	77	Drilled after 2016	-
19S24E35E001M	KSB-1628	Mid-Kaweah	Lower	26	-109	-92	-
19S24E36C002M	KSB-1903	Mid-Kaweah	Lower	27	-98	-43	-
19S25E06A001M	KSB-1862	Mid-Kaweah	Single	22	76	35	-
19S25E20P001M	KSB-1905	Mid-Kaweah	Upper	27	24	90	-
20S23E03L001M	KSB-1129	Mid-Kaweah	Upper	29	-9	-81	-
20S23E18R001M	KSB-0948	Mid-Kaweah	Upper	30	-66	-173	-
20S23E21B001M	KSB-1071	Mid-Kaweah	Upper	30	-66	-126	-
20S23E26C001M	KSB-1206	Mid-Kaweah	Upper	30	-64	-20	-
20S24E01H002M	KSB-1770	Mid-Kaweah	Lower	26	-289	-150	-
20S24E04K001M	KSB-1506	Mid-Kaweah	Lower	26	-123	-39	-
20S24E07C001M	KSB-1320	Mid-Kaweah	Upper	31	58	Drilled after 2016	-
20S24E11J002M	KSB-1695	Mid-Kaweah	Lower	26	-119	-121	-
20S24E16H001M	KSB-1538	Mid-Kaweah	Lower	31	-115	62	-
20S24E17P001M	KSB-1431	Mid-Kaweah	Upper	31	58	88	-
20S24E28L001M	KSB-1477	Mid-Kaweah	Upper	31	58	60	-
21S23E05A002M	KSB-0976	Mid-Kaweah	Upper	30	-84	-141	-
21S23E07J001M	KSB-0922	Mid-Kaweah	Upper	30	-36	-22	-
361856N1193313W001	KSB-1706	Mid-Kaweah	Lower	26	-136	-287	-

Note. bolded elevation indicates the minimum threshold assigned to the representative monitoring site

Appendix 5B Groundwater Level Sustainable Management Criteria Hydrographs



025−01 | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
Measurable Objective
2035 IM
2030 IM
2025 IM
Water Surface Elevation (ft)
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
Depth to Groundwater (ft)
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
Year
1995
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2005
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2015
2020
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2030
2035
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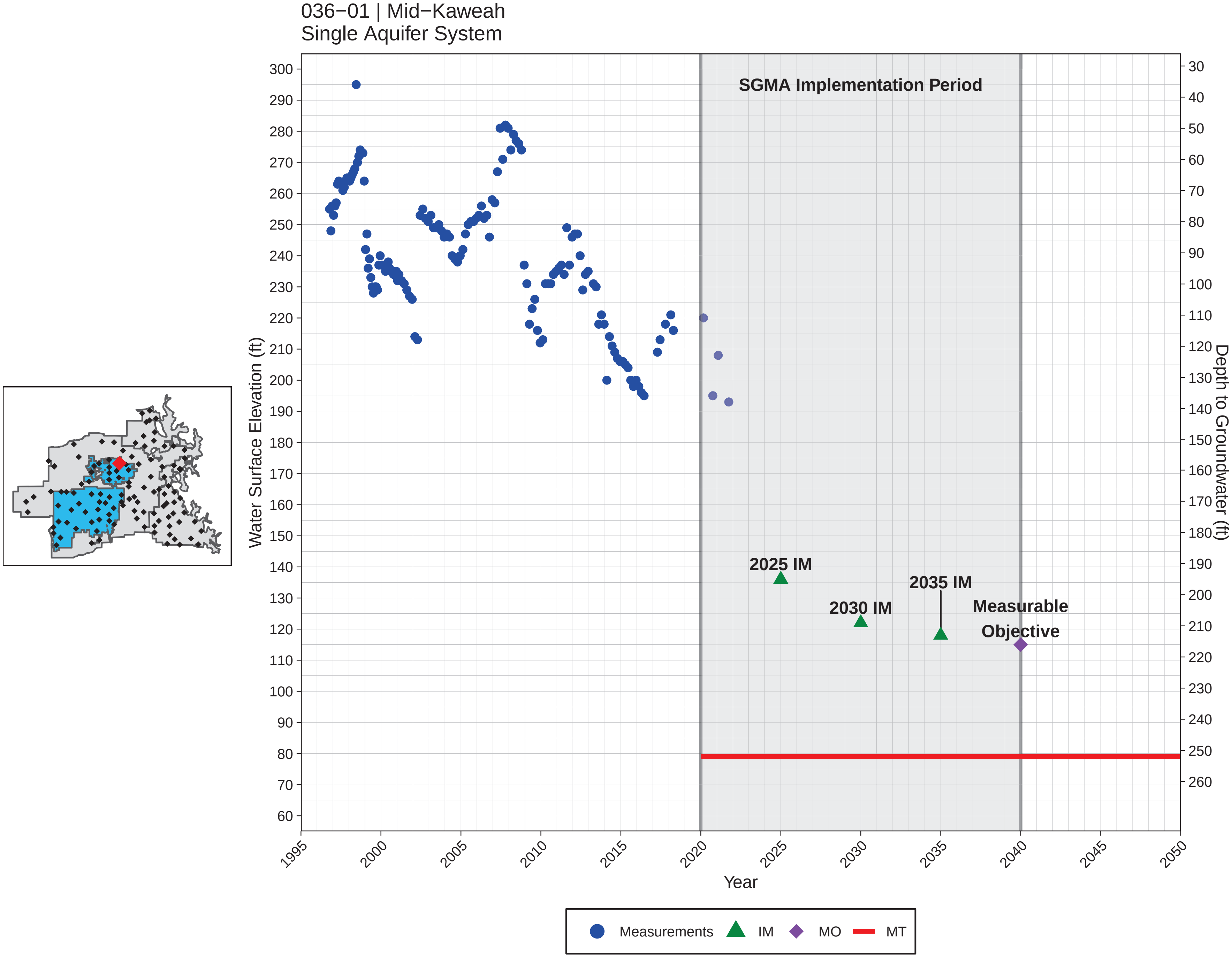
2050
Measurements
IM
MO
MT
Corcoran Clay


036−01 | Mid−Kaweah
Single Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
Measurements
IM
MO
MT
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
30
40
50
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70
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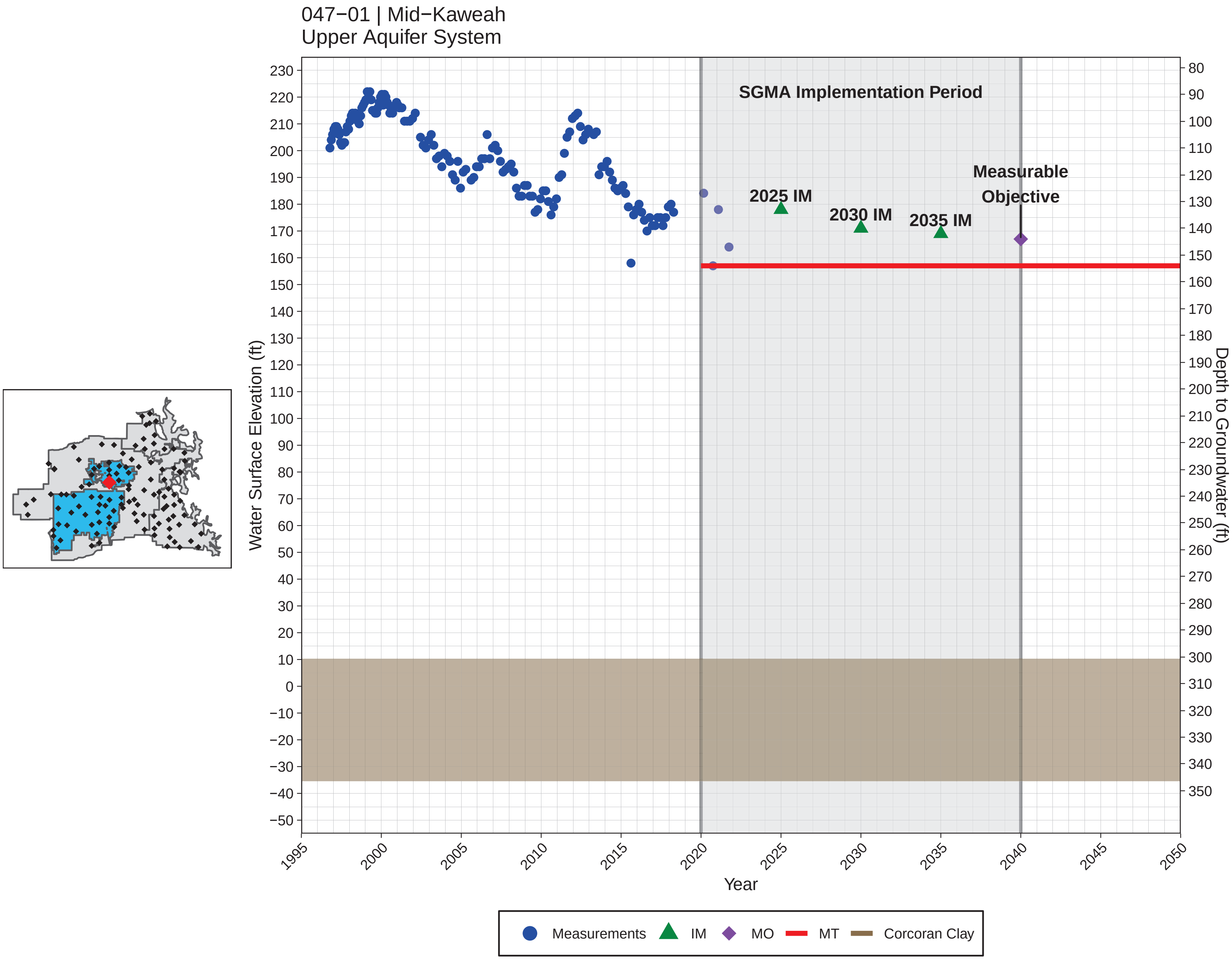
047−01 | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
Measurable
Objective
2025 IM
2030 IM
2035 IM
Water Surface Elevation (ft)
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
−50
Depth to Groundwater (ft)
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
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Year
1995
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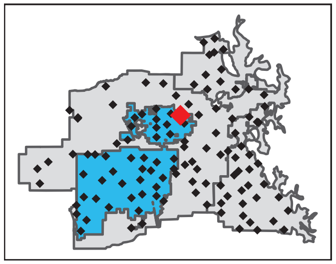
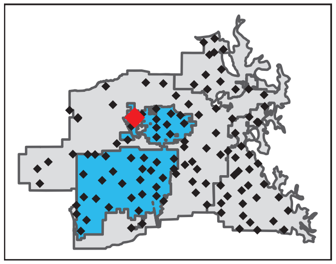
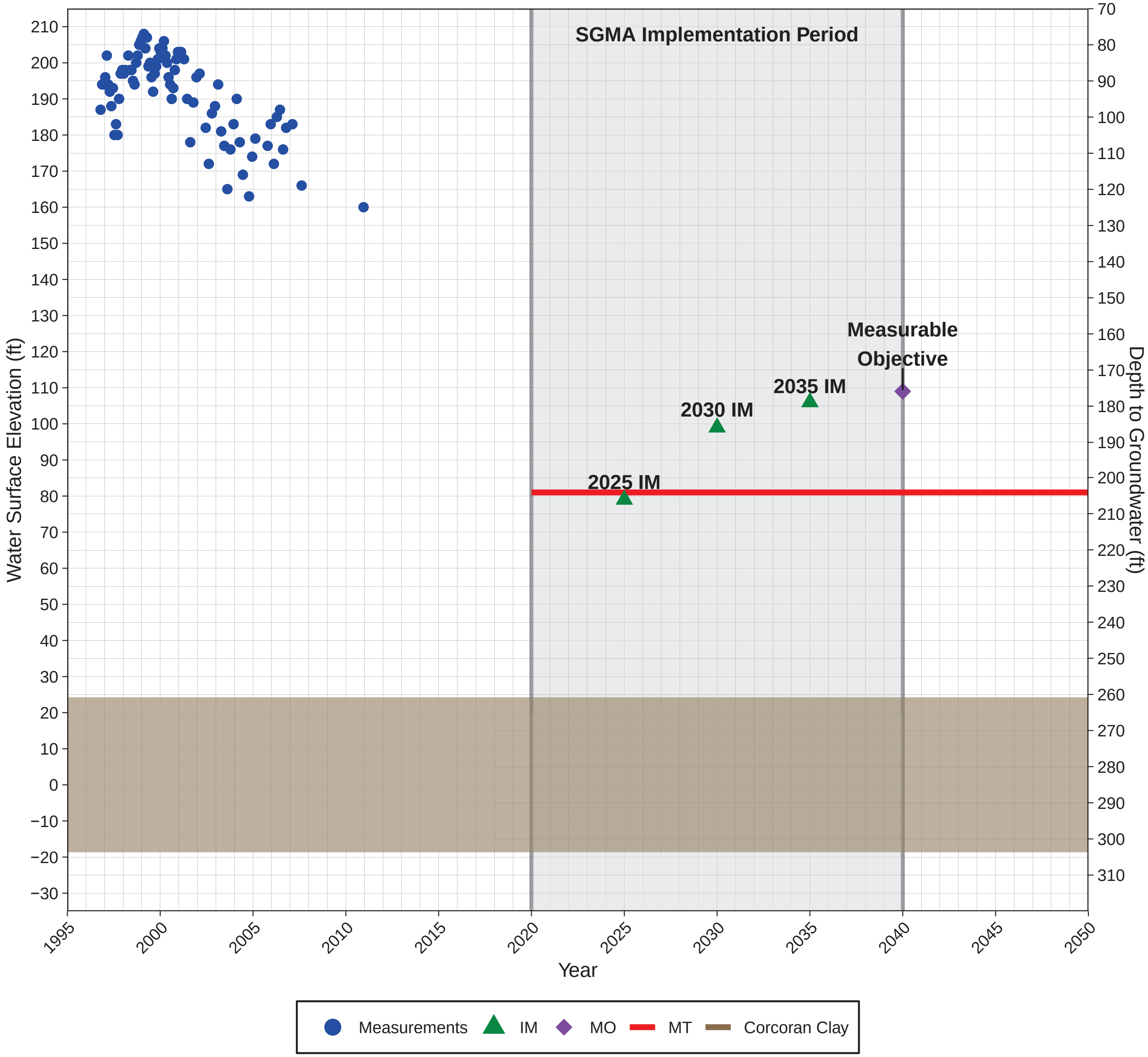
2020
2025
2030
2035
2040
2045
2050
● Measurements
▲ IM
◆ MO
MT
Corcoran Clay

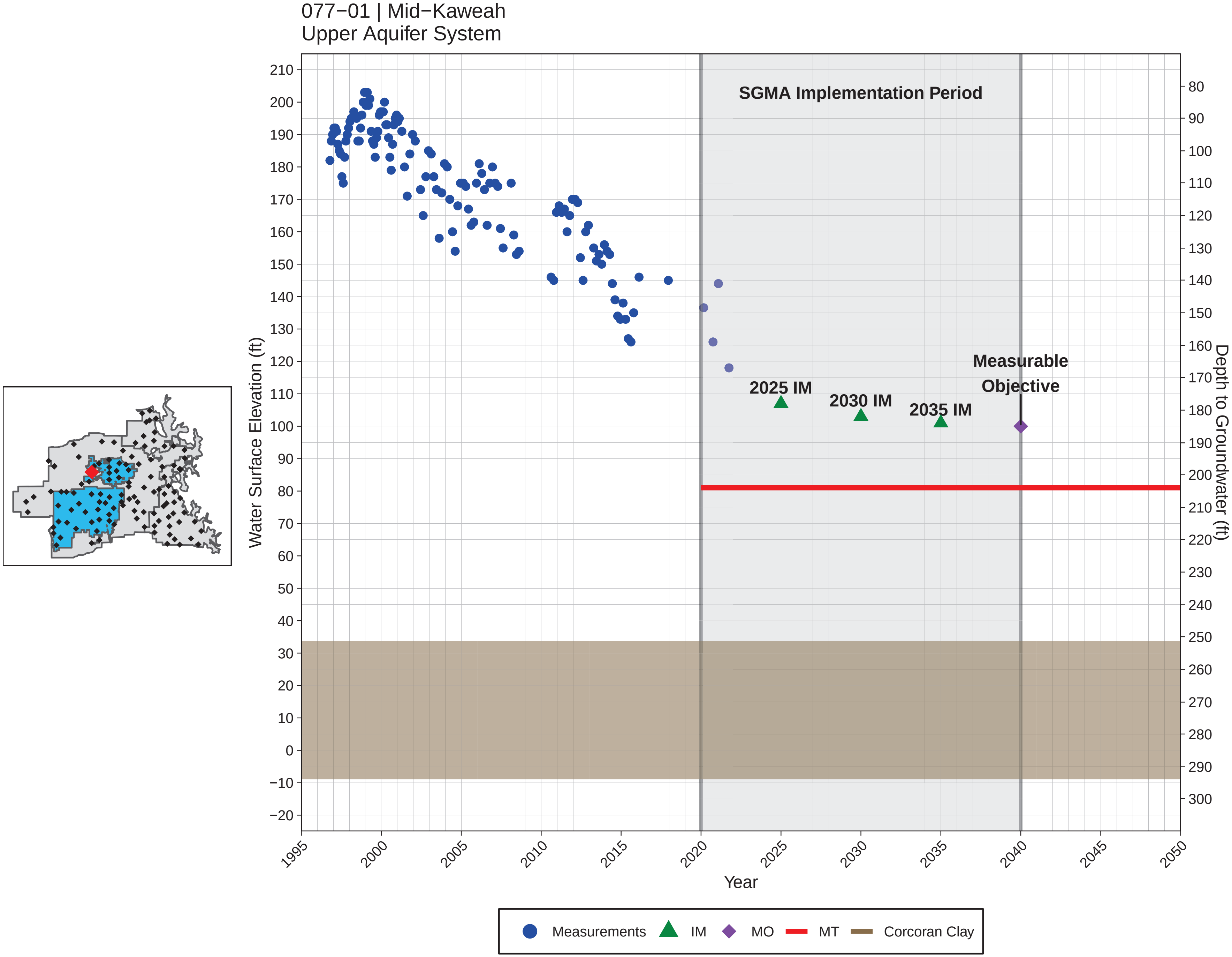
053−01 | Mid−Kaweah
Single Aquifer System



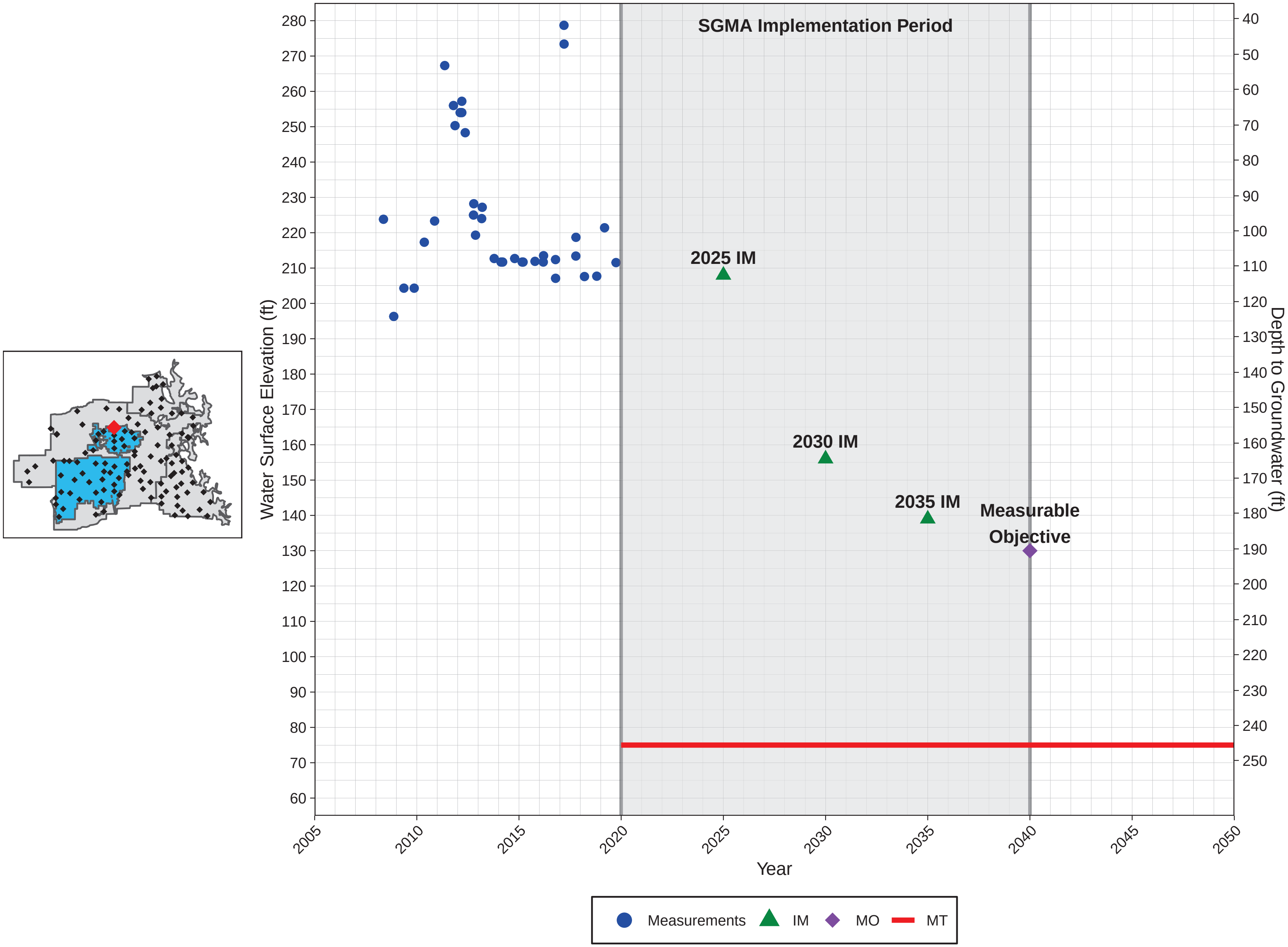
075−01 | Mid−Kaweah
Upper Aquifer System



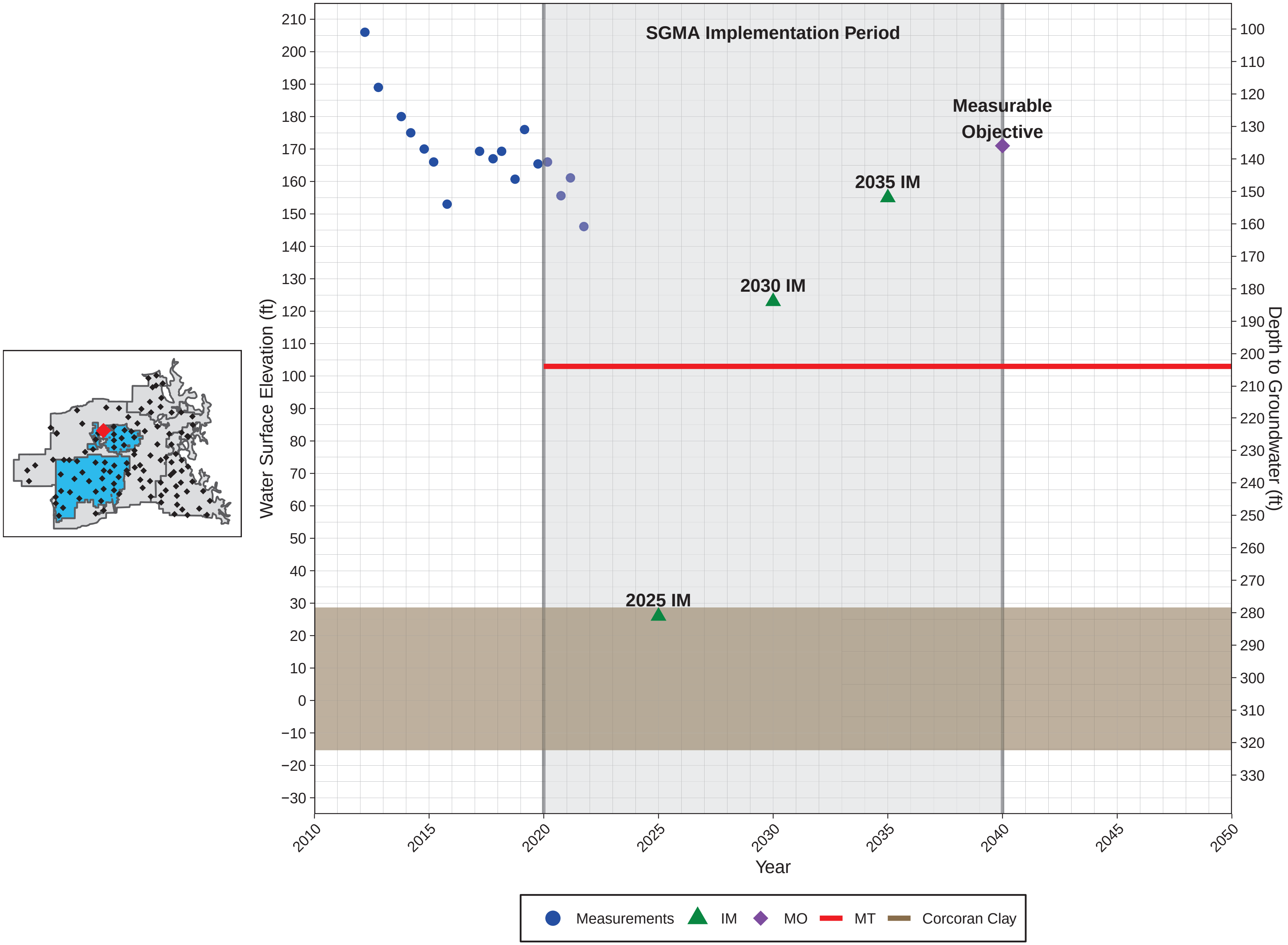


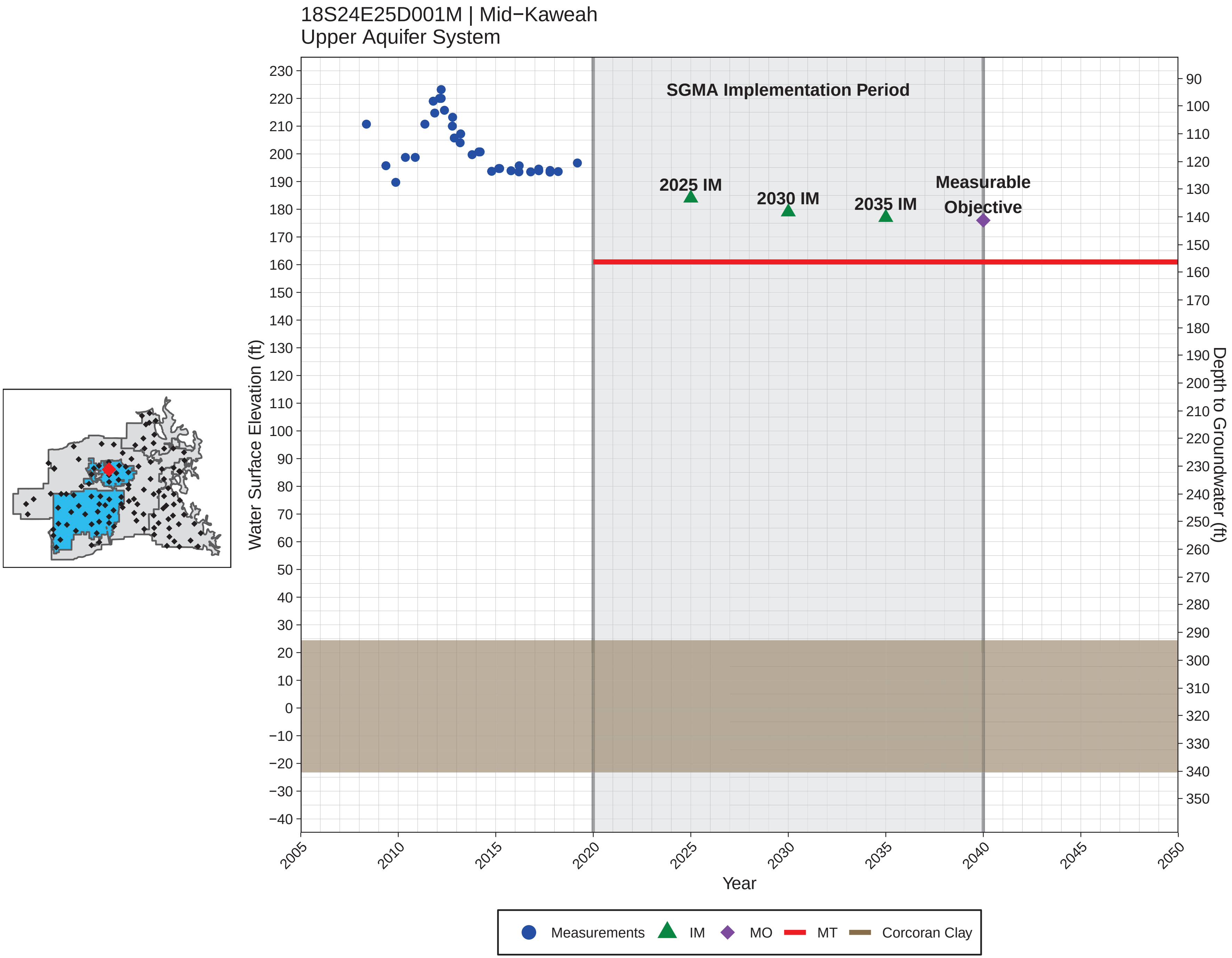

077−01 | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
Measurable Objective
2025 IM
2030 IM
2035 IM
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
Measurements
IM
MO
MT
Corcoran Clay

18S24E13N001M | Mid−Kaweah
Single Aquifer System



18S24E22E001M | Mid−Kaweah
Upper Aquifer System




18S24E25D001M | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
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2005
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2025
2030
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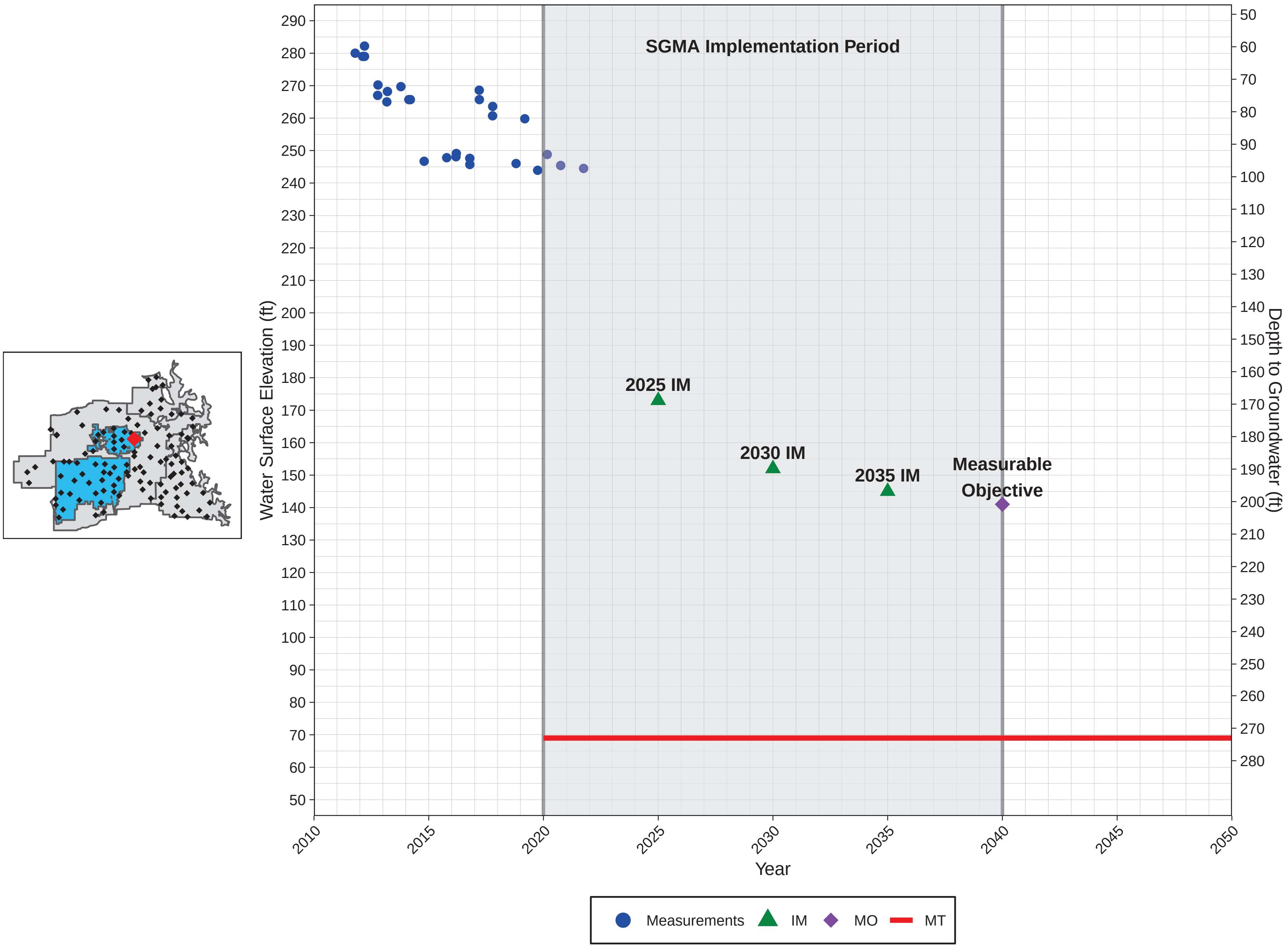
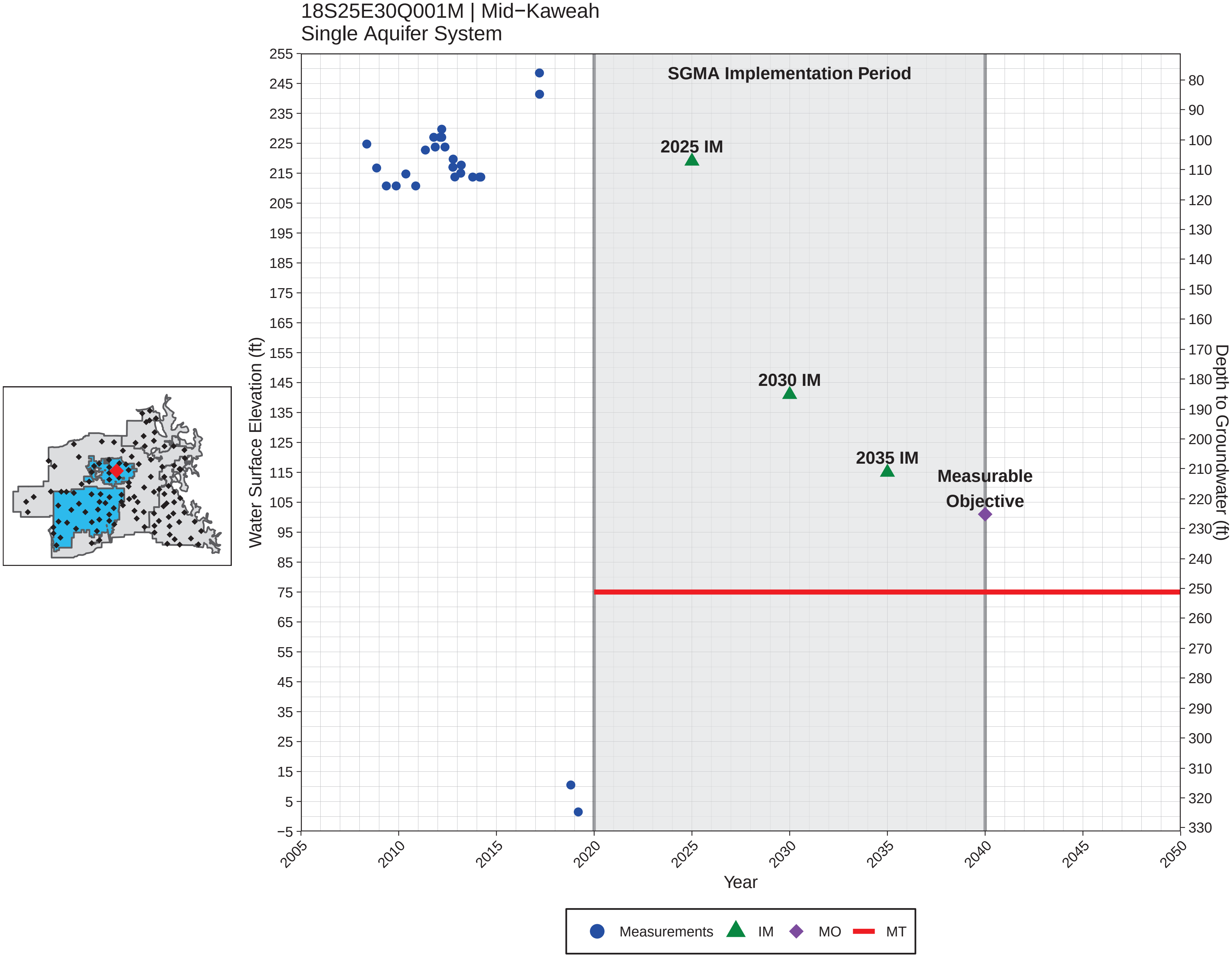
2050
● Measurements
▲ IM
◆ MO
MT
Corcoran Clay

18S25E28R001M | Mid−Kaweah
Single Aquifer System




18S25E30Q001M | Mid−Kaweah
Single Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
255
245
235
225
215
205
195
185
175
165
155
145
135
125
115
105
95
85
75
65
55
45
35
25
15
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2005
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Measurements
IM
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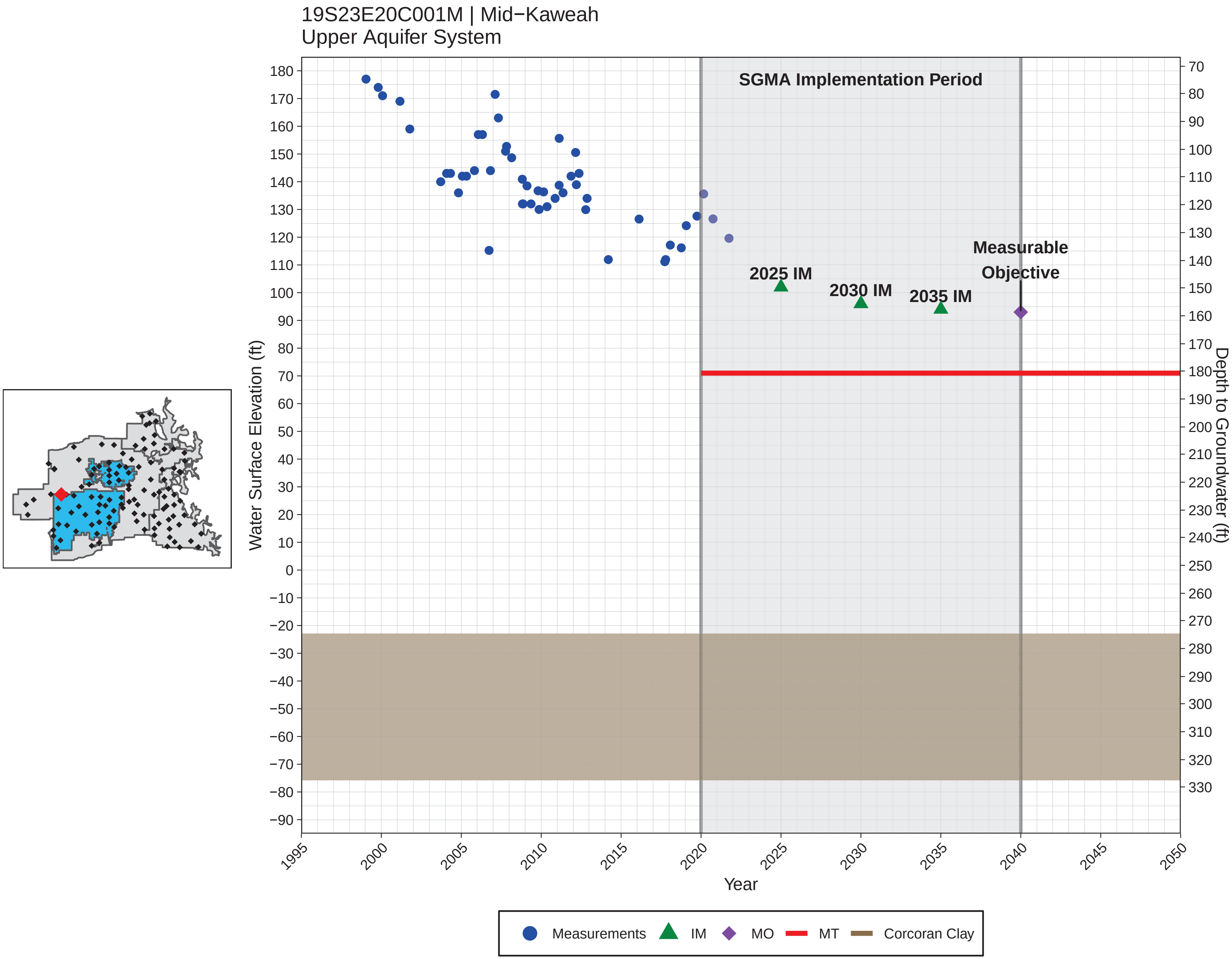
19S23E20C001M | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
180
170
160
150
140
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120
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30
20
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Measurements
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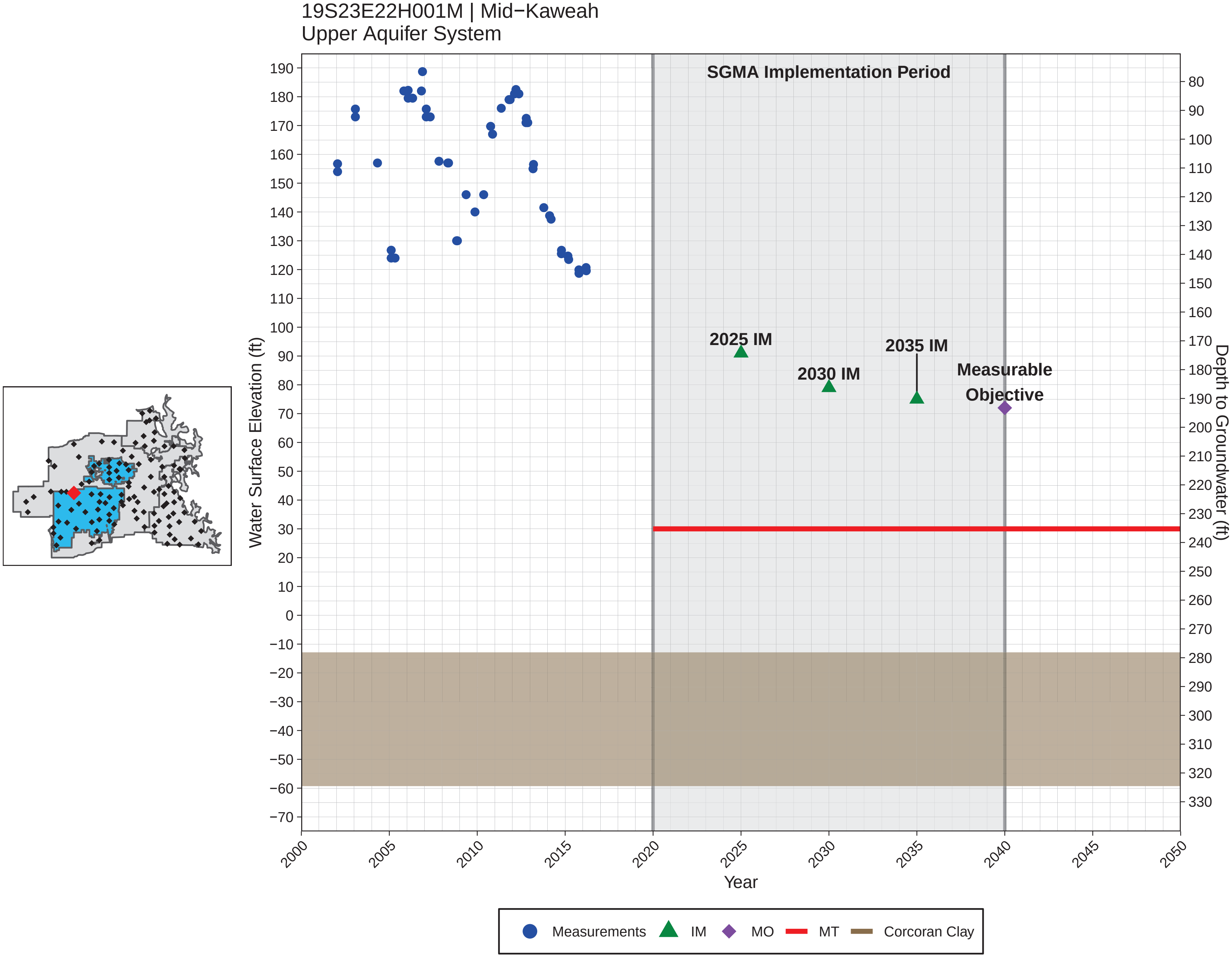
Corcoran Clay


19S23E22H001M | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
190
180
170
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Measurements
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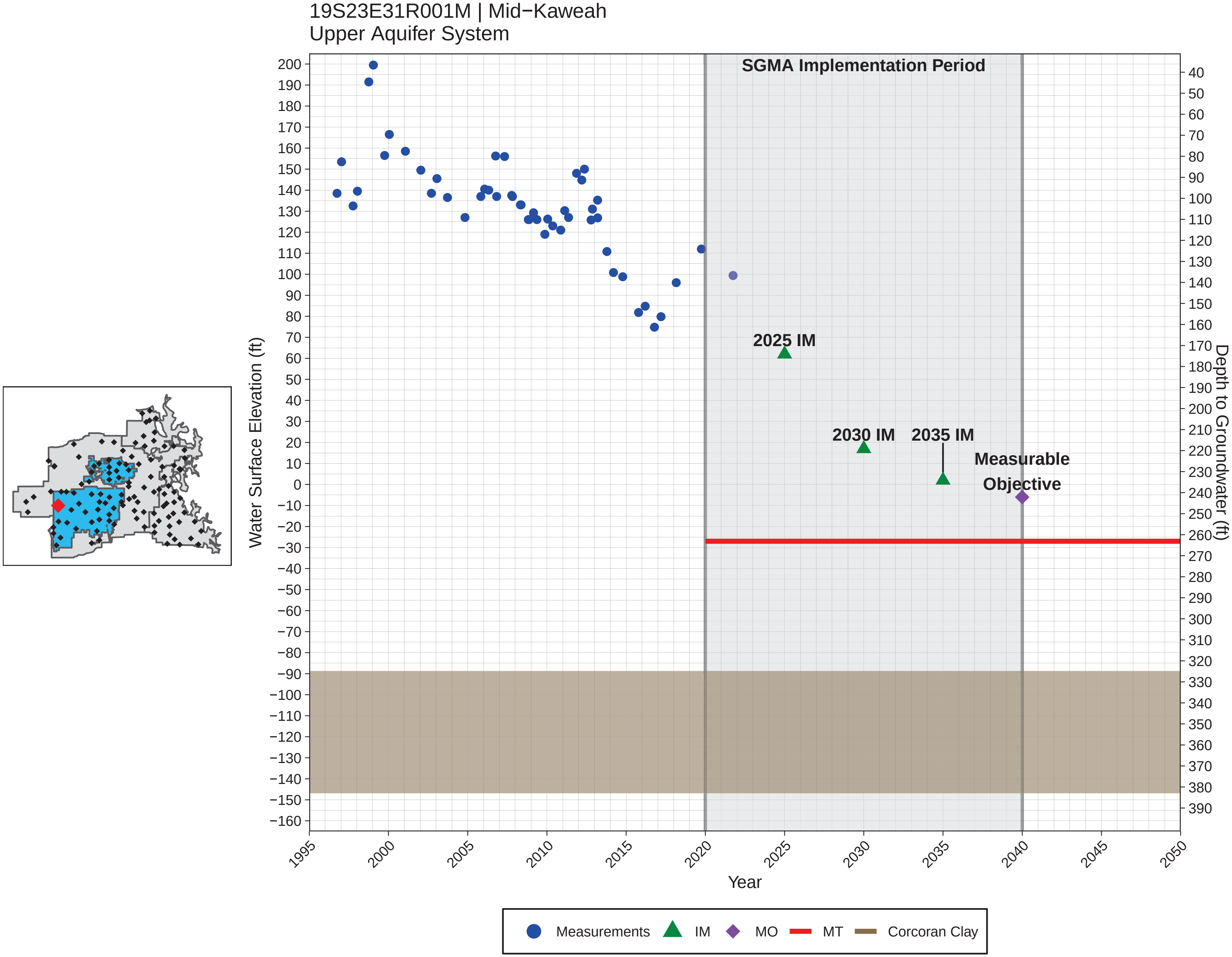
Corcoran Clay


19S23E31R001M | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
200
190
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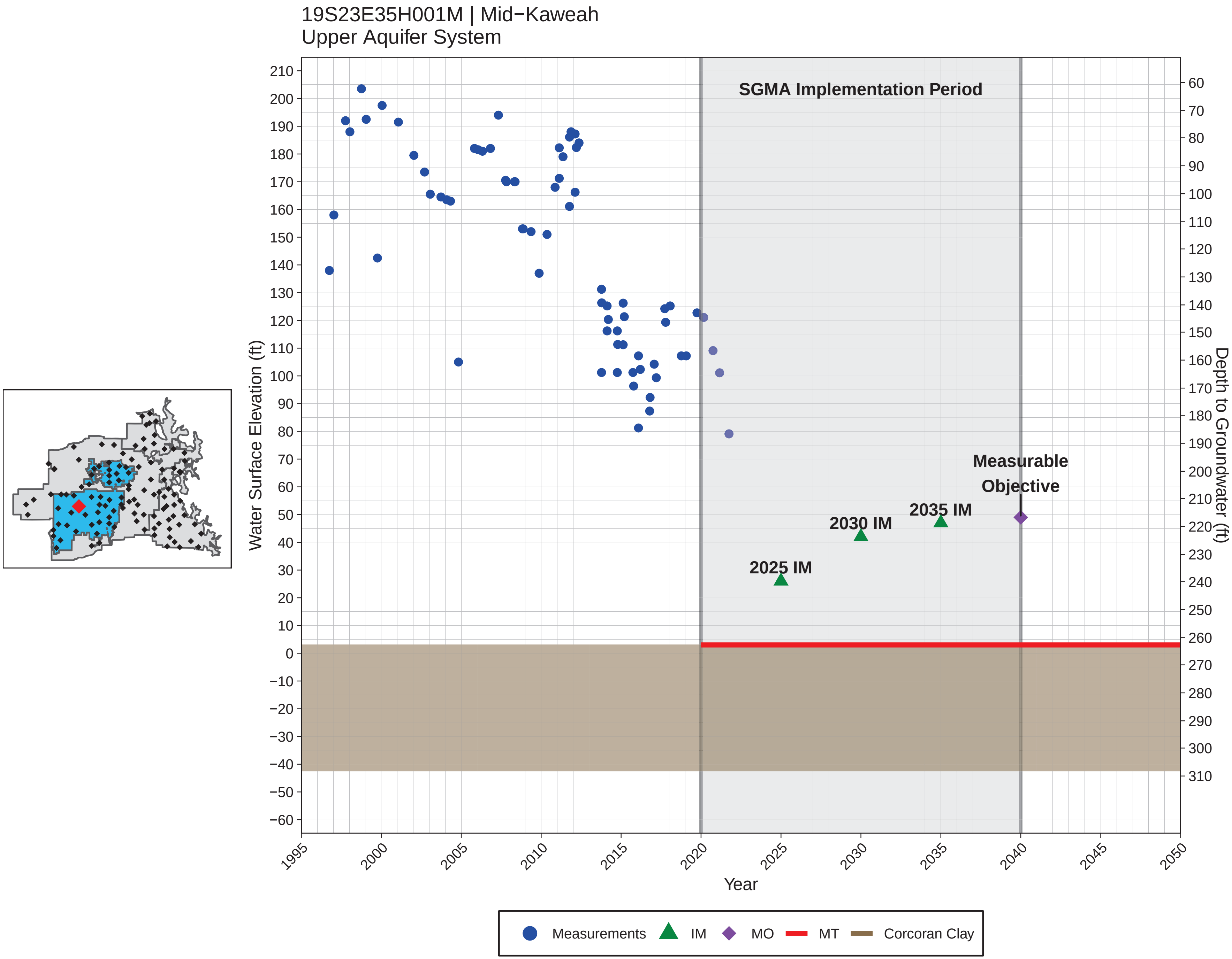
2050
Measurements
IM
MO
MT
Corcoran Clay


19S23E35H001M | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
Measurable Objective
2025 IM
2030 IM
2035 IM
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
210
200
190
180
170
160
150
140
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1995
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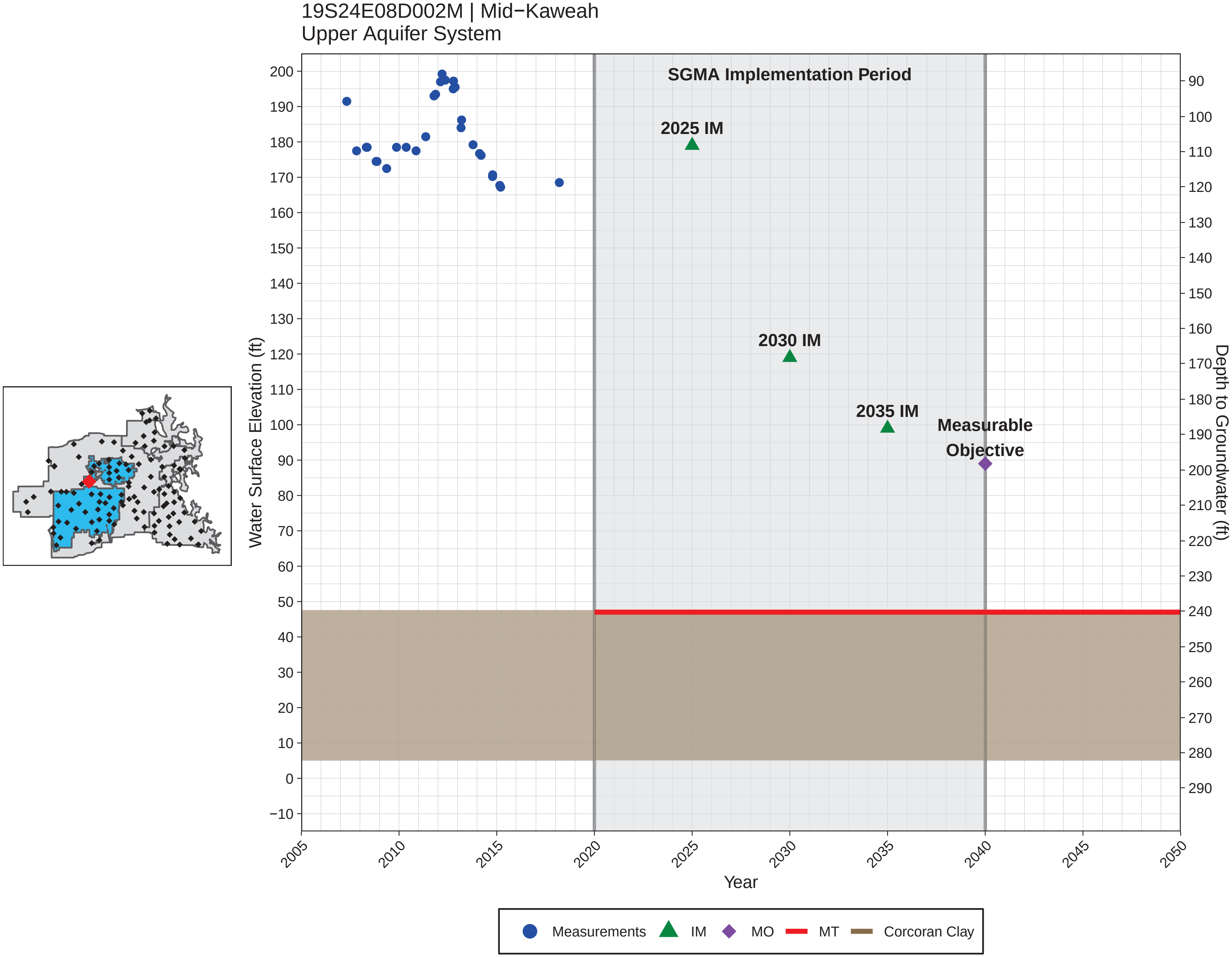
2050
Measurements
IM
MO
MT
Corcoran Clay


19S24E08D002M | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
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40
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10
0
−10
Depth to Groundwater (ft)
90
100
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120
130
140
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170
180
190
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210
220
230
240
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260
270
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Year
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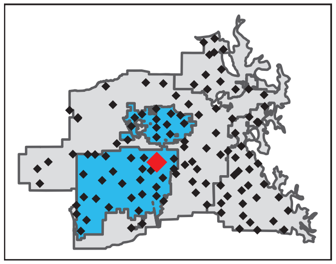
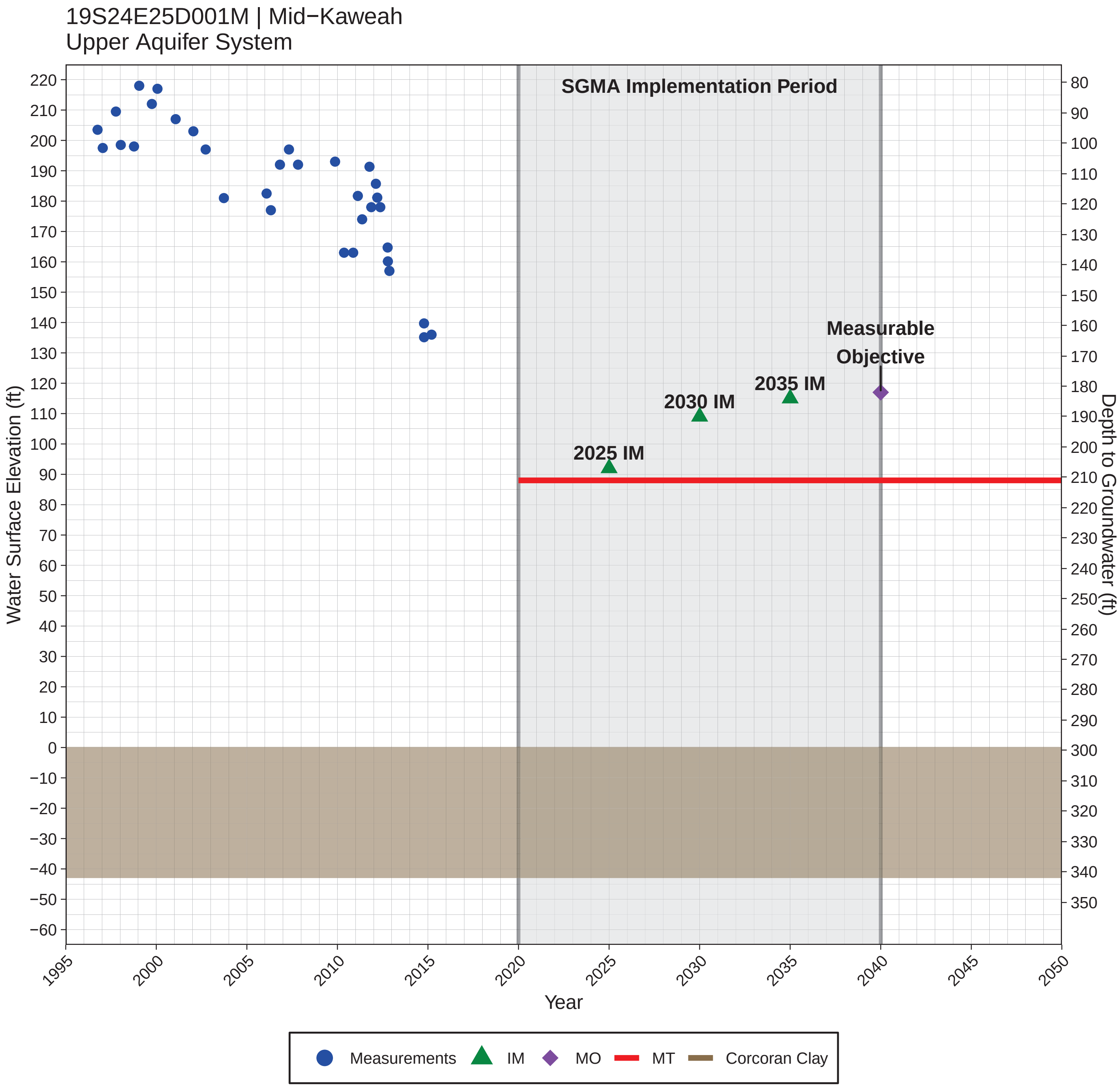
2050
Measurements
IM
MO
MT
Corcoran Clay




19S24E25D001M | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
Measurable Objective
2025 IM
2030 IM
2035 IM
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
220
210
200
190
180
170
160
150
140
130
120
110
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70
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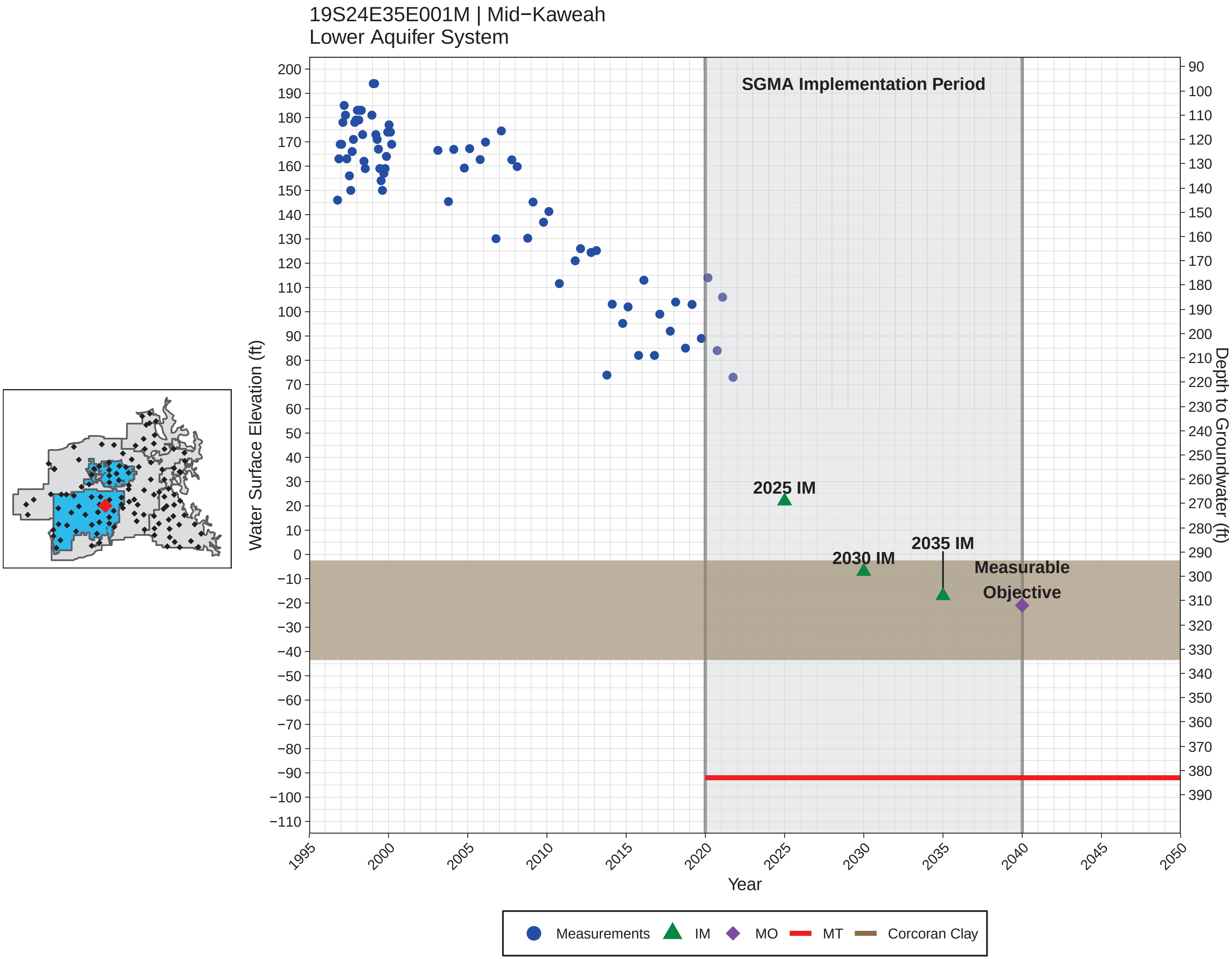
Measurements
IM
MO
MT
Corcoran Clay


19S24E35E001M | Mid−Kaweah
Lower Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
200
190
180
170
160
150
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−20
−30
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−50
−60
−70
−80
−90
−100
−110
Depth to Groundwater (ft)
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
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370
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Year
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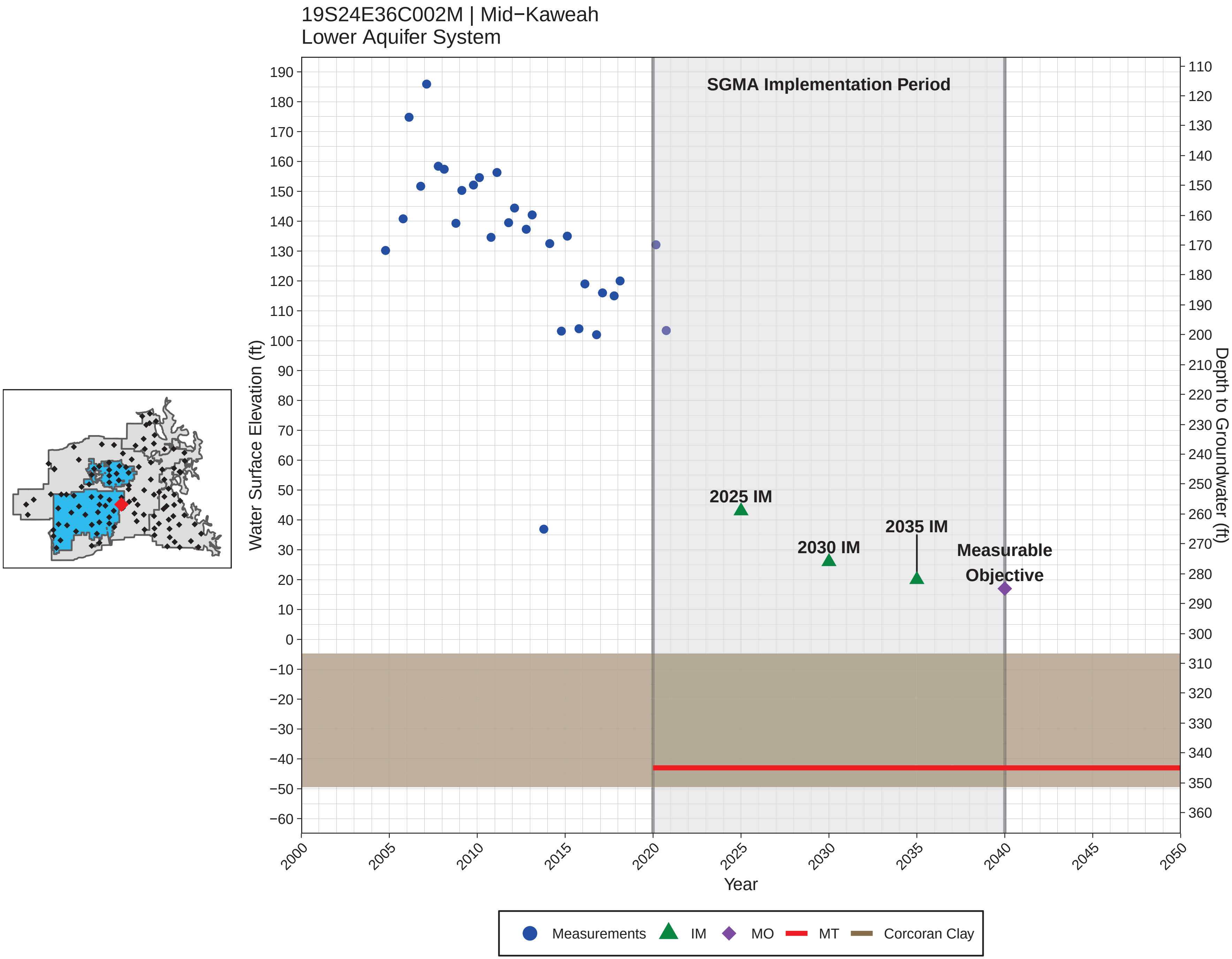
2045
2050
● Measurements
▲ IM
◆ MO
MT
Corcoran Clay


19S24E36C002M | Mid−Kaweah
Lower Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
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−60
110
120
130
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320
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2000
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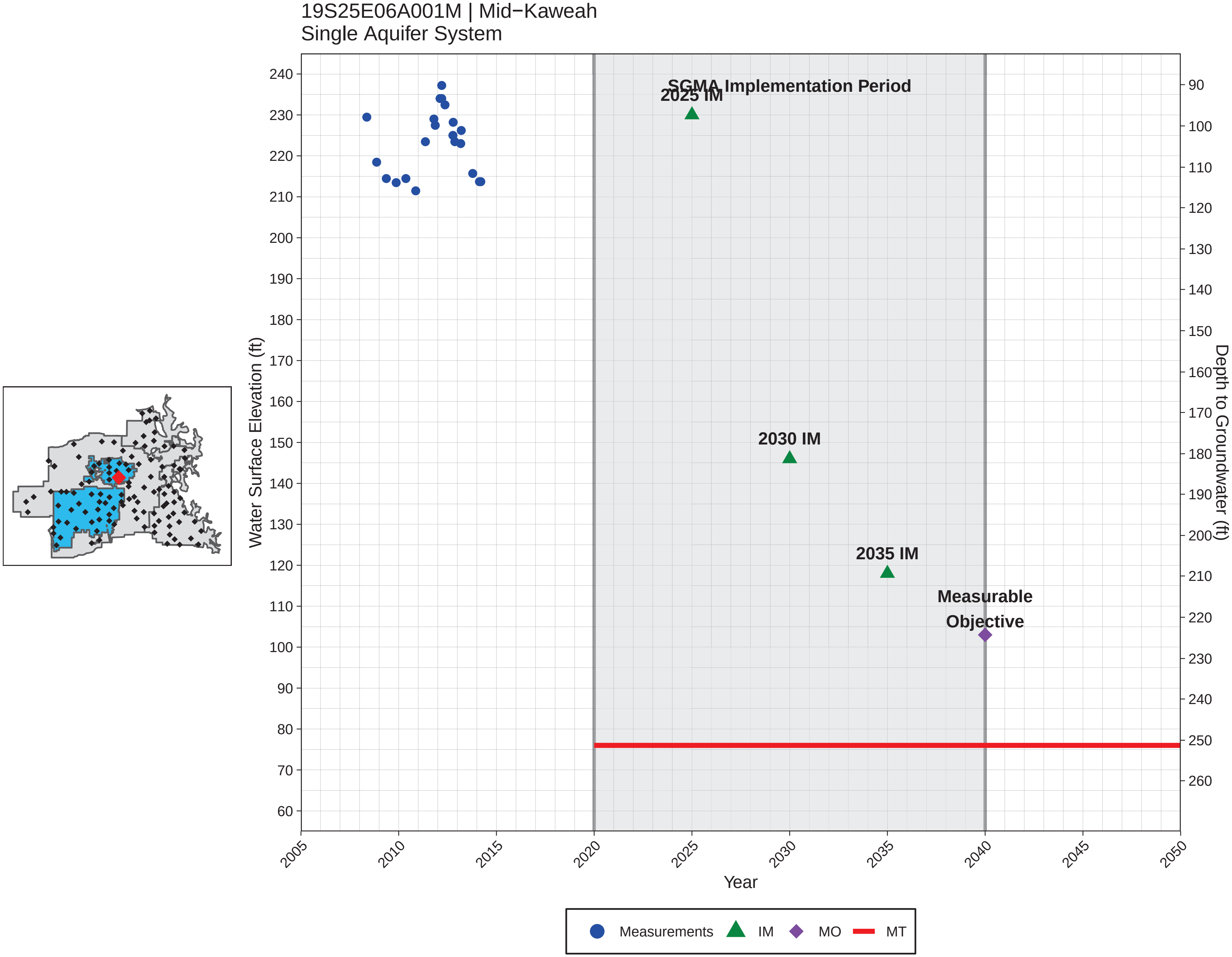
● Measurements
▲ IM
◆ MO
MT
Corcoran Clay


19S25E06A001M | Mid−Kaweah
Single Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
240
230
220
210
200
190
180
170
160
150
140
130
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90
80
70
60
90
100
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190
200
210
220
230
240
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2005
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2035
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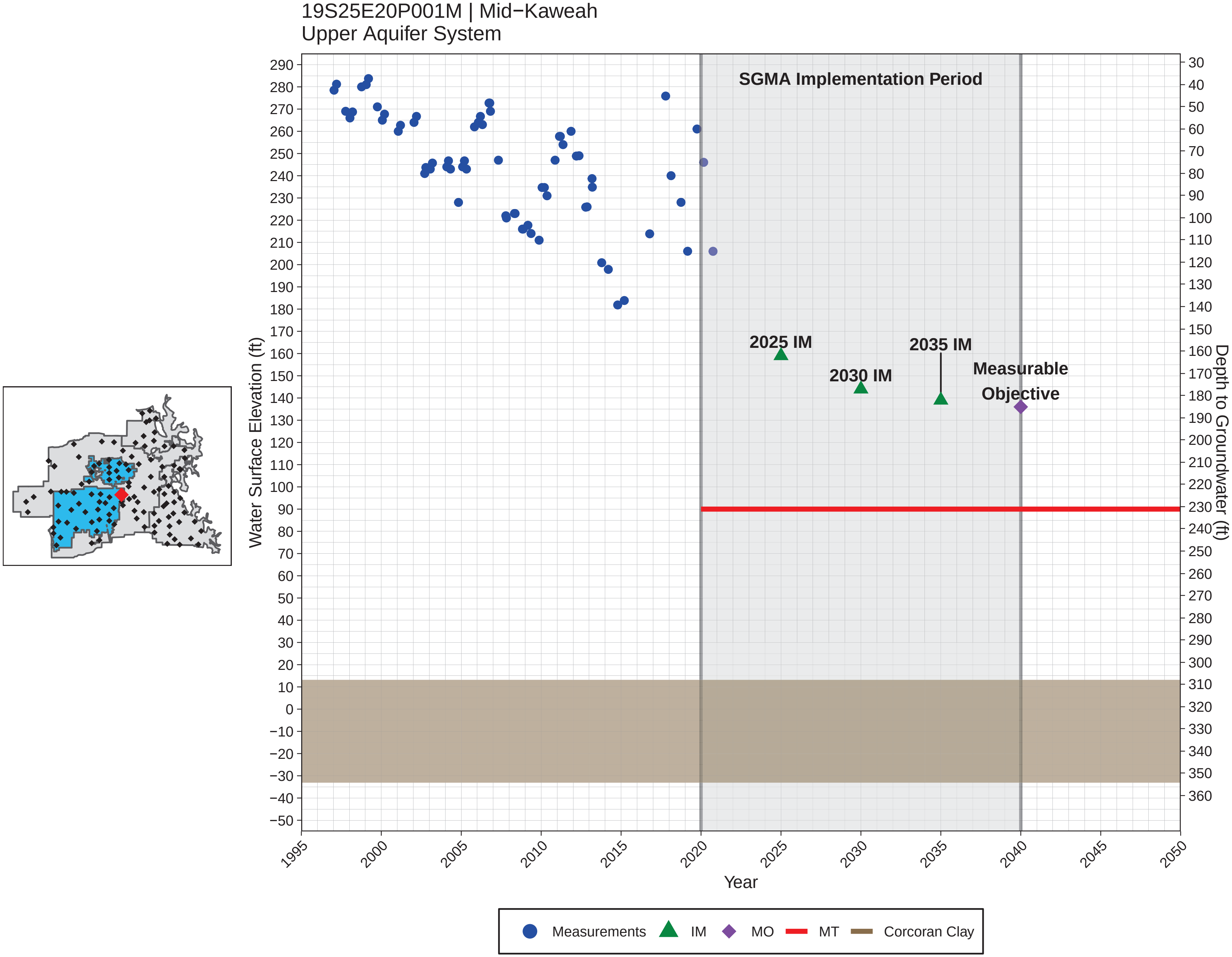
2045
2050
● Measurements
▲ IM
◆ MO
MT


