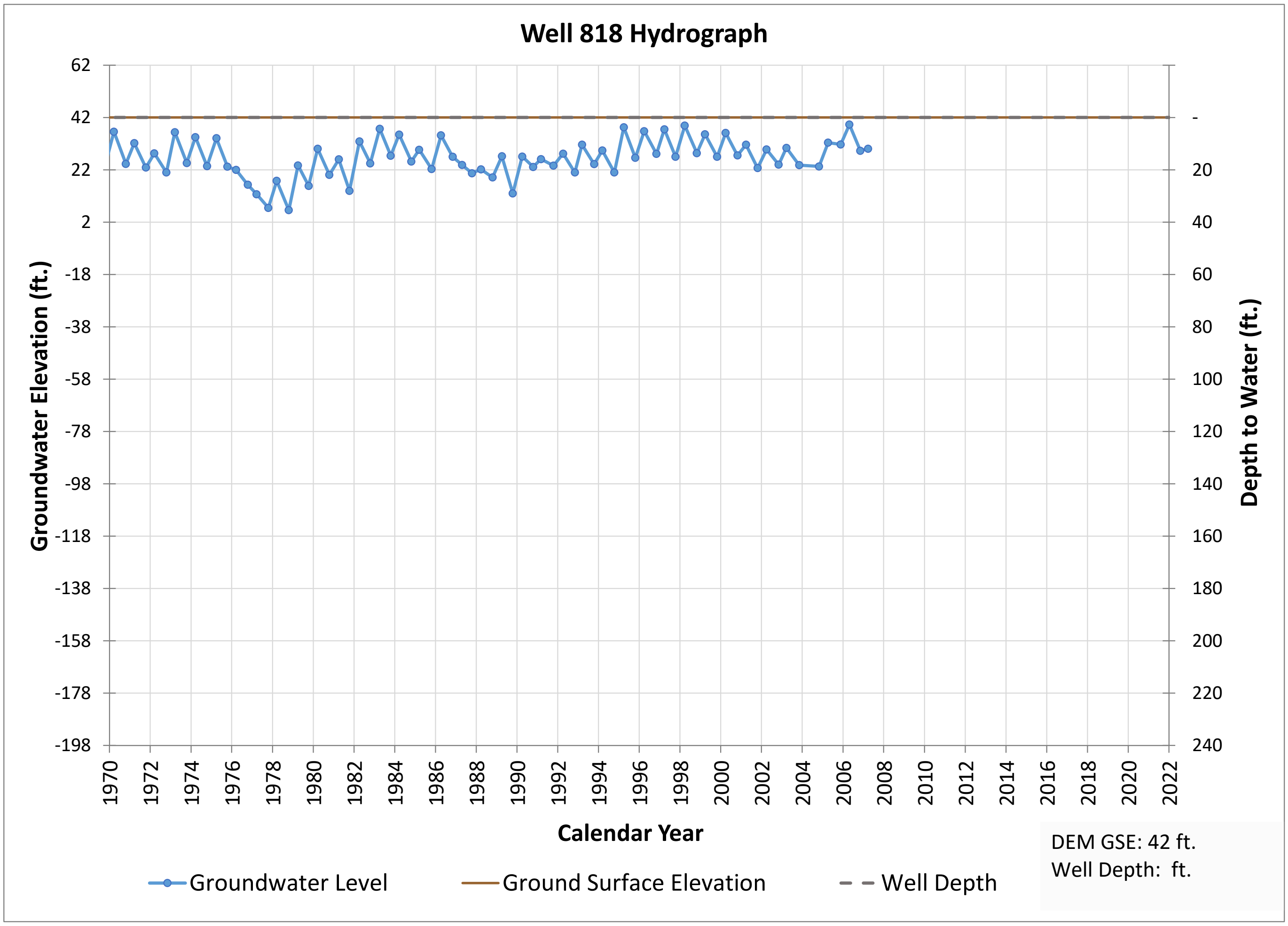
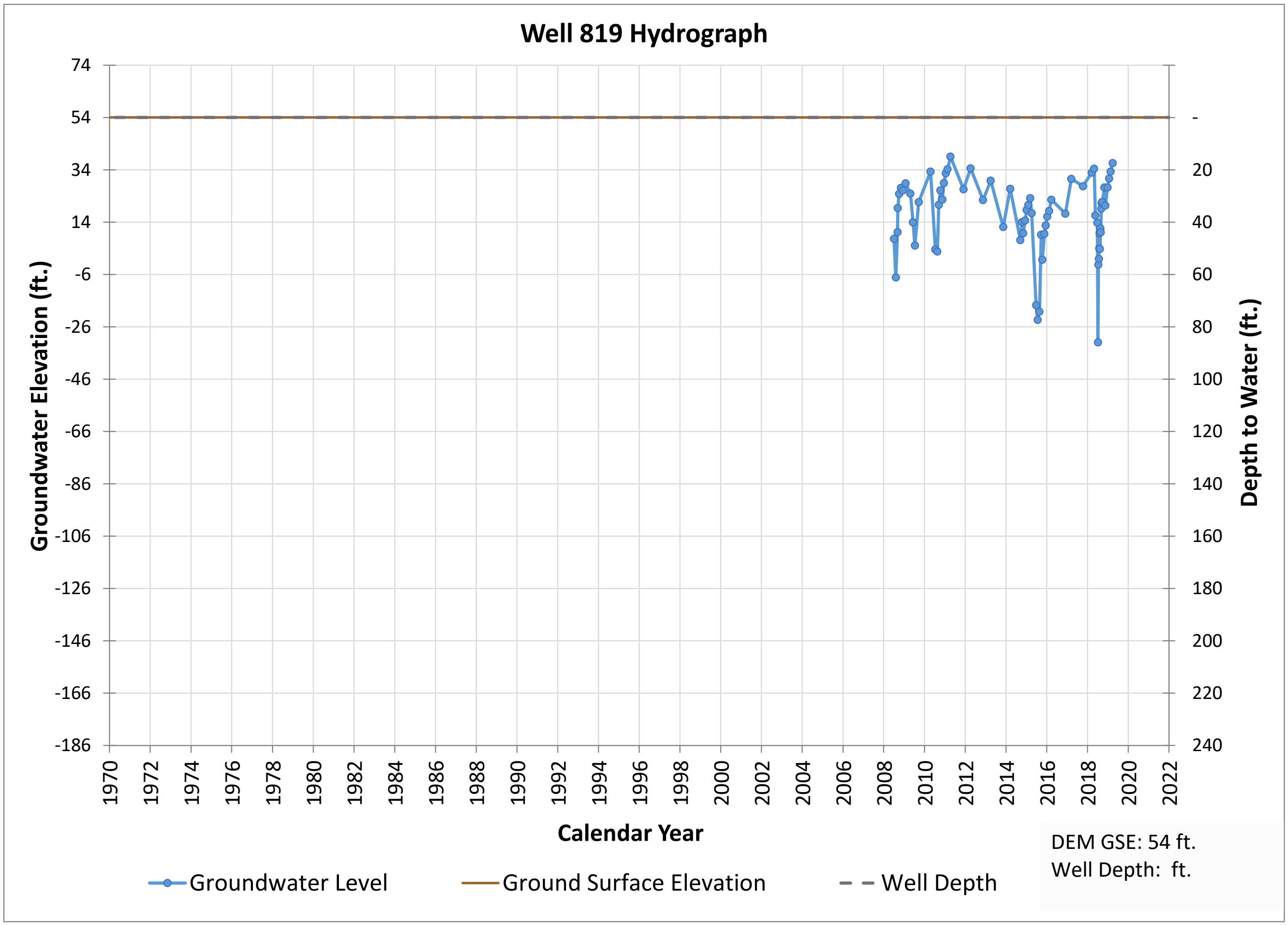
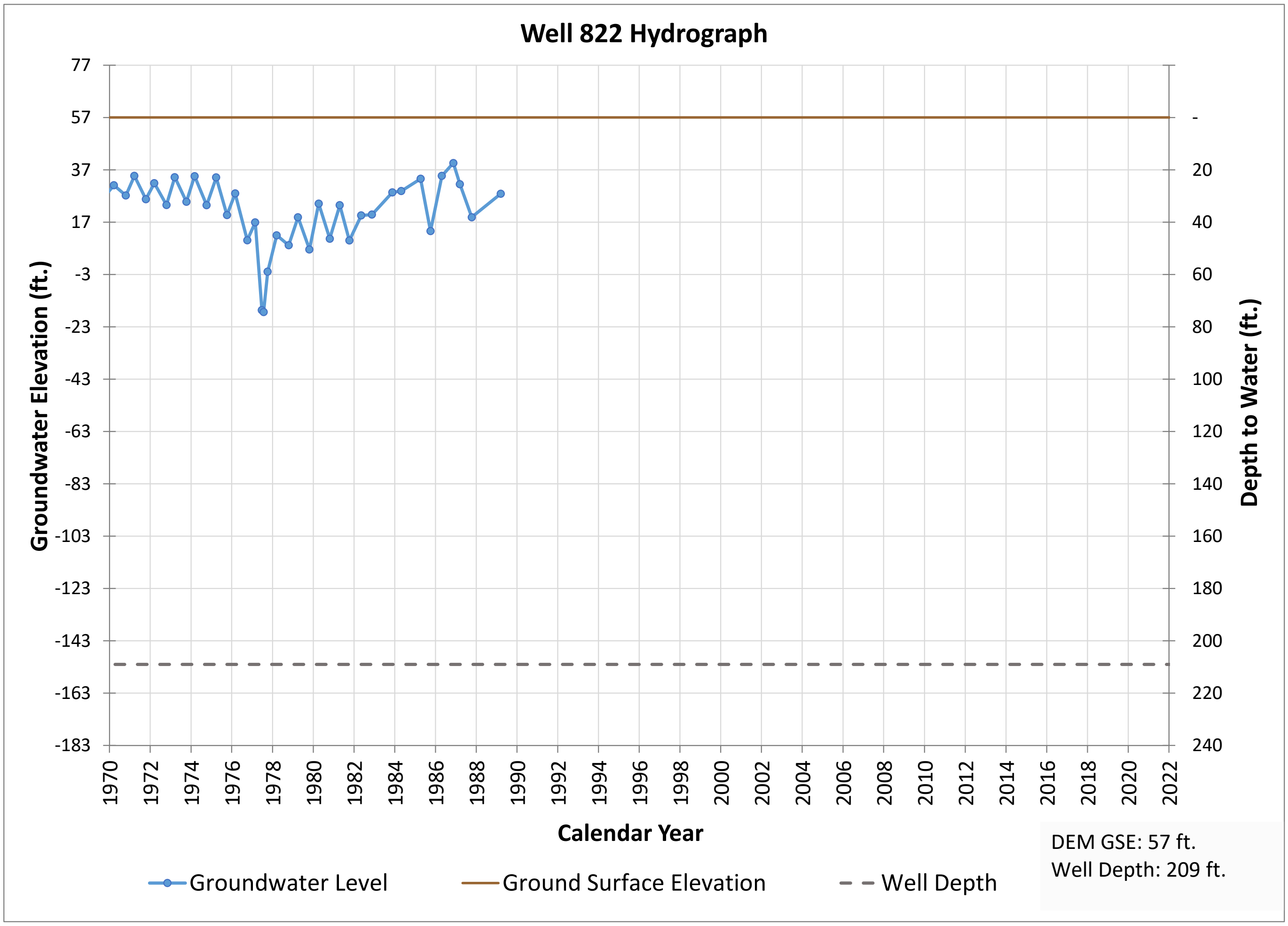
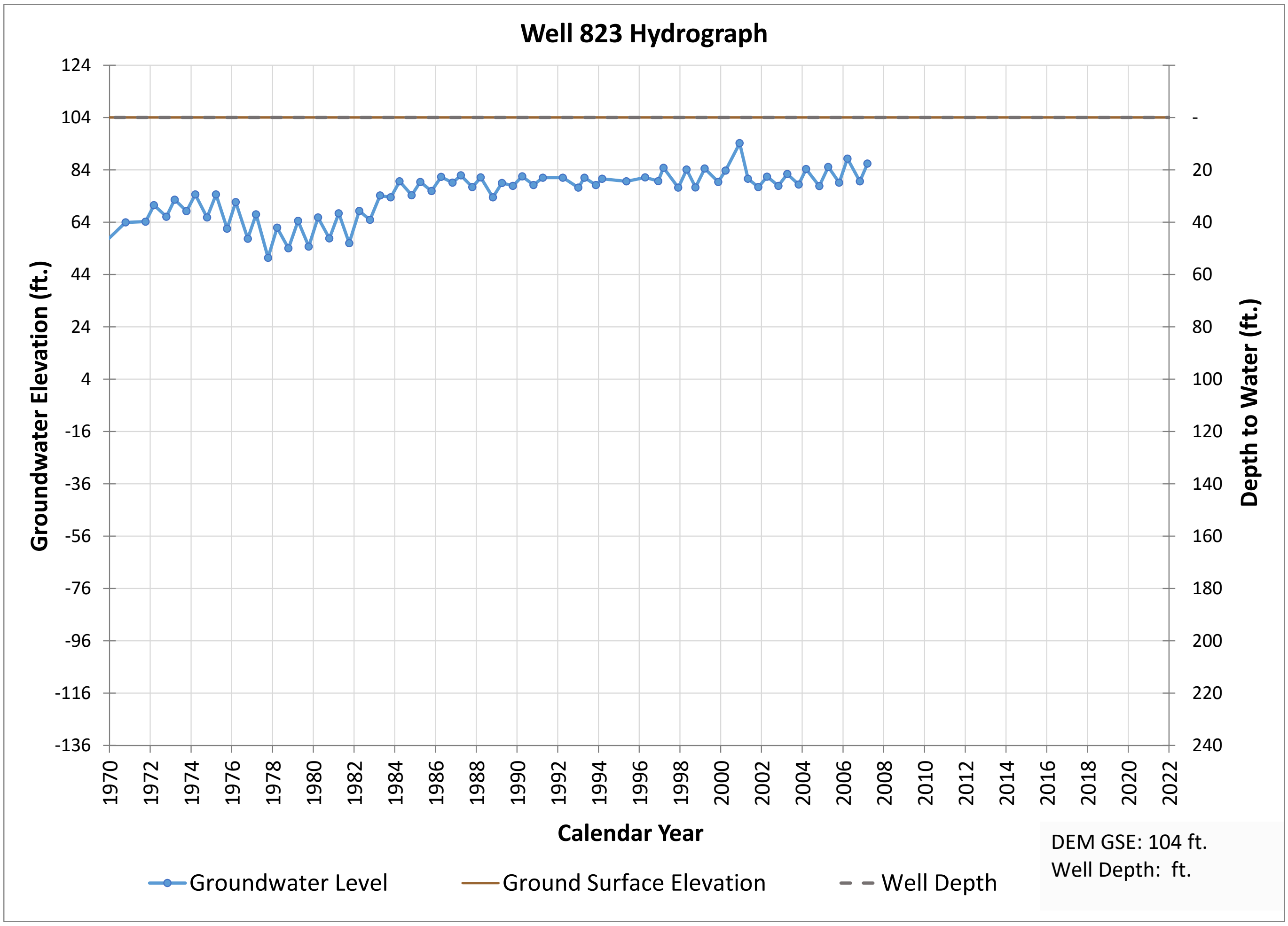

Well 818 Hydrograph
Groundwater Elevation (ft.)
62
42
22
2
-18
-38
-58
-78
-98
-118
-138
-158
-178
-198
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 42 ft.
Well Depth: ft.

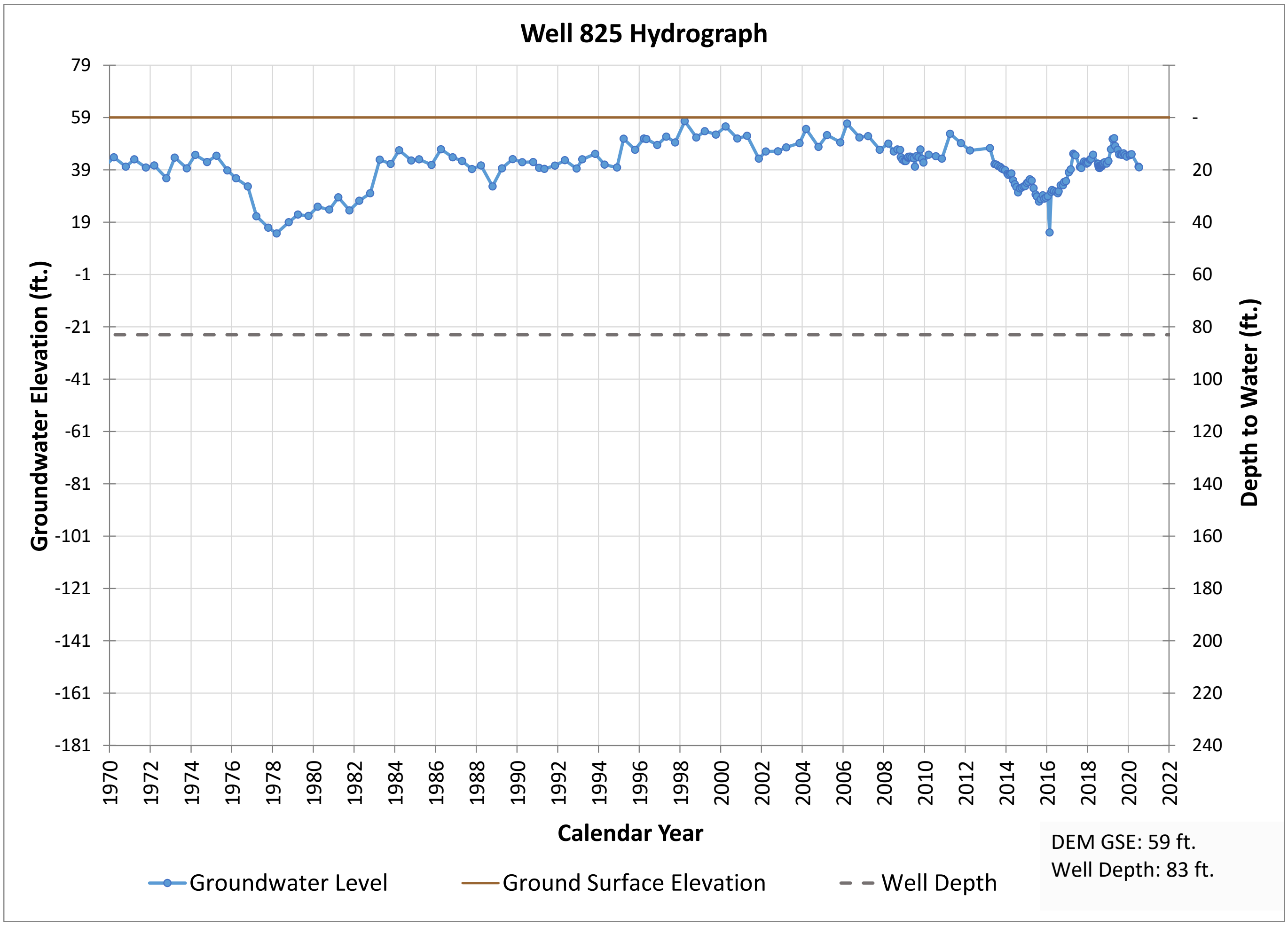


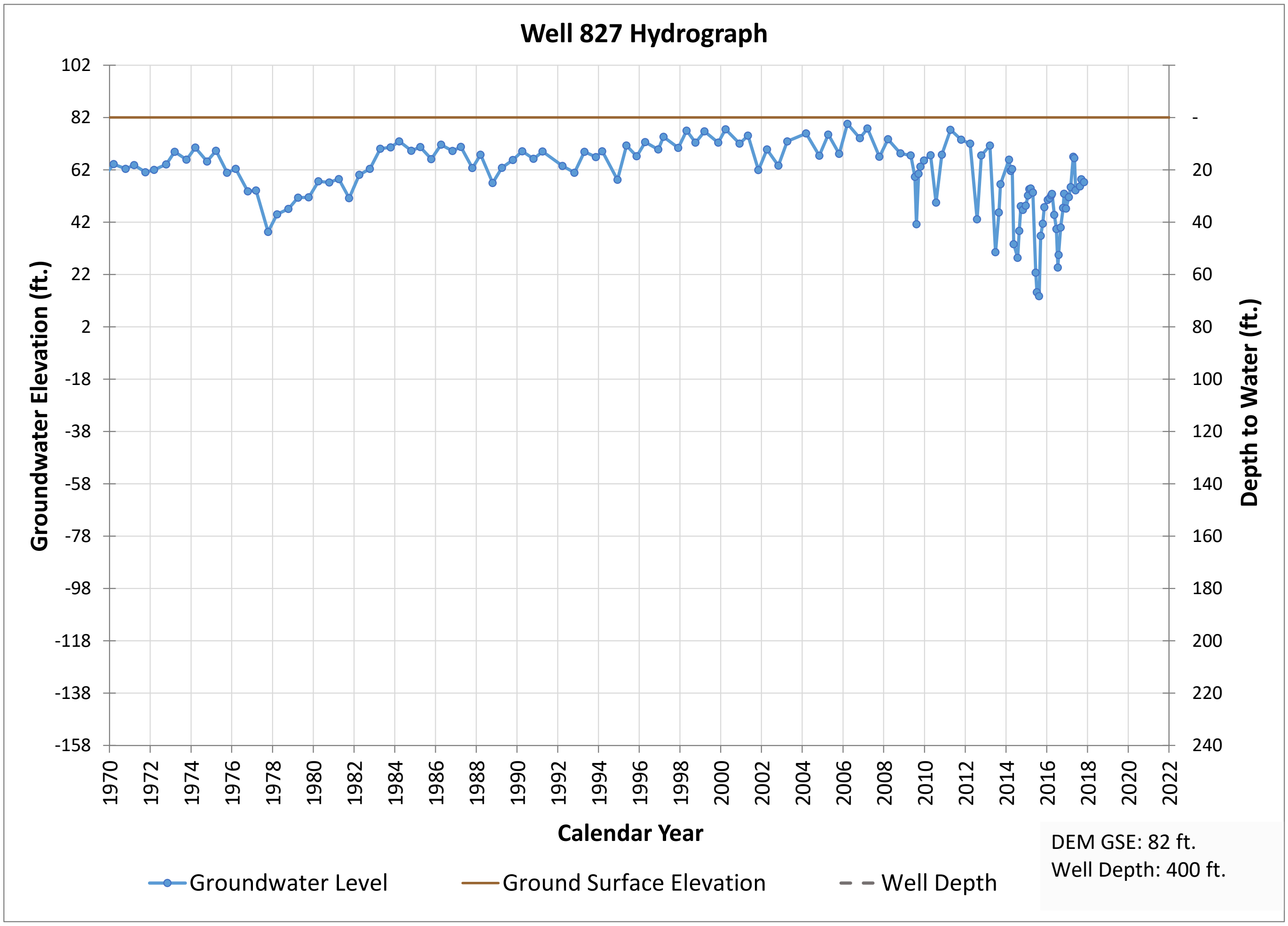
Well 819 Hydrograph

DEM GSE: 54 ft.
Well Depth: ft.