19S25E20P001M | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
2025 IM
2030 IM
2035 IM
Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
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Measurements
IM
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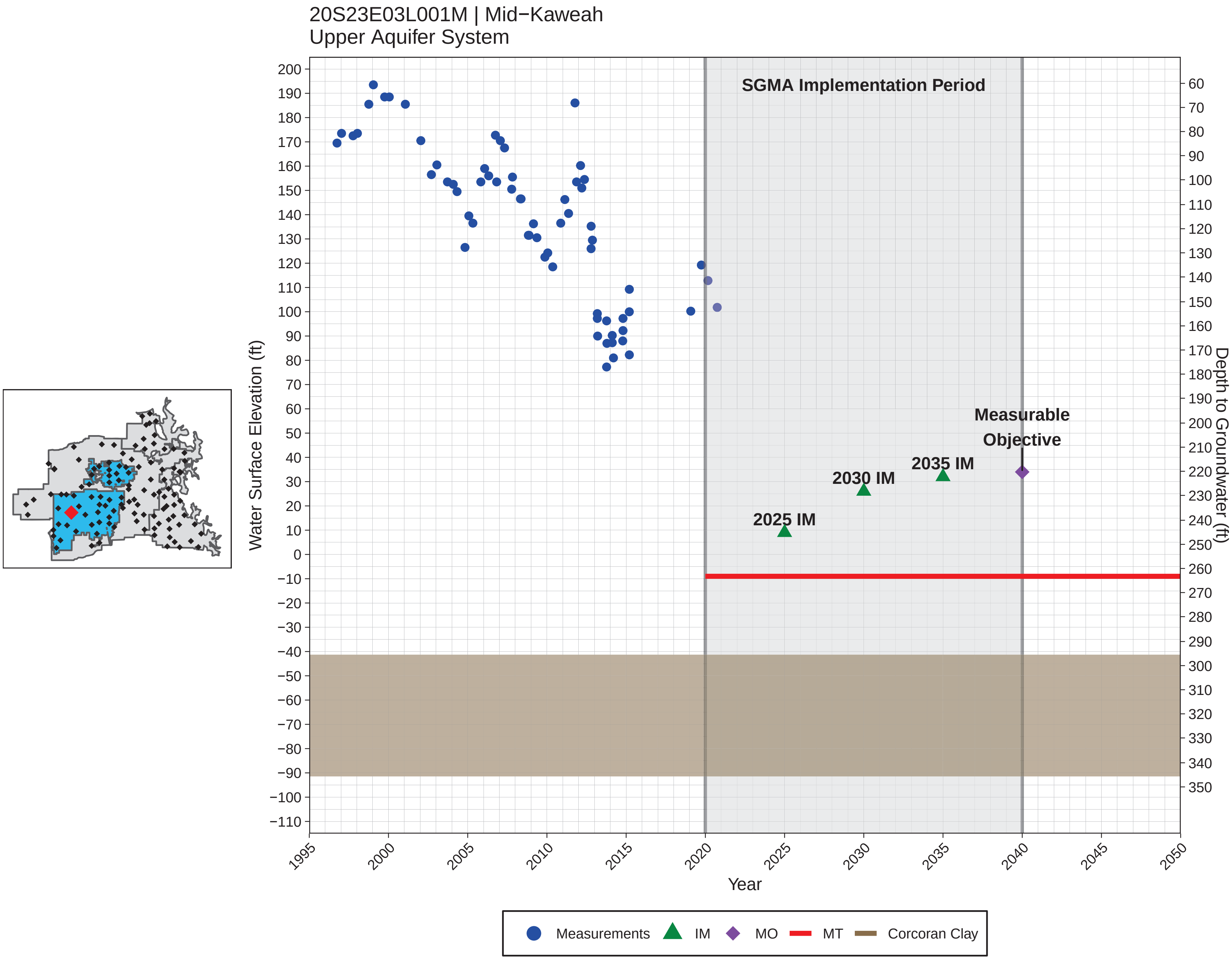
MT
Corcoran Clay


20S23E03L001M | Mid−Kaweah
Upper Aquifer System
SGMA Implementation Period
Measurable Objective
2025 IM
2030 IM
2035 IM
Water Surface Elevation (ft)
Depth to Groundwater (ft)
Year
200
190
180
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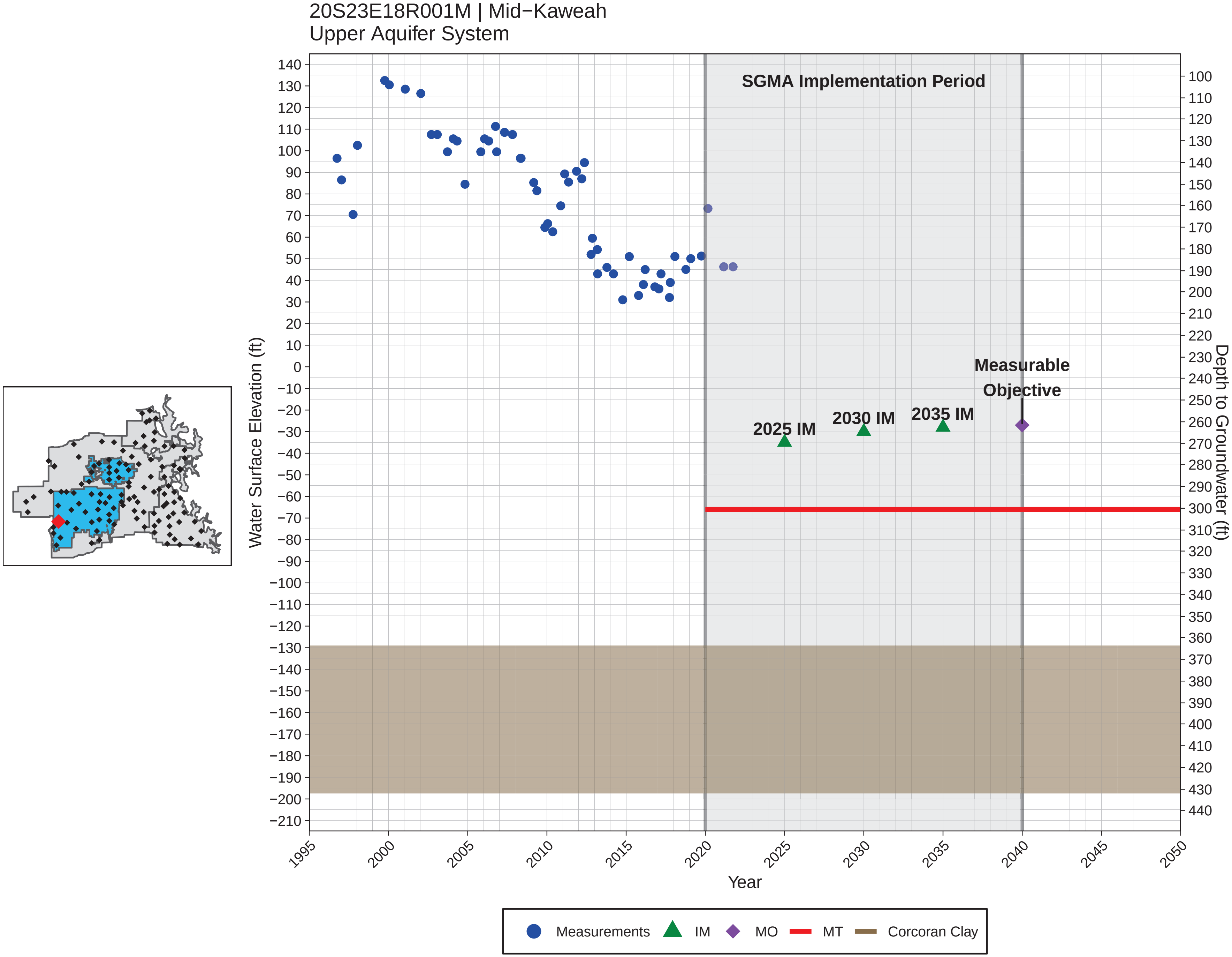
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SGMA Implementation Period
Measurable Objective
2025 IM
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Water Surface Elevation (ft)
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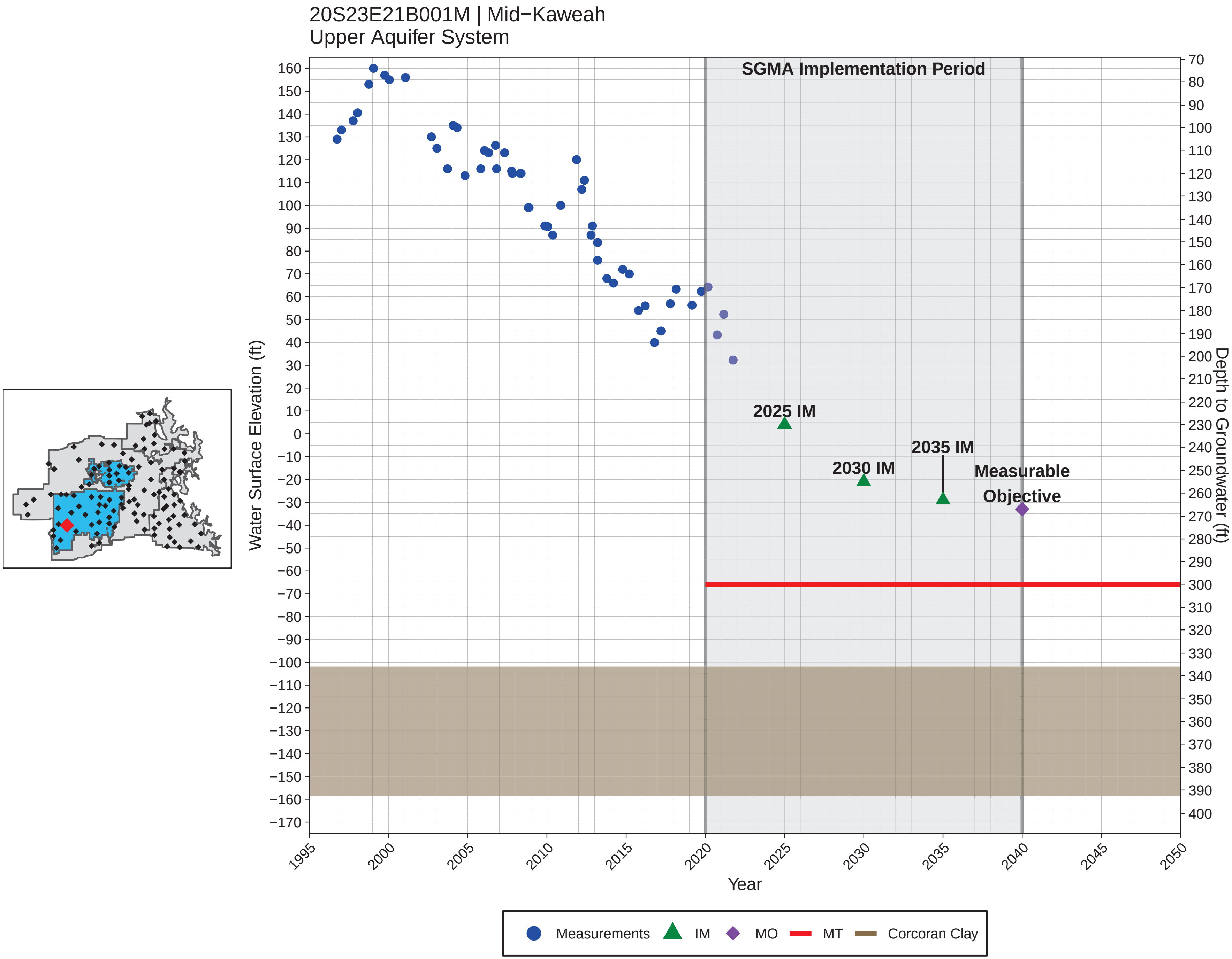
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Measurable
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Depth to Groundwater (ft)
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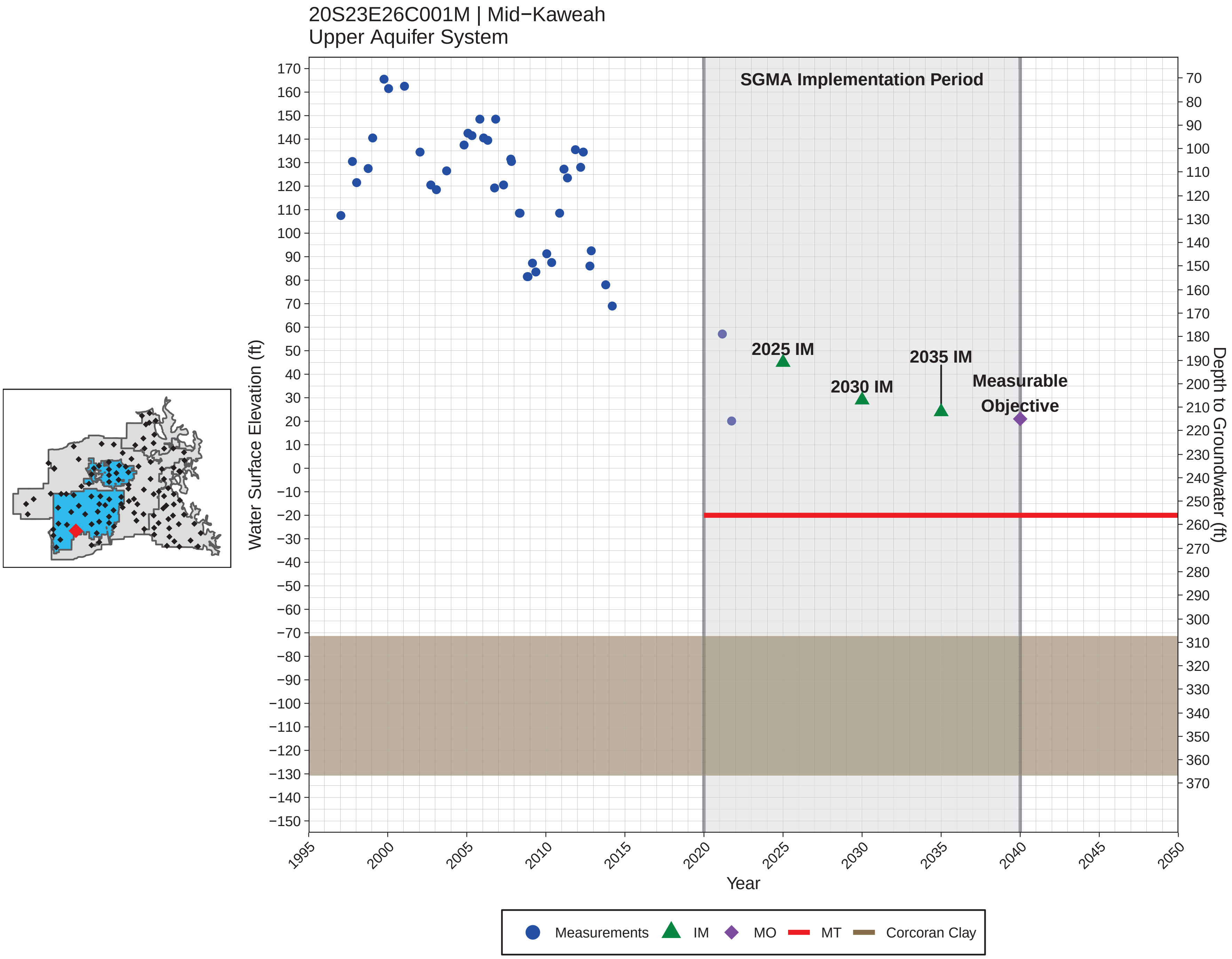
Corcoran Clay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Upper Aquifer System
SGMA Implementation Period
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Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
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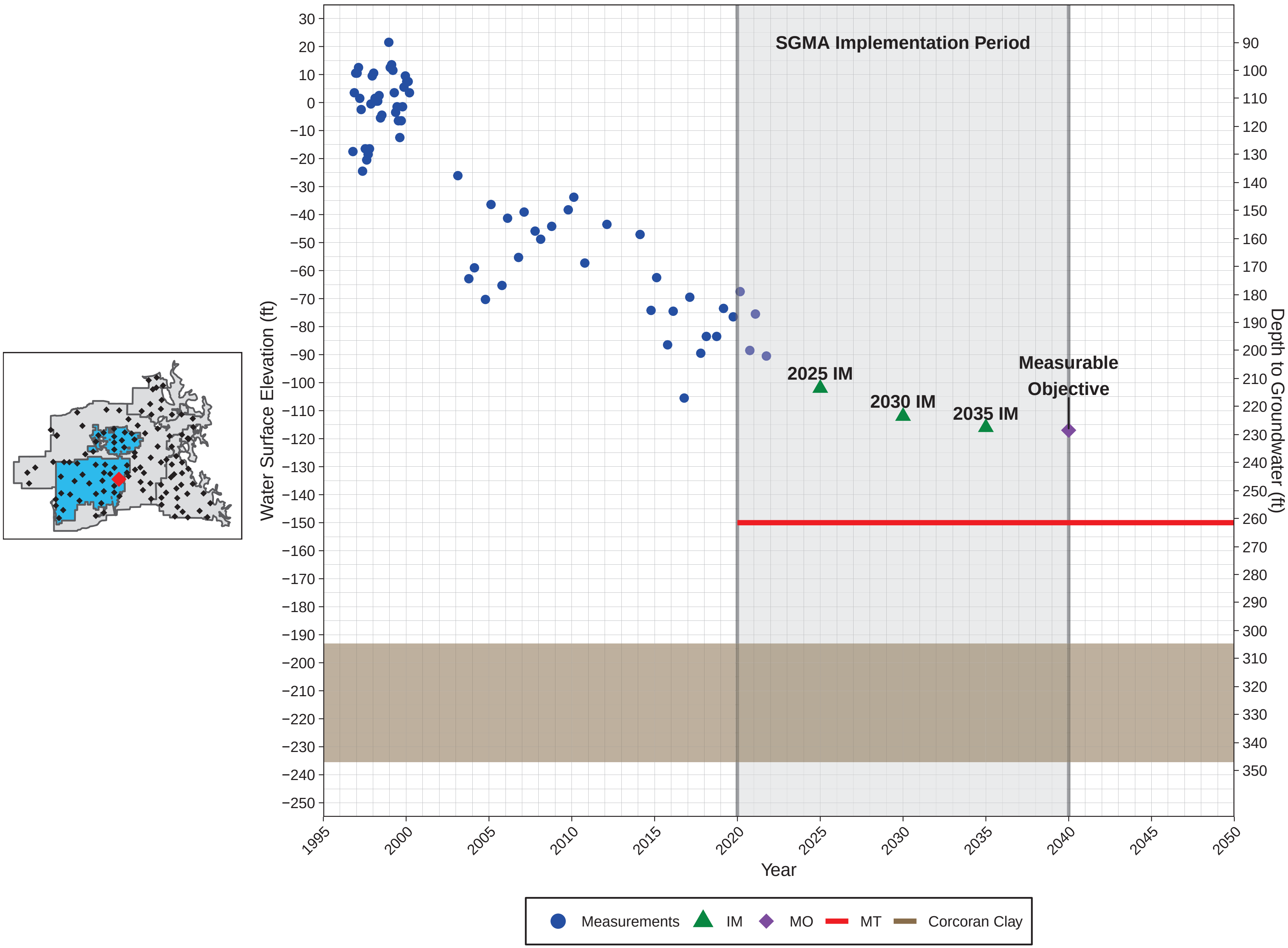
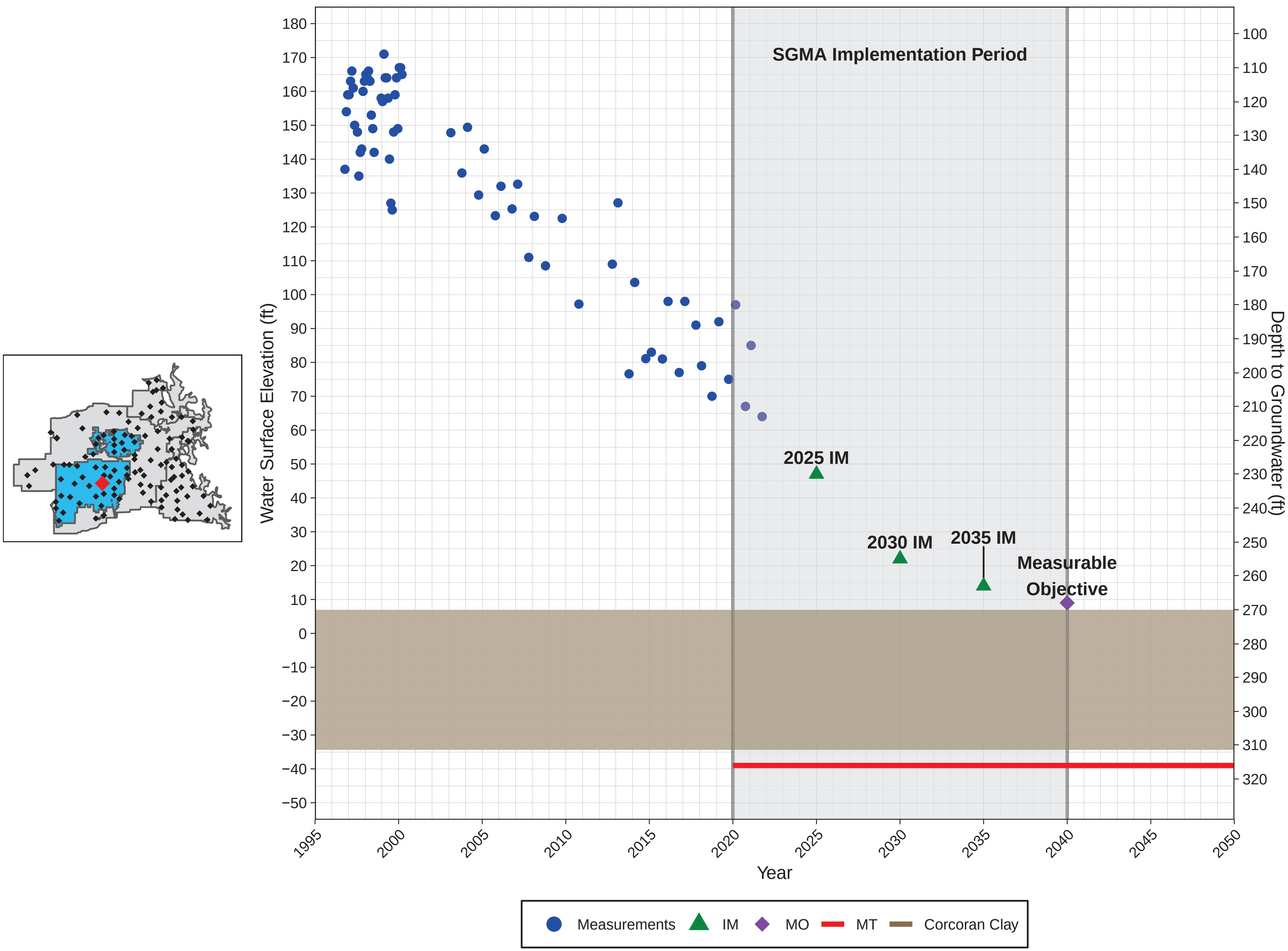
20S24E01H002M | Mid−Kaweah
Lower Aquifer System





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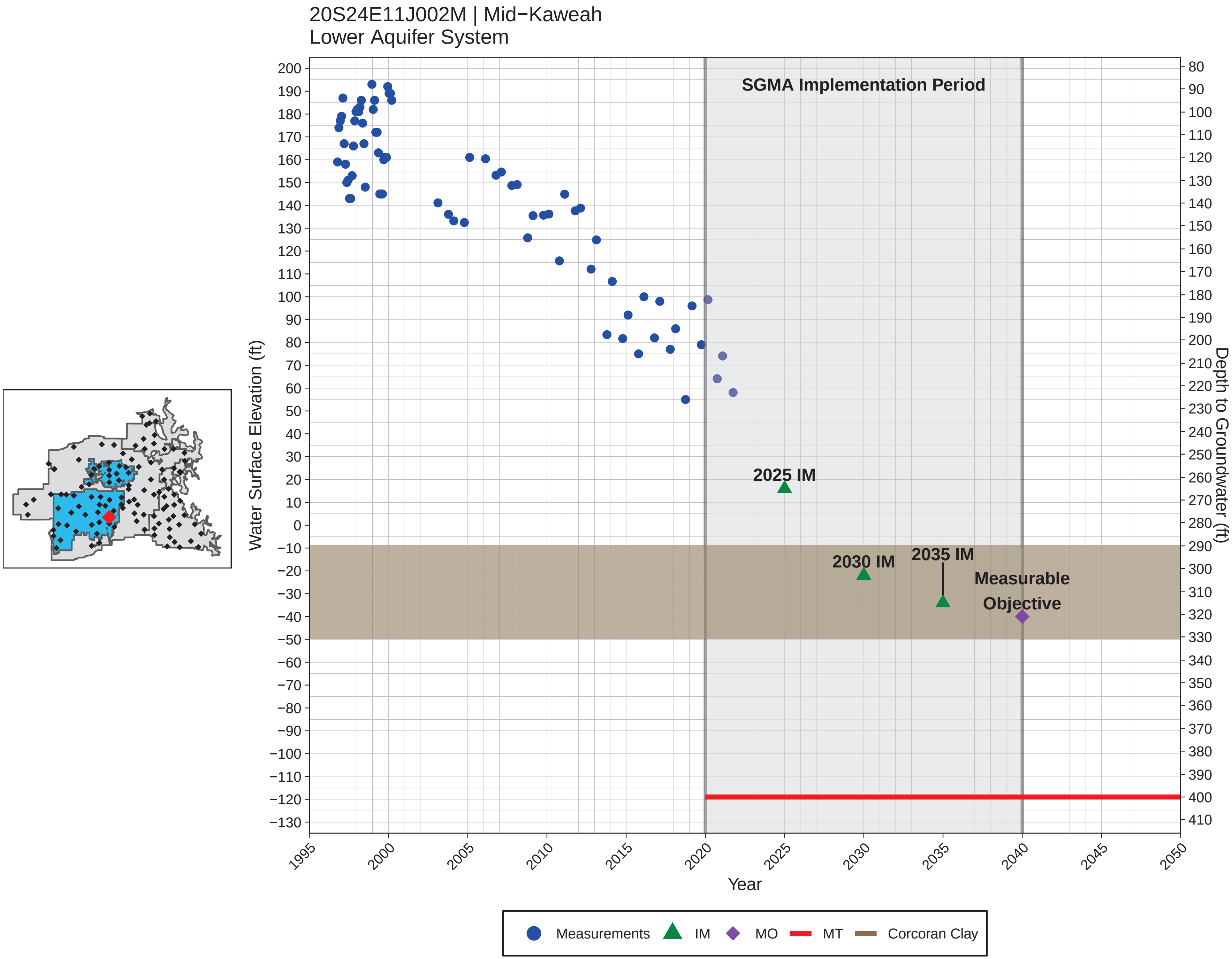
Lower Aquifer System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Lower Aquifer System
SGMA Implementation Period
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Measurable Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
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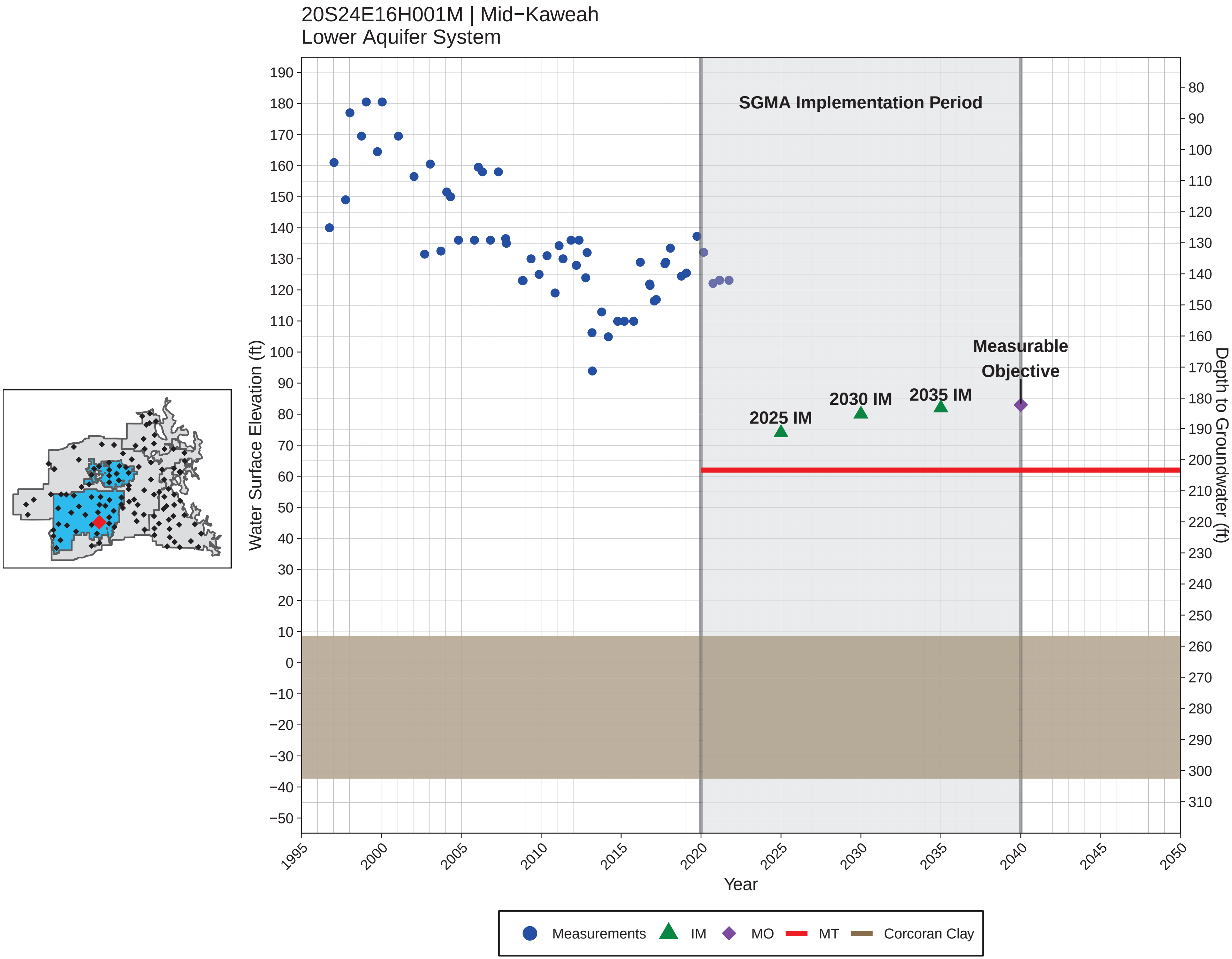
80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410
1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
● Measurements ▲ IM ◆ MO ▬ MT ▬ Corcoran Clay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Lower Aquifer System
SGMA Implementation Period
Measurable Objective
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2035 IM
Water Surface Elevation (ft)
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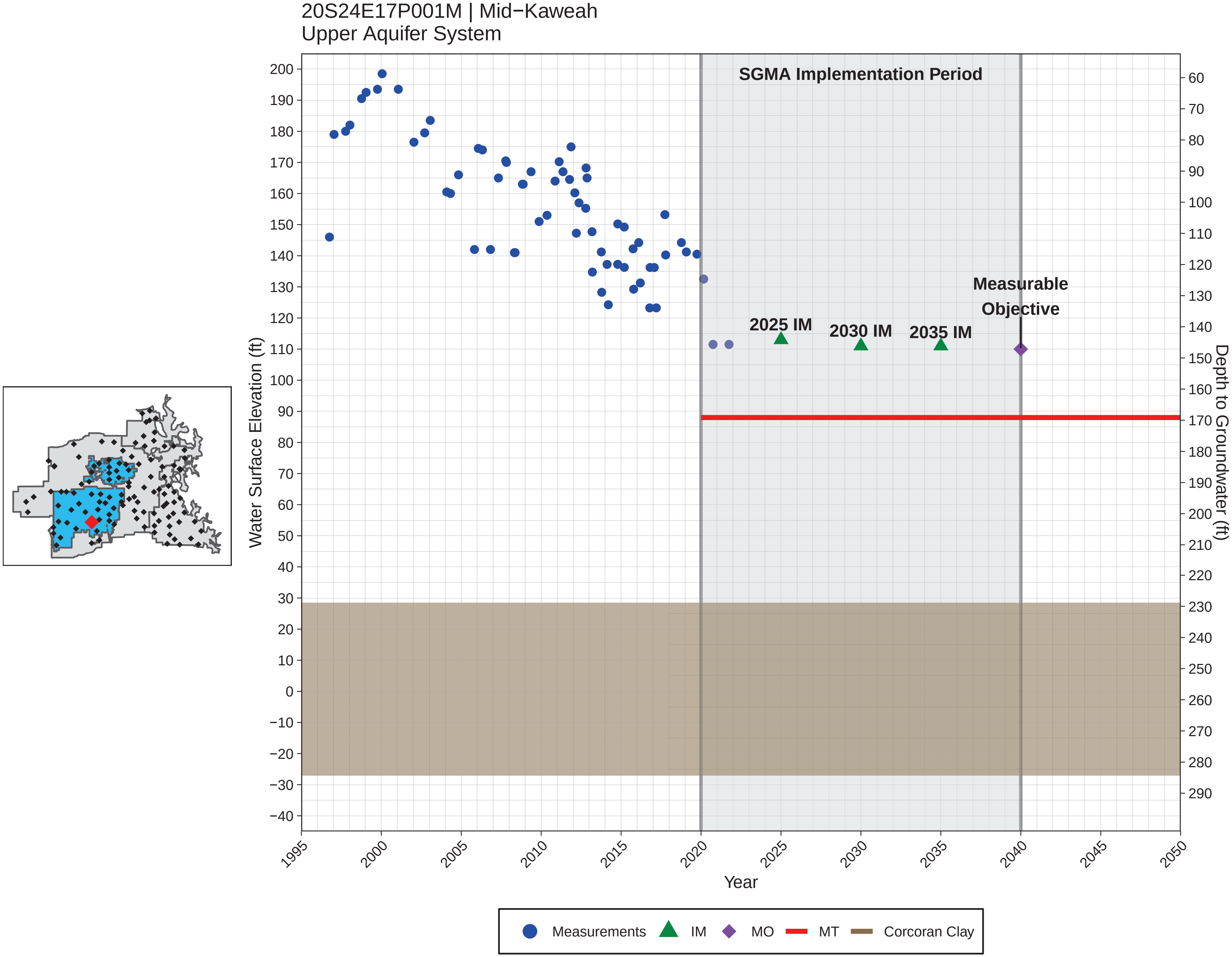
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SGMA Implementation Period
Measurable Objective
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2035 IM
Water Surface Elevation (ft)
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Measurements
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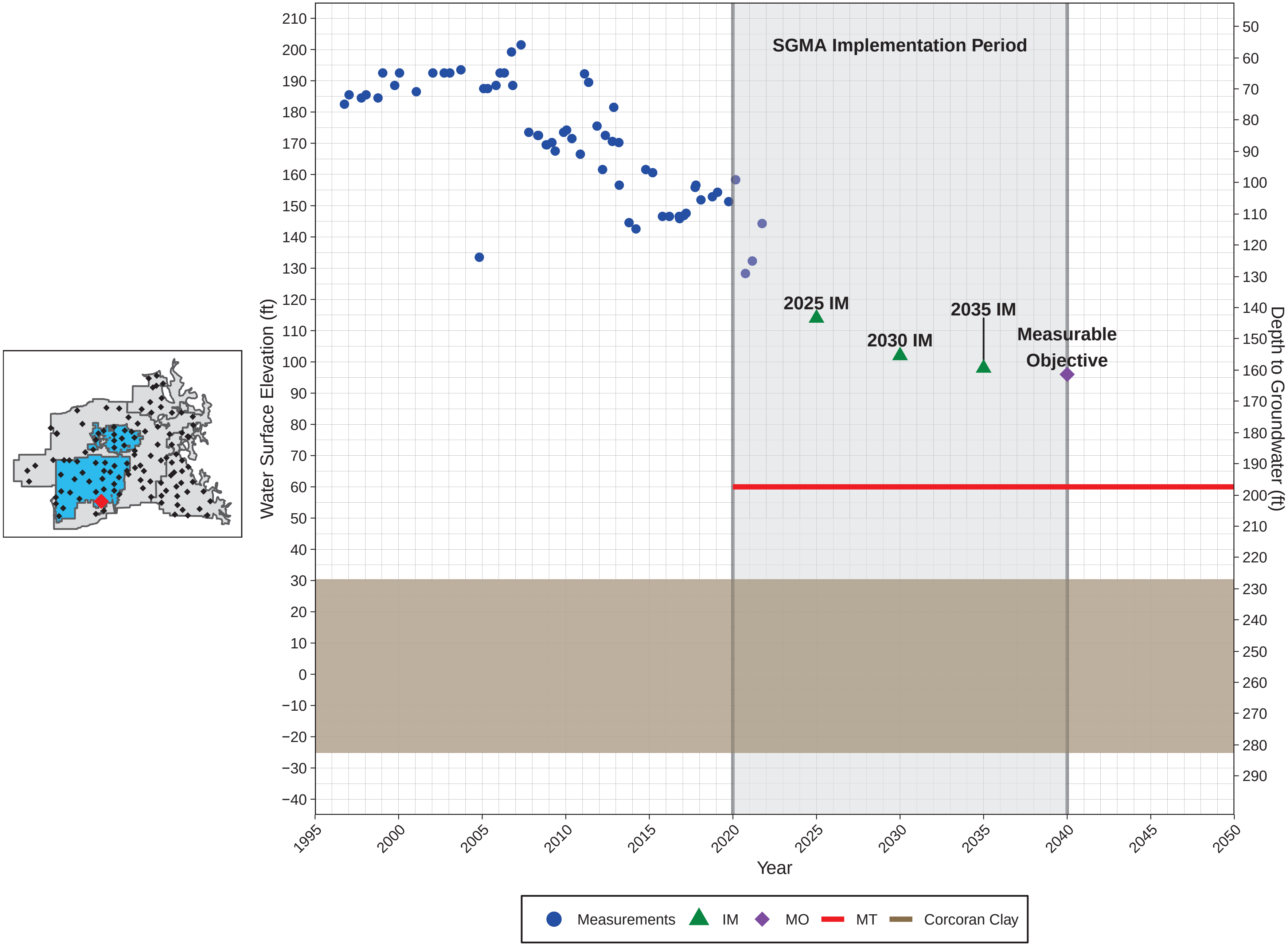
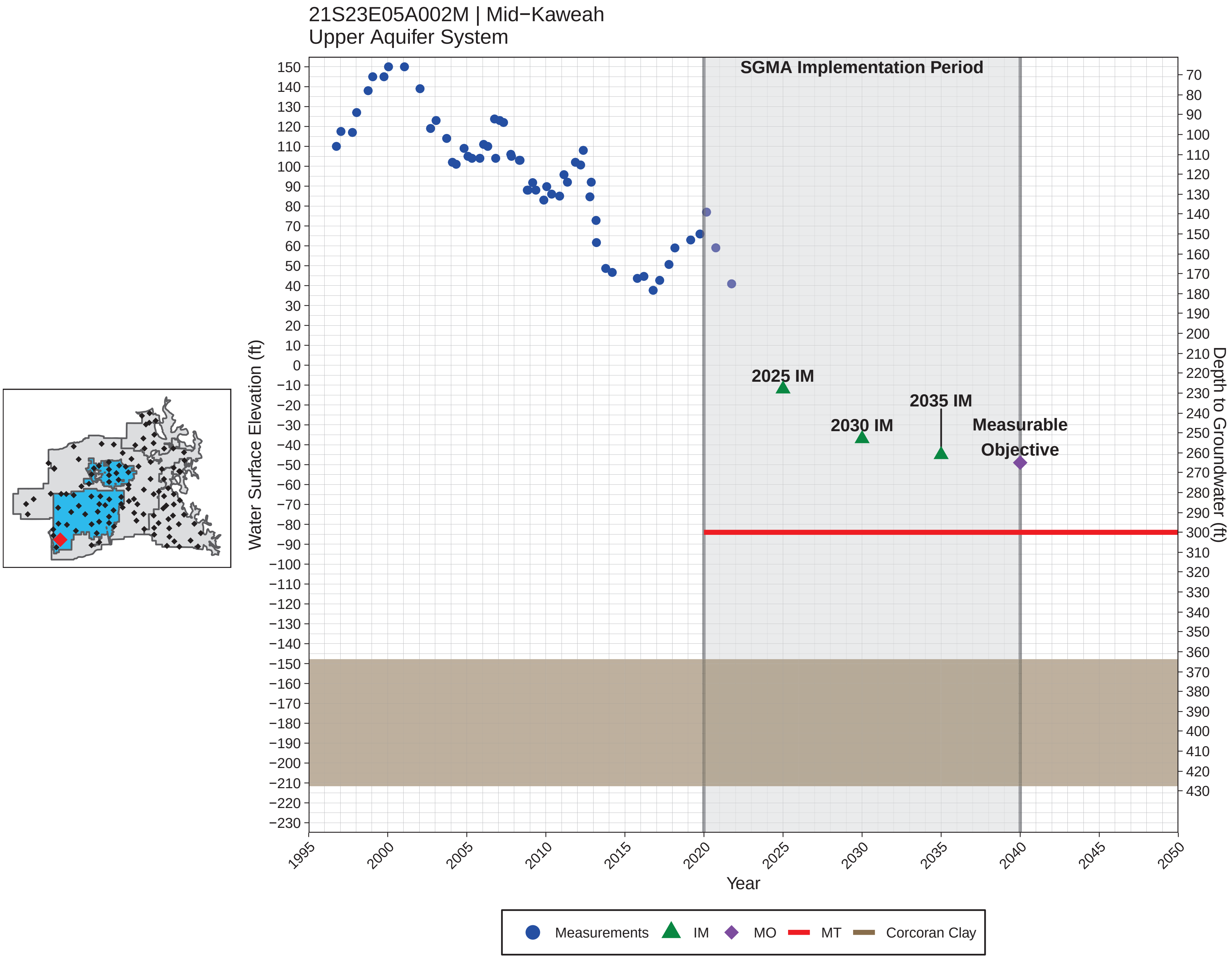
Corcoran Clay

20S24E28L001M | Mid−Kaweah
Upper Aquifer System

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Upper Aquifer System
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Measurable Objective
Water Surface Elevation (ft)
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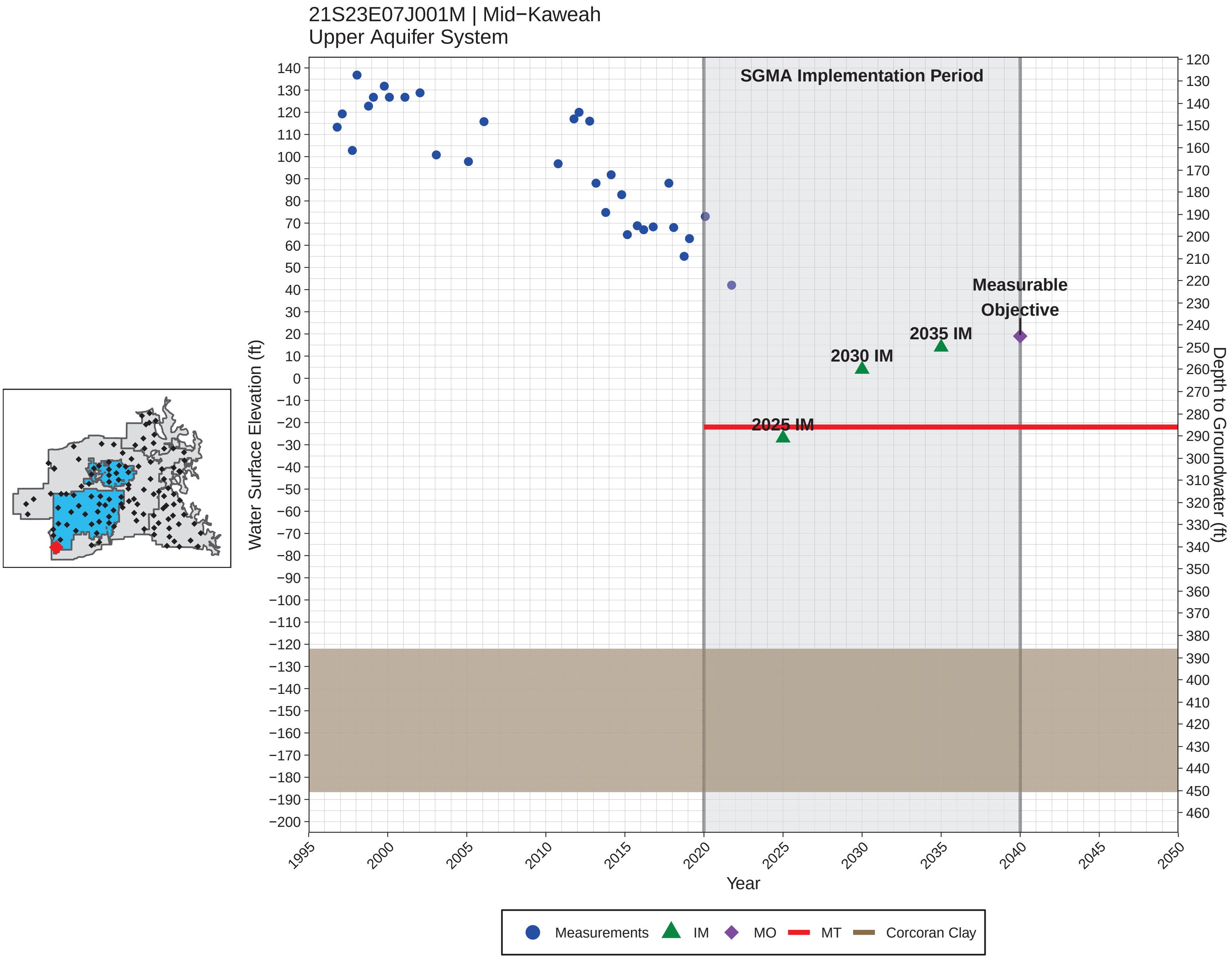
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SGMA Implementation Period
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Water Surface Elevation (ft)
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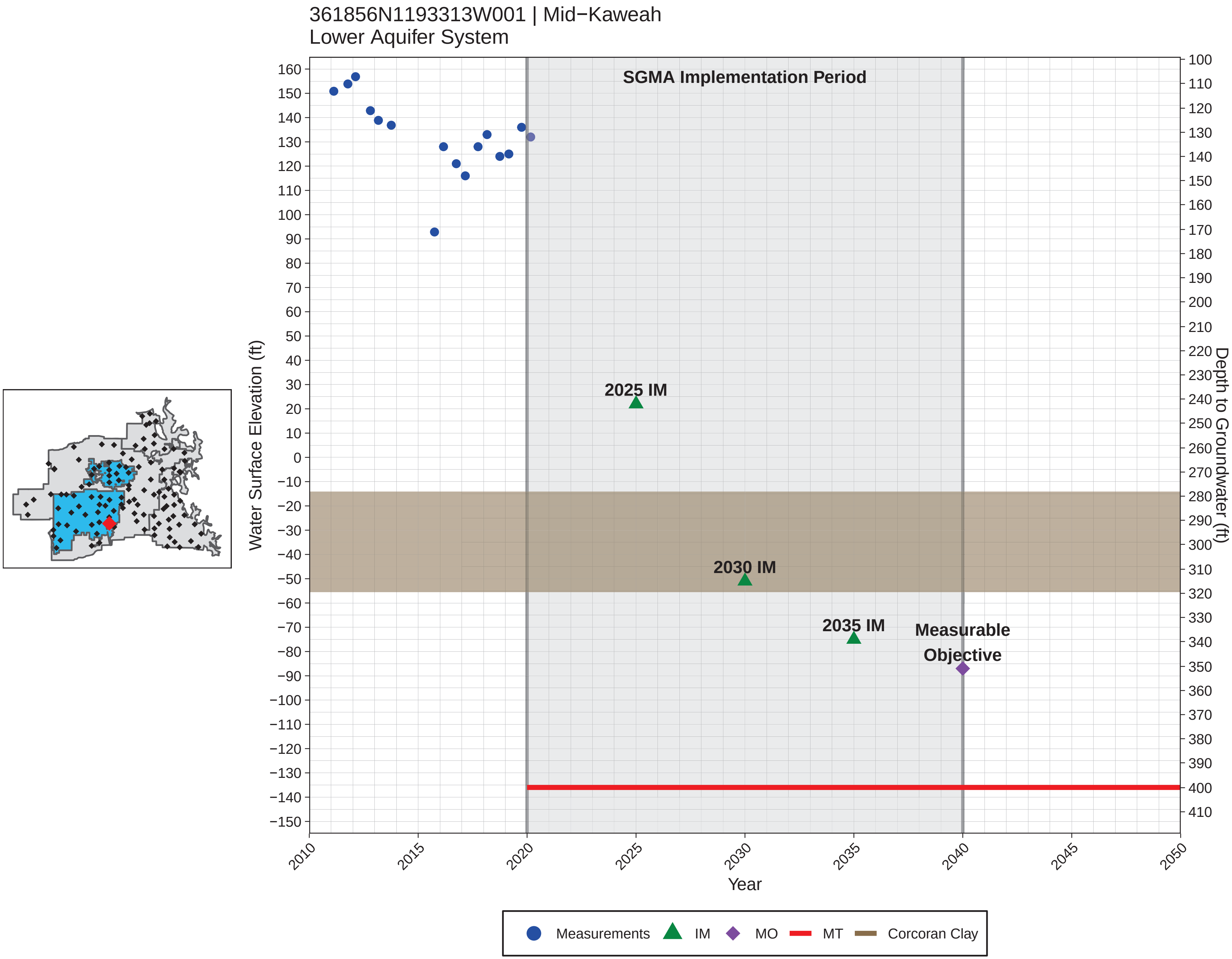
Corcoran Clay


361856N1193313W001 | Mid−Kaweah
Lower Aquifer System
SGMA Implementation Period
2025 IM
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Measurable
Objective
Water Surface Elevation (ft)
Depth to Groundwater (ft)
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Corcoran Clay

Appendix 5C Potential Well Impact Summary

1 SUMMARY PURPOSE

This summary describes all water supply well completion data available for the San Joaquin Valley - Kaweah Subbasin (Subbasin) since January 1, 2002. The purpose of this summary is estimate for the number of wells that may be impacted by groundwater levels declining to elevations protective of 90% of wells in the Subbasin (described in Appendix 5A). These estimates can be used by the Groundwater Sustainability Agencies (GSAs) to develop well mitigation plans for their respective Groundwater Sustainability Plans (GSPs).

The majority of minimum thresholds described in Appendix 5A are at higher elevations than elevations protective of 90% of wells. The estimates of potentially impacted wells therefore overestimate the number of wells. However, since these estimates are to be used for determining the magnitude of wells to be addressed by mitigation plans, they can be considered worst-case estimates.

2 WELL RECORDS IN THE KAWEAH SUBBASIN

A majority of water supply wells installed in the Subbasin since 2002 have well construction information available from Department of Water Resources (DWR) Well Completion Reports submitted by well drillers. These well records are used to develop chronic lowering of groundwater level sustainable management criteria (SMC), as described in Appendix 5A. This summary supplements potential well impacts described in Appendix 5A by including wells without completed well depth information.

2.1 Data Sources and Quality Control

Well completion information compiled in this appendix is from the DWR Well Completion Report (WCR) dataset, downloaded on March 1, 2022. The WCR dataset does not contain a complete accurate dataset, however, it is the best public source of data available. For example, some wells in the dataset are likely dry or have been destroyed. To filter out wells that may have been abandoned or no longer represent typical modern well depths and current groundwater elevations, only well records drilled since 2002 are used for analysis. Furthermore, well completion reports are not always accurately located. Where coordinates of wells are unavailable, DWR locates the well in the middle of the Public Land Survey System section. The location given by DWR in the WCR dataset is used in this analysis.

2.2 Total Well Records

The majority of water supply well records used in the analysis have known well depths, and the well use type for wells without well depth data are generally proportional to those with depth information. The number of wells installed in the Subbasin both with and without known well depths are included in Table 1. Approximately 3,758 supply wells have been installed in the Subbasin since 2002. Of these, 3,353, or about 89%, have well completion data in the WCR dataset and are used in the SMC analysis described in Appendix A. The proportion of wells used for various purposes is nearly identical for the full WCR dataset compared to the subset of wells with known depths; almost all supply wells are either used for agricultural use (55%) or domestic use (41%). Comparatively small numbers of wells are used for public supply (3%), and industrial (1%) purposes. Since the subset of wells with known depths includes a majority of well records in the dataset and closely approximates well types installed in the Subbasin, it is an appropriate dataset to use to develop mitigation plans.

Table 1. Water Supply Well Records by Use Type

Well Use	All Water Supply Well Records from Jan 1, 2002		Well Records with Depth Information	
	Number of Wells	Percentage	Number of Wells	Percentage
Agricultural	2,061	55%	1,859	55%
Domestic	1,546	41%	1,364	41%
Public Supply	129	3%	117	3%
Industrial	22	1%	13	<1%
TOTAL	3,758	-	3,353	-

2.3 Well Records by GSA

Table 2 summarizes the number of well records by well use type for each GSA. There are approximately 1,276 well records in East Kaweah, 1,814 in Greater Kaweah, and 668 in Mid-Kaweah.

Table 2. Summary of Wells by GSA

Well Use Type	East Kaweah		Greater Kaweah		Mid-Kaweah		Total
	Number of Wells	Percentage	Number of Wells	Percentage	Number of Wells	Percentage	
Domestic	463	36%	814	45%	269	40%	1,546
Agricultural	793	62%	914	50%	354	53%	2,061
Public Supply	17	1%	71	4%	41	6%	129
Industrial	3	<1%	15	1%	4	1%	22
Total	1,276	-	1,814	-	668	-	3,758

2.4 Well Records by Analysis Zone

Well records from each analysis zone may be used by GSAs for well mitigation plans. The total number of well records in each aquifer zone is summarized in Table 3. Figure 1 shows the location of the analysis zones.

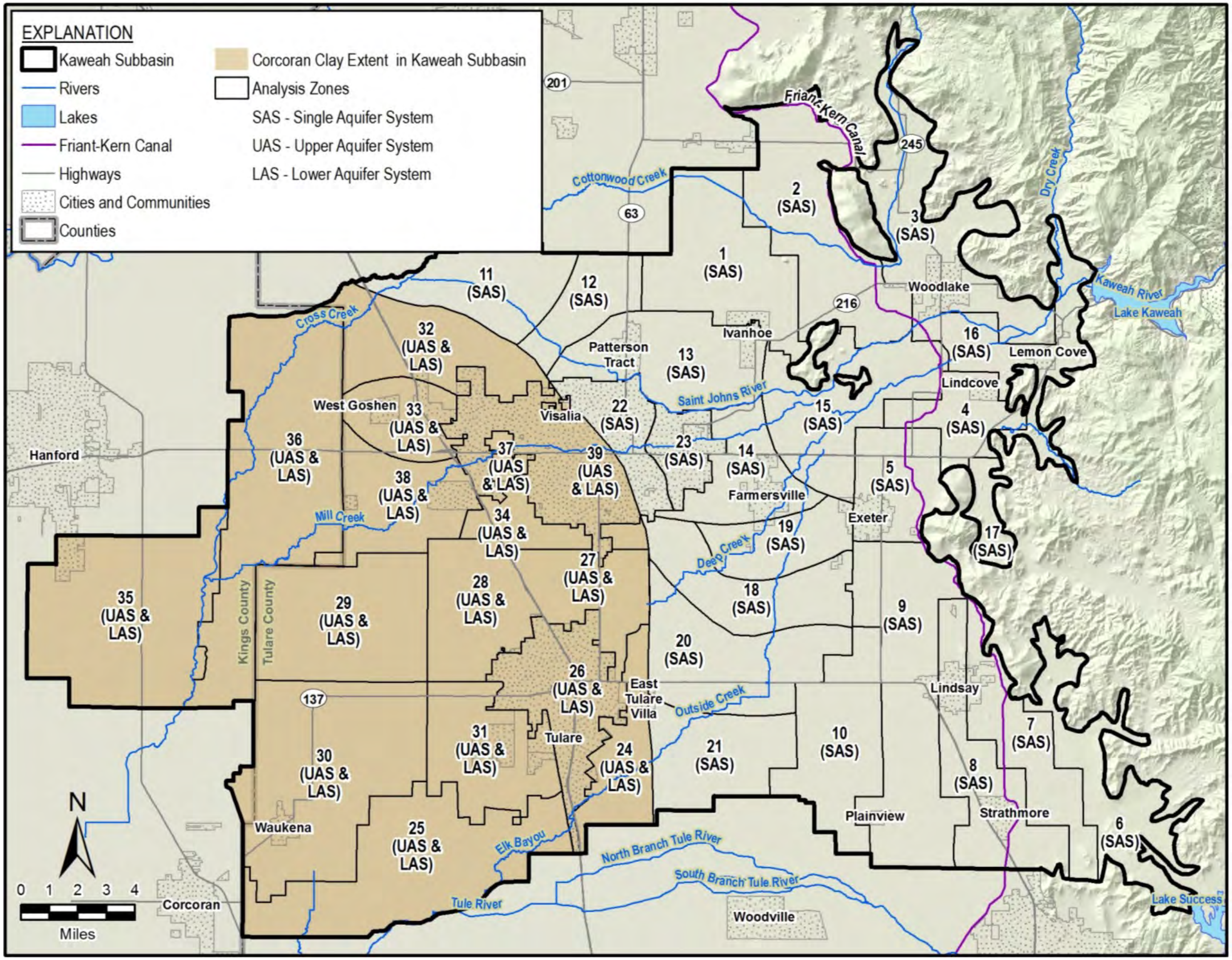

Figure 1. Kaweah Subbasin Analysis Zones

Table 3. Total Well Records by Analysis Zone

Analysis Zone	Agricultural Well Records	Domestic Well Records	Public Well Records	Industrial Well Records	Total Well Records
1	211	118	1	5	335
2	149	23	1	0	173
3	52	39	0	1	92
4	46	42	0	6	94
5	43	29	1	1	74
6	25	9	0	0	34
7	46	18	0	0	64
8	51	56	0	2	109
9	137	99	0	7	243
10	69	52	0	1	122
11	24	2	0	2	28
12	33	30	0	3	66
13	85	146	0	7	238
14	42	52	1	7	102
15	65	73	0	2	140
16	19	46	1	1	67
17	11	3	0	0	14
18	56	62	0	3	121
19	25	87	0	3	115
20	55	88	0	5	148
21	38	12	1	5	56
22	16	6	0	7	29
23	3	7	0	1	11
24	33	33	1	2	69
25	70	3	0	4	77
26	14	18	0	7	39
27	49	75	0	4	128
28	50	69	0	2	121
29	61	19	0	2	82
30	108	52	1	10	171
31	33	8	0	4	45
32	18	1	3	1	23
33	44	32	3	1	80
34	25	52	1	2	80
35	89	29	4	9	131
36	87	8	0	6	101
37	9	15	0	0	24
38	43	16	0	2	61
39	27	17	3	4	51
Total	2,061	1,546	22	129	3,758

3 POTENTIALLY IMPACTED WELLS

3.1 Well Records Shallower than Protective Well Depth by GSA

Wells shallower than protective well depths described in Appendix 5A may be impacted should groundwater elevations approach or exceed minimum thresholds during GSP implementation. The total number of well records shallower than protective well depths in each GSA is estimated using the percentage of wells shallower than the 90th percentile well depth by well use type. Selection of the 90th percentile well depth accounts for uncertainty in the data, especially regarding the likelihood the shallowest wells have been destroyed and replaced during ongoing dry conditions and declining groundwater levels. The analysis is completed using only wells with known well depths. The majority of minimum thresholds described in Appendix 5A are at higher elevations than elevations protective of 90% of wells. The tables that follow therefore overestimate the number of potentially impacted wells. However, since these estimates are to be used for determining the magnitude of wells to be addressed by mitigation plans, they can be considered worst-case estimates.

Table 4 through Table 6 show the approximate number of impacted wells in each GSA, including wells with unknown well depths.

- East Kaweah GSA – approximately 122 wells may be impacted, including 64 domestic wells, 55 agricultural wells, and 3 public supply wells (Table 4).
- Greater Kaweah GSA – approximately 167 wells may be impacted, including 105 domestic wells, 55 agricultural wells, and 7 public supply wells (Table 5).
- Mid-Kaweah GSA – approximately 43 wells may be impacted, including 22 domestic wells and 21 agricultural wells (Table 6).

Table 4. East Kaweah GSA Potentially Impacted Wells

Well Use Type	Well Records with Known Depth			All Well Records		
	Number of Wells	Number of Potentially Impacted Wells	Percentage Potentially Impacted Wells	Number of Wells	Number of Potentially Impacted Wells	Density of Impacted Wells (wells per square mile)
Domestic	418	58	14%	463	64	0.35
Agricultural	721	50	7%	793	55	0.30
Public Supply	16	3	19%	17	3	0.02
Industrial	2	0	0%	3	0	0
Total	1,157	111		1,276	122	0.67

Table 5. Greater Kaweah GSA Potentially Impacted Wells

Well Use Type	Well Records with Known Depth			All Well Records		
	Number of Wells	Number of Potentially Impacted Wells	Percentage Potentially Impacted Wells	Number of Wells	Number of Potentially Impacted Wells	Density of Impacted Wells (wells / square mile)
Domestic	732	96	13%	814	105	0.30
Agricultural	829	49	6%	914	55	0.16
Public Supply	64	6	10%	71	7	0.02
Industrial	8	0	0%	15	0	0
Total	1,633	151		1,814	167	0.48

Table 6. Mid-Kaweah GSA Potentially Impacted Wells

Well Use Type	Well Records with Known Depth			All Well Records		
	Number of Wells	Number of Potentially Impacted Wells	Percentage Potentially Impacted Wells	Number of Wells	Number of Potentially Impacted Wells	Density of Impacted Wells (wells / square mile)
Domestic	214	17	8%	269	22	0.13
Agricultural	309	18	6%	354	21	0.13
Public Supply	37	0	0%	41	0	0
Industrial	3	0	0%	4	0	0
Total	563	35		668	43	0.26

3.2 Well Records Shallower than Protective Well Depth by Analysis Zone

The total number of well records within each analysis zone may be used by the GSAs to estimate potential impacts to be addressed by Well Mitigation Programs. The approximate number of well records that are shallower than the protective well depth in each aquifer zone are summarized in Table 7. Figure 1 shows the location of the analysis zones.

Table 8. East Kaweah GSA Potentially Impacted Wells Summarized by Analysis ZoneTable 8 through Table 10 summarize estimated GSA-specific potential well impacts by well use type.

Table 7. Basinwide Potentially Impacted Wells Summarized by Analysis Zone

Analysis Zone	Agricultural Well Records	Domestic Well Records	Public Well Records	Industrial Well Records	Total Well Records
1	15	19	0	0	34
2	15	3	0	0	18
3	2	2	0	0	4
4	2	7	0	0	9
5	3	4	0	0	7
6	3	1	0	0	4
7	6	1	0	0	7
8	1	9	0	1	11
9	7	14	0	2	23
10	3	7	0	0	10
11	2	1	0	0	3
12	3	3	0	0	6
13	1	16	0	1	18
14	0	10	0	0	10
15	5	10	0	0	15
16	2	4	0	0	6
17	1	1	0	0	2
18	2	11	0	0	13
19	2	6	0	0	8
20	0	14	0	0	14
21	3	2	0	0	5
22	3	1	0	0	4
23	0	2	0	0	2
24	2	4	0	0	6
25	8	1	0	0	9
26	2	0	0	0	2
27	2	4	0	0	6
28	1	3	0	0	4
29	2	2	0	0	4
30	7	8	0	0	15
31	2	1	0	0	3
32	4	0	0	0	4
33	3	4	0	0	7
34	0	6	0	1	7
35	7	1	0	2	10
36	8	1	0	1	10
37	0	1	0	0	1
38	0	6	0	2	8
39	2	1	0	0	3
Total	131	191	0	10	332

Table 8. East Kaweah GSA Potentially Impacted Wells Summarized by Analysis Zone

Analysis Zone	Agricultural Well Records	Domestic Well Records	Public Well Records	Industrial Well Records	Total Well Records
1	15	19	0	0	34
2	15	3	0	0	18
3	2	2	0	0	4
4	1	5	0	0	6
5	2	3	0	0	5
6	3	1	0	0	4
7	6	1	0	0	7
8	1	9	0	1	11
9	7	14	0	2	23
10	3	7	0	0	10
Total	55	64	0	3	122

Table 9. Greater Kaweah GSA Potentially Impacted Wells Summarized by Analysis Zone

Analysis Zone	Agricultural Well Records	Domestic Well Records	Public Well Records	Industrial Well Records	Total Well Records
3	0	0	0	0	0
4	1	2	0	0	3
5	1	1	0	0	2
11	2	1	0	0	3
12	3	3	0	0	6
13	1	16	0	1	18
14	0	10	0	0	10
15	5	10	0	0	15
16	2	4	0	0	6
17	1	1	0	0	2
18	2	11	0	0	13
19	2	6	0	0	8
20	0	14	0	0	14
21	3	2	0	0	5
22	0	0	0	0	0
23	0	0	0	0	0
24	2	4	0	0	6
25	8	1	0	0	9
30	0	0	0	0	0
32	4	0	0	0	4
33	3	4	0	0	7
34	0	6	0	1	7
35	7	1	0	2	10
36	8	1	0	1	10
37	0	1	0	0	1
38	0	6	0	2	8
Total	55	105	0	7	167

Table 10. Mid-Kaweah GSA Potentially Impacted Wells Summarized by Analysis Zone

Analysis Zone	Agricultural Well Records	Domestic Well Records	Public Well Records	Industrial Well Records	Total Well Records
22	3	1	0	0	4
23	0	2	0	0	2
24	0	0	0	0	0
26	2	0	0	0	2
27	2	4	0	0	6
28	1	3	0	0	4
29	2	2	0	0	4
30	7	8	0	0	15
31	2	1	0	0	3
39	2	1	0	0	3
Total	21	22	0	0	43

Appendix 5D Water Storage Additions – An Alternative Approach

Appendix 5D: Water Storage Additions – An Alternative Approach

Estimated Water-Level Gains by MKGSA Projects

Applying the estimated projects' storage benefits over time as assumed herein, coupled with the annual storage depletion identified in Section 5.3.5 and using the relationship depicted on Figure 5-6, the change in water levels may be projected for the period 2020-2040, as shown in **Table 1**.

The table assumes a current water level of 150 feet in depth and an annual lowering of the regional water level, absent any projects or management actions, of 3.5 feet/year, characteristics typical of the TID region as a whole. This rate of reduction is ultimately overcome by the year 2040 when the water depth would level out at around 180 feet, absent any future hydrologic variability likely to occur.

Table 1: Added Storage and Measurable Objectives

Year	**Storage Added** (5-yr avg in AF)	**Water Level Measurable Objective (hypothetical)** (depth in feet)
2018	9,600	150
2019	9,600	152
2020	9,967	154
2021	10,150	156
2022	10,354	158
2023	10,668	160
2024	10,982	161
2025	11,336	163
2026	11,846	165
2027	12,262	166
2028	12,678	168
2029	13,094	170
2030	14,008	171
2031	14,766	172
2032	15,524	173
2033	16,282	174
2034	17,040	175
2035	17,040	176
2036	17,040	177
2037	17,040	178
2038	17,040	178
2039	17,040	179
2040	17,040	180

Notes:
(1) Beginning in 2031, pumping allocation activated to eliminate any residual shortfall after project implementation.
(2) Highlighted water levels denote hypothetical interim milestones.

Water level responses to projects and management actions will likely differ between the three Management Areas within the MKGSA; however, the groundwater storage measurable objective will be the primary metric used in uniform fashion across all three Areas.

Estimated Water Budget Accruals by MKGSA Projects

The water added to groundwater storage by MKGSA and associated reduction in water budget deficits, whether by recharge projects, optimal surface water management, or groundwater extraction reductions, can serve as a secondary metric with which to gage the effectiveness of GSP sustainability efforts. This would be done on a conservative basis, i.e., relying only on recently-implemented water exchange projects (as described in Section 7.3 of this Plan), and a phased implementation of groundwater extraction reductions across the Subbasin designed to leave water in storage (not extracted) sufficient to eradicate MKGSA's assumed annual hydrogeologic water budget deficit of about 13,000 AF, as discussed in Section 5.3.3 of the MKGSA GSP.

Table 2 shows the accumulated storage (water added) benefits of the Projects in Section 7 of the MKGSA GSP for which benefits have been estimated. The benefits shown generally represent the middle of the range presented in that section.

Table 2: Accumulated Storage Benefits

Year	Total Added Storage (AF)
2019	9,600
2020	10,700
2022	11,170
2025	12,470
2026	13,250
2030	17,040

Starting with the annual deficit of 13,000 AF and assuming all projects are online by 2030, this deficit would be eradicated. However, water level declines at the five-year Interim Milestones within the MKGSA region may or may not be fully arrested. The Subbasin GSAs, through their Coordination Agreement obligations, will continue to negotiate responsibilities in addressing these declines and eliminate any residual overdraft by 2040.

Coupling the annual deficit with water added by Projects and extraction reductions (Management Actions) results in a change in storage trajectory as listed in **Table 3** and graphically (red line) shown on **Figure 1**. This trajectory would be an optimal objective, consistent with §354.30(g) of the Regulations, and would result in a groundwater storage gain.

These secondary metrics are considered monolithic and apply across all three Management Areas of the MKGSA. Responsibilities towards obtaining these objectives and associated funding are as described in Section 7.5 of this Plan.

Hypothetical Interim Milestones to gage the water-added benefits of Projects and Management Actions are also depicted in **Figure 1**. For each five-year Interim Milestone, a trigger of 10 percent below the calculated groundwater budget increase could be employed to activate more stringent groundwater extraction limits should there be no other project activations in the foreseeable future.

The figure also indicates a hypothetical storage depletion Minimum Threshold of minus 252 TAF, which would otherwise occur by 2040 absent implementation of Projects and Management Actions.

This depletion volume is based on an average annual storage reduction of 12,600 AF (per the discussion in Section 2 regarding MKGSA's hydrogeologic water budget) times 20 years. As previously indicated in Section 5.3.1, however, water levels are to serve by proxy for the storage depletion Minimum Threshold.

Table 3: MKGSA Storage Optimal Objectives (in AF)

Year	MT=0.252 maf **Storage Optional Objective**	**Storage Added** (5-yr avg in AF)
2018	-	9,600
2019	(3,000)	9,600
2020	(4,900)	9,967
2021	(6,800)	10,150
2022	(8,230)	10,354
2023	(9,660)	10,668
2024	(11,090)	10,982
2025	(11,220)	11,336
2026	(10,570)	11,846
2027	(9,920)	12,262
2028	(9,270)	12,678
2029	(8,620)	13,094
2030	(4,180)	14,008
2031	260	14,766
2032	4,700	15,524
2033	9,140	16,282
2034	13,580	17,040
2035	18,020	17,040
2036	22,460	17,040
2037	26,900	17,040
2038	31,340	17,040
2039	35,780	17,040
2040	40,022	17,040

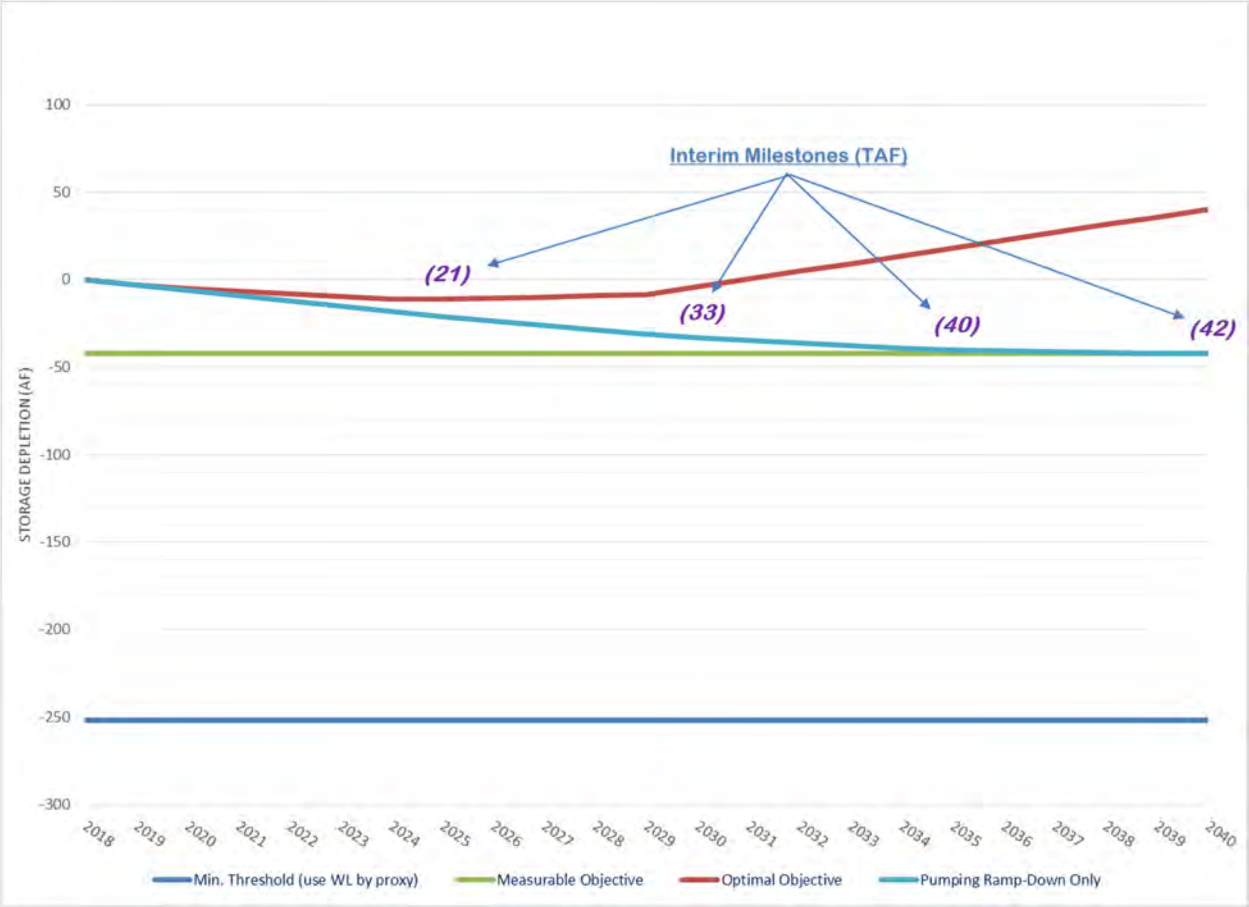

Figure 1: Hypothetical Representation of Measurable and Optimal Objectives

The reduction in storage range by 2040 between the optimal objective of a 40 TAF gain and the Measurable Objective of a 42 TAF reduction, as well as the buffer allowance down to the hypothetical Minimum Threshold of 252 TAF, will allow for sufficient operational flexibility to account for seasonal and long-term trends in hydrology and extended drought periods. These differentials are considered sufficient to account for the level of uncertainty associated with the understanding of the Subbasin, as described in the Basin Setting and its HCM.

The Projects envisioned in Section 7 of this Plan have a lengthy life span of more than 50 years, and the Management Actions will remain in force, as needed, commensurate with the Projects' accomplishments. Therefore, the path to Sustainable Yield by 2040, as inferred in **Figure 1**, is considered very likely and, in concert with the implementation measures of neighboring GSAs, sustainable groundwater management is possible beyond 2040 and over the full Planning and Implementation Horizon to 2070.

Appendix 5E Technical Approach for Developing Subsidence Sustainable Management Criteria in the Kaweah Subbasin

July 27, 2022

Technical Approach for Developing Subsidence Sustainable Management Criteria in the Kaweah Subbasin

Prepared for:

East Kaweah Groundwater Sustainability Agency
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ACRONYMS & ABBREVIATIONS

1-D Model	1-Dimensional Compaction Numerical Model
DWR	California Department of Water Resources
EKGSA	East Kaweah Groundwater Sustainability Agency
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
InSAR	Interferometric Synthetic Aperture Radar
SGMA	Sustainable Groundwater Management Act
SMC	Sustainable Management Criteria
Subbasin	Kaweah Subbasin
TID	Tulare Irrigation District
USGS	United States Geological Survey

1 INTRODUCTION

This technical report describes the methodology for developing land subsidence sustainable management criteria (SMC) for the San Joaquin Valley - Kaweah Subbasin (Subbasin). The revisions are in response to the California Department of Water Resources' (DWR) incomplete determination of the 3 Groundwater Sustainability Plans (GSPs) submitted in January 2020 (DWR, 2022). The 3 GSPs are implemented by 3 Groundwater Sustainability Agencies (GSAs) covering the entirety of the Subbasin: East Kaweah GSA, Greater Kaweah GSA, and Mid-Kaweah GSA.

DWR provided a staff report with a statement of findings explaining the incomplete determination for the Subbasin GSPs. The staff report states, "the Plan does not define sustainable management criteria for subsidence in the manner required by Sustainable Groundwater Management Act (SGMA) and the GSP Regulations." DWR's findings specified the following:

- Because Mid-Kaweah and Greater Kaweah did not define subsidence criteria based on conditions that would substantially interfere with land surface uses and users in the Subbasin, Department staff have no basis for evaluating whether continued subsidence predicted by the Plans (potentially 15 feet in the next 20 years in the southwest portion of the Subbasin) would cause significant and unreasonable impacts to land surface uses.
- The East Kaweah GSP better comports with expectations based on the GSP Regulations to develop sustainable management criteria for subsidence. The East Kaweah GSP states that an undesirable result would occur if there were "significant loss of functionality of a structure or a facility to the point that, due to subsidence, the feature cannot be operated as designed requiring either retrofitting or replacement." The East Kaweah GSP identified the Friant-Kern Canal as critical infrastructure for users in the GSA area and determined that a loss of more than 10% of its capacity would be unacceptable. The East Kaweah GSP identified that subsidence over 9.5 inches cumulatively would result in the 10% loss in capacity and, therefore, used 9.5 inches of cumulative subsidence as the minimum threshold.
- The differences between Greater Kaweah and East Kaweah GSPs creates the potential for inconsistency in groundwater management between the Subbasins GSPs. A portion of the Greater Kaweah GSP area bisects the East Kaweah GSP area in the vicinity of the Friant Kern Canal. Greater Kaweah's subsidence minimum thresholds in this area allow for 1.0 to 1.2 inches per year of subsidence, or 20 to 24 inches cumulatively over the 20-year implementation period. Neither the East Kaweah nor the Greater Kaweah GSPs nor the Subbasin Coordination Agreement explain how up to 24 inches of subsidence in the

Greater Kaweah area can be accommodated without interfering with the 9.5-inch limit set by East Kaweah to protect the conveyance capacity of the Friant-Kern Canal. The GSPs will need to reconcile this apparent discrepancy.

DWR's recommended corrective actions include the following:

- Mid-Kaweah and Greater Kaweah must define sustainable management criteria for land subsidence in the manner required by SGMA and the GSP Regulations. The GSAs should develop criteria, including minimum thresholds, measurable objectives, interim milestones, and undesirable results based on the amount of subsidence that would substantially interfere with land surface uses. Developed criteria should be supported with information on the effects of subsidence on land surface beneficial uses and users and the amount of subsidence that would substantially interfere with those uses and users.
- Greater Kaweah also must explain how their minimum thresholds in the vicinity of identified critical infrastructure (i.e., the Friant Kern Canal) will not substantially interfere with the Canal's use (identified by East Kaweah GSA as an undesirable result). Address how the amount of potential cumulative subsidence allowed for by Greater Kaweah's subsidence rates, which currently exceeds the amount identified by East Kaweah that would cause an undesirable result, are compatible or provide revised rates for the eastern portion of the Subbasin that are compatible.

The GSAs were given up to 180 days from the receipt of DWR's staff report to address the deficiencies for land subsidence SMC. This document and the GSP revisions fulfill that purpose.

1.1 General Approach Used to Develop Sustainable Management Criteria

The general approach described herein focuses on estimating future total subsidence over various time horizons and addressing potential damage to water conveyance infrastructure and deep wells. No reliable direct correlation between total subsidence and well collapse has been found. Significant and unreasonable impacts to deep wells are based on commonly used well designs that accommodate subsidence. In the future, should more detailed and local information become available on damage to wells caused by subsidence, this information would be used to re-evaluate the impact of subsidence on well infrastructure.

1.2 Data Sources

In response to DWR comments, the GSAs reviewed the data sources and methods used to select subsidence SMCs. Information and tools used for establishing revised subsidence SMC include:

- Groundwater level monitoring in the Subbasin 1999-2021
- Historical Interferometric Synthetic Aperture Radar (InSAR) measured subsidence data
- Local subsidence benchmark monitoring data
- Possible future groundwater elevations based on revised minimum thresholds
- A 1-Dimensional Compaction Numerical Model (1-D Model) developed by Stanford University researchers
- A subsidence spreadsheet prediction tool developed for the GSAs to simplify and extrapolate subsidence predictions from 1-D Model to the rest of the Subbasin
- Water conveyance infrastructure locations

2 METHODOLOGY USED TO ESTIMATE FUTURE SUBSIDENCE

The methodology presented in this section estimates the total future subsidence that is the basis for setting minimum thresholds. Total subsidence is the annual sum of active subsidence caused by the most recent year's lowering of groundwater levels and any residual subsidence from previous years. The method uses historical groundwater elevations, historical subsidence measurements, the 1-D subsidence model, a subsidence spreadsheet prediction tool, and revised chronic lowering of groundwater levels minimum thresholds to establish estimated rates of total future maximum (worst-case) subsidence.

The 1-D model was built and calibrated using the following data and approach:

- An initial model was developed using Fall groundwater levels to simulate historical subsidence between 1999 and 2021.
- The model was calibrated against 2015 to 2021 subsidence data collected using InSAR available from DWR.
- The model was extended from 2021 through 2070 using minimum thresholds as the ultimate groundwater elevations.
    - Chronic lowering of groundwater levels minimum thresholds described in Appendix 5A are used to estimate a groundwater elevation trend between 2021 and 2040.
    - The minimum threshold "worst-case" groundwater elevations are held stable in the model between 2040 and 2070.

The 1-D model results are used to develop a simplified subsidence spreadsheet prediction tool to extrapolate the 1-D model predictions to other areas in the Subbasin. The subsidence predictions from the spreadsheet tool are used to evaluate the impact that subsidence might have on conveyance infrastructure if groundwater levels stabilize in 2040 at the chronic lowering of groundwater levels minimum thresholds.

2.1 1-Dimensional Compaction Numerical Model

A 1-D Model developed by Stanford University researchers (Lees *et al.*, 2022) estimates subsidence in two locations in and adjacent to the Subbasin. Stanford University researchers calibrated historical subsidence at the South Hanford and Tulare Irrigation District (TID) Sites, shown on Figure 1 (Lees *et al*., 2022). Only the results from the South Hanford Site are published by Lees (2022). Stanford researchers used the calibrated 1-D Model to estimate the amount of future subsidence through 2070 at the two sites if groundwater elevation declines to the minimum thresholds.

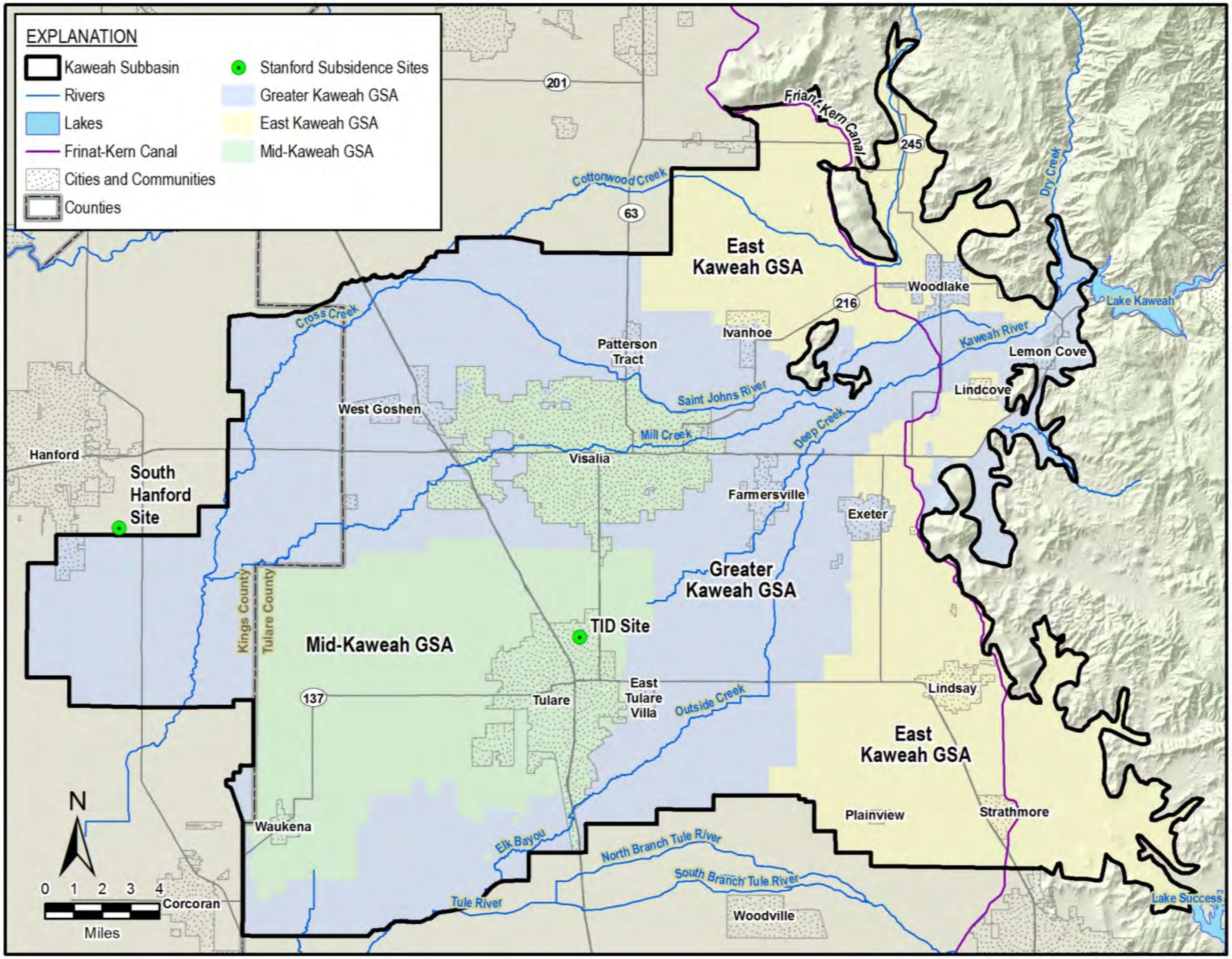


Figure 1. Subsidence Prediction Locations, derived from Lees *et al.*, 2022

2.1.1 Data Sources and Equations

The 1-D Model is built using governing equations for clay compaction with reduction in groundwater head. The equations were originally described in the late 1970s in a United States Geological Survey report (Helm, 1975). The Lees *et al.* (2022) model uses the number and thickness of various clay layers from geophysical logs, historical groundwater elevation data, and historical subsidence estimates from 1952 to 2017 to build and calibrate a model to match subsidence observations. Multiple physical parameters are adjusted to assess sensitivity and uncertainty and develop a range of potential solutions. The calibration results in reasonable values for vertical hydraulic conductivity, specific storage, initial stress, aquifer depth, and the residual timescale for subsidence (Lees *et al.*, 2022).

2.1.2 1-D Model Results

The 1-D model results show significant residual subsidence related to overdraft in the Subbasin is expected to occur for many decades following stabilization of groundwater elevations (Lees *et al.*, 2022). Most compaction, about 90 to 94% at the South Hanford site, occurs in the lower aquifer below the Corcoran Clay.

The model’s subsidence predictions for the worst case of groundwater elevations declining and stabilizing at the minimum thresholds are shown on Figure 2 for the South Hanford site and Figure 3 for the TID site. The blue lines on these figures show historical and predicted shallow aquifer groundwater elevations. The red lines on these figures show historical and predicted deep aquifer groundwater elevations. These lines demonstrate how groundwater elevations equilibrate at minimum thresholds beginning in 2040. The yellow line on these figures is the model-estimated subsidence, and the green dots are the measured subsidence from InSAR data.

Predicted subsidence at the South Hanford site is about 27 feet from 2020 to 2040 and about 18 feet from 2040 to 2070, for a total future subsidence of 45 feet. Predicted subsidence at the TID site is about 13 feet from 2020 to 2040 and about 8 feet from 2040 to 2070, for a total future subsidence of 21 feet. Models for both sites show residual subsidence continuing for decades after groundwater elevations stabilize in 2040. Figure 2 and Figure 3 do not show expected subsidence, but rather the maximum subsidence under worst-case conditions.

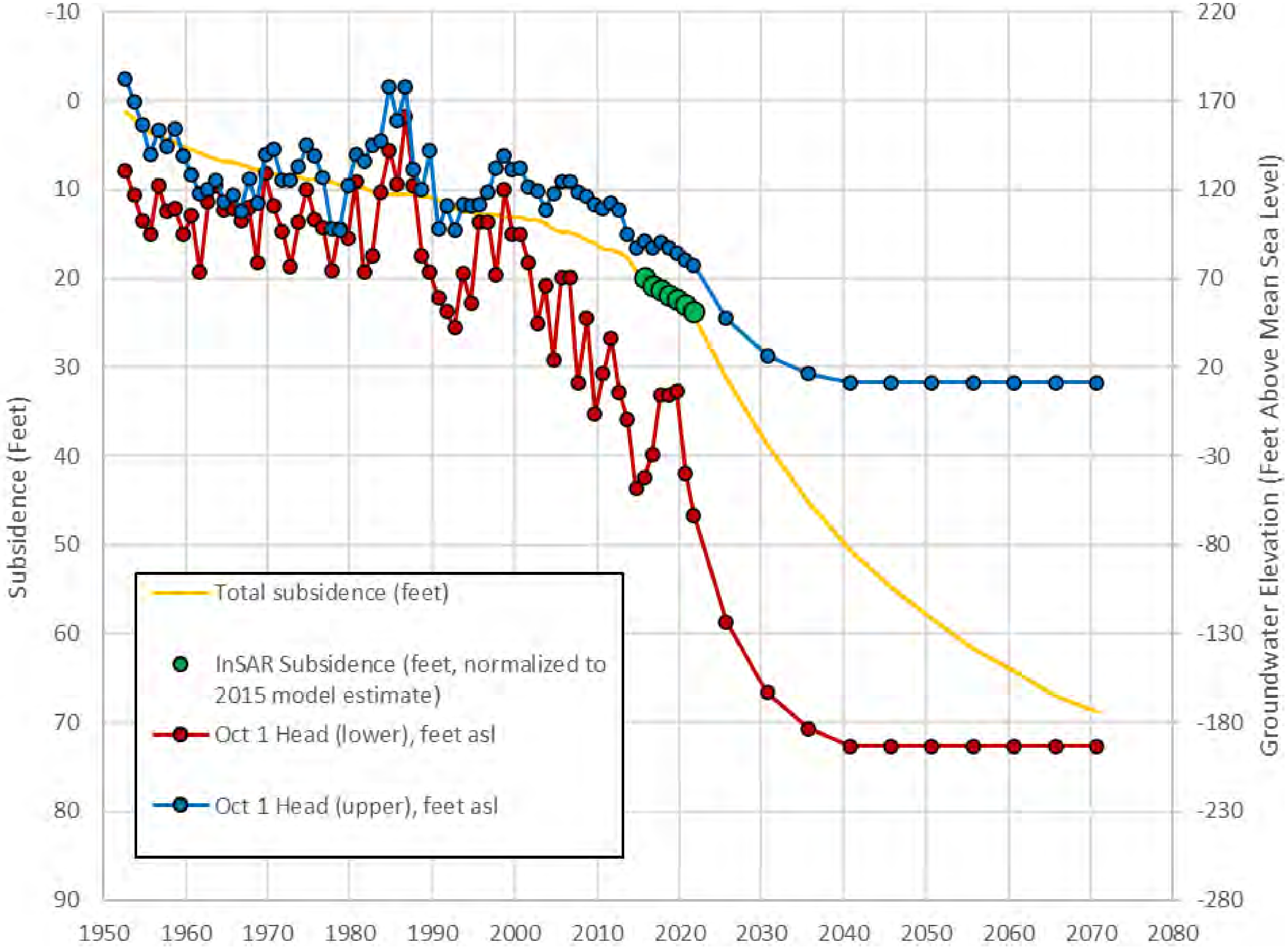


Figure 2. South Hanford Site Subsidence and Groundwater Elevation Time-Series, derived from Lees *et al*., 2022

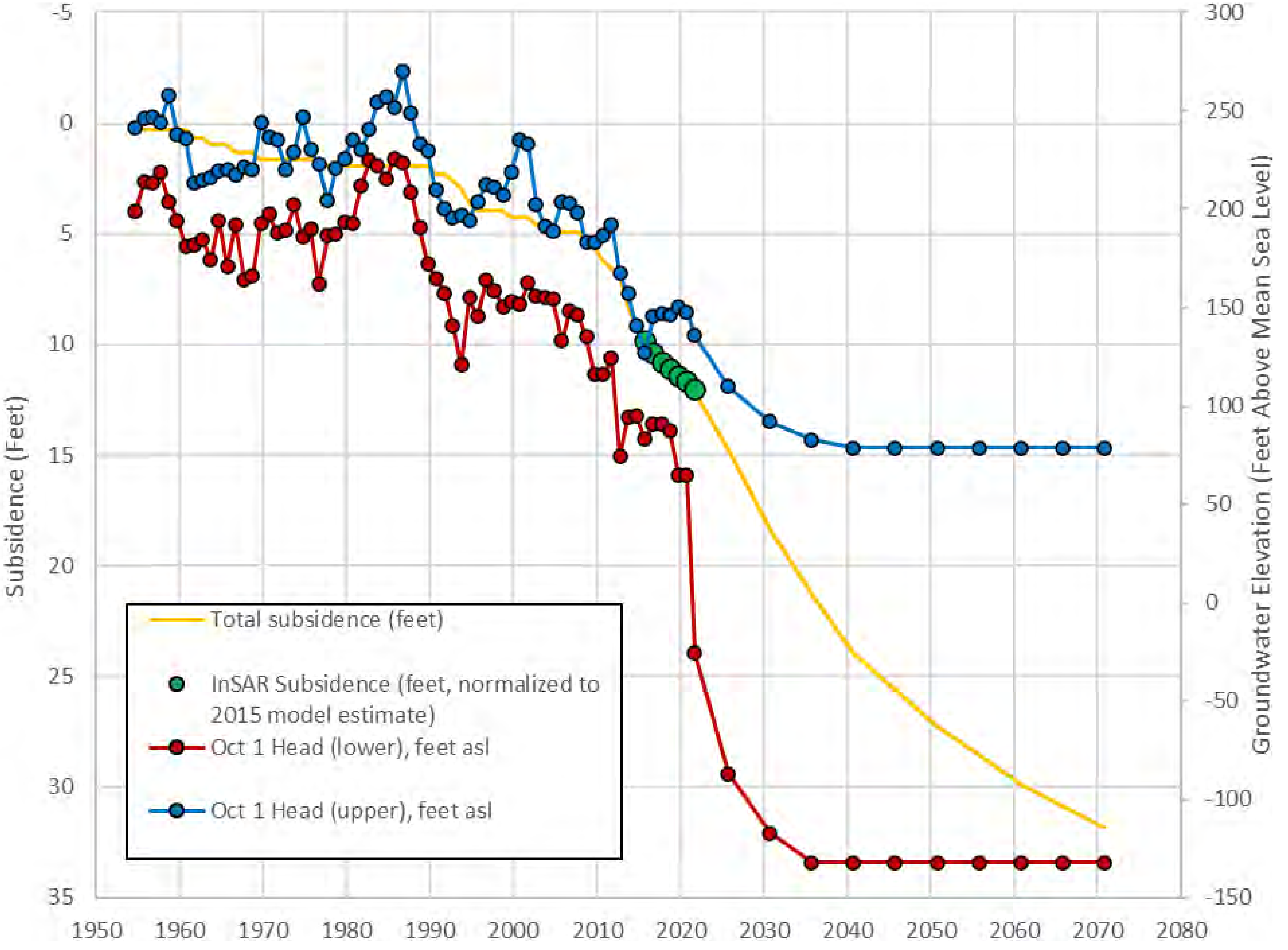


Figure 3. TID Site Subsidence and Groundwater Elevation Time-Series, derived from Lees *et al.*, 2022

2.1.3 Subsidence Spreadsheet Prediction Tool

Results from the 1-D Model are used to develop a simple spreadsheet tool to predict subsidence spatially throughout the Subbasin. A grid of 77 points plotted at 2-mile intervals is used to extrapolate the 1-D Model subsidence predictions (Figure 4). This grid is chosen to align with the United States Geological Survey's (USGS) textural model of the San Joaquin Valley (Faunt, 2009). The spreadsheet tool is used to predict subsidence at each point from 2020 to 2040, and from 2040 to 2070 based on historical groundwater elevation trends and chronic lowering of groundwater levels minimum thresholds provided by the GSAs.

2.1.4 Spreadsheet Tool Data Sources

The parameters in the spreadsheet tool are historical groundwater elevation, groundwater elevation minimum threshold, and estimated clay thickness. Fall groundwater elevation from the GSP groundwater model for years 1999 through 2017 and recent manual measurements in 2021 are used to estimate annual groundwater elevations. Groundwater elevation time series are compiled for the Lower and Upper Aquifer Systems in areas where the Corcoran Clay is present and for the Single Aquifer System in areas where Corcoran Clay is absent. An initial estimate of fine sediment thickness is derived from the USGS' textural model of the San Joaquin Valley. The textural model lumps silts and clays and therefore overestimates total clay thickness.

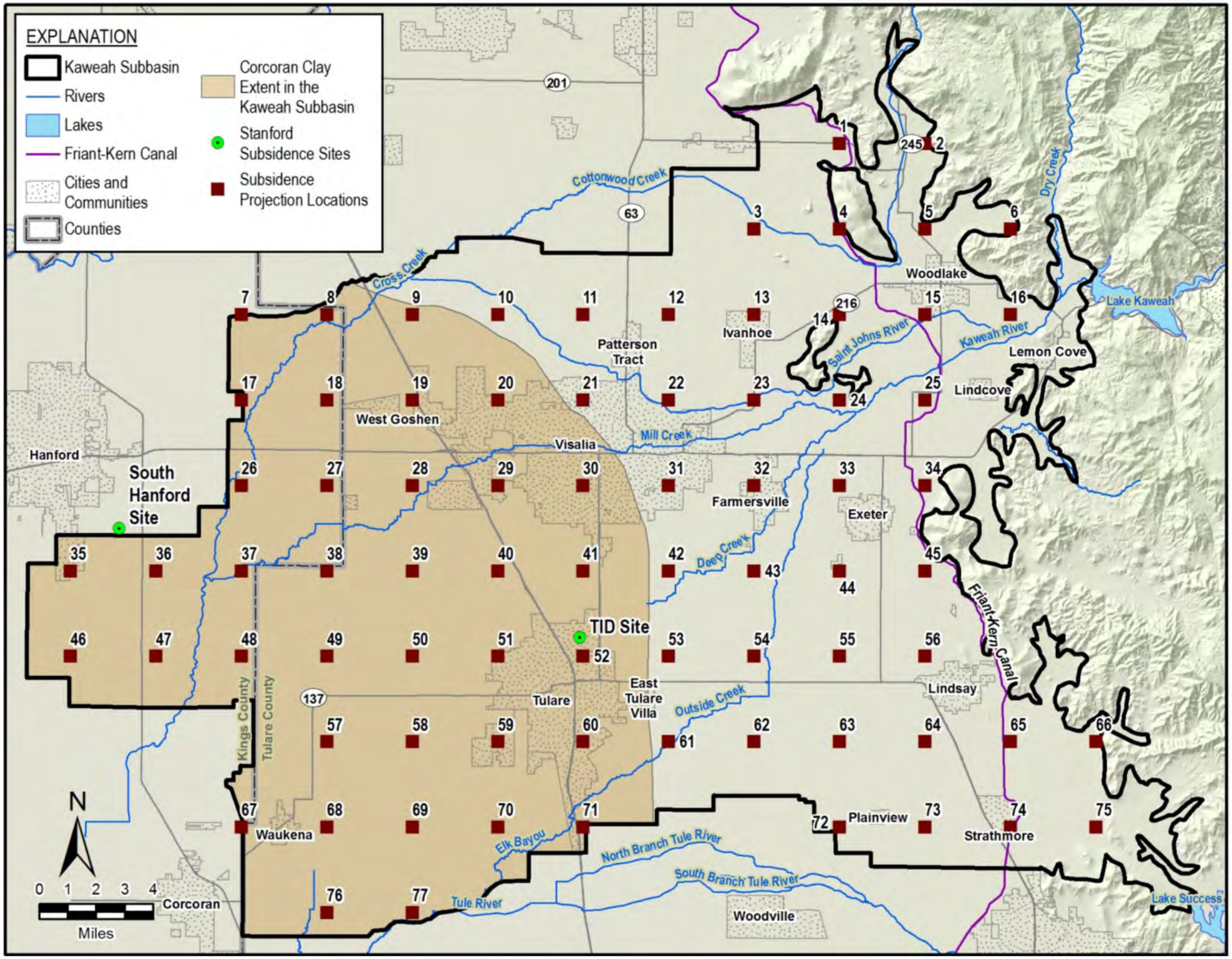


Figure 4. Subsidence Prediction Locations

2.1.5 Equations to Extrapolate Subsidence Across the Subbasin

A simplified set of equations is developed to extrapolate subsidence predicted from the 1-D Models for the South Hanford and TID sites to other locations with less refined data. An identical set of equations and variables are matched in the spreadsheet tool to the 1-D Model results at both the South Hanford and TID sites, only changing clay thickness to reflect site specific clay thickness at each site from geophysical logs.

A simplified equation for cumulative subsidence (Equation 1) is developed using scaling factor (Equation 2) and residual subsidence (Equation 3). These equations are empirical approximations of the more complex, physically based set of compaction equations described in Lees *et al*., 2022 and Helm, 1975:

Equation 1

$$Cumulative\ Subsidence = (Overdraft \times scaling\ factor) + \sum_{0}^{n} residual\ subsidence_{(n)}$$

Equation 2

$$Scaling\ factor = total\ clay\ thickness^{2} \times scaling\ coefficient$$

Equation 3

$$Residual\ subsidence_{(n)} = Active\ subsidence_{(n)} \times residual\ subsidence\ factor$$

Where n is the number of previous years of subsidence.

2.1.5.1 Equation 1: Cumulative Subsidence

$$Cumulative\ Subsidence = (Overdraft \times scaling\ factor) + \sum_{0}^{n} residual\ subsidence_{(n)}$$

The cumulative subsidence estimate is the sum of active subsidence from overdraft in the current year and residual subsidence from overdraft in all prior years. Active subsidence for the current year is calculated only if groundwater levels drop below the previously lowest measured groundwater levels.

Subsidence is influenced by groundwater levels in both the Upper and Lower Aquifer Systems. Lees *et al.* estimated that 93% of subsidence is related to overdraft in the Lower Aquifer System, and 7% of subsidence is related to overdraft in the Upper Aquifer System. Therefore, active subsidence is calculated for each aquifer and then weighted according to the percentages identified by Lees *et al*., 2022. In the Single Aquifer System area where the Corcoran Clay is not present, 7% of overdraft is assumed to contribute to subsidence because the Single Aquifer System is unconfined, like the Upper Aquifer System. Consequently, overdraft in the Single Aquifer System does not appear to cause as much subsidence as overdraft below the Corcoran Clay. This is supported by very little historical subsidence east of the Corcoran Clay observed in InSAR data from 2015 to 2022 (DWR InSAR data), or in DWR data from 1954 to 2006 (DWR TRE Altamira data), despite some observed historical overdraft.

2.1.5.2 Equation 2: Scaling Factor

$$Scaling\ factor = total\ clay\ thickness^2 \times scaling\ coefficient$$

A consistent scaling factor was applied to equation 1 by using a single scaling coefficient throughout the Subbasin and varying the total clay thickness. The clay thickness for South Hanford and TID sites was assigned using geophysical logs collected during well installations. Clay thickness was adjusted at other sites to calibrate the model as discussed in Section 2.1.7. The scaling coefficient is fit to the South Hanford and TID site data and held constant for the 77 prediction sites. This coefficient simplifies the governing differential equation described in Lees *et al*., 2022, that incorporates vertical hydraulic conductivity, storage coefficient, and the sum of squared individual clay layer thicknesses.

2.1.5.3 Equation 3: Residual Subsidence

$$Residual\ subsidence_{(n)} = Active\ subsidence_{(n)} \times residual\ subsidence\ factor$$

A simplified equation was developed to account for residual subsidence from previous years' active subsidence. The equation multiplies the active subsidence in any previous year by a residual subsidence factor that decreases over time. The equation is designed to add a lesser amount of residual subsidence over time as the effects of past overdraft diminish. The residual subsidence factor, shown on Figure 5, was fit to the 1-D Model data for South Hanford and TID sites and then applied throughout the Subbasin.

As an example, Figure 5 shows that after 50 years, only 20% of the active subsidence from the first year is added to the total subsidence calculation. Lees *et al*. (2022) and other research on subsidence has found that residual subsidence can occur for long periods, even after groundwater elevations stabilize. For example, at the South Hanford site, Lees *et al*. predicted that significant subsidence occurs for at least 64 years after overdraft stops and groundwater elevations are held constant. This long residual subsidence is due to much slower head equilibration and compaction in thick clay interbeds. Lees *et al.* acknowledges that this approach is conservative as they expect that the compressibility of clays will reduce over time as clays near ultimate compaction.

2.1.6 Spreadsheet Tool Development

Figure 6 shows how calculations from the spreadsheet tool fit the model used by Lees *et al*. for the South Hanford and TID sites. The results from Lees *et al*. are shown in yellow, and the results from the spreadsheet tool are shown in blue.

As shown on Figure 6, the spreadsheet tool is calibrated to groundwater elevation and subsidence from 1954 to 2017 to present. The 1954 to 1998 groundwater level and subsidence data are available at the South Hanford and TID sites, but not throughout the Subbasin. Subsidence predictions throughout the Subbasin were therefore based only on groundwater elevation data available from 1999 to 2021 and future estimated groundwater levels.

To demonstrate the effect of limiting the groundwater level data in the spreadsheet tool to data collected between 1999 and 2021, the fit between the spreadsheet tool using only data between 1999 and 2021 at the TID and South Hanford sites is shown with the Lees *et al*. results on Figure 7. The results on Figure 7 are not as accurate as the results using the more extensive groundwater elevation dataset from 1954 to 2017, shown on Figure 6. This is because residual subsidence from overdraft prior to 1999 is not accounted for in the Figure 7 results. However, Figure 7 shows that the error in the spreadsheet diminishes over time, suggesting the spreadsheet model remains valid for estimating long-term subsidence.

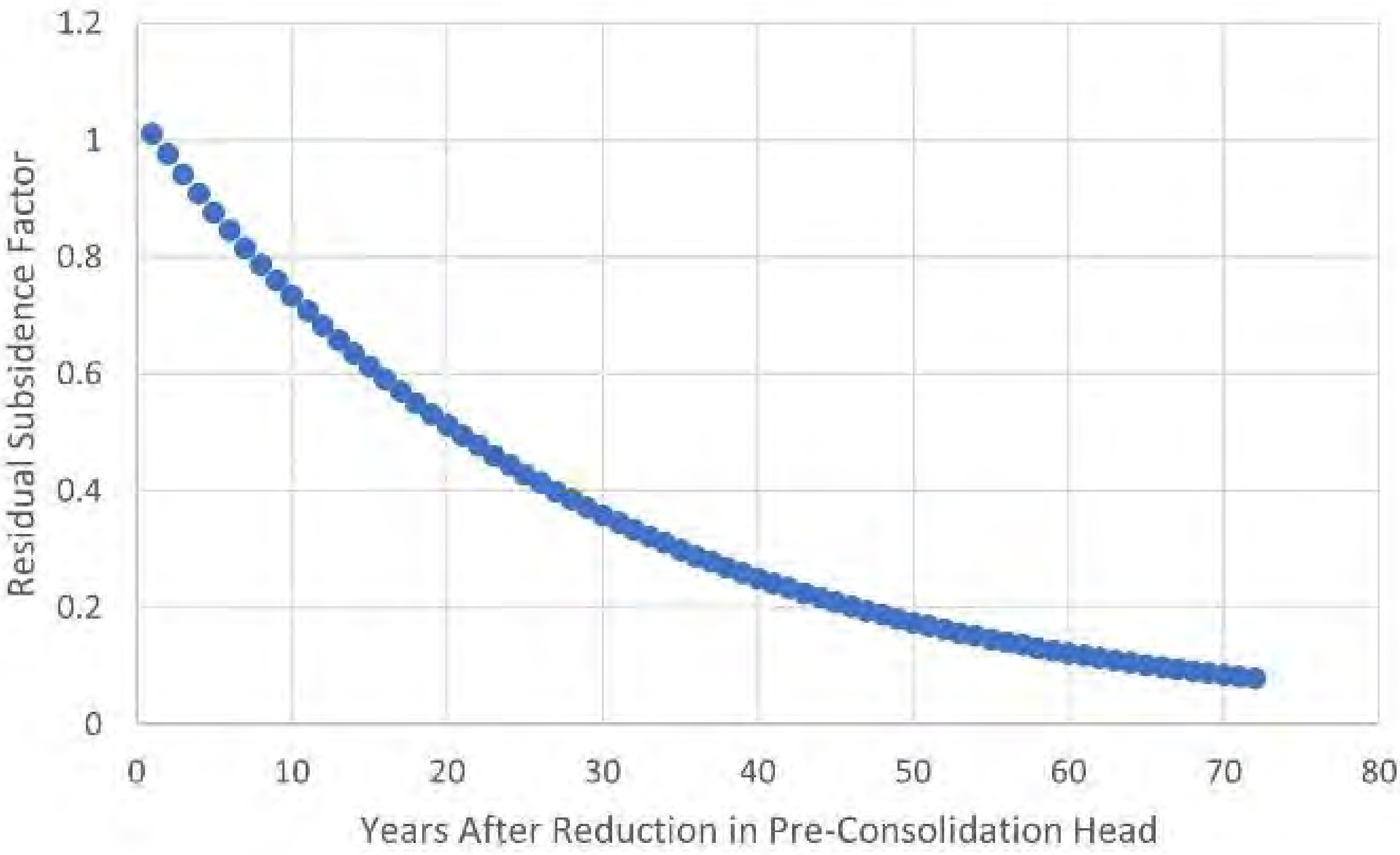
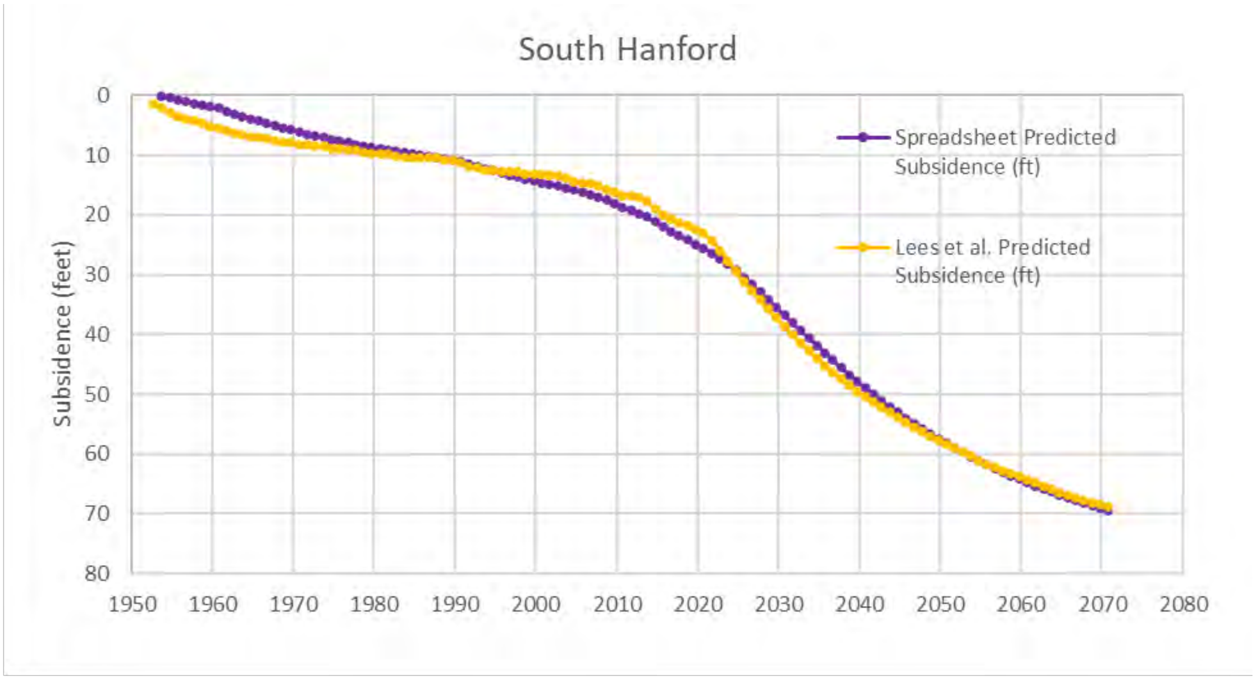


Figure 5. Residual Subsidence Factors for Years After Reduction in Pre-Consolidated Head



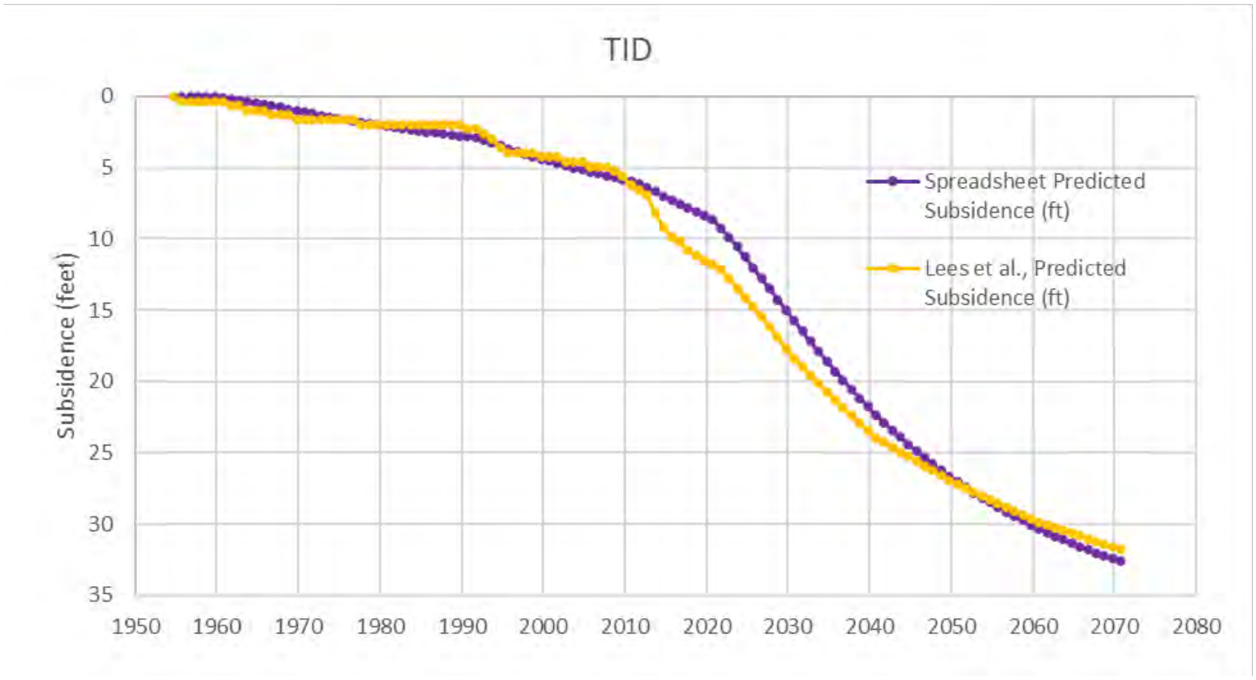
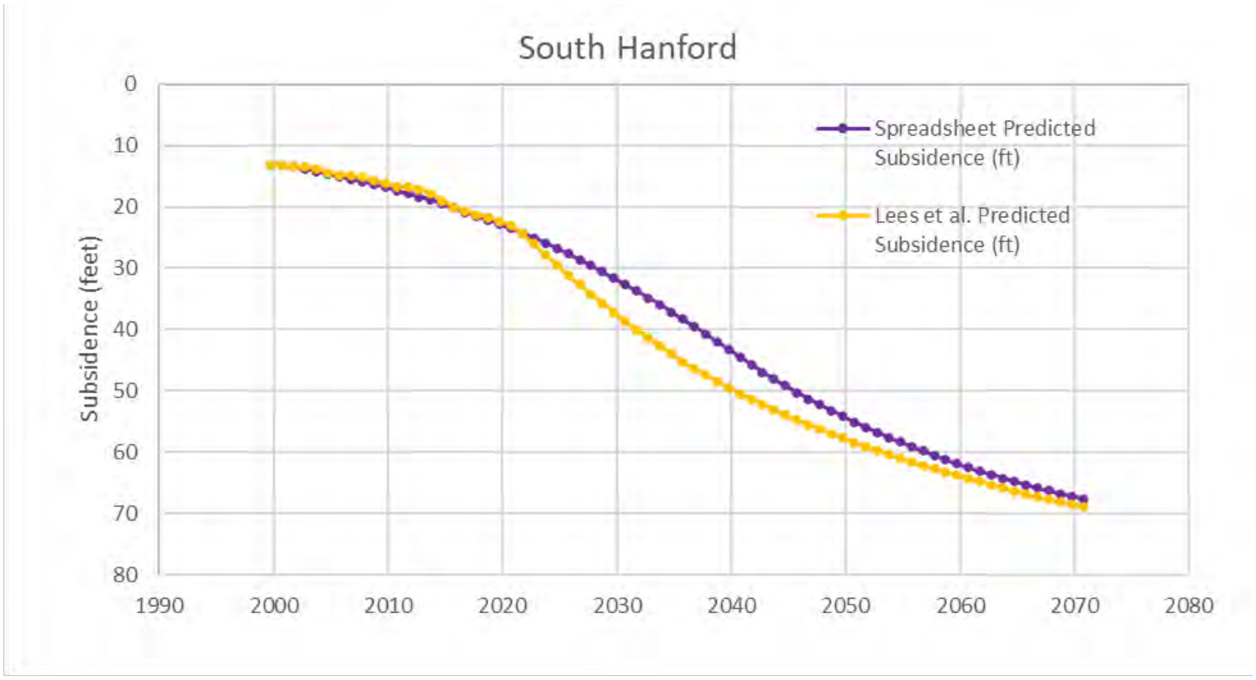


Figure 6. Spreadsheet and Model Predicted Subsidence at South Hanford and TID Sites, 1954-2070



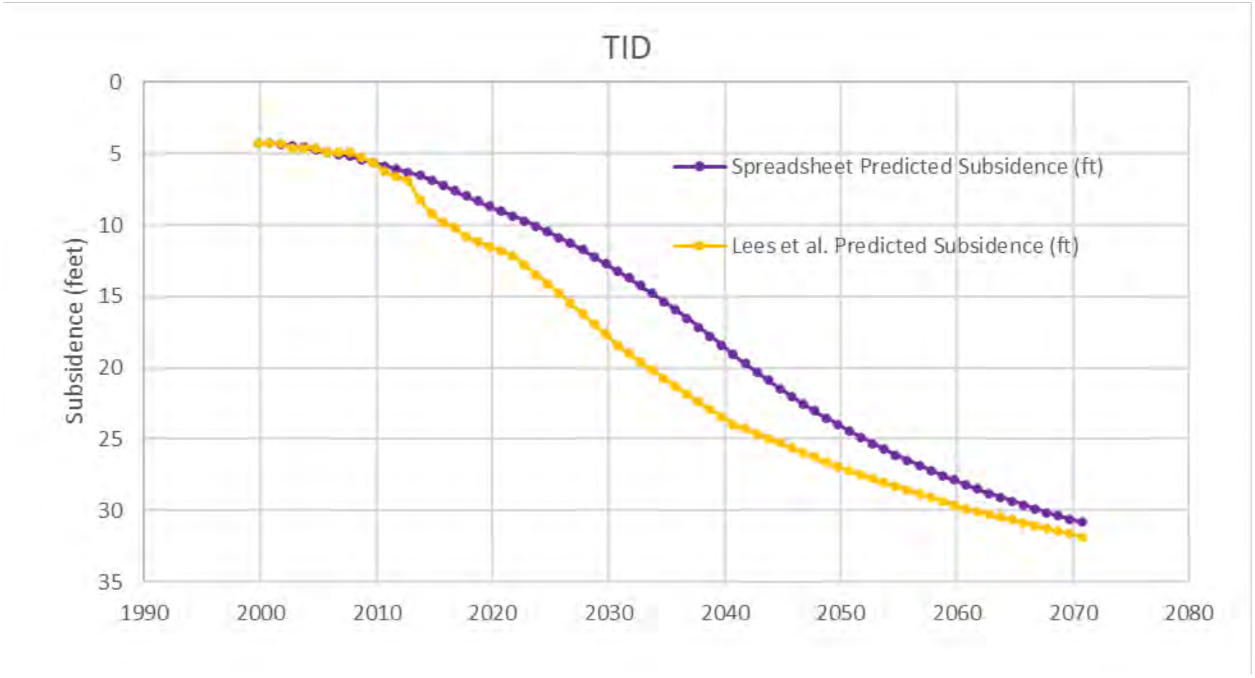


Figure 7. Spreadsheet and Model Predicted Subsidence at South Hanford and TID Sites, 1999-2070

2.1.7 Spreadsheet Tool Calibration

Total clay thickness is adjusted to calibrate the spreadsheet tool to match subsidence measured by InSAR between 2015 and 2021. The calibrated clay thickness is shown on Figure 8. This figure represents the total clay thickness, not the thickness of specific clay layers such as the Corcoran Clay. A comparison of the InSAR measured subsidence and calibrated model predicted subsidence is shown on Figure 9. Where subsidence was greatest in the western portion of the Subbasin, the model was calibrated to estimate slightly less subsidence than the InSAR data to account for underprediction shown on Figure 7. InSAR measured little to no subsidence in the eastern portion of the Subbasin where the Corcoran Clay is absent. The spreadsheet tool is not developed to estimate elastic subsidence or increase in land surface elevation when groundwater elevations increase, so subsidence in the eastern portion of the Subbasin may be slightly overestimated by this simplified approach.

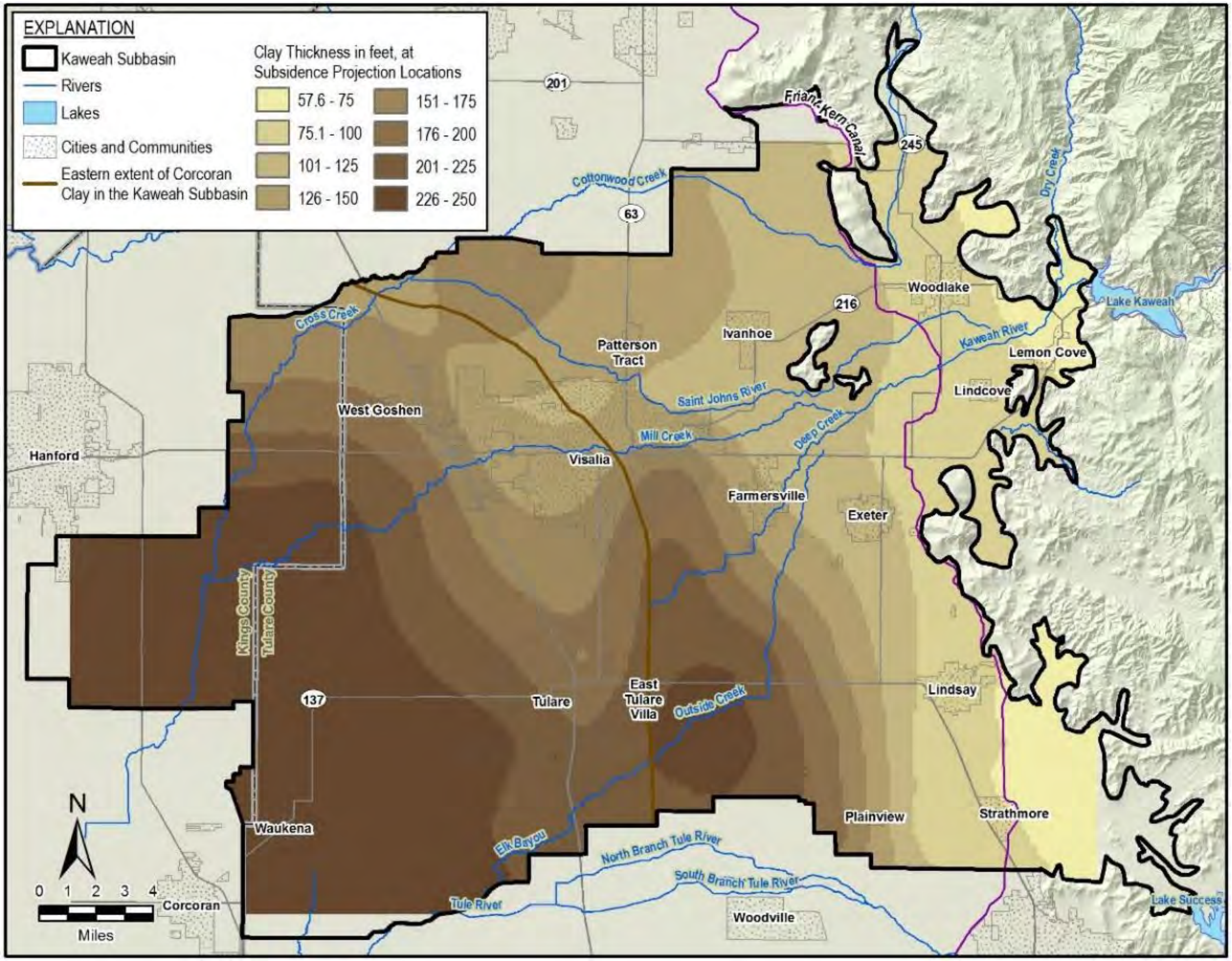


Figure 8. Clay Thickness from Spreadsheet Tool Calibration

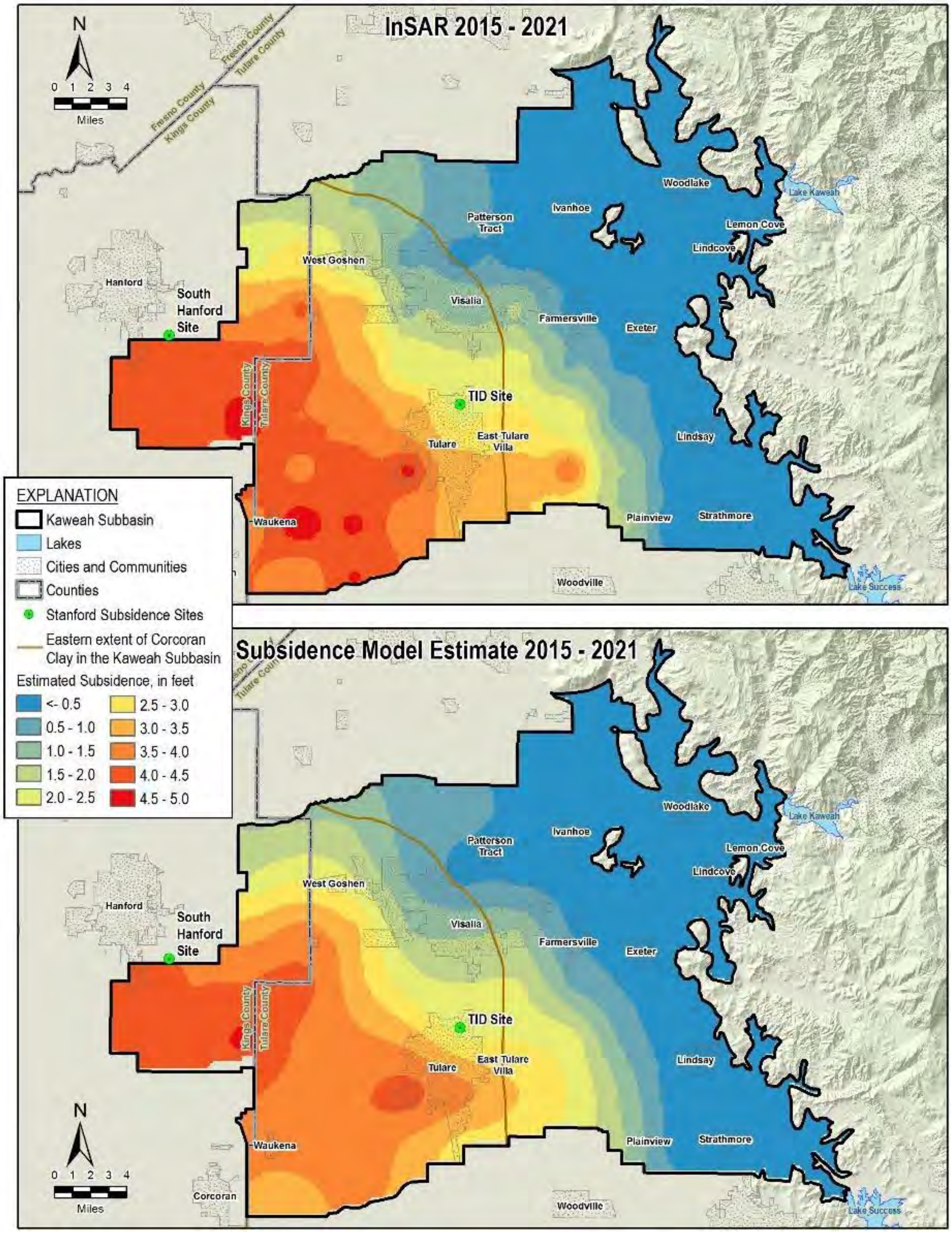


Figure 9. Subsidence from InSAR (top) Compared to Spreadsheet Model Estimate from 2015 to 2021 (bottom)

2.1.8 Spreadsheet Tool Results

Subsidence in the Subbasin is projected using the spreadsheet tool to continue over the SGMA planning and implementation horizon. This is substantiated by the results published by Lees *et al.*, 2022, which estimates up to 10 feet of subsidence will occur at the South Hanford site even if groundwater level declines are halted immediately.

2.1.8.1 Subsidence at Groundwater Elevation Minimum Thresholds

If groundwater elevations decrease and stabilize at the minimum threshold, up to 20.2 feet of subsidence could occur between 2020 and 2040 (1 foot/year) as shown on Figure 10. Up to 22.9 feet of subsidence could occur between 2040 and 2070 (0.76 feet/year) as shown on Figure 11. These results are similar to the 1-D model results at the South Hanford site, which predicts approximately 27 feet of subsidence between 2020 and 2040, and 18 feet of subsidence from 2040 to 2070.

All subsidence between 2040 and 2070 is residual subsidence. The model assumes that the Subbasin achieves sustainability in 2040, and no new subsidence is activated over the ensuing 30 years. The subsidence shown on Figure 11 is the cumulative result of progressively less subsidence every year since 2040.

Figure 12 shows that Subbasin-wide subsidence could range between less than 1 foot and 43.1 feet over the full 50-year planning and implementation horizon. This equates to subsidence rates up to 10.4 inches per year. The greatest subsidence is located near the South Hanford site. Very little subsidence is predicted to occur along the eastern edge of the Subbasin.

Subsidence is measured in the Subbasin at a series of subsidence monitoring points, shown on Figure 13. The estimated subsidence when groundwater elevations stabilize at the minimum thresholds is shown for each subsidence measuring point in Table 1 as both a total subsidence and an equivalent subsidence rate.

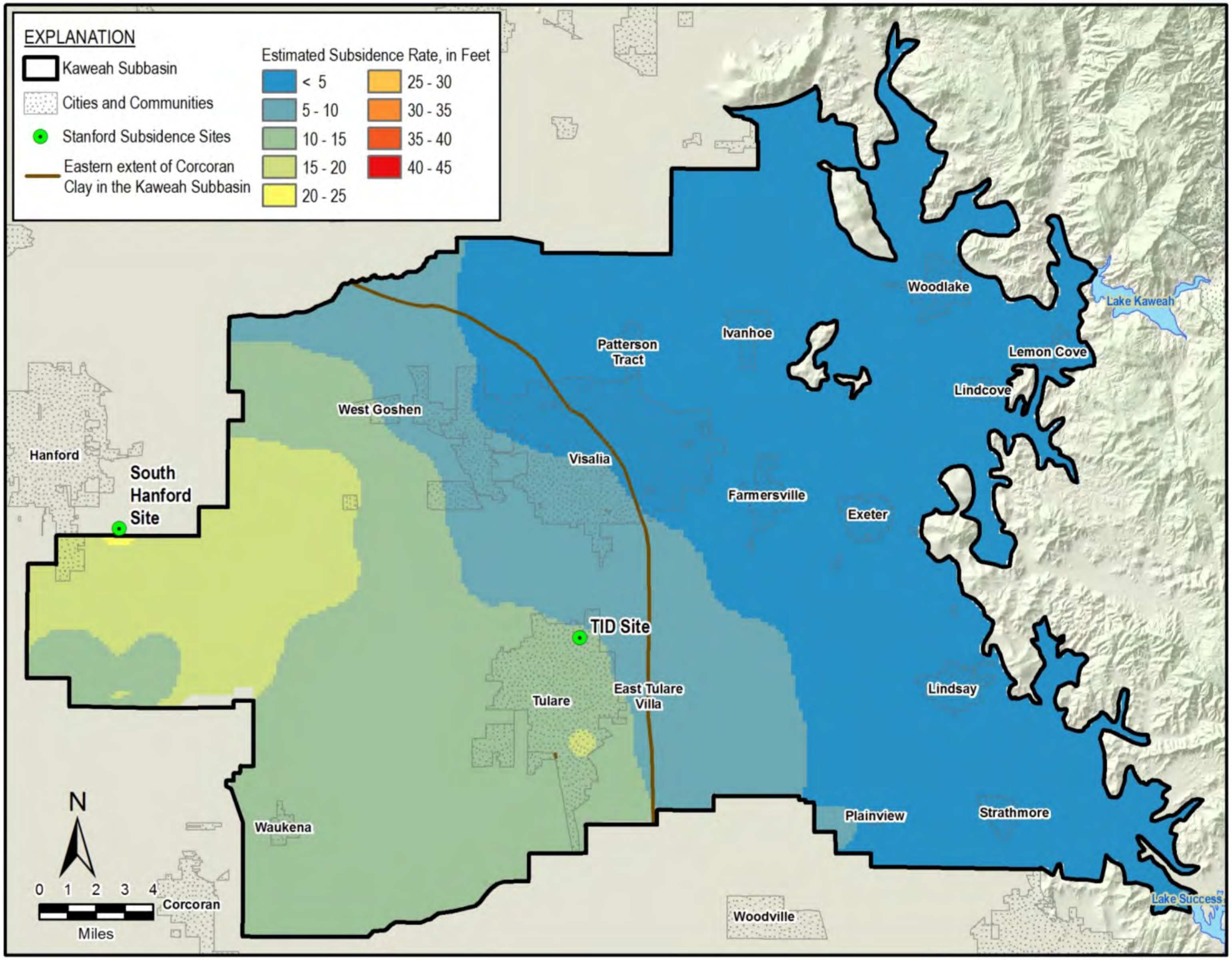


Figure 10. Spreadsheet Tool Estimated 2020 to 2040 Subsidence when Groundwater Levels Stabilize at Minimum Thresholds

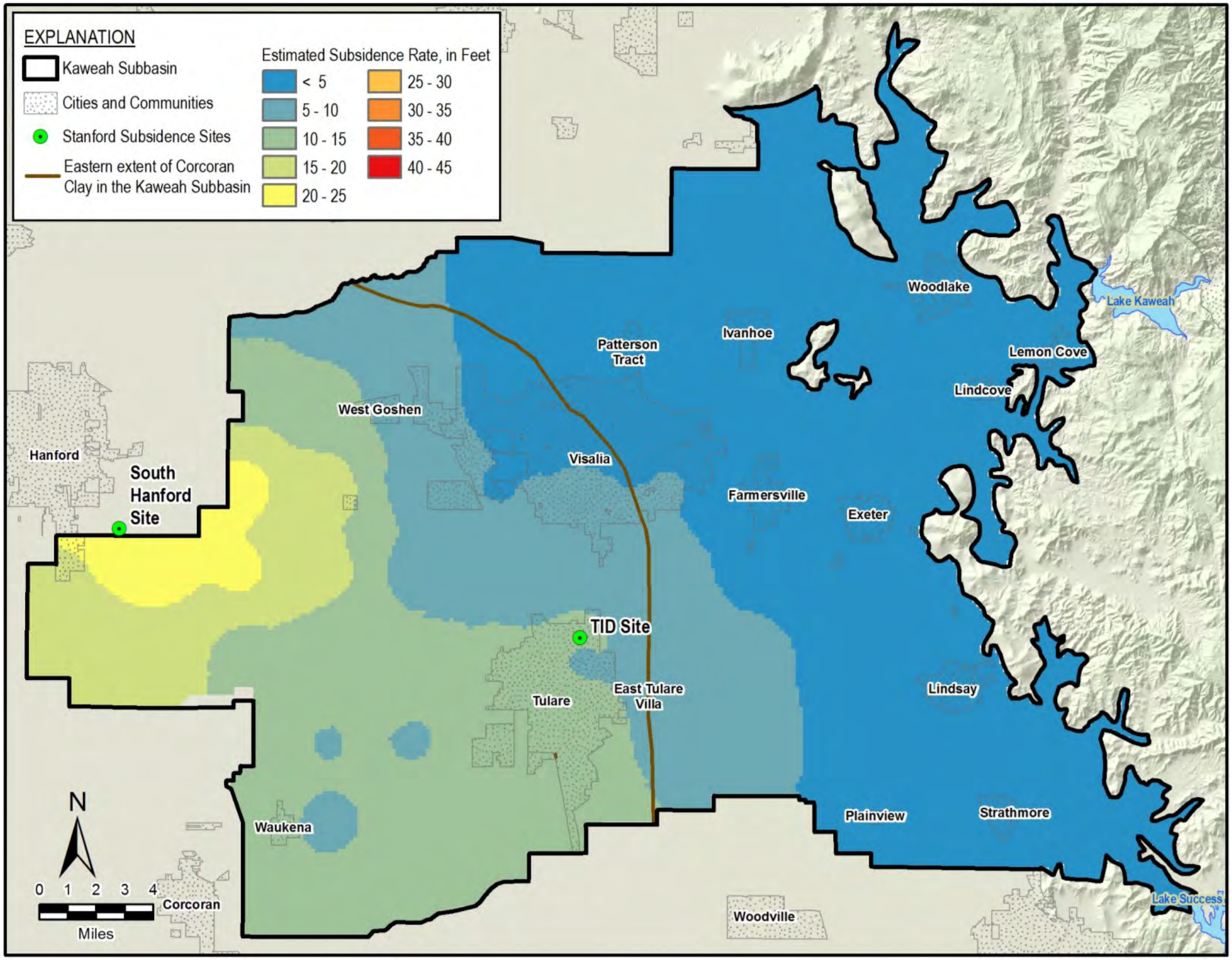


Figure 11. Spreadsheet Tool Estimated 2040 to 2070 Subsidence when Groundwater Levels Stabilize at Minimum Thresholds

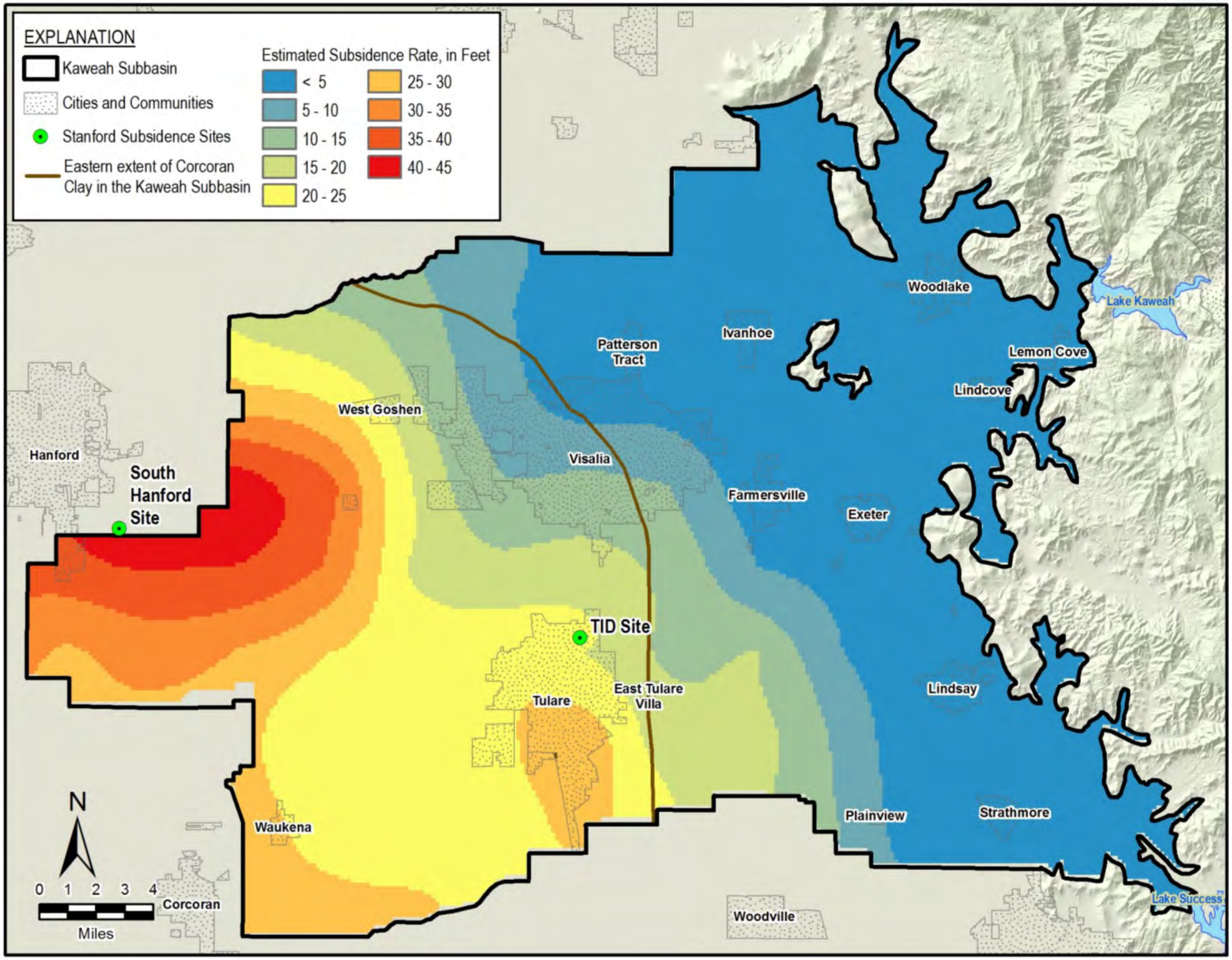


Figure 12. Spreadsheet Tool Estimated 2020 to 2070 Subsidence when Groundwater Levels Stabilize at Minimum Thresholds

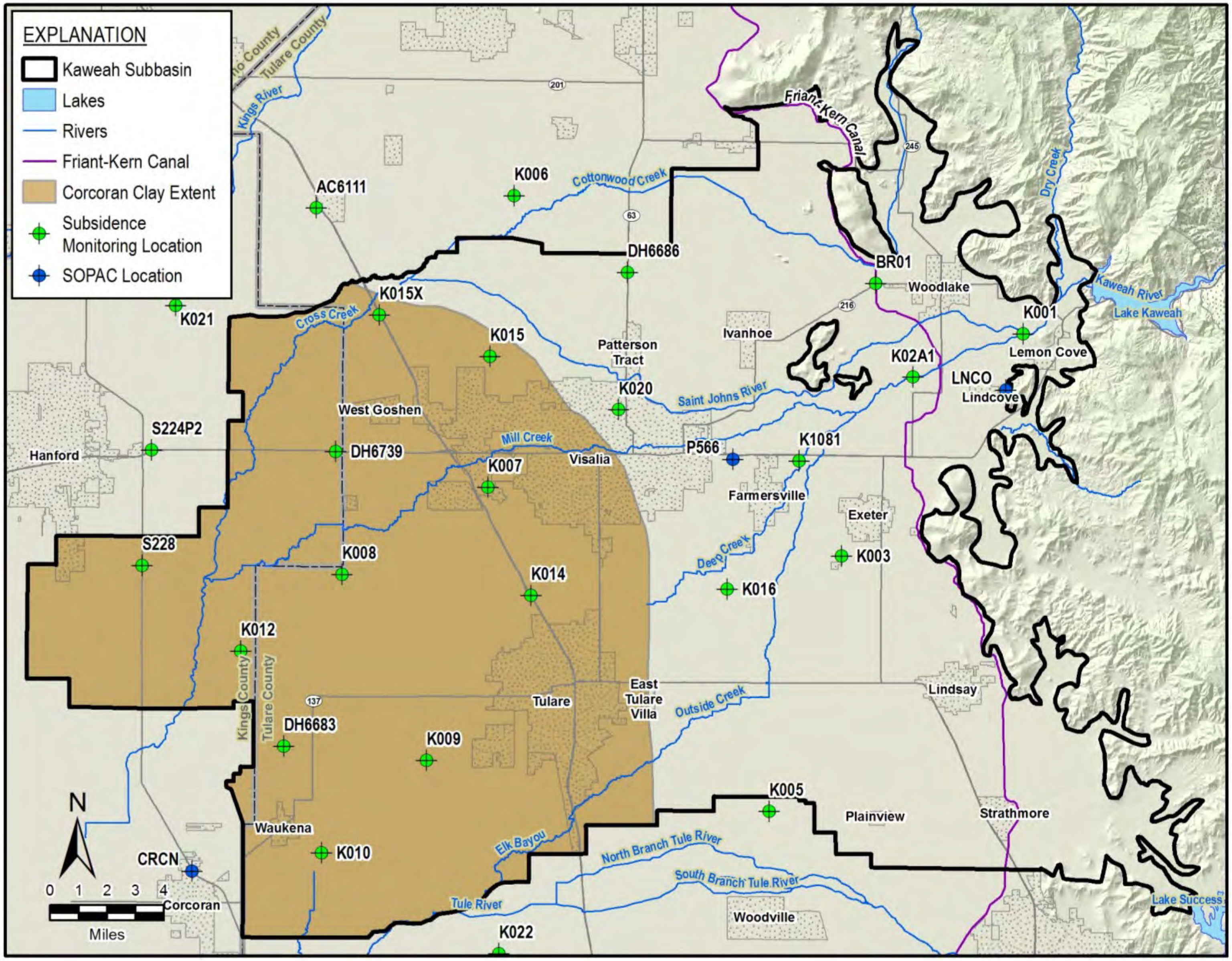


Figure 13. Subsidence Monitoring Points in and Around the Kaweah Subbasin

Table 1. Estimated Subsidence at Subbasin Monitoring Points when Groundwater Levels Stabilize at Minimum Thresholds

Subsidence Monitoring Point	2020 to 2040		2040 to 2070		2020 to 2070	
	Annual Subsidence (inch/year)	Total Subsidence (feet)	Annual Subsidence (inch/year)	Total Subsidence (feet)	Annual Subsidence (inch/year)	Total Subsidence (feet)
BR01	0.2	0.3	0.1	0.2	0.1	0.5
DH6683	7.6	12.7	4.4	10.9	5.7	23.6
DH6686	0.9	1.6	0.8	1.9	0.8	3.5
DH6739	9.5	15.9	6.1	15.2	7.5	31.1
K001	0.1	0.2	0.1	0.2	0.1	0.4
K003	0.7	1.2	0.6	1.4	0.6	2.6
K007	3.9	6.6	2.0	5.0	2.8	11.6
K008	9.8	16.3	6.2	15.5	7.6	31.8
K009	6.7	11.1	3.9	9.9	5.0	21.0
K010	7.9	13.2	4.3	10.9	5.8	24.0
K012	10.3	17.2	5.0	12.6	7.1	29.8
K014	5.9	9.9	3.7	9.2	4.6	19.1
K015	2.1	3.5	1.3	3.2	1.6	6.7
K015X	4.5	7.5	2.5	6.3	3.3	13.8
K016	2.6	4.4	2.1	5.2	2.3	9.5
K020	1.1	1.9	0.9	2.2	1.0	4.0
K02A1	0.1	0.2	0.1	0.2	0.1	0.4
K1081	0.3	0.5	0.1	0.4	0.2	0.9
P566	0.9	1.4	0.6	1.6	0.7	3.0
S228	10.8	18.0	9.0	22.5	9.7	40.5

2.1.8.2 Subsidence at Groundwater Elevation Measurable Objectives

If groundwater elevations decrease and stabilize at the measurable objectives in 2040, up to 18.9 feet of subsidence could occur between 2020 and 2040, as shown on Figure 14. Up to 16 feet of subsidence could occur between 2040 and 2070 as shown on Figure 15.

All subsidence between 2040 and 2070 is residual subsidence. The model assumes that the Subbasin achieves sustainability at the measurable objectives in 2040, and no new subsidence is activated over the ensuing 30 years. The subsidence shown on Figure 15 is the cumulative result of progressively less subsidence every year since 2040.

Figure 16 shows that subbasin-wide subsidence could range between less than 0.02 feet and 34.8 feet over the full 50-year planning and implementation horizon. This equates to subsidence rates of between 0.005 and 8.3 inches per year. The greatest subsidence is located near the South Hanford site and very little subsidence is predicted to occur along the eastern edge of the Subbasin.

The estimated subsidence when groundwater elevations stabilize at the measurable objective is shown for each of the subsidence measuring points in Table 2 as both a total subsidence and an equivalent subsidence rate.

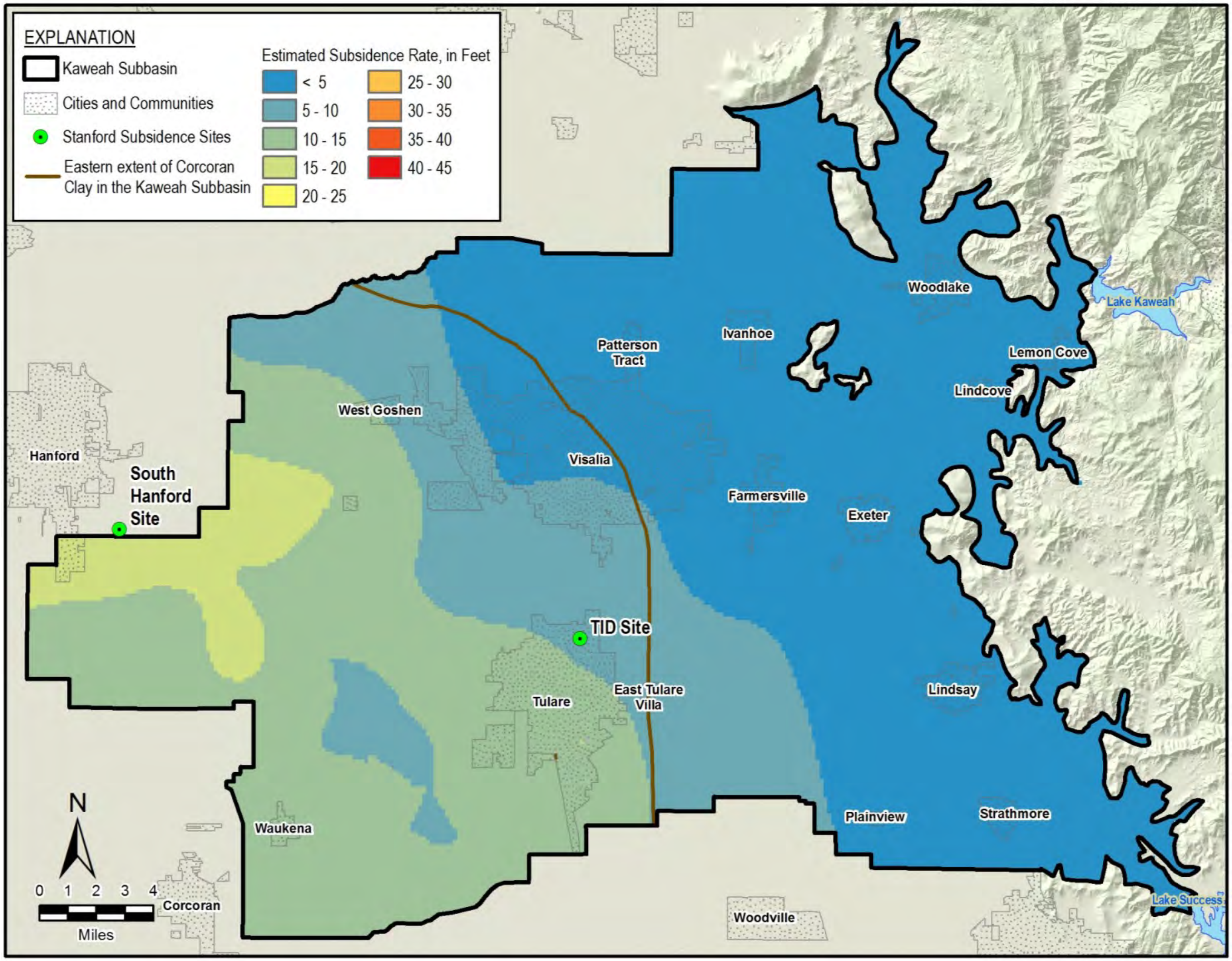


Figure 14. Spreadsheet Tool Estimated 2020 to 2040 Subsidence when Groundwater Levels Stabilize at Measaurable Objectives

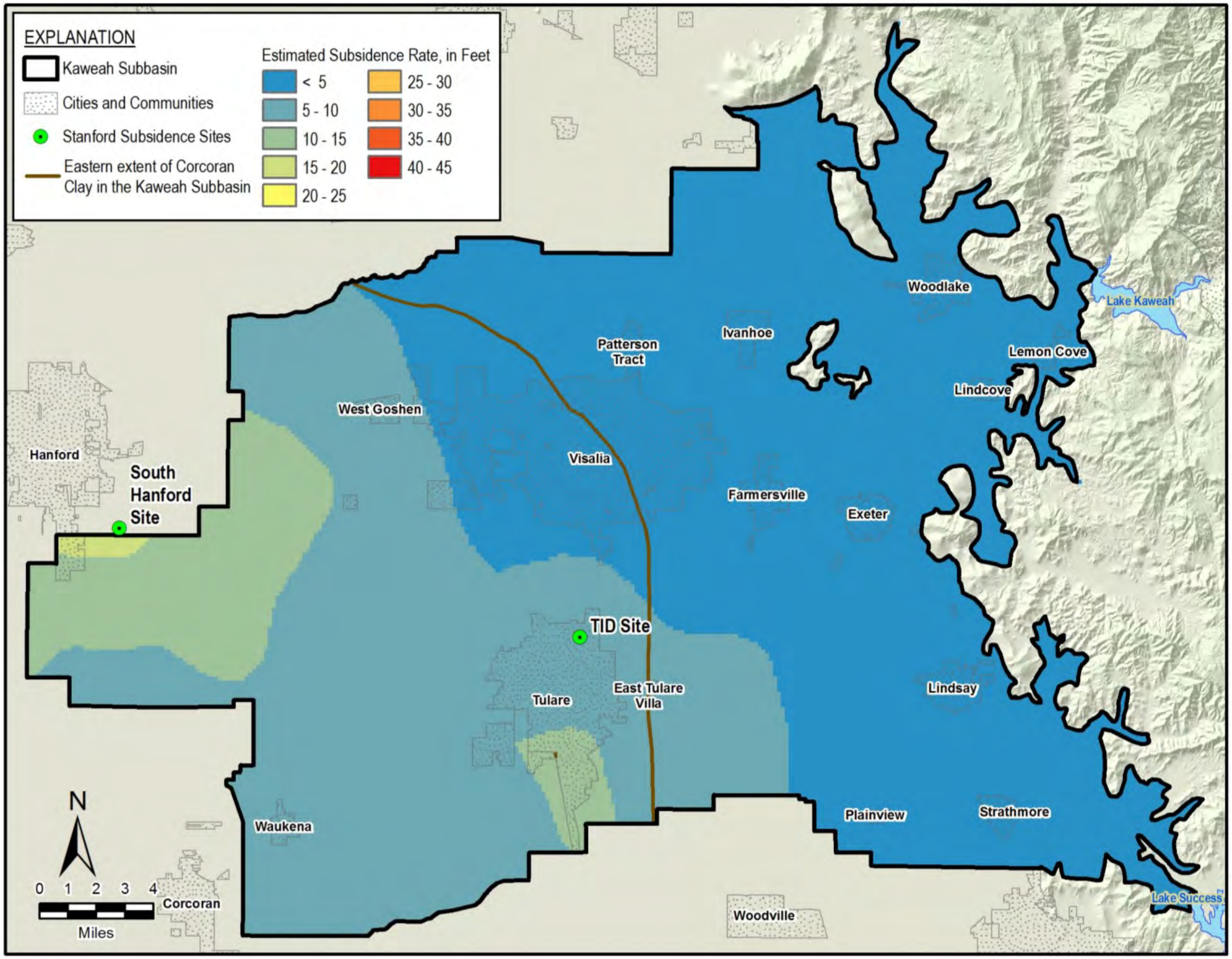


Figure 15. Spreadsheet Tool Estimated 2040 to 2070 Subsidence when Groundwater Levels Stabilize at Measaurable Objectives

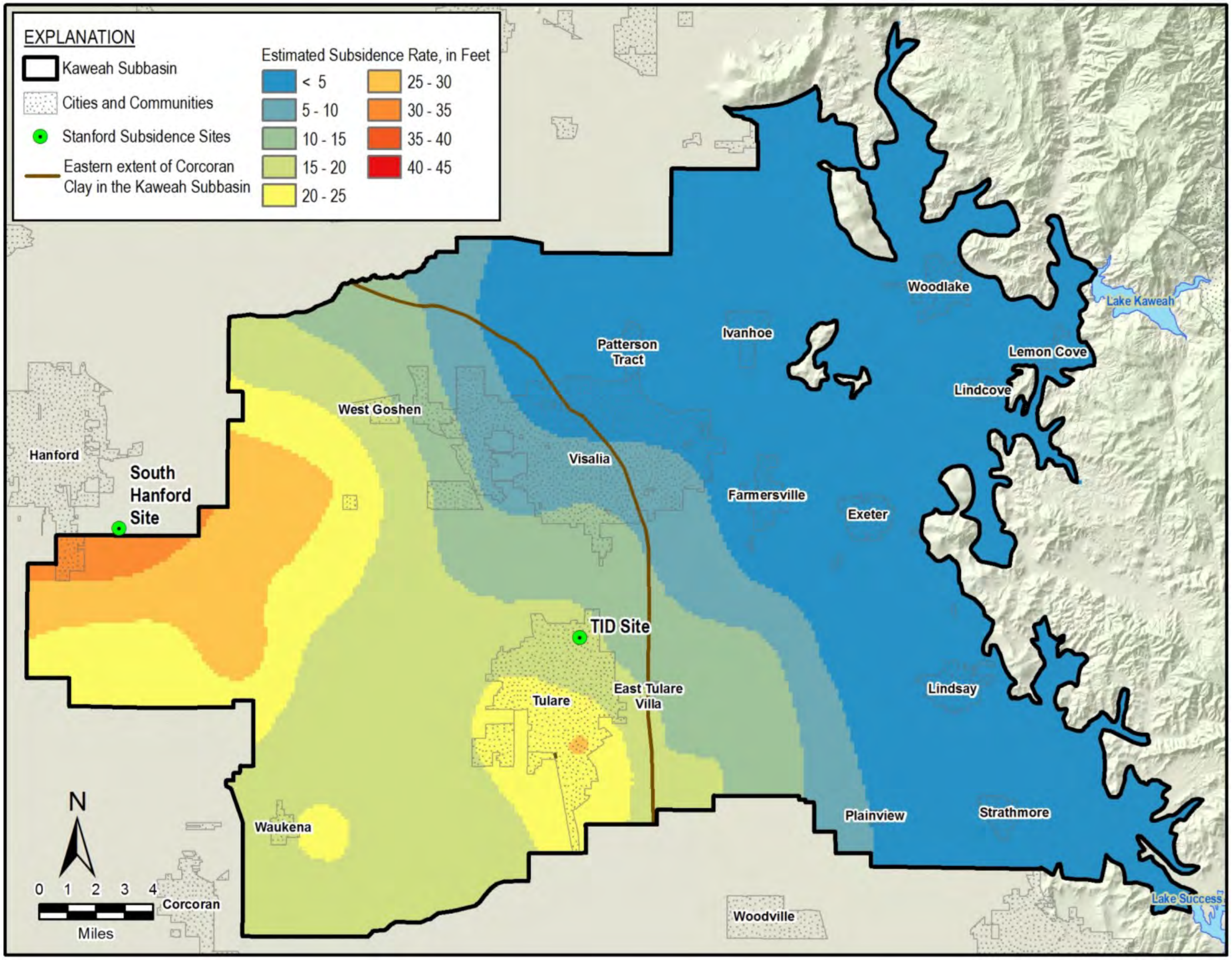


Figure 16. Spreadsheet Tool Estimated 2020 to 2070 Subsidence when Groundwater Levels Stabilize at Measaurable Objectives

Table 2. Estimated Subsidence at Subbasin Monitoring Points when Groundwater Levels Stabilize at Measurable Objectives

Subsidence Monitoring Point	2020 to 2040		2040 to 2070		2020 to 2070	
	Annual Subsidence (inch/year)	Total Subsidence (feet)	Annual Subsidence (inch/year)	Total Subsidence (feet)	Annual Subsidence (inch/year)	Total Subsidence (feet)
BR01	0.2	0.3	0.1	0.2	0.1	0.5
DH6683	6.8	11.4	3.0	7.5	4.5	18.9
DH6686	0.8	1.3	0.4	1.0	0.5	2.3
DH6739	8.1	13.4	3.7	9.2	5.4	22.6
K001	0.1	0.2	0.1	0.2	0.1	0.4
K003	0.6	1.0	0.3	0.7	0.4	1.7
K007	3.3	5.6	1.4	3.5	2.2	9.1
K008	7.8	12.9	3.4	8.5	5.1	21.4
K009	6.0	9.9	2.7	6.9	4.0	16.8
K010	7.3	12.1	3.3	8.1	4.9	20.3
K012	9.8	16.4	4.4	11.0	6.6	27.4
K014	5.2	8.7	2.4	6.0	3.5	14.7
K015	1.9	3.1	0.8	2.1	1.2	5.2
K015X	4.3	7.1	2.0	5.1	2.9	12.2
K016	2.3	3.8	1.2	3.0	1.6	6.8
K020	0.9	1.5	0.5	1.2	0.7	2.7
K02A1	0.1	0.2	0.1	0.1	0.1	0.4
K1081	0.3	0.6	0.1	0.3	0.2	0.9
P566	0.8	1.4	0.4	1.1	0.6	2.5
S228	9.8	16.4	5.8	14.4	7.4	30.8

2.2 Impact of Subsidence on Conveyance Infrastructure

Infrastructure in the Subbasin that may be affected by subsidence include roads, bridges, gas and water pipelines, power lines, canals, ditches, flood control waterways, railroad tracks, and wells. Although InSAR data show that up to 5 feet of subsidence has occurred in the Subbasin between 2015 and 2021, a survey of local infrastructure impacts indicated there has been no widespread damage caused by subsidence other than damage noted to water conveyance infrastructure and groundwater wells.