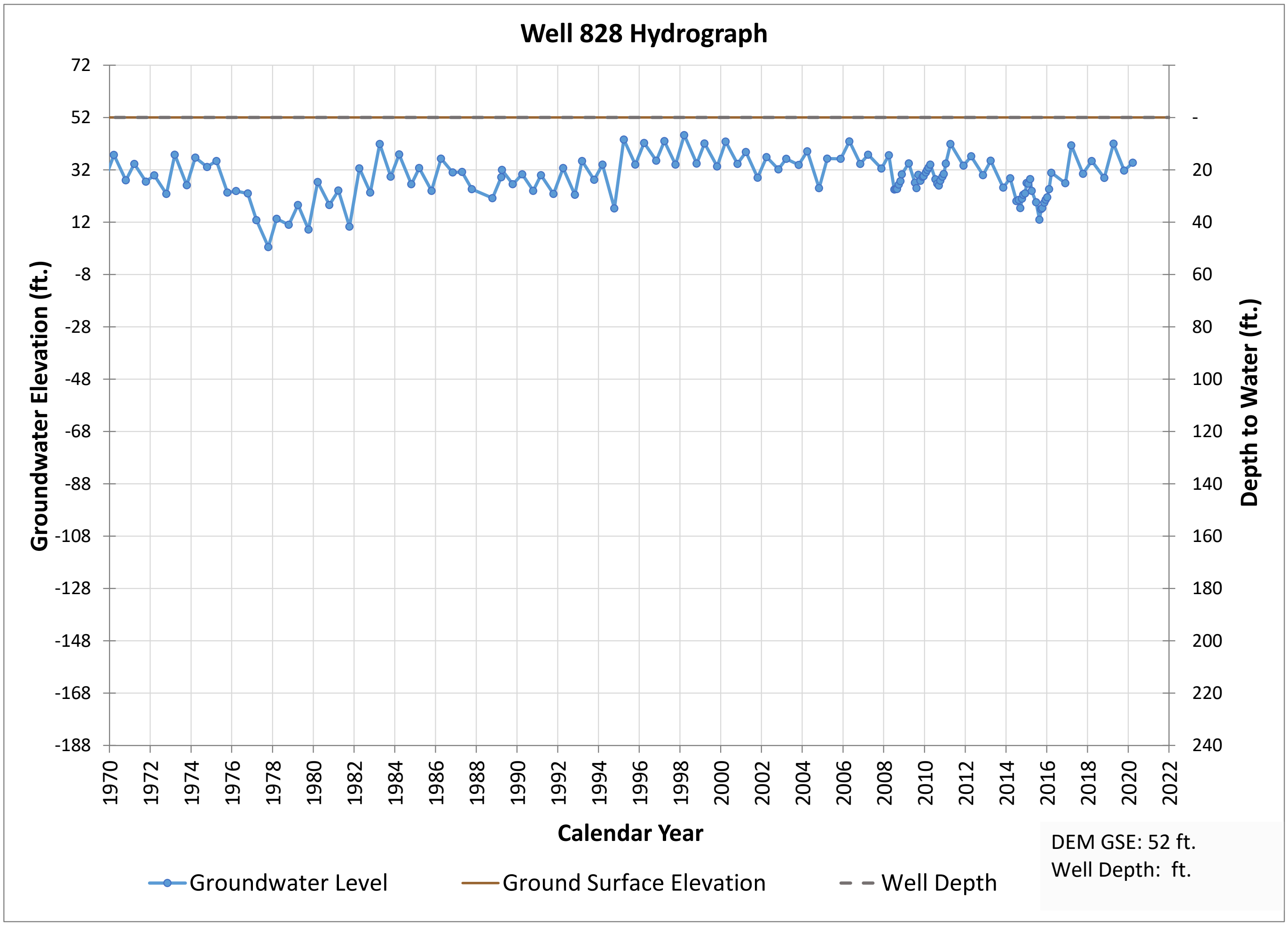

Well 822 Hydrograph
Groundwater Elevation (ft.)
Depth to Water (ft.)
77
57
37
17
-3
-23
-43
-63
-83
-103
-123
-143
-163
-183
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 57 ft.
Well Depth: 209 ft.

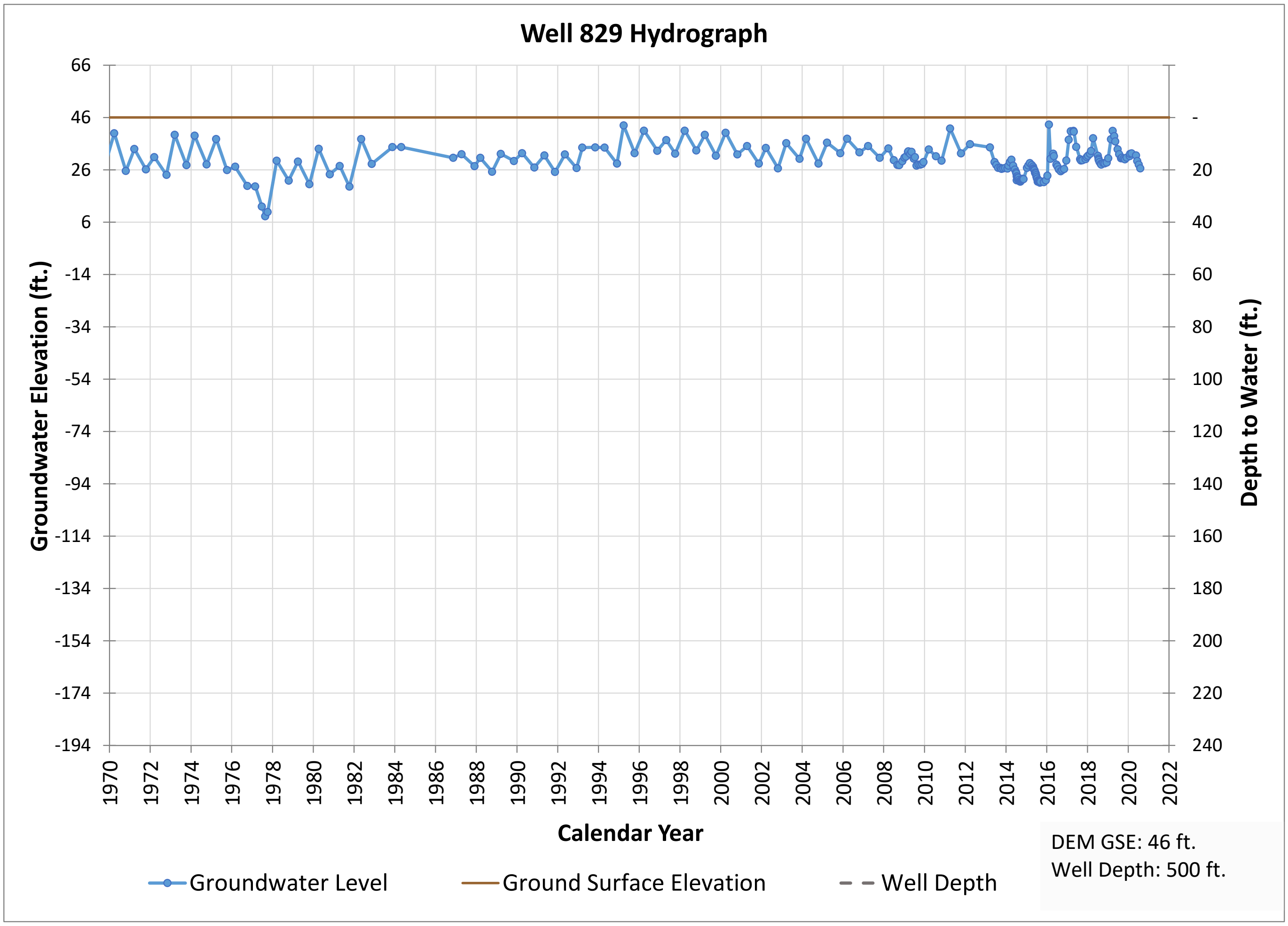

Well 823 Hydrograph
Groundwater Elevation (ft.)
124
104
84
64
44
24
4
-16
-36
-56
-76
-96
-116
-136
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 104 ft.
Well Depth: ft.

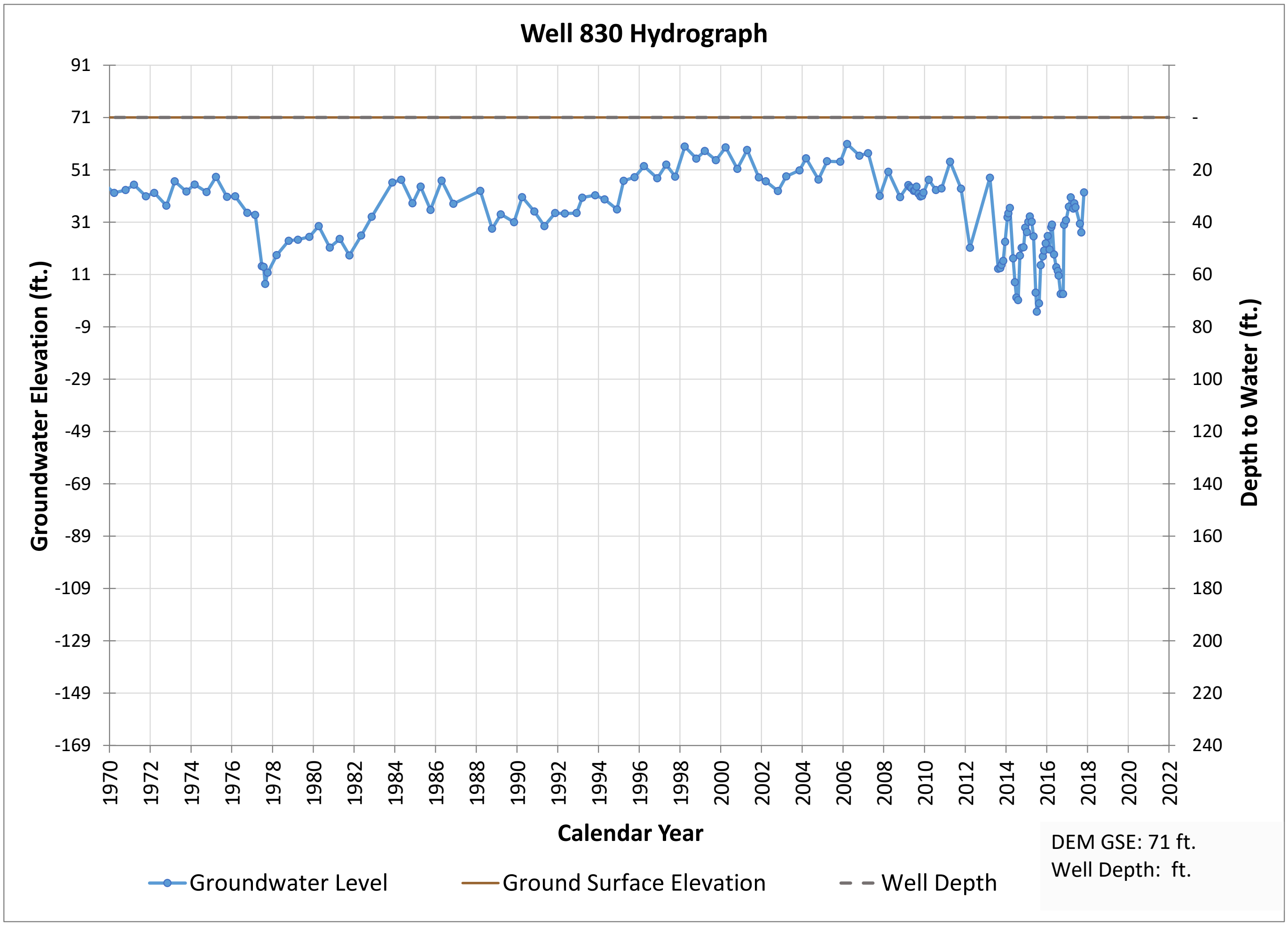
Well 825 Hydrograph
Groundwater Elevation (ft.)
Depth to Water (ft.)
79
59
39
19
-1
-21
-41
-61
-81
-101
-121
-141
-161
-181
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 59 ft.
Well Depth: 83 ft.

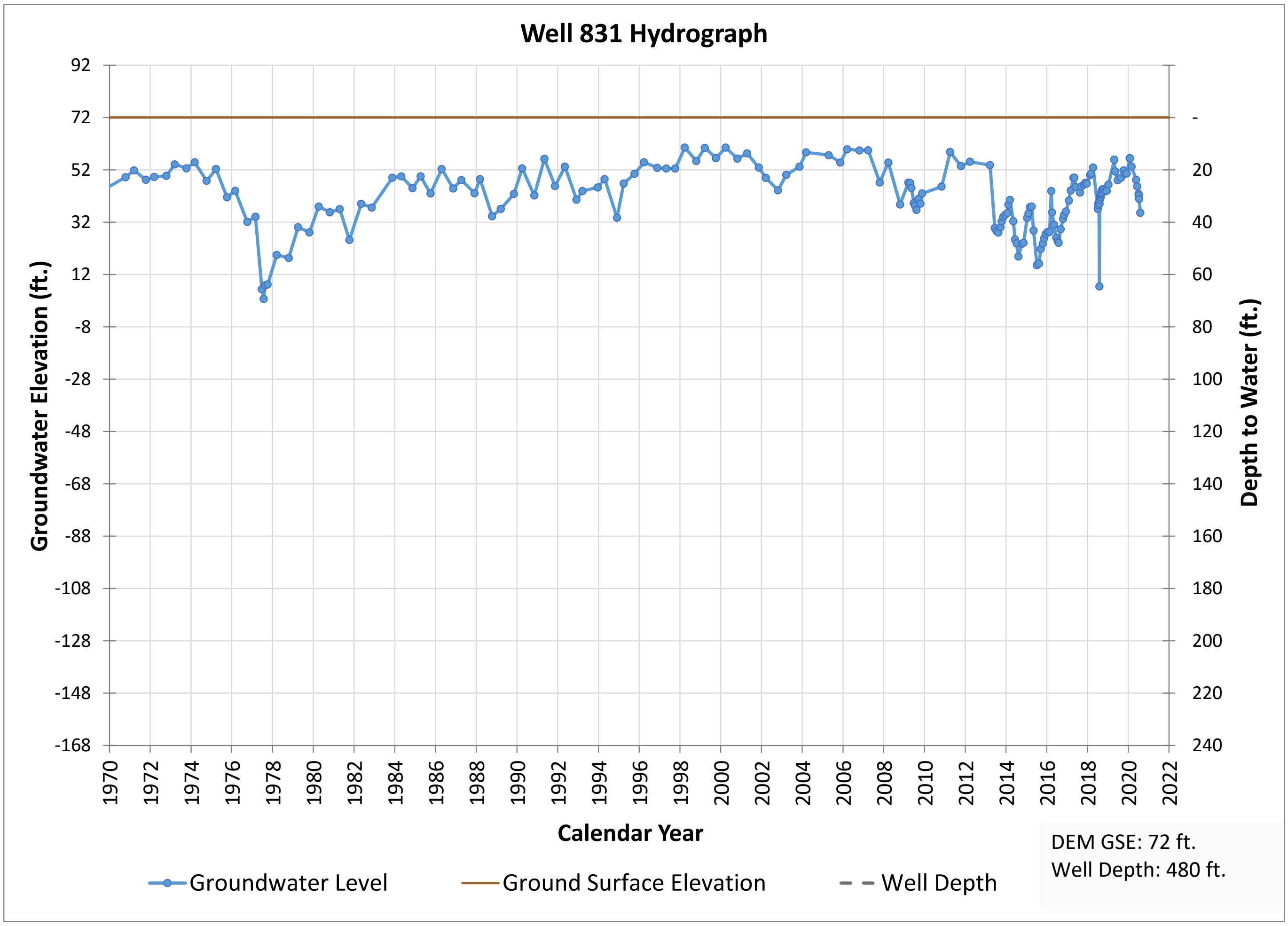


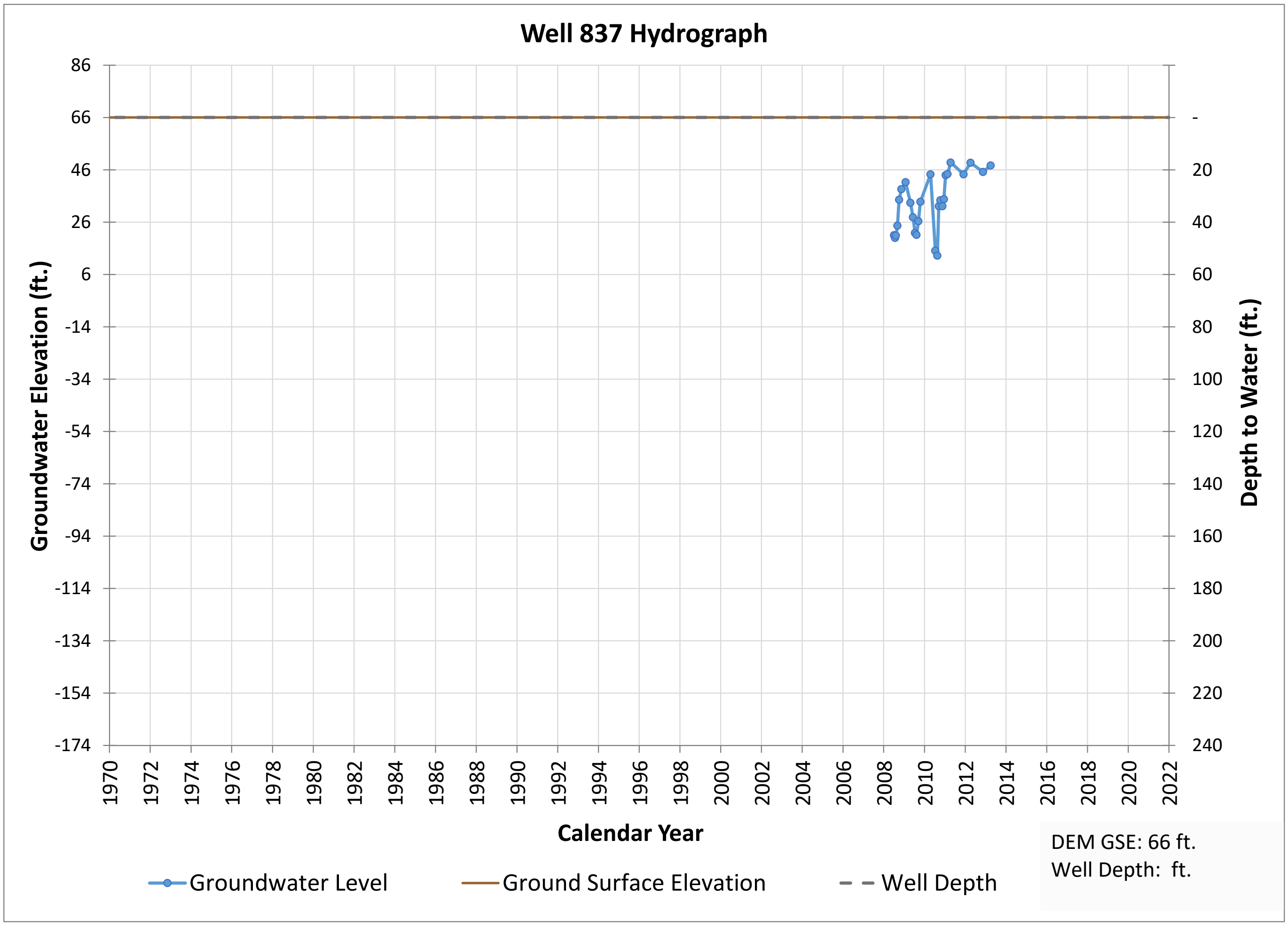
DEM GSE: 82 ft.
Well Depth: 400 ft.

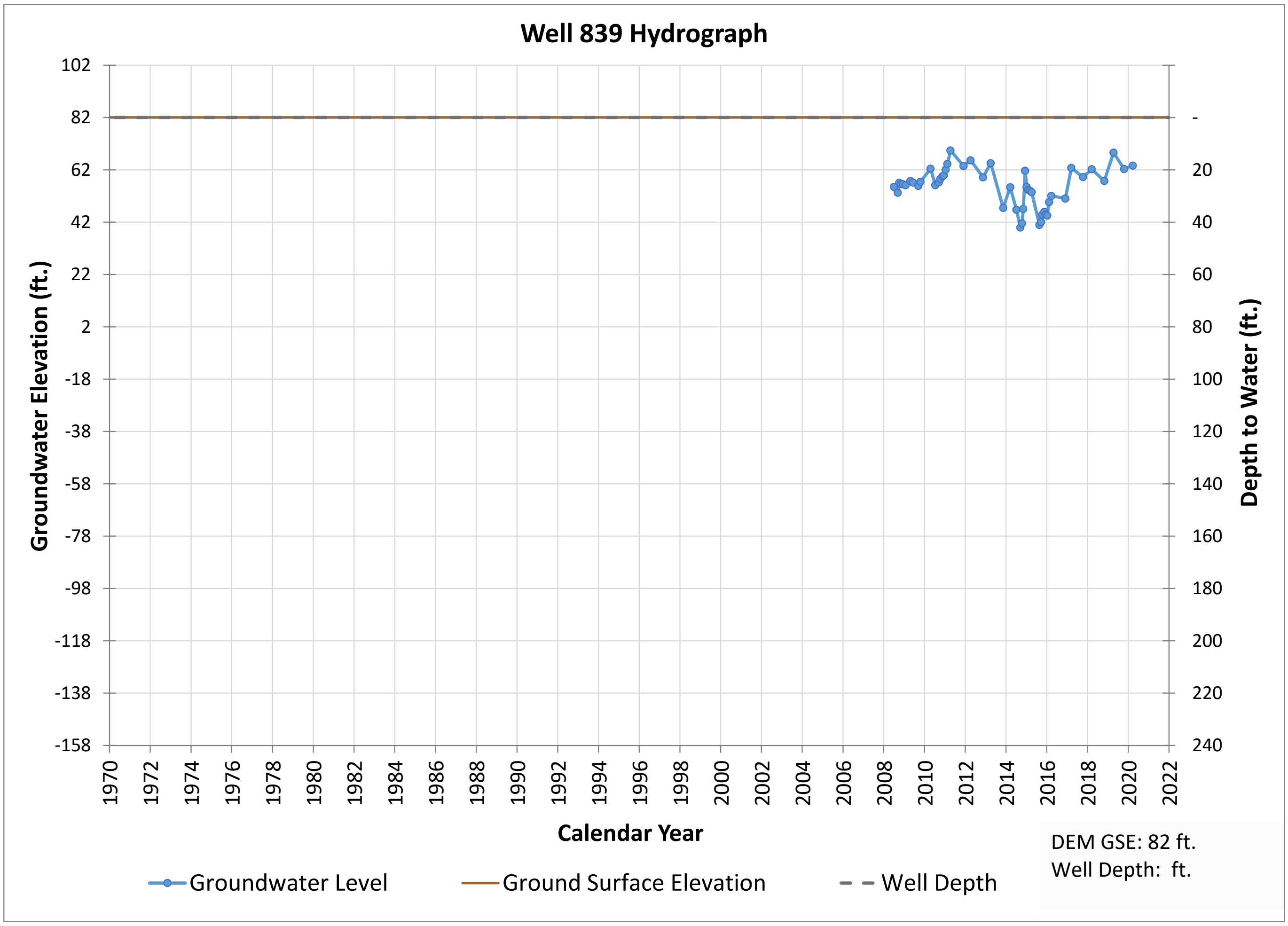

Well 828 Hydrograph
Groundwater Elevation (ft.)
72
52
32
12
-8
-28
-48
-68
-88
-108
-128
-148
-168
-188
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 52 ft.
Well Depth: ft.

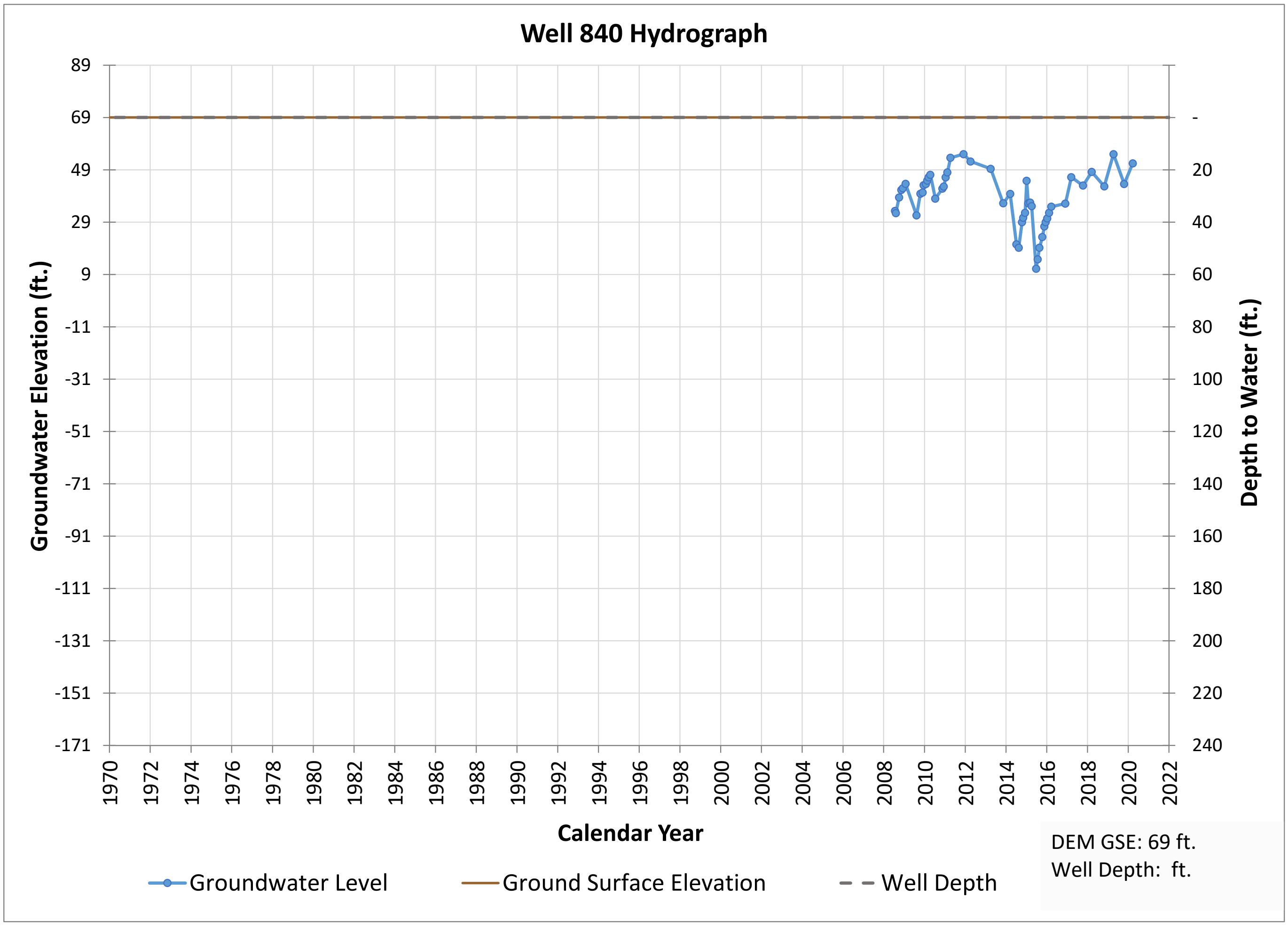

Well 829 Hydrograph
66
46
26
6
-14
-34
-54
-74
-94
-114
-134
-154
-174
-194
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 46 ft.
Well Depth: 500 ft.

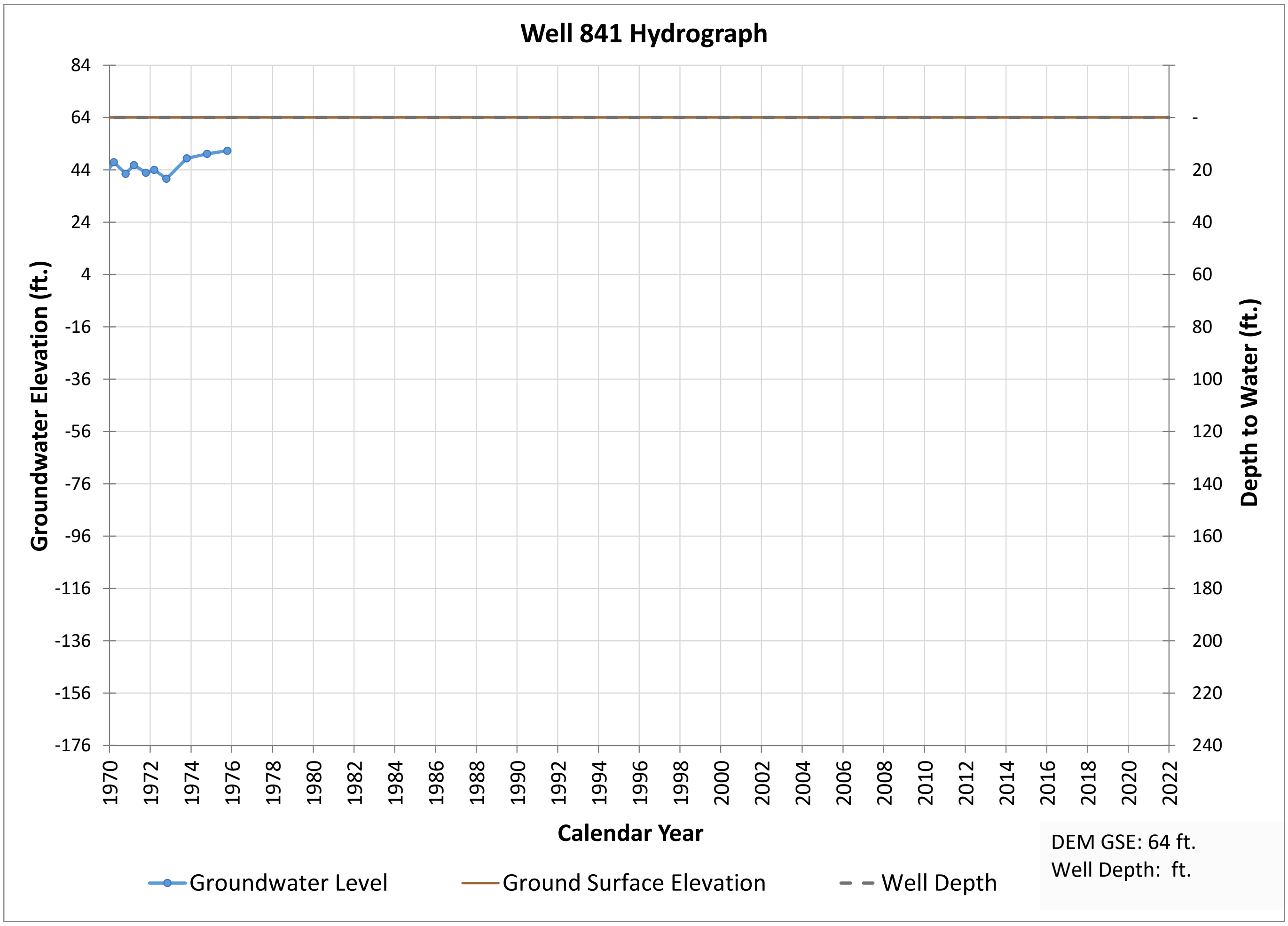

Well 830 Hydrograph
Groundwater Elevation (ft.)
91
71
51
31
11
-9
-29
-49
-69
-89
-109
-129
-149
-169
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 71 ft.
Well Depth: ft.

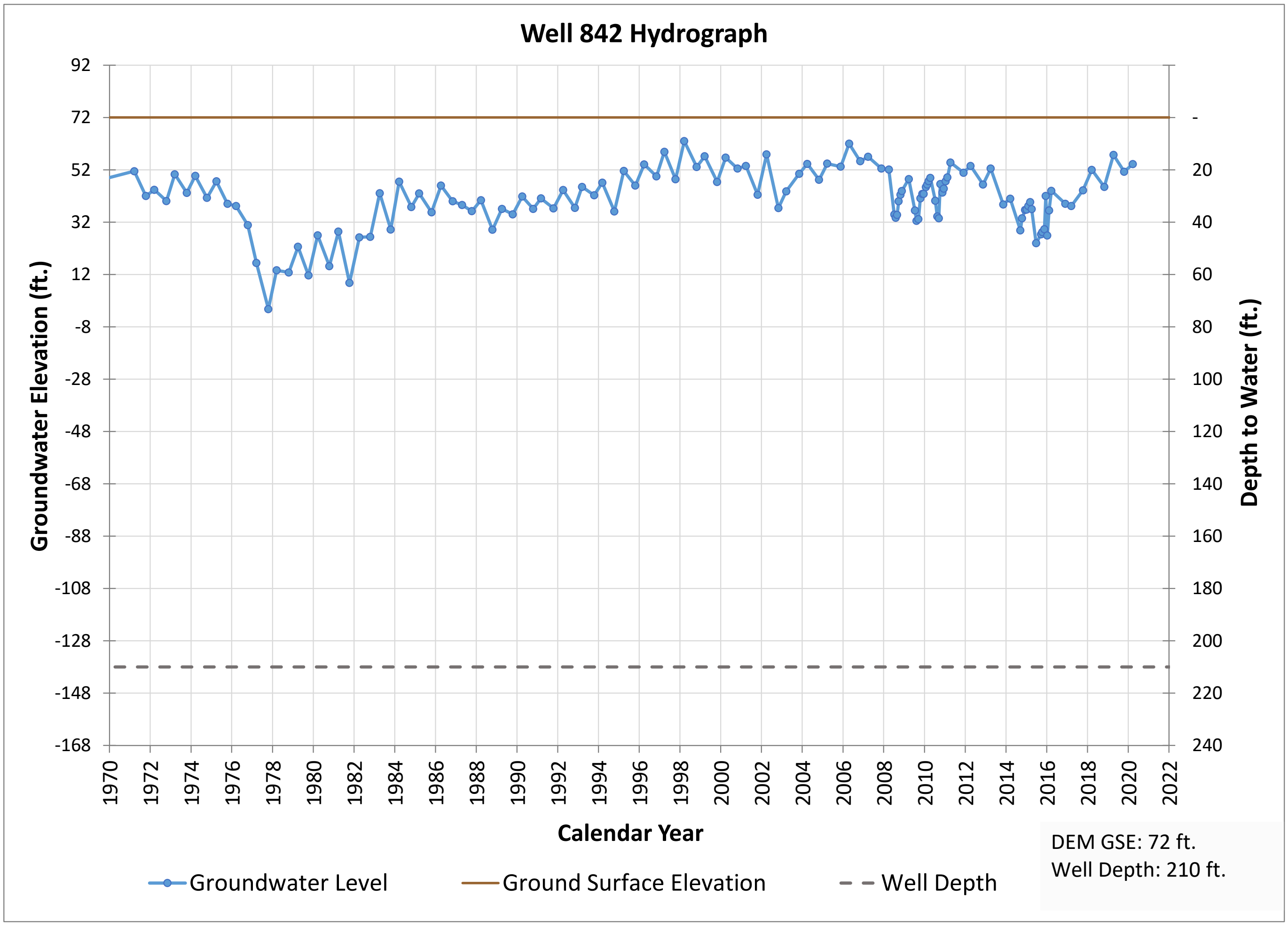

Well 831 Hydrograph
92
72
52
32
12
-8
-28
-48
-68
-88
-108
-128
-148
-168
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 72 ft.
Well Depth: 480 ft.

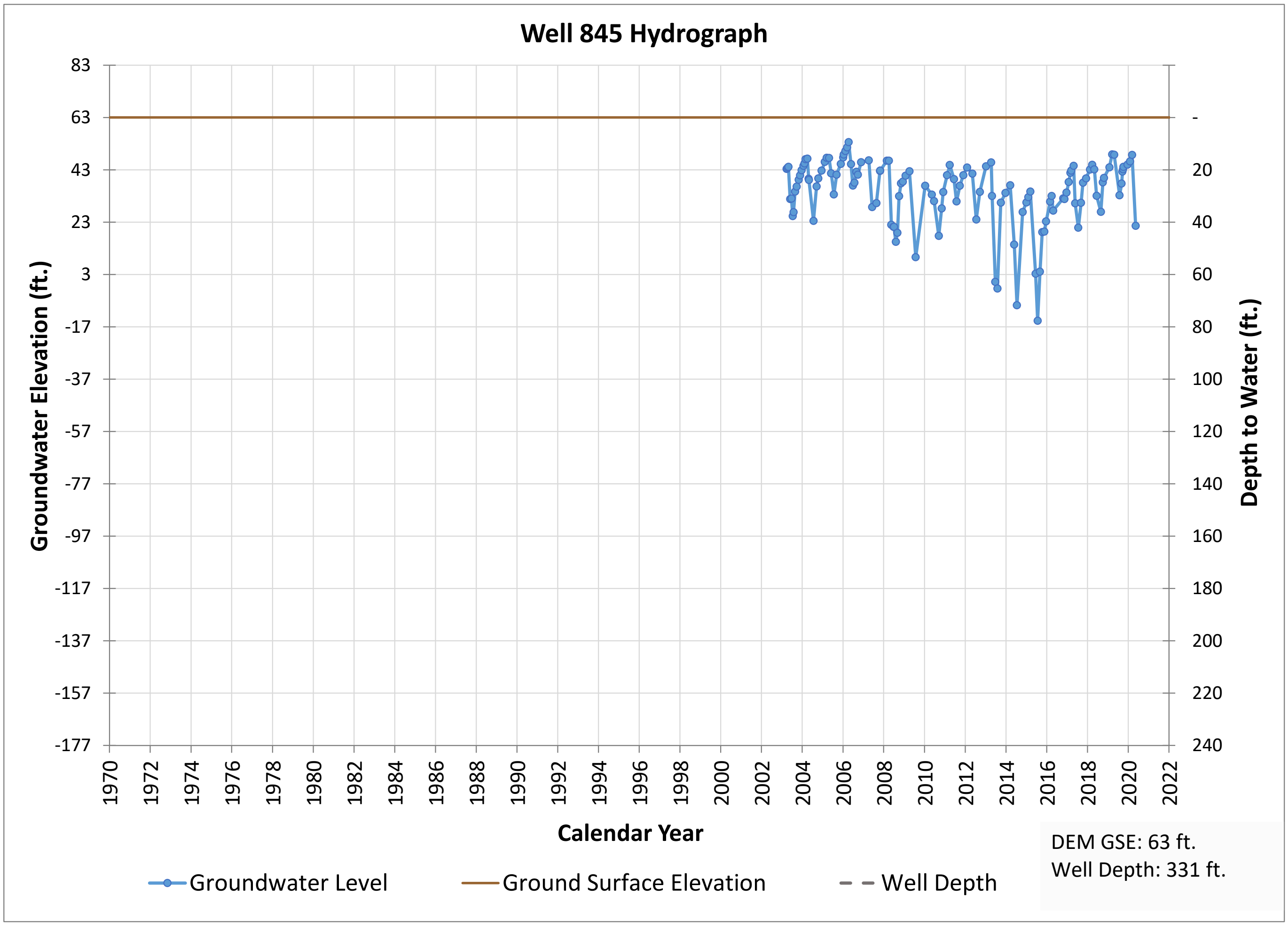

Well 837 Hydrograph
Groundwater Elevation (ft.)
86
66
46
26
6
-14
-34
-54
-74
-94
-114
-134
-154
-174
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 66 ft.
Well Depth: ft.

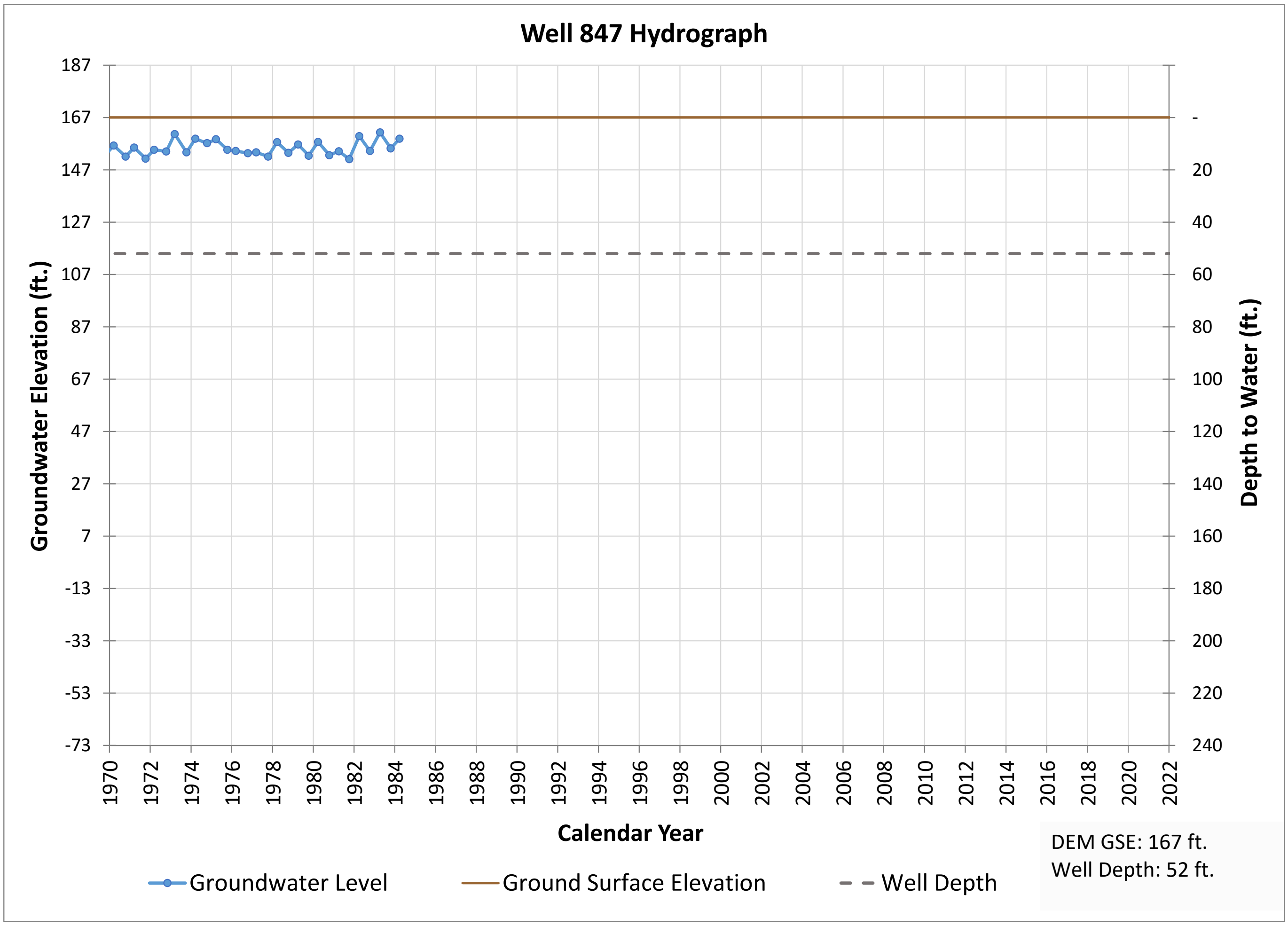

Well 839 Hydrograph
Groundwater Elevation (ft.)
102
82
62
42
22
2
-18
-38
-58
-78
-98
-118
-138
-158
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 82 ft.
Well Depth: ft.


Well 840 Hydrograph
Groundwater Elevation (ft.)
Depth to Water (ft.)
89
69
49
29
9
-11
-31
-51
-71
-91
-111
-131
-151
-171
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 69 ft.
Well Depth: ft.

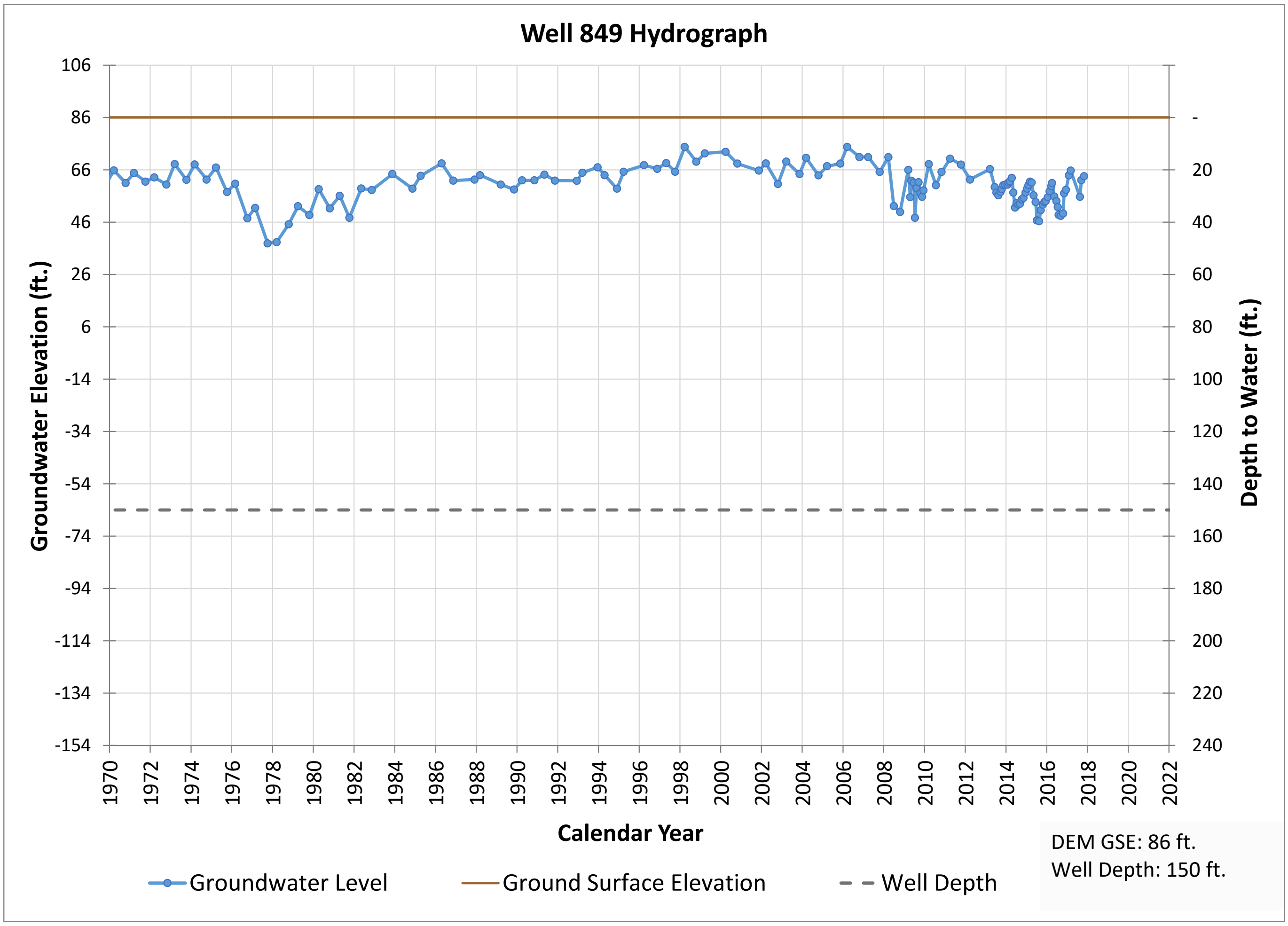

Well 841 Hydrograph
84
64
44
24
4
-16
-36
-56
-76
-96
-116
-136
-156
-176
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 64 ft.
Well Depth: ft.

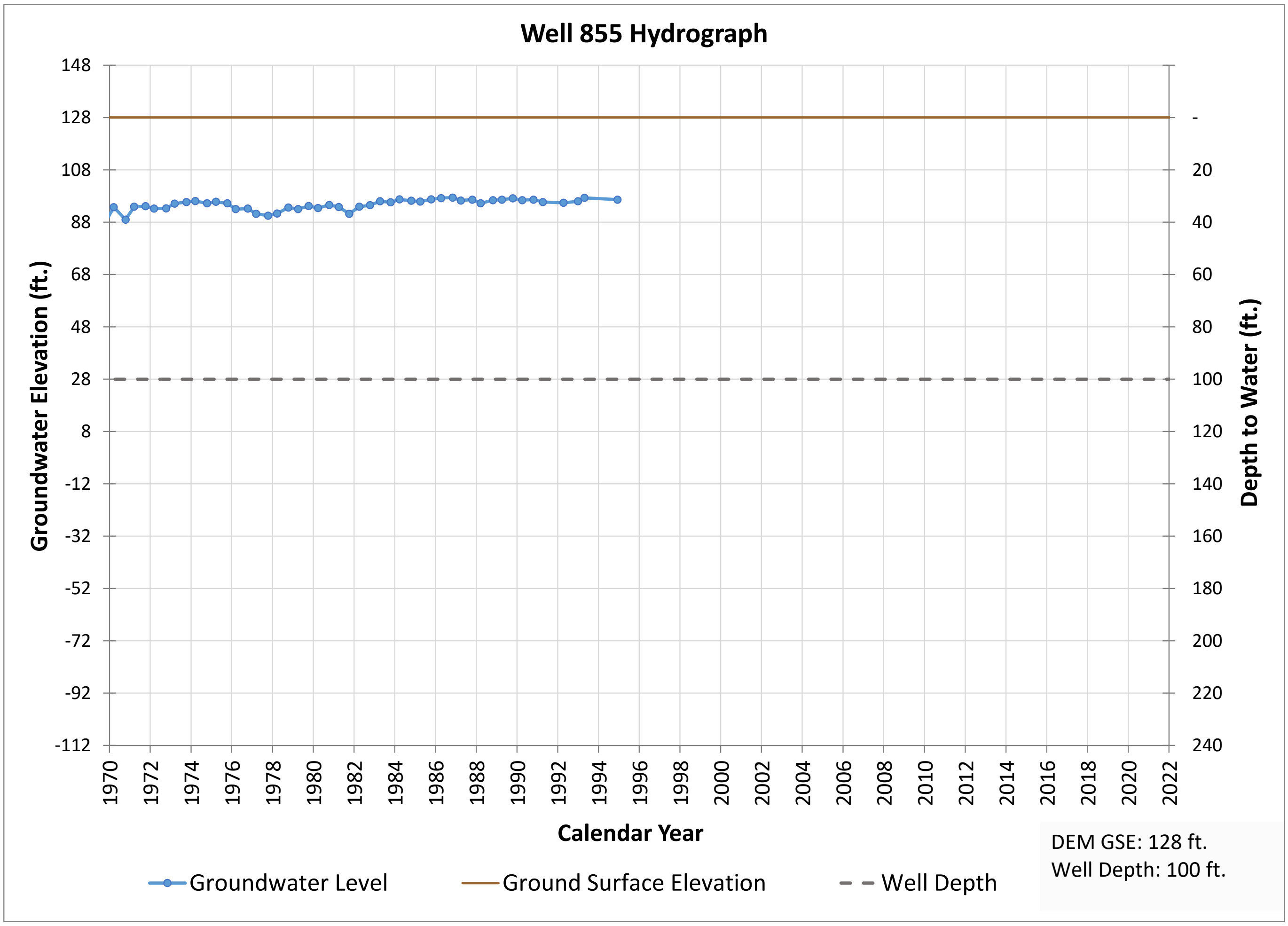

Well 842 Hydrograph
92
72
52
32
12
-8
-28
-48
-68
-88
-108
-128
-148
-168
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 72 ft.
Well Depth: 210 ft.