Subsidence predictions from the spreadsheet tool described in Section 2.1.8 are used to evaluate potential impacts to water conveyance infrastructure in the Subbasin, including subsidence along the Friant-Kern Canal and other important conveyance infrastructure described below. Water conveyance infrastructure including the Friant-Kern Canal and other important local conveyance is shown on Figure 17.

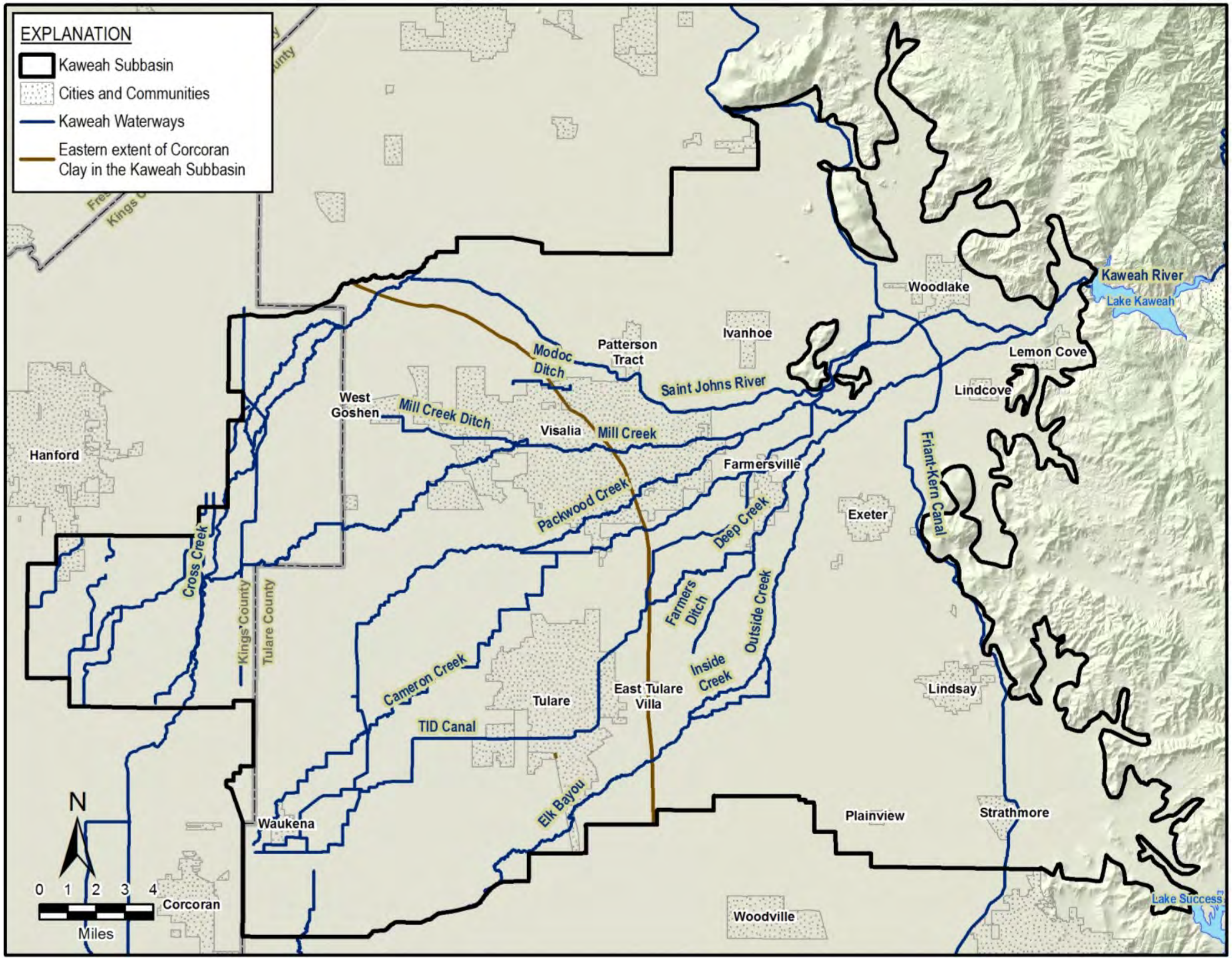


Figure 17. Conveyance Infrastructure Locations

2.2.1 Friant-Kern Canal

The East Kaweah Groundwater Sustainability Agency (EKSGA) identified the Friant-Kern Canal as the sole conveyance infrastructure in their portion of the Subbasin with potential to experience significant and unreasonable impacts due to subsidence. The EKGSA determined that a 10% loss of capacity would be significant and unreasonable. Using canal cross section and elevation data, EKGSA estimated that approximately 10 inches of total subsidence in the Subbasin would reduce the canal carrying capacity by 10%. This equates to a 50-year subsidence rate of 0.2 inches per year.

The subsidence spreadsheet tool was used to estimate the maximum subsidence along the Friant-Kern Canal. Figure 18 shows the maximum predicted subsidence along the Friant-Kern canal between 2020 and 2040 when groundwater levels are held at minimum thresholds. The maximum subsidence is 0.69 feet, or 0.41 inches per year. Figure 19 shows the maximum predicted subsidence between 2040 and 2070 when groundwater levels are held at minimum thresholds. The maximum subsidence is 0.69 feet, or 0.28 inches per year. Figure 20 shows the maximum predicted subsidence between 2020 and 2070 when groundwater levels are held at minimum thresholds. The maximum subsidence is 1.4 feet, or 0.34 inches per year.

Figure 21 shows the maximum predicted subsidence along the Friant-Kern Canal between 2020 and 2040 when groundwater levels are held at measurable objectives. The maximum subsidence is 0.55 feet, or 0.33 inches per year. Figure 22 shows the maximum predicted subsidence between 2040 and 2070 when groundwater levels are held at measurable objectives. The maximum subsidence is 0.39 feet, or 0.16 inches per year. Figure 23 shows the maximum predicted subsidence between 2020 and 2070 when groundwater levels are held at measurable objectives. The maximum subsidence is 0.94 feet, or 0.23 inches per year.

Estimated subsidence along the Friant-Kern Canal is greatest where it enters and leaves the Subbasin, which suggests there may be boundary errors in the analysis. These estimates at the boundaries are not considered reliable. Except for the boundaries, the greatest subsidence is estimated where the canal abuts the foothills in the middle of the Subbasin near the City of Exeter. The subsidence at this point is likely the maximum reliable subsidence from this analysis and is shown in Table 3. To date, very little subsidence has been noted in this area, as discussed in Section 2.1.7. Therefore, based on the model results, 10 inches (or 0.83 feet) of subsidence is possible, but not likely to occur and no significant impacts from subsidence to the Friant-Kern Canal are anticipated in the Subbasin.

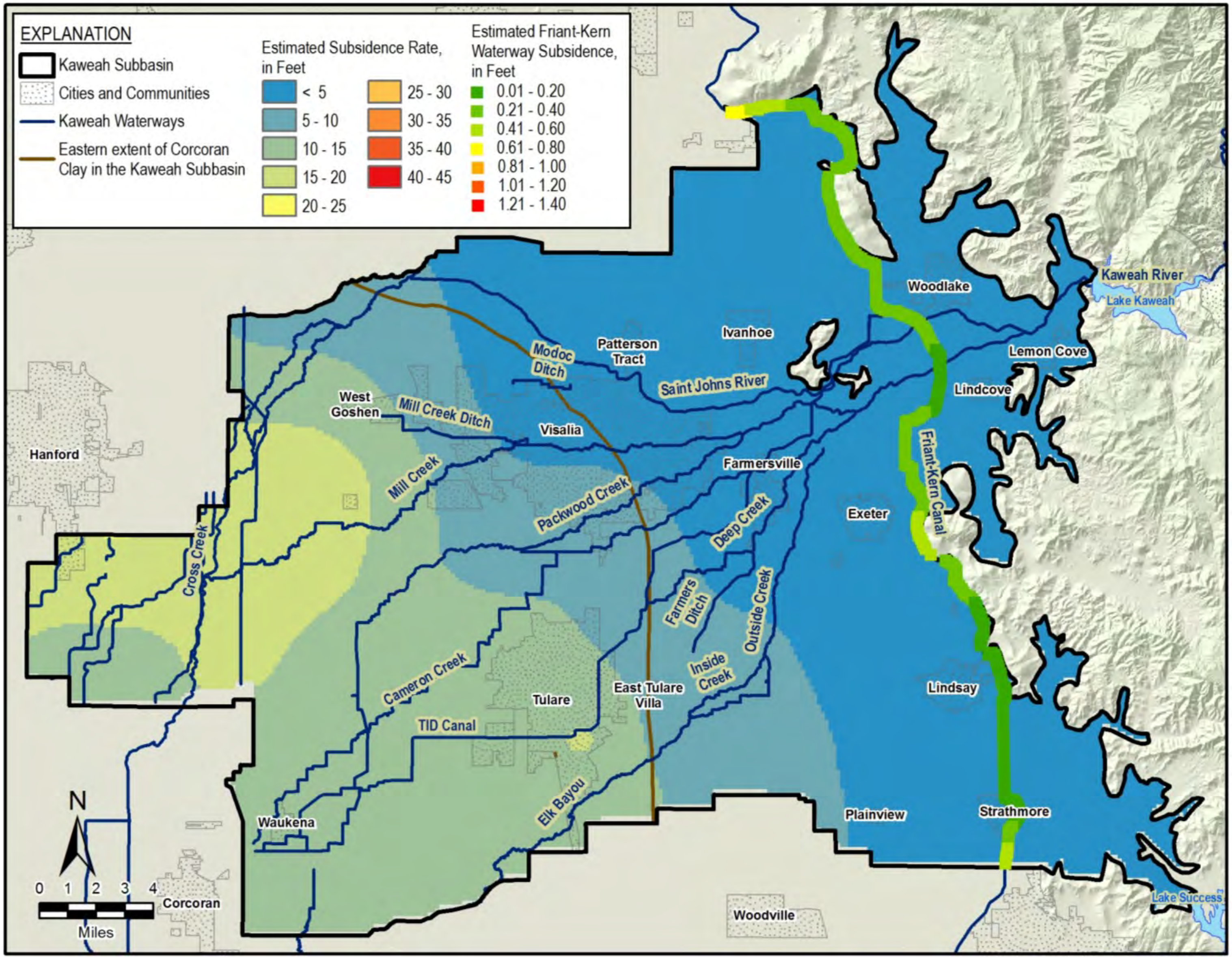


Figure 18. Estimated 2020 to 2040 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Minimum Thresholds

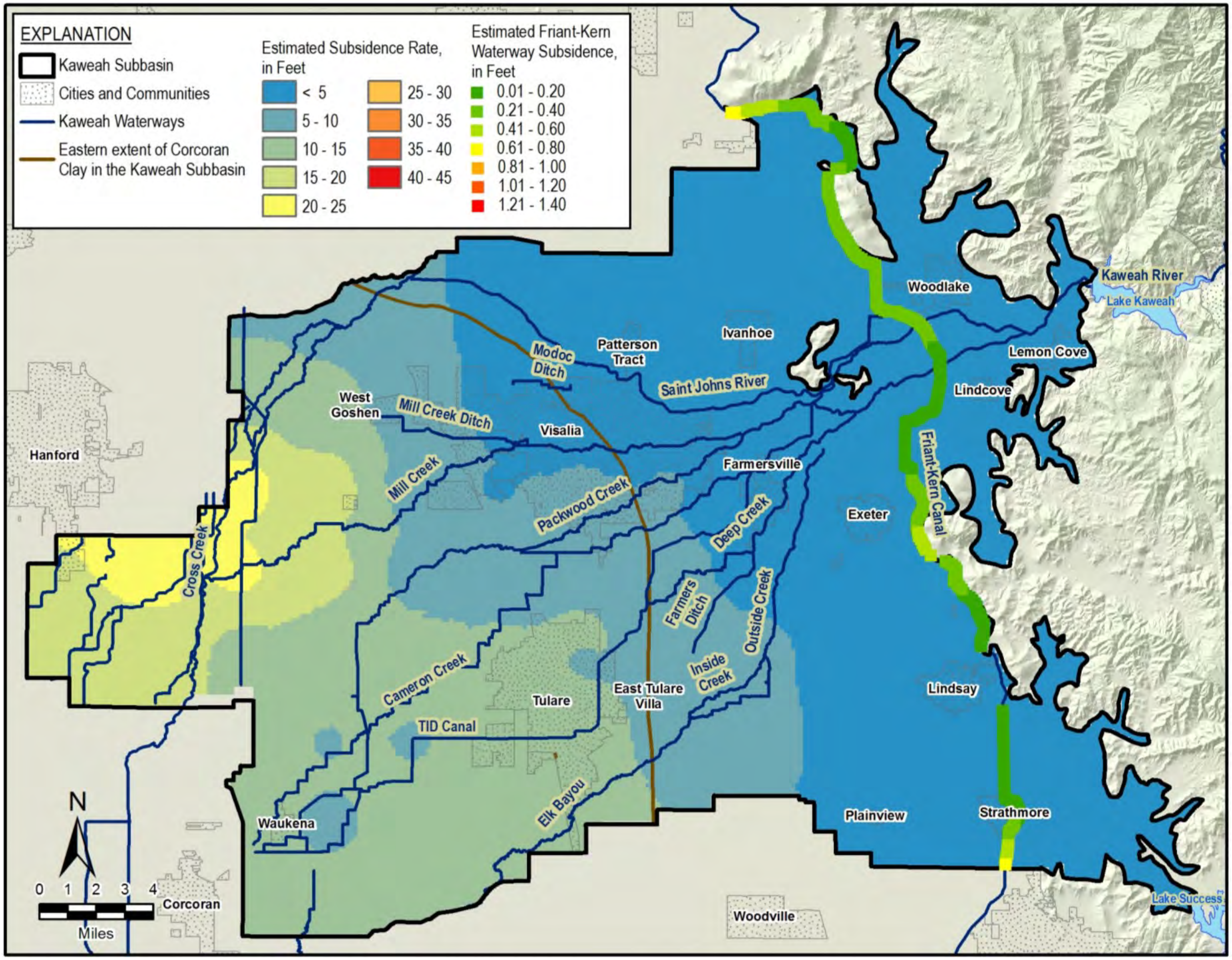


Figure 19. Estimated 2040 to 2070 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Minimum Thresholds

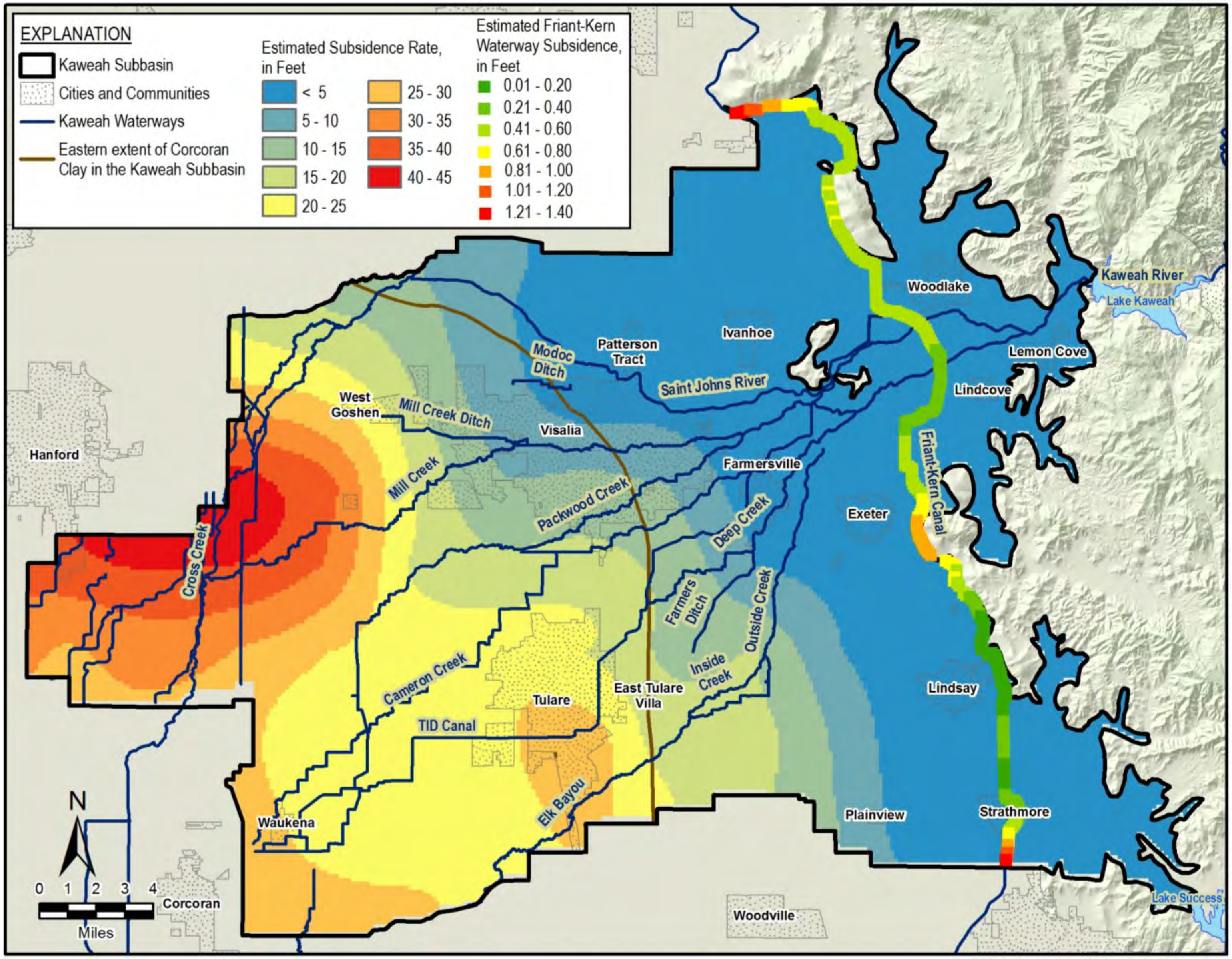


Figure 20. Estimated 2020 to 2070 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Minimum Thresholds

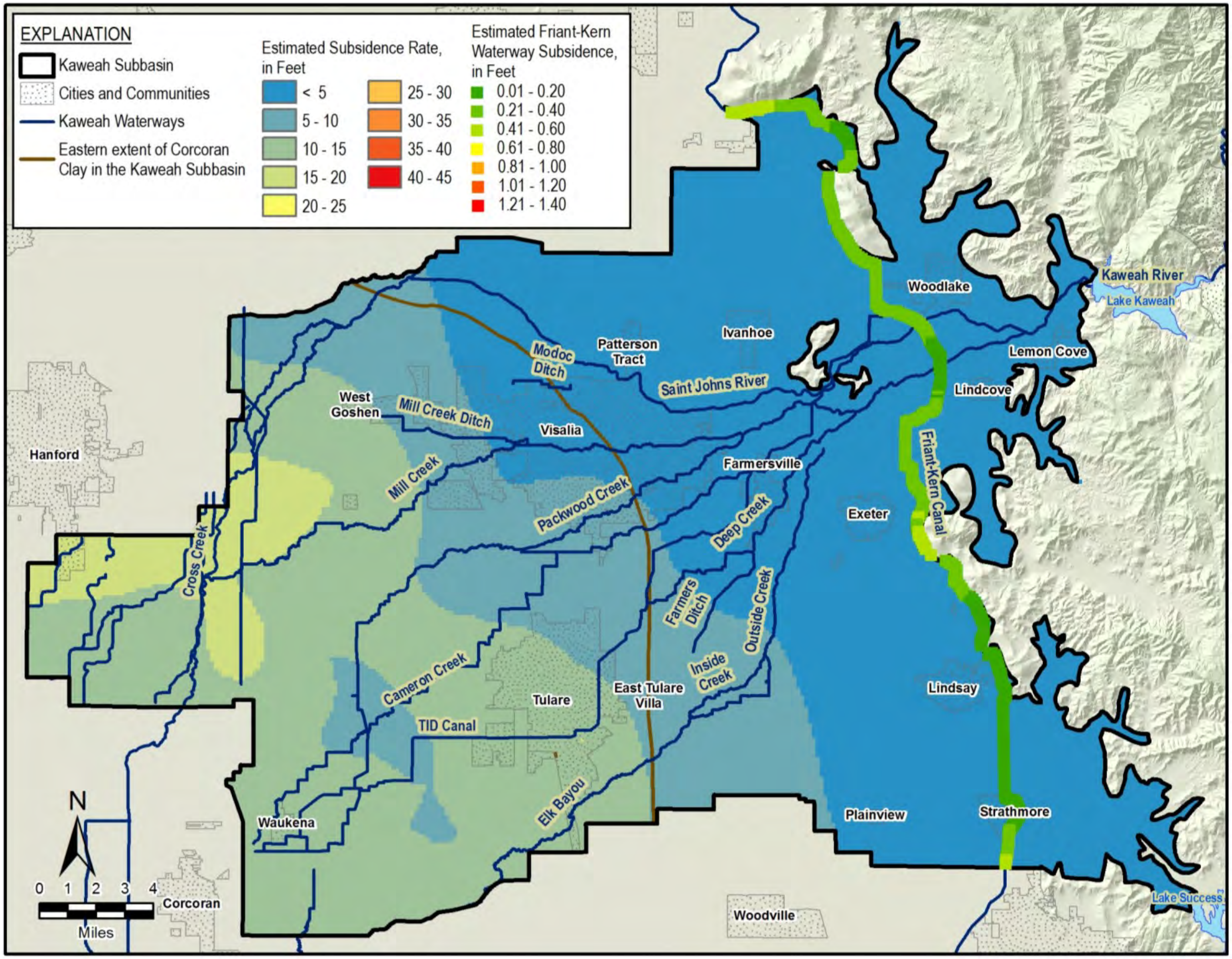


Figure 21. Estimated 2020 to 2040 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Measurable Objectives

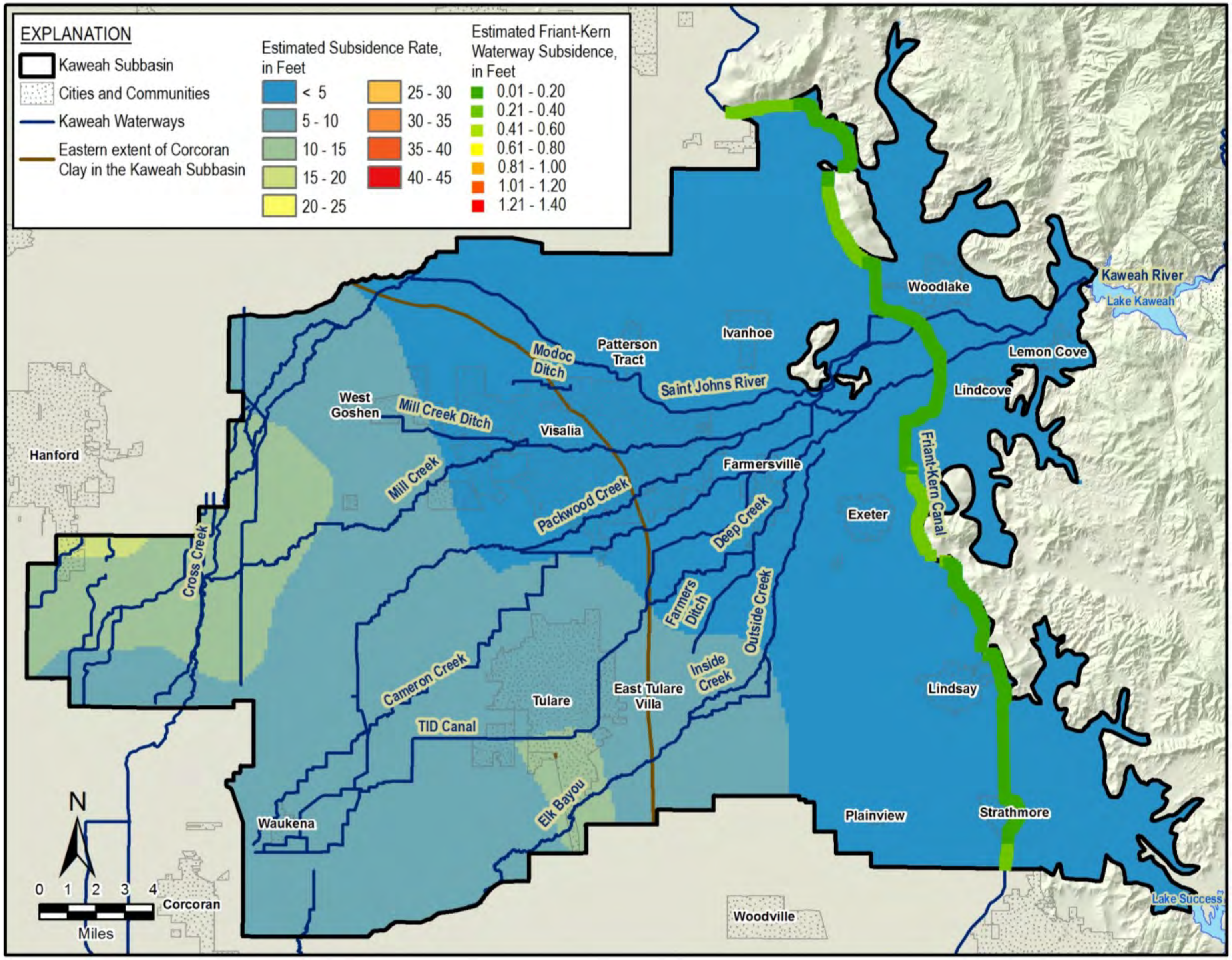


Figure 22. Estimated 2040 to 2070 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Measurable Objectives

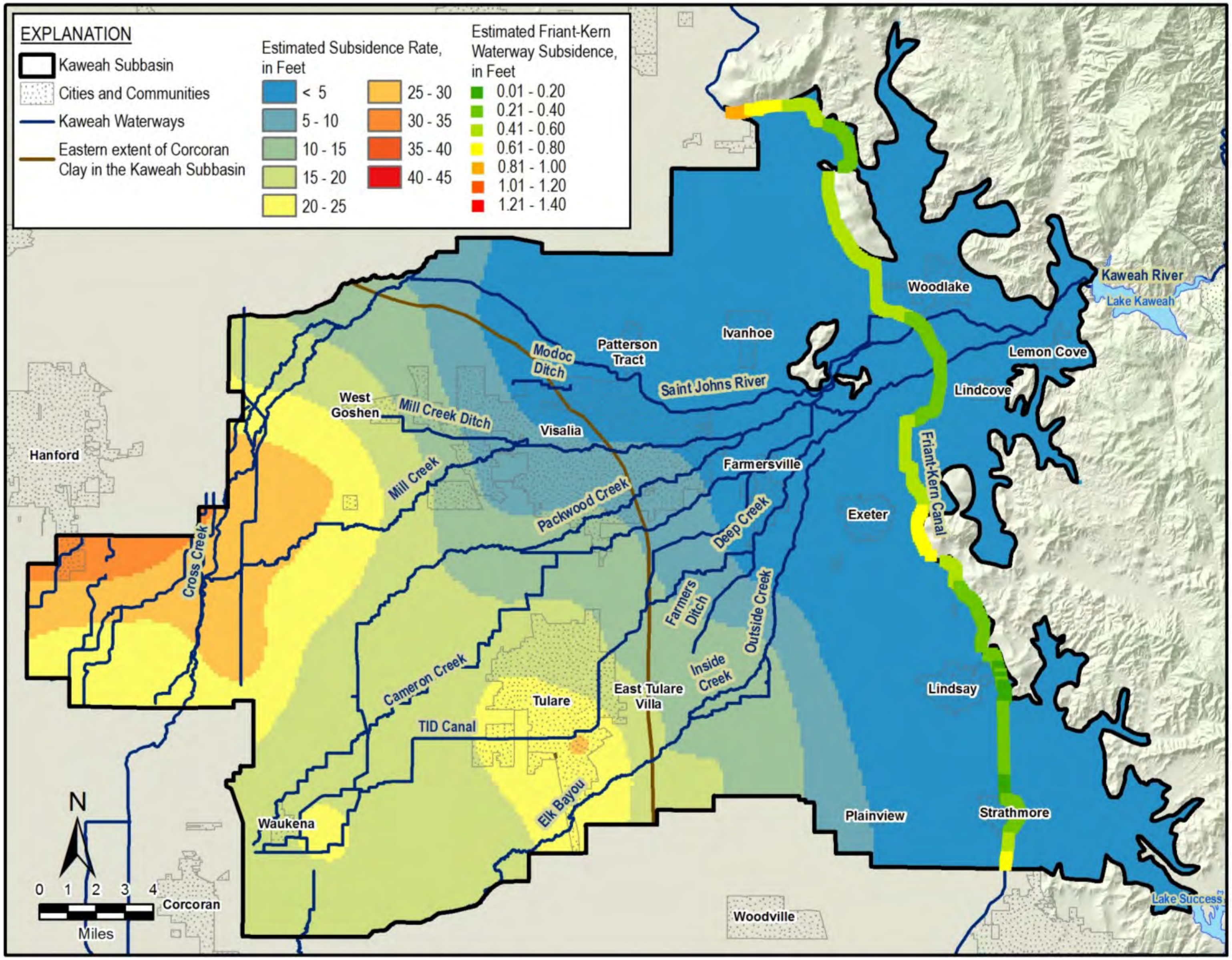


Figure 23. Estimated 2020 to 2070 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Measurable Objectives

Table 3. Maximum Estimated Subsidence Along the Friant-Kern Canal Near Exeter

Time Period	Total Subsidence (feet)	Equivalent Subsidence Rate (inch/yr)
Groundwater Levels Stabilize at Minimum Thresholds		
2020 to 2040	0.50	0.30
2040 to 2070	0.43	0.17
2020 to 2070	0.93	0.22
Groundwater Levels Stabilize at Measurable Objectives		
2020 to 2040	0.42	0.25
2040 to 2070	0.26	0.10
2020 to 2070	0.68	0.16

2.2.2 Conveyance Infrastructure

The capacity of water conveyance infrastructures other than the Friant-Kern canal is impacted only if they subside more upstream than downstream, because the subsidence flattens the conveyance gradient and causes a reduction in capacity. The GSAs determined that a 10% loss of capacity in any of these conveyances would be significant and unreasonable.

Based on experience with the TID main canal, the 10% loss of capacity is equated to differential subsidence where a waterway's upstream subsidence is 1 foot more than its downstream subsidence over 1.5 miles. Each major waterway is analyzed using the total subsidence maps shown in Section 2.1.8, and greater than 1 foot of differential subsidence over 1.5 miles is predicted on 11 conveyance reaches.

Figure 24 through Figure 26 show the locations of conveyance infrastructure that would potentially be significantly impacted for various levels of subsidence. Figure 24 through Figure 26 show which conveyance infrastructures may be significantly impacted if groundwater levels are held at minimum thresholds. Figure 27 through Figure 29 show which conveyance infrastructures may be significantly impacted if groundwater levels are held at measurable objectives. These figures show the number and extent of conveyance infrastructure that should be included in the GSA's mitigation plans.

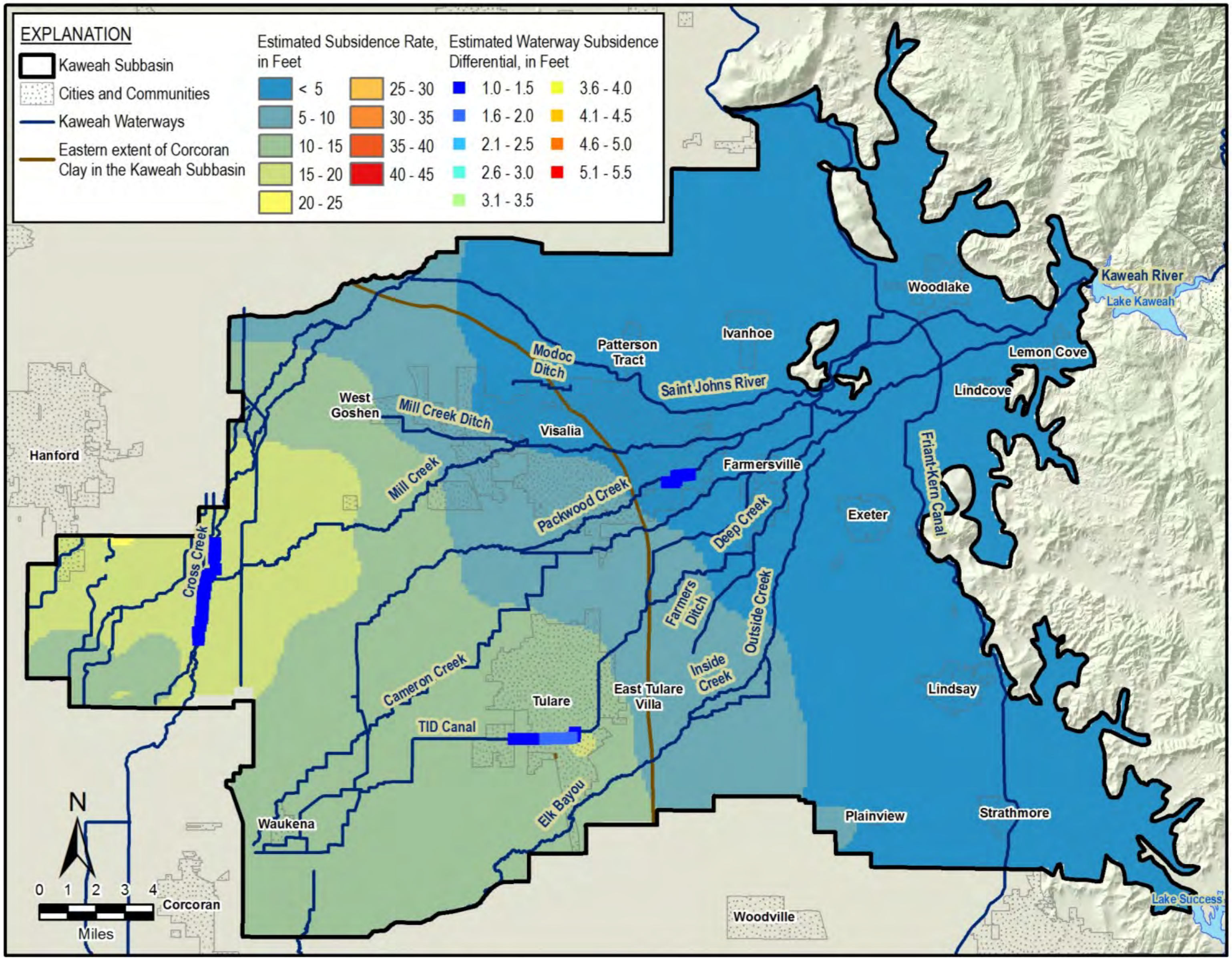


Figure 24. Estimated 2020 to 2040 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Minimum Thresholds

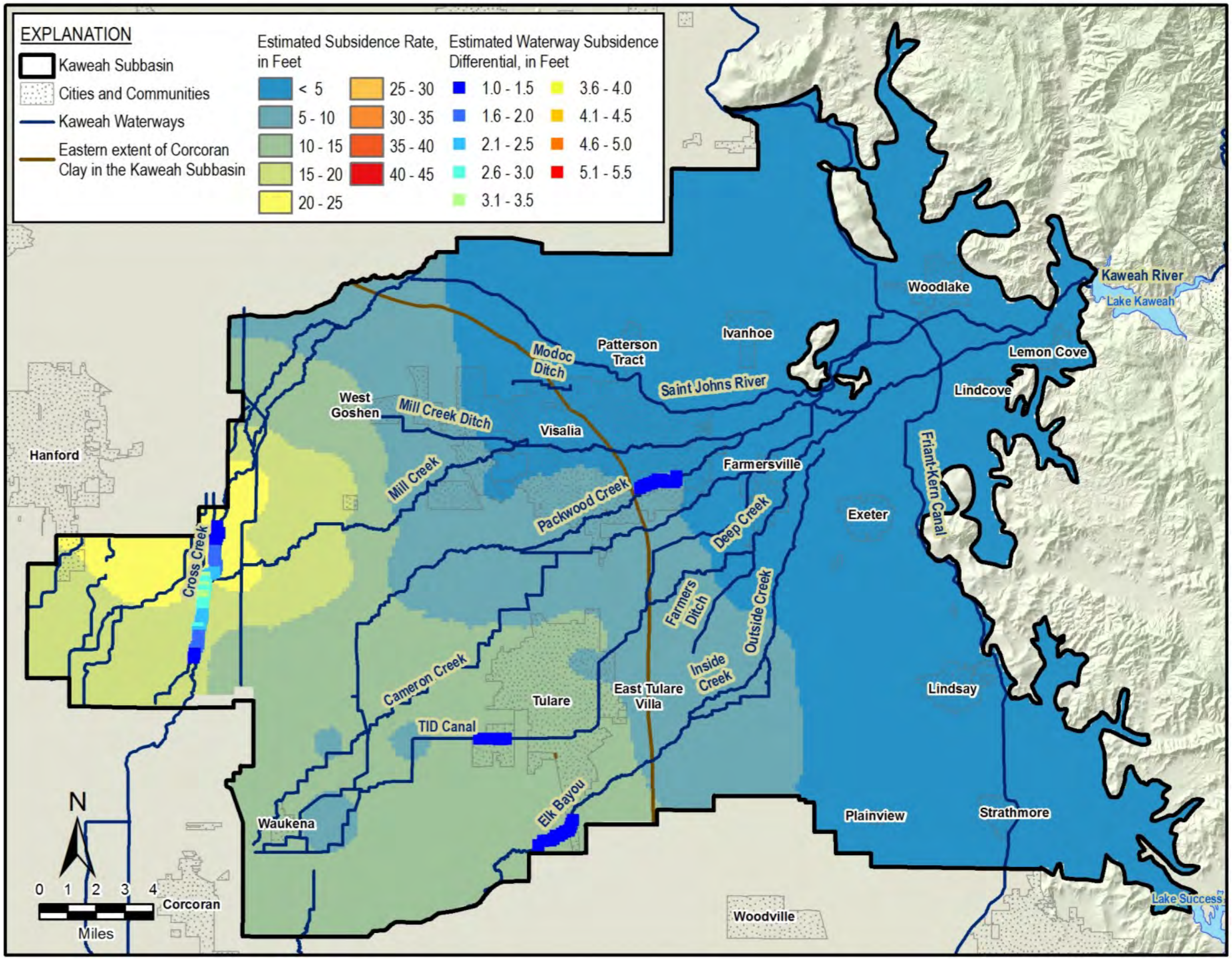


Figure 25. Estimated 2040 to 2070 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Minimum Thresholds

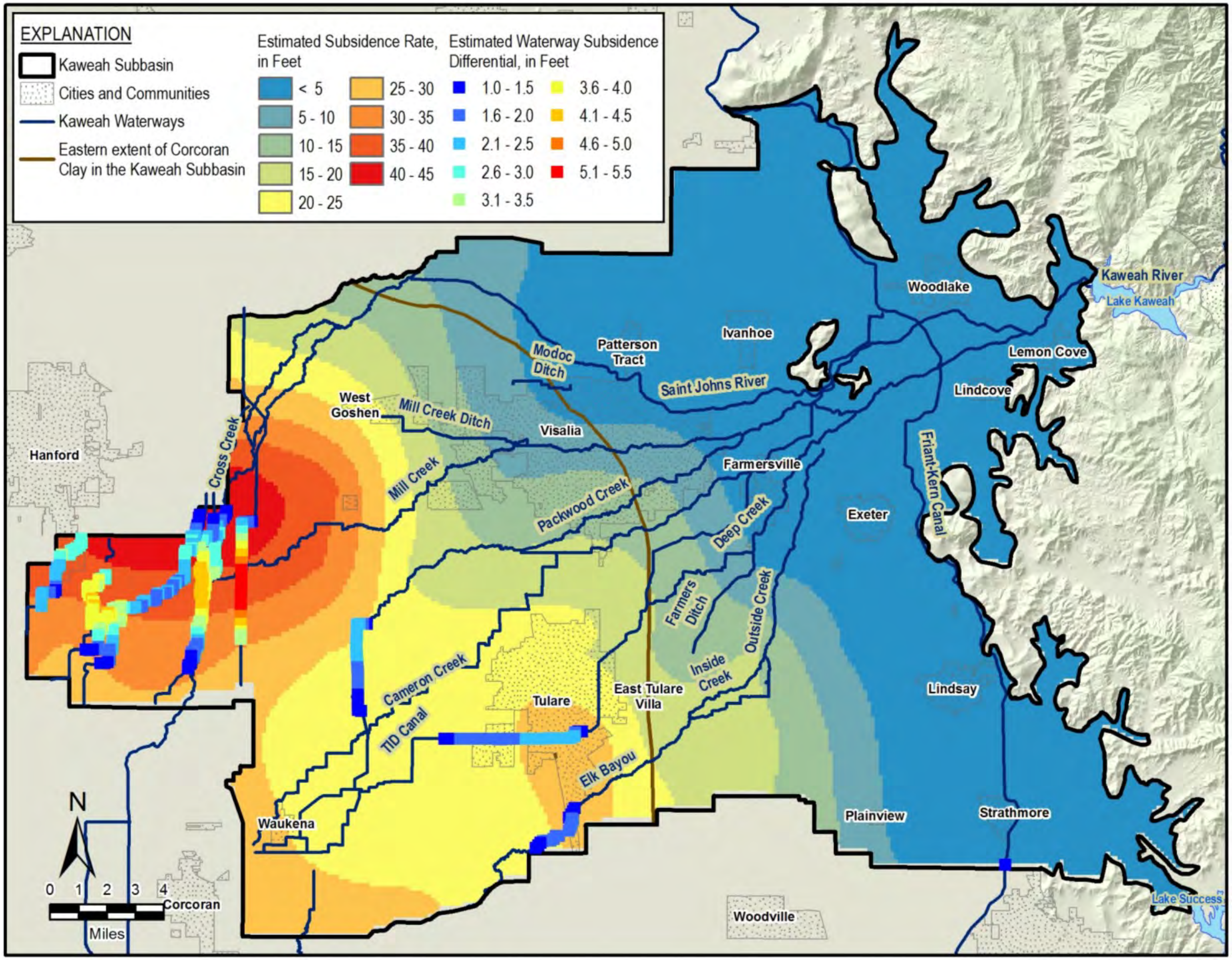


Figure 26. Estimated 2020 to 2070 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Minimum Thresholds

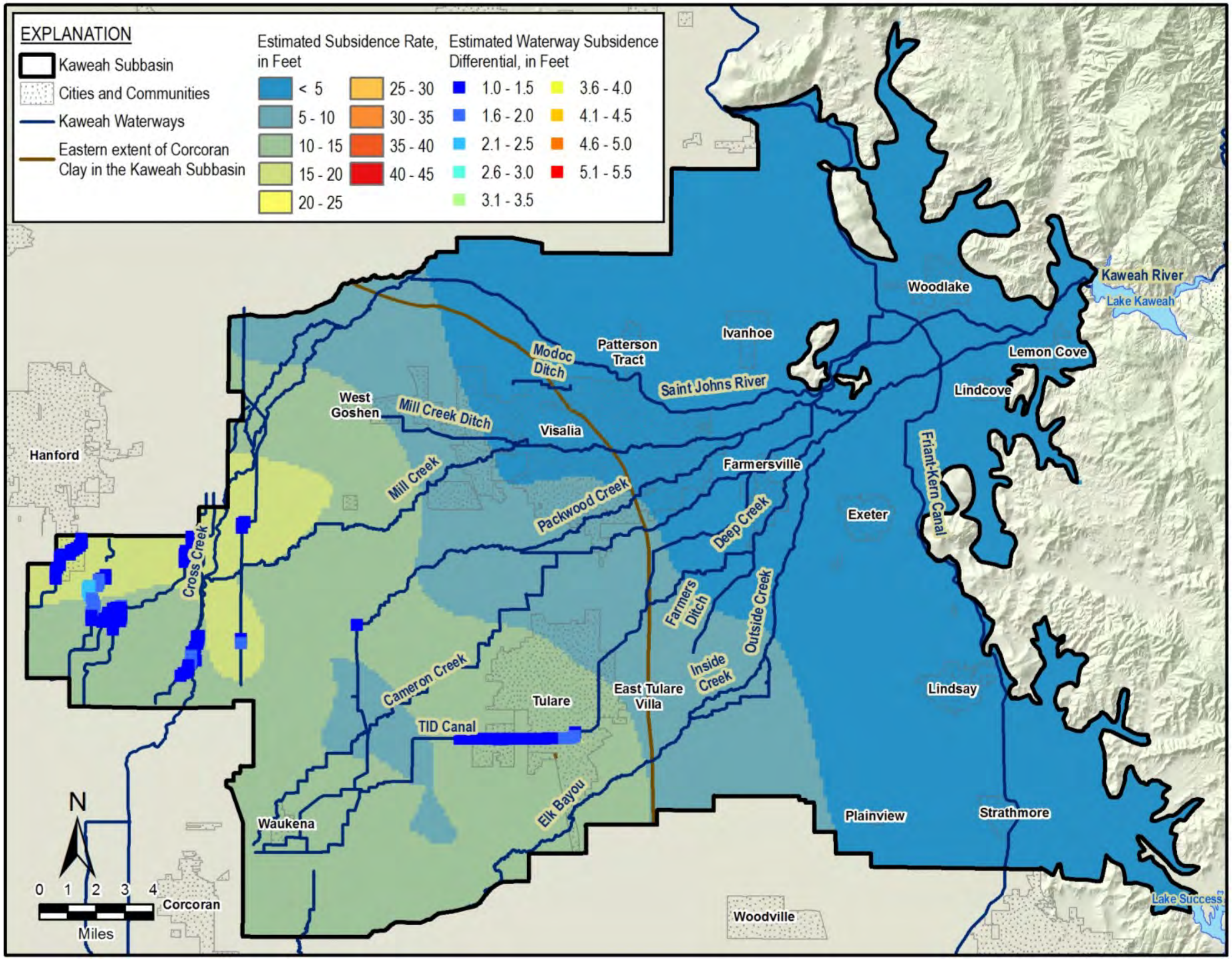


Figure 27. Estimated 2020 to 2040 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Measurable Objectives

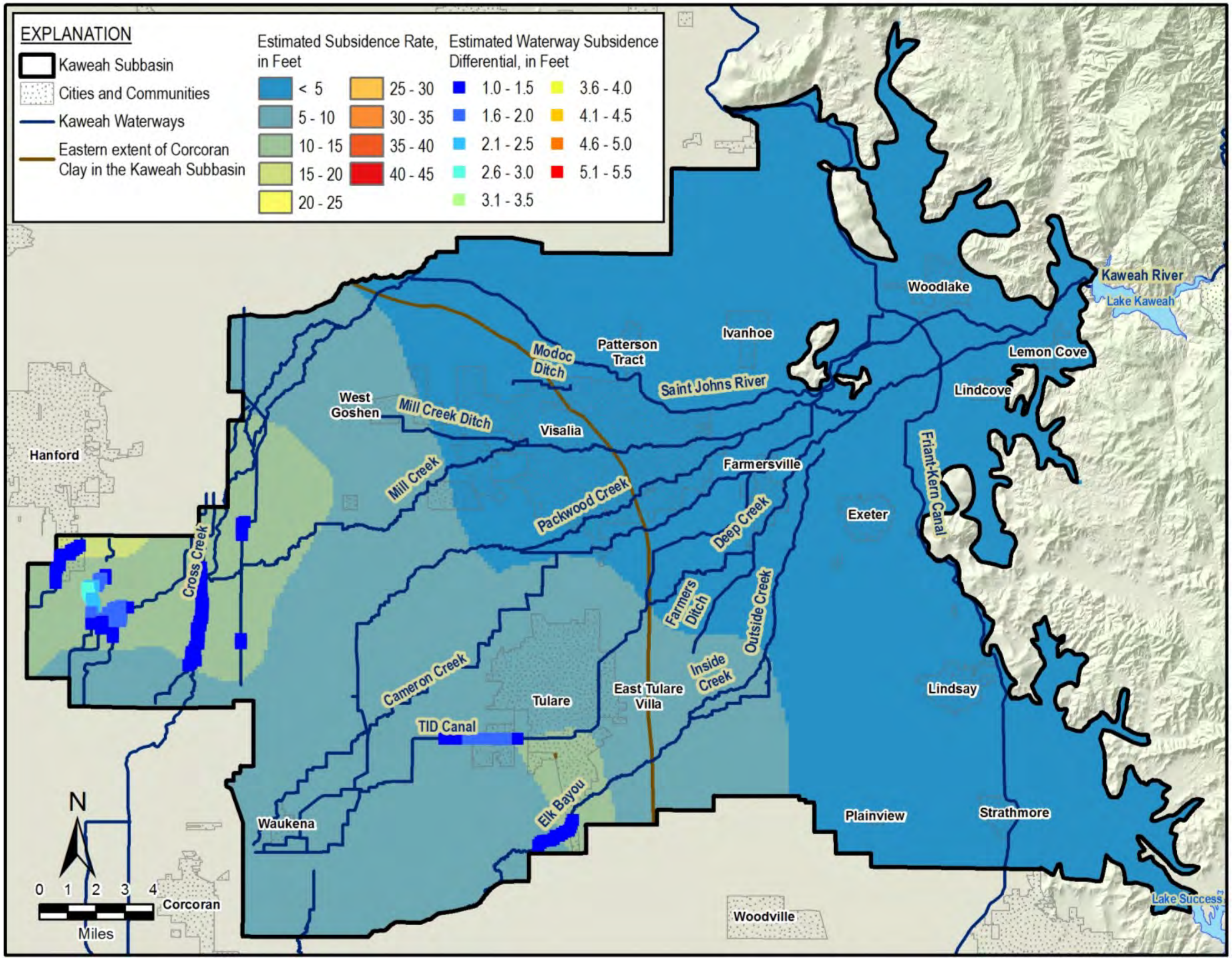


Figure 28. Estimated 2040 to 2070 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Measurable Objectives

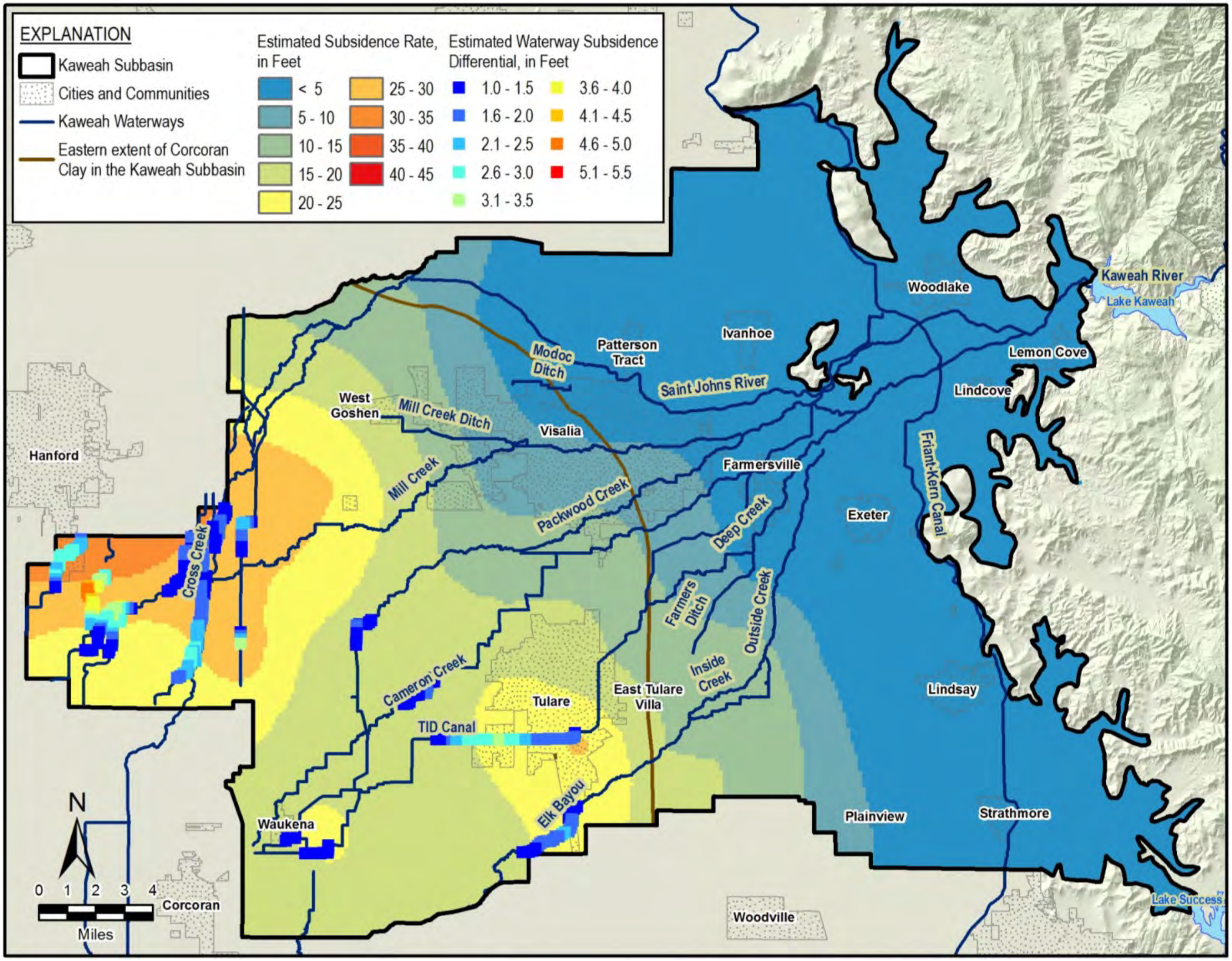


Figure 29. Estimated 2020 to 2070 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Measurable Objectives

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Appendix 7

7A Groundwater Recharge Capacity Evaluation Phase III: Hydrogeologic Investigations to Maximize Recharge Capacity

7B Integration of InSAR with Airborne Geophysical Data for the Development of Groundwater Models

7C Hydrogeologic Framework of Selected Areas of the Kaweah Sub-Basin Region in Tulare and Kings Counties, California

7D Tulare Irrigation District System Optimization Review Study Report

7E Appendix Y.1 – Y.4 Recharge Project Data

7F Emergency Ordinance to Establish an Extraction Limitation for the Mid Kaweah Groundwater Sustainability Agency Service Area

Appendix 7A Groundwater Recharge Capacity Evaluation Phase III: Hydrogeologic Investigations to Maximize Recharge Capacity

REPORT

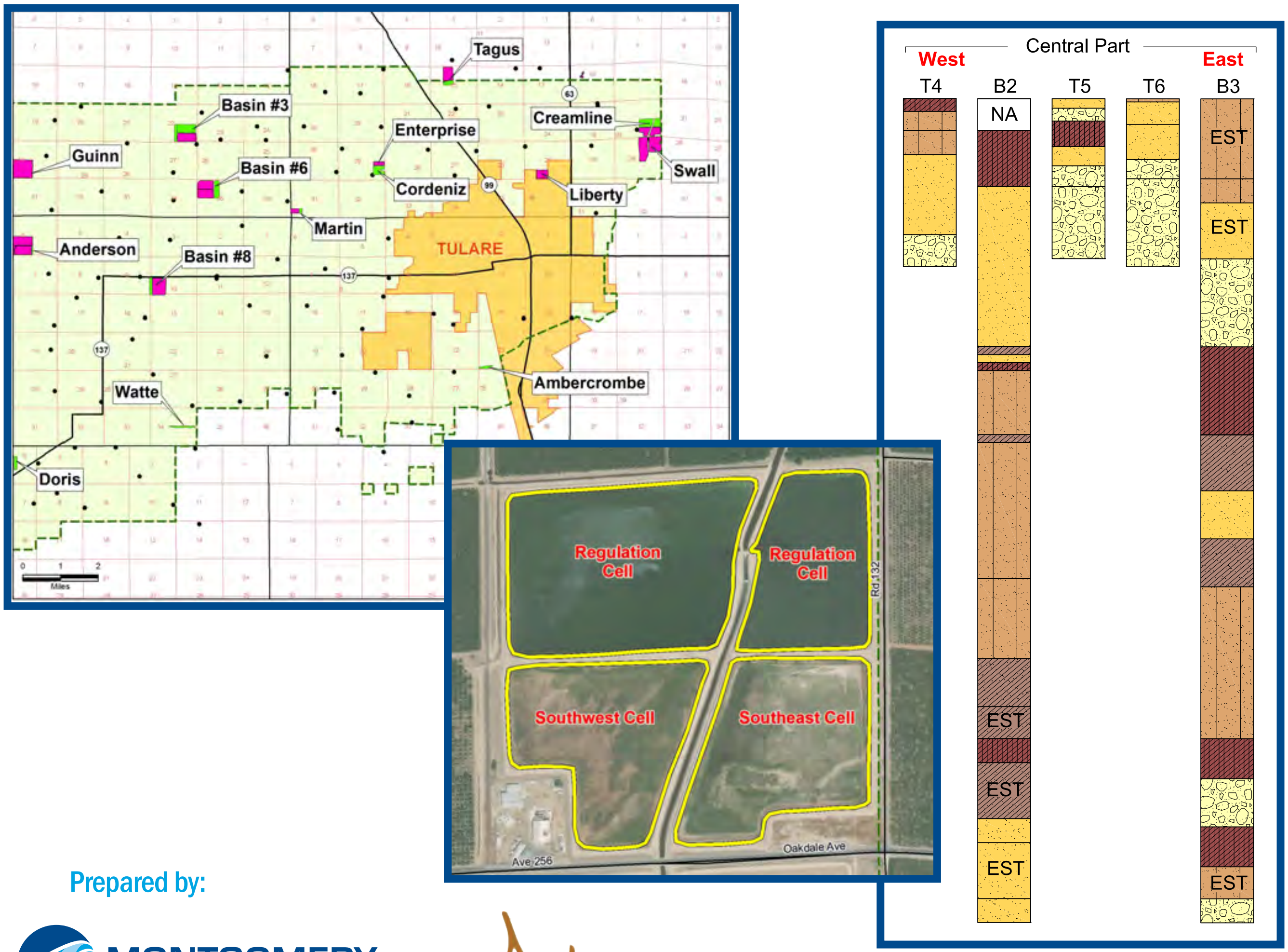
February 26, 2018

Prepared for:

TULARE IRRIGATION DISTRICT
FORMED IN 1889

Groundwater Recharge Capacity Evaluation Phase III: Hydrogeologic Investigations to Maximize Recharge Capacity

Tulare Irrigation District, Tulare County, California



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February 26, 2018

Groundwater Recharge Capacity Evaluation Phase III: Hydrogeologic Investigations to Maximize Recharge Capacity

TULARE IRRIGATION DISTRICT, TULARE COUNTY, CALIFORNIA

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1 INTRODUCTION

Tulare Irrigation District (TID or District) wishes to increase recharge capacity within the District to augment its ability to accept and utilize surface water supplies and better balance groundwater use with recharge. A map of the entire District is shown on **Figure 1**. As part of continuing work to evaluate recharge capacity and strategies for achieving groundwater sustainability within TID's service area, HydroMetrics Water Resources Inc. (HydroMetrics WRI) retained Montgomery & Associates (M&A) to design and conduct hydrogeologic investigations for characterizing recharge capacity of TID's existing basins and for assessing the feasibility of enhancing recharge capacity. The goal of the study was to obtain as much useful information as possible regarding recharge capacity in the District within the established funding limits for this study.
To this end, M&A worked closely with HydroMetrics WRI and the District to develop a project approach that prioritized the most meaningful investigations to provide an initial framework for identifying opportunities and strategies for enhancement of recharge rates and aquifer storage. These strategies may provide the basis for future grant applications. Methods and results of the study are summarized in this report.

2 PROJECT BACKGROUND AND APPROACH

2.1 Previous Investigations

Previous investigations have focused on the District's water use and demands, including evaluation of groundwater overdraft and associated aquifer replenishment needs and opportunities for conjunctive use. Other investigations assessed subsurface lithology and implications for recharge at sites of interest to the District (associated with land purchases). Results of these investigations provide much of the basis for our project understanding and the approach developed for the present recharge feasibility assessment. Relevant reports and information include:

- A September 2015 report prepared by HydroMetrics WRI, titled "Tulare Irrigation District, Groundwater Recharge Capacity Evaluation" (HydroMetrics WRI, 2015);
- The District's 2012 Agricultural Water Management Plan (TID, 2012);
- Reports providing results of previous drilling investigations at the Martin Basin (BSK, 2007), Swall Basin (BSK, 2008), and Cordinez Basin (BSK, 2013); and documenting installation of four monitor wells in the northcentral part of the District (BSK, 2016); and
- Additional data and critical input provided by TID, including observations and information gleaned during the site visit conducted by M&A and HydroMetrics WRI on June 20, 2016.

For the purpose of evaluating recharge feasibility of existing basins targeted for the present study, results of BSK's drilling investigations for the Martin Basin and Swall Basin provided useful information for subsurface lithologic conditions and negated the need to conduct additional drilling at these basins. Because recharge feasibility investigations had already been conducted to support the design of the Enterprise Basin expansion (the added "cell" is identified as the Cordinez Basin), and this basin was being prepared for expansion at the time of M&A's field investigations, it was not targeted for further investigations or evaluation of enhanced recharge capacity. After the Cordinez Basin is constructed and operated, data for operational infiltration rates can be used together with the lithologic characterization to assess the recharge capacity and possible enhancements if warranted. It should be noted that the terminology used in this report for referencing TID's recharge basins is as follows:

- All of the recharge basins investigated for this study consist of two or more "sub-basins", which are referred to as "cells". The term "basin" (with an associated identifier) is used to refer to the entire group of cells comprising the basin. The term "cell" (with an associated identifier) is used to refer to a specific cell within the overall basin (e.g. Basin No. 6 North Cell.)

- There are two types of cells in most basins: recharge (or "sinking") cells and regulation (or "running") cells. Recharge cells are operated and maintained specifically for recharging water, whereas regulation cells are typically smaller and are used chiefly to regulate surface water flows to the recharge cells within the same basin and to the recharge basins located downstream in the recharge system. With the exception of the Swall Basin, all of the recharge basins investigated for this study have one regulation cell and one or more recharge cells. The Swall Basin consists of three recharge cells with no regulation cell (flow regulation occurs in the adjacent Creamline Basin).

- The terms "basin" and "cell" are capitalized when referring to a specific recharge basin or recharge cell by its identifier.

- Overall, the District operates 12 basins that include recharge cells and three additional basins that consist solely of a regulation cell. This tally includes the Enterprise and Cordinez Basins as separate recharge basins, although the Cordinez Basin is actually the expanded portion of the Enterprise Basin and is currently under construction.

2.2 Conjunctive Use

In 2015, HydroMetrics WRI conducted a comprehensive study to evaluate the overall conjunctive potential of the District's water distribution system to determine the required recharge capacity in relation to crop demands, groundwater percolation characteristics, and availability of surface water supplies. This study includes a detailed water budget for the District for the period 1999 through 2012 and provides important information regarding conditions relevant to recharge. Results of the study are given in HydroMetrics WRI's 2015 report listed above.

The HydroMetrics WRI report addressed Task 3 of the United States Bureau of Reclamation (USBR) grant titled *Tulare Irrigation District Conjunctive Exchange Program*. The present recharge feasibility study and report addresses follow-up investigations for Phase III of the conjunctive exchange program. Phase III focuses on hydrogeologic characterization of the recharge basins to further develop strategies and identifies opportunities for increasing recharge capacity to better utilize surface water supplies as they become available and achieve more sustainable conditions.

The 2015 HydroMetrics WRI study resulted in the following relevant findings and/or conclusions, which provided much of the motivation for the present recharge feasibility study:

- An estimated average of 20,000 acre-feet per year (AF/yr) of additional managed aquifer recharge (either direct or in-lieu) is required to ensure as much recharge occurs in the District’s service area as is extracted from groundwater within the District boundaries.
- Existing recharge basins will be inadequate to recharge all of the supplemental water needed to balance groundwater withdrawals.
- Pumping outside the District’s service area creates groundwater underflow (and loss of groundwater in storage) out of the District of approximately 15,500 AF/yr, which will likely increase in the future as demand outside of the District’s service area increases.
- Recharge capacity in the District can be increased by any or a combination of (1) increasing the number of recharge basins, (2) on-farm recharge, and/or (3) improving recharge capacity of existing basins.

The HydroMetrics WRI study also identified several potential options for TID to acquire additional surface water supplies, which would be needed to reduce groundwater withdrawals for agricultural irrigation (direct use/in-lieu recharge) and for aquifer storage to balance groundwater withdrawals and move closer to sustainable groundwater use.

A critical element in taking advantage of additional or surplus surface water supplies is the ability to accept and store the water during periods when it cannot be used directly. This requires developing a larger recharge capacity within the District. An important consideration for evaluating recharge capacity is that surface water availability can be highly variable from year to year. Several years of limited surface water availability would create a groundwater storage deficit that cannot be alleviated by recharging an additional 20,000 acre-feet (AF) for the next several years. Instead, the additional recharge capacity needs to be much larger than this volume so that as much surface water as possible can be captured and recharged during the periods when it is available. This need for additional capacity is highlighted by the recent years of drought and resultant absence of surface water deliveries to the District, during which time groundwater withdrawals were maximized, and the volume of groundwater in storage was further depleted.

2.3 Project Approach

The hydrogeologic investigations for this study were conducted in general accordance with the Draft Scope of Work, titled *Groundwater Recharge Capacity Evaluation, Phase III Hydrogeologic Investigations to Maximize Recharge Capacity* (HydroMetrics WRI and M&A, 2016). Investigations included exploration trenching and exploration drilling for lithologic characterization of selected existing recharge basins and infiltration testing of the same basins plus some additional basins. In general, recharge basins targeted for investigation were prioritized by the District based on historical use and associated importance of each basin within the District's water conveyance and recharge system, and on the District's empirical knowledge of basin performance. Due to the large number of recharge basins and the extremely large floor area of the basins (nearly 2 square miles), and to the limited funding, it was not possible to investigate all 12 recharge basins (consisting of a total of 17 recharge cells) or to conduct each type of investigation in all the selected basins. Therefore, the overall approach for the study was to obtain as much useful information as possible regarding recharge capacity in the District within the established funding limits. This approach required flexibility in implementing the work plan during the course of field operations, such that the extent and type of investigations conducted in a given basin could be modified based on real-time findings from completed investigations in that basin. In this manner, the investigations targeted the most meaningful data for the goals of the study within the limited number of basins investigated. During the field investigations, M&A staff coordinated with the District and HydroMetrics WRI regarding on-going findings to determine/confirm subsequent investigations in selected basins to develop the most useful and cost-effective approach.

Based on discussions with TID, recharge basins of primary interest to the District include the Creamline Basin, Swall Basin, Basin No. 3, and Basin No. 6 **(Figure 1)**. Based on empirical evidence, the Swall Basin East Cell was thought to have higher infiltration capacity than most of TID's basins. These selected basins are not only operationally important, but they represent differing geographic portions (and potentially differing lithologic conditions), across the north half of the District. Although it would be ideal to investigate all existing basins throughout the entire District, the north half of the District was prioritized for this study because the District emphasizes recharge operations in the north half. This is due to the fact that both groundwater flow and surface water flow are generally from northeast to southwest across the District. Therefore, groundwater flow out of the District and excess surface water exiting the southwest corner of the District are reduced by increasing recharge in the up-gradient portions of the District.

It is also important to note that this study and associated hydrogeologic investigations focused chiefly on use of existing recharge basins (surface infiltration basins) as the recharge method. The present study does not attempt to address other parcels of land that could potentially be available for construction of new recharge facilities, due both to the general lack of available parcels and the excessive costs of purchasing land and constructing new conveyance canals or pipelines. However, an overview of alternative recharge methods such as vadose zone injection wells, direct injection into the aquifer using deep wells, and on-farm recharge is provided in this report.

The most critical depth interval for determining the feasibility of surface infiltration basins is the near-surface zone (upper 10 to 20 feet) underlying the basin floor. Therefore, characterization of the near-surface zone was a primary focus of the study, which led to conduct of exploration trenching in four basins (total of five cells). Results of the near-surface characterization were closely evaluated during trenching investigations; if conditions appeared to be generally favorable for recharge (or could be favorable with deepening of the basins to feasible depths), exploration drilling was targeted for that basin to evaluate deeper vadose zone conditions. As a result of this real-time evaluation, exploration drilling was conducted in only two prioritized basins (total of three cells).

The work plan initially included infiltration testing, potentially using both operational testing (during actual surface water deliveries and associated recharge operations) and small-scale infiltration tests using a ring-infiltrometer. Ring-infiltrometer tests involve substantial effort and costs relative to the applicability of the results to the generally very large areas of the basins investigated. Also, the onset of heavy winter precipitation and excess surface water deliveries provided the opportunity to conduct more meaningful and representative large-scale tests via measurement of actual infiltration rates for entire basins during long-term wetting cycles. As described in **Section 3.4**, these operational tests require a minimal amount of set up with relatively small effort to collect data during the test period. Therefore, we were able to conduct operational infiltration testing at five basins (total of seven cells) to obtain valuable information for the existing infiltration capacity for these basins. This formal testing process had not been done previously for the District's recharge basins. The results of the operational tests serve to document existing recharge capacity within the District, thereby providing a stronger basis for evaluating the need for and potential benefits of recharge enhancement options.

3 METHODS FOR HYDROGEOLOGIC INVESTIGATIONS

Hydrogeologic investigations for evaluation of recharge feasibility of TID's basins consisted of: (1) exploration trenching operations for lithologic and stratigraphic characterization of the near-surface zone (defined as approximately the upper 10 to 12 feet); (2) exploration drilling operations for lithologic and stratigraphic characterization of the vadose zone to a depth of approximately 50 feet below land surface (bls); and (3) large-scale operational infiltration testing to determine/document the current infiltration capacity. As described in **Section 2.1**, the investigations targeted the most meaningful data for the goals of the study and were conducted in a flexible manner to develop the most useful and cost-effective approach. As a starting point, the recharge basins targeted for trenching investigations were prioritized by TID. Site maps for all basins/cells that were investigated for this study, including the locations of field investigations, are shown on **Figures 2 through 7**. Methods for these field investigations are provided in the following sections.

3.1 Lithologic Characterization and Preparation of Graphic Logs

Lithologic descriptions were prepared by M&A for soil samples obtained from the exploration trenches and split-spoon samples obtained from the exploration borings, and graphic logs were prepared for the trench and boring profiles based on these lithologic descriptions. Lithologic descriptions and graphic logs for the exploration trenches and exploration borings are provided in **Appendix A and Appendix B**, respectively. The methodology used for describing the samples and presenting the lithologic information is described in detail in the following paragraphs.

Detailed lithologic descriptions were prepared by evaluating and estimating particle size distribution and degree of lithification for the sediment and drill cuttings samples, chiefly using manual methods. Selected samples of sediments from the trenches and borings were submitted to the geotechnical testing laboratory Terracon in Tucson, Arizona, for determination of particle size distribution and plasticity indices (Atterberg limits). The laboratory results are summarized in **Table 1**; laboratory reports are provided in **Appendix C**. Laboratory results provided a means for evaluating and adjusting results of manual estimation methods. Particle size ranges for the gravel, sand, and fine (silt and clay) fractions were based on the United States Department of Agriculture system. Lithologic descriptions include a descriptor for manually-determined "cohesiveness" to provide a relative estimate of clay content (cohesiveness is generally used in place of plasticity to distinguish between manual descriptions and laboratory-determined plasticity indices/ categories).