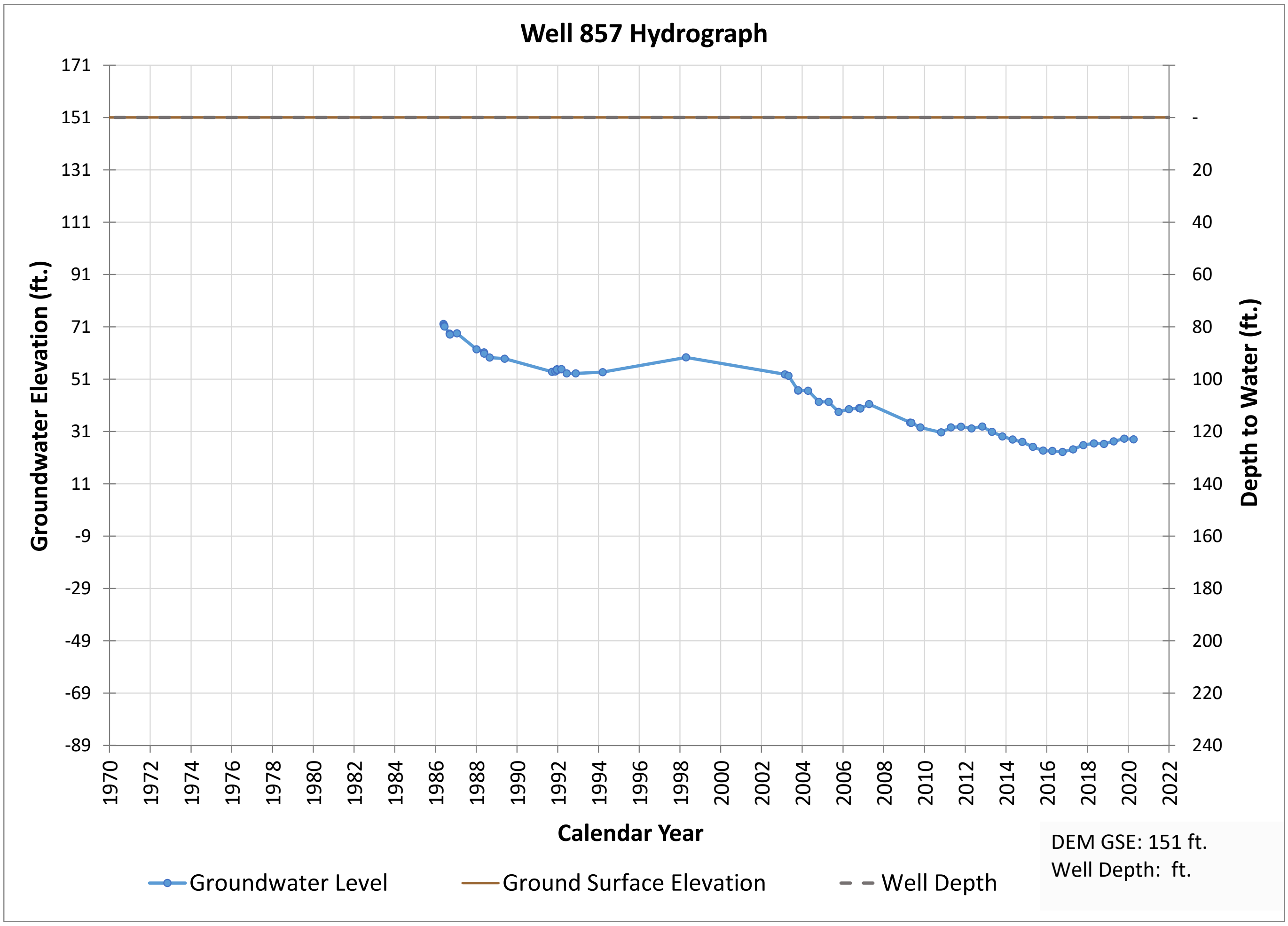

Well 845 Hydrograph
Groundwater Elevation (ft.)
83
63
43
23
3
-17
-37
-57
-77
-97
-117
-137
-157
-177
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 63 ft.
Well Depth: 331 ft.



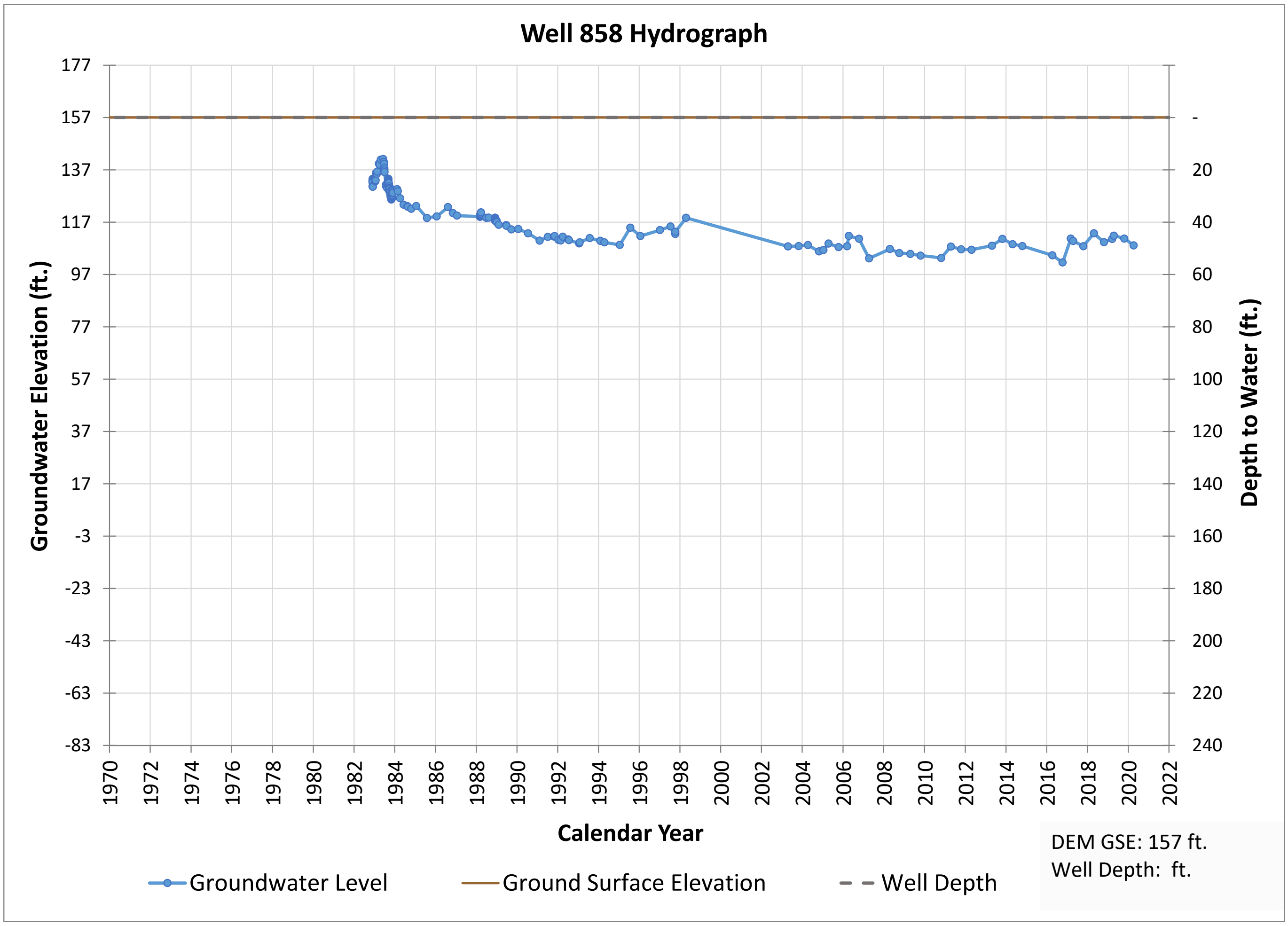
Well 847 Hydrograph
Groundwater Elevation (ft.)
187
167
147
127
107
87
67
47
27
7
-13
-33
-53
-73
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 167 ft.
Well Depth: 52 ft.

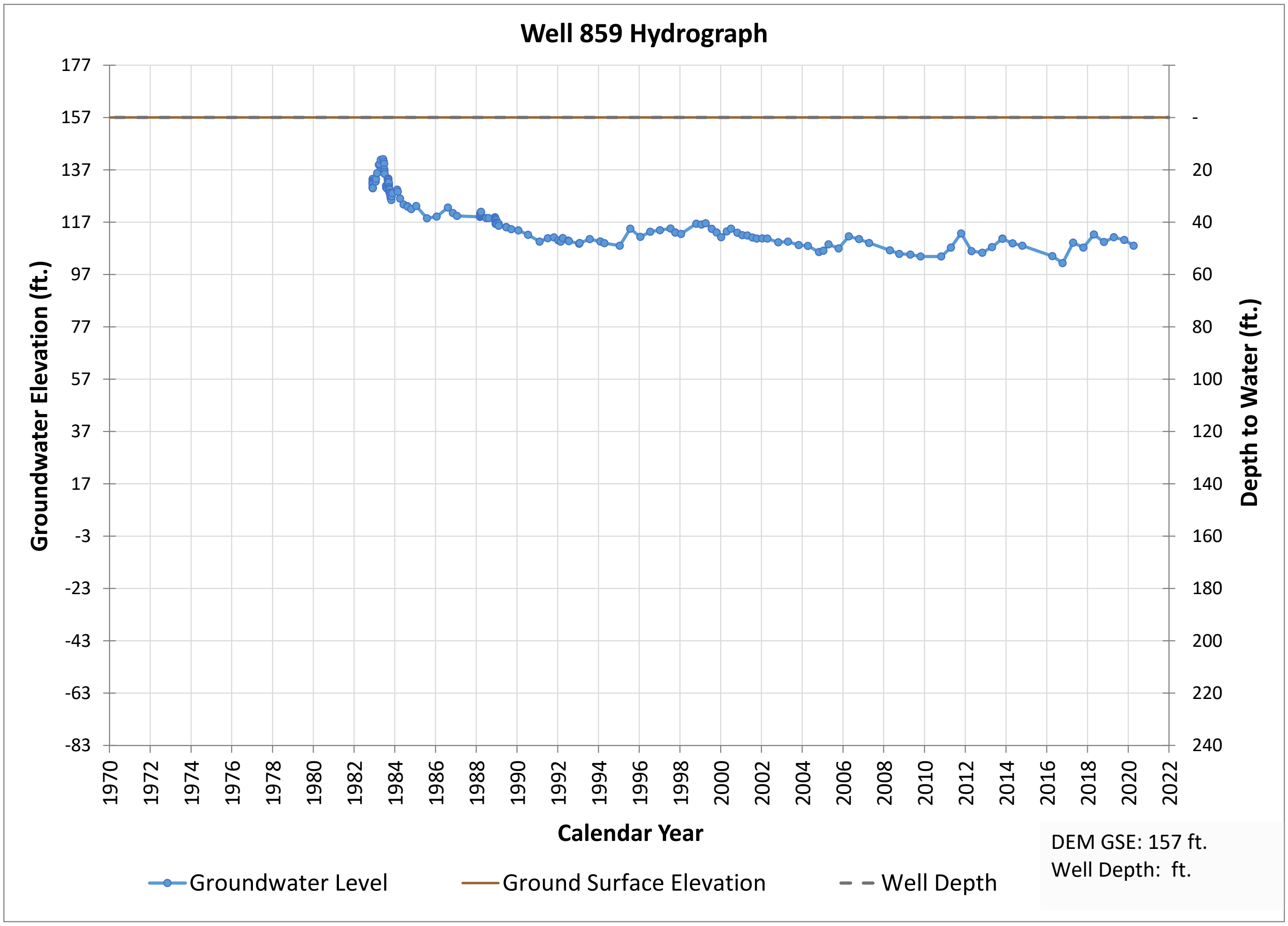

Well 849 Hydrograph
106
86
66
46
26
6
-14
-34
-54
-74
-94
-114
-134
-154
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 86 ft.
Well Depth: 150 ft.

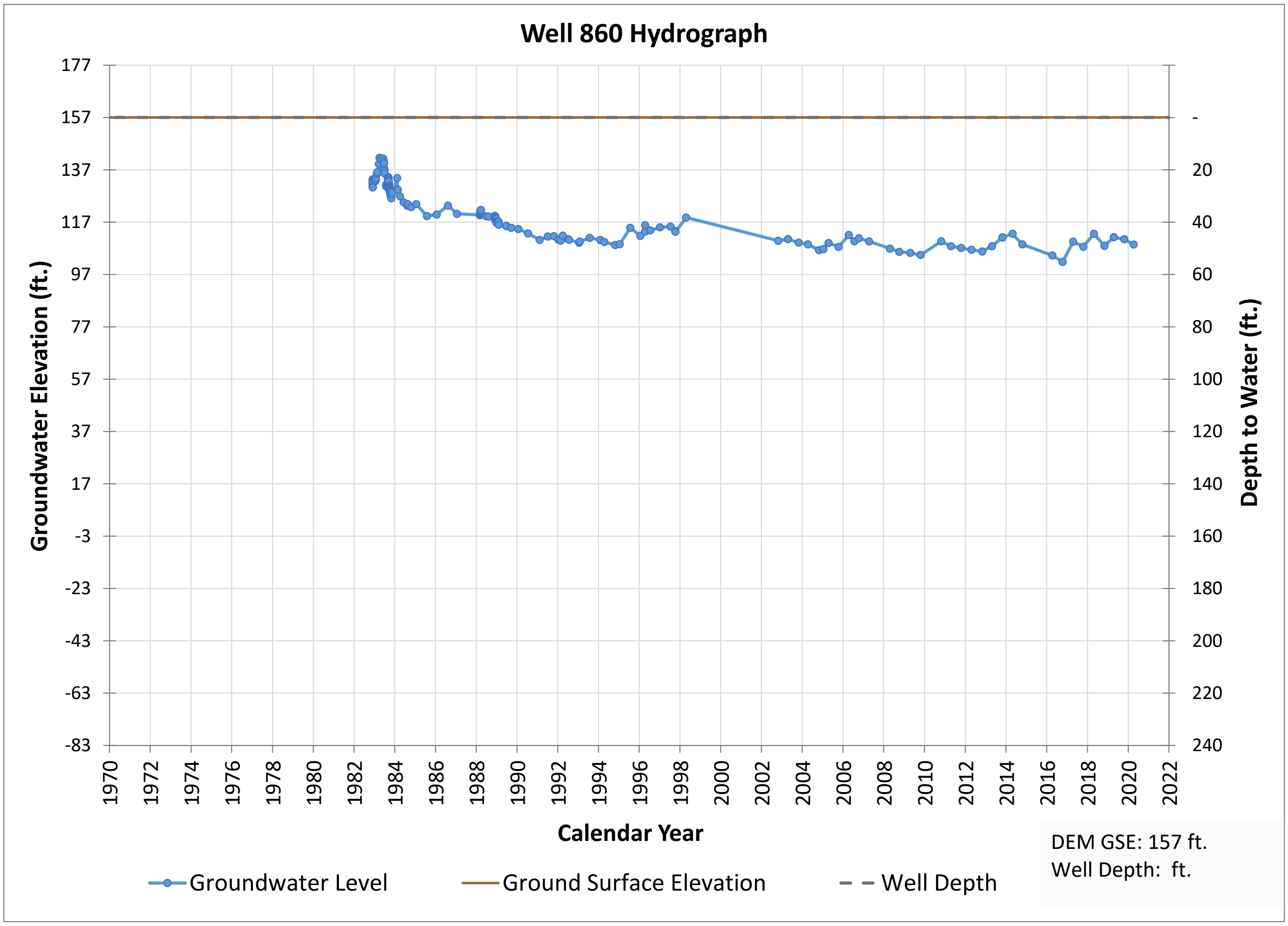
Well 855 Hydrograph
148
128
108
88
68
48
28
8
-12
-32
-52
-72
-92
-112
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 128 ft.
Well Depth: 100 ft.

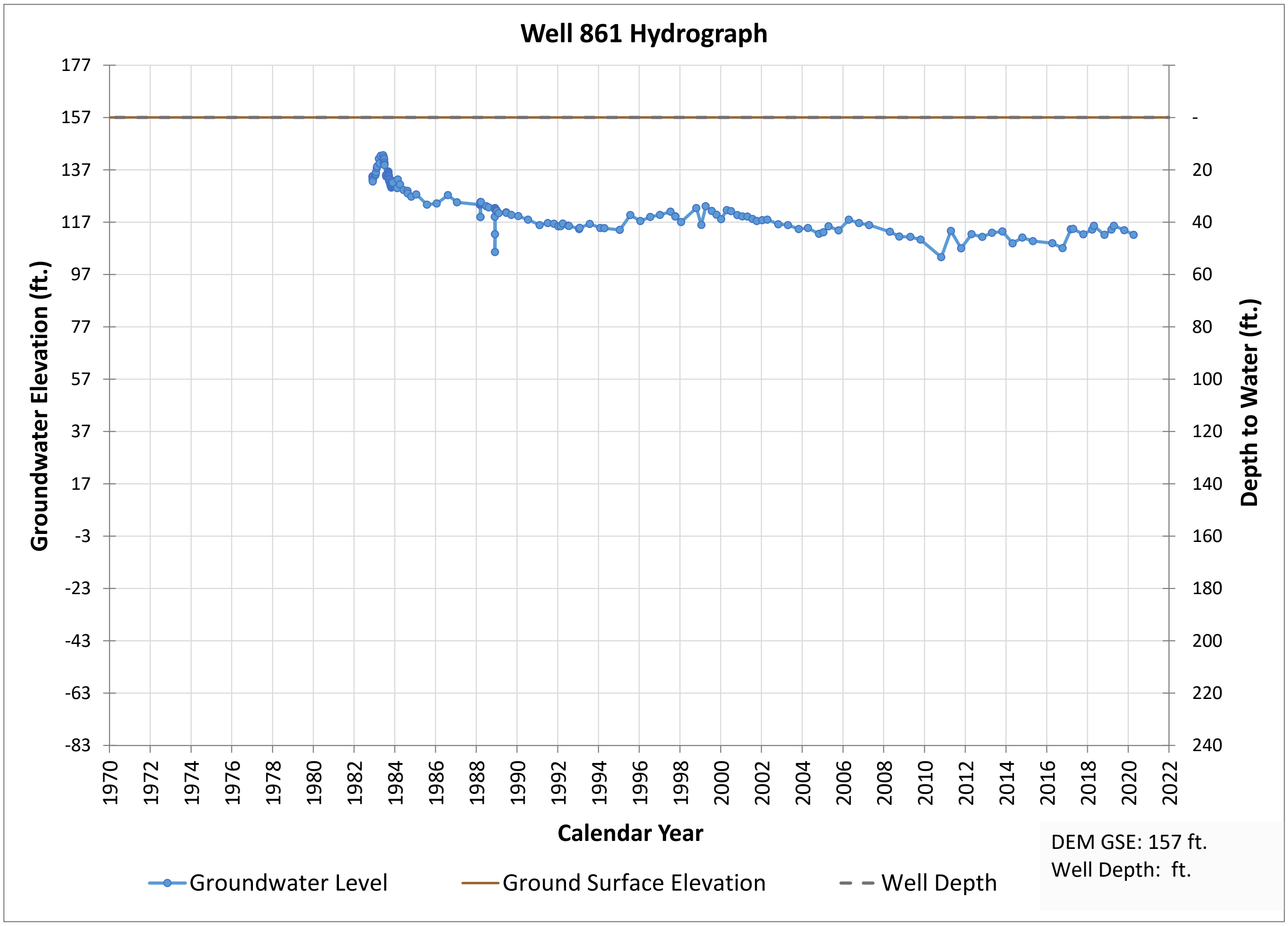


DEM GSE: 151 ft.
Well Depth: ft.

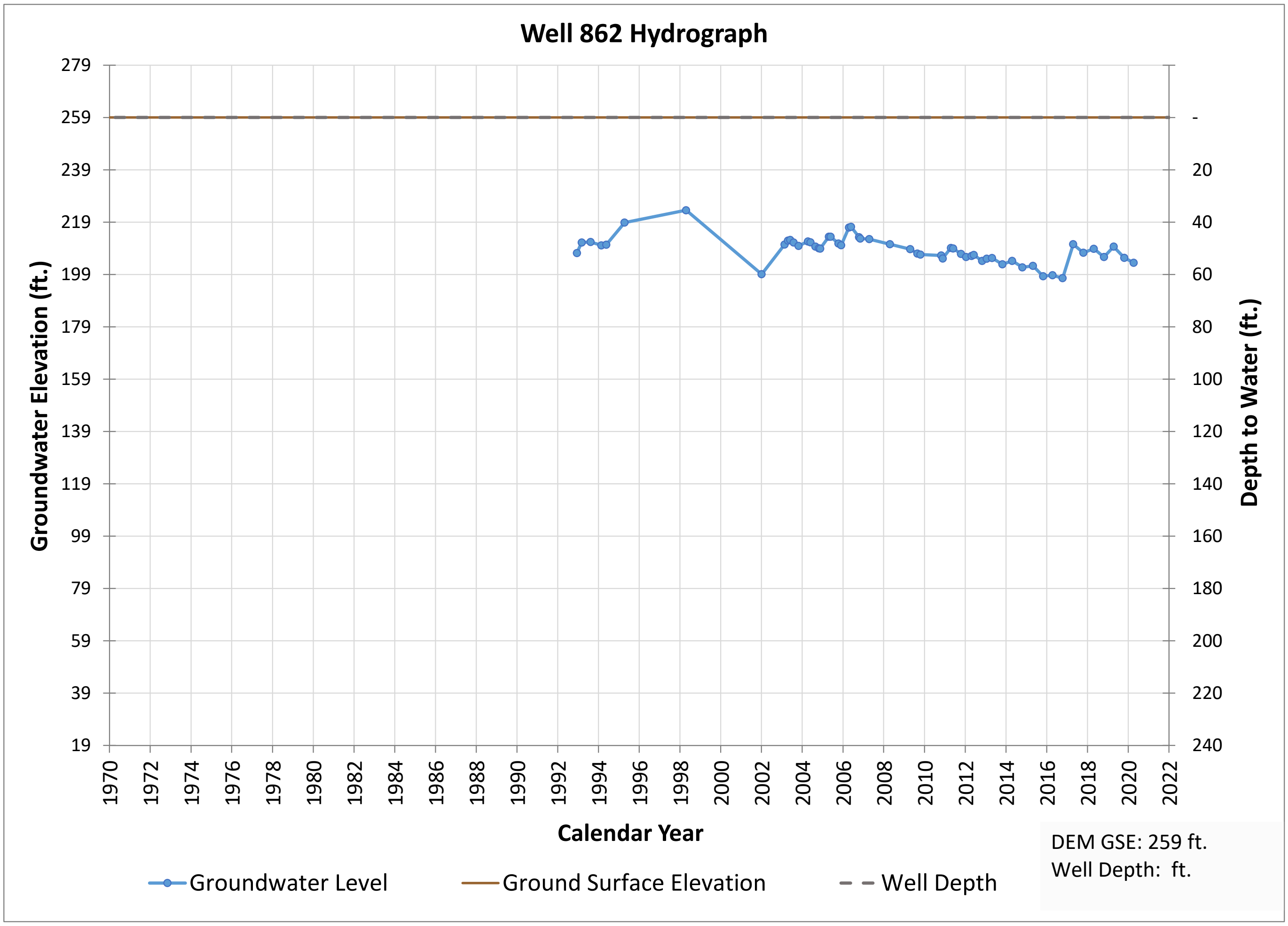

Well 858 Hydrograph
Groundwater Elevation (ft.)
177
157
137
117
97
77
57
37
17
-3
-23
-43
-63
-83
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 157 ft.
Well Depth: ft.

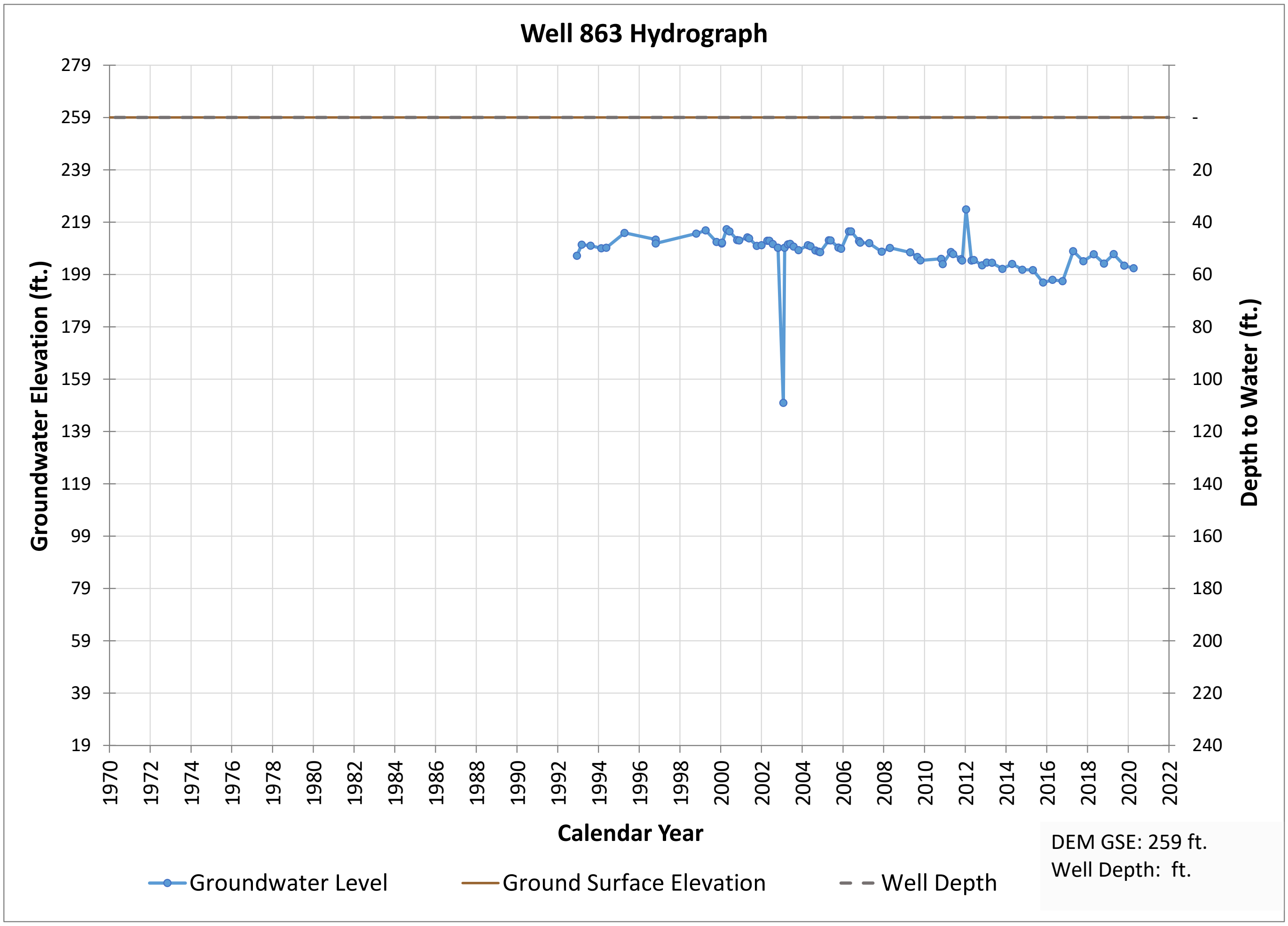

Well 859 Hydrograph
Groundwater Elevation (ft.)
177
157
137
117
97
77
57
37
17
-3
-23
-43
-63
-83
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 157 ft.
Well Depth: ft.

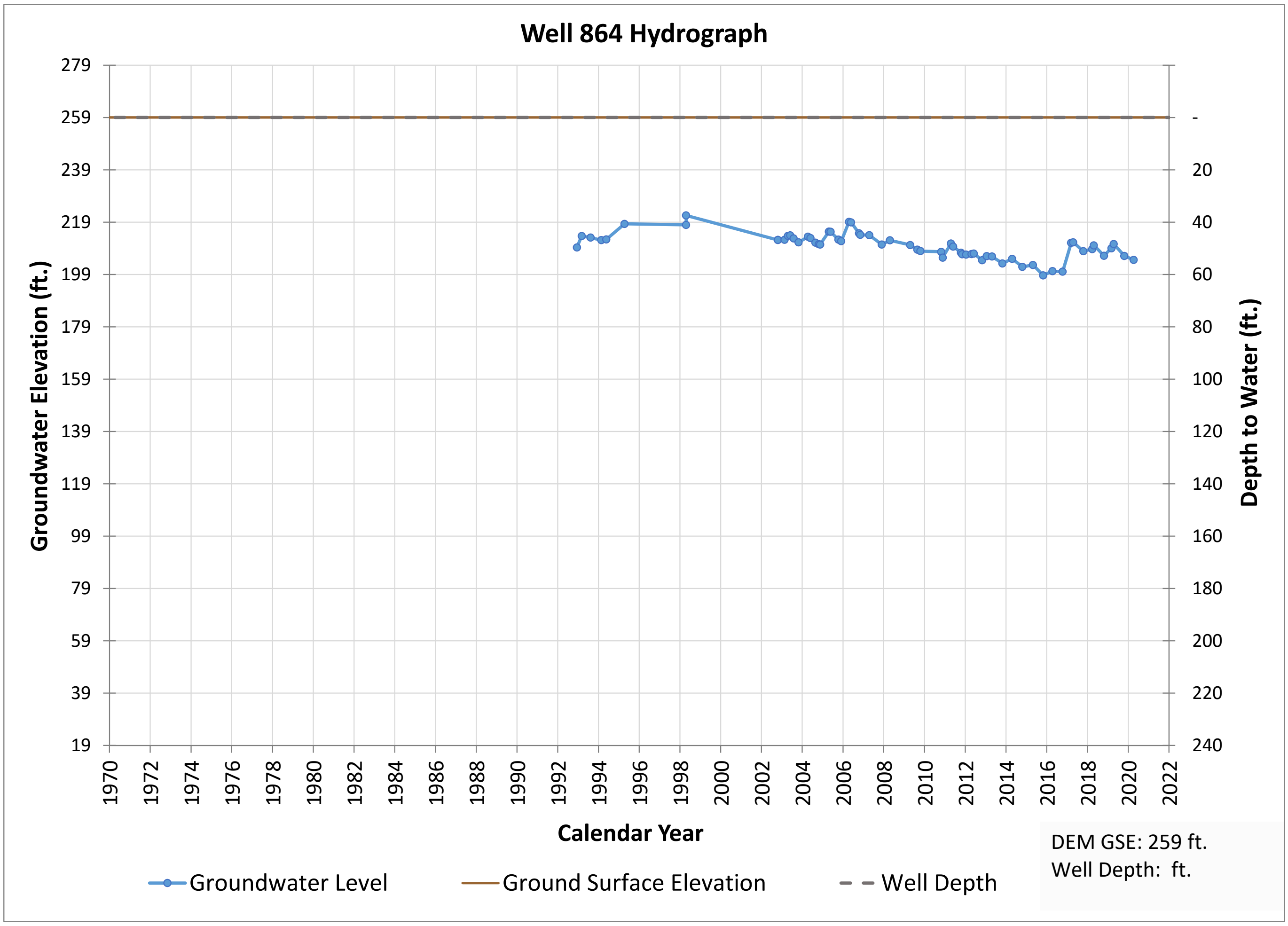

Well 860 Hydrograph
Groundwater Elevation (ft.)
Depth to Water (ft.)
177
157
137
117
97
77
57
37
17
-3
-23
-43
-63
-83
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 157 ft.
Well Depth: ft.

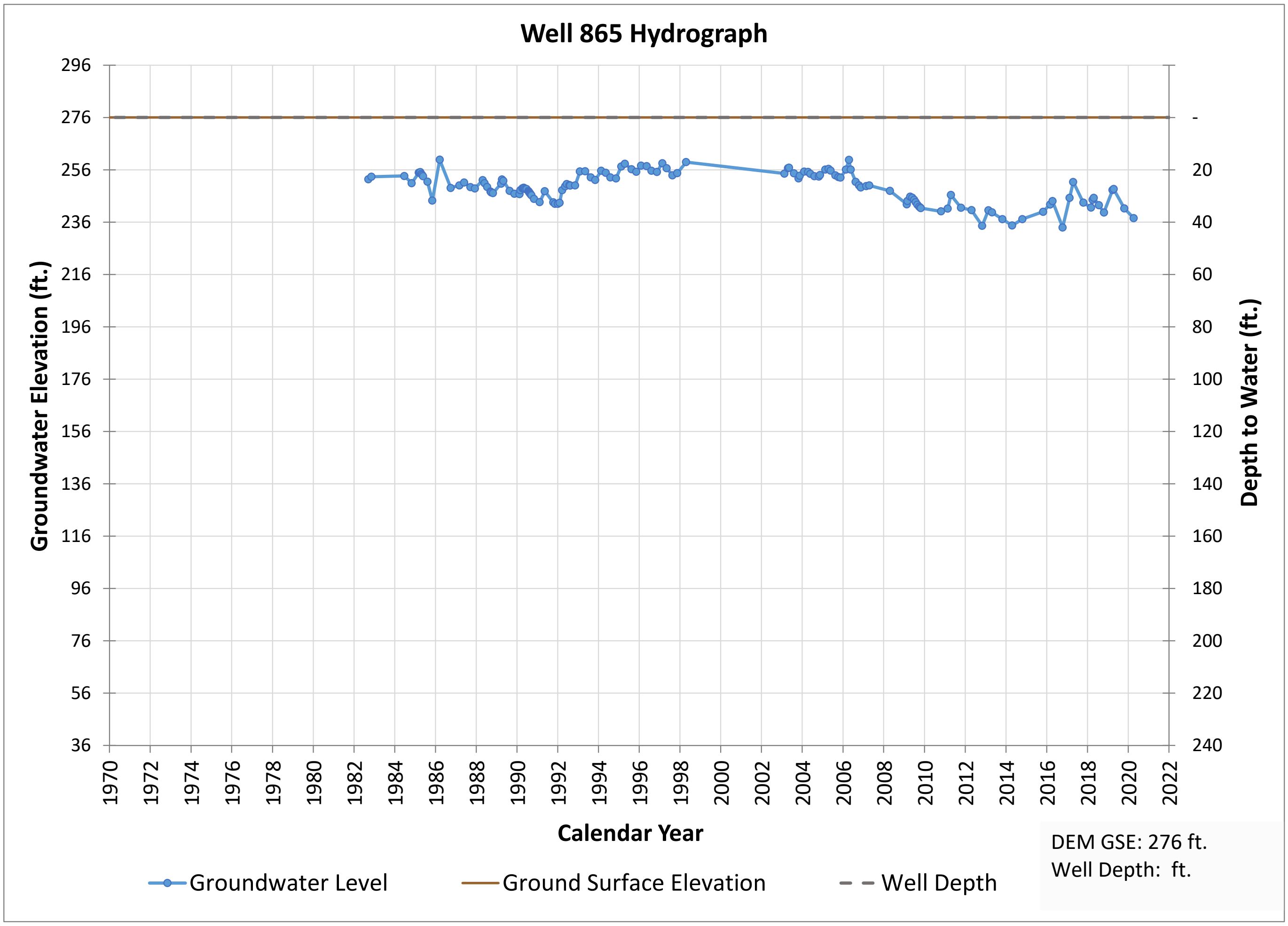


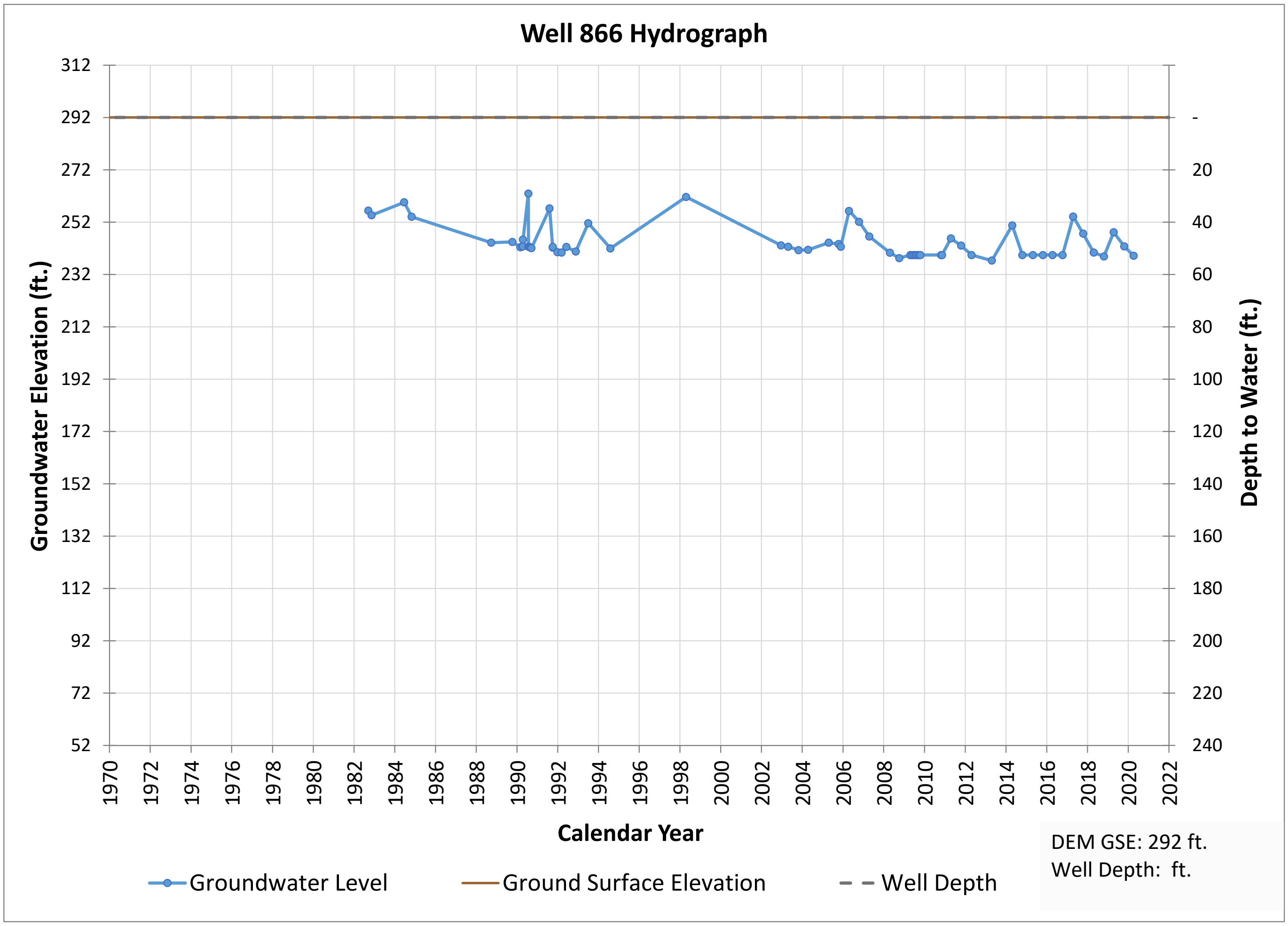
DEM GSE: 157 ft.
Well Depth: ft.

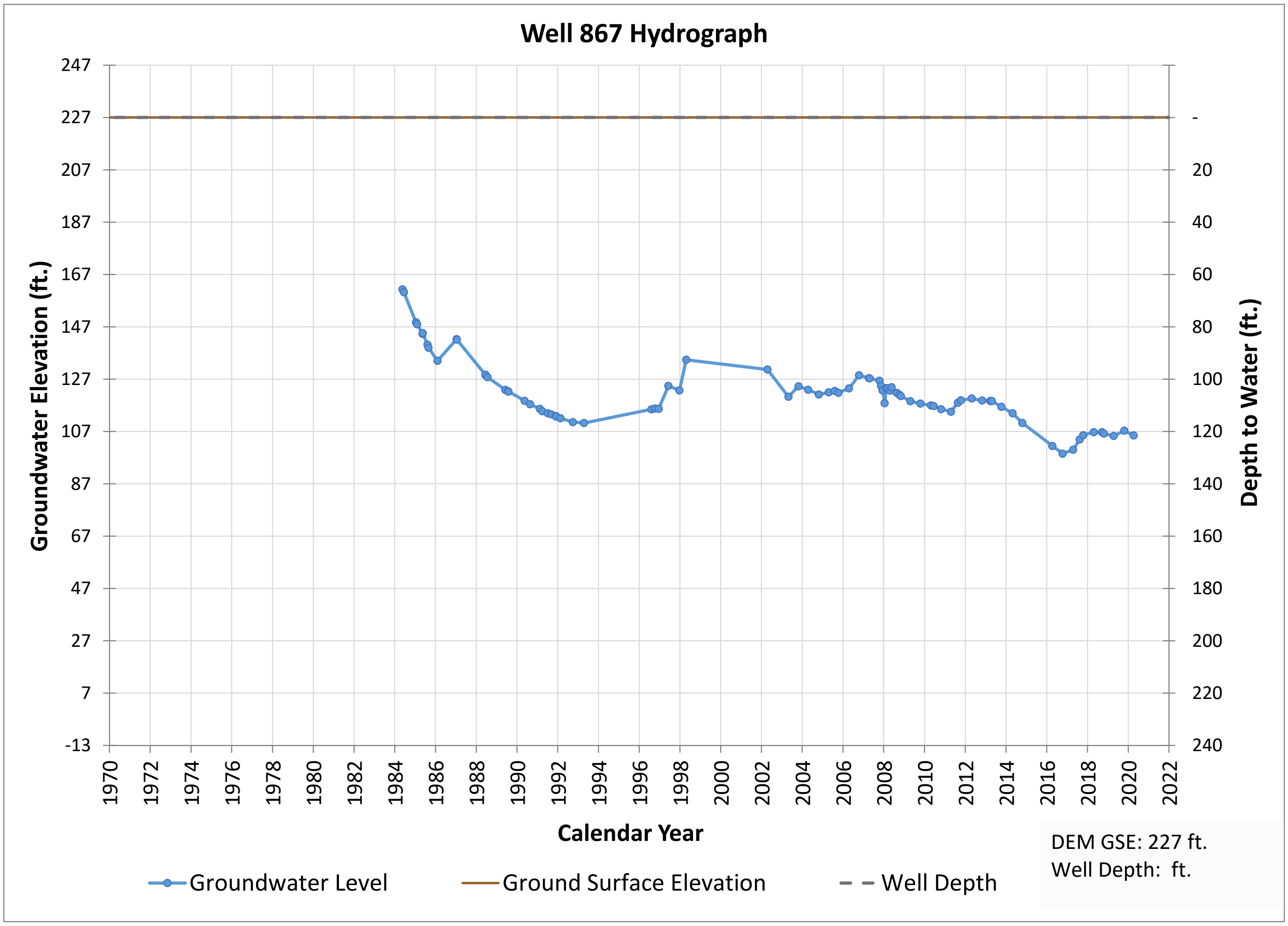

Well 862 Hydrograph
Groundwater Elevation (ft.)
279
259
239
219
199
179
159
139
119
99
79
59
39
19
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 259 ft.
Well Depth: ft.

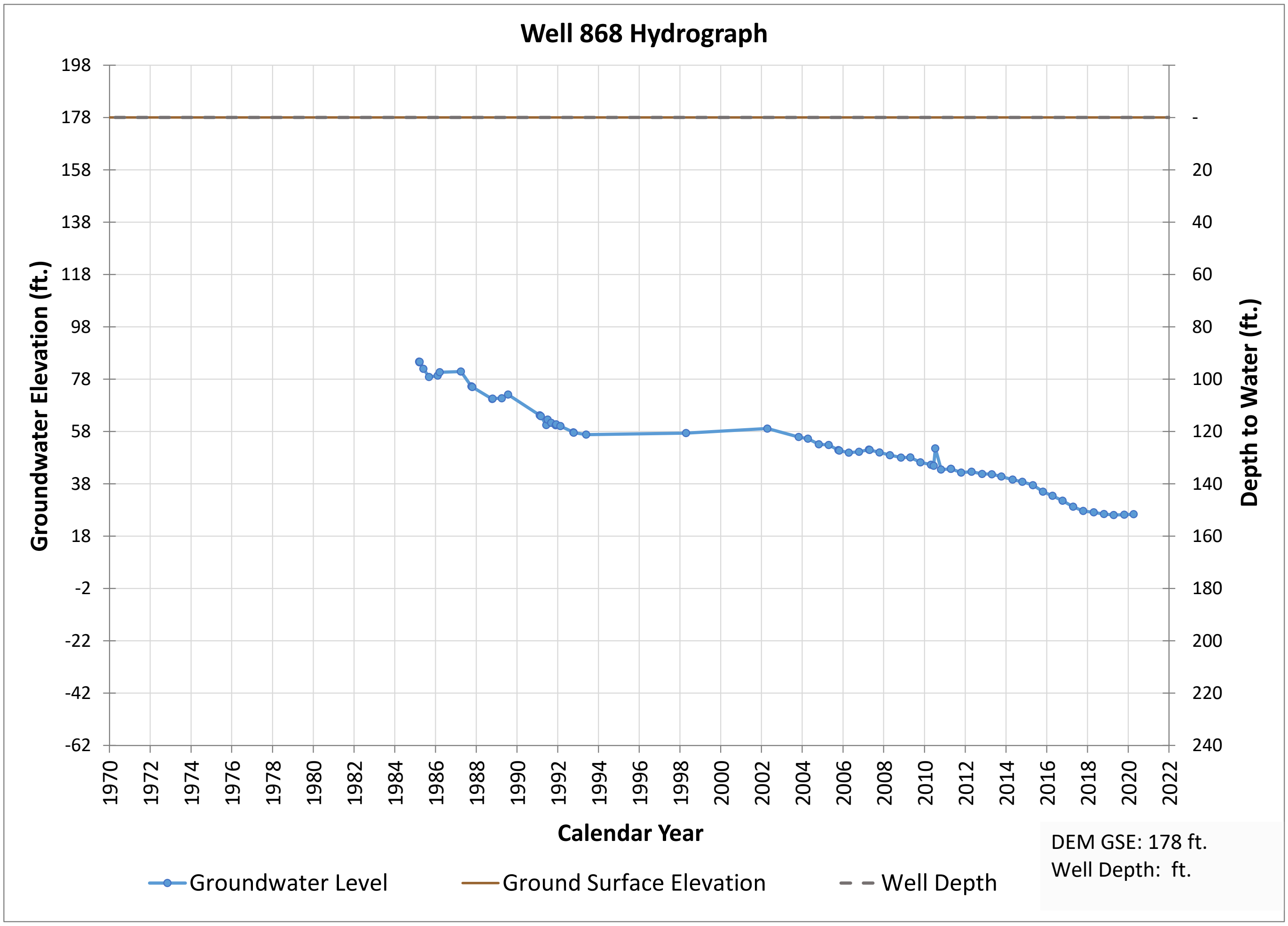

Well 863 Hydrograph
Groundwater Elevation (ft.)
279
259
239
219
199
179
159
139
119
99
79
59
39
19
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 259 ft.
Well Depth: ft.