The sediment type/name for each lithologic description (e.g., Sandy Clayey Silt, Silty Sand, etc.) is based on M&A's standard procedure for describing sediments; the textural component with the highest content is listed last, preceded by the component of next highest content, and so on. However, the sediment type/name is followed by the Unified Soil Classification System (USCS) descriptor (e.g., ML, SM, etc.). It is important to note that for the majority of the fine-grained intervals with notable cohesiveness (plasticity) encountered in the trenches and borings, the appropriate USCS descriptor could be ML or CL depending on the magnitude and ratio of the liquid limit and plasticity index, which were only measured by the laboratory for a few samples. Therefore, the USCS descriptors used for this sediment type are "ML/CL."

Based on field observations and detailed lithologic descriptions, sediments were classified into five categories based on lithologic properties and the estimated permeability; which were used to prepare graphic logs for the trenches and borings. Each "lithologic/permeability category" includes sediments or stratigraphic units with consistent or similar hydrogeologic properties, particularly those that affect vertical permeability. This classification of sediments provides a framework for evaluating relative permeability and, therefore, potentially favorable versus restrictive conditions and/or locations with regard to infiltration and downward movement of water. It should be noted that "permeability" as used in this report is synonymous with vertical hydraulic conductivity when used to describe the property of subsurface strata to transmit water downward, and is also synonymous with vertical "infiltration capacity" when used to describe near-surface sediments in the excavated recharge basins.

The five lithologic/permeability categories are defined based on particle size distribution (especially silt and clay content), cohesiveness, the degree of lithification of the sediments, and relative permeability estimated from these physical properties. Particle size distribution and cohesiveness are the primary factors in defining the categories; cohesiveness is closely related to clay content. The degree of lithification (such as carbonate cementation) can be important due to its effect on reducing permeability, but its overall importance is based on the lateral and vertical extent of lithified sediments. Sediments with a similar particle size distribution could be included in two or three different categories due to differences in degree of lithification. However, lithification is not a significant factor for evaluating permeability of the subsurface sediments at the TID recharge basins. The sediments encountered in the trenches generally had no observable cementation. In addition, nearly all the sediments intervals encountered in the borings were non-lithified (only a few thin weakly-lithified lenses were noted). Although the sediment texture and lithification cannot be precisely correlated to permeability, classifying the sediments into categories in accordance with estimated permeability provides a means for comparing hydrogeologic conditions and evaluating sediment layers that would potentially control or limit infiltration and recharge rates.

The five lithologic/permeability categories and corresponding symbols used to construct the graphic logs for the exploration trenches and exploration borings are shown in the explanation on **Figures 8 through 14** and are also shown on **Figure A-1 (Appendix A) and Figure B-1 (Appendix B)**. The descriptions for the five lithologic/permeability categories are the same for the trenches and borings. The five categories, as shown from top to bottom on the indicated figures, increase in silt and clay content and/or cohesiveness (degree of lithification is not a factor for the sediments encountered beneath the TID recharge basins). Both the upper two (1st and 2nd) categories include "coarse-grained" sediment types and are considered very favorable for downward movement of water during recharge operations. Both the lower two (4th and 5th) categories include "fine-grained" sediment types and are considered potentially unfavorable or impeding to downward movement of water. The middle (3rd) category includes "medium-grained" sediment types and is "intermediate" to the upper and lower two categories; this category is considered neither impeding nor highly transmissive to downward movement of water.

Descriptions for the five lithologic/permeability categories include estimated numerical ranges of permeability (or infiltration capacity) for the categories. These numerical ranges are not based on field infiltration rates measured in the TID basins (specific sediment intervals were not tested, as described in **Section 3.4**). Instead, the ranges are inferred from sediment lithology based on comparison and correlation of lithologic conditions encountered in the TID basins to similar sediment lithologies and associated infiltration test results for other recharge feasibility assessments that M&A has conducted. It is important to note that the numerical permeability ranges are approximate and are intended chiefly to frame the relative terms "very large," "large," "moderate," "small," and "very small" permeability.

3.2 Exploration Trenches

The purpose of the exploration trenching program was to characterize lithologic and stratigraphic conditions in the near-surface vadose zone sediments and to identify sediment strata that may be the controlling (limiting) layers for infiltration rates during recharge operations. The exploration trenching program was conducted during the period from October 4 through 13, 2016, and included the following basins/cells:

- Creamline Basin Southeast Cell (8 trenches)
- Basin No. 3 South Cell (11 trenches)
- Basin No. 6 North Cell (8 trenches)
- Basin No. 6 South Cell (7 trenches)
- Basin No. 8 (8 trenches)

Locations for the trenches are shown on the associated site maps **(Figures 2, 4, 5, and 6)**. The trenches were excavated to depths ranging from 10 to 12 feet (one trench was excavated to a depth of only 5 feet to determine the presence of a notable shallow layer observed in the nearest trenches). The trenches were approximately 15 feet long at land surface and became shorter with increasing depth. Trenches were excavated by TID staff using a backhoe. Because most of the basin floors are relatively level, the trench elevations within a given basin were essentially the same (exceptions are Basin No. 6 North and South Cells and Basin No. 8, as described in **Section 4.1**).

Lithologic and stratigraphic conditions encountered in the trenches were evaluated and described by an M&A geologist, and representative samples were obtained from all sediment strata of differing lithology. Selected samples of sediments from the trenches (typically a sample of one sediment layer per trench) were submitted to Terracon, Tucson, Arizona, for determination of particle size distribution and plasticity indices (Atterberg limits). In addition, a total of four samples were obtained for laboratory analysis of saturated hydraulic conductivity (K_{sat}); these samples were delivered to Technicon Engineering Services, Inc., Fresno, California. Detailed lithologic descriptions for the samples were prepared (in-house), which provide a continuous characterization of sediment strata encountered in the trenches. Sediments were described and classified in accordance with the methodology described in **Section 3.1**. Field descriptions of the trench profiles within a given basin were evaluated to determine if exploration drilling would be of more importance at that basin relative to other basins where trenching was conducted. Following completion of trenching operations, excavations were backfilled and the trench sites were restored to basin floor levels.

3.3 Exploration Borings

The purpose of the exploration drilling was to characterize lithologic and stratigraphic conditions in the vadose zone and to identify critical sediment strata that may potentially impede downward movement of water during recharge operations and/or cause perched water mounding. The borings were drilled to depths ranging from about 30 to 50 feet bls. Depth to groundwater is on the order of approximately 150 to 200 feet bls at the locations of the TID recharge basins investigated for this study; therefore, the borings represent only the upper part of the vadose zone. The exploration drilling program was conducted during the period from November 28 through 30, 2016. Drilling operations were conducted by Technicon Engineering Services using the hollow-stem auger drilling method; the auger flights were 4.25-inch inside diameter by 7.5-inch outside diameter. Samples of the sediments encountered in the boreholes were obtained using the modified California split-spoon, which has an inside diameter of 2.5 inches and length of 1.5 feet.

Based on the lithologic characterization of the near-surface zone from the exploration trenching program, two basins were selected for exploration borings:

- Creamline Basin Southeast Cell: three borings were drilled and sampled to depths ranging from 51.5 feet to 53 feet below the basin floor; locations of the borings are shown on **Figure 2**.

- Basin No. 6 North and South Cells: a total of five borings were drilled, four borings in the North Cell and one boring near the center of the South Cell; depths ranged from 31.5 to 51.5 feet below the basin floor; locations for the borings are shown on **Figure 5**.

Lithologic characterization of the borehole profiles was based chiefly on split-spoon samples, which were obtained at 2.5-foot intervals to a depth of 25 feet, and at 5-foot intervals below 25 feet. The 2.5-foot sampling frequency, combined with the 1.5-foot split-spoon length provided samples for lithologic evaluation that were nearly continuous in the upper 25 feet, which is the more critical zone in regard to the infiltration-limiting effect of low-permeability strata. Split-spoon samples were occasionally obtained at more frequent intervals at larger depths when a change in lithology was detected. Although drill cuttings emerging from the borehole for the auger drilling method may not reliably represent the interval being drilled, the cuttings produced between sampled intervals were examined in the field to check for possible changes in lithology between the sampled intervals. Small amounts of water were added to the boreholes during drilling to stabilize the boreholes. Following completion of drilling for each borehole, the borehole was abandoned by backfilling with drill cuttings.

Detailed lithologic descriptions for the split-spoon samples were prepared (in-house) to more accurately characterize sediment strata encountered in the boreholes. Sediments were described and classified in accordance with the methodology described in **Section 3.1**. Although detailed descriptions are only available for the discrete sampled intervals, field observations of the drill cuttings allowed a general evaluation of the drilled intervals between the discrete samples below a depth of 25 feet). For the graphic logs prepared for the borings, the drilled intervals between split-spoon samples include the note “EST” (for “estimated”) if the lithologic conditions based on auger cuttings were judged to be unreliable. In this manner, the lithologic logs prepared for the boreholes represent a reasonably reliable continuous characterization of sediments encountered in the boreholes. Selected split-spoon samples of sediments from the borings (one to three samples per boring) were submitted to Terracon for determination of particle size distribution and plasticity indices.

3.4 Infiltration Testing

The purpose of the infiltration testing program was to measure large-scale operational infiltration rates in selected TID basins to determine/document the current infiltration capacity within the District. This formal testing process had not been done previously, and the resultant infiltration capacities are necessary for evaluating the need for, and potential benefits of, recharge enhancement options. The excess and long-lived surface water deliveries to the District provided an unprecedented opportunity to conduct the operational testing in five basins (total of seven cells). Surface water deliveries to the District commenced in mid-January, and operational infiltration testing was conducted during the period from January 31 through July 14, 2017 (after which all the deliveries were needed for irrigation). Operational infiltration testing was conducted in the following basins, some of which were investigated by the exploration trenching and/or drilling programs for the present study (as indicated in parentheses below):

- Creamline Basin Southeast Cell (trenching and drilling)
- Creamline Basin Southwest Cell (no other investigations)
- Swall Basin East Cell (no other investigations for the present study but BSK conducted a drilling program in 2008)
- Swall Basin Northwest Cell (no other investigations for the present study but BSK conducted a drilling program in 2008)
- Basin No. 3 South Cell (trenching)
- Basin No. 6 North Cell (trenching and drilling)
- Martin Basin (no other investigations for the present study but BSK conducted a drilling program in 2007)

Operational infiltration rates were measured using the “falling-head” method as part of the on-going recharge operations. The simplified version of the falling-head test method consists simply of measuring the decline in basin water levels over time after delivery of water to the basin is shut off (with no releases of water from the basin other than infiltration). Each falling-head cycle was initiated by filling the basin to a targeted height of water and terminating the water delivery. A pressure transducer was placed on the basin floor near the basin margin so that a continuous record of declining water level in the basin could be obtained during the falling-head cycle. The end of the transducer cable was secured on a pole at the top of the basin bank to allow downloading of the data at (generally) 1-week intervals. Because all the basins had already been filled with water to take the excess surface water deliveries, the transducers were placed in the basin interior either by using a small raft or, where possible, by wading into the basin (for basins that were filled to a height of 4 feet or less). Due to the availability of four transducer setups, operational testing was conducted concurrently at (generally) four basins/cells.

TID staff monitored the falling-head tests (downloaded the water level data) while managing the surface water deliveries to maximize the number and length of the falling-head cycles to the extent possible. The water level data were transmitted to M&A's office and was processed by M&A to calculate infiltration rates. Based on the on-going data evaluation, M&A coordinated with TID regarding the termination of testing at each basin and the subsequent basin to test. TID staff moved and set up the transducer at each new basin to be tested.

The intended approach for the falling-head cycles was to conduct a minimum of three cycles at each basin tested, with each cycle consisting of filling the basin to a height of approximately 6 feet of water and allowing the water level to decline to 1 or 2 feet before re-filling. However, TID's logistical requirements for taking as much water as possible into TID's entire water distribution system due to the "flood release" conditions necessitated that, for many of the operational tests, the falling-head cycles consisted of filling the basins to variable levels and typically allowing the water levels to decline approximately 1 to 2 feet before re-filling. In some cases, a relatively long period of water level decline was interrupted by brief periods of discharging water to the basin, which resulted in several "mini" falling-head cycles instead of one long and continuous cycle. In addition, selected basins were prioritized for infiltration testing and had a larger number of falling-head cycles and/or a larger water level decline during the cycles. The number of falling-head cycles conducted at each of the seven basins/cells tested ranged from 1 to 11. Overall, the number and length of falling-head cycles and the magnitude of water decline during each cycle were variable. Despite the challenges of managing the excessive surface water deliveries while integrating the operational infiltration tests, useful and relatively conclusive data for infiltration capacity of the basins was obtained from the tests.

Water level measurements were recorded by the transducers at 15-minute intervals. Infiltration rates were calculated as “incremental” rates by dividing a measured water level decline by the 15-minute interval (increment) of time during which the decline occurred and converted to feet per day (ft/day). To negate the effects of short-term or small-scale fluctuations in the measured water levels and “smooth” the plotted infiltration rates with time, 12-hour rolling averages were determined (i.e., average of the calculated incremental rates for 48 consecutive 15-minute intervals). The measurements of water level decline were not corrected for evaporation losses due to the negligible effect; the maximum error in the calculated incremental infiltration rates is less than 5%.

Hydrographs were prepared for measured water levels and calculated incremental infiltration rates with time. After analyzing for any trends in the incremental rates for each falling-head cycle, the representative infiltration rate for that cycle was determined as the most stable rate achieved during the cycle based on professional judgment. For comparison, the average infiltration rate over the entire cycle was calculated. The representative infiltration rates determined for all cycles for a given test were evaluated to determine the representative overall infiltration rate for the basin. Because infiltration rates determined in this manner are a function of the “head” (height of water in the basin), incremental rates determined for a given value of head in one cycle should ideally be compared to incremental rates determined for the same value of head in other cycles. However, due to the typically substantial variability in the starting head and relatively small magnitude of decline for many of the falling-head cycles, these comparisons of “like conditions” were not often possible.

4 RESULTS OF HYDROGEOLOGIC INVESTIGATIONS

Hydrogeologic investigations conducted at the selected TID recharge basins included lithologic characterization from the trenching and drilling programs and operational infiltration testing. The investigations provide data for characterizing the upper part of the vadose zone at the basins, which is the basis for evaluating current recharge capacity and the feasibility of increasing basin recharge capacity, chiefly in regard to deepening the basins. Results of the investigations are summarized for each basin in the following sections; the lithologic characterization from the trenching and drilling programs is addressed first for all basins investigated, followed by results of the operational infiltration testing.

4.1 Lithologic Characterization

Lithologic characterization was based on exploration trenching at four basins (total of five cells) and exploration drilling at two basins. A total of 42 trenches were excavated, and eight borings were drilled for the present study. Trench and boring locations are shown on **Figures 2, 4, 5, and 6**. More than 350 soil samples were collected for detailed lithologic description. The samples were wet-sieved by M&A to better determine the content of sand versus fines (silt and clay). In addition, a total of 45 samples were submitted to Terracon for laboratory analysis of particle size distribution and plasticity indices to provide more accurate measurements of these parameters for supporting and/or adjusting manual descriptions. Results of laboratory analyses are summarized in **Table 1**.

Lithologic descriptions and graphic logs for the exploration trenches are provided in **Appendix A**. Lithologic descriptions and graphic logs for the exploration borings are provided in **Appendix B**. Laboratory reports for samples submitted for laboratory analyses are provided in **Appendix C**.

In the following summary of lithologic conditions encountered in the exploration trenches and borings, the terms “fine-grained,” “medium-grained,” and “coarse-grained” are used as general descriptors of the sediment types. The fine-grained sediments encountered consist chiefly of sandy silt, sandy silt and clay, and clayey silt. The medium-grained sediments consist chiefly of sandy silt/silty sand with nearly equal amounts of sand and silt. The coarse-grained sediments consist chiefly of sand, gravelly sand, and silty sand with very small silt content. **Section 3.1** describes the five lithologic/permeability categories used to prepare the graphic logs, and the Explanations on all the graphic log compilations **(Figures 8 through 14)** provide the specific sediment types and particle size ranges that pertain to each lithologic/permeability category.

It is important to note that the field evaluation/estimate of silt and clay content versus sand content in (especially) the medium-grained sediments was difficult because the sand size was predominantly fine to very fine **(Table 1)**. Wet sieving of the trench and boring samples in M&A's office following the field investigations was required to delineate better the sand content and silt and clay content, which was important for estimating the relative permeability and assigning the appropriate lithologic/permeability categories to the sediment layers encountered. The laboratory results for particle size distribution and Atterberg Limits (plasticity indices) for the selected samples submitted **(Table 1)** provide accurate measurements of these parameters and were used to evaluate and adjust results of the manual estimates.

Four sediment samples were submitted to Technicon for laboratory analysis of K_{sat} (together with particle size distribution and Atterberg Limits). Results of these analyses, together with descriptions of the samples submitted, are summarized below. The sample obtained from the Creamline Basin Southeast Cell (trench #6) targeted a medium-grained sediment type that was very prevalent in many of the basins/cells investigated. The remaining three samples targeted fine-grained sediment intervals that likely control infiltration rates in the basins.

- Creamline Basin Southeast Cell trench #6 @ 2.5-foot depth: fine sandy silt (ML) with 56% fines, non-plastic: K_{sat} **= 7.2 x 10^{-6} centimeters per second (cm/sec)**
- Basin No. 3 South Cell trench #3 @ 1.5-foot depth: sandy clayey silt (ML/CL) with 86% fines, plasticity index = 9.6: K_{sat} **= 7.6 x 10^{-7} cm/sec**
- Basin No. 6 South Cell trench #1 @ 4.5-foot depth: sandy clayey silt (CL) with 80% fines, plasticity index = 11.8: K_{sat} **= 1.7 x 10^{-6} cm/sec**
- Basin No. 6 North Cell trench #5 @ 2.0-foot depth: sandy clayey silt (CL) with 86% fines, plasticity index = 10.1: K_{sat} **= 3.4 x 10^{-6} cm/sec**

Although there was a limited number of K_{sat} analyses, these results are generally consistent with K_{sat} values expected for the sediment types tested (the K_{sat} value of 7.2 x 10^{-6} cm/sec for the sandy silt sample may be somewhat lower than expected) and demonstrate the impeding effect of these types of sediment layers. It is important to note that the laboratory results generally indicate much smaller K_{sat} values than the estimated permeability ranges (where “permeability” is synonymous with “infiltration capacity”) given in the Explanations on **Figures 8 through 14**. This difference is due to the fact that the permeability ranges assume that several feet of “head” is being applied, such as occurs in a recharge basin filled with water, whereas the laboratory K_{sat} values are based on a unit gradient. In addition, the large-scale infiltration capacity of a given sediment type is expected to be larger than a small-scale measurement of sampled sediments due to the multi-scale heterogeneities inherent in an actual recharge basin. Therefore, the K_{sat} values should be regarded as being proportional to the infiltration capacity as opposed to being equal to it.

4.1.1 Creamline Basin Southeast Cell

A total of eight trenches and three borings were installed in the Creamline Basin Southeast Cell **(Figure 2)**. The graphic logs for the eight trenches are shown together on **Figure 8**. The graphic logs for the trenches are arranged from left to right representing an overall orientation from west to east across the cell. Within this orientation, there are three groups of trenches arranged from north to south based on their locations, as shown on **Figure 2**. This arrangement of graphic logs provides a basis for comparing lithologic conditions encountered at a given trench to the nearest trenches while also evaluating possible stratigraphic relationships across the site.

The graphic logs for the three borings are shown on **Figure 9**; this figure also includes graphic logs for the trenches to provide a complete compilation of lithologic data for the cell. The arrangement of graphic logs on **Figure 9** provides the same orientation as described for **Figure 8**.

Inspection of the lithologic logs and graphic logs for the Creamline Basin Southeast Cell trenches indicates the following:

- Overall, lithologic and stratigraphic conditions encountered in the trenches indicate relatively heterogeneous conditions; the trench profiles generally include layers of most or all lithologic/permeability categories (fine, medium, and coarse-grained sediments of very small to very large estimated permeability).

- At most trenches, fine-grained sediments of small estimated permeability (sandy silt and clayey silt) were encountered in the upper 4 to 5 feet of the basin, although medium-grained sediments of moderate estimated permeability (silty sand/sandy silt) were also prevalent in this near-surface zone. At trench #8, located in the south part of the cell **(Figure 2)**, the fine-grained layer occurs just below the basin floor and is only 0.5-foot thick. The consistent occurrence of fine-grained layers within this near-surface zone suggests that these low-permeability sediments are likely continuous in this zone across most or all of the cell and limit or control the achievable infiltration rates in this cell (approximately 0.5 ft/day as described in **Section 4.2.1**).

- The fine-grained intervals in the upper 4 to 5 feet of the trench profiles are underlain by a heterogeneous sequence of medium to coarse-grained sediments with moderate to high estimated permeability to total excavated depths. This lower interval includes substantial thicknesses of relatively clean sand in trenches #2, #3, and #8. At trenches #5 and #6, the lower interval was relatively homogeneous, consisting of medium-grained sediments of moderate estimated permeability. However, at trench #5, which was the only trench excavated to a depth of 12 feet, fine-grained sediments of very low permeability were encountered from 11 to 12 feet.

- Because the field characterization of the trench profiles suggested that the primary limitation for infiltration rates is fine-grained sediments in the upper 4 to 5 feet, the Creamline Basin Southeast Cell was targeted for drilling to determine the depth and thickness of potential underlying low-permeability layers. Inspection of the lithologic logs and graphic logs **(Figure 9)** for the exploration borings indicates the following:

- Overall, sediments encountered in the upper part of the three borings are reasonably similar to the nearest trenches and/or are consistent with the lithologic relationships described above for the trenches. However, the lithologic and stratigraphic profiles for the three borings differ from each other substantially.

- In the western-most boring CL-B2, sediments encountered in the depth interval from approximately 5 to 23 feet below the basin floor are chiefly medium-grained with moderate estimated permeability. However, this interval is underlain by a relatively thick layer (10 feet) of (sandy) silt. A large interval of coarse-grained sediments of very high estimated permeability was encountered below the silt from about 35 feet to total boring depth of 53 feet.

- In the central boring CL-B-3, chiefly coarse-grained sediments with very high permeability were encountered in the depth interval from 5 to 29 feet below the basin floor. A 5-foot thick layer of fine-grained sediments of low estimated permeability was encountered from 29 to 34 feet, which was underlain by coarse and medium-grained sediments to total boring depth of 51.5 feet.

- In the eastern-most boring CL-B1, fine-grained sediments of small to very small estimated permeability were encountered in the depth interval from 12.5 to 20.5 feet below the basin floor. Alternating layers of chiefly medium and fine-grained sediments were encountered from 20.5 to total drilled depth of 51 feet.

The lithologic and stratigraphic conditions encountered in the exploration borings in the Creamline Basin Southeast Cell indicate substantial heterogeneity, both vertically and spatially. Large intervals of medium to coarse-grained sediments occur in the subsurface at borings CL-B2 and CL-B3, which would be favorable for downward movement of water. However, substantial intervals of fine-grained sediments were encountered in boring CL-B1, including a shallow interval at a depth of 12.5 feet. The thick fine-grained interval encountered in boring CL-B2 at a depth of 23 feet may be continuous with fine-grained intervals encountered at depths of 29 and 32 feet in borings CL-B3 and CL-B1, respectively, which suggests that a low-permeability layer may occur under much or most of the cell in this depth range. This layer would be expected to cause perched water mounding during recharge operations and likely also contributes to the low infiltration rates achieved in this cell; ramifications in regard to basin deepening are addressed in **Section 5.2**.

Results of the trench and boring characterization suggest that the central portion of the Creamline Basin Southeast Cell may have relatively favorable lithologic conditions for recharge. However, lithologic and stratigraphic conditions across the majority of the cell are generally similar (and less favorable) in regard to overall permeability, and therefore, infiltration capacity.

4.1.2 Basin No. 3 South Cell

A total of 11 trenches were installed in Basin No. 3 South Cell **(Figure 4)**. Graphic logs for the 11 trenches are shown on **Figure 10**, arranged from left to right, representing an overall north-south orientation across the cell. Within this orientation, the groups of trenches are arranged from west to east based on their locations.

Inspection of the lithologic logs and graphic logs for the Basin No. 3 South Cell trenches indicates the following:

- Overall, lithologic and stratigraphic conditions encountered in the trenches indicate very heterogeneous conditions, both vertically and aerially; the trench profiles generally include layers of most or all lithologic/permeability categories (fine, medium, and coarse-grained sediments of very small to very large estimated permeability).

- The common lithologic condition for most of the trenches is that fine-grained sediments of small to very small estimated permeability (sandy silt and clayey silt) are prevalent in most of the trenches and occur at variable depths throughout the trench profiles. These fine-grained intervals occur at overlapping depths at most of the trenches, suggesting that they collectively comprise a generally continuous low-permeability interval across most or all of this cell.

- Medium-grained sediments of moderate estimated permeability (sandy silt/silty sand) were also encountered at variable depths, and coarse-grained sediments of very large permeability (sand) were encountered in several trenches. Whereas these sediments provide preferential pathways for infiltrating water on a local scale, they would not be expected to substantially alleviate the large-scale impeding effect of the predominant and extensive fine-grained intervals in the upper 10 to 11 feet of the basin floor.

- The few intervals of coarse-grained sediments were encountered in several trenches/locations scattered across the cell (trenches #2, #4, #7, #9, and #10), and chiefly in the lower part of the trenches. Exploration drilling was not conducted in the Basin No. 3 South Cell, so it is not known how deep these coarse-grained intervals extend below 10 feet.

- The occurrence of coarse-grained sediments right at the floor surface to a depth of 5 feet at trench #10 is clearly a localized condition in the northeast portion of the cell. Loose sand caused the trench to continually collapse, preventing deeper excavation.

Due to the predominance of fine-grained sediments of small to very small estimated permeability encountered at many depths in most of the trenches, the Basin No. 3 South Cell would require excessive deepening to remove the sediment intervals that limit or control the infiltration rate (approximately 0.45 ft/day as described in **Section 4.2.5**). Therefore, exploration drilling was not conducted in this cell to evaluate the underlying lithologic conditions.

4.1.3 Basin No. 6 North Cell

A total of eight trenches and four borings were installed in Basin No. 6 North Cell **(Figure 5)**. Graphic logs for the eight trenches are shown on **Figure 11,** arranged from left to right, representing an overall north-south orientation across the cell. Within this orientation, there are three groups of trenches arranged from west to east based on their locations. The graphic logs for the four borings are shown on **Figure 12**, together with graphic logs for the trenches.

Inspection of the lithologic logs and graphic logs for the Basin No. 6 North Cell trenches indicates the following:

- Overall, lithologic and stratigraphic conditions encountered in the trenches indicate generally less heterogeneity than encountered in the Creamline Basin Southeast Cell and Basin No. 3 South Cell trenches, described previously. For the Basin No. 6 North Cell trench profiles, the vertical heterogeneity appears more significant than aerial heterogeneity.

- It is important to note that trenches #7, #8, and #9 were located on top of a relatively wide bench within the cell that occurs along the west and south perimeters of the basin. The bench is approximately 4 feet higher than the majority of the basin floor, which is accounted for in the vertical placement of the graphic logs shown on **Figure 11**. Therefore, for comparing lithologic conditions below the primary basin floor elevation, the upper 4 feet of the graphic logs for trenches #7, #8, and #9 should be disregarded.

- The most apparent and favorable lithologic/stratigraphic relationship is that substantial intervals of coarse-grained sediments of large to very large permeability (silty sand and sand) occur in approximately the lower half of most trenches profiles. With the exception of trench #3, the top of this coarse-grained interval was encountered below depths ranging from approximately 3 to 5 feet below the primary basin floor (also applies to trenches #7, #8, and #9 after adjusting for the bench height), although the trench #6 profile consists almost entirely of coarse-grained sediments.

- Heterogeneous sequences of fine, medium, and coarse-grained sediments were encountered in the upper 3 to 5 feet of most trenches.

- The trench #3 profile indicates a heterogeneous sequence of sediments over the entire excavated depth of 10 feet, including a fine-grained interval of small estimated permeability from 5.5 to 7.5 feet, underlain by medium-grained sediments; the fine-grained interval appears to be discontinuous (was not encountered in other trenches).

- With the exception of trenches #8 and #9, low permeability sediments were encountered in generally small intervals at varying depths and are likely discontinuous.
- The profiles for trenches #7 and #8 indicate medium-grained intervals of moderate estimated permeability in the upper 3.5 to 7.5 feet, and the trench #9 profile indicates a fine-grained interval of small estimated permeability in the upper 5 feet. However, lithologic conditions at depths below 4 feet in these trench profiles (equivalent to the primary basin floor) are similar to the profiles for the other trenches (excavated in the primary basin floor area).

Because the field characterization of the trench profiles suggested that lithologic conditions at depths below the upper 3 to 5 feet of the Basin No. 6 North Cell are chiefly coarse-grained and likely very favorable for infiltration, the cell was targeted for exploration drilling to determine if underlying conditions would generally support or potentially negate the favorable near-surface conditions and associated benefit of basin deepening. Inspection of the lithologic logs and graphic logs for the borings indicates the following:

- With the exception of boring No.6-B1, sediments encountered in the upper part of the four borings are reasonably similar to the nearest trenches, and the coarse-grained sediments encountered in the lower half of the trench profiles appear to extend to depths ranging from approximately 15 to 20 feet.
- At boring No.6-B1, located in the northwest corner of the cell, coarse-grained sediments of very large permeability (chiefly sand) were encountered over the entire depth interval from the basin floor to 20 feet below the floor.
- The lithologic and stratigraphic profiles below the coarse-grained “zone” for the four borings are similar in that they all consist of a heterogeneous sequence of sediments fitting within all five lithologic/permeability categories, but the depths and thicknesses of the variable sediment types differ between the borings.
- Notable layers of fine-grained sediments with small to very small estimated permeability were encountered in the intervals from 25.5 to 33 feet at boring No.6-B1, 35 to 45 feet at boring No.6-B2, and 15 to 24.5 feet at boring No.6-B3. Other thin layers of low-permeability sediments were also encountered in all four borings. Based on the depths and thickness of the

various fine-grained layers, it appears that most of the layers are generally discontinuous between borings. However, the aerial extent of any given layer encountered in the borings could be sufficient to cause significant perched water mounding in localized parts of the cell. This may be particularly true for the thick (9.5 feet) fine-grained interval encountered at a depth of 15 feet in boring No.6-B3.

- It should be noted that boring No.6-B4 was drilled on top of the 4-foot high bench within the North Cell (same bench described above for trenches #7, #8, and #9) in the southeast part of the cell. Due to the relatively large vertical scale used on **Figure 12**, the graphic log for this boring was not raised 4 feet relative to the other graphic logs, which does not alter the evaluation of lithologic and stratigraphic relationships between the borings.
- For purposes of evaluating overall vertical permeability of the vadose zone (below the depths of the trenches), the lithologic profile for boring No.6-B3 appears to be the most limiting to downward movement of water due to the 9.5-foot thick fine-grained interval encountered at a depth of 15 feet and to the occurrence of other deeper (but thin) fine-grained intervals. The lithologic profiles at the other three borings include substantial thicknesses of medium to coarse-grained sediments over the entire drilled depth intervals; the lithologic profile at boring No.6-B4 appears very conducive to downward movement of water (only two thin intervals of low-permeability sediments). The thick (10 feet) fine-grained interval encountered at a depth of 35 feet at boring No.6-B2 may be sufficiently deep to not limit infiltration rates, but it likely results in significant localized perched water mounding.

Overall, lithologic and stratigraphic characterization of the exploration trenches and borings in Basin No. 6 North Cell indicate that there are no relatively large and contiguous portions of the cell where lithologic conditions are notably better in regard to overall permeability, and therefore, infiltration capacity. Localized areas have larger thicknesses of coarse-grained sediments and/or fewer or thinner fine-grained intervals (e.g., northwest and southeast corners of the cell), but these more favorable conditions are not laterally extensive (i.e., differ at the nearest trenches and borings). Sediments encountered below depths of generally 3 to 5 feet are predominantly coarse-grained to depths of 15 to 20 feet and are underlain by a heterogeneous sequence of fine, medium, and coarse-grained layers to total drilled depths of 41 to 52 feet. Although substantial fine-grained intervals were encountered in the borings, they do not appear to be continuous over large areas. The fine-grained layers would likely result in perched water mounding that is locally significant, but there are sufficient thicknesses of medium to coarse-grained sediments below the near-surface zone across the cell that would be expected to provide a higher infiltration capacity than is currently being achieved (approximately 0.25 ft/day based on only two falling-head cycles, as described in **Section 4.2.6**). Therefore, removal of the generally fine-grained sediments in the upper 3 to 5 feet below the basin floor would alleviate the existing primary limitation to infiltration rates and would increase overall infiltration capacity to the extent dictated by the underlying heterogeneous sediments and localized fine-grained layers. Considerations for basin deepening are further addressed in **Section 5.2**.

4.1.4 Basin No. 6 South Cell

A total of seven trenches were installed in Basin No. 6 South Cell **(Figure 5)**. One boring was drilled near the center of the cell. Graphic logs for the seven trenches are shown on **Figure 13,** arranged from left to right, representing an overall north-south orientation across the cell. Within this orientation, there are three groups of trenches arranged from west to east based on their locations. Only one boring was drilled in the South Cell (No.6-B5), and it was relatively shallow (31 feet). Therefore, the graphic log for this boring is included with the trench graphic logs on **Figure 13**, but only the upper 15 feet of the boring graphic log is shown (the entire graphic log is given in **Appendix B**).

It is important to note that basin floor for Basin No. 6 South Cell does not have a flat topography but rather includes large soil mounds and depressed areas. The trench and boring locations avoided the mounds but the basin floor elevations at the trenches and boring varied somewhat (but are reasonably consistent). The graphic logs were positioned on **Figure 13** without attempting to account for possible differences in the elevations.

Inspection of the lithologic logs and graphic logs for the Basin No. 6 South Cell trenches and single boring indicates the following:

- Overall, the lithologic profiles for the South Cell trenches are notably different than the North Cell trenches (despite being adjacent to the North Cell), and especially exhibit more aerial heterogeneity. The primary difference is that the South Cell trench profiles contain more and/or thicker intervals of fine to medium-grained sediments of small to moderate estimated permeability and fewer intervals of coarse-grained sediments.

- At most South Cell trenches, fine-grained layers of small to very small estimated permeability were encountered at variable depths and extended to depths ranging from 4.3 feet below the basin floor to 11 feet (total excavated depth of trench #7). Sediments encountered in the upper 12 feet of boring No.6-B5 were essentially all fine-grained. Sediments of moderate to large estimated permeability underlay the fine-grained intervals to total excavated depths of 10 to 11 feet (except for trench #7 as noted).

- Exceptions to the general prevalence of fine-grained conditions include trenches #4 and #6, where no fine-grained sediments were encountered below a depth of 0.5 foot. These trenches are both located in the central “band” of the cell, but are separated by trench #5 and boring No.6-B5, where very thick sequences of fine-grained sediments were encountered. The trench #4 and #6 profiles include substantial intervals of coarse-grained sediments (trench #4 also has layers of moderate permeability sediments), but these more favorable conditions appear to be localized.

- Similar to the North Cell, characterization of the South Cell trenches (and boring) indicates that there are no relatively large and contiguous portions of the cell where lithologic conditions are notably better in regard to overall permeability, and therefore, infiltration capacity. Localized areas of more favorable near-surface sediments clearly occur such as described above for trenches #4 and #6, but these conditions are not extensive (i.e. conditions differ at the nearest trenches and borings).

Based on the field characterization of the Basin No. 6 South Cell trenches, which indicated generally large and/or deep intervals of fine-grained, low-permeability sediments in the near-surface zone, the South Cell was not targeted for exploration drilling. However, the one boring drilled in this cell (No.6-B5), was added to the investigation (and only completed to 32 feet) to provide some indication of deeper lithologic conditions in the center of the cell. As described above, the upper 12 feet of the boring profile comprised fine-grained sediments of very small estimated permeability. This thick fine-grained zone was underlain by coarse-grained highly permeable sediments to a depth of 26 feet, where a 3-foot thick fine-grained layer was encountered (with coarse-grained sediments at the bottom of the boring). Although this single boring does not provide sufficient characterization of the deeper sediments in the South Cell to evaluate recharge feasibility, the generally large depths and thicknesses of fine-grained sediments in the near-surface zone would require excessive excavation to remove the sediments that likely limit or control infiltration rates. Therefore, additional characterization of deeper sediments in this cell was not warranted.

4.1.5 Basin No. 8

A total of eight trenches were installed in Basin No. 8 **(Figure 6)**. Graphic logs for the eight trenches are shown on **Figure 14**, arranged from left to right, representing an overall north-south orientation across the cell. Within this orientation, there are three groups of trenches arranged from west to east based on their locations.

It is important to note that basin floor for Basin No. 8 has a substantially variable topography with mounded and depressed areas, including a relatively deep channel that divides the northwest and southeast portions of the basin. The trench locations avoided the highest and lowest areas so that the basin floor elevations at the trenches were reasonably similar. Therefore, the graphic logs were positioned on **Figure 14** without attempting to account for possible differences in the elevations.

Inspection of the lithologic logs and graphic logs for the Basin No. 8 trenches indicates the following:

- Overall, lithologic and stratigraphic conditions encountered in the trenches indicate substantial heterogeneity across the basin, both spatially and vertically (to total excavated depths). The sediments encountered in all the trenches are represented by four of the five lithologic/permeability categories (all five categories for two of the trenches).

- The most apparent and also most critical lithologic/stratigraphic relationship is that substantial intervals of fine-grained sediments of small to very small estimated permeability (sandy silt and clayey silt) were encountered at variable depths and thicknesses and extended to depths ranging from 5.5 to 11 feet below the basin floor. Relatively thick sequences of fine-grained sediments were encountered in trenches #1, #3, #4, and #8 (thickness ranged from 3.5 to 6 feet), while relatively thin fine-grained layers were encountered at the remaining trenches (#2, #5, #6, and #7).

- Comparison of the graphic logs on **Figure 14** indicates that fine-grained intervals were encountered within the general depth range from about 3 or 4 feet to 7 feet (or more) below the basin floor in all the trenches. Although the fine-grained intervals in several of the trenches within this depth range were very thin, their presence in all the trenches suggests that a relatively continuous layer or zone of fine-grained sediments (of variable thickness) may be continuous across most or all of the basin within this depth range.

- Operational infiltration testing was not conducted in Basin No. 8; therefore, the infiltration capacity of the basin has not been measured. However, TID staff has observed that infiltration rates in this basin are very low. This anecdotal information supports the occurrence of a relatively continuous zone of fine-grained sediments in the shallow subsurface that is limiting infiltration rates to very low levels.

- Three of the four trenches at which the shallow fine-grained zone described above is thin (trenches #2, #5, and #7) are located in the central part of the basin, and the fourth (trench #6) in located in the northwest part of the basin **(Figure 6)**. If the shallow fine-grained zone in the vicinity of these trenches is, in fact, discontinuous, it is possible that these general areas may have relatively favorable near-surface conditions for infiltration assuming that the upper 2 feet of fine-grained sediments would be removed (trenches #5 and #6 have fine-grained sediments in the upper 2 feet). Medium to coarse-grained sediments of moderate to very large estimated permeability underlay the thin fine-grained intervals to total excavated depth of 11 feet in these four trenches.

- Due in part to the prevalence and large depth of fine-grained sediments encountered in about half of the trenches, exploration drilling was not conducted in Basin No. 8. Therefore it is not known if lithologic conditions below the trenched depths are conducive or limiting to infiltration, which would be particularly useful in further evaluating the basin areas where lithologic conditions in the upper 11 feet appear relatively favorable for infiltration (i.e., trenches #2, #5, #6, and #7 at which the shallow fine-grained zone is very thin). In any event, deepening Basin No. 8 to significantly increase infiltration capacity would require excessive excavation of a large part of the basin and would not be cost-effective.

4.1.6 Swall Basin

Exploration trenching and drilling were not conducted in the Swall and Martin Basins as part of the study. However, drilling investigations for subsurface lithologic characterization were previously conducted for the Swall Basin site (BSK, 2008) and Martin Basin site (BSK, 2007). These investigations were conducted to support the acquisition of land for recharge basins and for the recharge basin design. BSK’s reports for these investigations provide useful information for subsurface lithologic conditions and were used in the present study, together with results of operational infiltration testing, to evaluate the feasibility of recharge enhancements at these basins. Because the District already possesses these reports, they are not provided in this report but are referenced in **Section 7**.

In 2008, BSK drilled a total of eight borings at the Swall Basin site at locations that would become the Northwest, Southwest, and East Cells; boring locations are shown on **Figure 3**. The lithologic and stratigraphic characterization provided in the BSK report is based on specified depths below the original land surface. Based on results of BSK's characterization, the Swall Basin East Cell and Northwest Cell were excavated to depths of approximately 8 feet and 10 feet, respectively (estimated from M&A's field observations and input from the District). The Southwest Cell floor is assumed to also be 10 feet below the original land surface. Therefore, the present summary of subsurface conditions is based on specified depths below the basin floor (disregards the interval of sediments that were excavated). The borings were drilled to depths ranging from 25 to 51 feet below the original land surface, which corresponds to depths of approximately 15 to 41 feet below the basin floors. The BSK report includes detailed lithologic descriptions of the borings and a lithologic cross-section, which are the basis of the following summary of subsurface conditions, adjusted to account for the depths of the basin floors:

- The Swall Basin cells were excavated to their existing depths of approximately 8 to 10 feet to remove a relatively thick surface interval of silty sand and intersect an underlying zone of relatively clean sand in areas that correspond to approximately the north half of the Northwest Cell and most or all of the East Cell). The sand layer presumably occurs at or near the basin floor of these areas and extends to depths of approximately 10 below the basin floors. Large "streaks" of surface sand are visible in portions of the East Cell. In the area of the Southwest Cell and approximate south half of the Northwest Cell, the silty sand sediments extend several feet below the existing basin floors and are underlain by layers of sand, silty sand, and sandy/silty clay of varying thickness (up to 4 or 5 feet thick).

- Sediments in the interval underlying the upper 10 feet of the basin floors (described above) appear to consist of generally fine-grained sediments. This fine-grained interval is approximately 3 to 5 feet thick in the area of the Southwest Cell and south half of the Northwest Cell and comprises chiefly sandy or clayey silt. The corresponding fine-grained interval in the north half of the Northwest Cell and all of the East Cell ranges in thickness from approximately 4 to 10 feet and comprises chiefly sandy or silty clay with some sandy or clayey silt lenses.

- The fine-grained interval is underlain by a layer of silty sand across all cells of the Swall Basin; this layer is 10 to 12 feet thick in the area of the Southwest Cell and south half of the Northwest Cell but thins to approximately 4 to 7 feet thick in the north half of the Northwest Cell and the East Cell. Where the silty sand layer thins, a lens of sandy or silty clay occurs below the silty sand, ranging in thickness from approximately 2 to 7 feet.

- Underlying the chiefly sandy silt layer described above at a depth of approximately 25 feet below the basin floors (and extending to total drilled depths) is a thick interval of variable sediment types and thicknesses, including lenses of fine-grained sediments, silty sand, and sand. This lower zone is approximately 11 to 13 feet thick.

- Overall, sediments underlying the basin floor in all three Swall Basin cells to a depth of approximately 10 feet are either coarse-grained sand with large to very large estimated permeability (Northwest Cell and all of the East Cell) or medium-grained silty sand with moderate estimated permeability, and would be expected to support substantial infiltration capacity in the cells. However, the underlying fine-grained interval encountered in all the borings has small estimated permeability, is relatively thick, and may be continuous across the entire Swall Basin area (as implied by BSK's lithologic cross-section). Because this fine-grained interval is only 10 feet below the basin floors, it is likely that it limits or controls the sustainable infiltration rates in these cells (approximately 0.45 to 0.5 ft/day based on the operational infiltration tests, as described in **Sections 4.2.3 and 4.2.4**), which are much lower than would be expected for the overlying sand and/or silty sand.

4.1.7 Martin Basin

In 2007, BSK drilled a total of five borings at the Martin Basin site at locations that would become the recharge cell and the regulation cell; boring locations are shown on **Figure 7**. The lithologic and stratigraphic characterization provide in the BSK report is based on specified depths below the original land surface. Based on results of BSK's characterization, the Martin Basin recharge cell was excavated to a depth of approximately 8 or 9 feet. Therefore, as for the Swall Basin lithologic evaluation, the present summary of subsurface conditions is based on specified depths below the basin floor. The borings were drilled to depths ranging from 20 to 25.5 feet below the original land surface, which corresponds to depths of approximately 11 to 16.5 feet below the basin floor. The BSK report includes detailed lithologic descriptions of the borings and a lithologic cross-section. Due to the relative consistency of subsurface conditions encountered in the borings, the narrative provided in BSK's report is simple, and the following description includes (slightly revised) excerpts from the report, with specified depths adjusted as warranted to account for the depths of the basin floor:

- Subsurface soils encountered beneath the site were relatively consistent between the borings.

- Silty sand, with varying silt content, was encountered in all borings (with the exception of boring B-4, located in the northwest corner of the basin) in the interval from the original land surface to depths ranging from 8 to 11 feet. The content of fines within this surface interval was measured to vary from approximately 20% fines up to 50% fines. Boring B-4 encountered silty sand/sandy silt in the upper 9 feet. Note that this upper silty sand zone was largely removed by excavating the basin.

- A layer of sandy silt was encountered below the surface silty sand interval in all borings (although the silt content appeared to be just a little higher than 50%). The thickness of the sandy silt interval was 3 to 4 feet. This sandy silt layer presumably comprises the sediments on and directly below the existing basin floor.

- Sediments encountered in the borings below the sandy silt layer in the approximate depth range of 4 to 10 feet below the basin floor were somewhat variable but included chiefly silty sand and sand, which would be expected to comprise good infiltration media. However, sandy silt was encountered in the bottom of some of the borings and may represent another sandy silt interval, but the thickness and continuity of this layer cannot be determined from these borings. The top of this sandy silt layer occurs at a depth of approximately 9 to 10 feet below the basin floor.

- Overall, sediments underlying the basin floor in the Martin Basin to a depth of approximately 3 to 4 feet appear to comprise fine-grained sandy silt with small estimated permeability, which were underlain by an approximately 6-foot thick interval of medium and coarse-grained sediments of moderate to large estimated permeability, and possibly another fine-grained interval of unknown thickness (at bottom depths of the borings). The fine-grained near-surface sediments in the basin would likely be the most limiting or controlling factor for sustainable infiltration rates (approximately 0.6 ft/day based on the operational infiltration tests, as described in **Section 4.2.7**). Due to the shallow depths of the borings and the large depth of the Martin Basin, this drilling program only characterized subsurface conditions to depths of 11 to 16 feet below the existing basin floor, and it is possible that additional impeding layers occur below this depth interval (as suggested by the sandy silt encountered in the bottom of several borings) that might also limit infiltration capacity. Drilling and trenching were not conducted in the Martin Basin because the planned Parjana study would have provided additional funding and opportunities for lithologic characterization.

4.1.8 Lithology of Deeper Zones

Data for hydrogeologic characterization of the deeper vadose zone and aquifer sediments in the northcentral part of the District was available from drilling and installation of four dual-completion monitor wells in this region (BSK, 2016). BSK's report included drillers' logs and geophysical logs (E-logs), which provide a reasonable overall characterization of lithologic conditions to relatively large depths, but none of these wells are sufficiently close to the TID basins investigated for the present study to reliably apply the deeper characterization to the basin sites. In addition, the drillers' logs consist of brief and very general sediment types with many intervals of "lumped" sediment types and are therefore difficult to use in evaluating the recharge characteristics. The one possible exception in regard to proximity of these wells to a TID basin is Well #1, which is located approximately 1.25 miles south of the Martin Basin. The driller's log for this well indicates "brown clay" in the top 40 feet, underlain by "medium sand" to a depth of 60 feet, with sand and clay to 80 feet and clay to 120 feet. The driller's log also indicates a predominance of clay in the interval from 260 to 360 feet, which likely corresponds to the Corcoran Clay. E-logs for this well indicate a general alternating sequence of low-resistivity (fine-grained) and high-resistivity (coarse-grained) sediments. The depth intervals from approximately 150 to 350 feet and 510 to 660 feet bls chiefly comprise low-resistivity sediments; the shallower of these two intervals could correspond to the Corcoran Clay.

4.2 Operational Infiltration Testing

Operational infiltration rates were measured using the falling-head method as part of the on-going recharge operations. As described in **Section 3.4**, the number and length of falling-head cycles and the magnitude of water decline during each cycle were variable. Despite the challenges of conducting the operational tests while managing the excessive surface water deliveries to the District, useful and relatively conclusive data for infiltration capacity of the basins were obtained from the tests. The following considerations are important for evaluating the test results and their applicability to the overall recharge feasibility assessment:

- Results of operational infiltration testing provide direct measurements of the actual infiltration capacity of the basin tested under the actual conditions of basin use and the surface water discharged to the basin. The measured infiltration capacity is a function of the combined or cumulative effects of the surface and subsurface sediment stratigraphy, inclusive of all large-scale and small-scale heterogeneities. Whereas these results are ideal for evaluating the existing infiltration capacity of the TID basins, the operational tests do not provide data for evaluating the infiltration capacity of specific sediment intervals.

- Because the incremental infiltration rates determined through the falling-head method for these operational tests are a function of the “head” (height of water in the basin), incremental rates determined for a given value of head in one cycle should ideally be compared to incremental rates determined for the same value of head in other cycles. However, due to the typical variability in the starting head and relatively small magnitude of decline for many of the falling-head cycles, these comparisons of “like conditions” were not often possible, especially when comparing results for different basins.

- Conducting multiple falling-head cycles for each test was intended to provide sufficient data to determine if a relatively steady infiltration rate was established, which would be considered the representative infiltration rate. Because the basins had been filled and were recharging water for a substantial period before the operational testing, relatively steady infiltration rates might have been expected shortly into the test. However, as described above, the variability in the starting heads and ending heads of the falling-head cycles for a given test contributed to the differences in the representative infiltration rates determined for the falling-head cycles for some basins/tests.

- Infiltration rates measured over the test duration might have been affected by basin “clogging” due to the deposition of suspended sediments (silt and clay) in the surface water delivered; at times, the water deliveries were observed to be substantially silt-laden. Due to the large rates and long duration of the surface water deliveries in 2017, it is possible that basin clogging had a larger effect on the infiltration rates than would occur with smaller winter deliveries. If true, the measured operational infiltration rates might represent conservatively small estimates of achievable infiltration capacity, but this condition could also be considered a more appropriate measure of sustainable infiltration capacity in evaluating the overall recharge capacity of the District.

- A potentially critical "unknown" factor in evaluating the infiltration test results is the effect that shallow perched water mounding might have had on limiting or controlling infiltration rates. If a perched water mound developed above a relatively continuous low-permeability layer in the subsurface and rose to the basin floor during recharge operations, the measured infiltration rates might be chiefly controlled by the low-permeability layer rather than the near-surface sediments. This is an important factor in evaluating recharge basin enhancements. Additional monitoring of subsurface conditions using shallow piezometers installed above sediment intervals of concern would be required to evaluate the effect of perched water conditions.

Operational infiltration testing was conducted at five basins (total of seven cells). Results of the operational infiltration tests are summarized in **Table 2**, which provides the starting water level height (head), total water level decline, and two separate estimates of the associated infiltration rate determined for each falling-head cycle. The first estimate is labeled "Calculated Cycle Infiltration Rate" and is the average infiltration rate over the entire cycle, which is used chiefly for comparison purposes. As described in **Section 3.4**, after analyzing for any trends in the incremental rates for each falling-head cycle, the "Representative Cycle Infiltration Rate" was determined as the most stable rate achieved during a substantial portion of the cycle based on professional judgment. The representative infiltration rates determined for all cycles for a given test were evaluated to determine the "Representative Overall Infiltration Rate" for the test.

It is important to note that the water level declines for each falling-head cycle for a given basin were evaluated for consistency and continuity, both within each cycle and in relation to other cycles conducted at the given basin. For most basins, one or more falling-head cycles exhibited inconsistent or aberrant water level responses/trends and associated incremental infiltration rates calculated based on these questionable responses. Based on M&A's professional judgment, selected falling-head cycles with inconsistent or aberrant behavior were determined to be unrepresentative and/or unusable and were excluded from further analysis. In many cases, the inconsistent behavior was likely due to relatively small, periodic (or continuous) inflows of water into the recharge cell being tested from the associated regulation cell during the falling-head cycle in question. This condition was likely unavoidable due to the very large and continuous surface water deliveries (flood release conditions in TID's water distribution system). The result of adding water to a basin/cell during a falling-head cycle would be smaller water level declines with time and associated underestimation of infiltration rates. For some of the excluded falling-head cycles, the reason for the inconsistent rates of water level decline is not clear.

Relevant aspects of the operational tests conducted in each basin/cell are described in the following sections.

4.2.1 Creamline Basin Southeast Cell

Operational infiltration testing was conducted at the Creamline Basin Southeast Cell from January 30 through March 16 (45 days). During this period, a total of five “usable” falling-head cycles were observed. Duration of the falling-head cycles ranged from 48 to 180 hours.

A hydrograph of basin water levels recorded during testing at the Creamline Basin Southeast Cell is shown on **Figure 15**. Incremental infiltration rates computed from the continuous water level data for this cell is shown on **Figure 16**, which allows evaluation of trends in infiltration rate with time during each falling-head cycle. As described in **Section 3.4**, the graphed values are 12-hour rolling averages of the calculated incremental infiltration rates. Test results indicate the following:

- The highest infiltration rates for the entire test were observed during the first and longest falling-head cycle (FH-1). During this cycle, average infiltration rates ranged from 0.37 to 0.88 ft/day. The rates were highest near the beginning of the cycle and generally declined as the cycle progressed due to decreasing head.

- Infiltration rates observed during the remaining falling-head cycles (FH-2 through FH-5) were generally similar (including similar variation), ranging overall from 0.40 to 0.62 ft/day.

- For all falling-head cycles, the incremental infiltration rates appear to indicate a series of consecutive increasing and decreasing trends. Although the cause of this behavior is not certain, the District has indicated it was likely due to small periodic releases of water into the basin during the cycles to accommodate fluctuations in the District distribution system. During the first cycle, M&A’s field geologist observed water occasionally overtopping the inflow gate.

- Representative infiltration rates for each falling-head cycle were estimated based on all calculated incremental infiltration rates during the cycle **(Table 2)**. Representative cycle infiltration rates were typically 0.5 ft/day but ranged as high as 0.6 ft/day. Based on comparison of the results for the five falling-head cycles, the overall representative rate for the Creamline Basin

Southeast Cell was determined to be 0.5 ft/day for an average head of 4 to 5 feet.

4.2.2 Creamline Basin Southwest Cell

Infiltration testing was conducted at the Creamline Basin Southwest Cell from February 7 through March 16 (37 days). During this period, a total of five usable falling-head cycles were observed. Duration of the falling-head cycles ranged from 25 to 80 hours. A hydrograph of basin water levels recorded during the test period is shown on **Figure 17**. Computed average (incremental) infiltration rates are shown on **Figure 18**. Test results indicate the following:

- Infiltration rates observed during all the falling-head cycles (FH-1 through FH-5) follow a similar trend: rates increase sharply at the beginning of the cycle, become relatively stable, and then decrease sharply at the end of the cycle. The cause of this unusual pattern, repeated for all cycles, is uncertain. It may be related to water eventually overtopping the inflow gate (as described above for the Southeast Cell) after the basin has been filled and the gate closed. It is also possible (but speculative) that it is related to shallow perched water mounding that rises and eventually reduces the infiltration rates at the surface. Note that this sharp reduction in infiltration rates is not believed to be due solely to decreasing head, although it likely contributes to the trend. Infiltration rates at the beginning and end of the cycles are not considered representative.

- Infiltration rates observed during the stable portions of the falling-head cycles were relatively similar, ranging from 0.42 to 0.58 ft/day. The lowest infiltration rates were observed for cycle FH-4, for which the smallest head occurred.

- Representative cycle infiltration rates estimated for the five cycles range from 0.44 to 0.53 ft/day (**Table 2**). Based on comparison of the results for the five falling-head cycles, the overall representative rate for the Creamline Basin Southwest Cell was determined to be 0.5 ft/day for an average head of 3 to 4 feet.

4.2.3 Swall Basin East Cell

Infiltration testing was conducted at the Swall Basin East Cell from February 7 through June 9 (122 days). During this period, four usable falling-head cycles were observed. Duration of the falling-head cycles ranged from 55 to 186 hours. A hydrograph of basin water levels recorded during the test period is shown on **Figure 19**. Computed average (incremental) infiltration rates are shown on **Figure 20**. Test results indicate the following:

- The highest infiltration rates were observed during the first and longest falling-head cycle (FH-1). During this cycle, infiltration rates ranged from 0.48 to 0.69 ft/day. The rates were highest near the beginning of the cycle and generally declined along a relatively consistent trend as the cycle progressed, which is due to decreasing head (declined from 7.5 to 3.1 feet). However, based on the notably smaller infiltration rates observed for the remaining cycles, it is possible that deposition of suspended fine-grained sediments in the water resulted in clogging of the basin floor. This interpretation is not certain because the average heads for the remaining cycles were also smaller than for the first cycle.

- Infiltration rates observed during falling-head cycles FH-2, FH-3, and FH-4 were very similar (within each cycle and between cycles), ranging overall from 0.39 to 0.48 ft/day. The observed rates indicate a slightly decreasing trend, which is due to decreasing head.

- Representative cycle infiltration rates estimated for the four cycles range from 0.42 ft/day to 0.55 ft/day **(Table 2)**. Based on comparison of the results for the four falling-head cycles, the overall representative rate for the Swall Basin East Cell was determined to be 0.45 ft/day for an average head of 5 to 6 feet.

4.2.4 Swall Basin Northwest Cell

Infiltration testing was conducted at the Swall Basin Northwest Cell from March 10 through April 20 (41 days) but only one falling-head cycle could be conducted (at the beginning of the test period) due to the on-going filling of the cell and simultaneous pumping of water out of the cell and into the East Cell. The duration of the falling-head cycle was 164 hours. A hydrograph of basin water levels recorded during the test period is shown on **Figure 21**. Computed average (incremental) infiltration rates are shown on **Figure 22**. Test results indicate the following:

Infiltration rates observed during the single falling-head cycle (FH-1) ranged from 0.40 to 0.72 ft/day. Rates fluctuated within this range and appear to indicate a series of consecutive increasing and decreasing trends. Although the cause of this behavior is not certain, it was likely due to small periodic releases of water into the basin during the cycle or perhaps pumping of water out of the basin and into the East Cell (described above). The overall representative rate for the Swall Basin Northwest Cell (based on only one cycle) was determined to be 0.53 ft/day for an average head of 6.5 feet.

4.2.5 Basin No. 3 South Cell

Infiltration testing was conducted at the Basin No. 3 South Cell from March 16 to June 9 (85 days). During this period, five usable falling-head cycles were observed. Duration of the falling-head cycles ranged from 33 to 102 hours. A hydrograph of basin water levels recorded during the test period is shown on **Figure 23**. Computed average (incremental) infiltration rates are shown on **Figure 24**. Test results indicate the following:

- Inspection of water level data indicate that at least nine falling-head cycles occurred during the test period. However, water level data indicate that relatively continuous inflow likely occurred during four of the cycles. During these cycles, computed infiltration rates were generally less than 0.18 ft/day and were considerably less than rates observed during the other five cycles. Infiltration rates measured during these periods are considered unrepresentative of the basin sediments and were excluded from further analysis.

- Infiltration rates measured during the selected five cycles (FH-1, FH-2, FH-3, FH-4, and FH-5) are more comparable than for the excluded cycles and are believed to be more representative of the basin sediments.

- During falling-head cycles FH-1 through FH-5, infiltration rates indicated a large overall range from 0.20 to 0.74 ft/day. The highest rates were observed during cycles FH-1 and FH-3 (ranging from 0.4 to 0.72 ft/day), while rates observed for cycles FH-2, FH-4, and FH-5 were comparable and ranged from 0.2 to 0.51 ft/day. The reason for this discrepancy is not certain, especially because the average heads were similar for all five cycles. It is possible that the cycles with the smaller observed infiltration rates were also affected to some degree by on-going inflow. The reliability of the measured infiltration rates is likely questionable, but the overall rate determined from evaluation of all cycles is likely reasonably representative of the basin sediments.

- During the FH-1, FH-2, FH-3, FH-4, and FH-5 cycles, infiltration rates declined sharply along relatively consistent trends as the cycles progressed. The decreasing trends are likely a function of decreasing head, which is more pronounced for these cycles because the average head (1 to 2 feet) was much smaller than for other basins/cells tested.

- Representative cycle infiltration rates estimated for the five cycles range from 0.35 to 0.55 ft/day **(Table 2)**. Based on comparison of the results for the five falling-head cycles, the overall representative rate for the Basin No. 3 South Cell was determined to be 0.45 ft/day for an average head of only 1 to 2 feet.

4.2.6 Basin No. 6 North Cell

Infiltration testing was conducted at the Basin No. 6 North Cell from June 15 to July 14 (29 days). During this period, two usable falling-head cycles were observed. A hydrograph of basin water levels recorded during the test period is shown on **Figure 25**. Computed average (incremental) infiltration rates are shown on **Figure 26**. It should be noted that the pressure transducer for measuring water levels (heads) was placed on top of the 4-foot high bench that occurs along the south and west periphery of the cell **(Figure 5)**. Therefore, the actual heads were 4 feet larger across the majority of the cell than was measured. The head values given in **Table 2** for this infiltration test were adjusted by adding 4 feet. Test results indicate the following:

- Duration of the first falling-head cycle (FH-1) was 68 hours. During the FH-1 cycle, infiltration rates ranged from 0.20 to 0.30 ft/day. Infiltration rates generally increased along a relatively consistent trend as the cycle progressed and peaked at 0.30 ft/day before declining to 0.27 ft/day at the end of the cycle.

- Duration of the second falling-head cycle (FH-2) was 240 hours, nearly 4 times longer than FH-1. The observed infiltration rates indicated similar magnitudes and trends as for FH-1 except that the initial rising trend was interrupted by a period of relatively steady rates.

- In general, the initial increasing trend in observed infiltration rates during both cycles is unusual (especially considering that the head is decreasing) and suggests that there might be a loss of water from the cell other than through infiltration. However, if this was the case, the measured infiltration rates would be expected to be substantially larger than 0.2 to 0.3 ft/day. (Note that evaporation loss is less than 0.5 inch per day, which is much less than the measured infiltration rates.) Assuming that there is no means of outflow from the North Cell, it can only be concluded that the infiltration rates increased for an extended period during the cycles.

- Despite the questionable trends described above, infiltration rates observed during the two falling-head cycles vary over a relatively small range and are believed to be relatively reliable. Representative cycle infiltration rate estimated for both cycles was 0.25 ft/day **(Table 2)**. Therefore, the overall representative infiltration rate for the Basin No. 6 North Cell was determined to be 0.25 ft/day for an average head of 5 feet. This is the smallest infiltration rate measured for all the basins/cells tested.

4.2.7 Martin Basin

Infiltration testing was conducted at the Martin Basin from March 16 through August 4 (141 days). During this period, 10 usable falling-head cycles were observed. Duration of the falling-head cycles ranged from 35 to 115 hours. A hydrograph of basin water levels recorded during the test period is shown on **Figure 27**. Computed average (incremental) infiltration rates are shown on **Figure 28**. Test results indicate the following:

- Inspection of the water level data indicate that at least 13 falling-head cycles occurred during the testing period. However, water level data indicate that inflow occurred during several cycles. A total of 10 falling-head cycles were considered for analysis.

- The first falling-head cycle conducted from April 1 through April 19 appears to have been interrupted by small amounts of inflow throughout the cycle and a notable amount of inflow about midway through the cycle. Therefore, only the first part of the cycle (FH-1) was used for infiltration rate analysis.

- Another notable falling-head cycle not used for infiltration rate analysis started on June 23; water levels declined sharply, resulting in uncharacteristically high infiltration rates (more than 2 ft/day). The sharp decline in water level suggests that there might be a loss of water from the basin other than through infiltration, but there is no apparent means for such a loss. This cycle was disregarded based on the assumption that there must be a plausible explanation for the anomalous results.

- During the FH-1 cycle, infiltration rates increased from 0.53 ft/day to rates as high as 0.86 ft/day. Infiltration rates declined at the end of the cycle, just before the inflow interruption occurred. Although the second portion of the cycle was excluded from analysis due to the inflows, the rates continued decreasing during this period as the head declined substantially.

- Infiltration rates observed during falling-head cycles FH-2 through FH-8 follow a similar trend. Infiltration rates as high as 1.48 ft/day were observed at the beginning of the cycles, followed by an immediate sharp decline as head decreased. These results demonstrate that relatively high infiltration rates

(1 ft/day or more) might be sustainable in this basin if large heads are maintained.

- For all falling-head cycles except for FH-1, as head dropped below approximately 6 feet, infiltration rates generally stabilized at values within the range of 0.3 to 0.5 ft/day. For cycles FH-9 and FH-10, the beginning heads were 6.3 feet, and the associated infiltration rates started at 0.5 ft/day and declined to 0.3 ft/day. It is important to note that the heads used throughout the test at the Martin Basin were relatively large, ranging from 8 feet to 4.5 feet (end of cycle FH-10). The substantially lower infiltration rates at heads smaller than 6 feet (which is still a relatively large head) again demonstrates the particularly high dependence of infiltration rates on the head at this basin.

- Representative cycle infiltration rates estimated for the 10 cycles ranged from 0.4 to 0.8 ft/day **(Table 2)**. Based on comparison of the results for the 10 falling-head cycles, the overall representative rate for the Martin Basin was determined to be 0.6 ft/day for an average head of 4 to 6 feet. However, as described above, at heads greater than about 6 or 7 feet, sustainable infiltration rates are significantly higher, perhaps more than 1 ft/day.

5 EVALUATION OF RECHARGE FEASIBILITY

Analysis and comparison of lithologic information derived from the exploration trenches and borings provides a basis for evaluating occurrence, thickness, and distribution of near-surface sediment strata that likely control the current infiltration capacity of the recharge basins investigated and for identifying subsurface sediment strata that may potentially impede infiltration. Results of the operational infiltration tests allow quantification of the existing infiltration capacity of these basins, which is critical for evaluating the District's overall recharge capacity. In addition, this hydrogeologic characterization provides a baseline for evaluating the extent of infiltration rate improvement that might be achieved through basin deepening, and therefore, the feasibility and cost-effectiveness of basin deepening. It is important to note that budget constraints limited the number of basins that could be investigated for the present study, as well as the type or extent of investigations at selected basins. Therefore, the present evaluation of recharge feasibility does not address all District recharge facilities. Despite this partial assessment, the hydrogeologic characterization conducted in the recharge basins/cells prioritized for this study provides valuable information for evaluating the feasibility of recharge enhancements at many of the basins in the north half of the District, which may be more operationally important.

The feasibility of enhancing recharge capacity within the District depends on several important considerations that have been addressed to varying degrees in this study, including:

- Estimates of infiltration capacity for the basins in their current state and estimated capacity if the basins would be deepened to reach more favorable infiltration media. The potential enhancement of infiltration capacity in selected basins is evaluated based on: (1) results of the lithologic and stratigraphic characterization from the trenching and drilling programs and the estimated infiltration rates inferred from this characterization; and (2) comparison and correlation of lithologic conditions encountered in the TID basins to similar sediment lithologies and associated infiltration test results (including operational infiltration rates) for other recharge feasibility assessments that M&A has conducted.

- Evaluation of feasible overall recharge rates, potential constraints and opportunities, conceptual modifications to recharge basin design (i.e., depth), and other factors for achieving recharge capacity goals.

- Analysis of the feasibility and cost-effectiveness of possible strategies for improving overall infiltration capacity in the District.

5.1 Existing Recharge Capacity within the District

There are two primary sources of recharge capacity within the District related to the District’s water distribution system: (1) constructed recharge basins (and regulation basins, although not maintained to maximize recharge); and (2) the extensive system of water delivery canals to the recharge basins and associated irrigation ditches that deliver water to farms. Additional sources of recharge capacity, implemented for the first time in 2017, include flooding of farm fields if and when appropriate based on crop type (nut trees versus annual vegetable and cotton crops) and planting schedules, and use of existing borrow pits (depressions created by excavating material that was used for fill material in farming operations).

It is important to note that another source of recharge that occurs continuously and diffusely throughout the District is the deep percolation of applied irrigation water that is not used consumptively by the crops or evaporated. Although the “recharge rate” for deep percolation is very small and difficult to estimate, it is occurring over the very large area of farm fields within the District. HydroMetrics WRI (2015) reported that the average annual volume of deep percolation (or “irrigation return flows”) in the District from 1999 through 2012 was estimated to be approximately 65,100 AF. For the present study, this very large volume of recharge is not considered a component of the District’s “recharge capacity” in regard to evaluating recharge enhancement opportunities, but clearly is an important component of the District’s water balance. Similarly, the contribution of precipitation to total recharge volume is not a component of recharge capacity. HydroMetrics WRI (2015) reported that the average annual volume of percolation of precipitation (minus evaporation) in the District from 1999 through 2012 was estimated to be approximately 11,400 AF.

5.1.1 Existing Recharge Capacity of TID Basins

Results of operational infiltration testing provide the most accurate estimates of the infiltration capacity of the basins/cells investigated to date. The tests were conducted at seven recharge cells (five basins), all located in approximately the north half of the District. Although the tests targeted the basins/cells of most interest or importance, there are 17 “recharge” cells (includes Basin No. 3 North Cell) in the District totaling 923 acres; the cells tested represent a total of 263 acres, which is only 29% of the total recharge cell area. Therefore, the infiltration capacity of the majority of recharge cells and all of the regulation cells has not been determined through testing, which means that estimates of recharge capacity of the District's basins requires assumptions regarding infiltration rates for most basins/cells.

A listing of all basins/cells in the District (recharge and regulation) and associated floor areas is given in **Table 3**. These acreages were determined by M&A based on digital analysis of the investigated basins/cells using Geographic Information Systems (GIS) and BING^{TM} imagery and on acreages listed in Table 3 of HydroMetrics WRI's 2015 report for the remaining basins (these acreages were also determined by digital analysis). The floor areas of the District's basins are delineated as follows:

- Total area of recharge basins/cells: 923 acres
- Total area of regulation basins/cells: 196 acres
- Total area of all basins/cells: 1,119 acres

It should be noted that the acreages determined in this manner are still approximate but are believed to be accurate within a few percent. The total area of all recharge and regulation cells has been estimated by TID to be between 1,300 and 1,400 acres, although this larger total area is likely due to using the areas of the parcels in which the basins were constructed and not the basin footprint. The acreages listed above are more conservative and are used for the following recharge capacity analysis.

To estimate the recharge capacity of the District's basins, the following approach was used; the representative infiltration rates used in this approach for each basin/cell are given in **Table 3**:

- For the recharge basins/cells at which operational infiltration testing was conducted, the representative infiltration rate was multiplied by the floor area for each basin/cell to compute the daily infiltration capacity (volume) in AF.
- For the two recharge basins/cells in which exploration trenching was conducted but not infiltration testing (Basin No. 6 South Cell and Basin No. 8), the infiltration rate assigned to each of these basins was the rate measured for a basin/cell that has similar lithologic conditions in the near-surface zone. Inspection of the graphic logs for the basins/cells in which trenching was conducted **(Figures 8 through 14)** indicates that the near-surface zone at the Basin No. 3 South Cell generally has similar lithologic conditions (overall) as encountered in both the Basin No. 6 South Cell and Basin No. 8.

The representative infiltration rate for the Basin No. 3 South Cell was determined to be 0.45 ft/day (for a head of only 1 to 2 feet; **Table 3**); therefore this same rate was assigned to both the Basin No. 6 South Cell and Basin No. 8. This infiltration rate was multiplied by the floor area for the two basins/cells to compute the daily infiltration capacity (volume) in AF.

- For all remaining recharge basins/cells in the District, the sustainable infiltration capacity was assumed to be equal to the average of all the "Representative Overall Infiltration Rates" for the seven basins/cells tested, which is 0.46 ft/day. This infiltration rate is nearly the same as the rate of 0.5 ft/day assumed by HydroMetrics WRI (2015) for their water balance analysis for the District. The infiltration rate of 0.46 ft/day was multiplied by the floor area for all the relevant basins/cells to compute the daily infiltration capacity (volume) in AF.
- The 11 regulation cells within the District are assumed to have a very small sustainable infiltration capacity due to long-term deposition of fines from the surface water deliveries, which first pass through the regulation cells before entering the associated recharge cells. The regulation cells are generally not rehabilitated by removal of surface fines (scraping) or surface scarification (disking or plowing) to restore the achievable infiltration capacity. The infiltration rate for all the regulation cells was assumed by HydroMetrics WRI to be 0.25 ft/day, and this value was adopted for the present study. However, it is important to note that this value is subjective and is not based on measurements of infiltration rate in any regulation cell. In any event, the infiltration rate of 0.25 ft/day was multiplied by the floor area for all the regulation cells to compute the daily infiltration capacity (volume) in acre-feet.

An example calculation of estimated recharge capacity for the Creamline Basin Southeast Cell is provided below, assuming a 90 day period of surface water delivery to the cell:

- basin/cell area = approximately 27.6 acres
- representative/sustainable infiltration rate = 0.5 ft/day
- daily recharge volume = 13.8 AF
- recharge volume for a 90-day water delivery period = 1,240 AF

This same calculation was conducted for all of the District's recharge and regulation basins based on the measured and assumed values for representative infiltration capacity (described above). Results of the calculations are given in **Table 3**, which include estimated recharge volumes for several water delivery periods (90, 120, and 180 days), similar to the approach used and presented in Table 8 of HydroMetrics WRI's 2015 report.

The total existing recharge capacity of the District's recharge and regulation basins is calculated to be 467 acre-feet per day (AF/day), which corresponds to recharge volumes of approximately:

- 42,000 AF for 90 days of continuous surface water delivery
- 56,000 AF for 120 days of continuous surface water delivery
- 84,000 AF for 180 days of continuous surface water delivery

5.1.2 Existing Recharge Capacity of TID's Water Distribution System

The second primary source of recharge capacity within the District is the extensive system of water delivery canals to the recharge basins and associated irrigation ditches that deliver water to the farms. Compared to large basins, infiltration rates in the thin and lengthy canals/ditches are augmented by the subsurface lateral flow of infiltrating water, which can increase the infiltration capacity substantially relative to the infiltration area within the canal/ditch. In addition, because the canals/ditches spread the infiltration out over long distances (the infiltration area is much less confined than for large basins), the occurrence of an impeding layer several feet below the canal/ditch would have little effect on the infiltration capacity compared to large basins. For basins, lateral flow around the boundaries only adds a small additional capacity relative to the large basin size, and a subsurface impeding layer may ultimately be controlling/limiting the capacity.

Relevant information provided by the District regarding the District's canals and ditches and overall water distribution system, together with estimated recharge rates/volumes, is summarized as follows:

- The total length of the surface water conveyance/distribution system is more than 300 miles, consisting of both the large capacity canals that deliver water to the recharge and regulation cells (for further distribution to all parts of the District) and the smaller capacity ditches that deliver water to the farms.

- All the large capacity canals and smaller capacity ditches are “earthen” (unlined with concrete or other “impervious” coating) and therefore have substantial infiltration “losses,” which translates to recharge capacity.

- The canals and ditches are maintained annually, including weed control and re-grading of the banks, with sediment removal/excavation as warranted. Due to the high volume and sediment load of the surface water deliveries this past year, the ditches and canals are currently being re-graded and sediment removed. These activities may be chiefly for the purpose of maintaining the flow capacity of the canals and ditches, but they also likely maintain higher infiltration rates, which increases the recharge capacity.

- Based on the District’s analysis of their surface water distribution “losses” (canals and irrigation ditches) for the period 1981 to 2012, the average <u>annual</u> loss (i.e. recharge volume) was approximately 40,000 AF.

- In past years, when there was limited surface water for recharge, the District typically distributed water to the recharge basin system during January and February and would only utilize canals that delivered water to the basins (did not use irrigation ditches). The estimated flows during this 2-month period were estimated to be approximately 250 to 300 cubic feet per second (cfs), which corresponds to recharge volumes of approximately 30,000 to 36,000 AF (includes both the basins and canals). Based on the recharge analysis described in **Section 5.1.1**, the estimated recharge volume of the District’s recharge and regulation basins (combined) would be approximately 28,000 AF for 60 days of continuous surface water delivery. Based on these separate sources of recharge estimates, the recharge capacity of (only) the primary canals that deliver water to the recharge basins would be on the order of 2,000 to 8,000 AF for a 2-month period. However, this estimate is believed to be substantially lower than actually occurred because the District did/does not likely use all the recharge basins during the typical 2-month recharge period (the estimate of 28,000 AF for a 2-month period for the entire recharge system is likely too high).

- The District’s Main Intake Canal extends from outside the north District boundary into the District; this canal is earthen, but the banks are armored with rip-rap. Water loss through this canal has been estimated at approximately 15,000 AF/yr. This large loss translates to recharge immediately “upstream” from the District but has not been included in the District’s estimates of recharge capacity for its water distribution system.