Well 864 Hydrograph
Groundwater Elevation (ft.)
Depth to Water (ft.)
279
259
239
219
199
179
159
139
119
99
79
59
39
19
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 259 ft.
Well Depth: ft.

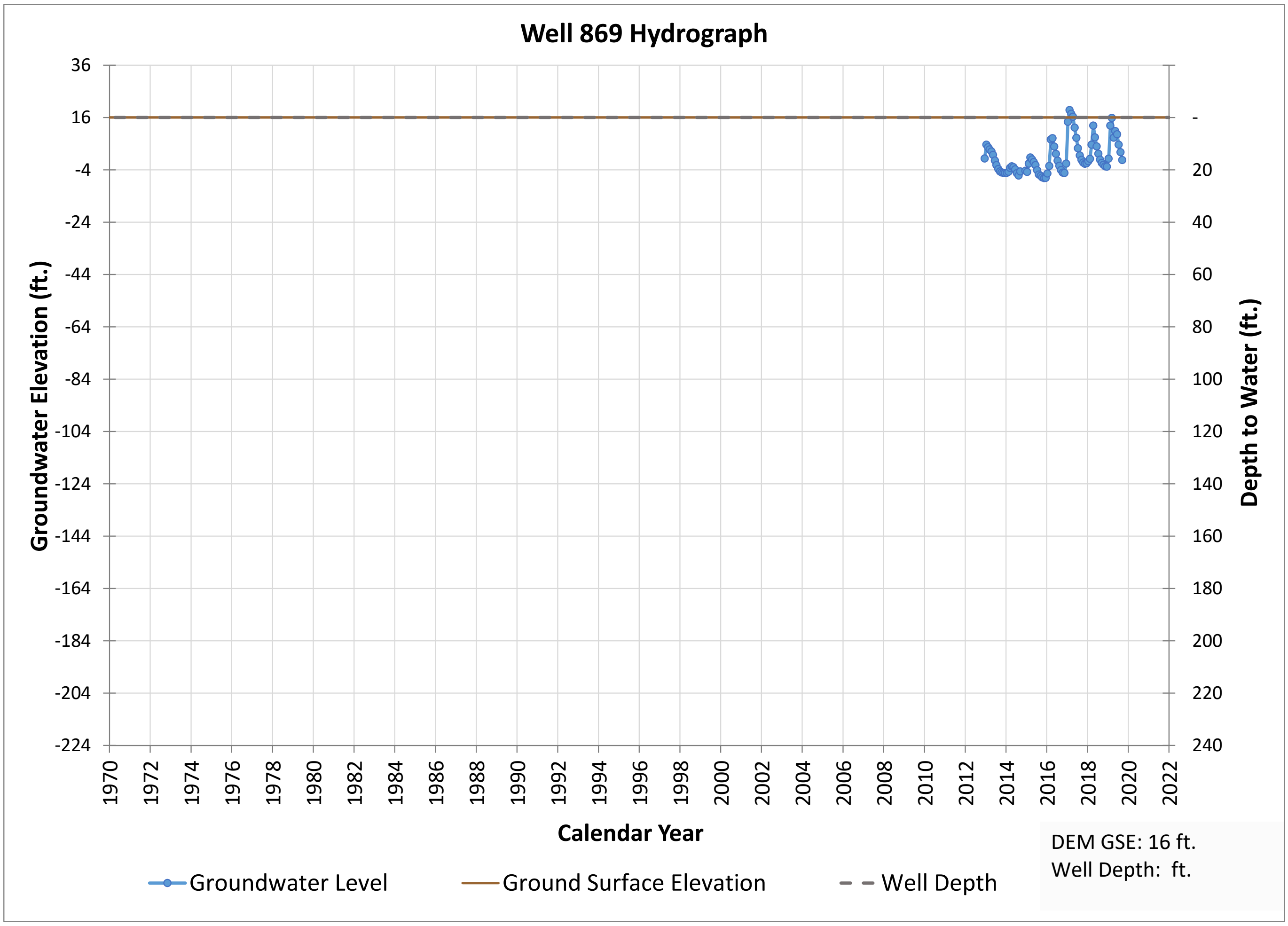

Well 865 Hydrograph
Groundwater Elevation (ft.)
296
276
256
236
216
196
176
156
136
116
96
76
56
36
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 276 ft.
Well Depth: ft.


Well 866 Hydrograph
Groundwater Elevation (ft.)
312
292
272
252
232
212
192
172
152
132
112
92
72
52
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 292 ft.
Well Depth: ft.

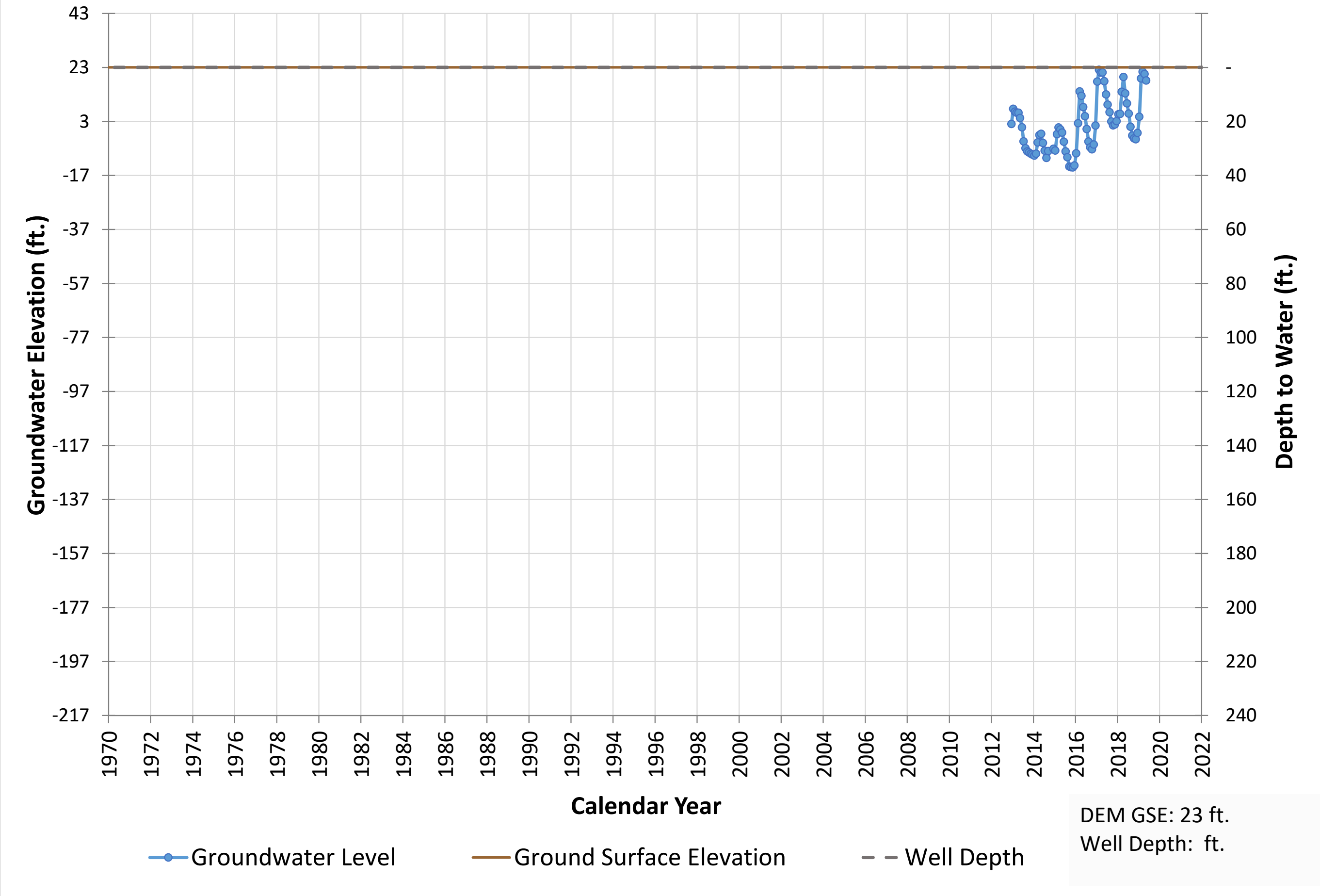

Well 867 Hydrograph
Groundwater Elevation (ft.)
247
227
207
187
167
147
127
107
87
67
47
27
7
-13
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 227 ft.
Well Depth: ft.



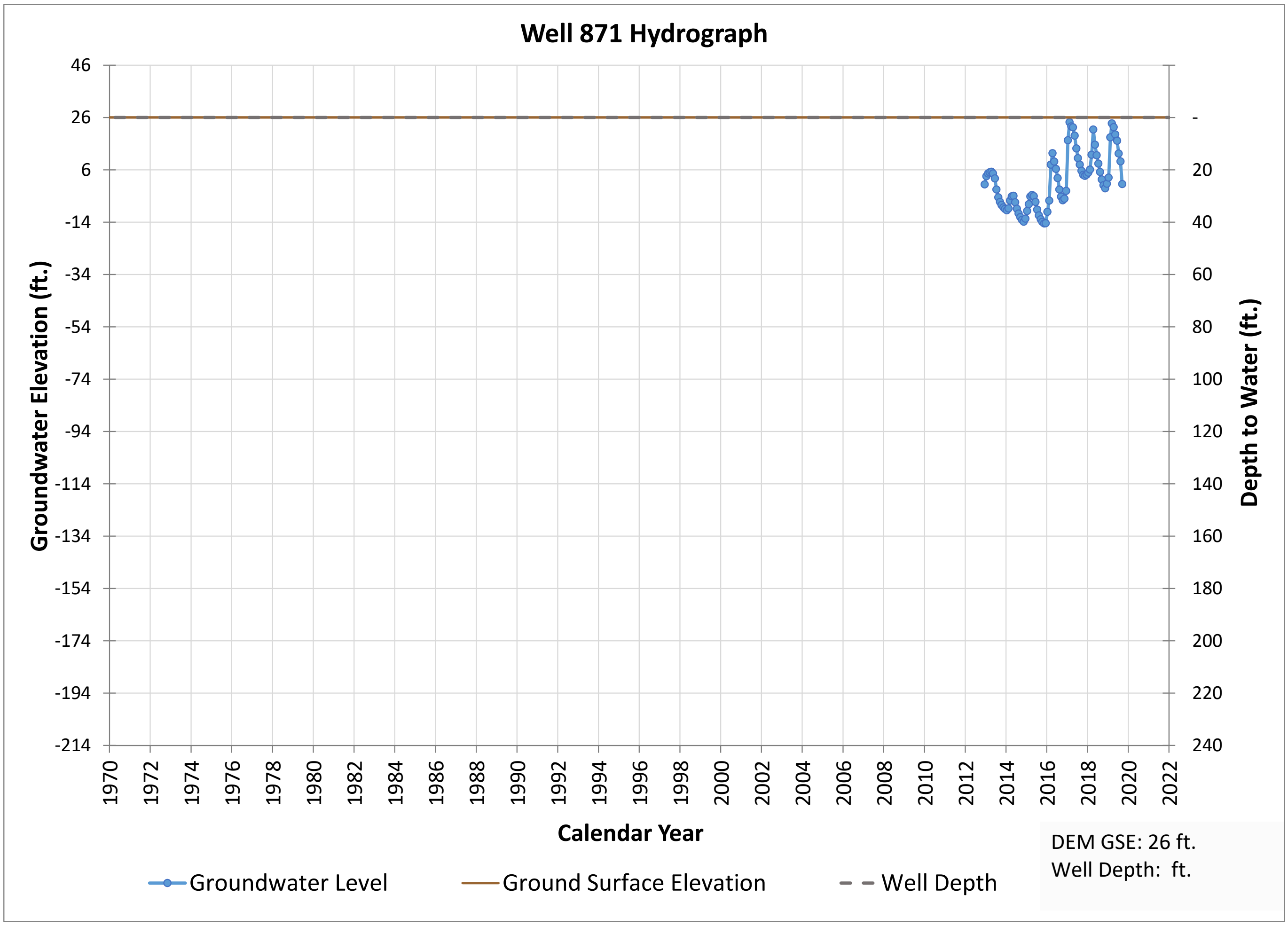
Well 868 Hydrograph
Groundwater Elevation (ft.)
Depth to Water (ft.)
198
178
158
138
118
98
78
58
38
18
-2
-22
-42
-62
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 178 ft.
Well Depth: ft.


Well 869 Hydrograph
Groundwater Elevation (ft.)
36
16
-4
-24
-44
-64
-84
-104
-124
-144
-164
-184
-204
-224
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 16 ft.
Well Depth: ft.

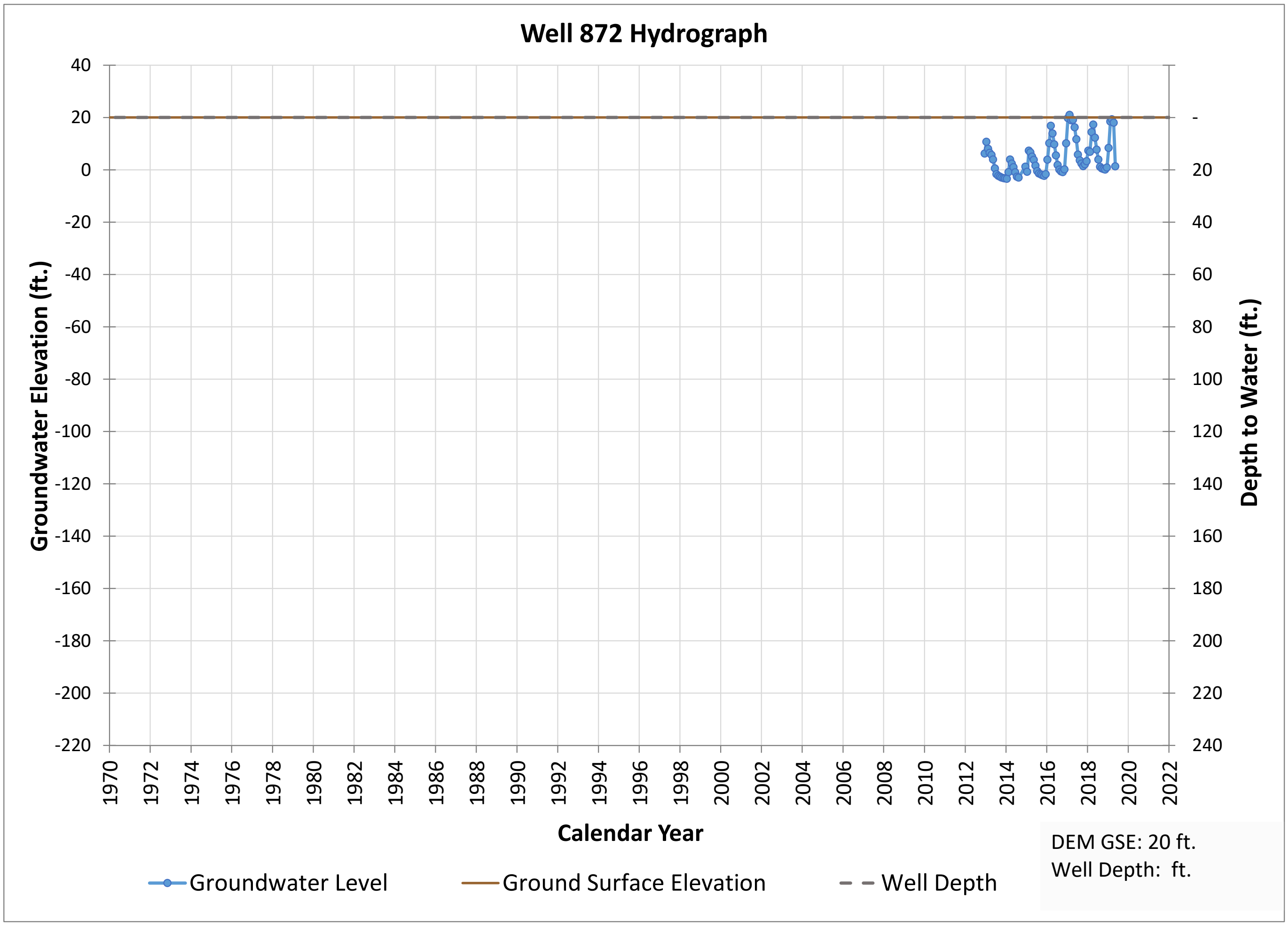
Well 870 Hydrograph

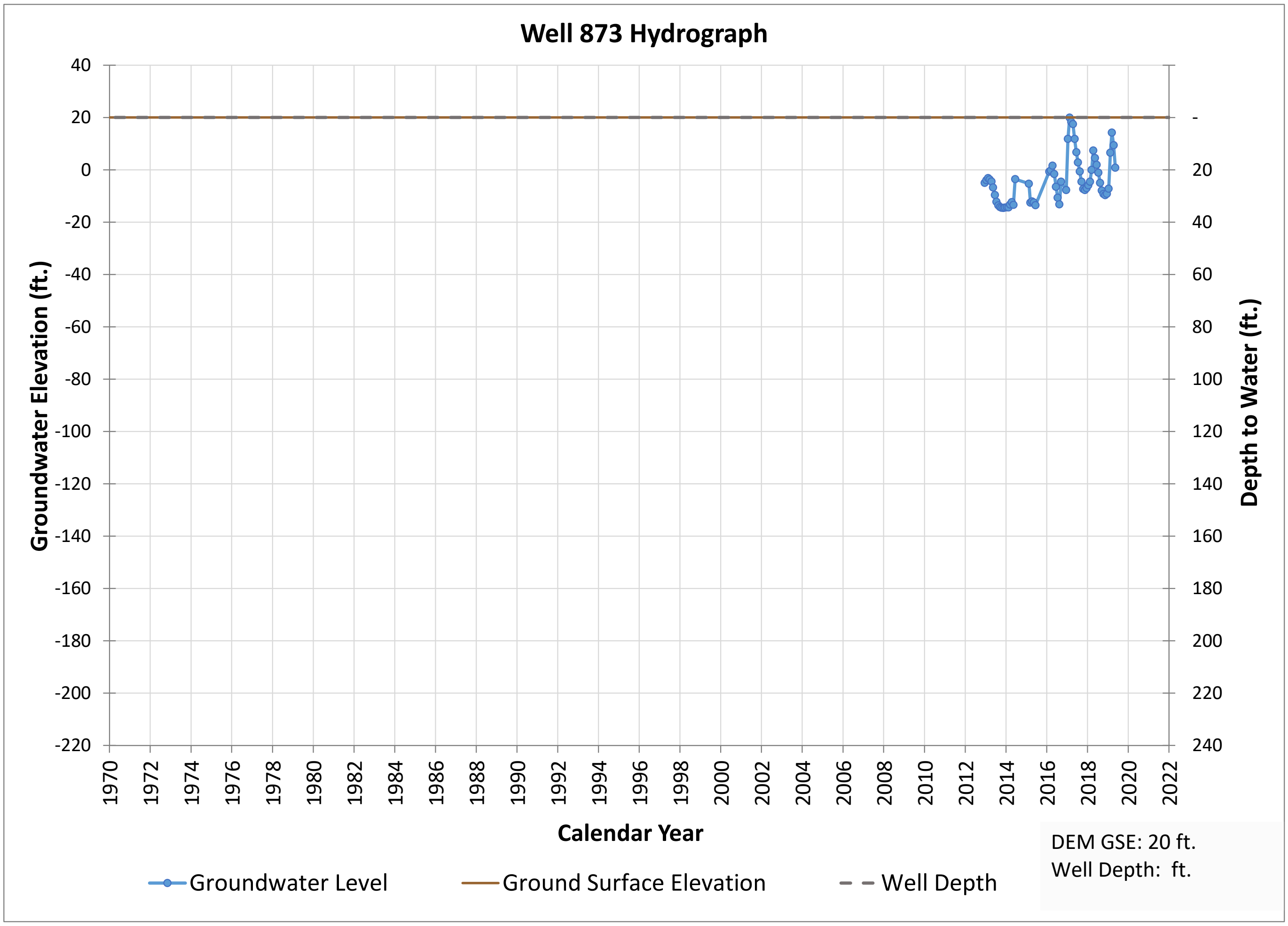


DEM GSE: 23 ft.
Well Depth: ft.

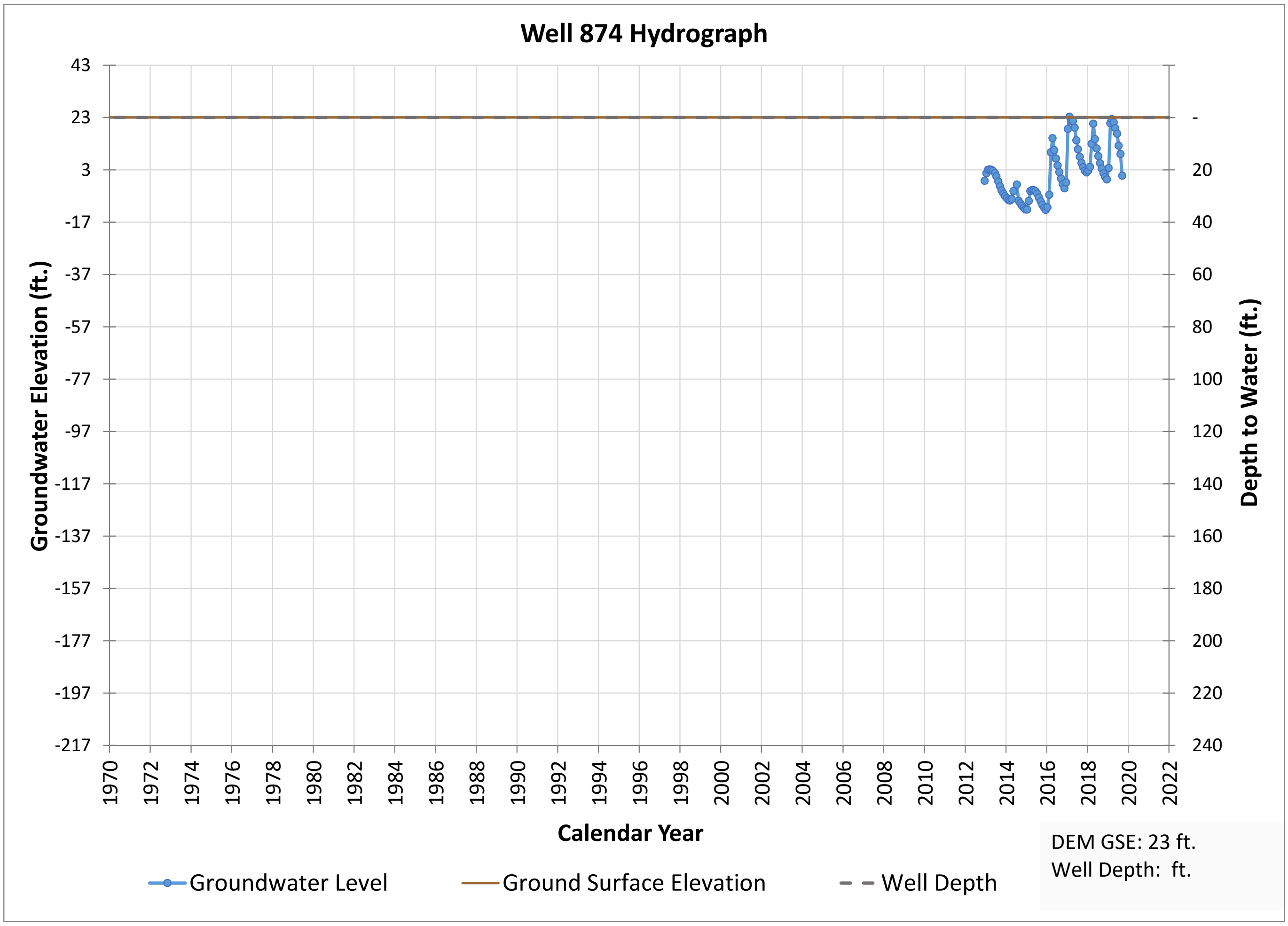


DEM GSE: 26 ft.
Well Depth: ft.

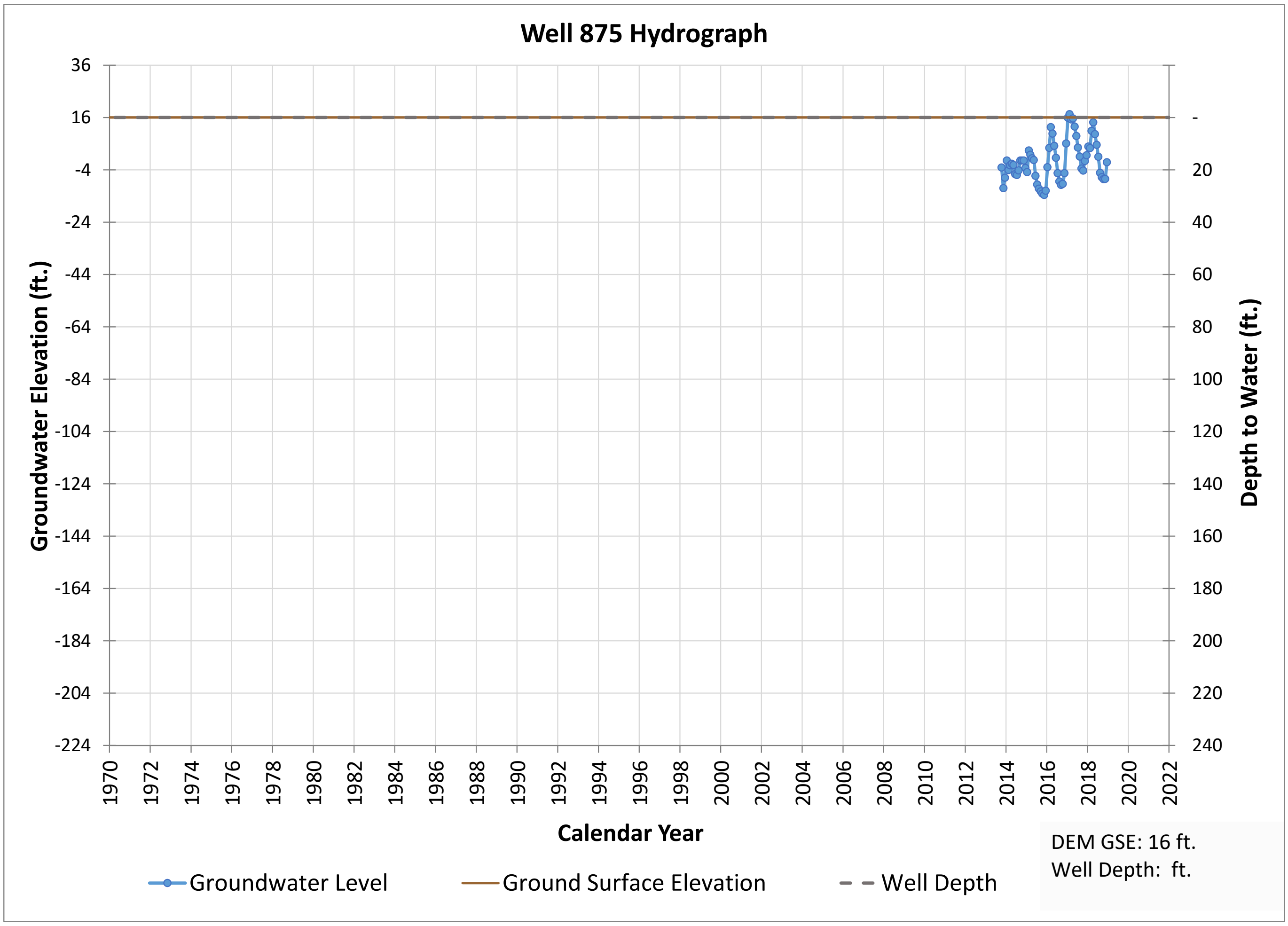

Well 872 Hydrograph
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 20 ft.
Well Depth: ft.



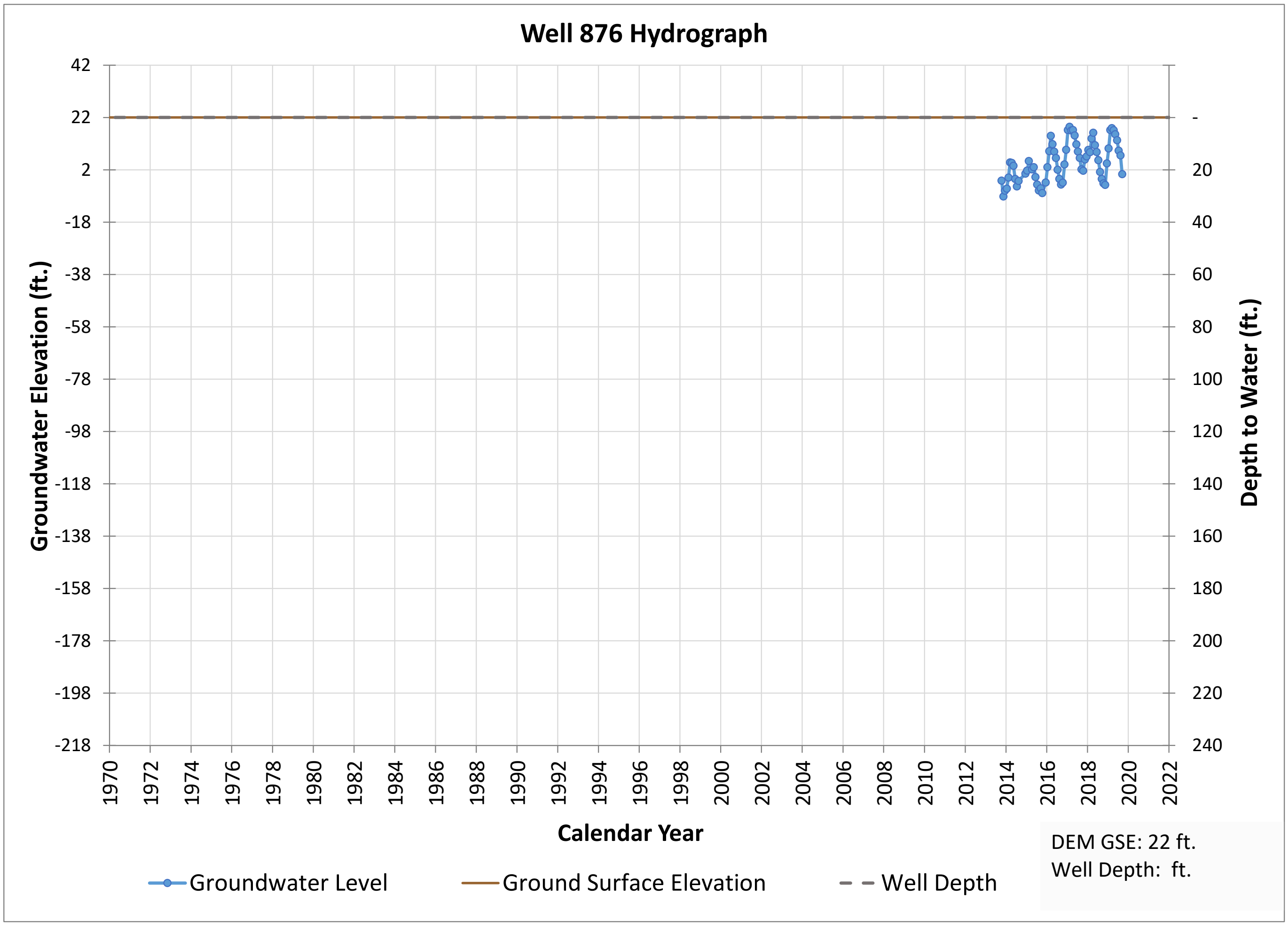
Well 873 Hydrograph
Groundwater Elevation (ft.)
Depth to Water (ft.)
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 20 ft.
Well Depth: ft.

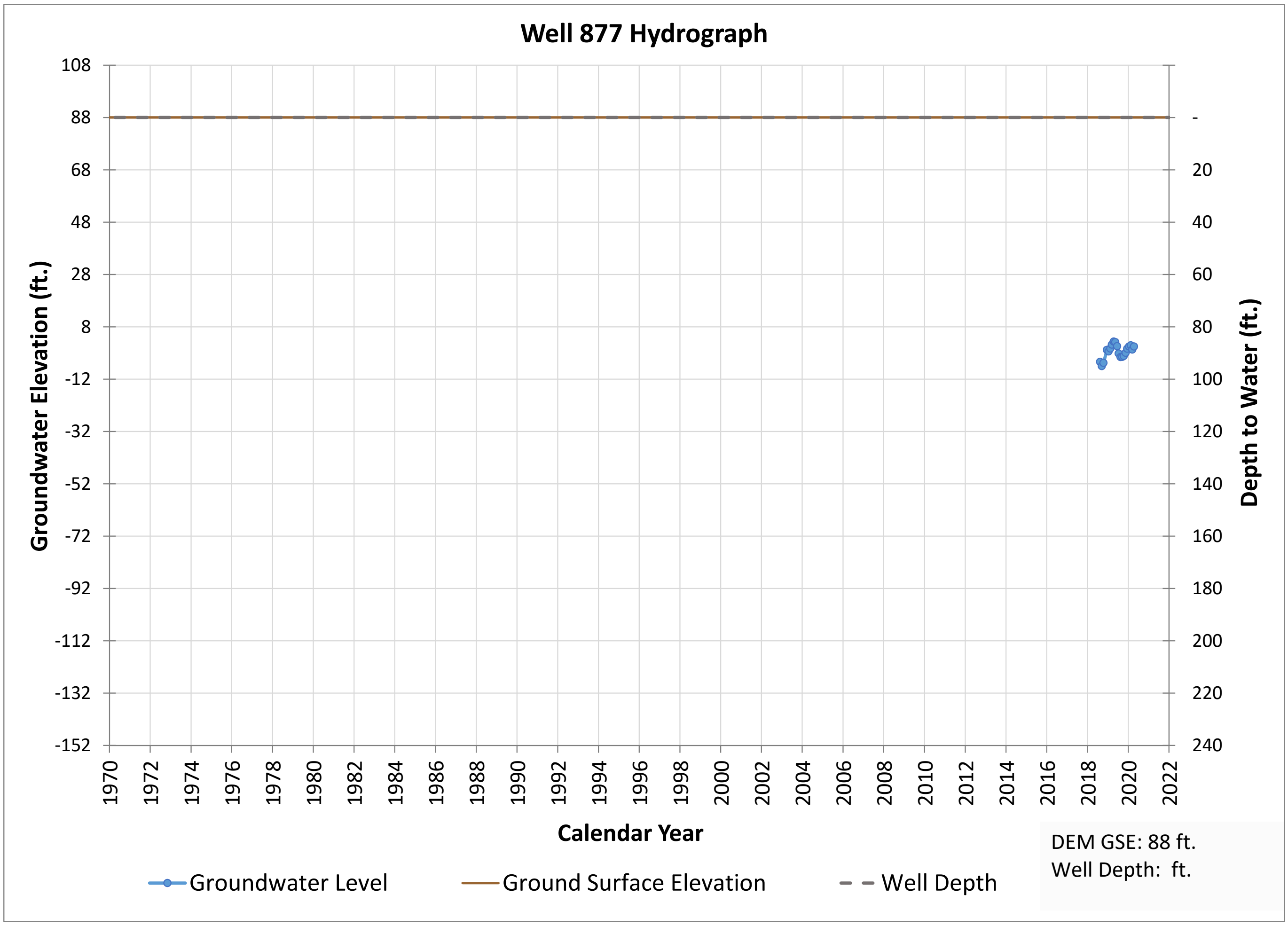


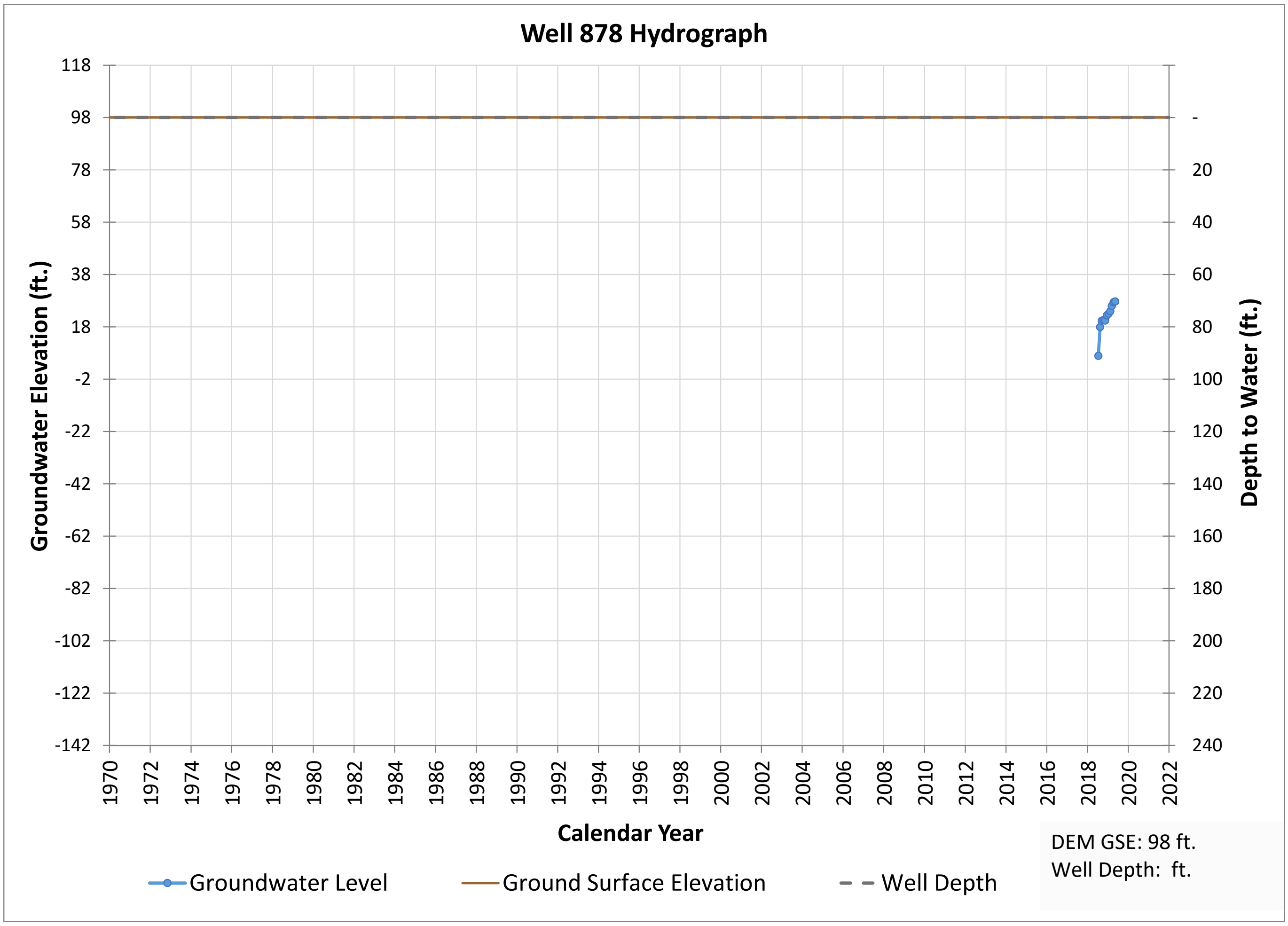
DEM GSE: 23 ft.
Well Depth: ft.

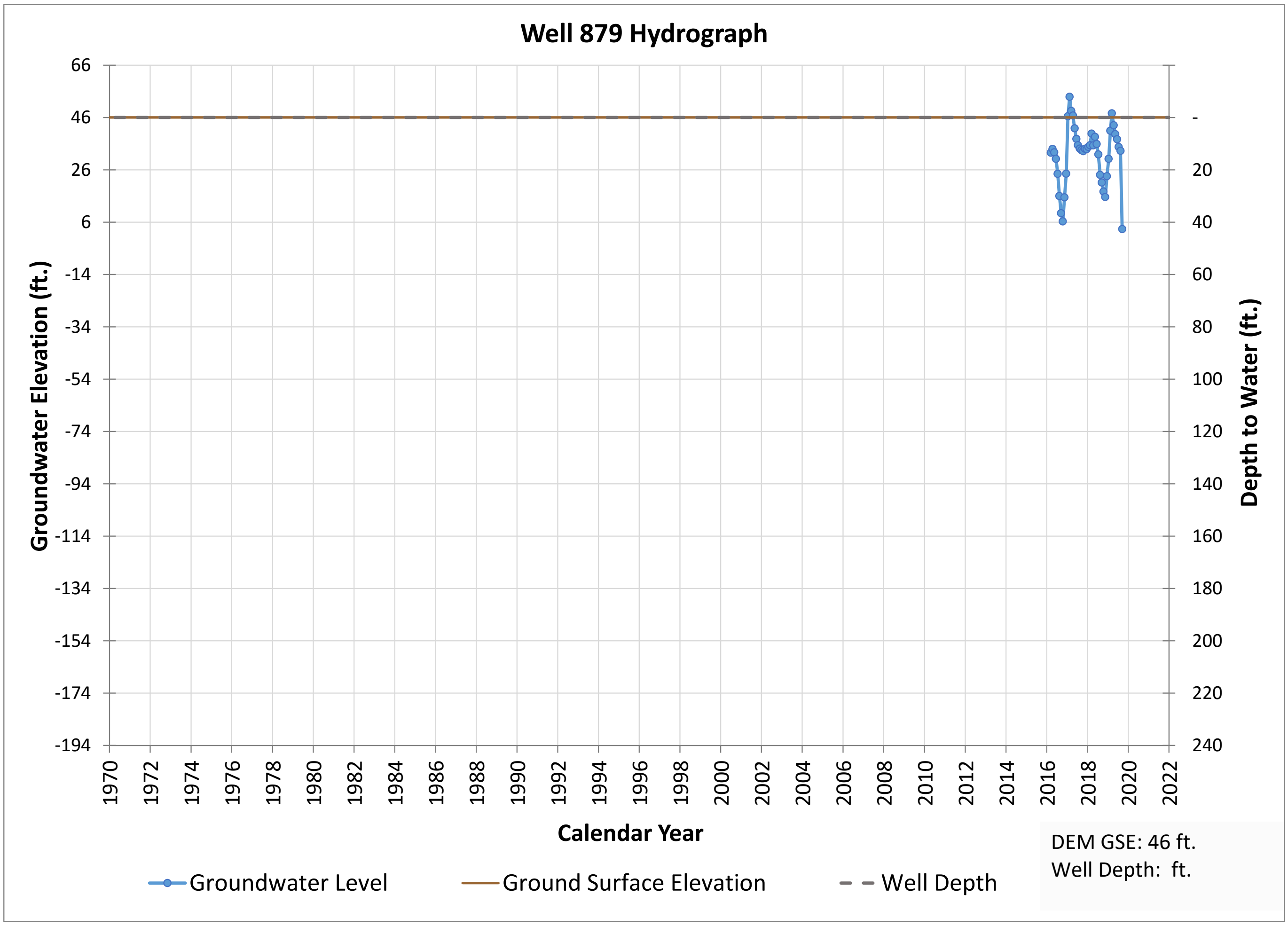


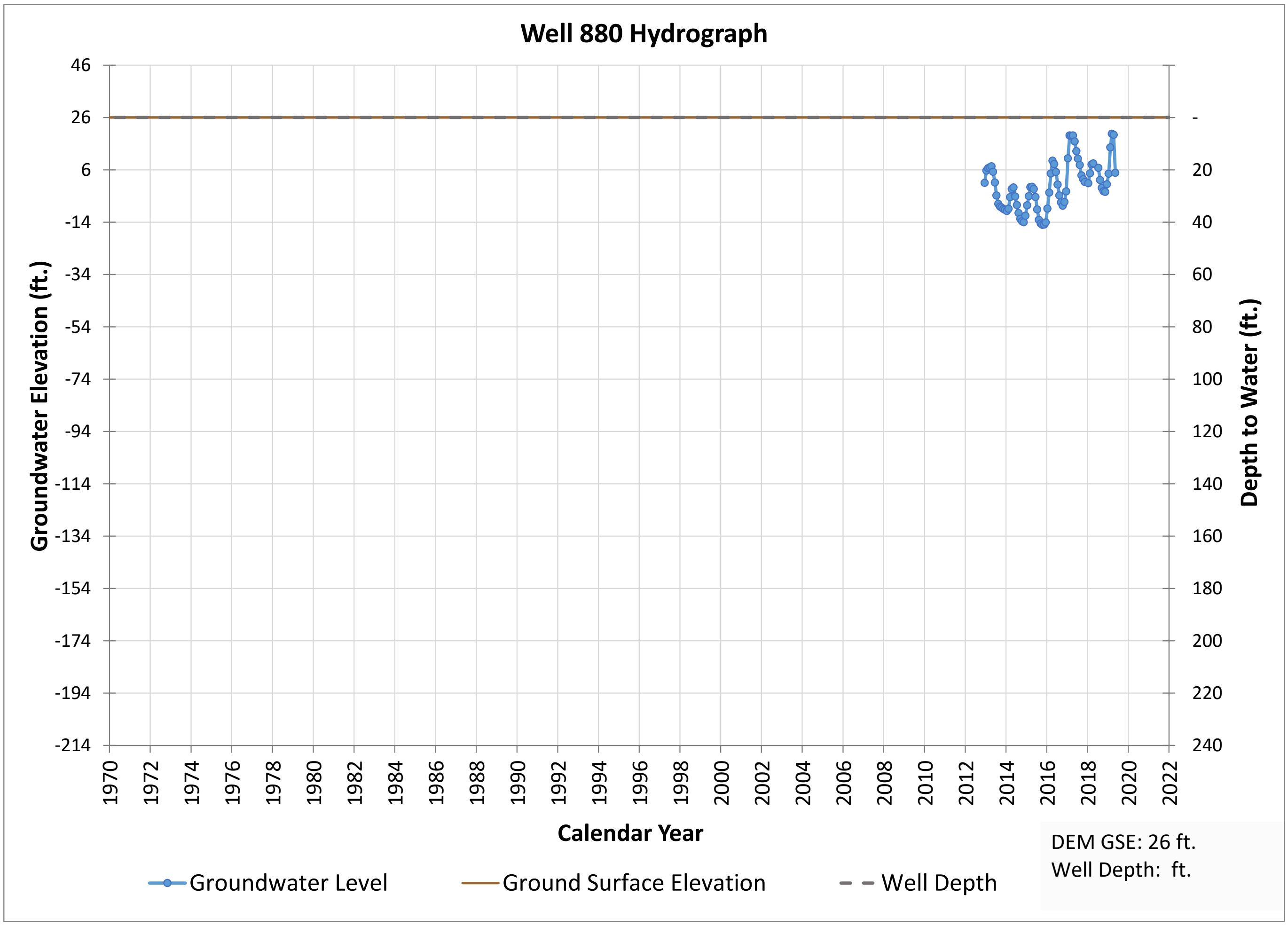
DEM GSE: 16 ft.
Well Depth: ft.