- **2017 RECHARGE DISTRIBUTION**: The long duration of excess surface water deliveries in 2017 due to flood release conditions prompted the District to implement an aggressive approach for maximizing recharge and receiving/storing as much water as possible. This approach also provided the opportunity to evaluate flow capacity and recharge capacity of the entire water distribution system (this period was from January through July, at which time irrigation demand took most of the water deliveries, although pre-irrigation demand started in March or April). This aggressive approach and resulting estimates of canal capacities and “losses” (recharge) versus recharge volumes in the basins are summarized as follows:

  Overall Recharge Utilization

  - All recharge and regulation basins were used.
  - Most of the canals and irrigation ditches were filled with water.
  - The District’s summary of the 2017 flood release water use indicates that flows for the recharge system were 320 cfs and that losses (flows) in the canals and ditches beyond the recharge system were 100 cfs.
  - The District incentivized water rates to promote earlier and higher pre-irrigation, resulting in recharge of an additional 135 cfs in January and February, equal to a total applied volume of approximately 16,070 AF (but this is considered to be consumptively used by crops and is not included as a component of the District’s recharge capacity).
  - 600 acres of farm land were flooded for recharge purposes, and accessible borrow pits at six farms were filled with water; the pits ranged from approximately 0.5 to 2 acres in size; water deliveries for the on-farm recharge and “special projects” was approximately 25 cfs for 2 months and 20 cfs for 6 months, respectively, resulting in a total recharge volume of approximately 10,120 AF.
  - Use of all these means of recharge allowed the District to recharge approximately 465 cfs during January and February with flows of 420 cfs or more dedicated to recharge through July.
  - ***Assuming that flows of 420 cfs in the recharge system and irrigation ditches (combined) continued through July, the total volume recharged in the District in 2017 was approximately 185,000 AF (includes on-farm and borrow pit recharge of approximately 10,000 AF).***

Recharge System

- Assuming that inflows to the recharge system (includes recharge and regulation basins and recharge system canals) of 320 cfs continued for 7 months, the resulting total recharge volume in the recharge system is calculated to be approximately 133,000 AF. For comparison, HydroMetrics WRI (2015) estimated that the average annual recharge volume in the District's recharge system from 1999 through 2012 was approximately 56,300 AF.
- Based on the infiltration capacities measured for selected recharge basins and assumed for other recharge and regulation basins, and on the resulting overall estimate of existing recharge capacity of 467 AF/day **(Section 5.1.1; Table 3)**, the estimated recharge volume for all the District's recharge and regulation basins (combined) for the 7-month period from January through July is calculated to be approximately 98,000 AF (does not include the canals in the recharge system).

Canals and Ditches

- As indicated previously, flows (losses) in the canals and ditches beyond the recharge system were indicated to be 100 cfs; assuming this flow rate continued for 7 months (both prior to irrigation and as part of full-scale irrigation), the resulting total "loss" (i.e., recharge volume) is calculated to be approximately 41,700 AF.
- The estimated recharge volume for only the recharge system canals within the recharge system is calculated to be 35,000 AF for the 7-month period (133,000 – 98,000 AF). The total estimated recharge volume for all the canals and irrigation ditches in the District is then calculated to be 76,700 AF for the 7-month period (41,700 + 35,000 AF).
- The analysis above indicates that the recharge system (basins and canals) accounted for 72% of the total recharged volume, and the recharge and regulation basins (excluding recharge system canals) accounted for 53% of the total recharged volume. In addition, all the canals and ditches (combined) accounted for 41% of the total recharged volume, of which 22% is from the irrigation ditches and 19% is from the recharge system canals.

The key findings from all the information described above regarding intake flows and estimated recharge capacity of the District's water distribution system are related to better quantifying the sources of recharge capacity and identifying the opportunities for maximizing recharge capacity when excess surface water is available. The recharge capacity within the District was essentially maximized in 2017 and indicated that the recharge system (recharge and regulation cells and associated canals) can sustain approximately 320 cfs, and that the irrigation canals and ditches add another 100 cfs of recharge capacity. Use of on-farm flooding added another 25 cfs for 2 months and borrow pit recharge added another 20 cfs for 6 months. Therefore, the maximum recharge capacity is on the order of 465 cfs (disregarding pre-irrigation flows), although it may be feasible to increase on-farm recharge in the future. It is important to note that the intake capacity from the Main Intake Canal is approximately 900 cfs, which can be augmented through other canals if needed to increase the intake capacity to approximately 1,200 cfs. This total intake capacity is nearly sufficient to fill all available basins, canals, and irrigation ditches within the District and still meet irrigation demand.

Perhaps the most relevant aspect of this analysis is that the irrigation ditch losses of 100 cfs represent a source of recharge capacity that has typically not been used by the District prior to the start of irrigation, but is available if and when needed during periods when there is excess surface water, such as this past year. If the irrigation ditches are filled with water for recharge purposes during the typical 2-month period preceding pre-irrigation, flows of 100 cfs would result in recharge of an additional 11,900 AF.

5.2 Basin Deepening

As described previously, the primary focus of the hydrogeologic investigations conducted for this recharge feasibility study was to evaluate the existing recharge capacity of TID’s basins and to assess the opportunities and feasibility of enhancing recharge capacity, chiefly through basin modifications by basin deepening. The underlying premise is that if removal of near-surface low-permeability sediments from selected basins would expose favorable infiltration media to sufficient depths, basin deepening could be the most cost-effective means for enhancing recharge capacity and for maintaining the increased infiltration rates relative to other methods (addressed in **Section 5.3**).

Evaluation of the lithologic and stratigraphic characterization of the upper part of the vadose zone from the exploration trenching and drilling programs **(Section 4.1)**, combined with results of the operational infiltration testing **(Section 4.2)**, provides a basis for selecting existing basins/cells that would be amenable to deepening as a means of improving the infiltration capacity and for determining the associated excavation depths. This determination assumes that removal of as much as 5 feet of sediments from the basin floor would be considered, although feasible excavation depths would ultimately be constrained by cost considerations and availability of adequate spoil storage areas at or near the basin locations. Opportunities for selling or otherwise removing the excavated material to potential takers may arise in the future, but the present analysis does not account for these possibilities. If and when the District identifies such opportunities, the cost-effectiveness of basin deepening might be improved such that larger depths of excavation could be considered and/or additional (lower priority) basins could be considered for deepening.

Based on the rationale described above and results of the lithologic and stratigraphic characterization, Basin No. 6 North Cell and the Martin Basin would likely have significantly improved infiltration capacity through basin deepening (or would be candidates pending further investigation). Potential improvement of infiltration capacity for the Creamline Basin Southeast Cell is less conclusive, but this cell is also considered a candidate for basin deepening. For each of these identified basins/cells, the overall lithologic and stratigraphic conditions are summarized below (taken from **Section 4.1**), including the recommended depth of sediment removal for each basin/cell. This assessment includes an estimate of the potential increase in infiltration capacity, which is based entirely on inference to the subsurface lithologic conditions encountered at each basin/cell and professional judgment (refer to descriptions of the five lithologic-permeability categories defined for the trench and boring graphic logs). It is important to reiterate that the estimated increase in infiltration capacity is critical to the assessment and cannot be accurately or reliably determined without infiltration testing in the near-surface sediments following removal of the targeted depth of sediments. Therefore, this analysis is necessarily approximate but is intended to provide a means for evaluating the general feasibility and cost-effectiveness of basin deepening for the selected basins/cells.

5.2.1 Creamline Basin Southeast Cell

Fine-grained sediments of small estimated permeability (sandy silt and clayey silt) were encountered in the upper 4 to 5 feet of most trenches excavated in this cell **(Figure 9)**. The consistent occurrence of fine-grained layers within this near-surface zone suggests that these low-permeability sediments are likely continuous in this zone across most or all of the cell and limit or control the achievable infiltration rates (approximately 0.5 ft/day as described in **Section 4.2.1**). The fine-grained near-surface zone is underlain by a heterogeneous sequence of medium to coarse-grained sediments with moderate to high estimated permeability to depths of 10 feet or more. Therefore, removal of the upper 5 feet of sediments from the basin floor would be expected to increase infiltration capacity significantly.

Sediment intervals encountered in the three borings indicated substantial heterogeneity, both vertically and aerially. Large intervals of medium to coarse-grained sediments occur in the subsurface at borings CL-B2 and CL-B3, which would be favorable for downward movement of water, but substantial intervals of fine-grained sediments were encountered in boring CL-B1, including a shallow interval at a depth of 12.5 feet **(Figure 9)**. The thick fine-grained interval encountered in boring CL-B2 at a depth of 23 feet may be continuous with fine-grained intervals encountered at depths of 29 and 32 feet in borings CL-B3 and CL-B1, respectively, which suggests that a low-permeability layer may occur under much or most of the cell in this depth range. This layer would be expected to cause perched water mounding during recharge operations and could potentially limit infiltration rates to levels similar to existing rates. Therefore, the benefit of deepening the Creamline Basin Southeast Cell is not clear, and additional exploration borings would be required to better evaluate the thickness and continuity of the subsurface fine-grained layers.

Despite the uncertain limitation to sustainable infiltration rates represented by the subsurface fine-grained layers, the following analysis demonstrates the potential improvement of infiltration capacity based on removing the upper 5 feet of generally fine-grained sediments across the basin.

- basin area = approximately 27.6 acres
- existing representative infiltration rate = 0.5 ft/day
- sustainable infiltration rate is estimated to increase to approximately **1.0 ft/day**
- additional recharge volume = 1,240 AF for a 90-day period of surface water delivery

5.2.2 Basin No. 6 North Cell

Infiltration capacity at Basin No. 6 North Cell is expected to improve substantially by basin deepening, and likely more than the other basins/cells investigated. Sediments encountered below depths of generally 3 to 5 feet are predominantly coarse-grained to depths of 15 to 20 feet and are underlain by a heterogeneous sequence of fine, medium, and coarse-grained layers to total drilled depths of 41 to 52 feet **(Figure 12)**. Although substantial fine-grained intervals were encountered in the borings, they do not appear to be continuous over large areas. The fine-grained layers would likely result in perched water mounding that is locally significant, but there are sufficient thicknesses of medium to coarse-grained sediments below the near-surface zone across the cell that would be expected to provide a higher infiltration capacity than is currently being achieved (approximately 0.25 ft/day based on only two falling-head cycles, as described in **Section 4.2.6**). Therefore, removal of the generally fine-grained sediments in the upper 3 to 5 feet below the basin floor would alleviate the existing primary limitation to infiltration rates and would increase overall infiltration capacity to the extent dictated by the underlying heterogeneous sediments and localized fine-grained layers.

The following analysis demonstrates the potential improvement of infiltration capacity based on removing the upper 5 feet of generally fine-grained sediments across the basin. It is important to note that removal of only 3 feet of sediments would also improve infiltration capacity across much of the basin, but likely to a smaller extent than removal of 5 feet of sediments because there would be more areas where fine-grained sediments occur in the upper 2 feet of the deepened basin **(Figure 11)**. The smaller cost of removing 3 feet of sediments versus 5 feet, while still realizing a significant improvement in infiltration capacity, might be an important factor.

- basin area = approximately 47.4 acres
- existing representative infiltration rate = 0.25 ft/day
- sustainable infiltration rate is estimated to increase to approximately **1.5 ft/day**
- additional recharge volume = 5,330 AF during a 90-day period of surface water delivery

The existing representative infiltration rate of 0.25 ft/day used for this analysis appears unusually low and is based on only two falling-head cycles conducted at Basin No. 6 North Cell. Therefore, the actual existing infiltration rate may be slightly higher than 0.25 ft/day with a corresponding smaller estimated increase in recharge volume for the deepened basin. If only 3 feet of sediments would be removed from the basin, the increase in infiltration capacity, and therefore recharge volume, may be on the order of 50% to 75% of the values indicated above (i.e., additional recharge volume would be 2,667 to 4,000 AF).

5.2.3 Martin Basin

Sediments underlying the basin floor in the Martin Basin to a depth of approximately 3 to 4 feet appear to comprise fine-grained sandy silt with small estimated permeability, which were underlain by an approximately 6-foot thick interval of medium and coarse-grained sediments of moderate to large estimated permeability, and possibly another fine-grained interval of unknown thickness (at bottom depths of the borings). The fine-grained near-surface sediments in the basin would likely be the most limiting or controlling factor for sustainable infiltration rates (approximately 0.6 ft/day based on the operational infiltration tests, as described in **Section 4.2.7**, although rates higher than 1 ft/day were achieved with heads of 7 to 8 feet).

Due to the shallow depths of the borings and the large depth of the Martin Basin, this drilling program only characterized subsurface conditions to depths of 11 to 16 feet below the existing basin floor, and it is possible that additional impeding layers occur below this depth interval (as suggested by the sandy silt encountered in the bottom of several borings) that might also limit infiltration capacity. If a relatively thick and continuous interval of fine-grained low-permeability sediments occurs at these relatively shallow depths, it would be expected to cause perched water mounding during recharge operations and could potentially limit infiltration rates to levels similar to existing rates. Therefore, the benefit of deepening the Martin Basin is not clear, and additional deeper exploration borings would be required to better evaluate the thickness and continuity of the subsurface fine-grained layers. The Martin Basin Demonstration Project (Parjana EGRP study) would have included installation of piezometers and provided valuable information for deeper lithologic characterization and for evaluating the extent of possible perched water mounding.

Because the currently characterized lithologic conditions at the Martin Basin suggest that removal of 3 to 4 feet of fine-grained sediments would reach medium to coarse-grained sediments of moderate to high estimated permeability across the basin, the following analysis was conducted to demonstrate the potential improvement of infiltration capacity based on removing the upper 4 feet. The estimated resulting infiltration rate is based on the assumption that a fine-grained interval of small thickness and (and relatively discontinuous) would occur at a depth of approximately 6 feet below the deepened basin floor.

- basin area = approximately 14.3 acres
- existing representative infiltration rate = 0.6 ft/day
- sustainable infiltration rate is estimated to increase to approximately **1.5 ft/day**
- additional recharge volume = 1,160 AF for a 90-day period of surface water delivery

Overall, deepening of Basin No. 6 North Cell by 5 feet is estimated to improve infiltration capacity significantly (as much as 5,330 AF during a 90-day period of surface water delivery). The potential improvement of infiltration capacity for the Creamline Basin Southeast Cell and Martin Basin is estimated to be much smaller (1,240 and 1,160 AF, respectively). However, additional lithologic characterization (exploration borings) might indicate that potential impeding layers in the subsurface would not be as limiting to achievable infiltration rates as suggested by the currently available lithologic data, which would result in higher estimated values of increased recharge volumes for these two basins/cells.

5.2.4 Cost Analysis for Deepening Selected Basins

Results of the analyses above for potential recharge capacity improvements from deepening the three basins are summarized in **Table 4** for several periods of surface water deliveries (90, 120, and 180 days). In addition, estimated excavation costs for deepening the basins, together with three measures/parameters for comparing the relative benefit and cost effectiveness, are given in **Table 4**. The excavation cost estimates are based on a unit cost of $2.5 per cubic foot of excavated material based on input from the District and the assumption that excavated material could be stockpiled at the basin sites (no off-site haulage). For this analysis, it is assumed that deepening the basins would not require any modifications to the water intake structures or other infrastructure. However, modifications will need to be taken into consideration during future design and construction activities associated with deepening operations. Because the three basins differ in size, existing infiltration capacity, and estimated increase in infiltration capacity from basin deepening, the three measures/parameters were calculated to allow a more useful comparison of the relative effectiveness of deepening the three basins. It should be noted that the "existing" infiltration rate used for each basin in this analysis is equal to the overall representative rates determined from the operational infiltration rates, described in **Section 4.2** and given in **Table 2**).

The first two measures used in this analysis address cost-effectiveness of deepening the basins. The first measure is the "normalized" cost for a unit increase in infiltration capacity, where the "unit" is 0.5 ft/day. This measure is heavily based on the basin size (lower excavation costs for smaller basins) and is intended only to frame the excavation costs in relation to the infiltration rate improvements. The second measure of cost-effectiveness is the normalized cost for a unit increase in recharge volume based on a 90-day surface water delivery period, where the unit is 1,000 AF. This measure provides the best means for comparing the cost-effectiveness of deepening the basins. The third measure is the number of days required to recharge an additional 1,000 AF of water based on the estimated increase in infiltration capacity and the basin area. This measure is not cost related, but rather addresses the impact of limited delivery periods and associated differences in the additional volumes of water that could be recharged.

The analysis indicates that deepening Basin No. 6 North Cell by 5 feet to achieve an estimated infiltration capacity of 1.5 ft/day is very costly ($1,225,000) due to the large cell size and associated excavation volume, which would include removal of the existing 4-foot high "bench" within the cell. Deepening this cell only 3 feet to achieve an estimated infiltration capacity closer to 1 ft/day would reduce excavation costs to $843,000. Estimated costs for deepening the Creamline Basin Southeast Cell by 5 feet and the Martin Basin by 4 feet are $557,000 and $231,000, respectively. However, deepening the Basin No. 6 North Cell by 5 feet is much more cost effective ($230,000 per 1,000 AF recharge increase) than deepening the Creamline Basin Southeast Cell by 5 feet ($448,000 per 1,000 AF recharge increase) due to the much larger increase in recharge volume for the Basin No. 6 North Cell (5,330 AF versus 1,240 AF for a 90-day delivery period). Deepening the Martin Basin by 4 feet is the most cost-effective option ($199,000 per 1,000 AF recharge increase). As described above, a critical aspect of this analysis is that the Basin No. 6 North Cell, if deepened to 5 feet, is estimated to recharge an additional 1,000 AF every 17 days (and every 28 days if deepened to 3 feet), whereas the Creamline Basin Southeast Cell and Martin Basin are estimated to require 72 and 78 days, respectively.

5.2.5 Other Basins/Cells Investigated

The other basins/cells investigated for the present study are evaluated to not benefit from basin deepening to feasible depths, or in some cases, lithologic data are not available (exploration trenching and/or drilling has not been conducted). These basins/cells include:

- Creamline Basin Southwest Cell: lithologic data not available
- Swall Basin East, Northwest, and Southwest Cells: available lithologic data from BSK drilling program indicates that a relatively thick and likely continuous fine-grained interval occurs at a depth of approximately 10 feet below the basin floors, which is too deep to feasibly remove.
- Basin No. 3 North Cell: lithologic data not available
- Basin No. 3 South Cell: trenching investigations indicate that fine-grained sediments of small to very small estimated permeability (sandy silt and clayey silt) are prevalent across most of the cell, generally extending to depths of 6 to 11 feet, which is too deep to feasibly remove.
- Basin No. 6 South Cell: trenching investigations indicate that fine-grained layers of small to very small estimated permeability occur at variable depths in the near-surface zone across the cell, extending to depths ranging from 4.3 feet to 11 feet below the basin floor. Although localized areas within this cell have more favorable lithologic conditions, the large excavation depths generally required to remove the fine-grained layers across most of the cell are not feasible.

- Basin No. 8: trenching investigations indicate that substantial intervals of fine-grained sediments of small to very small estimated permeability (sandy silt and clayey silt) were encountered at variable depths and thicknesses and extended to depths ranging from 5.5 to 11 feet below the basin floor. Similar to Basin No. 6 South Cell, portions of Basin No. 8 have more favorable lithologic conditions, but the large excavation depths generally required to remove the fine-grained layers across most of the basin are not feasible.

5.3 Alternative Methods for Increasing Recharge Capacity

Although the primary focus of the hydrogeologic investigations conducted for this study was to evaluate the feasibility of enhancing recharge capacity of the District's existing recharge basins, other methods for increasing recharge capacity are potentially available and are addressed below for completeness. Alternative methods include vadose zone and deep (direct) injection wells, and infiltration trenches or boreholes constructed inside the existing recharge basins. Use of settling basins for specific applications is also evaluated as a means for minimizing the amount of suspended sediments in water delivered to recharge basins and/or wells. These methods are not believed to be cost-effective and/or generally feasible relative to basin modifications. However, a final alternative recharge method, on-farm recharge, has a large potential for increasing recharge capacity during periods when farm fields are idle before the growing season.

5.3.1 Injection Wells

A primary advantage of injection wells is that they have a small footprint and therefore can be installed along easements or other available small parcels to avoid the expense of purchasing or leasing large tracts of land. In addition, if the upper part of the vadose zone contains substantial fine-grained low-permeability layers, injection wells might provide higher recharge rates than possible through surface basins. For some localities, injection wells might provide the only feasible means of recharge. However, there are critical potential disadvantages with injection wells, especially where large injection rates are needed, as described below.

DIRECT INJECTION

Conceptually, a significant advantage of direct injection is that it would provide a means to recharge the deeper part of the aquifer, beneath the Corcoran Clay, where piezometric levels and pore pressures may have declined across the District due to extensive pumping for irrigation during the years when surface water was not available or was limited. It is not known if surface recharge is resulting in replenishment of chiefly the "perched aquifer" above the Corcoran Clay or if sufficient amounts of water are moving through this aquitard to the deeper aquifer. Despite this potentially favorable application of direct injection wells, the California Regional Water Quality Control Board and/or California Department of Water Resources would require that injected water essentially meets potable water quality standards, which likely is a fatal flaw for injecting untreated surface water. In addition, there are significant technical and economic drawbacks:

- Lithologic and hydraulic data are sparse for the regional aquifer across the District. A summary of drillers' logs and geophysical logs for four monitor wells drilled to a depth of 670 feet in the northcentral part of the District (BSK, 2016) are summarized in **Section 4.1.8**. Data for lithologic conditions and hydraulic conductivity of the aquifer are critical for evaluating potential injection rates and, therefore, the number of wells and cost-effectiveness of this recharge method

- Deep injection wells and associated pipelines and infrastructure are costly. Although costs could vary substantially based on well diameter and depth, it is reasonable to assume that the cost per well and associated infrastructure could be $500,000 or more.

- Because the surface water to be injected contains suspended sediments, which could plug the borehole walls and/or gravel pack relatively quickly, the water would likely have to be filtered or carefully managed in settling basins, which adds another significant cost component. Microbiological growth can also cause significant clogging. An advantage of direct injection wells over vadose zone injection wells is that they can be rehabilitated to a large degree through periodic pumping to remove the clogging material.

- A simple analysis demonstrates the cost-effectiveness of direct injection within the District based on limited knowledge of deeper hydrogeologic conditions. Assuming a well depth on the order of 800 feet or more and a relatively heterogeneous sequence of sediments (moderately permeable aquifer), sustainable injection rates of 500 to 1,000 gallons per minute (gpm) might be achieved. For a 90-day period of injection, these injection rates would result in recharge of approximately 200 to 400 AF. Three to six wells (estimated cost of $1.5 million to $3 million) would be required to achieve the same estimated increase in recharge capacity as deepening the Martin Basin by 4 feet (at an estimated cost of $231,000, **Table 4**). In addition, the cost for sediment removal and treatment of water to a potable standard would need to be considered. The values and assumptions used in this analysis are very approximate, but clearly demonstrate the high relative cost of direct injection wells for the District's situation (i.e., large recharge basins already exist).

VADOSE ZONE INJECTION WELLS

The success of vadose zone injection wells depends on lithologic conditions (and associated permeability) in the vadose zone. Lithologic data obtained from the exploration drilling program for this study, together with results of previous drilling investigations at selected basins, provide characterization of hydrogeologic conditions in the upper 25 to 50 feet of the vadose zone. Borings at the Creamline Basin Southeast Cell and Basin No. 6 North Cell were drilled to depths as large as 51 feet and provide some basis for evaluating the feasibility of vadose zone injection. Borings at the Swall Basin (all three cells) and the Martin Basin were drilled to depths of only 20 to 25 feet and do not allow evaluation of recharge feasibility for vadose zone injection wells.

Vadose zone injection wells share the same advantages as direct injections wells in regard to small land requirement and flexibility for installation in small available areas. They are most considered for localities where land availability is limited and for vadose zone conditions where a near-surface layer of fine-grained low-permeability sediments is too deep to feasibly excavate but is underlain by predominantly high-permeability sediments. The well depth would be determined by the depth to groundwater level and the lithologic conditions of the vadose zone. Based on a generic depth to water of 180 feet within the District, vadose zone injection wells would likely be targeted for depths no greater than 100 to 120 feet if lithologic conditions are favorable to those depths, but could also be substantially shallower. Vadose zone conditions at the two recharge basins where the exploration borings were drilled to 51 feet (Creamline Basin Southeast Cell and Basin No. 6 North Cell) indicated generally heterogeneous conditions, both vertically and spatially, including areas of relatively thick coarse-grained sediments **(Section 4.1)**. If deeper conditions are similar to the upper 51 feet, significant intervals of moderately to highly permeable sediments would be expected to occur adjacent to the perforated interval of wells installed to depths of approximately 100 feet.

Vadose zone injection wells also share the same disadvantages as direct injection wells. In particular, clogging of the borehole walls could occur relatively rapidly due to suspended sediments in the water and would require filtering of the water before injection or use of settling basins. Microbiological growth can also cause significant clogging. Contrary to direct injection wells, vadose wells cannot be rehabilitated very effectively in most cases, chiefly due to lack of a sufficient saturated interval surrounding the well to allow pumping. Therefore, these wells typically have a limited effective life span and would need to be periodically replaced; a replacement schedule of 5 to 10 years is often assumed.

Costs for vadose zone injection wells vary substantially based on the depth and diameter of the well and other design/equipping considerations. The simplest wells consist of a gravel-filled borehole (3 to 4-foot diameter) with injection (educter) casing installed down the center with separate perforated piping to allow entrapped air to escape. For a typical vadose zone injection well installed to depths of 80 to 100 feet, a reasonable estimated total cost would be on the order of $100,000.

A simple analysis demonstrates the cost-effectiveness of vadose zone injection within the District based on a very limited lithologic characterization of the vadose zone. Assuming a well depth of 100 feet and moderately permeable sediments (on average), sustainable injection rates of 200 to 400 gpm might be achieved. For a 90-day period of injection, these injection rates would result in recharge of approximately 80 to 160 AF. Seven to 14 wells (estimated cost of $700,000 to $1.4 million) would be required to achieve the same estimated increase in recharge capacity as deepening the Martin Basin by 4 feet (at an estimated cost of $231,000). In addition, costs for removal of suspended sediments in the injected water and periodic replacement of the wells would need to be incorporated, which further reduces the low cost-effectiveness of vadose zone injection wells.

It is recognized that a drilling contractor proposed an installation cost for vadose zone injection wells to the District that is lower than the estimate of $100,000 used in the cost analysis above. However, even if the actual cost would be would be substantially less than $100,000, vadose zone wells would still not be cost effective if factoring in clogging and well replacement costs.

5.3.2 Injection Trenches and Boreholes

Infiltration trenches and shallow large-diameter boreholes, backfilled with sand or gravel, are occasionally installed within existing recharge basins in an attempt to enhance recharge rates. These low-cost structures would be considered for situations where a near-surface impeding layer is sufficiently shallow to penetrate with a backhoe/trackhoe but too deep to feasibly deepen the entire basin. For these trenches and boreholes to be effective, the underlying sediments would need to be of high permeability.

These structures can lose their effectiveness quickly due to clogging with fine-grained sediments washed into the trench or borehole from the basin surface and/or from the fine-grained layer penetrated by the unlined trench or borehole walls. Whereas there are ways to construct these structures that would prolong their effectiveness, this would increase the cost. Although an analysis of cost-effectiveness is not included in this evaluation, these structures are most applicable or potentially feasible for small basins or small recharge volumes. A very large trench or borehole "gallery" would be needed to significantly improve the infiltration capacity for large basins, such as the District's existing recharge basins. Based on these factors, infiltration trenches and boreholes are not considered feasible options for improving infiltration capacity of the District's recharge basins and are not recommended.

5.3.3 Settling Basins

Surface water delivered to the District contains suspended sediments (silt, clay, and fine sand) that settle out in the basins and canals/ditches and can form a low-permeability skin (clogging layer) that further impedes infiltration rates. At times the surface water inflows are notably laden with fines, especially during the flood release conditions that occurred in 2017. The water delivered to the recharge system flows within the large-capacity canals to the recharge basin sites, where it is first discharged into the regulation cells and then spills over into the recharge cells. Whereas much of the suspended sediments settles out in the canals and regulation cells, there is still a suspended sediment load in the water spilled into the recharge basins, which could become significant in years where there is a long duration of surface water delivery and/or high flow rate. Additional residence time in the regulation basins, and/or use of additional basins for settling, would provide water to the recharge basins that is relatively devoid of suspended sediments. This would be expected to minimize basin floor clogging and result in higher sustainable infiltration rates for a longer period of time and/or reduce the frequency of basin floor rehabilitation.

It is important to note that the benefit of additional settling may not be substantial at most of the District's existing recharge basins in their current form due to the prevalence of fine-grained low-permeability sediments in the near-surface zone underlying the basin floors (as addressed in **Sections 4.0 and 5.0**). The permeability of the surface skin/clogging layer may not be any lower than the permeability of the existing near-surface sediments, although the surface skin would likely be continuous over the entire basin floor. However, if selected basins would be deepened to reach higher-permeability sediments (such as the Basin No. 6 North Cell) **(Section 5.2)**, basin clogging would likely be a significant factor and would need to be more carefully managed to maximize achievable infiltration capacity.

Due to the large expense of land and lack of available land within the District, it is assumed that construction of additional basins for settling purposes is generally not feasible; the limited benefit in most years of typical surface water delivery duration and rates, and would not warrant the large expense. Despite this unfavorable evaluation, opportunities could potentially arise in the future for constructing one or more settling basins at strategic locations along the recharge system canals, which could be worthy of consideration. In addition, as described in the previous section, use of injection wells (especially vadose zone injection) to augment recharge capacity would require water that has very low suspended sediment content, which could include the use of a settling basin.

Another means of providing additional settling capacity has been suggested by the District for the specific situation posed by the Creamline and Swall Basins/Cells, located in the northeast corner of the District **(Figure 1)**, where most of the surface water enters the District. The Northeast and Northwest Cells of the Creamline Basin are regulation cells and allow settling of a substantial portion of the suspended sediments. Water from these cells spills over into the Southeast and Southwest Cells (recharge cells), where the remaining sediment load is ultimately deposited. The Swall Basin is located immediately south of the Creamline Basin Southeast and Southwest Cells (separated by Avenue 256). If a buried pipeline would be installed from each of the Southeast and Southwest Cells to the Swall Basin East and Northwest cells, respectively, water of greater clarity could flow (in a regulated manner) from the Creamline Basin cells to the Swall Basin cells, which would minimize the suspended sediment content of water delivered to the Swall Basin cells and thereby minimize the development of a clogging layer on these cells. Is this manner, the Creamline Basin Southeast and Southwest Cells would provide a second level of settling (no differently than currently occurs) and additional clarification of the water recharged in the Swall Basin cells. Because the Creamline Basin Southeast and Southwest Cells would have more water moved into and through them for this scenario, a thicker clogging layer would be expected to form in these cells, but this may not significantly affect the infiltration capacity due to the generally fine-grained sediments that already occur in the near-surface zone underlying the basin floors.

There are two key considerations for implementing this plan. First, if the Creamline Basin Southeast Cell would be targeted for deepening to reach higher-permeability sediments **(Section 5.2.1)**, it could be counterproductive to use it as a flow-through settling basin due to the likely thicker clogging layer that would form, as described above. Secondly, as described in **Section 5.2.4**, the current low infiltration capacity of the Swall Basin cells may be limited or controlled by a relatively thick and likely continuous fine-grained interval that occurs at a depth of approximately 10 feet below the basin floors. If this is true, minimizing the clogging layer may not result in significant improvement of recharge rates. Both of these conditions/considerations would need to be further evaluated through additional investigations at the Creamline and Swall Basins.

5.3.4 On-Farm Recharge

As described in **Section 5.1.2**, recharge volumes in 2017 were increased by more than 10,000 AF by flooding farm fields of willing farmers and by incentivizing additional “pre-irrigation”. On-farm recharge represents a potentially large source of recharge capacity prior to the planting season if more farmers can be encouraged to participate in these activities. In addition, this means of recharge is a very low-cost option, depending chiefly on the District’s cost incentives. This option also has the advantage of distributing recharge over the entire District and would not be not be limited by subsurface low-permeability layers due to the wide-spread application of water across the farm fields. Finally, because fields have been irrigated for many years, the underlying vadose zone sediments already have a relatively high water content; therefore, the applied water would result in eventual recharge of the aquifer as opposed to being held in the sediments.

It is understood that the District is actively pursuing this largely un-tapped opportunity, which could greatly increase recharge volumes if many farmers participate, even though limited to the time period preceding planting (with sufficient non-application time to allow for surface soil drying).

6 SUMMARY AND RECOMMENDATIONS

The primary goals of the present recharge feasibility study were to better characterize recharge capacity of the District's surface water distribution system and evaluate the feasibility of increasing the capacity, chiefly through selected hydrogeologic investigations at targeted recharge basins. This study provides a framework for developing strategies and identifying opportunities for augmenting recharge capacity and maximizing storage of surface water supplies when available. These strategies lead to greater groundwater sustainability and may provide the basis for future grant applications. This study was conducted as part of Phase III of the USBR conjunctive exchange program grant and builds on HydroMetrics WRI's 2015 study and report regarding the overall conjunctive potential of the District.

It is important to note that the relatively limited funding for this study allowed selected hydrogeologic investigations to be conducted at only nine cells (six basins) and required prioritization of the basins to be investigated based on input from the District. In addition, the most meaningful investigations were conducted at the selected basins to provide as much useful information as possible for identifying opportunities and strategies for increasing recharge capacity. Due to the limited number of basins/cells investigated, potential future investigations at other recharge basins in the District are also identified.

6.1 Summary of Recharge Feasibility Investigations

Hydrogeologic investigations conducted at the selected TID recharge basins included lithologic characterization from trenching and drilling programs and operational infiltration testing at selected basins. The investigations provide data for characterizing the upper part of the vadose zone at the basins, which is the basis for evaluating current recharge capacity and the feasibility of increasing basin recharge capacity, chiefly in regard to deepening the basins. Investigations conducted at each of the selected basins include:

- Creamline Basin Southeast Cell: trenching, drilling, and infiltration testing
- Creamline Basin Southwest Cell: only infiltration testing
- Swall Basin East Cell: only infiltration testing for the present study, but BSK conducted a drilling program in 2008 for lithologic characterization

- Swall Basin Northwest Cell: only infiltration testing for the present study, but BSK conducted a drilling program in 2008 for lithologic characterization
- Swall Basin Southwest Cell: no investigations for the present study, but BSK conducted a drilling program in 2008 for lithologic characterization
- Basin No. 3 South Cell: trenching and infiltration testing
- Basin No. 6 North Cell: trenching, drilling, and infiltration testing
- Basin No. 6 South Cell: trenching and one drilled borehole
- Basin No. 8: only trenching
- Martin Basin: only infiltration testing for the present study, but BSK conducted a drilling program in 2007 for lithologic characterization
- Enterprise/Cordinez Basins: no investigations for the present study, but BSK conducted a drilling program in 2013 for lithologic characterization

6.1.1 Lithologic Characterization

Results of the trenching and drilling investigations (including BSK's drilling programs) at the relevant basins/cells listed above indicate generally heterogeneous lithologic and stratigraphic conditions underlying the basin floors to depths ranging from 20 to 51 feet. Although a wide variety of conditions were encountered at the basins investigated **(Section 4.1)**, the most consistent and critical aspect was the occurrence of fine-grained low-permeability sediment layers in the near-surface zone underlying the basin floors. In most basins/cells investigated, these fine-grained intervals are relatively thick and appear sufficiently continuous to limit or control the infiltration capacity.

For the basins/cells in which drilling was conducted (including BSK's drilling programs), the deeper lithologic conditions typically included significant intervals of all sediment types (fine, medium, and coarse-grained sediments). However, the most critical aspect was the general occurrence of fine-grained low-permeability sediment layers at relatively shallow depths (generally within depths ranging from approximately 15 to 20 feet below the basin floors, but as shallow as 10 to 12 feet for selected basins/cells). In most basins/cells investigated, these fine-grained intervals are relatively thick and may be sufficiently continuous to impede downward movement of water and cause perched water mounding, which might be as limiting to the achievable infiltration rates as the near-surface fine-grained sediments. The exception was Basin No. 6 North Cell, where substantial fine-grained intervals were also encountered in the borings, but do not appear to be continuous over large areas. The fine-grained layers would likely result in perched water mounding that is locally significant, but there are sufficient thicknesses of medium to coarse-grained sediments below the near-surface zone across the cell that would be expected to provide a higher infiltration capacity than is currently being achieved (approximately 0.25 ft/day based on only two falling-head cycles, as described in **Section 4.2.6**).

6.1.2 Infiltration Testing

Results of the operational infiltration testing indicate that existing infiltration rates are low at the seven cells in which the testing was conducted, ranging from 0.25 ft/day for the Basin No. 6 North Cell to 0.6 ft/day for the Martin Basin **(Section 4.2)**. These low infiltration rates are chiefly due to the occurrence of fine-grained low-permeability sediment layers in the near-surface zone underlying the basin floors. In most basins/cells investigated, these fine-grained intervals are relatively thick and appear sufficiently continuous to limit or control the infiltration capacity. It is important to note that deposition of fines suspended in the surface water deliveries could have caused some reduction in the infiltration capacity determined through the operational testing, either prior to the start of the test period or during the test period. In any event, the low measured infiltration rates are generally consistent with the prevalent fine-grained sediments in the near-surface zone.

6.1.3 Existing Recharge Capacity within the District

The two primary sources of recharge capacity within the District include: (1) constructed recharge basins (and regulation basins, although not maintained to maximize recharge); and (2) the extensive system of water delivery canals to the recharge basins and associated irrigation ditches that deliver water to the farms. Additional sources of recharge capacity, implemented for the first time this past year, include flooding of farm fields if and when possible, and use of existing borrow pits.

Estimates of infiltration capacity for the District's recharge basins were prepared based on: (1) results of operational infiltration testing for the basins/cells investigated; (2) assumed infiltration capacity for the remaining recharge basins and all the regulation cells (based on previous estimates/assumptions by HydroMetrics WRI [2015] and comparison of lithologic conditions at basins/cells not investigated to basins/cells that were investigated); (3) basin/cell acreages determined through digital analysis by M&A and HydroMetrics WRI; and (4) surface water delivery periods of 90, 120, and 180 days.

Based on these measured and assumed parameters and the approximate basin/cell areas, the recharge capacities were estimated.

The District has 17 recharge cells totaling 923 acres (includes the Basin No. 3 North Cell, the infrequently used Liberty Basin, and the nearly completed Cordinez Basin) and 11 regulation basins totaling 196 acres **(Table 3)**. The total area determined through digital analysis for all recharge and regulation cells is 1,119 acres.

The total existing recharge capacity of the District's recharge and regulation basins is calculated to be 467 AF/day, which corresponds to recharge volumes of approximately:

- 42,000 AF for 90 days of continuous surface water delivery
- 56,000 AF for 120 days of continuous surface water delivery
- 84,000 AF for 180 days of continuous surface water delivery

Recharge capacity of the District's extensive system of recharge system canals and irrigation ditches (totaling more than 300 miles) was estimated chiefly based on the measured inflows for the 2017 surface water delivery period. The District maximized use of all canals and ditches (together with all basins) due to the flood release conditions, which provided the opportunity to estimate the total recharge capacity of the water distribution system. Based on information for inflow rates and durations provided by the District, the following recharge capacities were estimated for the canals/ditches and for the total water distribution and recharge system:

- Flows (losses) in the canals and ditches beyond the recharge system were indicated to be 100 cfs; assuming this flow rate continued for 7 months (both prior to irrigation and as part of full-scale irrigation), the resulting total "loss" (i.e. recharge volume) is calculated to be approximately 41,700 AF.
- Inflows to the recharge system (includes recharge and regulation basins and recharge system canals) were indicated to be 320 cfs; assuming this flow rate continued for 7 months, the resulting total recharge volume is calculated to be approximately 133,000 AF.
- Assuming that flows of 420 cfs in the recharge system and irrigation ditches (combined) continued through July, the total volume recharged in the District in 2017 was approximately 185,000 AF (includes on-farm and borrow pit recharge of approximately 10,000 AF).

- Based on the analysis presented in **Section 5.1.1**, the estimated total recharge capacity for all the District's recharge and regulation basins was estimated to be 467 AF/day, or 98,000 AF for a 7-month surface water delivery period. Therefore, the estimated recharge volume for only the canals within the recharge system is calculated to be 35,000 AF for the 7-month period (133,000 AF – 98,000 AF). The total estimated recharge volume for all the canals and irrigation ditches in the District is then calculated to be 76,700 AF for the 7-month period (41,700 AF + 35,000 AF).

- The analysis above indicates that the recharge system (basins and canals) accounted for 72% of the total recharged volume and the irrigation ditches accounted for 23%; on-farm and borrow pit recharge account for the remaining 5%.

- Based on the District's analysis of their surface water distribution "losses" (canals and irrigation ditches) for the period 1981 to 2012, the average annual loss (i.e., recharge volume) was approximately 40,000 AF.

- Based on the intake capacity of the Main Intake Canal (900 cfs), which can be augmented through other canals if needed to increase the intake capacity to 1,200 cfs, there is nearly sufficient flow capacity to fill all available basins, canals, and irrigation ditches within the District and still meet irrigation demand.

- Perhaps the most relevant aspect of this analysis is that the irrigation ditch losses of 100 cfs represent a potential source of recharge capacity that has typically not been used by the District prior to the start of irrigation. If the ditches would be filled with water for recharge purposes during the typical 2-month period preceding pre-irrigation, flows of 100 cfs would result in recharge of an additional 11,900 AF, which substantially exceeds the estimated improvement in recharge capacity/volume from deepening selected basins.

6.1.4 Basin Deepening

The goal of basin deepening is to remove the near-surface fine-grained sediments that control or limit infiltration capacity to reach more favorable infiltration media (medium to coarse-grained sediments). Based on the lithologic and stratigraphic characterization of the upper part of the vadose zone from the exploration trenching and drilling programs **(Section 4.1)**, combined with results of the operational infiltration testing **(Section 4.2)**, only three of the recharge basins/cells investigated appear appropriate for deepening as a means of improving the infiltration capacity. This assessment assumes that removal of no more than approximately 5 feet of sediments from the basin floor would be considered feasible due to excavation costs and spoil storage requirements. However, the District may determine that feasible excavation depths are smaller or larger than 5 feet, which could affect the selection of basins/cells considered for deepening.

- Basin No. 6 North Cell, if deepened by 5 feet, is estimated to have an increased infiltration capacity up to approximately 1.5 ft/day (currently 0.25 ft/day based on operational infiltration testing).

- The Martin Basin may have significantly improved infiltration capacity by removing the upper 4 feet of sediments depending on the lithologic conditions deeper than approximately 10 to 15 feet below the basin floor (depth of BSK's borings). A small thickness of sandy silt was encountered at the bottom of several borings; if this relatively shallow fine-grained layer is thick and extensive, it could potentially limit infiltration capacity to a similar level as currently exists, negating the benefit of basin deepening. Therefore, additional and deeper exploration drilling would be needed to characterize these conditions before a complete assessment of the potential infiltration rate improvement can be made. If the sandy silt layer is thin and/or discontinuous, infiltration capacity of the deepened basin is estimated to increase up to approximately 1.5 ft/day (currently 0.6 ft/day based on operational infiltration testing). It is important to note that infiltration rates at the Martin Basin were greater than 1 ft/day when the basin water levels (heads) were approximately 7 feet or higher; infiltration rates at this basin were more responsive to the imposed heads than the other basins tested.

- The Creamline Basin Southeast Cell is also a candidate for basin deepening (by 5 feet) based on the near-surface conditions. Infiltration capacity of this cell is estimated to increase up to approximately 1.0 ft/day (currently 0.5 ft/day based on operational infiltration testing). However, the occurrence of deeper fine-grained low-permeability layers at variable depths across the cell (based on three borings) indicates an uncertain continuity of the fine-grained layers **(Figure 9)**. If continuous, infiltration capacity would likely be controlled or limited by these impeding layers, and the potential improvement of infiltration capacity from basin deepening would likely be negated. As for the Martin Basin, additional exploration drilling would be required to better characterize the depth, thickness, and continuity of these subsurface layers.

The estimated increase in recharge volumes (for a 90-day delivery period) resulting from deepening the Basin No. 6 North Cell, Martin Basin, and Creamline Basin Southeast Cell are 5,330 AF, 1,240 AF, and 1,160 AF, respectively **(Table 4)**. A simple cost analysis based entirely on excavation volumes indicates that deepening the Basin No. 6 North Cell by 5 feet (including removal of the existing bench) is very costly ($1.2 million) due to the large cell size and associated excavation volume. Estimated excavation costs for the Martin Basin and Creamline Basin Southeast Cell are $231,000 and $557,000, respectively. However, deepening the Basin No. 6 North Cell is more cost-effective in terms of the increased infiltration capacity ($230,000 per 1,000 AF increase) than deepening the Creamline Basin Southeast Cell ($448,000 per 1,000 AF increase) due to the much larger increase in recharge volume for the Basin No. 6 North Cell **(Table 4)**. Deepening the Martin Basin is the most cost-effective option ($199,000 per 1,000 AF increase) if fine-grained subsurface intervals are determined to not limit the achievable infiltration capacity.

The estimated delivery periods to recharge an additional 1,000 AF at the deepened Basin No. 6 North Cell, Martin Basin, and Creamline Basin Southeast Cell are 17 days, 78 days, and 72 days, respectively.

It is important to note that the comparisons of cost-effectiveness for deepening the three recharge cells described above provide a potential basis for prioritizing the cells considered for deepening. However, any of these basin deepening options may be relatively cost-effective in the long term, relative to the cost of water, based on the cumulative increase in water volume stored over many years of recharge operations. For example, based on the average estimated increase in recharge volumes for these three recharge cells if deepened (approximately 2,600 AF/yr), an additional total recharge volume of 78,000 AF would be achieved over a 30-year period. If the highest cost of excavation is assumed ($1.2 million for Basin No. 6 North Cell), the resulting unit cost is approximately $15 per AF of increased recharge capacity, which translates to an inexpensive source of stored water.

6.1.5 Alternative Methods of Increasing Recharge Capacity

Alternative recharge methods were considered as a means to augment recharge capacity within the District. These methods include vadose zone and deep (direct) injection wells, and infiltration trenches or boreholes installed inside the existing recharge basins. Use of settling basins for specific applications was also evaluated as a means for minimizing the amount of suspended sediments in water delivered to recharge basins and/or wells. Because many recharge basins already exist in the District and provide a very large total recharge capacity, evaluation of these alternative recharge methods was necessarily based on the feasibility of these alternative methods in relation to the existing capacity, basin modifications, and other opportunities related to the District's surface water distribution system. One highly advantageous opportunity is on-farm recharge, which is an emerging method that was also evaluated as an alternative recharge option.

Based on the evaluation provided in **Section 5.3**, with the exception of on-farm recharge, none of the alternative methods are considered feasible options for improving infiltration capacity of the District's recharge basins and are not recommended. The overriding reason is that they do not provide substantial additional recharge capacity relative to the cost of installation (i.e., are not cost effective).

- Regarding deep/direct injection wells, in addition to the large installation costs, California regulatory agencies would require that injected water essentially meets potable water quality standards, which likely is a fatal flaw for injecting untreated surface water.

- Vadose zone injection wells would not be cost effective due to the relatively low injection capacity and the need for many wells to significantly augment recharge capacity. In addition, injection of untreated surface water would likely cause the vadose zone injection wells to plug relatively quickly and result in additional efforts and costs to replace the wells.

- Infiltration trenches and boreholes are most applicable to small recharge projects and would likely also have a limited period of effectiveness.

- Whereas additional settling basins (other than regulation cells) would minimize the clogging effect of suspended sediments within associated recharge basins, the cost and additional land area required would likely be prohibitive. However, a variation of the settling basin concept being considered by the District consists of connecting the Creamline Basin recharge cells to the Swall Basin recharge cells so that the Creamline Basin recharge cells provide a second level of suspended sediment settling for water delivered to the Swall Basin recharge cells. This concept may have merit depending on additional investigation of the subsurface lithologic conditions to better evaluate if infiltration capacity would still be controlled or limited by deeper low-permeability layers.

On-farm recharge represents a potentially large source of capacity prior to the planting season if more farmers can be encouraged to participate in these activities. Recharge volumes in 2017 were increased by more than 10,000 AF by flooding farm fields of willing farmers and by incentivizing additional "pre-irrigation." In addition, this means of recharge is a very low-cost option, depending chiefly on the District's cost incentives. It is understood that the District is actively pursuing this largely un-tapped opportunity.

6.2 Recommendations

Evaluation of results and findings from all components of the present study lead to a number of considerations and recommendations regarding improvement of recharge capacity within the District, including the need or benefit of additional investigations when funding might be available. M&A's recommendations are summarized below based on several focus areas.

6.2.1 Feasibility of Options for Increasing Recharge Capacity

UTILIZATION OF IRRIGATION DITCHES

The most available and cost-effective means of improving recharge capacity of the District's surface water distribution system is to maximize use of the irrigation ditches during periods when they otherwise would not be needed to meet pre-irrigation or full irrigation demand. As described in **Section 5.1.2**, if the irrigation ditches would be filled with water for recharge purposes during the typical 2-month period preceding pre-irrigation, flows of 100 cfs in the irrigation ditch system would result in recharge of an additional 11,900 AF, which substantially exceeds the estimated improvement in recharge capacity/volume from deepening selected basins. Additional considerations include:

- This recommendation assumes that the recharge system basins and canals would be also be fully utilized during the "recharge season" (i.e., additional recharge capacity is needed).

- It is understood that flows as high as 100 cfs in the irrigation ditch system during non-irrigation periods are likely only achievable during periods of very high surface water availability such as occurred in 2017. However, the use of existing canals and ditches during these periods incurs no additional capital costs and is generally available if and when the capacity is needed. If more frequent re-grading and sediment removal in the ditches would be required to maximize infiltration capacity, this cost would need to be factored in, but it is very unlikely that it would be sufficient to result in less cost-effective recharge compared to basin deepening.

- The relatively large additional recharge capacity provided by the irrigation ditches may invoke the concept of installing similar ditches along the edge of farm fields that would only be filled/used for recharge purposes when excess water is available. The feasibility of this option would require an analysis of costs for constructing the ditches and associated valves and inflow structures. However, the primary reason that the existing irrigation ditch system provides substantial additional recharge capacity is the extensive length of the system (likely more than half of the approximate 300 miles of delivery canals and irrigation ditches, combined). The infiltration capacity per unit length of the irrigation ditches is very small and it is very unlikely that installation of “several miles” of additional ditches would result in a significant increase in recharge capacity (and there might also be operational challenges), and would therefore not be cost-effective or feasible.

ON-FARM RECHARGE

On-farm recharge, including flooding farm fields and increasing pre-irrigation water applications, represents a potentially large source of additional recharge capacity in the District and is a very low-cost option. It is recommended that the District continues to aggressively pursue this largely un-tapped opportunity.

BASIN DEEPENING

As described in **Section 6.1.4**, only three of the recharge basins/cells investigated appear appropriate or feasible for deepening as a means of improving the infiltration capacity, including the Basin No. 6 North Cell, Martin Basin, and Creamline Basin Southeast Cell. However, only the Basin No. 6 North Cell is estimated to have a substantial improvement (increased infiltration capacity up to approximately 1.5 ft/day with a corresponding increase in recharge volume of 5,330 AF for a 90-day delivery period). Because this improvement in recharge capacity would require removal of the upper 5 feet of basin sediments (plus removal of the existing benches), estimated costs are very large (more than $1.2 million). Therefore, the feasibility or cost-effectiveness of deepening the Basin No. 6 North Cell is questionable and is clearly much smaller than for the option of fully utilizing irrigation ditches. However, if additional recharge capacity is needed after the ditches are fully used for irrigation demand, deepening the Basin No. 6 North Cell may then be beneficial.

The Martin Basin and the Creamline Basin Southeast Cell may have significantly improved infiltration capacity through basin deepening depending on the thickness and continuity of subsurface fine-grained layers encountered in exploration borings drilled in or at these basins/sites (for the present study and previously by BSK). Therefore, if these basins/cells would be considered for deepening, additional exploration drilling and trenching would be required to better characterize lithologic conditions. In any event, the potential improvement of infiltration capacity for the Creamline Basin Southeast Cell through basin deepening (increased infiltration capacity up to approximately 1.0 ft/day with a corresponding increase in recharge volume of only 1,240 AF for a 90-day delivery period) would likely not warrant the large cost for removal of the upper 5 feet of basin sediments ($557,000).

For all recharge basins at which operational infiltration testing was conducted, measured infiltration rates were typically slightly higher for larger heads as would be expected, although the impact of the higher heads was small. In general, it is not necessarily the case that maximizing heads results in maximum infiltration rates, especially over lengthy recharge periods when large heads could cause some compression of near-surface fine-grained layers. It would be difficult to determine the optimal head for each basin without extensive operational infiltration testing over a long time period. Based on results of the tests conducted for the present study, it appears that use of moderate heads (approximately 3 to 4 feet) at most basins would provide relatively similar infiltration rates as the use of higher heads, negating the motivation to increase heads (with the exception of the Martin Basin, addressed below). In addition, it is understood that operational considerations for delivering water through the water distribution system will likely dictate the amount and duration of water delivery to a given recharge basin via the regulation cells regardless of any potential benefit of targeting an optimal head. This consideration is especially relevant to periods of high water availability, such as this past year, where the District needs to accept and recharge as much water as possible.

It is important to note that for the Martin Basin, infiltration rates were significantly higher at heads of approximately 7 feet or more (approximately 0.6 ft/day for lower heads and more than 1.0 ft/day for high heads). The larger impact of the higher heads may be due to more substantial lateral flow in the subsurface layers (that have relatively higher permeability) with increasing head, or that the higher water levels in the basin intersect a higher permeability layer near the top of the basin. These effects would be more significant at the Martin Basin due to its relatively small size (14.5 acres) compared to the other basins investigated. Therefore, maximizing heads during recharge operations at the Martin Basin is recommended.

Evaluation of constructing new recharge basins was not included in the present study because it would require a recharge siting investigation and obtaining data for site-specific lithologic conditions at identified sites, which is a more comprehensive and costly effort than could be conducted under the available budget. However, it is clear that the cost for constructing new basins would be much larger than for deepening existing basins, especially if land acquisition and construction of a new segment of delivery canal are required. To provide a general idea of capital costs for constructing a new recharge basin facility, the District estimates that the purchase cost for farm land (assuming no existing tree crops) is on the order of $25,000 per acre and the cost to construct recharge basins and appurtenances is approximately $20,000 per acre (based on costs incurred to develop existing recharge facilities). Therefore, the total cost for land acquisition and recharge facility development would be approximately $45,000 per acre, resulting in a cost on the order of $1.8 million for a facility consisting of 40 acres of recharge basins. This cost is not necessarily prohibitive if the chosen site would have relatively high infiltration capacity, which would need to be evaluated through site-specific hydrogeologic investigations.

ALTERNATIVE RECHARGE METHODS

Alternative recharge methods (other than on-farm recharge) include vadose zone and deep/direct injection wells, infiltration trenches or boreholes installed inside the existing recharge basins, and construction and use of new basins as settling basins. These methods are generally not feasible or cost-effective for augmenting recharge capacity within the District (or within a given basin) and are therefore not recommended. However, it is possible that special circumstances or opportunities could arise that might warrant consideration of these methods.

6.2.2 Additional Investigations

Hydrogeologic investigations have been conducted at 12 recharge cells (eight basins) in the District, which includes various combinations of trenching, drilling (M&A and BSK), and operational infiltration testing (as listed in **Section 6.1**). These investigations targeted basins/cells that are all located in approximately the north half of the District. There are 17 recharge cells in the District totaling 923 acres; the cells that have received some type of investigation represent a total of 482 acres, which is 52% of the total recharge cell area. Therefore, the lithologic conditions and/or infiltration capacity of approximately half of the recharge cell area has not been investigated. Regarding only operational infiltration testing, the cells at which this testing was conducted represent a total of 264 acres, which is only 29% of the total recharge cell area. Based on anecdotal information and general observations, the recharge cells in approximately the south half of the District are believed to relatively fine-grained with “small” infiltration capacity.

If and when funding would be available, hydrogeologic investigations are recommended for selected recharge basins/cells already investigated and for additional basins/cells to better quantify existing recharge capacity within the District's recharge system and to evaluate the feasibility of recharge enhancement (especially basin deepening) at the selected basins. It is understood that available funding if secured, would limit the scope and number of investigations that could be conducted, but the following list provides an initial assessment and prioritization of potential projects.

- As described in **Section 6.1.4**, additional borings are highly recommended for the Martin Basin and the Creamline Basin Southeast Cell if deepening of these basins would be considered. Confirming and/or better characterizing the thickness and continuity of subsurface fine-grained layers (encountered in exploration borings) is critical to evaluating the feasibility of basin deepening. Additional trenching and/or drilling should also be included in evaluating basin deepening for the Basin No. 6 North Cell even though results of the completed investigations indicate that infiltration capacity can be significantly improved through removal of the upper 5 feet. The number and locations of trenches and borings in this cell are pretty sparse in relation to the large cell size. The additional "in-fill" of lithologic data would be important for confirming the generally favorable conditions before investing more than $1.2 million on basin deepening, and would also allow a more complete or accurate assessment of the depth of surface sediment removal across the cell. This same approach should be used for any basin/cell to be considered for basin deepening.

- Based chiefly on the large basin/cell sizes, the Guinn Basin and Anderson Basin recharge cells would be prioritized for lithologic investigations, perhaps followed by the Creamline Basin Southwest Cell and the Basin No. 3 North Cell. The Tagus Basin, located outside the District's north boundary, is assumed to also have lower priority.

- Similar to the present study, exploration trenching would be conducted at the basins/cells to first evaluate the near-surface lithologic conditions and determine if fine-grained low-permeability sediments are too thick and deep to allow significant infiltration capacity improvement through basin deepening. Exploration drilling would be recommended only if near-surface fine-grained sediments occur chiefly in the upper 5 feet and could be feasibly removed.

- BSK conducted exploration drilling at the Swall Basin site (before the cells were excavated. Trenching or direct-push investigations would be useful in one or more of the cells, especially the East Cell, to better characterize the near-surface zone across the entire area of this large cell and evaluate the depth and thickness of the layer that is controlling or limiting infiltration rates.

- When sufficient surface water deliveries occur in the future, low-cost operational infiltration testing is highly recommended for as many additional basins as possible. Operational infiltration testing should be prioritized to target the two basins/cells at which trenching investigations were conducted for the present study, but infiltration testing was not (Basin No. 3 South Cell and Basin No. 8). Additional infiltration testing should be conducted at the Basin No. 6 North Cell; only two falling-head cycles were completed at this cell, which indicated a surprisingly low infiltration rate of 0.25 ft/day. Infiltration testing should also be prioritized for Basin No. 6 South Cell and Basin No. 8.

- At selected basins where lithologic characterization indicates potential impeding layers at depths between approximately 10 to 15 below the basin floor, shallow piezometers could be installed manually at the edge of the basins to provide measurements of potential perched water mounding during operational infiltration testing. The results would allow evaluation of the potential limiting effect of the impeding layers on the measured infiltration rates.

- For basin/cells that might considered for deepening (Basin No. 6 North Cell, Creamline Basin Southeast Cell, and Martin Basin), smaller-scale infiltration tested should be conducted at the targeted depths of basin deepening to better quantify potential infiltration rates and confirm the benefit of deepening the basin before committing to the associated efforts and costs. Alternatively (or in addition), a moderately-sized test basin (1 acre or more) could first be excavated within the recharge basin to the targeted depth of deepening, and several falling-head cycles could be conducted to determine a more reliable estimate of the improved infiltration rate.

6.2.3 Other Considerations Related to Groundwater Sustainability Planning

The benefits of maximizing recharge capacity in 2017 are very apparent from the relatively rapid groundwater level response observed. Comparison of groundwater levels across the District in the Fall of 2017 to the Fall of 2016 (based on the District’s data) indicates that groundwater levels rose substantially, ranging from approximately 10 to 40feet or more, with the largest rise occurring generally in the north half and southwest corner of the District. The larger groundwater level rise in the north half of the District is consistent with the large number and high overall capacity of recharge basins in the north half relative to the south half. Relevant considerations for groundwater sustainability include the following:

- Despite the large and rapid groundwater level response in 2017, it is not known if surface recharge is resulting in replenishment of chiefly the shallow or "perched" aquifer above the Corcoran Clay or if sufficient amounts of water are moving through this aquitard to recharge the deeper (confined) aquifer zone. Based on limited lithologic and geophysical data for deep wells **(Section 4.1.8)**, depth to the top of the Corcoran Clay may be on the order of 200 feet and thickness may range from approximately 100 to 200 feet across much of the District. It is important to note that, based on recent geophysical surveys, this clay unit thins and/or is discontinuous in the northeast part of the District (essentially east of State Highway 99) and may also have variable thickness and continuity across other parts of the District.

- It is assumed that most irrigation wells are completed to depths below the Corcoran Clay and are perforated across most of the installed depth, and would therefore extract groundwater from both above and below the clay unit. If this is the case, it is likely that piezometric levels and pore pressures have declined in the deeper aquifer zone across the District due to extensive pumping for irrigation during the years when surface water was limited or not available. In addition, groundwater levels measured in these wells could represent a composite piezometric level of the (assumed) separate aquifer zones or may simply measure the phreatic surface of the shallow aquifer.

- If most of the wells are chiefly completed to depths above the clay unit (which seems unlikely), groundwater extraction would be occurring from only above the clay unit and the measured groundwater levels would accurately represent the phreatic surface of the shallow aquifer zone. In this event, the piezometric level of the deeper aquifer zone would not be known, but desaturation of this zone would not be a concern. It is very unlikely that the irrigation wells are perforated only below the Corcoran Clay (there would not have been a rapid groundwater level rise from recharge in 2017), but this would represent the worst condition in relation to long-term drawdown and possible desaturation of the deep aquifer zone.

- The uncertainty regarding the representativeness of measured groundwater levels is due to lack of knowledge of the depths and perforated intervals for the large number of irrigation wells within the District. Therefore, it is highly recommended that well construction records be obtained from the California Department of Water Resources, if available. If records are not available, the District could attempt to measure total depths and perforated intervals for selected wells. It is recognized that measurements of the perforated intervals would require raising the pump head and video logging the well, which would incur a significant effort and cost. However, critical aspects of evaluating groundwater sustainability within the District include understanding the difference in piezometric levels of the two aquifer zones, documenting the potential degree of desaturation of the deep aquifer zone, and developing strategies for replenishing the deep aquifer zone to prevent subsidence and balance pumping (assuming irrigation wells are completed in the deep zone).

- In addition to pursuing records or direct measurements of well depths and perforated intervals, it is recommended that the District install appropriately designed monitor wells at selected locations across the District. These wells could be constructed similarly to the four dual-completion monitor wells installed in 2016 in the northcentral part of the District (BSK, 2016). Unlike the majority of irrigation wells currently used for groundwater level monitoring, the new monitor wells would be screened in targeted intervals to provide representative water level measurements for both aquifer zones (above and below the Corcoran Clay), as described above.

- Evaluation of recharge enhancement options should include considerations related to identifying areas within the District where recharge would provide the greatest water resource benefit, to the extent possible. Possible examples include:

    - Due to the apparent absence of the Corcoran Clay in the northeast part of the District, more focused recharge in this area would allow recharge of the aquifer in a manner that would promote replenishment of the deep aquifer zone underlying the eastern extent of the clay unit. This condition would favor augmentation of recharge capacity at the Creamline and Swall basins/cells.

    - Deepening of the Creamline Basin Southeast Cell and lithologic investigations at the Creamline Basin Southwest Cell are included in the recommendations above. In addition, possible use of the Creamline Basin Southeast Cell as a secondary settling basin for water delivered to the Swall Basin is being evaluated by the District.

7 REFERENCES CITED

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8 ACRONYMS & ABBREVIATIONS

AF	acre-feet
AF/day	acre-feet per day
AF/yr	acre-feet per year
bls	below land surface
cfs	cubic feet per second
cm/sec	centimeters per second
District	Tulare Irrigation District
ft/day	feet per day
GIS	geographic information system
gpm	gallons per minute
HydroMetrics WRI	HydroMetrics Water Resources Inc.
K_{sat}	saturated hydraulic conductivity
M&A	Montgomery & Associates
TID	Tulare Irrigation District
USBR	United States Bureau of Reclamation
USCS	Unified Soil Classification System

TABLE 1. SUMMARY OF LABORATORY RESULTS FOR SOIL PHYSICAL ANALYSES FOR SOIL SAMPLES OBTAINED AT SELECTED RECHARGE BASINS TULARE IRRIGATION DISTRICT, TULARE COUNTY, CALIFORNIA

BASIN / CELL	FIELD STUDY[a]	TRENCH OR BORING IDENTIFIER	SAMPLE INTERVAL (ft, bls)[b]	PARTICLE SIZE ANALYSIS (SIEVE ANALYSES)[c]						PLASTICITY INDICES[d]			SEDIMENT DESCRIPTION[e]
				GRAVEL	SAND				SILT & CLAY	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	
					COARSE	MEDIUM	FINE	TOTAL					
				……………………………percent……………………………									
Creamline Basin Southeast Cell	Trench	CL-1	0.6 - 1.5	0	22	9	22.9	53.9	46.1	28	20	**8**	SILTY CLAYEY SAND; non-lithified; slightly to moderately cohesive
	Trench	CL-2	1.4 - 3	0	4	2	41.7	47.7	52.3	---	---	**NP**	SANDY SILT/SILTY SAND; non-lithified; non-cohesive
	Trench	CL-3	1.8 - 3	0	13	7	31.4	51.4	48.6	---	---	**NP**	SILTY SAND/SANDY SILT; non-lithified; non-cohesive
	Trench	CL-4	0.3 - 2.5	2	23	7	22.3	52.3	45.7	25	17	**8**	SILTY SAND/SANDY SILT; non-lithified; slightly cohesive
	Trench	CL-5	3 - 5	1	3	1	7.6	11.6	87.4	29	22	**7**	SILT; non-lithified; slightly cohesive
	Trench	CL-6	2.5 - 5	0	10	8	37.1	55.1	44.9	---	---	**NP**	SILTY SAND; non-lithified; non-cohesive
	Trench	CL-7	1.4 - 4	0	8	5	22.4	35.4	64.6	24	19	**5**	SANDY SILT; non-lithified; slightly cohesive
	Trench	CL-8	2.8 - 5	1	32	16	25.0	73.0	26.0	---	---	**NP**	SAND with SILT; non-lithified; non-cohesive
	Boring	B1	13.5 - 16	1	8	6	21.0	35.0	64.0	35	15	**20**	SANDY SILT AND CLAY; non-lithified; moderately to very cohesive
	Boring	B1	35 - 36.5	1	6	2	31.1	39.1	59.9	28	22	**6**	SANDY SILT; non-lithified; slightly cohesive
	Boring	B1	45 - 46.5	0	12	5	26.7	43.7	56.3	34	21	**13**	SANDY SILT; non-lithified; slightly to moderately cohesive
	Boring	B2	22.5 - 28	1	4	2	10.1	16.1	82.9	33	23	**10**	SILT AND CLAY with SAND; non-lithified; moderately cohesive
	Boring	B2	32.5 - 33	0	6	4	22.3	32.3	67.7	38	23	**15**	SANDY SILT AND CLAY; non-lithified; moderately cohesive
	Boring	B3	29 - 34	3	9	4	21.0	34.0	63.0	33	19	**14**	SANDY SILT AND CLAY; non-lithified; moderately cohesive

TABLE 1. SUMMARY OF LABORATORY RESULTS FOR SOIL PHYSICAL ANALYSES
FOR SOIL SAMPLES OBTAINED AT SELECTED RECHARGE BASINS
TULARE IRRIGATION DISTRICT, TULARE COUNTY, CALIFORNIA

				PARTICLE SIZE ANALYSIS (SIEVE ANALYSES)[c]						PLASTICITY INDICES[d]			
		TRENCH	SAMPLE	GRAVEL	SAND				SILT &	LIQUID	PLASTIC	PLASTICITY	
	FIELD	OR BORING	INTERVAL		COARSE	MEDIUM	FINE	TOTAL	CLAY	LIMIT	LIMIT	INDEX	
BASIN / CELL	STUDY[a]	IDENTIFIER	(ft, bls)[b]	……………………………..percent………………………………									SEDIMENT DESCRIPTION[e]
Basin No. 3 South Cell	Trench	#1	0.6 - 2.4	0	7	2	21.5	30.5	69.5	22	18	**4**	SANDY SILT; non-lithified; slightly cohesive
	Trench	#2	0.3 - 2	1	6	3	37.1	46.1	52.9	21	17	**4**	SANDY SILT; non-lithified; slightly cohesive
	Trench	#3	0.3 - 2.5	0	7	2	15.1	24.1	75.9	28	15	**13**	SILT AND CLAY with SAND; non-lithified; moderately cohesive
	Trench	#4	1.6 - 3.5	0	6	7	39.2	52.2	47.8	23	16	**7**	SILTY SAND; non-lithified; slightly cohesive
	Trench	#5	0 - 1	1	9	7	23.1	39.1	59.9	25	17	**8**	SANDY CLAYEY SILT; non-lithified; slightly to moderately cohesive
	Trench	#6	1.5 - 4	1	11	4	20.6	35.6	63.4	28	19	**9**	SANDY SILT AND CLAY; non-lithified; slightly to moderately cohesive
	Trench	#8	0.3 - 1.8	0	7	5	32.6	44.6	55.4	25	17	**8**	SANDY SILT AND CLAY; non-lithified; slightly to moderately cohesive
	Trench	#8	1.8 - 3.2	0	7	5	32.5	44.5	55.5	24	18	**6**	SANDY SILT; non-lithified; slightly cohesive
	Trench	#9	4 - 6	0	3	1	12.1	16.1	83.9	27	23	**4**	SILT with SAND; non-lithified; slightly cohesive
	Trench	#11	4 - 5.2	0	1	3	31.4	35.4	64.6	44	22	**22**	SANDY SILT and CLAY; non-lithified; moderately to very cohesive
Basin No. 6 North Cell	Trench	#2	0.7 - 2	0	18	5	17.6	40.6	59.4	30	16	**14**	SANDY SILT AND CLAY; non-lithified; moderately cohesive
	Trench	#4	0 - 0.8	0	2	1	4.1	7.1	92.9	38	22	**16**	SILT AND CLAY; non-lithified; moderately to very cohesive
	Trench	#5	1.4 - 3	0	11	6	15.5	32.5	67.5	27	16	**11**	SANDY SILT AND CLAY; non-lithified; moderately cohesive
	Trench	#8	2.6 - 6	0	15	7	30.7	52.7	47.3	23	17	**6**	SILTY SAND; non-lithified; slightly cohesive
	Boring	B2	17 - 21	1	9	5	28.5	42.5	56.5	21	15	**6**	SANDY SILT; non-lithified; slightly cohesive
	Boring	B2	40 - 41.5	1	8	4	26.5	38.5	60.5	34	15	**19**	SANDY SILT AND CLAY; non-lithified; moderately cohesive
	Boring	B3	15.5 - 21	0	3	2	18.3	23.3	76.7	31	20	**11**	SILT with SAND; non-lithified; slightly to moderately cohesive
	Boring	B3	30.5 - 40	0	5	5	35.6	45.6	54.4	24	19	**5**	SANDY SILT; non-lithified; slightly cohesive
	Boring	B4	21.5 - 25	1	19	12	34.6	65.6	33.4	34	22	**12**	SILTY SAND; non-lithified; slightly cohesive

TABLE 1. SUMMARY OF LABORATORY RESULTS FOR SOIL PHYSICAL ANALYSES
FOR SOIL SAMPLES OBTAINED AT SELECTED RECHARGE BASINS
TULARE IRRIGATION DISTRICT, TULARE COUNTY, CALIFORNIA

BASIN / CELL	FIELD STUDY[a]	TRENCH OR BORING IDENTIFIER	SAMPLE INTERVAL (ft, bls)[b]	PARTICLE SIZE ANALYSIS (SIEVE ANALYSES)[c]						PLASTICITY INDICES[d]			SEDIMENT DESCRIPTION[e]
				GRAVEL	SAND				SILT & CLAY	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	
					COARSE	MEDIUM	FINE	TOTAL					
				…………………………..percent……………………………									
Basin No. 6 South Cell	Trench	#1	1.3 - 4.5	0	2	1	49.7	52.7	47.3	---	---	**NP**	SILTY SAND; non-lithified; non-cohesive
	Trench	#3	0.5 - 2.2	0	1	2	40.7	43.7	56.3	25	20	**5**	SANDY SILT; non-lithified; slightly cohesive
	Trench	#4	4 - 6.5	1	5	2	42.6	49.6	49.4	28	18	**10**	SANDY SILT/SILTY SAND; non-lithified; slightly to moderately cohesive
	Trench	#5	0.4 - 1.6	0	2	2	31.0	35.0	65.0	26	22	**4**	SANDY SILT; non-lithified; slightly cohesive
	Trench	#6	0.4 - 1.6	1	15	8	25.3	48.3	50.7	27	17	**10**	SANDY SILT/SILTY SAND; non-lithified; slightly to moderately cohesive
	Trench	#9	2.2 - 4.4	0	5	4	24.1	33.1	66.9	26	18	**8**	SANDY SILT AND CLAY; non-lithified; slightly to moderately cohesive
	Boring	B5	26 - 29	0	4	3	16.7	23.7	76.3	38	20	**18**	SILT AND CLAY with SAND; non-lithified; moderately to very cohesive
Basin No. 8	Trench	#3	7 - 11	2	5	3	15.1	23.1	74.9	34	21	**13**	SILT AND CLAY with SAND; non-lithified; moderately cohesive
	Trench	#4	2.8 - 5	1	6	1	19.4	26.4	72.6	---	---	**NP**	SILT with SAND; non-lithified; non-cohesive
	Trench	#7	4.5 - 6	2	6	3	11.4	20.4	77.6	46	22	**24**	SILT AND CLAY with SAND; non-lithified; moderately to very cohesive
	Trench	#8	1.4 - 3	3	4	1	26.7	31.7	65.3	27	18	**9**	SANDY SILT AND CLAY; non-lithified; slightly to moderately cohesive
	Trench	#8	3.6 - 4.8	0	3	1	17.1	21.1	78.9	29	20	**9**	SILT AND CLAY with SAND; non-lithified; slightly to moderately cohesive

NOTE: All samples were obtained by Montgomery & Associates and were analyzed by Terracon of Tucson, Arizona.

[a] Field studies included exploration trenches (Trench) and exploration borings (Boring).

[b] ft, bls = feet below land surface

[c] Particle size distribution was determined by mechanical sieve analysis using ASTM method D422; particle size ranges for gravel, sand, and silt and clay fractions are based on the U.S. Department of Agriculture system, except that the division between sand and fines (silt and clay) was based on the No. 200 sieve instead of the No. 230 sieve.

[d] Plasticity indices were determined using ASTM method D4318. "**NP**" = non-plastic

[e] Sediment descriptions are based on manual methods by Montgomery & Associates' geologists.

--- = Not applicable

TABLE 2. SUMMARY OF RESULTS OF FALLING-HEAD CYCLES FOR OPERATIONAL INFILTRATION TESTS CONDUCTED IN RECHARGE BASINS
TULARE IRRIGATION DISTRICT, TULARE COUNTY, ARIZONA

BASIN / CELL	CYCLE	CYCLE LENGTH (hours)	BEGINNING HEAD[a] (feet)	HEAD DECLINE[b] (feet)	CALCULATED CYCLE INFILTRATION RATE[c] (feet/day)	REPRESENTATIVE CYCLE INFILTRATION RATE[d] (feet/day)	REPRESENTATIVE OVERALL INFILTRATION RATE[e] (feet/day)
Creamline Basin Southeast Cell	1	180	5.06	4.64	0.62	0.6	0.5 (for average head of 4 to 5 feet)
	2	48	5.43	1.00	0.50	0.55	
	3	57	4.37	1.18	0.50	0.5	
	4	54	4.52	1.12	0.50	0.5	
	5	68	5.22	1.42	0.50	0.5	
Creamline Basin Southwest Cell	1	25	4.56	0.53	0.51	0.5	0.5 (for average head of 3 to 4 feet)
	2	66	4.08	1.34	0.49	0.53	
	3	80	4.90	1.48	0.44	0.52	
	4	66	3.24	1.18	0.43	0.44	
	5	52	4.34	0.90	0.42	0.47	
Swall Basin East Cell	1	186	7.51	4.37	0.56	0.55	0.45 (for average head of 5 to 6 feet)
	2	55	6.11	1.03	0.45	0.45	
	3	71	5.42	1.26	0.43	0.42	
	4	63	4.67	1.12	0.43	0.42	
Swall Basin Northwest Cell	1	164	9.48	3.63	0.53	0.53	0.53 (for average head of 6.5 feet)
Basin No. 3 South Cell	1	33	1.71	0.73	0.53	0.5	0.45 (for average head of 1 to 2 feet)
	2	74	2.82	1.14	0.37	0.35	
	3	56	2.66	1.27	0.54	0.55	
	4	102	3.14	1.40	0.33	0.35	
	5	50	2.77	0.68	0.33	0.4	
Basin No. 6 North Cell	1	68	6.23[f]	0.51	0.18	0.25	0.25 (for average head of 5 feet)
	2	96	5.41[f]	1.02	0.26	0.25	
Martin Basin	1	41	5.88	1.15	0.67	0.7	0.6 (for average head of 4 to 6 feet)
	2	35	7.98	1.15	0.79	0.7	
	3	50	7.44	1.35	0.65	0.5	
	4	51	7.98	1.65	0.78	0.8	
	5	56	6.60	1.56	0.67	0.8	
	6	88	7.47	2.02	0.55	0.6	
	7	53	7.80	1.70	0.77	0.7	
	8	84	7.70	2.16	0.62	0.6	
	9	68	6.26	1.19	0.42	0.4	
	10	115	6.28	1.89	0.39	0.4	

[a] Beginning Head = basin water level at beginning of falling-head cycle

[b] Head Decline = water level decline in basin at end of falling-head cycle

[c] Calculated Cycle Infiltration Rate = head decline in basin divided by length of falling-head cycle, converted to feet per day

[d] Representative Cycle Infiltration Rate = rate selected to be most representative for the falling-head cycle based on analysis of all calculated incremental infiltration rates during the cycle; may be the Calculated Infiltration Rate or an average of consecutive incremental rates (12-hour rolling average) during the middle to late portions of the cycle.

[e] Representative Overall Infiltration Rate = rate selected to be the most representative for the entire testing period based on the cycle infiltration rates

[f] The pressure transducer was placed on top of the 4-foot high bench along the south boundary of Basin No. 6 North Cell; most of the basin floor had a head approximately 4 feet larger than was measured; therefore, the measured values were increased by 4 feet to represent conditions in most of the basin.

TABLE 3. SUMMARY OF APPROXIMATE BASIN AREA AND ESTIMATED RECHARGE CAPACITY FOR EXISTING BASINS
TULARE IRRIGATION DISTRICT, TULARE COUNTY, CALIFORNIA

BASIN / CELL	APPROXIMATE AREA[a] (acres)	BASIN TYPE[b]	REPRESENTATIVE INFILTRATION RATE[c] (feet/day)	ESTIMATED RECHARGE VOLUMES FOR SELECTED WATER DELIVERY PERIODS (acre-feet)			
				Daily[d]	90 days	120 days	180 days
Creamline Basin Southeast Cell	27.6	recharge	0.50	13.8	1,241	1,654	2,481
Creamline Basin Southwest Cell	26.0	recharge	0.50	13.0	1,170	1,560	2,341
Creamline Basin Northeast Cell	19.9	regulation	0.25	5.0	448	598	897
Creamline Basin Northwest Cell	38.4	regulation	0.25	9.6	864	1,152	1,728
Swall Basin East Cell	57.1	recharge	0.45	25.7	2,313	3,083	4,625
Swall Basin Northwest Cell	34.6	recharge	0.50	17.3	1,557	2,076	3,114
Swall Basin Southwest Cell	29.9	recharge	0.46	13.8	1,239	1,651	2,477
Basin No. 3 South Cell	56.1	recharge	0.45	25.2	2,272	3,029	4,544
Basin No. 3 North Cell	57.0	recharge[e]	0.46	26.2	2,359	3,145	4,717
Basin No. 3 West Cell	15.8	regulation	0.25	3.9	355	473	710
Basin No. 6 North Cell	47.4	recharge	0.25	11.8	1,066	1,421	2,132
Basin No. 6 South Cell	49.9	recharge	0.45	22.5	2,022	2,696	4,045
Basin No. 6 East Cell	32.2	regulation	0.25	8.0	723	965	1,447
Basin No. 8 East Cell	83.1	recharge	0.45	37.4	3,366	4,488	6,732
Basin No. 8 West Cell	24.4	regulation	0.25	6.1	549	731	1,097
Martin Basin West Cell	14.3	recharge	0.60	8.6	774	1,033	1,549
Martin Basin East Cell	5.0	regulation	0.25	1.3	113	150	225
Tagus Basin North Cell	47.3	recharge	0.46	21.8	1,959	2,612	3,918
Tagus Basin South Cell	14.4	regulation	0.25	3.6	324	431	647
Enterprise Basin	14.6	recharge	0.46	6.7	604	806	1,209
Cordeniz Basin[f]	40	recharge	0.46	18.4	1,656	2,208	3,312
Liberty Basin[g]	40	recharge	0.46	18.4	1,656	2,208	3,312
Guinn Basin	153	recharge	0.46	70.4	6,334	8,446	12,668
Anderson Basin North Cell	145	recharge	0.46	66.7	6,003	8,004	12,006
Anderson Basin South Cell							
Anderson Basin West Cell	4	regulation	0.25	1.0	90	120	180

TABLE 3. SUMMARY OF APPROXIMATE BASIN AREA AND ESTIMATED RECHARGE CAPACITY FOR EXISTING BASINS
TULARE IRRIGATION DISTRICT, TULARE COUNTY, CALIFORNIA

BASIN / CELL	APPROXIMATE AREA[a] (acres)	BASIN TYPE[b]	REPRESENTATIVE INFILTRATION RATE[c] (feet/day)	ESTIMATED RECHARGE VOLUMES FOR SELECTED WATER DELIVERY PERIODS (acre-feet)			
				Daily[d]	90 days	120 days	180 days
Doris Basin	15	regulation	0.25	3.8	338	450	675
Watte Basin	16	regulation	0.25	4.0	360	480	720
Ambercrombie Basin	11	regulation	0.25	2.8	248	330	495
TOTAL RECHARGE CELL AREA	922.9	TOTAL RECHARGE VOLUMES:		467	42,002	56,002	84,004
TOTAL REGULATION CELL AREA	196.0						
TOTAL COMBINED AREA	1,118.9						

[a] Basin/cell areas for the basins investigated (Creamline Basin down through Martin Basin shown above) were determined by Montgomery & Associates by digitizing the basin boundaries using Geographic Information Systems (GIS) based on recent aerial photographs (BING™ imagery). Basin acreages for the remaining basins were taken from Table 3 of HydroMetrics WRI's 2015 report.

[b] Basin types consist of "recharge" cells (used specifically for infiltrating water) and "regulation" cells (used for regulating/distributing water within the recharge system). Recharge and regulation cells are also known as "sinking" and "running" cells, respectively.

[c] The representative infiltration rate for each basin/cell is based on infiltration test results for the cells tested **(Table 2)** and is estimated/assumed for the remaining basins/cells, as described in **Section 5.1**.

[d] Daily recharge volume = basin/cell area multiplied by the representative infiltration rate

[e] Basin No. 3 North Cell is typically operated as a regulation cell even though designed as a recharge cell. For the purposes of the present study, it is considered a recharge cell.

[f] Cordeniz Basin is essentially an expansion of the Enterprise Basin and is currently under construction (indicated area is approximate); the entire basin area is assumed to be a recharge cell.

[g] Liberty Basin is a very shallow (bermed) field occasionally used for recharge; indicated area is approximate.

TABLE 4. ESTIMATED RECHARGE CAPACITY IMPROVEMENT AND COSTS FOR DEEPENING SELECTED RECHARGE BASINS, TULARE IRRIGATION DISTRICT, TULARE COUNTY, CALIFORNIA

	CREAMLINE BASIN SOUTHEAST CELL	BASIN NO. 6 NORTH CELL		MARTIN BASIN
		5 FEET[a]	3 FEET[a]	
APPROXIMATE BASIN AREA (acres)	27.6	47.4	47.4	14.3
CURRENT INFILTRATION RATE (feet/day)[b]	0.5	0.25	0.25	0.6
ESTIMATED INFILTRATION RATE FOR DEEPENED BASIN (feet/day)[c]	1.0	1.5	1.0	1.5
ESTIMATED INCREASE IN INFILTRATION RATE FOR DEEPENED BASIN (feet/day)	0.5	1.25	0.75	0.9
ESTIMATED INCREASE IN RECHARGE VOLUME[d] (acre-feet)				
Daily	13.8	59.3	35.6	12.9
90 Days	1,242	5,333	3,200	1,158
120 Days	1,656	7,110	4,266	1,544
180 Days	2,484	10,665	6,399	2,317
DEPTH OF DEEPENING (feet)[e]	5	5	3	4
VOLUME OF SPOIL (cubic yards)	222,640	490,120	337,176	92,283
EXCAVATION COST ($2.50/cy)[f]	$556,600	$1,225,300	$842,940	$230,707
NORMALIZED COST (per 0.5 foot/day increase)[g]	$556,600	$490,120	$561,960	$128,170
NORMALIZED COST (per 1,000 acre-feet increase assuming 90-day delivery)[h]	$448,148	$229,780	$263,460	$199,177
NUMBER OF DAYS TO RECHARGE ADDITIONAL 1,000 ACRE-FEET	72	17	28	78

[a] Two scenarios for basin deepening are provided for Basin No. 6 North Cell: (1) removal of 5 feet of sediments, which is estimated to increase infiltration capacity by 1.25 feet/day; and (2) removal of 3 feet of sediments, which is estimated to increase infiltration capacity by 0.75 feet/day

[b] Refer to **Section 4.2** of report and **Table 2**

[c] Refer to **Section 5.2** of report

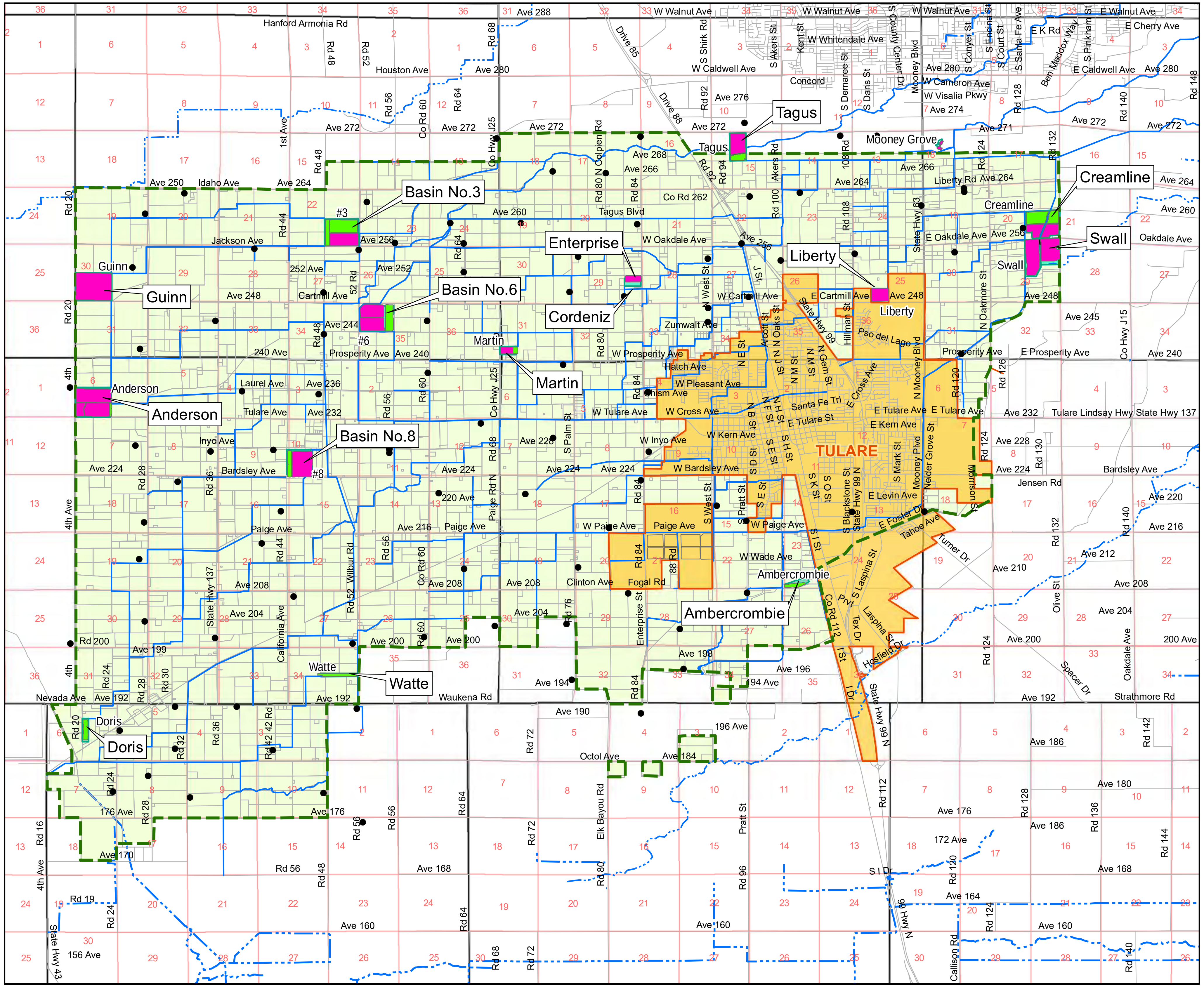
[d] Estimated increase in recharge volume equals the estimated increase in infiltration rate multiplied by the basin area multiplied by the surface water delivery period

[e] Refer to **Section 5.2** of report

[f] Excavation cost is based on a unit cost of $2.50 per cubic yard (cy), assuming that spoil is stockpiled on-site

[g] Excavation cost is expressed per unit of increased recharge capacity, where the unit is 0.5 feet/day

[h] Excavation cost is expressed per unit of increased recharge volume, where the unit is 1,000 acre-feet



EXPLANATION

- 🟩 Tulare Irrigation District Boundary
- 🟧 City Limits
- ― Tulare County Street
- Stream
- Creek
- Irrigation Ditch
- ● Deep Well

Type of Basin/Cell

- 🟪 Recharge
- 🟩 Regulation

N

0 1 2 3 4
Miles

Coordinate System: WGS84

TULARE IRRIGATION DISTRICT
FORMED IN 1889

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TULARE IRRIGATION DISTRICT

2018

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FIGURE 1

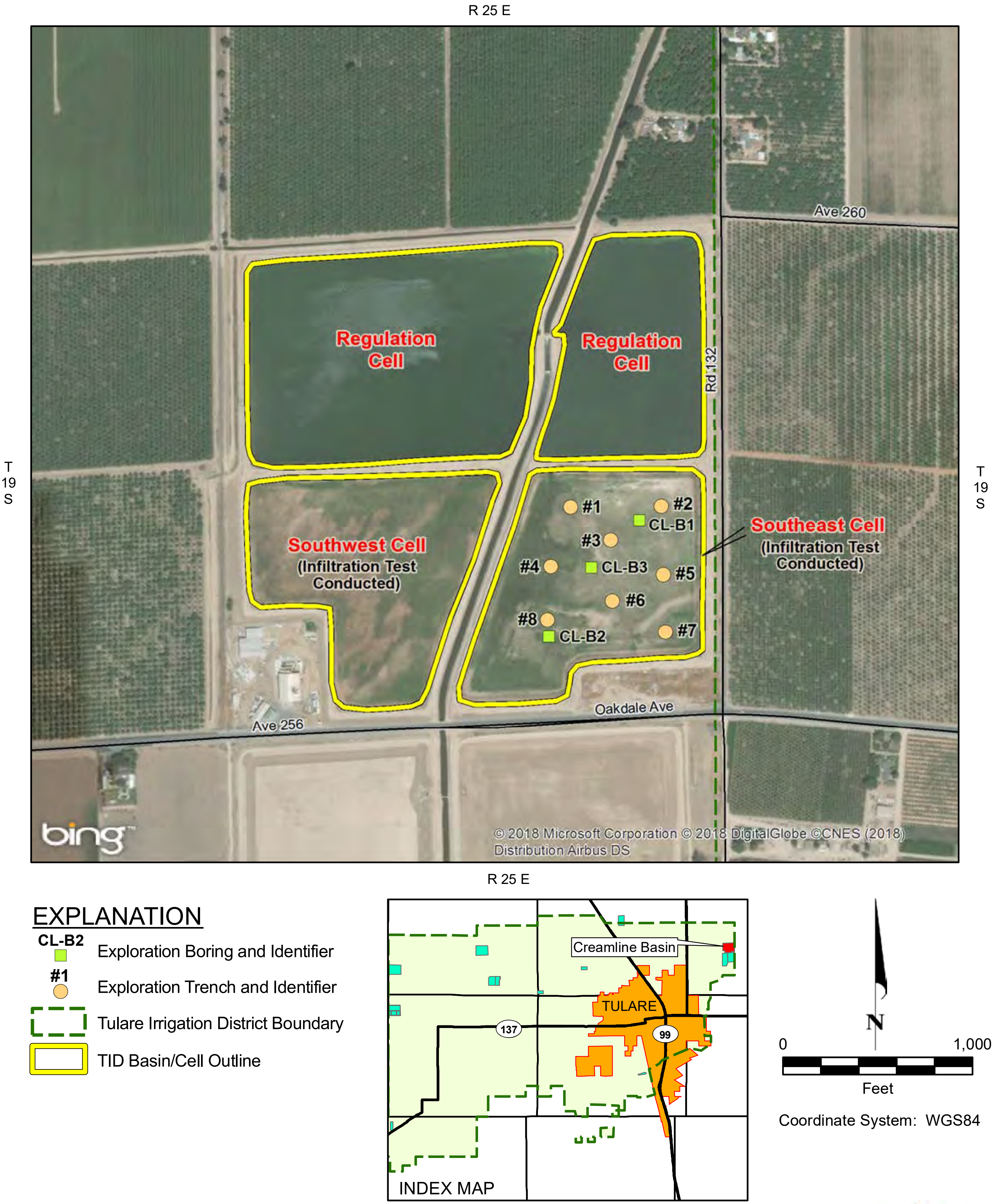

FIGURE 2. SITE MAP FOR CREAMLINE BASIN

GIS\1465\Basin_creamline\11October2017

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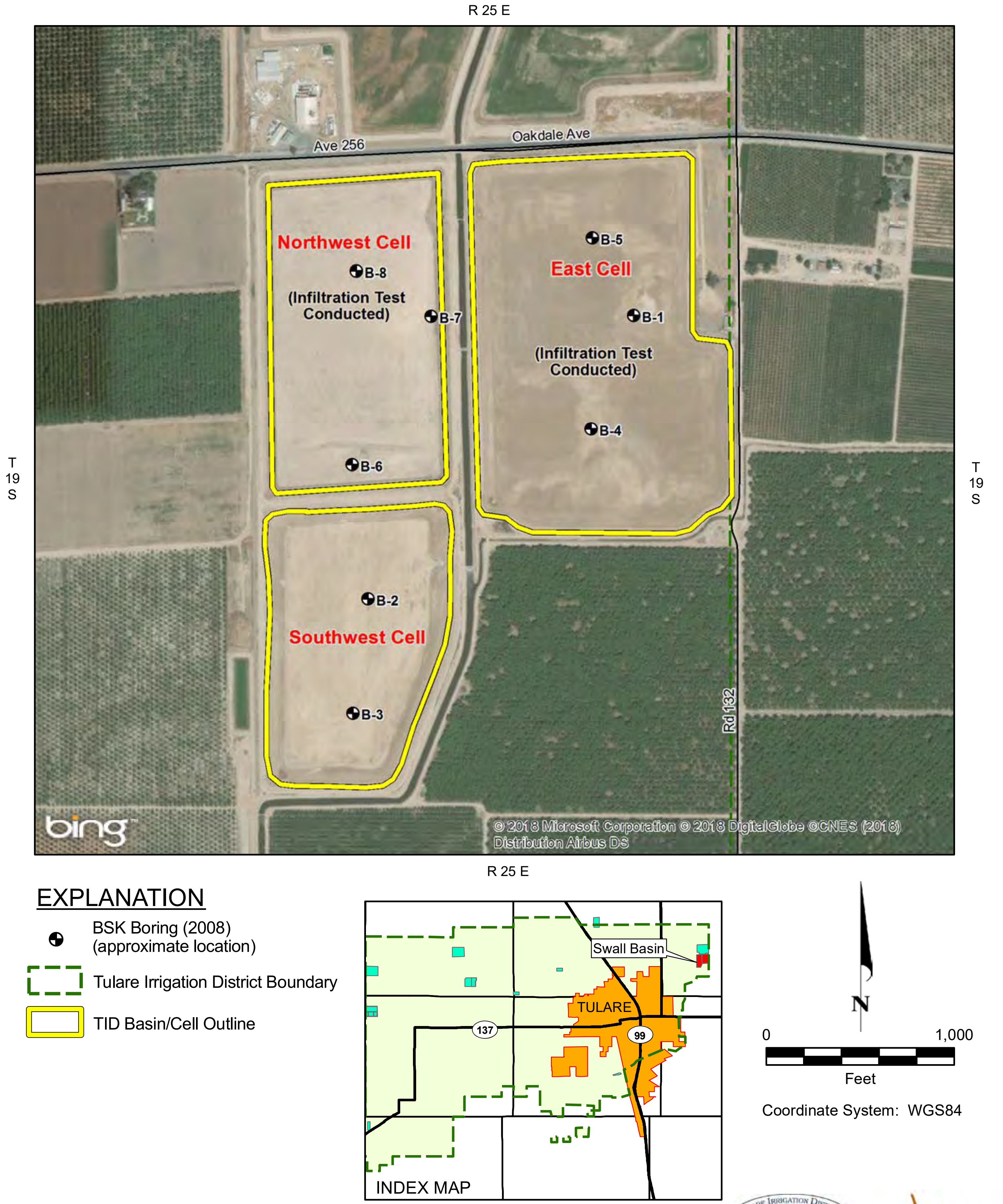

FIGURE 3. SITE MAP FOR SWALL BASIN

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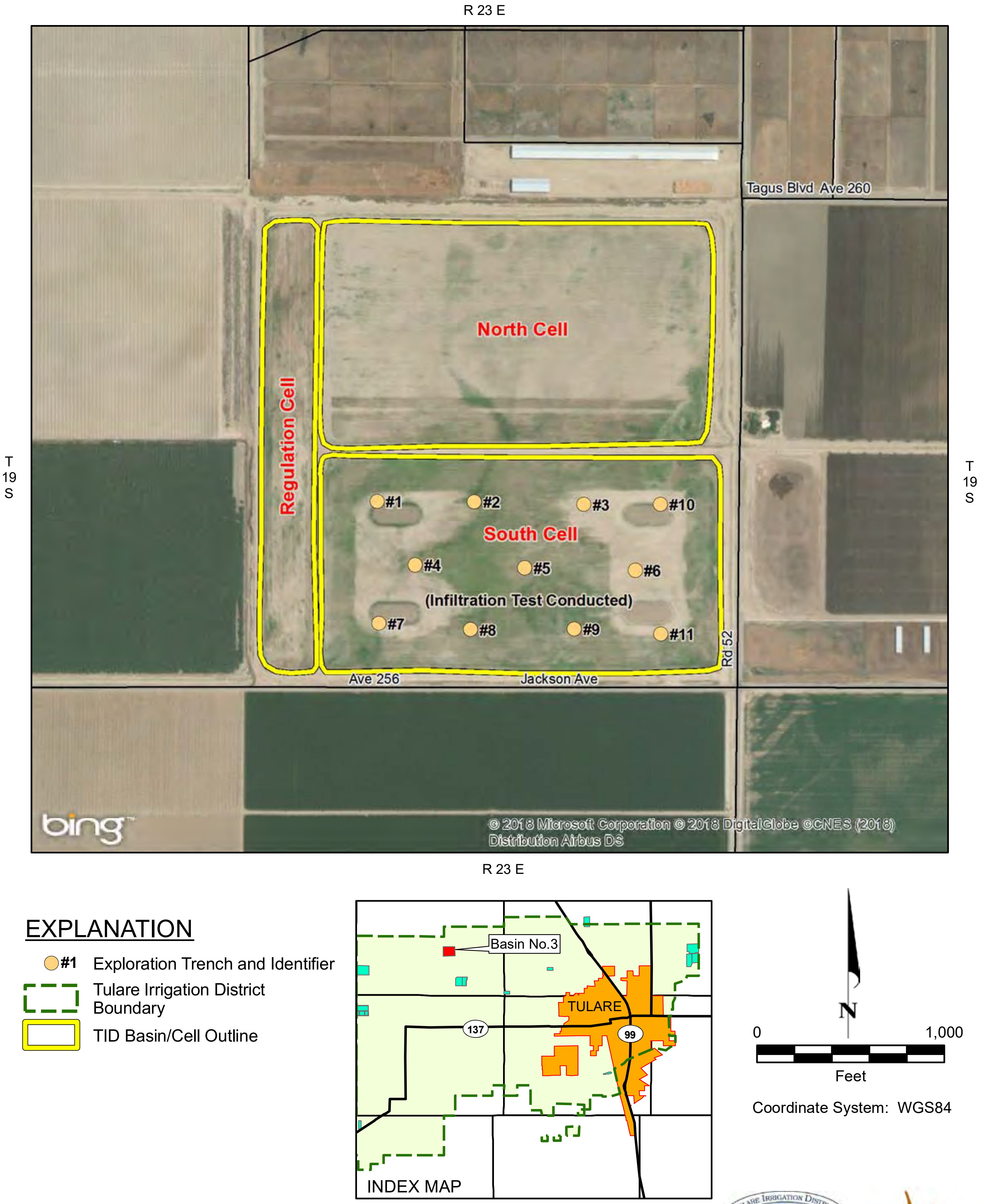

FIGURE 4. SITE MAP FOR BASIN NO.3

GIS\1465\Basin_Number3\06Oct2016

Tulare Irrigation District

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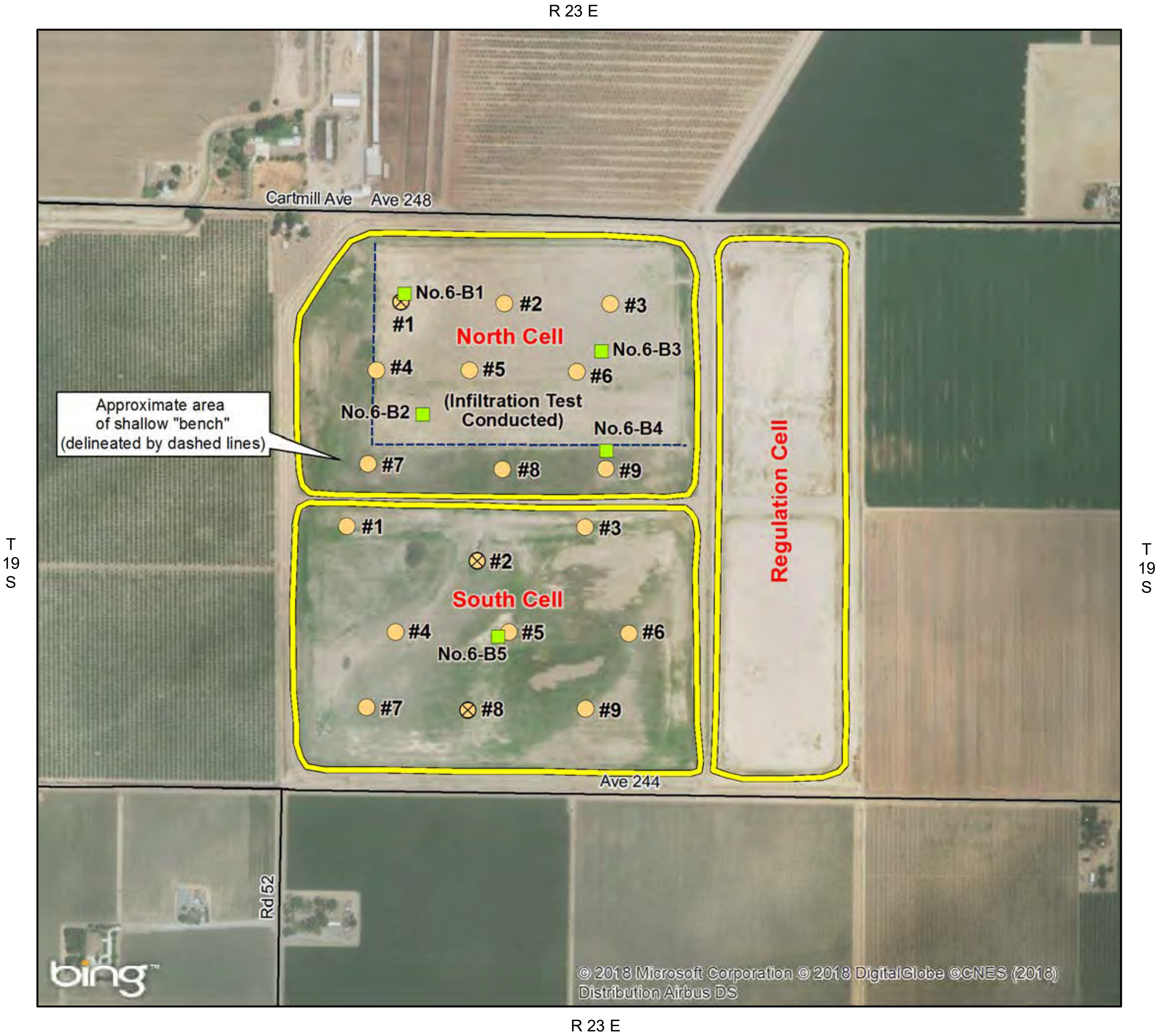


EXPLANATION

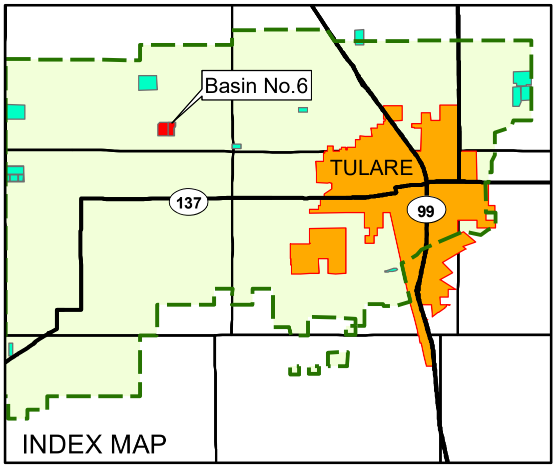
🟩 **No.6-B5** Exploration Boring and Identifier

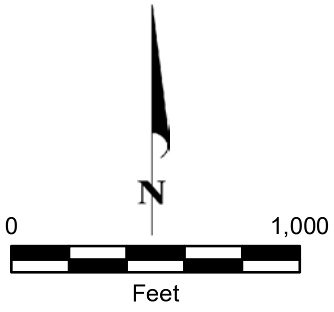
● **#2** Exploration Trench and Identifier

⊗ = planned but not excavated

▭ Tulare Irrigation District Boundary

▭ TID Basin/Cell Outline





Coordinate System: WGS84

FIGURE 5. SITE MAP FOR BASIN NO. 6

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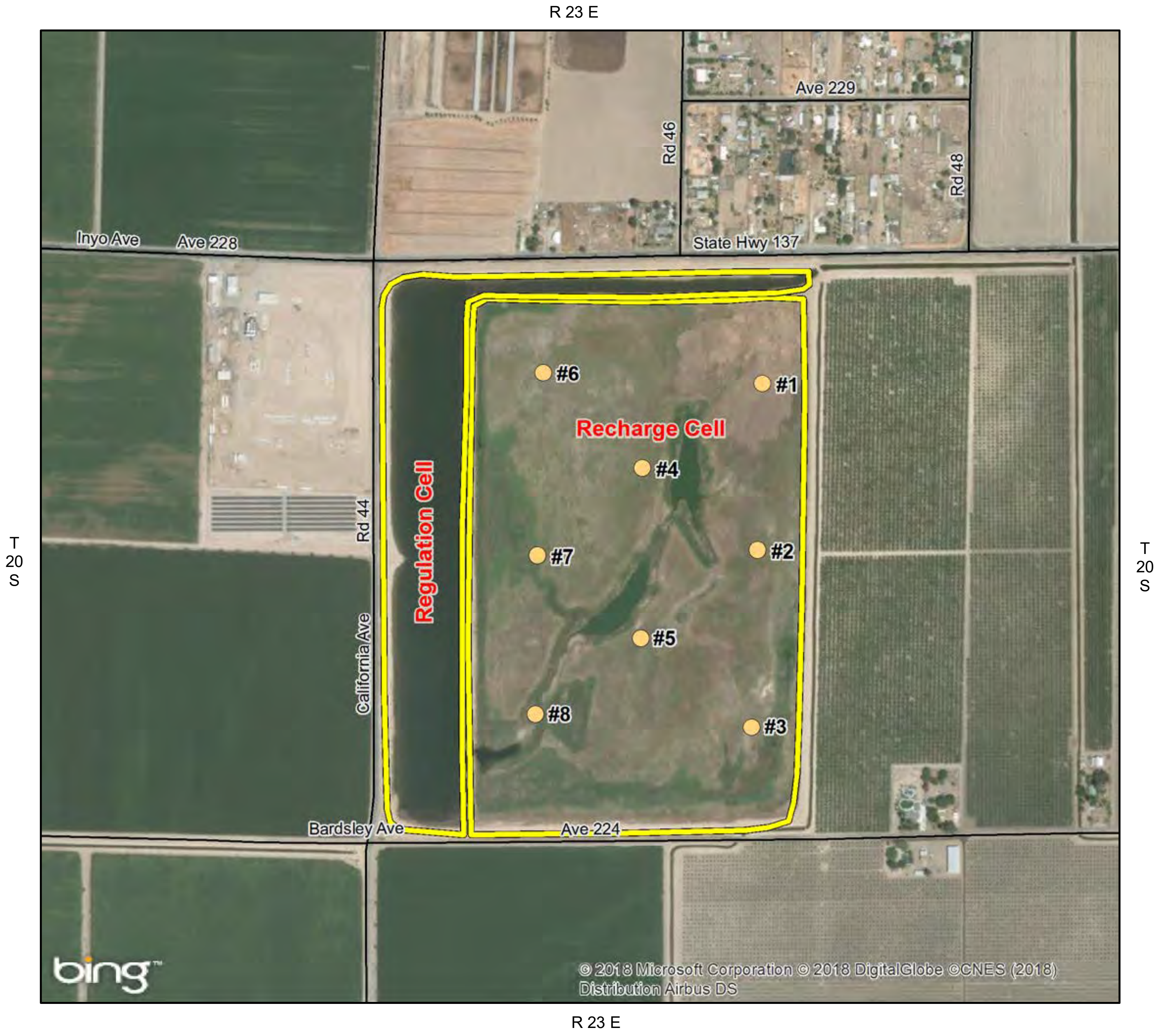
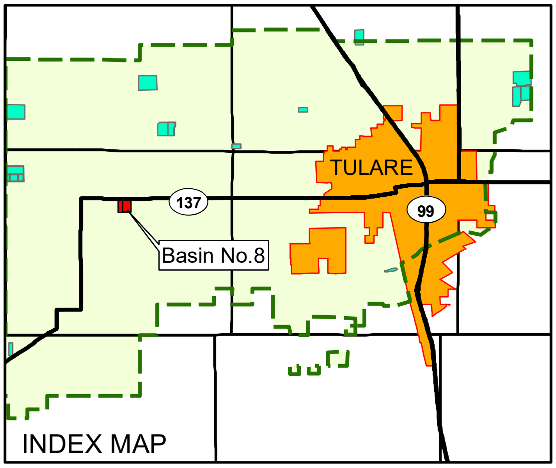
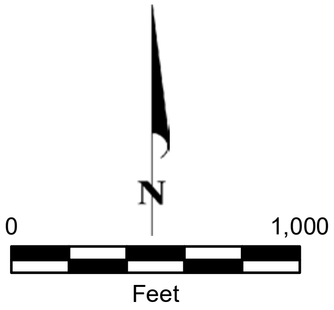
GIS\1465\Basin_Number6_V2\14Nov2017



EXPLANATION

#7 ●	Exploration Trench and Identifier
▭ (green dashed)	Tulare Irrigation District Boundary
▭ (yellow)	TID Basin/Cell Outline





Coordinate System: WGS84

FIGURE 6. SITE MAP FOR BASIN NO. 8

GIS\1465\Basin_Number 8\06Oct2017

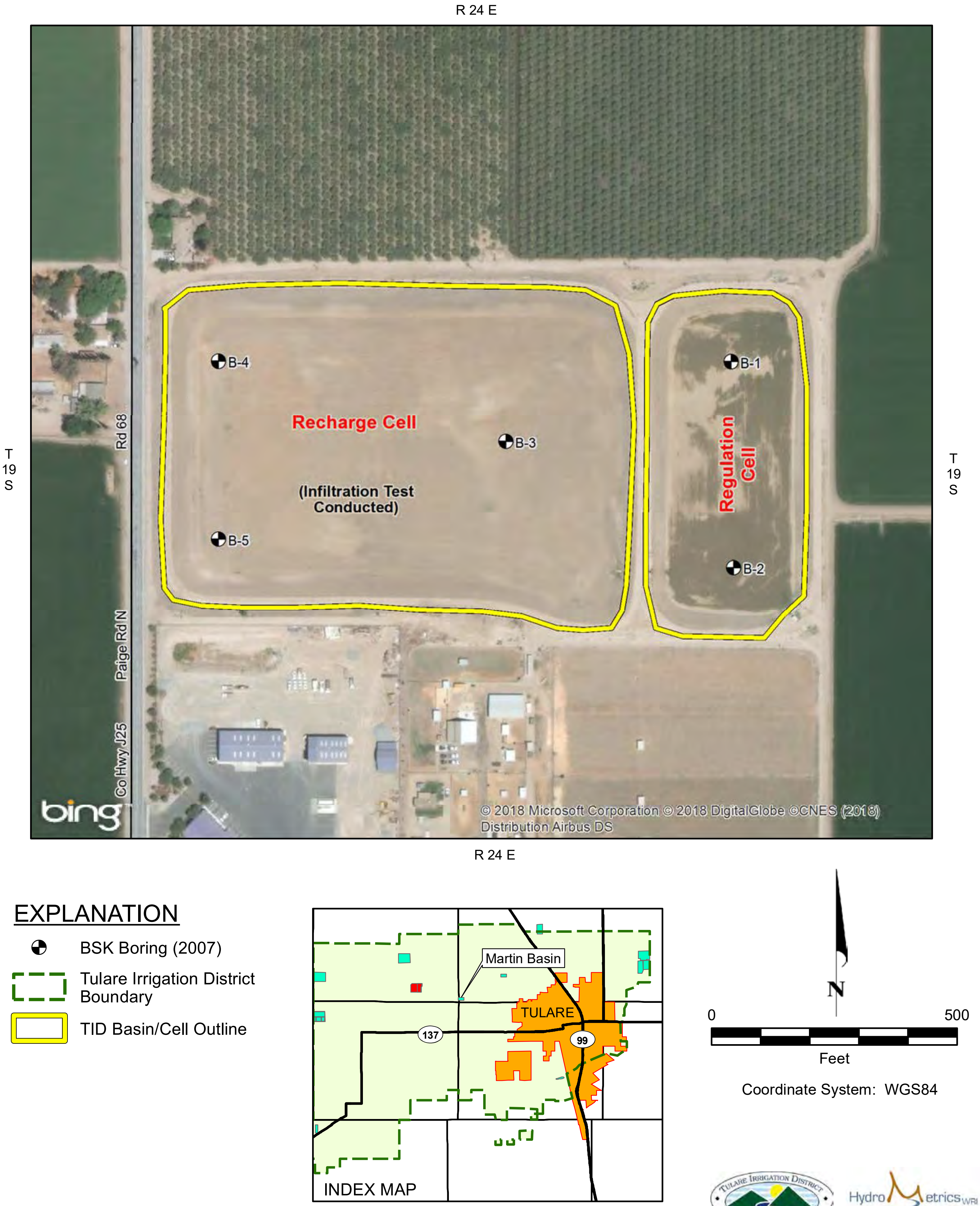
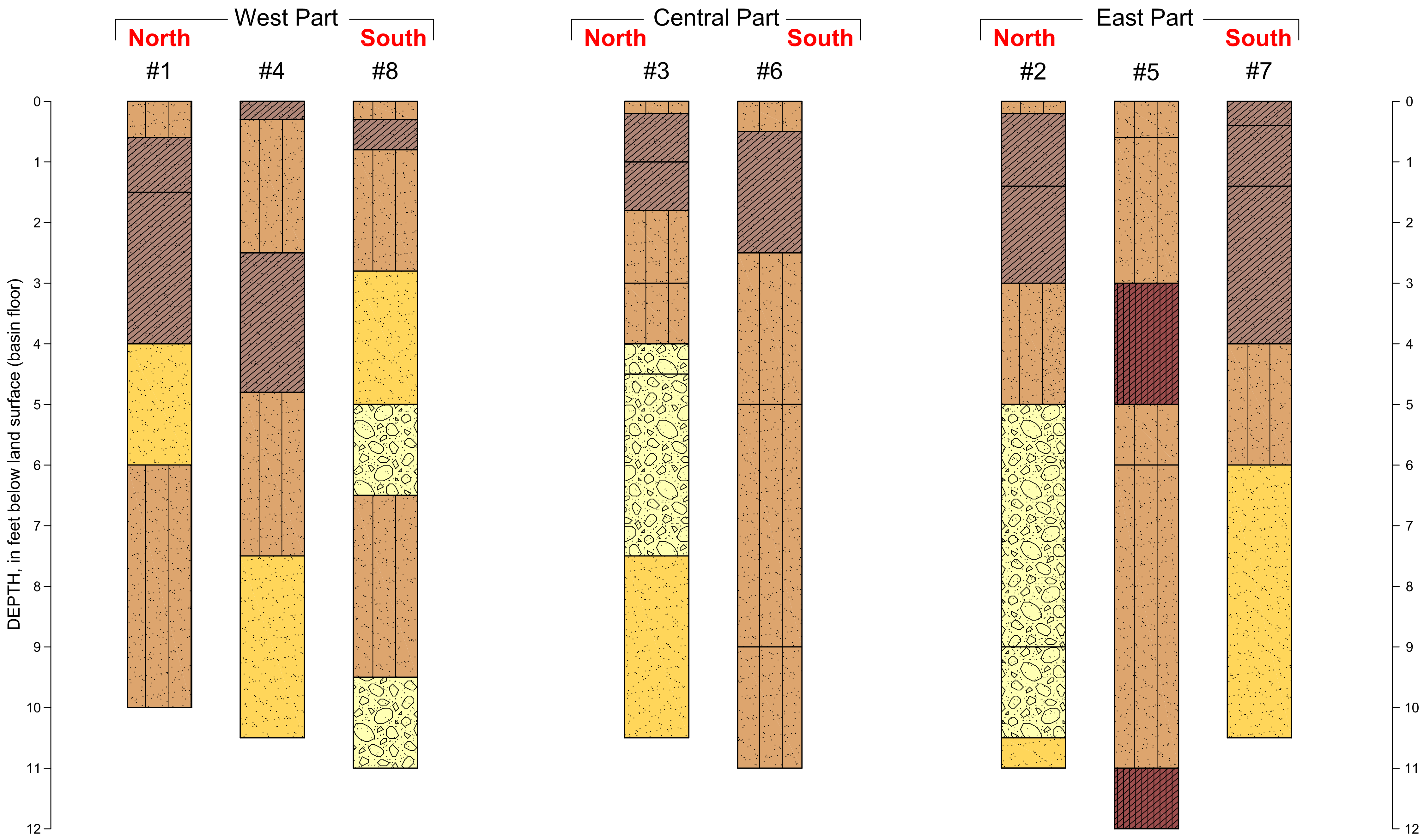


FIGURE 7. SITE MAP FOR MARTIN BASIN

GIS\1465\Basin_martin\09Oct2017



EXPLANATION

LITHOLOGIC/PERMEABILITY CATEGORIES

░	SAND; SILTY SAND (may have minor gravel content). Generally less than or equal to 20% silt; non-cohesive and non-lithified. VERY LARGE estimated permeability (>3 feet/day)
▒	SILTY (FINE) SAND, (may have minor clay content). Generally 25% to 35% silt and clay; generally non to slightly cohesive and non-lithified. LARGE estimated permeability (1.5 to 3 feet/day)
▥	SILTY (FINE) SAND, SANDY SILT, (CLAYEY) SANDY SILT. Generally 40% to 55% silt and clay; generally non to slightly cohesive and non-lithified, but includes some moderately cohesive sediments. MODERATE estimated permeability (0.8 to 1.5 feet/day)
▨	SANDY SILT; (CLAYEY) SANDY SILT. Generally 55% to 70% silt and clay; generally very slightly to moderately cohesive and non-lithified. SMALL estimated permeability (0.4 to 0.8 feet/day)
▩	(SANDY) CLAYEY SILT, (SANDY) SILT AND CLAY. Generally greater than or equal to 75% silt and clay; generally slightly to very cohesive. VERY SMALL estimated permeability (<0.4 feet/day)

Land surface elevation is relatively level across the basin

GRAPHIC LOGS FOR EXPLORATION TRENCHES AT CREAMLINE BASIN SOUTHEAST CELL

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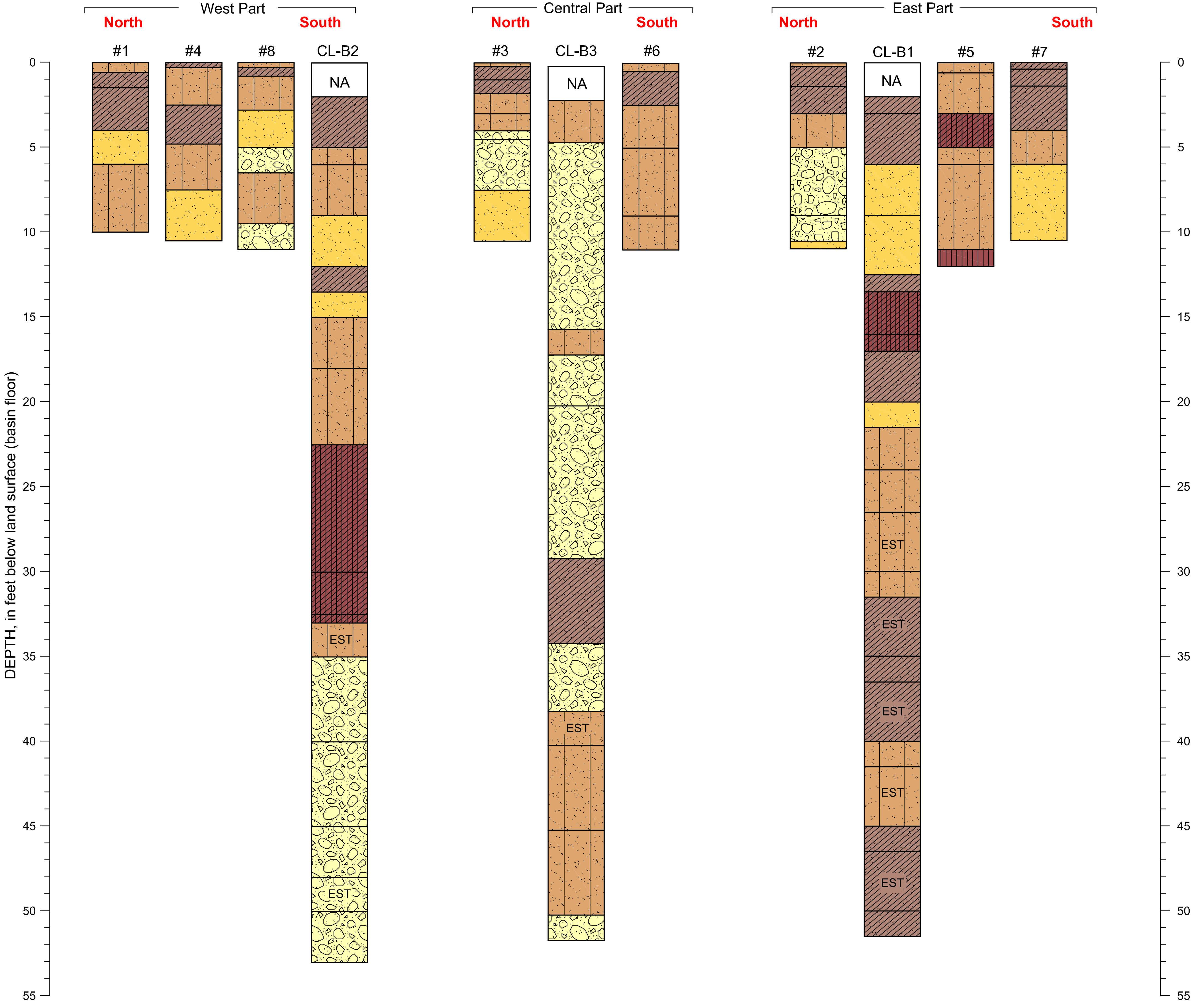
FIGURE 8

Drafting\1465.03\trenchXS_CreamlineBasin\26Feb2018



EXPLANATION

LITHOLOGIC/PERMEABILITY CATEGORIES

▒	SAND; SILTY SAND (may have minor gravel content). Generally less than or equal to 20% silt; non-cohesive and non-lithified. VERY LARGE estimated permeability (>3 feet/day)
🟨	SILTY (FINE) SAND, (may have minor clay content). Generally 25% to 35% silt and clay; generally non to slightly cohesive and non-lithified. LARGE estimated permeability (1.5 to 3 feet/day)
🟫	SILTY (FINE) SAND, SANDY SILT, (CLAYEY) SANDY SILT. Generally 40% to 55% silt and clay; generally non to slightly cohesive and non-lithified, but includes some moderately cohesive sediments. MODERATE estimated permeability (0.8 to 1.5 feet/day)
▨	SANDY SILT; (CLAYEY) SANDY SILT. Generally 55% to 70% silt and clay; generally very slightly to moderately cohesive and non-lithified. SMALL estimated permeability (0.4 to 0.8 feet/day)
🟥	(SANDY) CLAYEY SILT, (SANDY) SILT AND CLAY. Generally greater than or equal to 75% silt and clay; generally slightly to very cohesive. VERY SMALL estimated permeability (<0.4 feet/day)

Land surface elevation is relatively level across the basin

NA = Not Available (no lithologic description)

EST = Estimated lithology based on auger cuttings

GRAPHIC LOGS FOR EXPLORATION BORINGS AND TRENCHES AT CREAMLINE BASIN SOUTHEAST CELL

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FIGURE 9

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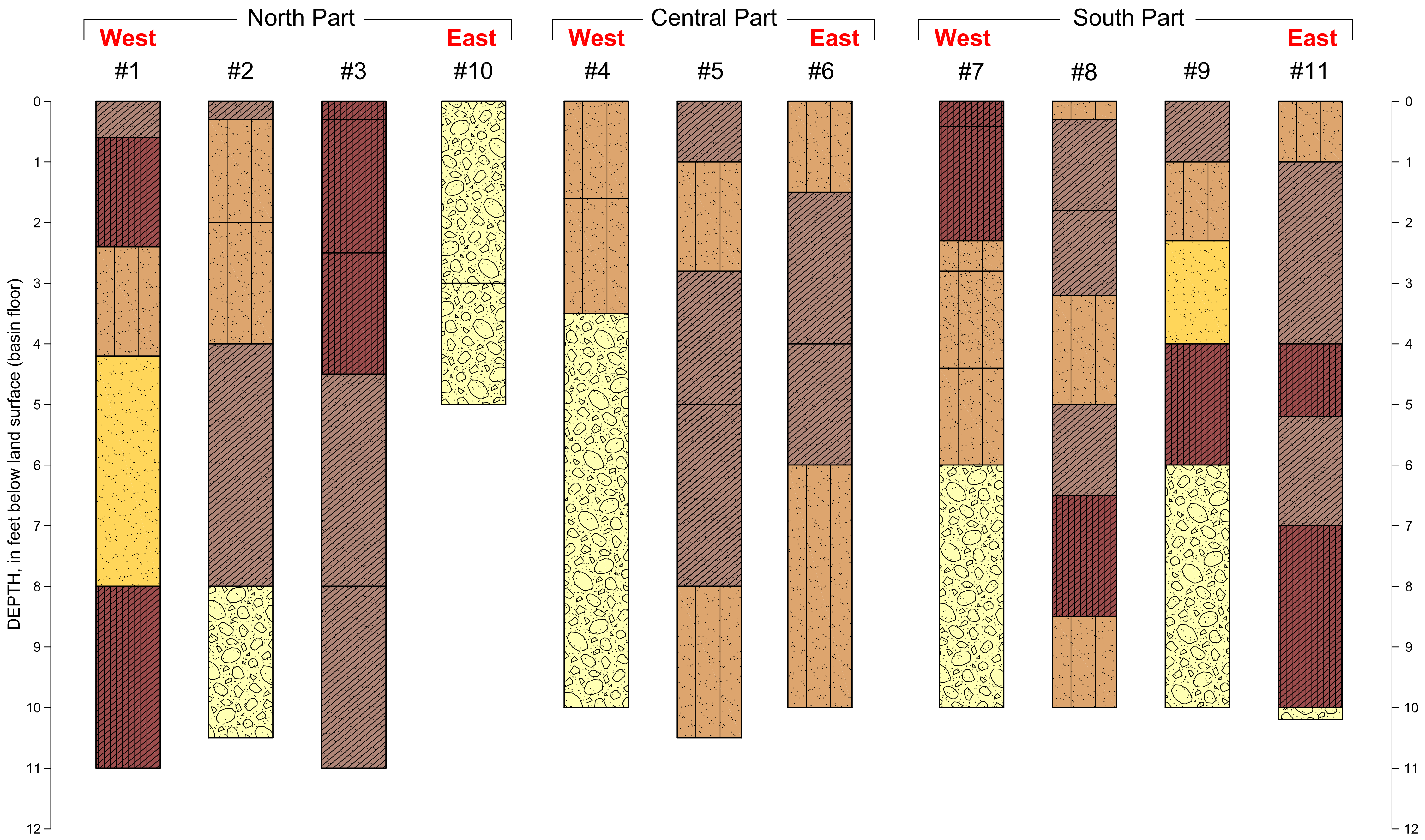

EXPLANATION

LITHOLOGIC/PERMEABILITY CATEGORIES

▨	SAND; SILTY SAND (may have minor gravel content). Generally less than or equal to 20% silt; non-cohesive and non-lithified. VERY LARGE estimated permeability (>3 feet/day)
▨	SILTY (FINE) SAND, (may have minor clay content). Generally 25% to 35% silt and clay; generally non to slightly cohesive and non-lithified. LARGE estimated permeability (1.5 to 3 feet/day)
▨	SILTY (FINE) SAND, SANDY SILT, (CLAYEY) SANDY SILT. Generally 40% to 55% silt and clay; generally non to slightly cohesive and non-lithified, but includes some moderately cohesive sediments. MODERATE estimated permeability (0.8 to 1.5 feet/day)
▨	SANDY SILT; (CLAYEY) SANDY SILT. Generally 55% to 70% silt and clay; generally very slightly to moderately cohesive and non-lithified. SMALL estimated permeability (0.4 to 0.8 feet/day)
▨	(SANDY) CLAYEY SILT, (SANDY) SILT AND CLAY. Generally greater than or equal to 75% silt and clay; generally slightly to very cohesive. VERY SMALL estimated permeability (<0.4 feet/day)

Land surface elevation is relatively level across the basin

Tulare Irrigation District
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GRAPHIC LOGS FOR EXPLORATION TRENCHES AT BASIN NO. 3 SOUTH CELL

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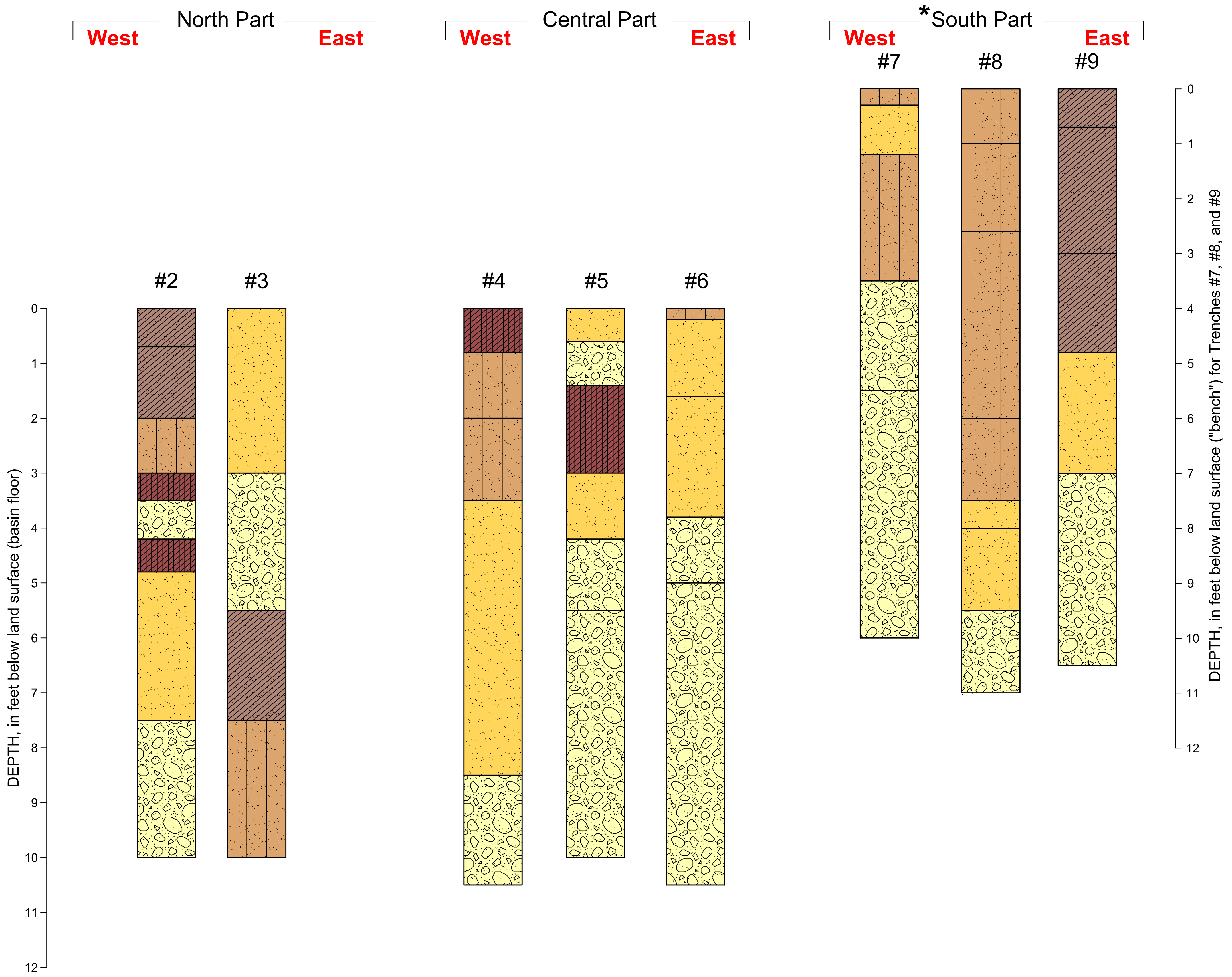
FIGURE 10

Drafting\1465.03\trenchXS_Basin#3\26Feb2018



EXPLANATION

LITHOLOGIC/PERMEABILITY CATEGORIES

░	SAND; SILTY SAND (may have minor gravel content). Generally less than or equal to 20% silt; non-cohesive and non-lithified. VERY LARGE estimated permeability (>3 feet/day)
🟨	SILTY (FINE) SAND, (may have minor clay content). Generally 25% to 35% silt and clay; generally non to slightly cohesive and non-lithified. LARGE estimated permeability (1.5 to 3 feet/day)
▥	SILTY (FINE) SAND, SANDY SILT, (CLAYEY) SANDY SILT. Generally 40% to 55% silt and clay; generally non to slightly cohesive and non-lithified, but includes some moderately cohesive sediments. MODERATE estimated permeability (0.8 to 1.5 feet/day)
▨	SANDY SILT; (CLAYEY) SANDY SILT. Generally 55% to 70% silt and clay; generally very slightly to moderately cohesive and non-lithified. SMALL estimated permeability (0.4 to 0.8 feet/day)
▩	(SANDY) CLAYEY SILT, (SANDY) SILT AND CLAY. Generally greater than or equal to 75% silt and clay; generally slightly to very cohesive. VERY SMALL estimated permeability (<0.4 feet/day)

*Land surface elevation is relatively level across the basin floor except for a 4-foot high bench along south and west sides of the basin (see Figure 5)

GRAPHIC LOGS FOR EXPLORATION TRENCHES AT BASIN NO. 6 NORTH CELL

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FIGURE 11

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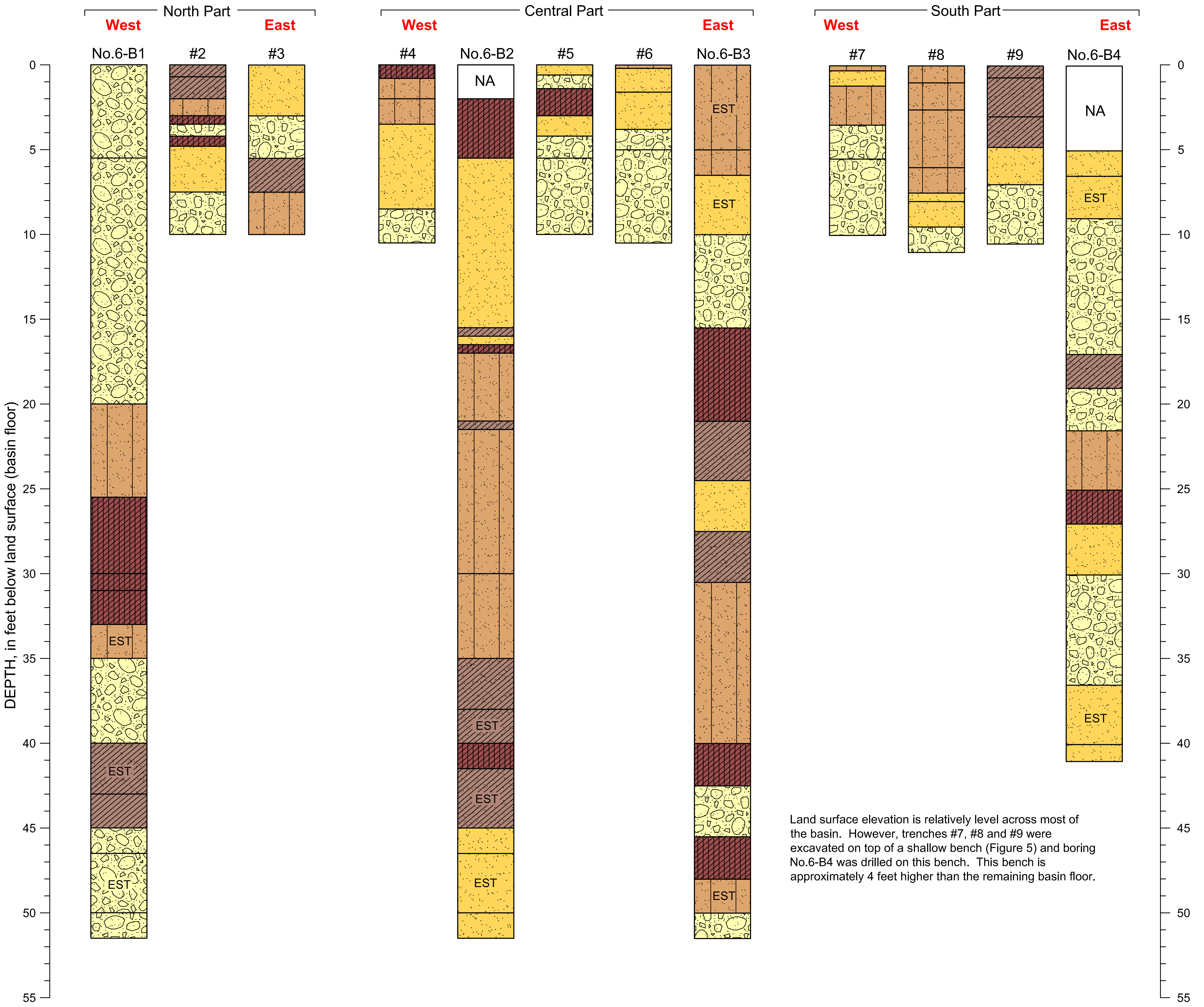

Land surface elevation is relatively level across most of the basin. However, trenches #7, #8 and #9 were excavated on top of a shallow bench (Figure 5) and boring No.6-B4 was drilled on this bench. This bench is approximately 4 feet higher than the remaining basin floor.

EXPLANATION

LITHOLOGIC/PERMEABILITY CATEGORIES

▨	SAND; SILTY SAND (may have minor gravel content). Generally less than or equal to 20% silt; non-cohesive and non-lithified. VERY LARGE estimated permeability (>3 feet/day)
🟨	SILTY (FINE) SAND, (may have minor clay content). Generally 25% to 35% silt and clay; generally non to slightly cohesive and non-lithified. LARGE estimated permeability (1.5 to 3 feet/day)
🟧	SILTY (FINE) SAND, SANDY SILT, (CLAYEY) SANDY SILT. Generally 40% to 55% silt and clay; generally non to slightly cohesive and non-lithified, but includes some moderately cohesive sediments. MODERATE estimated permeability (0.8 to 1.5 feet/day)
▨	SANDY SILT; (CLAYEY) SANDY SILT. Generally 55% to 70% silt and clay; generally very slightly to moderately cohesive and non-lithified. SMALL estimated permeability (0.4 to 0.8 feet/day)
🟥	(SANDY) CLAYEY SILT, (SANDY) SILT AND CLAY. Generally greater than or equal to 75% silt and clay; generally slightly to very cohesive. VERY SMALL estimated permeability (<0.4 feet/day)

NA = Not Available (no lithologic description)

EST = Estimated lithology based on auger cuttings

TULARE IRRIGATION DISTRICT
FORMED IN 1889

HydroMetrics WRI

GRAPHIC LOGS FOR EXPLORATION BORINGS AND TRENCHES AT BASIN NO.6 NORTH CELL

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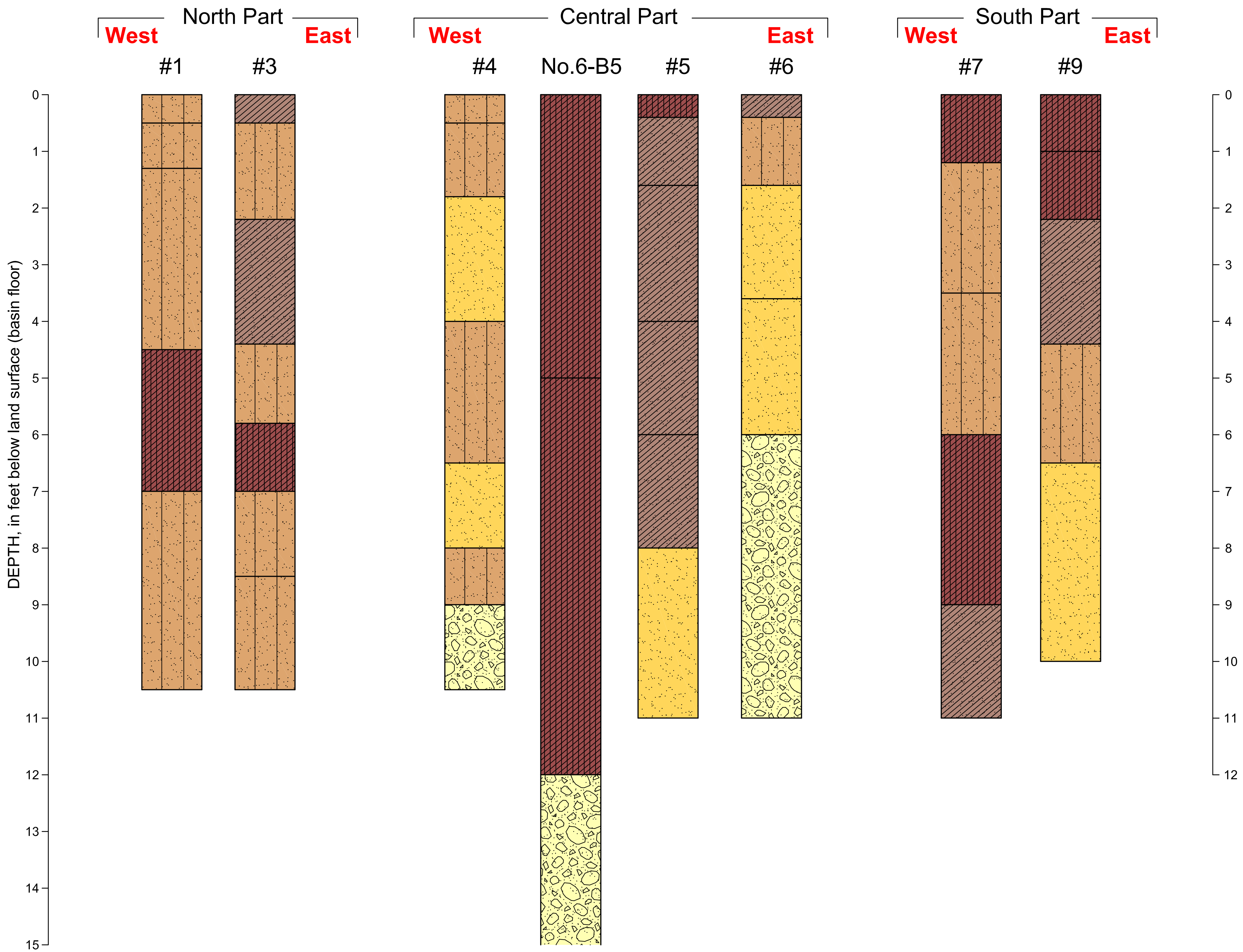
FIGURE 12

Drafting\1465.03\Trench_BoreholeXS_Basin#6NORTH\26Feb2018



Note: Boring No. 6-B5 was drilled to a depth of 32 feet but only the upper 15 feet are shown here.

EXPLANATION

LITHOLOGIC/PERMEABILITY CATEGORIES

▨	SAND; SILTY SAND (may have minor gravel content). Generally less than or equal to 20% silt; non-cohesive and non-lithified. VERY LARGE estimated permeability (>3 feet/day)
▨	SILTY (FINE) SAND, (may have minor clay content). Generally 25% to 35% silt and clay; generally non to slightly cohesive and non-lithified. LARGE estimated permeability (1.5 to 3 feet/day)
▨	SILTY (FINE) SAND, SANDY SILT, (CLAYEY) SANDY SILT. Generally 40% to 55% silt and clay; generally non to slightly cohesive and non-lithified, but includes some moderately cohesive sediments. MODERATE estimated permeability (0.8 to 1.5 feet/day)
▨	SANDY SILT; (CLAYEY) SANDY SILT. Generally 55% to 70% silt and clay; generally very slightly to moderately cohesive and non-lithified. SMALL estimated permeability (0.4 to 0.8 feet/day)
▨	(SANDY) CLAYEY SILT, (SANDY) SILT AND CLAY. Generally greater than or equal to 75% silt and clay; generally slightly to very cohesive. VERY SMALL estimated permeability (<0.4 feet/day)

Land surface elevation is somewhat uneven across the basin; however, elevations of the trench locations are reasonably consistent

GRAPHIC LOGS FOR EXPLORATION TRENCHES AT BASIN NO. 6 SOUTH CELL

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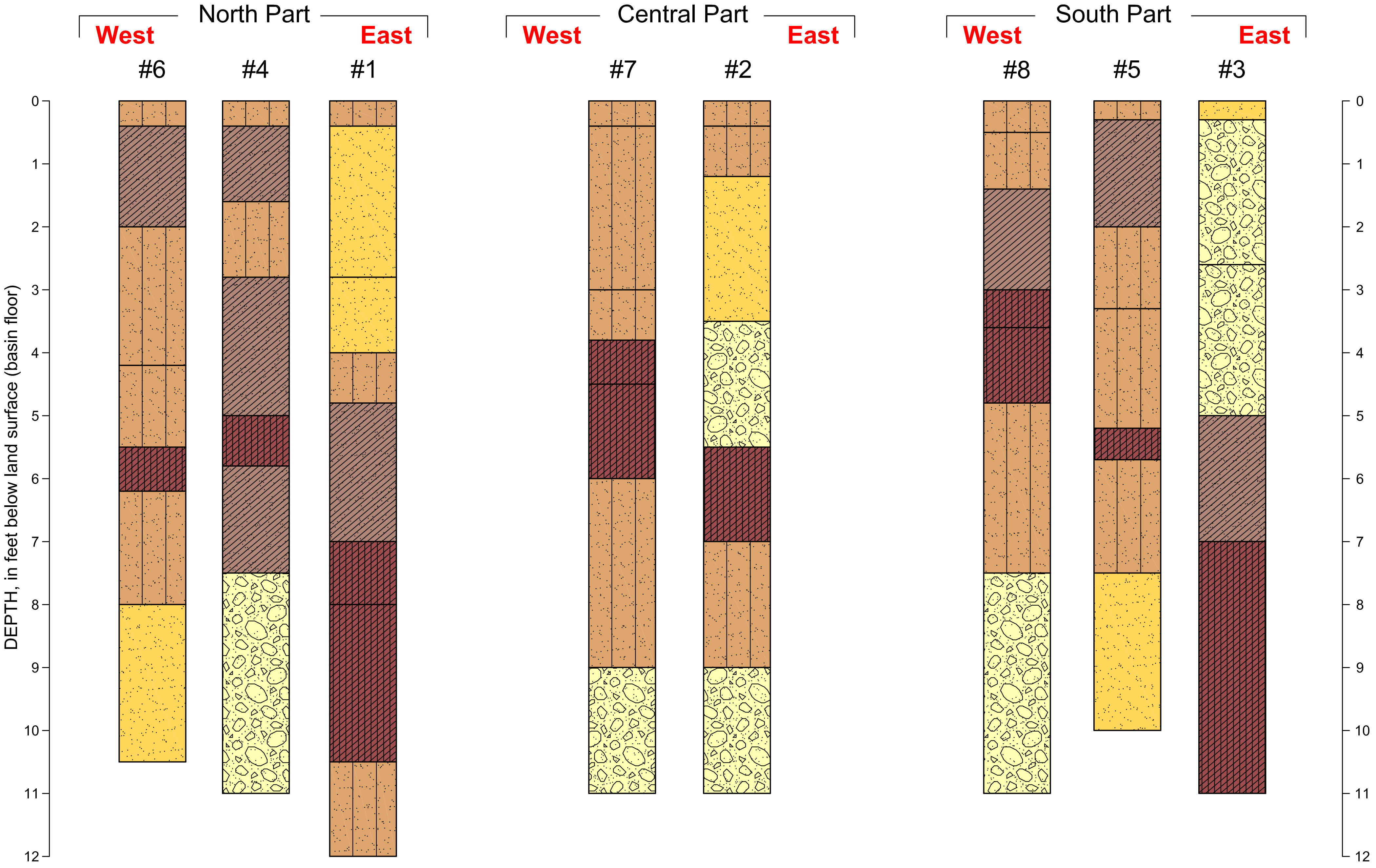
FIGURE 13

Drafting\1465.03\trenchXS_Basin#6_V2\26Feb2018



EXPLANATION

LITHOLOGIC/PERMEABILITY CATEGORIES

SAND; SILTY SAND (may have minor gravel content). Generally less than or equal to 20% silt; non-cohesive and non-lithified. VERY LARGE estimated permeability (>3 feet/day)

SILTY (FINE) SAND, (may have minor clay content). Generally 25% to 35% silt and clay; generally non to slightly cohesive and non-lithified. LARGE estimated permeability (1.5 to 3 feet/day)

SILTY (FINE) SAND, SANDY SILT, (CLAYEY) SANDY SILT. Generally 40% to 55% silt and clay; generally non to slightly cohesive and non-lithified, but includes some moderately cohesive sediments. MODERATE estimated permeability (0.8 to 1.5 feet/day)

SANDY SILT; (CLAYEY) SANDY SILT. Generally 55% to 70% silt and clay; generally very slightly to moderately cohesive and non-lithified. SMALL estimated permeability (0.4 to 0.8 feet/day)

(SANDY) CLAYEY SILT, (SANDY) SILT AND CLAY. Generally greater than or equal to 75% silt and clay; generally slightly to very cohesive. VERY SMALL estimated permeability (<0.4 feet/day)

The basin floor has substantial topographic variation but land surface elevations at the trench locations are generally similar

GRAPHIC LOGS FOR EXPLORATION TRENCHES AT BASIN NO. 8

2018

MONTGOMERY & ASSOCIATES
Water Resource Consultants

FIGURE 14

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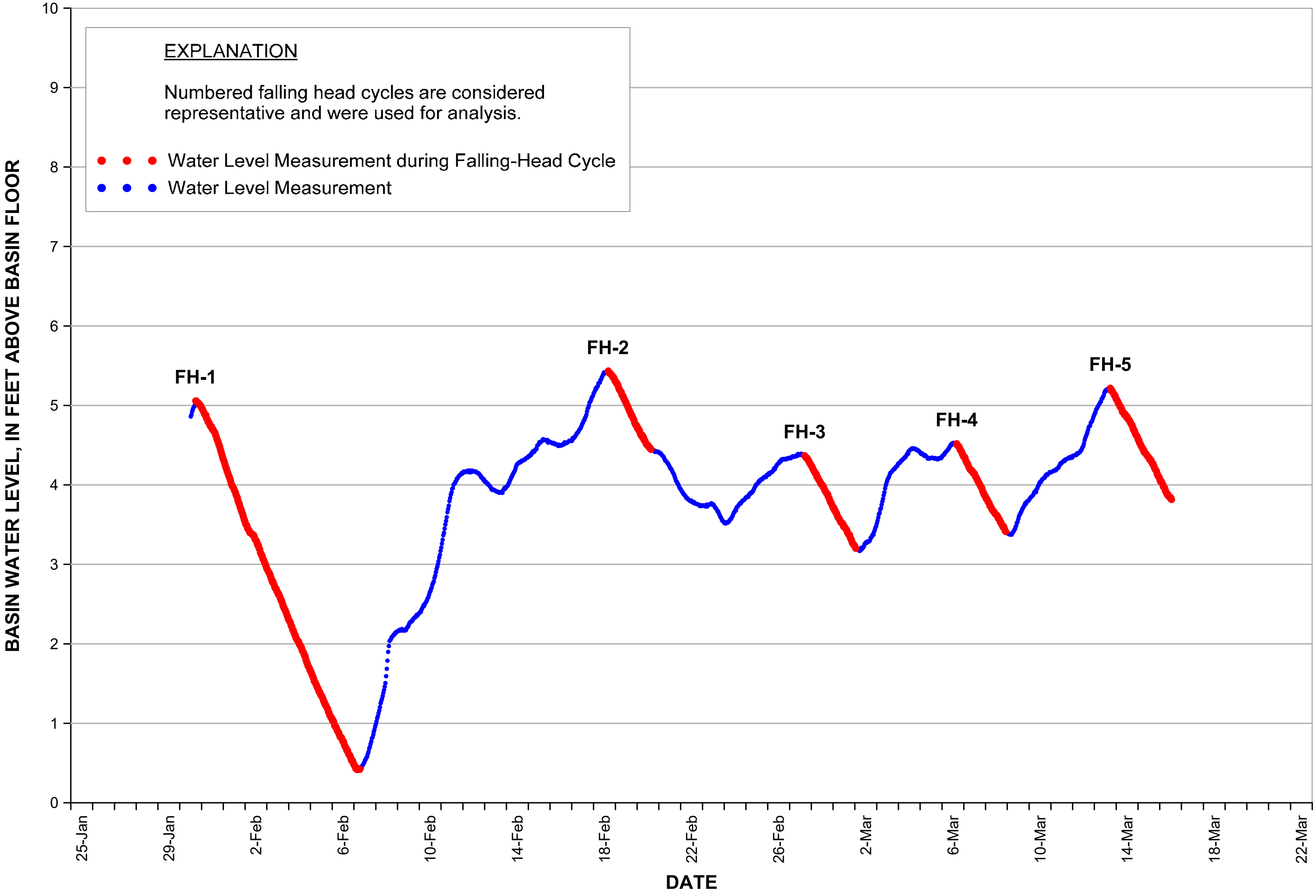

FIGURE 15. CREAMLINE BASIN SOUTHEAST CELL: HYDROGRAPH OF FALLING-HEAD CYCLES FOR OPERATIONAL INFILTRATION TESTS
TULARE IRRIGATION DISTRICT

MONTGOMERY & ASSOCIATES

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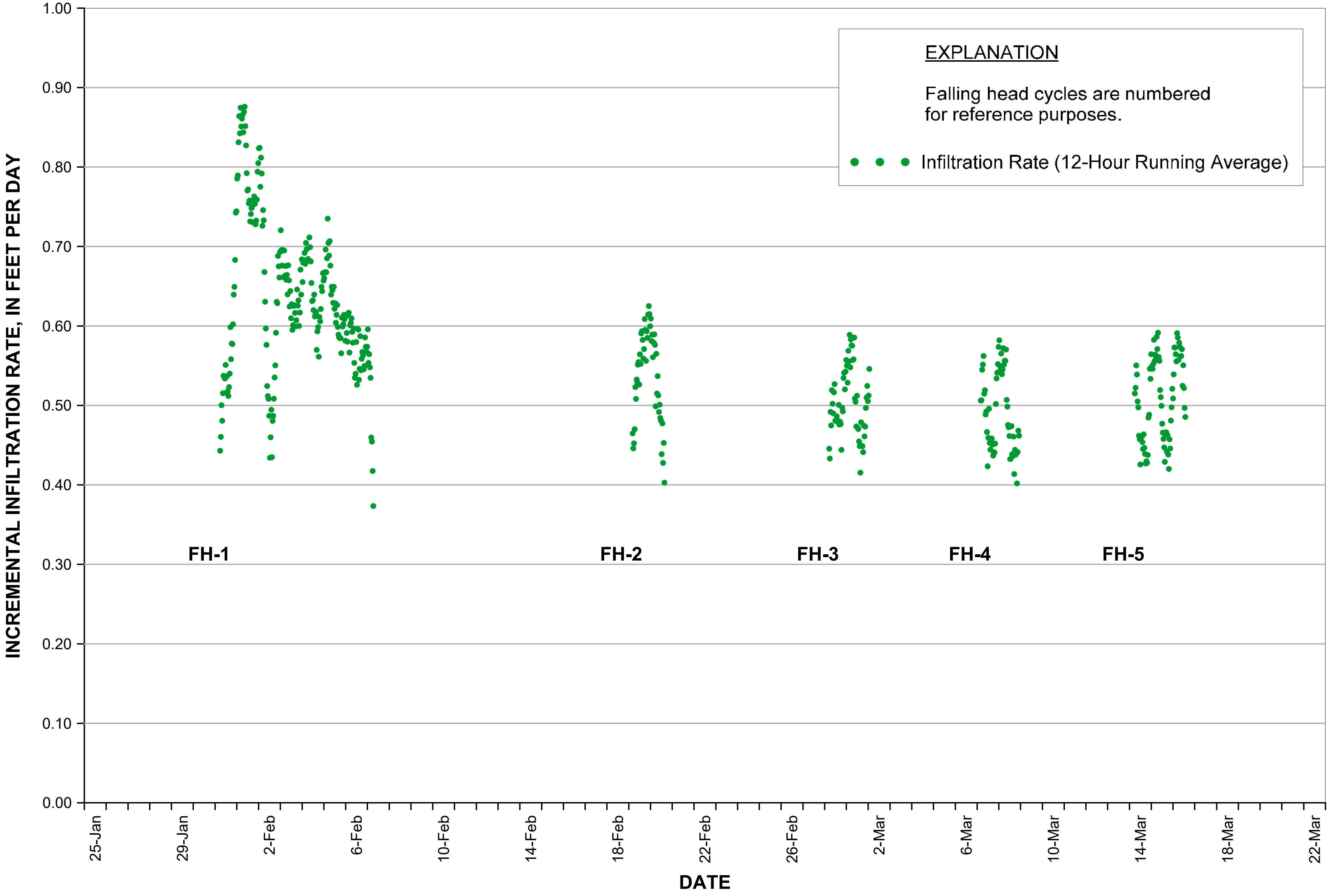

FIGURE 16. CREAMLINE BASIN SOUTHEAST CELL: INCREMENTAL INFILTRATION RATES MEASURED DURING FALLING-HEAD CYCLES TULARE IRRIGATION DISTRICT

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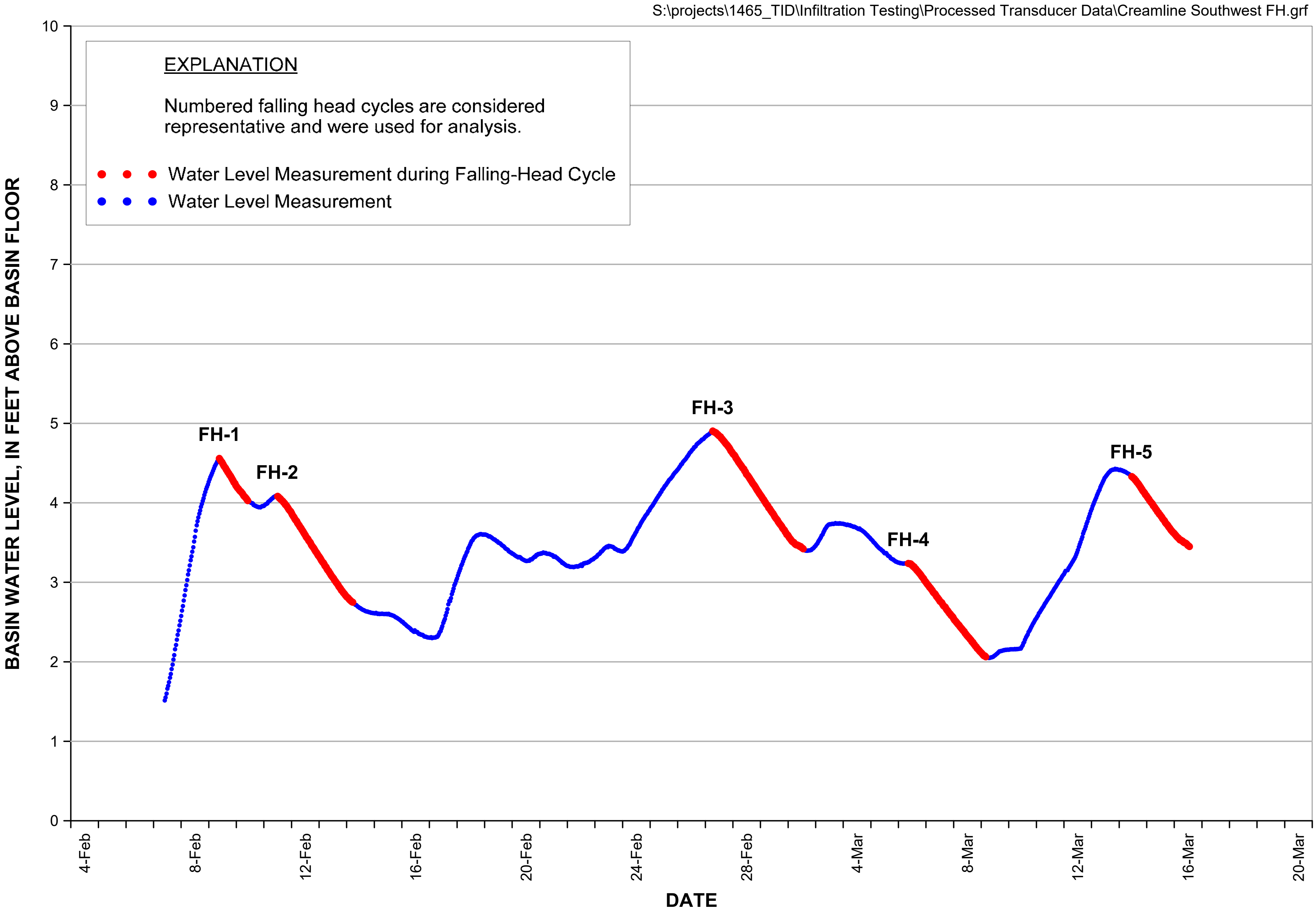

FIGURE 17. CREAMLINE BASIN SOUTHWEST CELL: HYDROGRAPH OF FALLING-HEAD CYCLES FOR OPERATIONAL INFILTRATION TESTS
TULARE IRRIGATION DISTRICT

MONTGOMERY & ASSOCIATES

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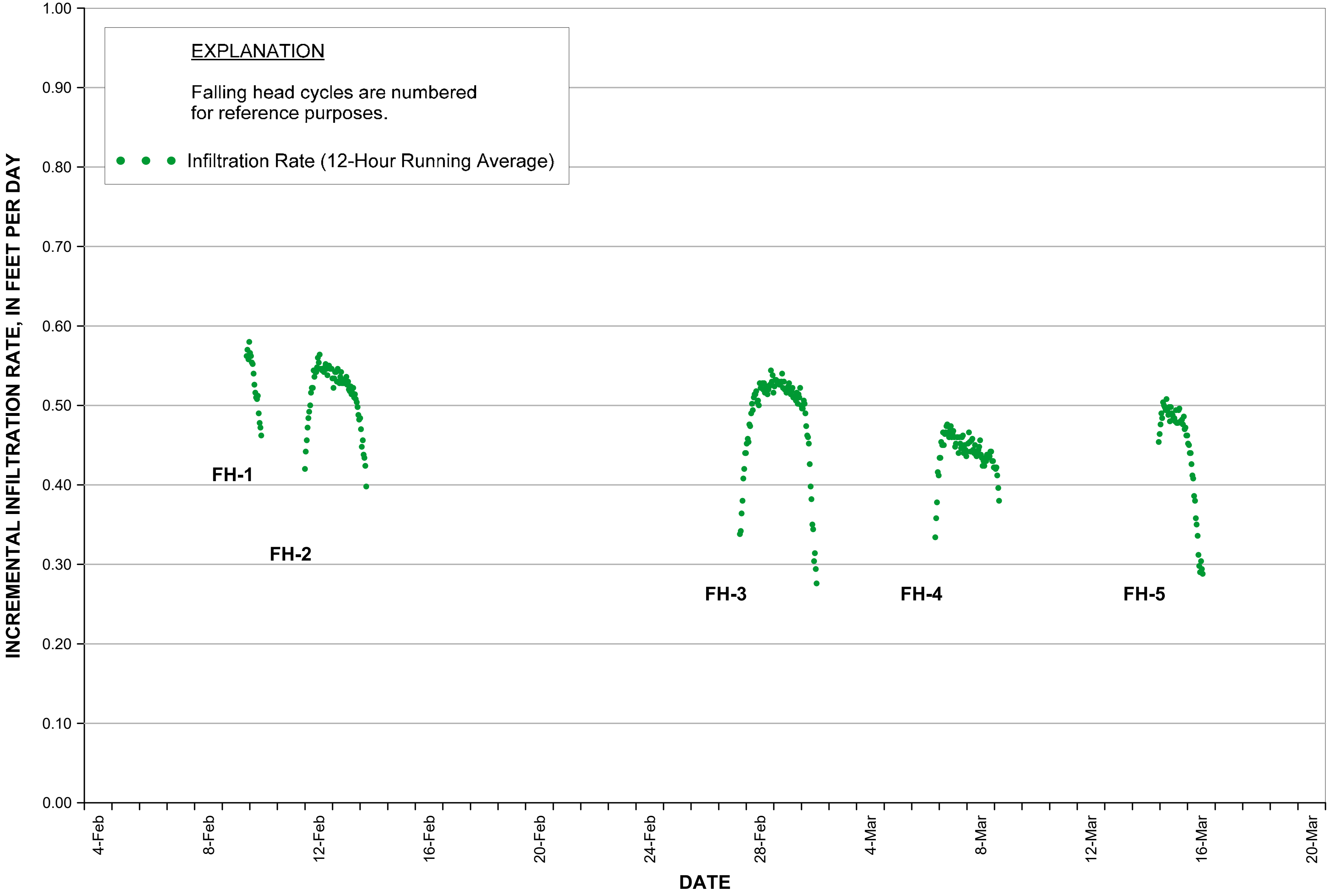

FIGURE 18. CREAMLINE BASIN SOUTHWEST CELL: INCREMENTAL INFILTRATION RATES MEASURED DURING FALLING-HEAD CYCLES TULARE IRRIGATION DISTRICT

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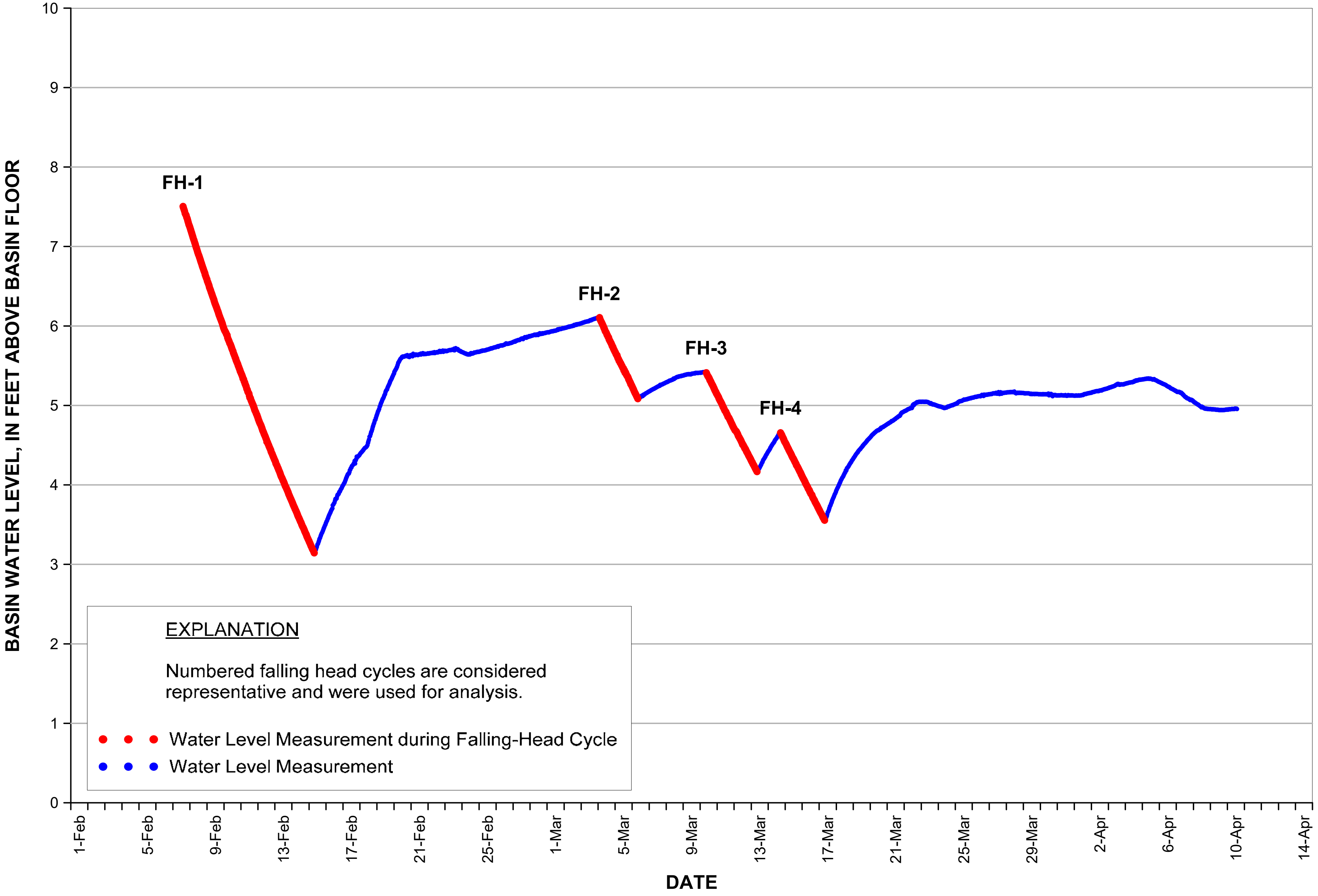

FIGURE 19. SWALL BASIN EAST CELL: HYDROGRAPH OF FALLING-HEAD
CYCLES FOR OPERATIONAL INFILTRATION TESTS
TULARE IRRIGATION DISTRICT

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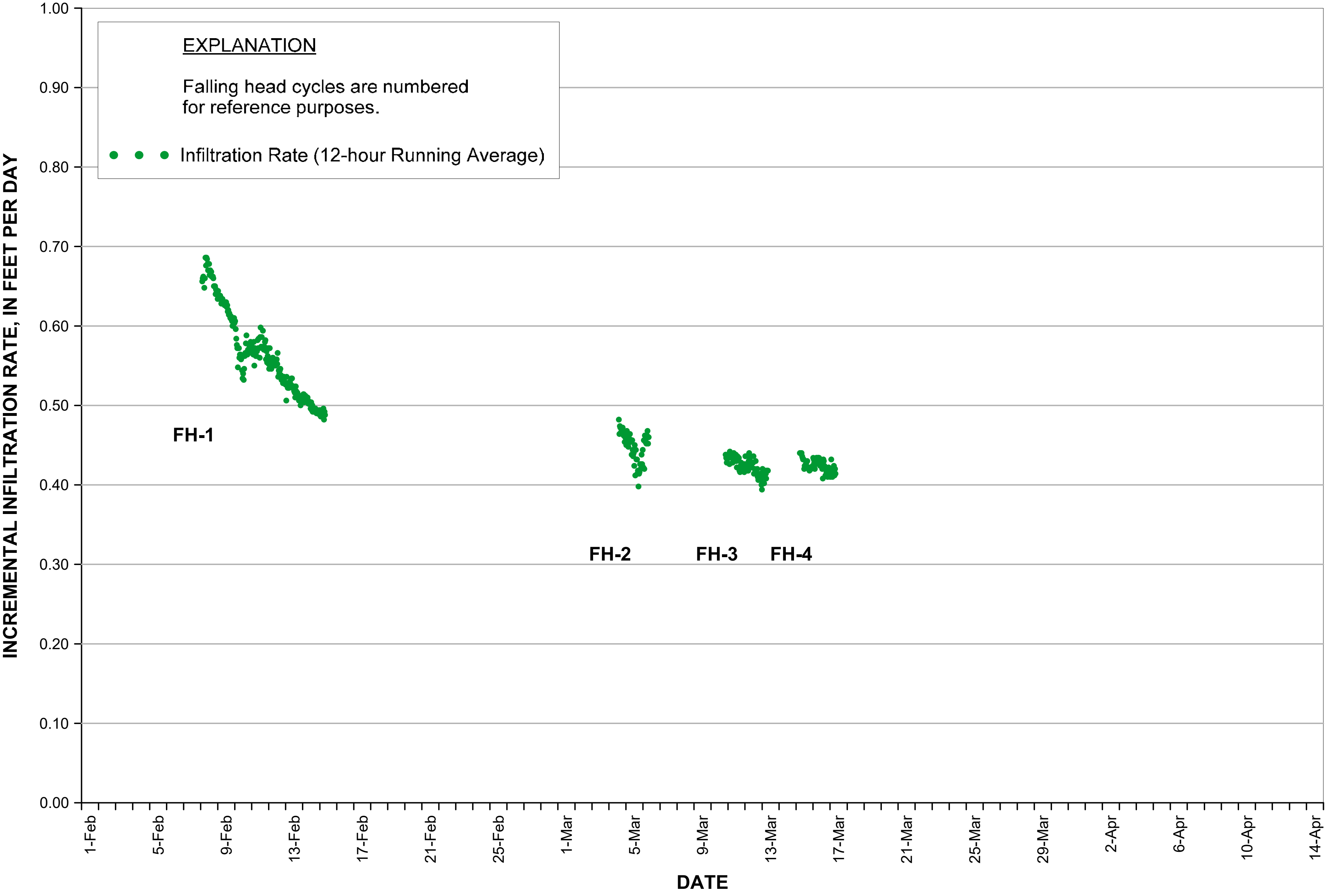

FIGURE 20. SWALL BASIN EAST CELL: INCREMENTAL INFILTRATION RATES MEASURED DURING FALLING-HEAD CYCLES TULARE IRRIGATION DISTRICT

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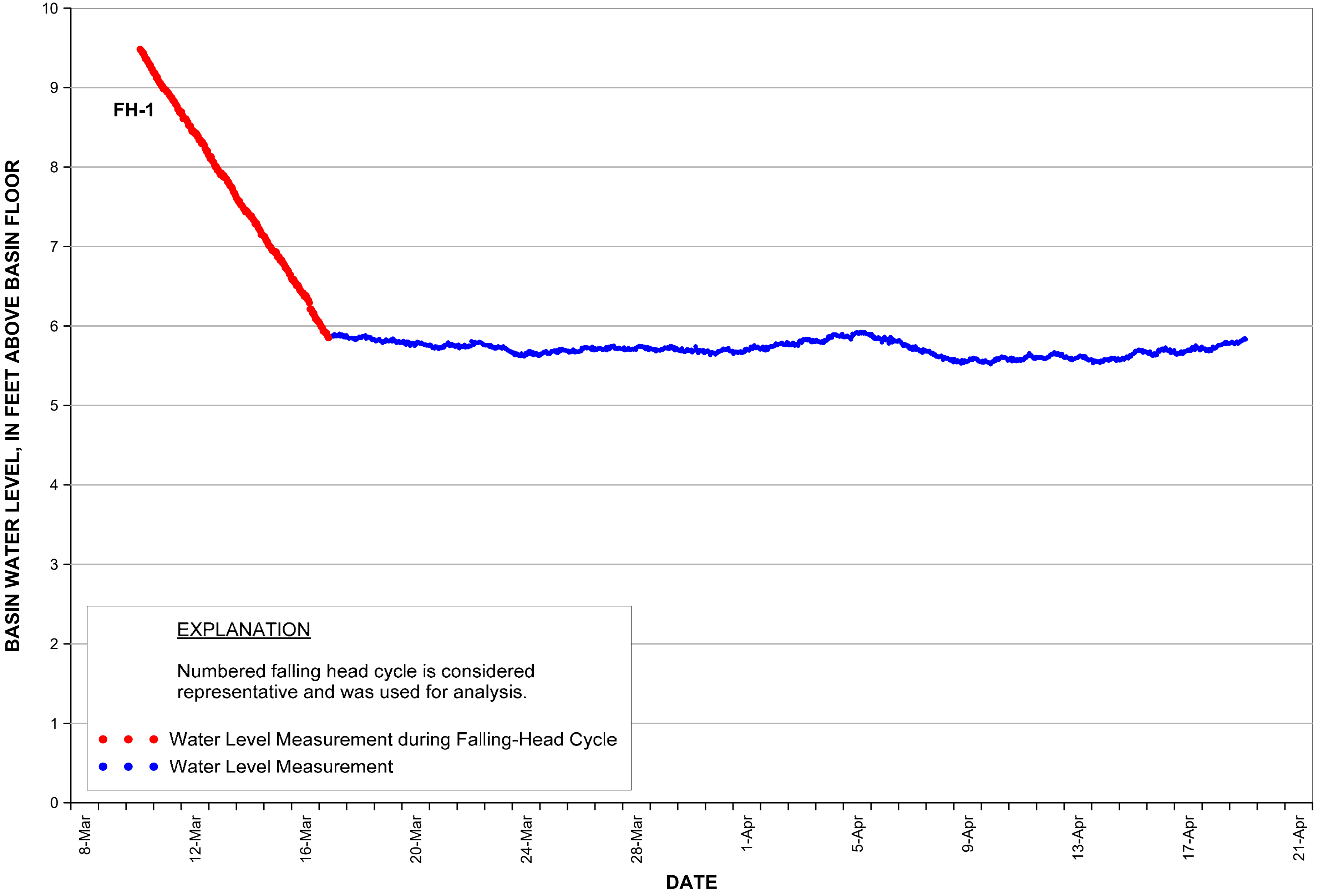

FIGURE 21. SWALL BASIN NORTHWEST CELL: HYDROGRAPH OF FALLING-HEAD CYCLES FOR OPERATIONAL INFILTRATION TESTS
TULARE IRRIGATION DISTRICT

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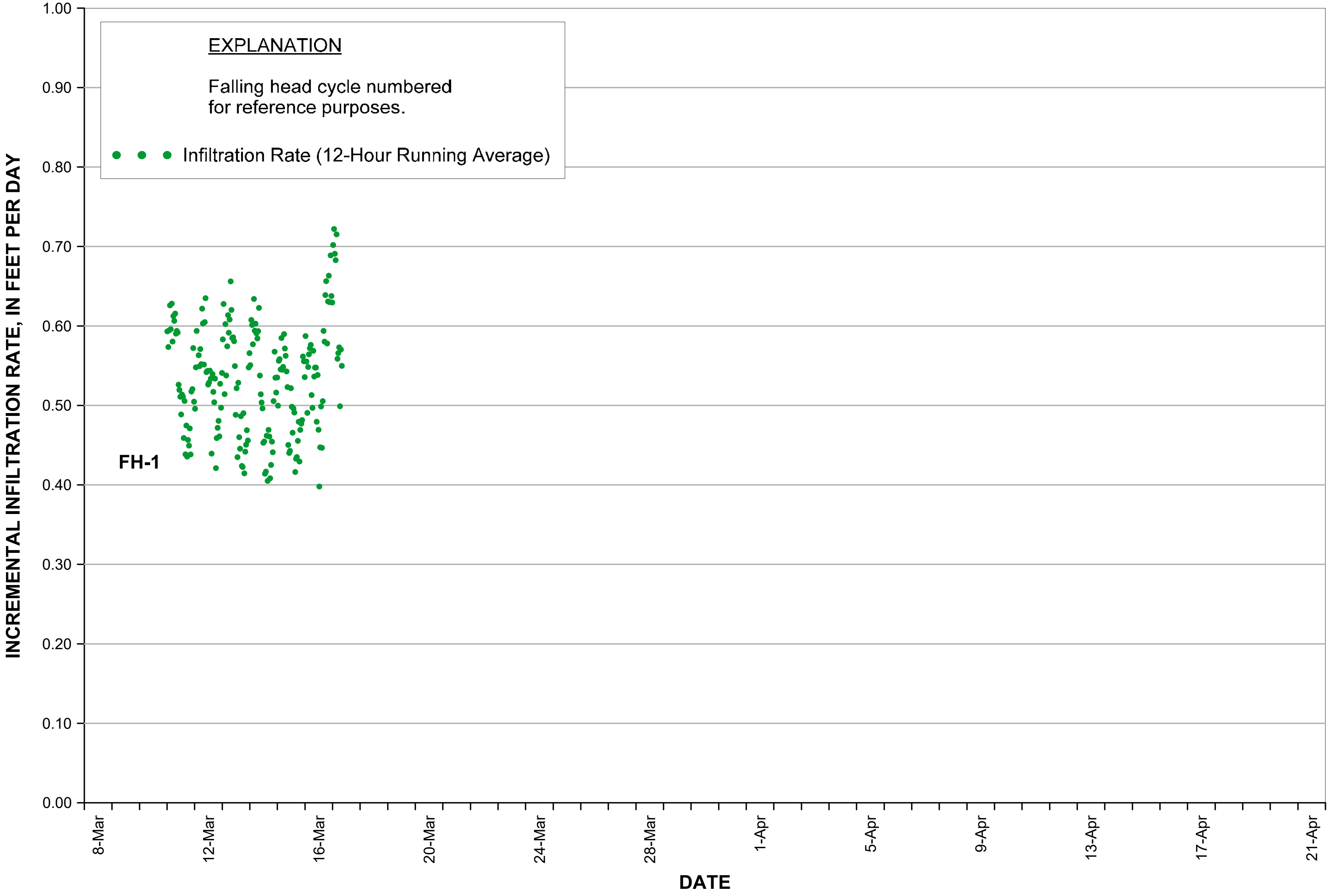

FIGURE 22. SWALL BASIN NORTHWEST CELL: INCREMENTAL INFILTRATION
RATES MEASURED DURING FALLING-HEAD CYCLES
TULARE IRRIGATION DISTRICT

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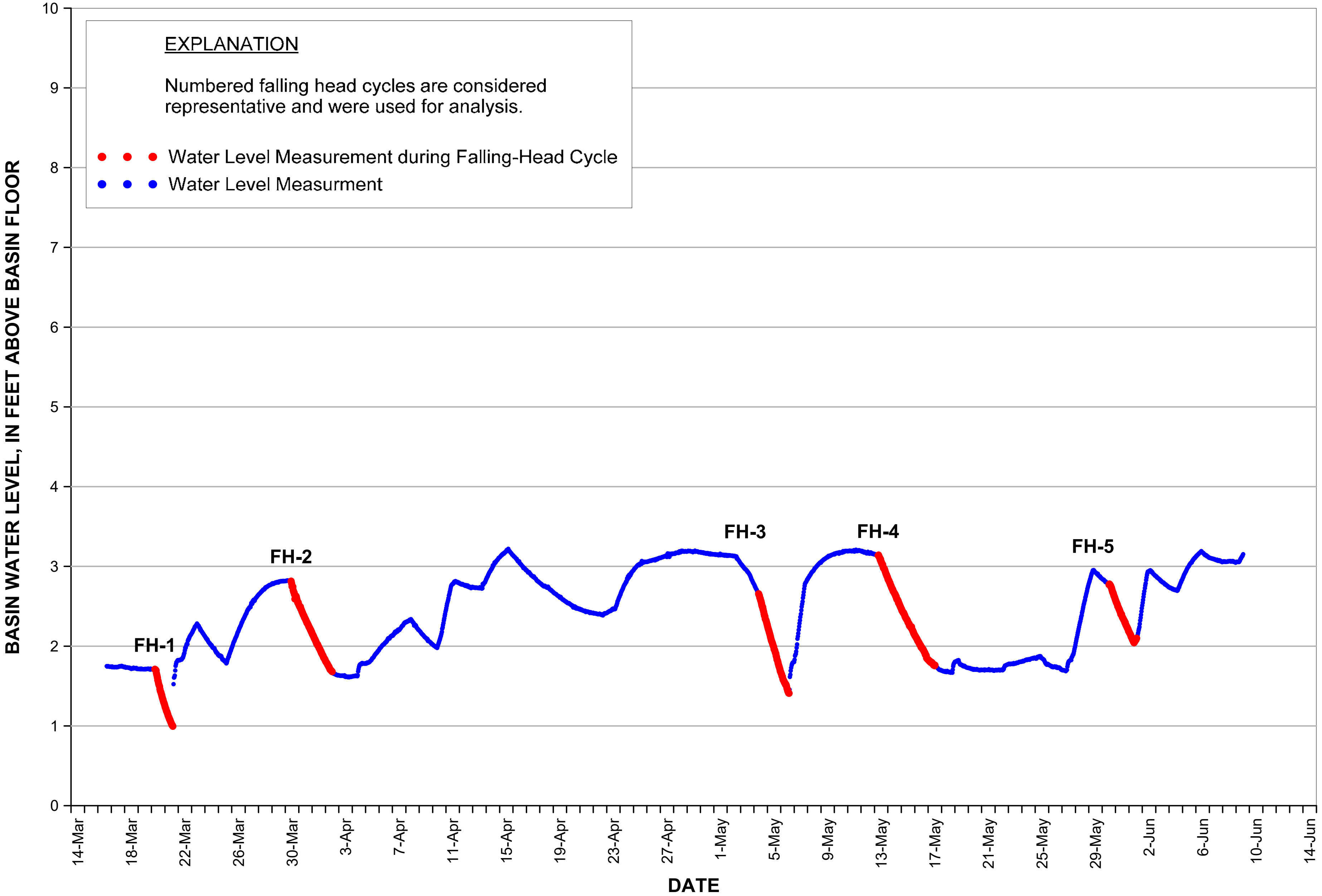

FIGURE 23. BASIN NO. 3 SOUTH CELL: HYDROGRAPH OF FALLING-HEAD CYCLES FOR OPERATIONAL INFILTRATION TESTS TULARE IRRIGATION DISTRICT

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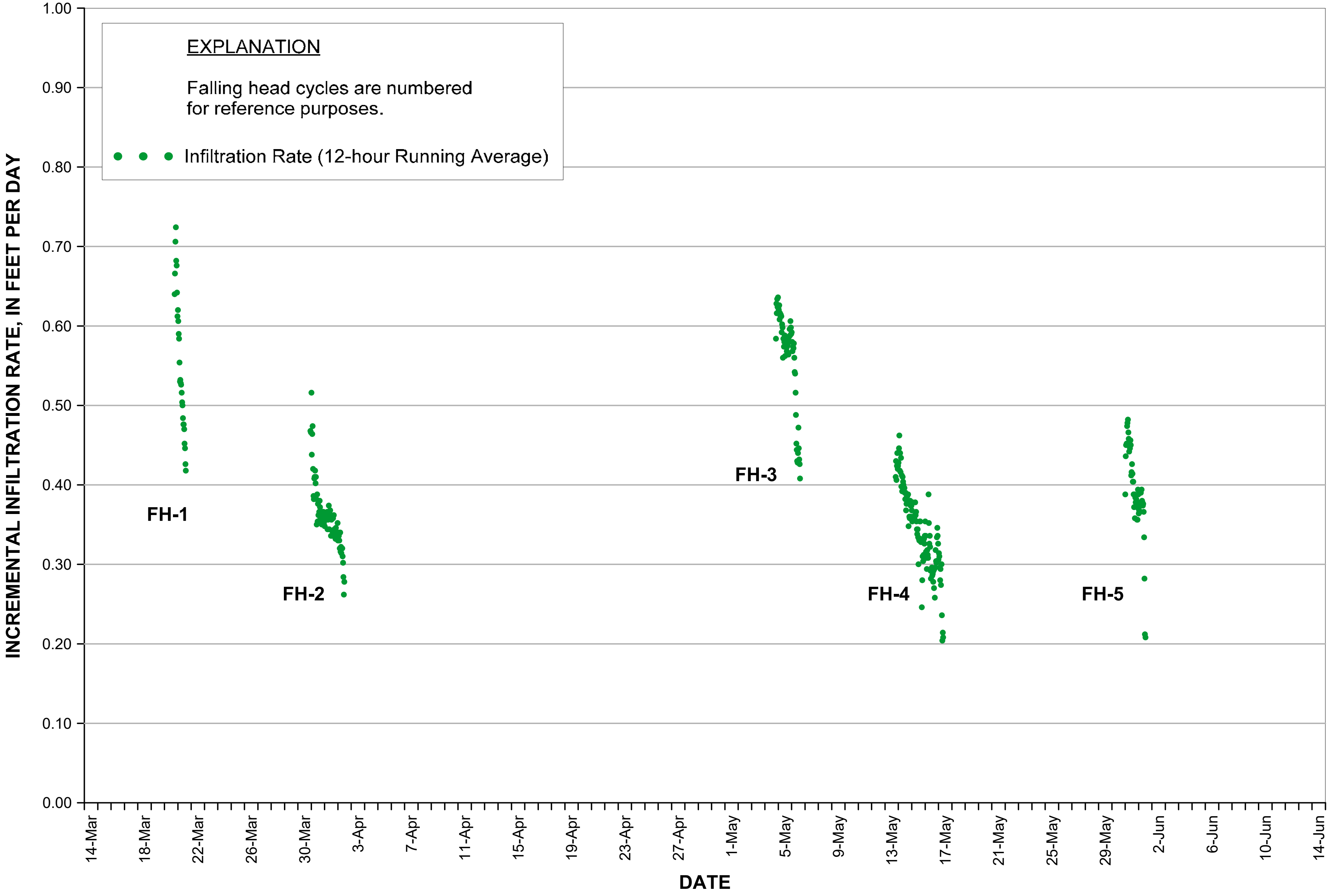

FIGURE 24. BASIN NO. 3 SOUTH CELL: INCREMENTAL INFILTRATION RATES MEASURED DURING FALLING-HEAD CYCLES TULARE IRRIGATION DISTRICT

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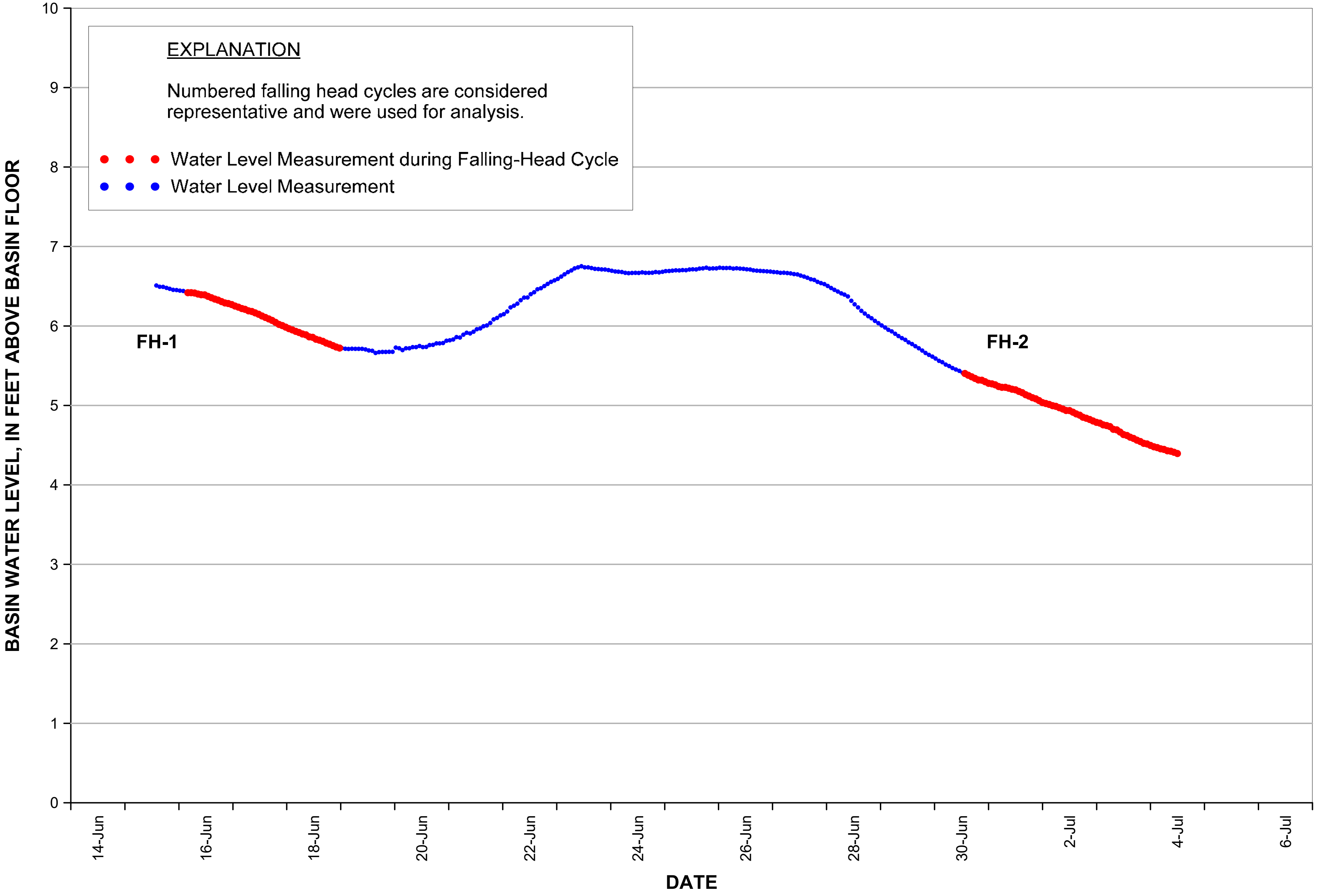

FIGURE 25. BASIN NO. 6 NORTH CELL: HYDROGRAPH OF FALLING-HEAD CYCLES FOR OPERATIONAL INFILTRATION TESTS TULARE IRRIGATION DISTRICT

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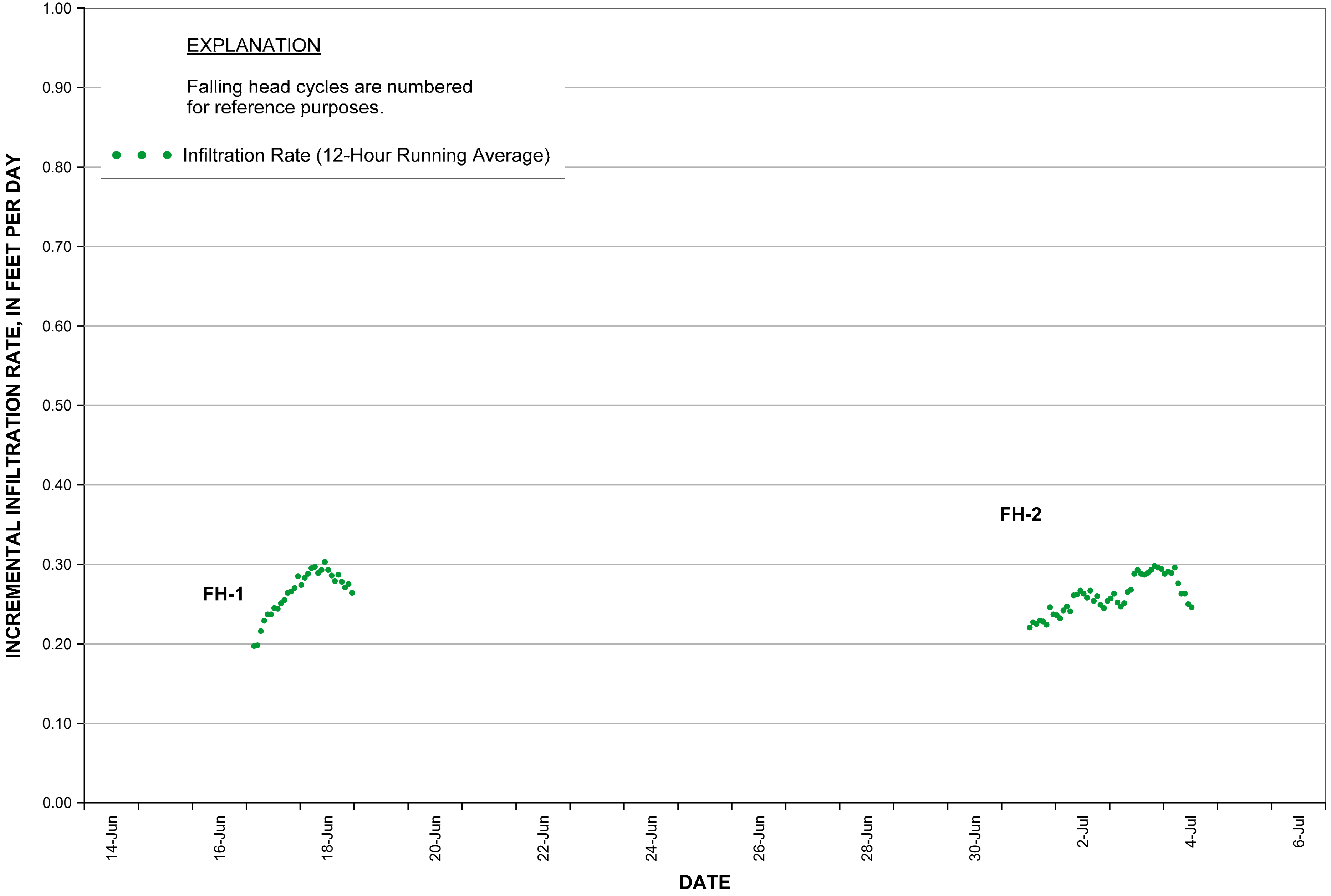

FIGURE 26. BASIN NO. 6 NORTH CELL: INCREMENTAL INFILTRATION RATES
MEASURED DURING FALLING-HEAD CYCLES
TULARE IRRIGATION DISTRICT

MONTGOMERY & ASSOCIATES

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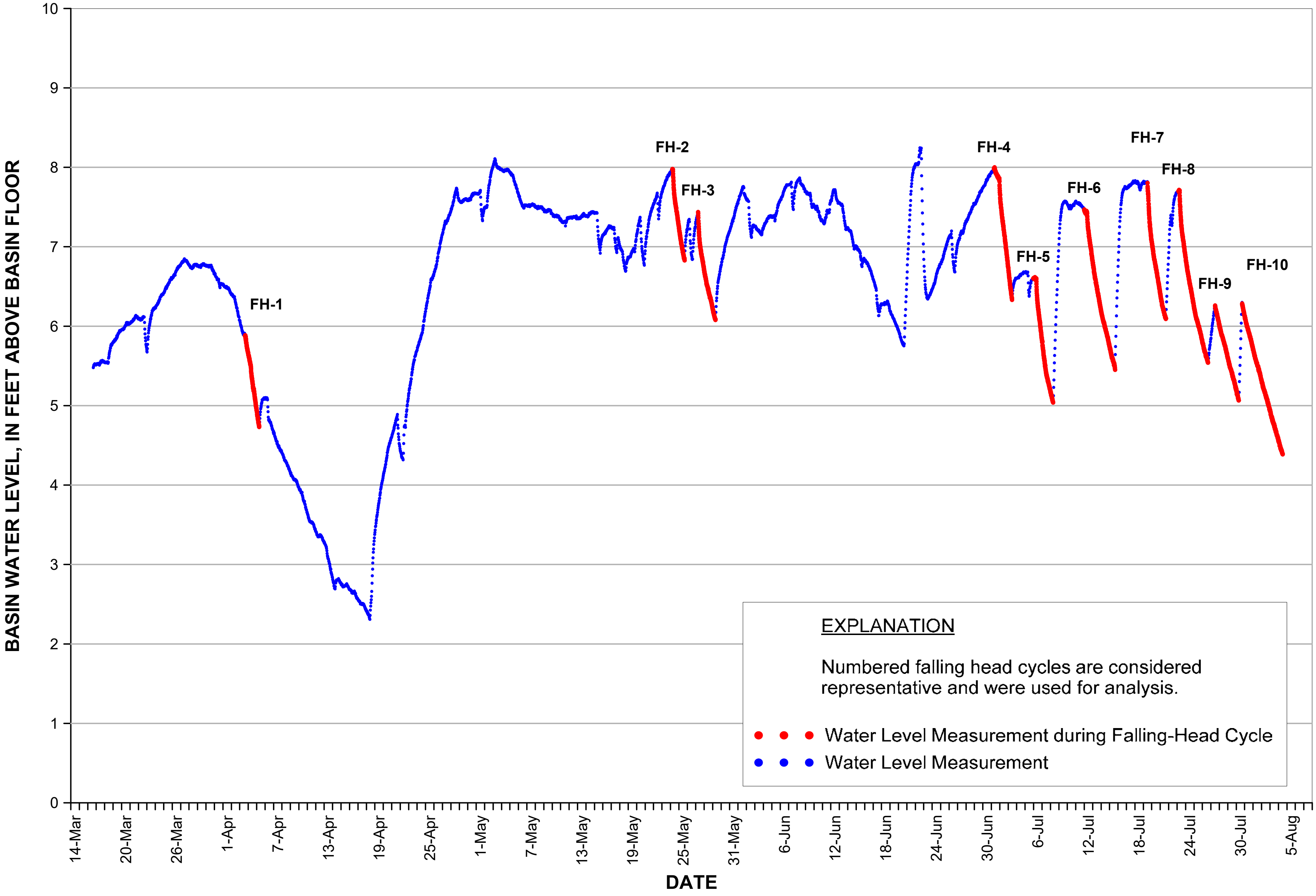

FIGURE 27. MARTIN BASIN: HYDROGRAPH OF FALLING-HEAD CYCLES
FOR OPERATIONAL INFILTRATION TESTS
TULARE IRRIGATION DISTRICT

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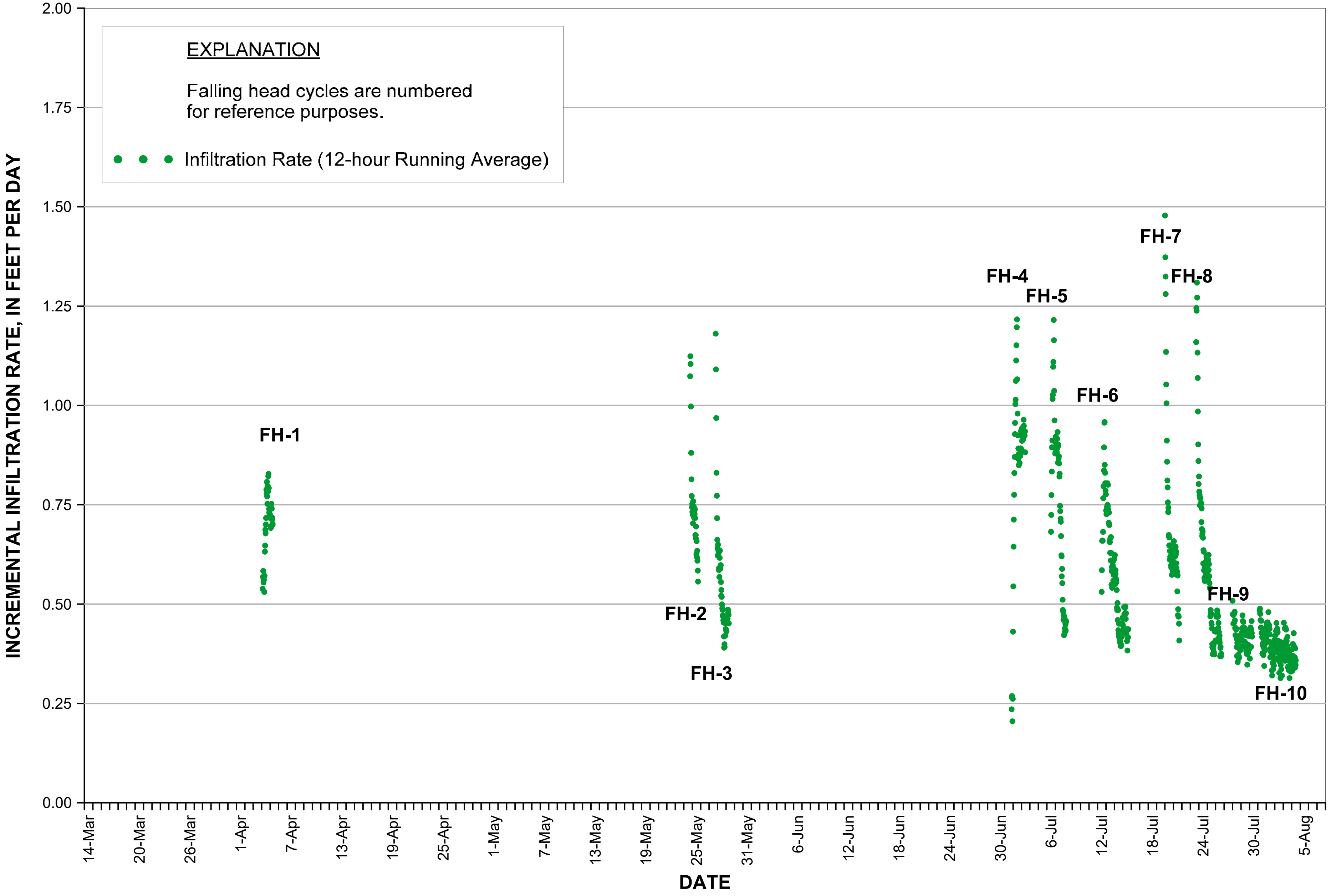

FIGURE 28. MARTIN BASIN: INCREMENTAL INFILTRATION RATES MEASURED DURING FALLING-HEAD CYCLES TULARE IRRIGATION DISTRICT

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Appendix A

Lithologic Descriptions and Graphic Logs for Exploration Trenches

FIGURE A-1. EXPLANATION OF GRAPHIC SYMBOLS FOR THE FIVE LITHOLOGIC / PERMEABILITY CATEGORIES USED IN GRAPHIC LOGS FOR EXPLORATION TRENCHES

Tulare Irrigation District, California

	GRAPHIC LOG	DESCRIPTION OF LITHOLOGIC/PERMEABILITY CATEGORY	ESTIMATED PERMEABILITY
	⁂	SAND; SILTY SAND (may have minor gravel content). Generally less than or equal to 20% silt; non-cohesive and non-lithified.	VERY LARGE estimated permeability (>3 feet/day)
	░	SILTY (FINE) SAND, (may have minor clay content). Generally 25% to 35% silt and clay; generally non to slightly cohesive and non-lithified.	LARGE estimated permeability (1.5 to 3 feet/day)
	▥	SILTY (FINE) SAND, SANDY SILT, (CLAYEY) SANDY SILT. Generally 40% to 55% silt and clay; generally non to slightly cohesive and non-lithified, but includes some moderately cohesive sediments.	MODERATE estimated permeability (0.8 to 1.5 feet/day)
	▨	SANDY SILT; (CLAYEY) SANDY SILT. Generally 55% to 70% silt and clay; generally very slightly to moderately cohesive and non-lithified.	SMALL estimated permeability (0.4 to 0.8 feet/day)
	▦	(SANDY) CLAYEY SILT, (SANDY) SILT AND CLAY. Generally greater than or equal to 75% silt and clay; generally slightly to very cohesive.	VERY SMALL estimated permeability (<0.4 feet/day)

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APPENDIX A. GRAPHIC LOG FOR SOIL SAMPLES FROM EXPLORATION TRENCH 1 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

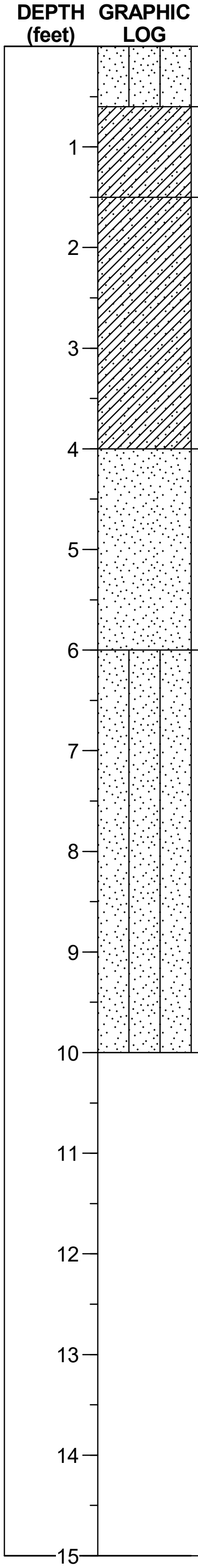
EXCAVATION METHOD / COMPANY: BACKHOE / TID

LOGGED BY: J. Laney / R. Johnson

DEPTH EXCAVATED: 10.0 feet

DATE EXCAVATED: 10/04/2016

TRENCH LENGTH: 15 feet



GENERAL DESCRIPTION	GRAVEL /SAND /FINES PERCENT*	COMMENTS
SANDY SILT / SILTY FINE SAND (ML/SM)	0 / 50 / 50	Non-lithified; loose; non-cohesive; dry
CLAYEY SANDY SILT (ML)	0 / 50 / 50	Non-lithified; firm; moderately cohesive; moist
(CLAYEY) SANDY SILT (ML/CL)	0 / 30 / 70	Non-lithified; slightly cohesive; moist; includes pockets of increased clay content (moderately cohesive)
SILTY SAND (SM)	5 / 65 / 30	Non-lithified; non-cohesive; moist
SILTY SAND (SM)	TR / 55 / 45	Non-lithified; soft; slightly to very slightly cohesive; very moist

TD: 10.0 feet

* Gravel/sand division based on Wentworth scale; grain size fractions estimated using manual field methods.
Trace represented by "tr".

APPENDIX A. LITHOLOGIC DESCRIPTIONS FOR SOIL SAMPLES FROM EXPLORATION TRENCH 1 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

EXCAVATION METHOD / COMPANY: BACKHOE / TID

LOGGED BY: J. Laney / R. Johnson

DEPTH EXCAVATED: 10.0 feet

DATE EXCAVATED: 10/04/2016

TRENCH LENGTH: 15 feet

DEPTH INTERVAL (feet)	DESCRIPTION
0.0 - 0.6	**SANDY SILT / SILTY FINE SAND (ML/SM)**: Dark grayish brown [10YR4/2]; very fine to medium sand 50%, silt 50%. Non-lithified. Loose. Non-cohesive. Dry. Reaction to acid: strong.
0.6 - 1.5	**CLAYEY SANDY SILT (ML)**: Dark grayish brown [10YR4/2]; very fine to medium sand 50%, silt and clay 50%. Non-lithified. Firm. Moderately cohesive. Moist. Reaction to acid: very strong.
1.5 - 4.0	**(CLAYEY) SANDY SILT (ML/CL)**: Dark grayish brown [10YR4/2]; silt and clay 70%, very fine to coarse sand 30%. Non-lithified. Slightly cohesive. Moist. Reaction to acid: very strong. Includes pockets of increased clay content (moderately cohesive).
4.0 - 6.0	**SILTY SAND (SM)**: Dark grayish brown [10YR4/2]; fine to very coarse sand 65%, silt 30%, gravel 5%. Gravel fraction: subangular granules to 0.25 inch. Non-lithified. Non-cohesive. Moist. Reaction to acid: strong.
6.0 - 10.0	**SILTY SAND (SM)**: Dark grayish brown [10YR4/2]; fine to very coarse sand 55%, silt and clay 45%, trace gravel. Gravel fraction: subangular granules to 0.25 inch. Non-lithified. Soft. Slightly to very slightly cohesive. Very moist. Reaction to acid: strong.

Gravel/sand division based on Wentworth scale. Grain size fractions estimated using manual field methods.

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APPENDIX A. GRAPHIC LOG FOR SOIL SAMPLES FROM EXPLORATION TRENCH 2 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

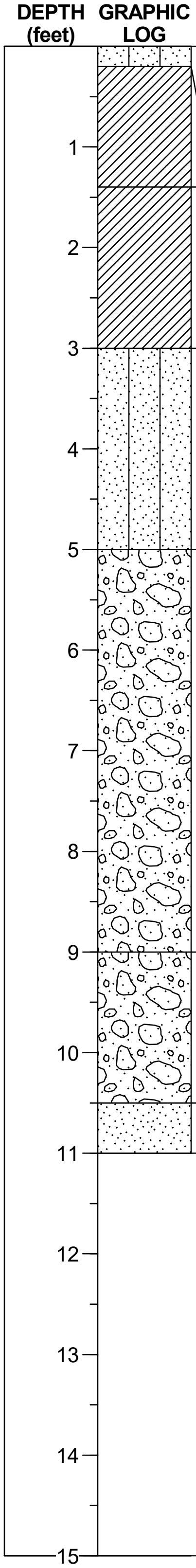
EXCAVATION METHOD / COMPANY: BACKHOE / TID

LOGGED BY: J. Laney / R. Johnson

DEPTH EXCAVATED: 11.0 feet

DATE EXCAVATED: 10/04/2016

TRENCH LENGTH: 15 feet



GENERAL DESCRIPTION	GRAVEL /SAND /FINES PERCENT*	COMMENTS
SANDY SILT / SILTY FINE SAND (ML/SM)	50 / 50	Non-lithified; loose; non-cohesive; dry
SANDY SILT (ML)	30 / 70	Non-lithified; firm; slightly cohesive; moist
SANDY SILT (ML)	45 / 55	Non-lithified; firm; non-cohesive; moist
SANDY SILT / SILTY FINE SAND (ML/SM)	50 / 50	Non-lithified; firm; non-cohesive; moist
SILTY SAND (SM)	80 / 20	Non-lithified; loose; non-cohesive; moist
SILTY SAND (SM)	80 / 20	Non-lithified; soft; non-cohesive; very moist
SILTY SAND (SM)	70 / 30	Non-lithified; loose; non-cohesive; moist

TD: 11.0 feet

* Gravel/sand division based on Wentworth scale; grain size fractions estimated using manual field methods.
Trace represented by "tr".

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APPENDIX A. LITHOLOGIC DESCRIPTIONS FOR SOIL SAMPLES FROM EXPLORATION TRENCH 2 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

EXCAVATION METHOD / COMPANY: BACKHOE / TID

LOGGED BY: J. Laney / R. Johnson

DEPTH EXCAVATED: 11.0 feet

DATE EXCAVATED: 10/04/2016

TRENCH LENGTH: 15 feet

DEPTH INTERVAL (feet)	DESCRIPTION
0.0 - 0.2	**SANDY SILT / SILTY FINE SAND (ML/SM)**: very fine to medium sand 50%, silt 50%. Non-lithified. Loose. Non-cohesive. Dry. Reaction to acid: strong.
0.2 - 1.4	**SANDY SILT (ML)**: silt and clay 70%, very fine to medium sand 30%. Non-lithified. Firm. Slightly cohesive. Moist. Reaction to acid: very strong.
1.4 - 3.0	**SANDY SILT (ML)**: silt 55%, very fine to medium sand 45%. Non-lithified. Firm. Non-cohesive. Moist. Reaction to acid: strong.
3.0 - 5.0	**SANDY SILT / SILTY FINE SAND (ML/SM)**: very fine to medium sand 50%, silt 50%. Non-lithified. Firm. Non-cohesive. Moist. Reaction to acid: none.
5.0 - 9.0	**SILTY SAND (SM)**: very fine to coarse sand 80%, silt 20%. Non-lithified. Loose. Non-cohesive. Moist. Reaction to acid: none.
9.0 - 10.5	**SILTY SAND (SM)**: very fine to very coarse sand 80%, silt 20%. Non-lithified. Soft. Non-cohesive. Very moist. Reaction to acid: none.
10.5 - 11.0	**SILTY SAND (SM)**: very fine to coarse sand 70%, silt 30%. Non-lithified. Loose. Non-cohesive. Moist. Reaction to acid: none.

Gravel/sand division based on Wentworth scale. Grain size fractions estimated using manual field methods.

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APPENDIX A. GRAPHIC LOG FOR SOIL SAMPLES FROM EXPLORATION TRENCH 3 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

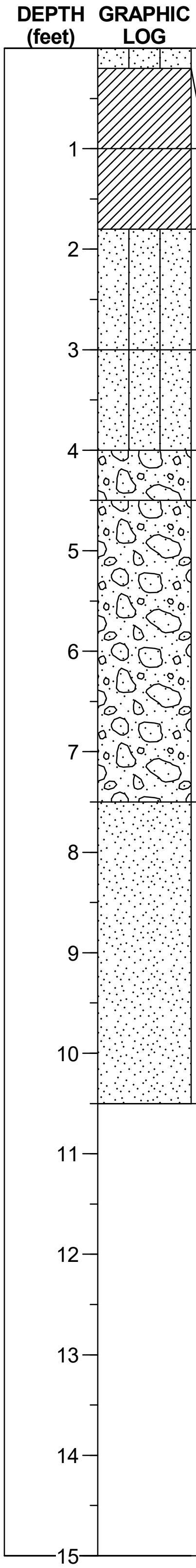
EXCAVATION METHOD / COMPANY: BACKHOE / TID

LOGGED BY: J. Laney / R. Johnson

DEPTH EXCAVATED: 10.5 feet

DATE EXCAVATED: 10/04/2016

TRENCH LENGTH: 15 feet



GENERAL DESCRIPTION	GRAVEL /SAND /FINES PERCENT*	COMMENTS
SANDY SILT / SILTY SAND (ML/SM)	50 / 50	Non-lithified; loose; non-cohesive; dry
(CLAYEY) FINE SANDY SILT (ML)	45 / 55	Non-lithified; firm; slightly to moderately cohesive; moist
FINE SANDY SILT (ML)	40 / 60	Non-lithified; firm; slightly cohesive; moist
SANDY SILT / SILTY FINE SAND (ML/SM)	50 / 50	Non-lithified; firm; non-cohesive; moist
SILTY SAND (SM)	55 / 45	Non-lithified; slightly cohesive; moist
WELL-GRADED SAND (SM-SW)	90 / 10	Non-lithified; loose; non-cohesive; moist
WELL-GRADED SAND (SW)	95 / 5	Non-lithified; loose; non-cohesive; moist
SILTY SAND (SM)	TR / 70 / 30	Non-lithified; non-cohesive; very moist

TD: 10.5 feet

* Gravel/sand division based on Wentworth scale; grain size fractions estimated using manual field methods.
Trace represented by "tr".

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APPENDIX A. LITHOLOGIC DESCRIPTIONS FOR SOIL SAMPLES FROM EXPLORATION TRENCH 3 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

EXCAVATION METHOD / COMPANY: BACKHOE / TID
LOGGED BY: J. Laney / R. Johnson
DEPTH EXCAVATED: 10.5 feet
DATE EXCAVATED: 10/04/2016
TRENCH LENGTH: 15 feet

DEPTH INTERVAL (feet)	DESCRIPTION
0.0 - 0.2	**SANDY SILT / SILTY SAND (ML/SM)**: Very dark grayish brown [10YR3/2]; very fine to coarse sand 50%, silt 50%. Non-lithified. Loose. Non-cohesive. Dry. Reaction to acid: none.
0.2 - 1.0	**(CLAYEY) FINE SANDY SILT (ML)**: Very dark grayish brown [10YR3/2]; silt and clay 55%, very fine to medium sand 45%. Non-lithified. Firm. Slightly to moderately cohesive. Moist. Reaction to acid: weak.
1.0 - 1.8	**FINE SANDY SILT (ML)**: Very dark grayish brown [10YR3/2]; silt and clay 60%, very fine to medium sand 40%. Non-lithified. Firm. Slightly cohesive. Moist. Reaction to acid: weak.
1.8 - 3.0	**SANDY SILT / SILTY FINE SAND (ML/SM)**: Very dark grayish brown [10YR3/2]; very fine to medium sand 50%, silt 50%. Non-lithified. Firm. Non-cohesive. Moist. Reaction to acid: none.
3.0 - 4.0	**SILTY SAND (SM)**: Dark brown [10YR3/3]; fine to very coarse sand 55%, silt and clay 45%. Non-lithified. Slightly cohesive. Moist. Reaction to acid: none.
4.0 - 4.5	**WELL-GRADED SAND (SM-SW)**: Dark yellowish brown [10YR3/4]; very fine to very coarse sand 90%, silt 10%. Non-lithified. Loose. Non-cohesive. Moist. Reaction to acid: none.
4.5 - 7.5	**WELL-GRADED SAND (SW)**: Dark yellowish brown [10YR3/4]; very fine to very coarse sand 95%, silt 5%. Non-lithified. Loose. Non-cohesive. Moist. Reaction to acid: none.
7.5 - 10.5	**SILTY SAND (SM)**: Dark yellowish brown [10YR3/4]; very fine to very coarse sand 70%, silt 30%, trace gravel. Non-lithified. Non-cohesive. Very moist. Reaction to acid: none.

Gravel/sand division based on Wentworth scale. Grain size fractions estimated using manual field methods.

APPENDIX A. GRAPHIC LOG FOR SOIL SAMPLES FROM EXPLORATION TRENCH 4 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

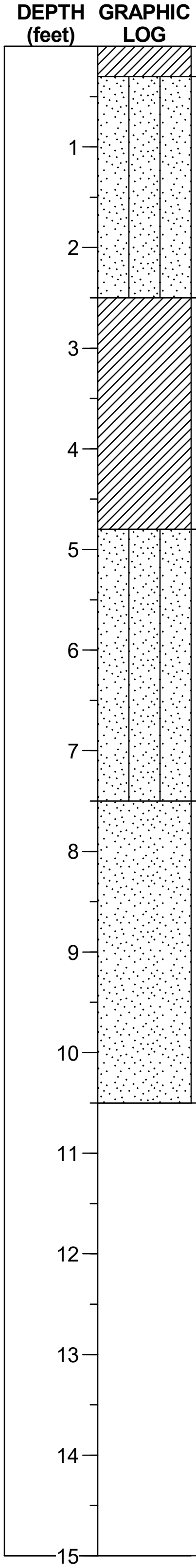
EXCAVATION METHOD / COMPANY: BACKHOE / TID

LOGGED BY: J. Laney / R. Johnson

DEPTH EXCAVATED: 10.5 feet

DATE EXCAVATED: 10/05/2016

TRENCH LENGTH: 15 feet



GENERAL DESCRIPTION	GRAVEL /SAND /FINES PERCENT*	COMMENTS
(CLAYEY) SANDY SILT (ML)	35 / 65	Non-lithified; loose; slightly to moderately cohesive; dry
SANDY SILT / SILTY SAND (ML/SM)	35 / 65	Non-lithified; firm; slightly cohesive; moist
(CLAYEY) SANDY SILT (ML)	45 / 55	Non-lithified; firm; slightly to moderately cohesive; moist
SILTY SAND / SANDY SILT (SM/ML)	50 / 50	Non-lithified; soft; slightly cohesive; very moist; includes pockets of increased silt content
SILTY SAND (SM)	65 / 35	Non-lithified; soft; non-cohesive; very moist

TD: 10.5 feet

* Gravel/sand division based on Wentworth scale; grain size fractions estimated using manual field methods.
Trace represented by "tr".

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APPENDIX A. LITHOLOGIC DESCRIPTIONS FOR SOIL SAMPLES FROM EXPLORATION TRENCH 4 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

EXCAVATION METHOD / COMPANY: BACKHOE / TID

LOGGED BY: J. Laney / R. Johnson

DEPTH EXCAVATED: 10.5 feet

DATE EXCAVATED: 10/05/2016

TRENCH LENGTH: 15 feet

DEPTH INTERVAL (feet)	DESCRIPTION
0.0 - 0.3	**(CLAYEY) SANDY SILT (ML)**: Very dark grayish brown [10YR3/2]; silt and clay 65%, very fine to coarse sand 35%. Non-lithified. Loose. Slightly to moderately cohesive. Dry. Reaction to acid: very strong.
0.3 - 2.5	**SANDY SILT / SILTY SAND (ML/SM)**: Very dark grayish brown [10YR3/2]; silt and clay 65%, very fine to coarse sand 35%. Non-lithified. Firm. Slightly cohesive. Moist. Reaction to acid: very strong.
2.5 - 4.8	**(CLAYEY) SANDY SILT (ML)**: Dark grayish brown [10YR4/2]; silt and clay 55%, very fine to medium sand 45%. Non-lithified. Firm. Slightly to moderately cohesive. Moist. Reaction to acid: very strong.
4.8 - 7.5	**SILTY SAND / SANDY SILT (SM/ML)**: Dark grayish brown [10YR4/2]; very fine to coarse sand 50%, silt and clay 50%. Non-lithified. Soft. Slightly cohesive. Very moist. Reaction to acid: weak. Includes pockets of increased silt content.
7.5 - 10.5	**SILTY SAND (SM)**: Dark brown [10YR3/3]; very fine to coarse sand 65%, silt 35%. Non-lithified. Soft. Non-cohesive. Very moist. Reaction to acid: none.

Gravel/sand division based on Wentworth scale. Grain size fractions estimated using manual field methods.

APPENDIX A. GRAPHIC LOG FOR SOIL SAMPLES FROM EXPLORATION TRENCH 5 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

EXCAVATION METHOD / COMPANY: BACKHOE / TID

LOGGED BY: J. Laney / R. Johnson

DEPTH EXCAVATED: 12.0 feet

DATE EXCAVATED: 10/04/2016

TRENCH LENGTH: 15 feet

DEPTH (feet)	GRAPHIC LOG	GENERAL DESCRIPTION	GRAVEL /SAND /FINES PERCENT*	COMMENTS
	░	**SILTY FINE SAND (SM)**	60 / 40	Non-lithified; loose; very slightly cohesive; dry
1 2	░	**SILTY FINE SAND (SM)**	55 / 45	Non-lithified; soft; very slightly cohesive; moist
3 4	▨	**SILT (ML)**	10 / 90	Non-lithified; firm; slightly cohesive; moist
5	░	**SANDY SILT (ML)**	45 / 55	Non-lithified; soft; slightly cohesive; very moist
6 7 8 9 10	░	**SANDY SILT / SILTY SAND (ML/SM)**	50 / 50	Non-lithified; soft; slightly cohesive; very moist
11	▨	**CLAYEY SANDY SILT (ML/CL)**	30 / 70	Non-lithified; soft; moderately cohesive; very moist
12 13 14 15		TD: 12.0 feet		

* Gravel/sand division based on Wentworth scale; grain size fractions estimated using manual field methods.
Trace represented by "tr".

APPENDIX A. LITHOLOGIC DESCRIPTIONS FOR SOIL SAMPLES FROM EXPLORATION TRENCH 5 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

EXCAVATION METHOD / COMPANY: BACKHOE / TID
LOGGED BY: J. Laney / R. Johnson
DEPTH EXCAVATED: 12.0 feet
DATE EXCAVATED: 10/04/2016
TRENCH LENGTH: 15 feet

DEPTH INTERVAL (feet)	DESCRIPTION
0.0 - 0.6	**SILTY FINE SAND (SM)**: Dark olive brown [2.5Y3/3]; very fine to coarse sand 60%, silt 40%. Non-lithified. Loose. Very slightly cohesive. Dry. Reaction to acid: strong.
0.6 - 3.0	**SILTY FINE SAND (SM)**: Dark olive brown [2.5Y3/3]; very fine to coarse sand 55%, silt 45%. Non-lithified. Soft. Very slightly cohesive. Moist. Reaction to acid: very strong.
3.0 - 5.0	**SILT (ML)**: Dark olive brown [2.5Y3/3]; silt and clay 90%, very fine to medium sand 10%. Non-lithified. Firm. Slightly cohesive. Moist. Reaction to acid: strong.
5.0 - 6.0	**SANDY SILT (ML)**: Dark olive brown [2.5Y3/3]; silt and clay 55%, very fine to medium sand 45%. Non-lithified. Soft. Slightly cohesive. Very moist. Reaction to acid: none.
6.0 - 11.0	**SANDY SILT / SILTY SAND (ML/SM)**: Dark olive brown [2.5Y3/3]; very fine to very coarse sand 50%, silt and clay 50%. Non-lithified. Soft. Slightly cohesive. Very moist. Reaction to acid: none.
11.0 - 12.0	**CLAYEY SANDY SILT (ML/CL)**: Olive brown [2.5Y4/3]; silt and clay 70%, very fine to medium sand 30%. Non-lithified. Soft. Moderately cohesive. Very moist. Reaction to acid: none.

Gravel/sand division based on Wentworth scale. Grain size fractions estimated using manual field methods.

APPENDIX A. GRAPHIC LOG FOR SOIL SAMPLES FROM EXPLORATION TRENCH 6 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

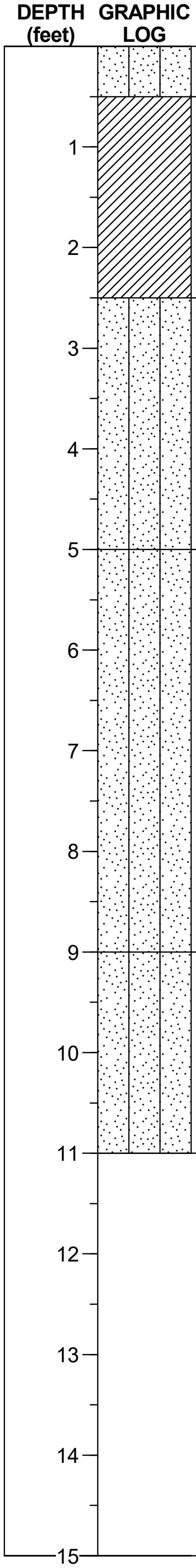
EXCAVATION METHOD / COMPANY: BACKHOE / TID

LOGGED BY: J. Laney / R. Johnson

DEPTH EXCAVATED: 11.0 feet

DATE EXCAVATED: 10/04/2016

TRENCH LENGTH: 15 feet



GENERAL DESCRIPTION	GRAVEL /SAND /FINES PERCENT*	COMMENTS
FINE SANDY SILT (ML)	45 / 55	Non-lithified; loose; very slightly cohesive; dry
CLAYEY SANDY SILT (ML/CL)	40 / 60	Non-lithified; firm; moderately cohesive; moist
SILTY FINE SAND (SM)	55 / 45	Non-lithified; soft; slightly cohesive; moist
(CLAYEY) SILTY SAND (SM)	55 / 45	Non-lithified; firm; slightly to moderately cohesive; moist
SILTY SAND (SM)	60 / 40	Non-lithified; soft; very slightly cohesive; moist

TD: 11.0 feet

* Gravel/sand division based on Wentworth scale; grain size fractions estimated using manual field methods.
Trace represented by "tr".

APPENDIX A. LITHOLOGIC DESCRIPTIONS FOR SOIL SAMPLES FROM EXPLORATION TRENCH 6 CREAMLINE BASIN SOUTHEAST CELL TULARE IRRIGATION DISTRICT, CALIFORNIA

EXCAVATION METHOD / COMPANY: BACKHOE / TID

LOGGED BY: J. Laney / R. Johnson

DEPTH EXCAVATED: 11.0 feet

DATE EXCAVATED: 10/04/2016

TRENCH LENGTH: 15 feet

DEPTH INTERVAL (feet)	DESCRIPTION
0.0 - 0.5	**FINE SANDY SILT (ML)**: Very dark grayish brown [2.5Y3/2]; silt 55%, very fine to medium sand 45%. Non-lithified. Loose. Very slightly cohesive. Dry. Reaction to acid: very strong.
0.5 - 2.5	**CLAYEY SANDY SILT (ML/CL)**: Very dark grayish brown [2.5Y3/2]; silt and clay 60%, very fine to medium sand 40%. Non-lithified. Firm. Moderately cohesive. Moist. Reaction to acid: very strong.
2.5 - 5.0	**SILTY FINE SAND (SM)**: Dark olive brown [2.5Y3/3]; very fine to medium sand 55%, silt and clay 45%. Non-lithified. Soft. Slightly cohesive. Moist. Reaction to acid: none.
5.0 - 9.0	**(CLAYEY) SILTY SAND (SM)**: Dark olive brown [2.5Y3/3]; very fine to medium sand 55%, silt and clay 45%. Non-lithified. Firm. Slightly to moderately cohesive. Moist. Reaction to acid: none.
9.0 - 11.0	**SILTY SAND (SM)**: Dark olive brown [2.5Y3/3]; very fine to coarse sand 60%, silt 40%. Non-lithified. Soft. Very slightly cohesive. Moist. Reaction to acid: none.

Gravel/sand division based on Wentworth scale. Grain size fractions estimated using manual field methods.