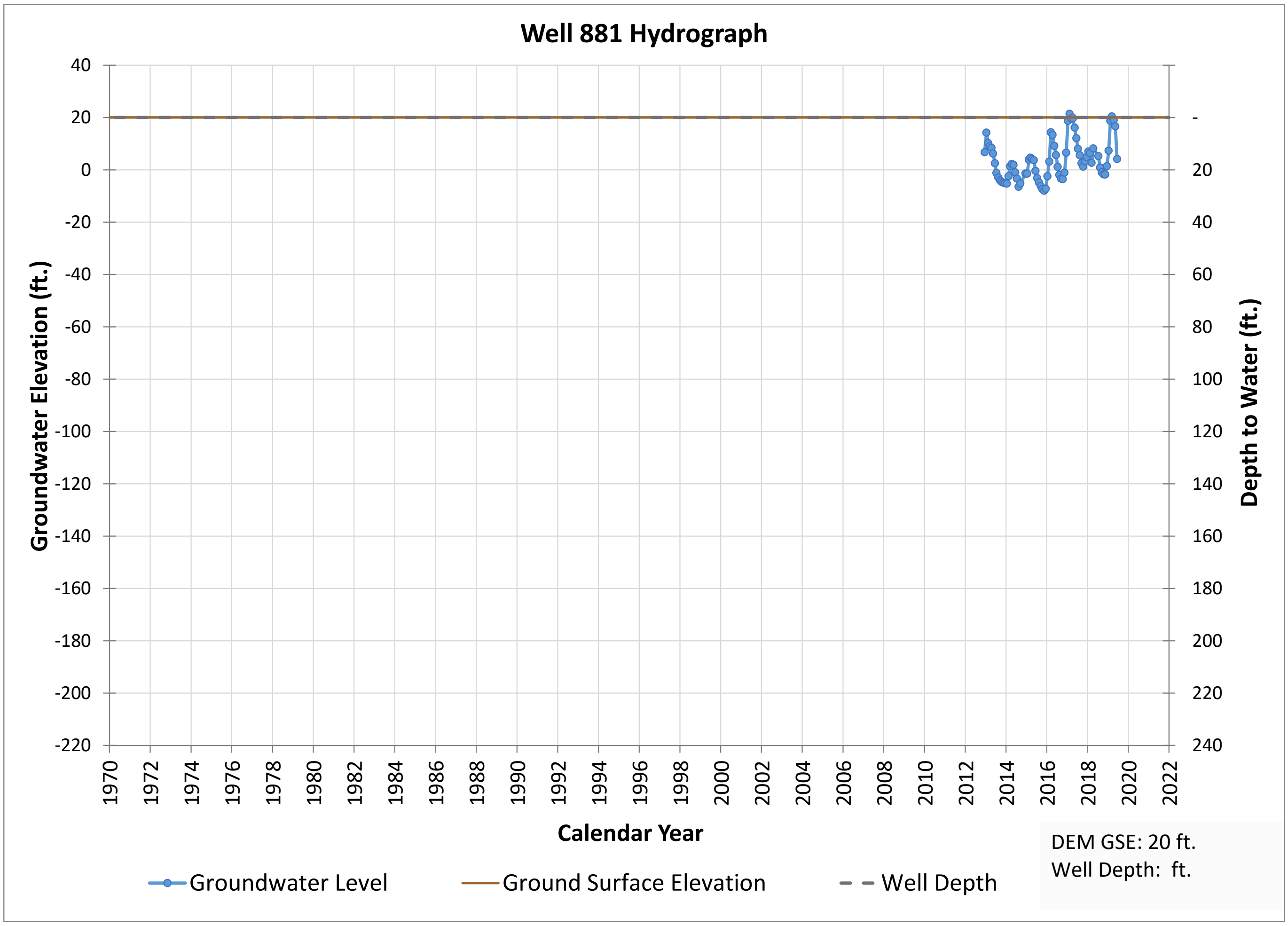

Well 876 Hydrograph
Groundwater Elevation (ft.)
42
22
2
-18
-38
-58
-78
-98
-118
-138
-158
-178
-198
-218
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 22 ft.
Well Depth: ft.

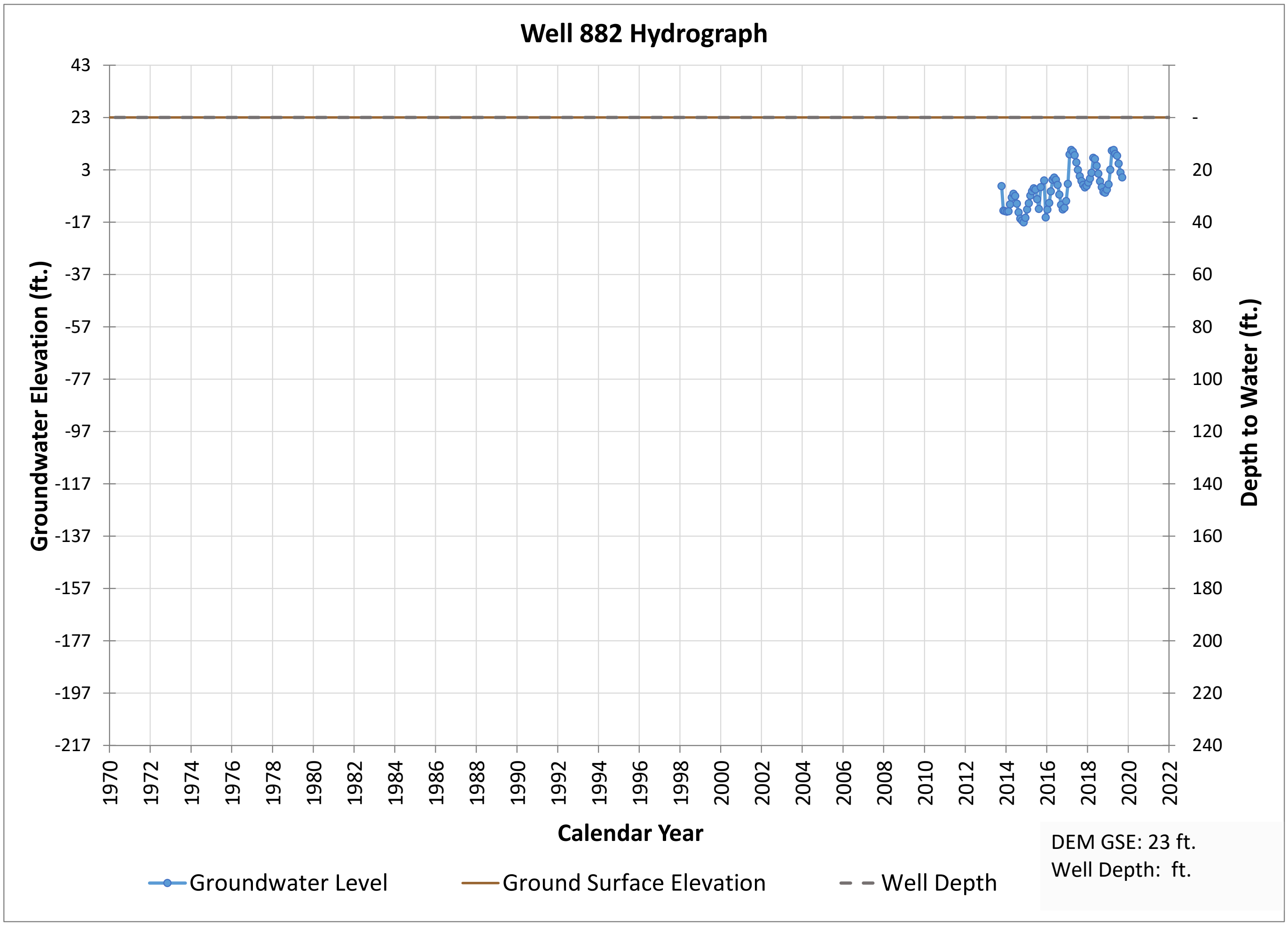

Well 877 Hydrograph
Groundwater Elevation (ft.)
108
88
68
48
28
8
-12
-32
-52
-72
-92
-112
-132
-152
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 88 ft.
Well Depth: ft.

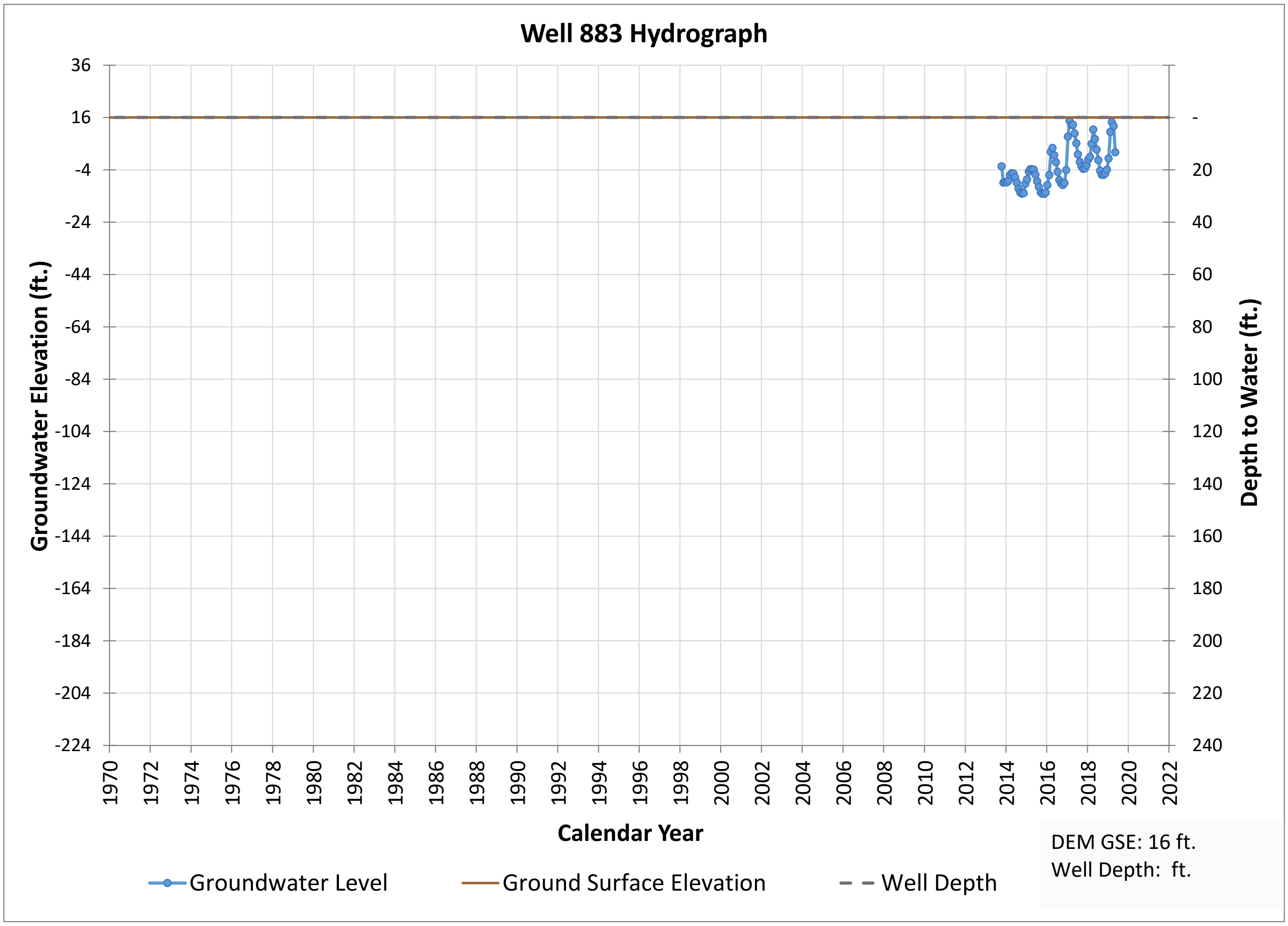

Well 878 Hydrograph
Groundwater Elevation (ft.)
Depth to Water (ft.)
118
98
78
58
38
18
-2
-22
-42
-62
-82
-102
-122
-142
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 98 ft.
Well Depth: ft.

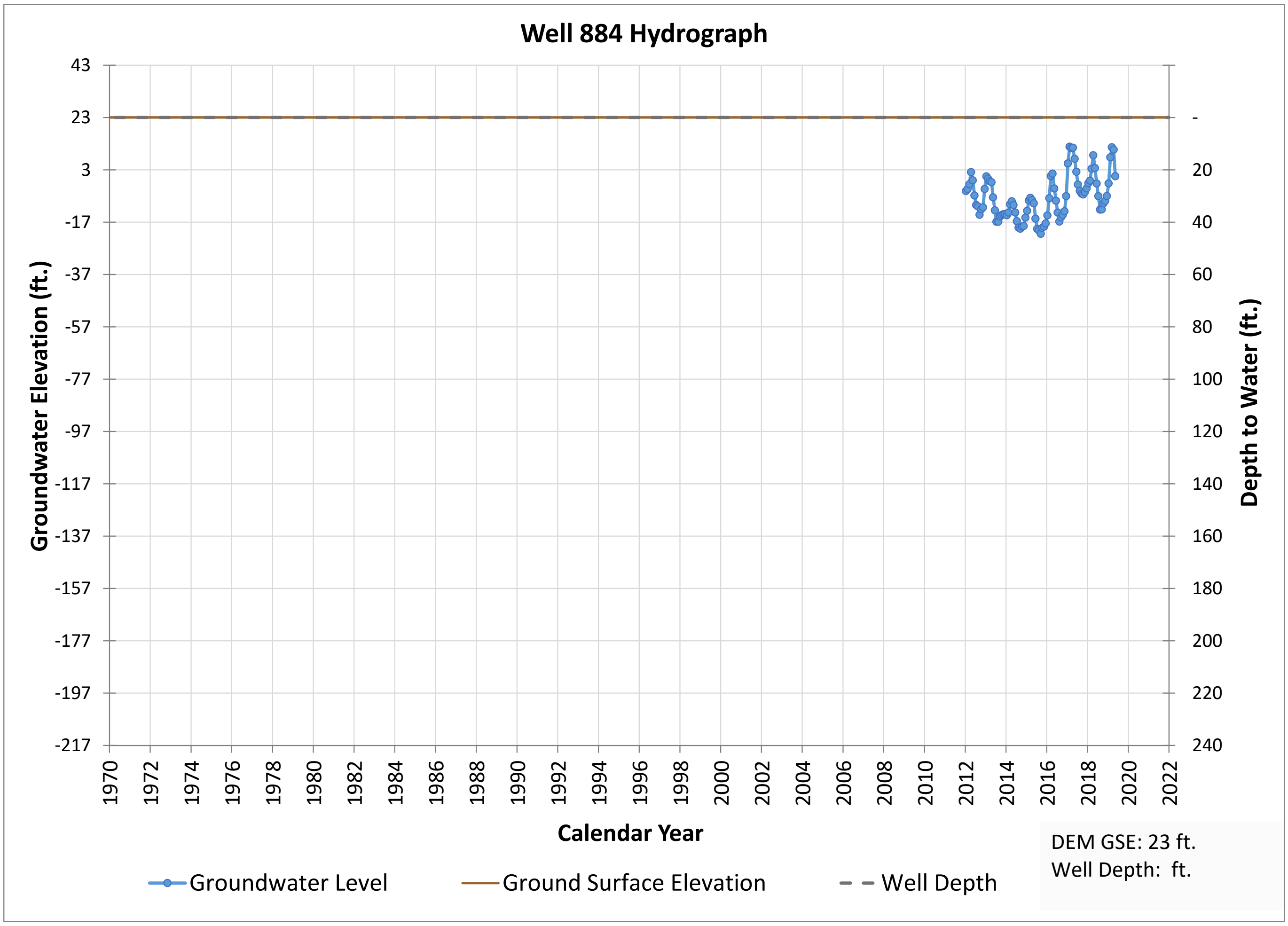

Well 879 Hydrograph
66
46
26
6
-14
-34
-54
-74
-94
-114
-134
-154
-174
-194
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 46 ft.
Well Depth: ft.


Well 880 Hydrograph
46
26
6
-14
-34
-54
-74
-94
-114
-134
-154
-174
-194
-214
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 26 ft.
Well Depth: ft.

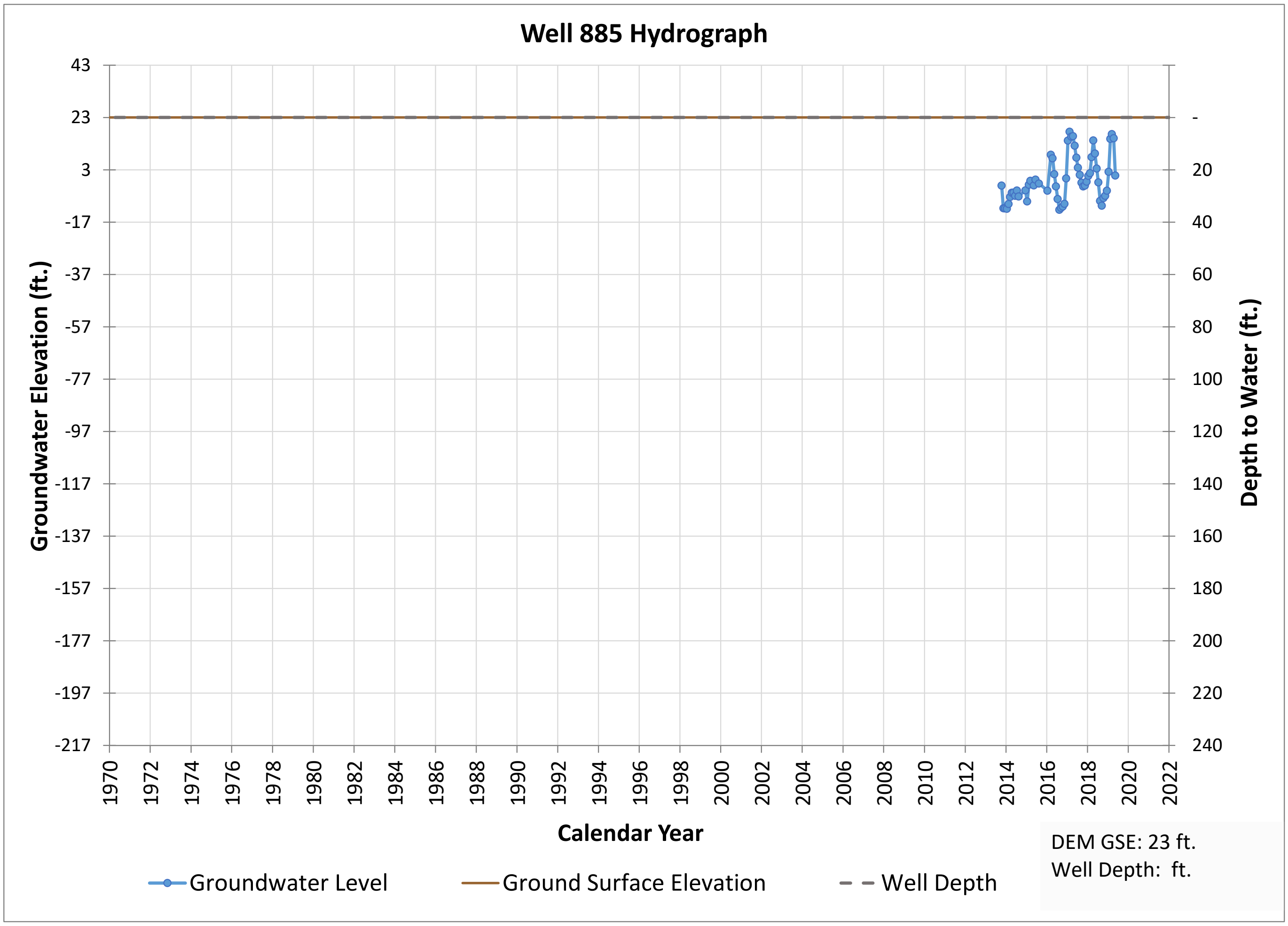
Well 881 Hydrograph
Groundwater Elevation (ft.)
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 20 ft.
Well Depth: ft.

Well 882 Hydrograph
Groundwater Elevation (ft.)
43
23
3
-17
-37
-57
-77
-97
-117
-137
-157
-177
-197
-217
Depth to Water (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 23 ft.
Well Depth: ft.

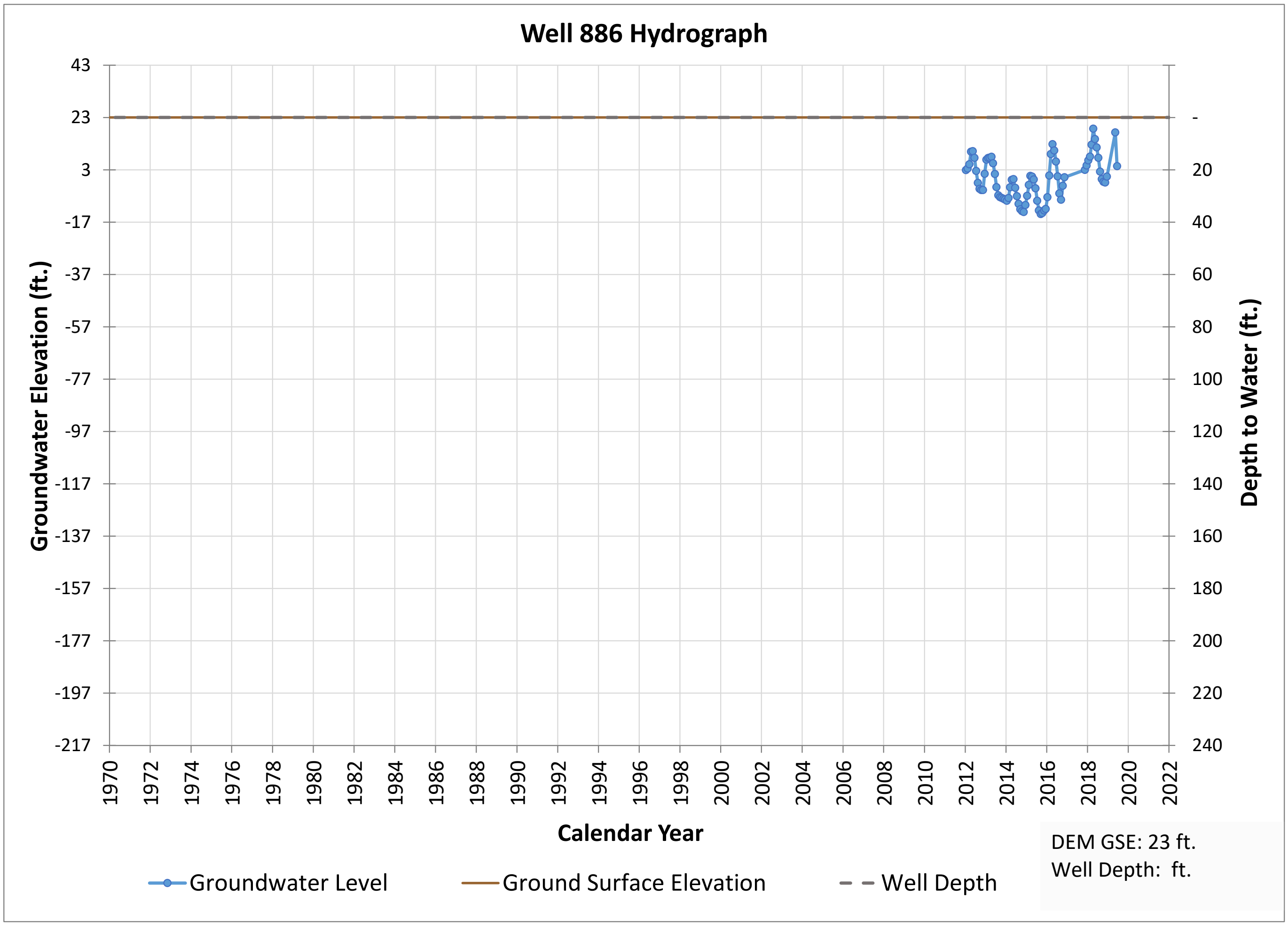
Well 883 Hydrograph
36
16
-4
-24
-44
-64
-84
-104
-124
-144
-164
-184
-204
-224
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 16 ft.
Well Depth: ft.



DEM GSE: 23 ft.
Well Depth: ft.



DEM GSE: 23 ft.
Well Depth: ft.


Well 886 Hydrograph
43
23
3
-17
-37
-57
-77
-97
-117
-137
-157
-177
-197
-217
Groundwater Elevation (ft.)
-
20
40
60
80
100
120
140
160
180
200
220
240
Depth to Water (ft.)
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
Calendar Year
Groundwater Level
Ground Surface Elevation
Well Depth
DEM GSE: 23 ft.
Well Depth: ft.

Appendix 2-D

Groundwater Quality and Land Subsidence (October 2021)

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Appendix 2-D: Groundwater Quality and Land Subsidence

Groundwater Quality

Review of Previous Studies

The investigation of the Folsom-East Sacramento area (DWR, 1964) is one of the earliest documents available that has assessed groundwater quality within the South American Subbasin (SASb). Following this report, DWR evaluated groundwater resources in Sacramento County in 1974 (Bulletin No. 118). More recent studies include an investigation of the groundwater quality in the southern Sacramento Valley conducted by the U.S. Geological Survey (USGS) in 2008, which was revised in 2018, and an assessment of the Sacramento-Amador Subwatershed performed by CH2M in 2016. Additionally, SCGA has produced three basin management reports with illustrations for the geographic occurrence of various water quality constituents, including total dissolved solids (TDS), iron, manganese, nitrate, and arsenic.

According to the 1964 and 1974 DWR studies, recharge water enters the groundwater system on the east side of the Subbasin. This carbon dioxide-rich water (derived from the atmosphere and the root zone) develops a mixed cation-bicarbonate composition as it dissolves calcium, magnesium, and sodium from the sediments. As groundwater migrates downgradient and deeper into the aquifer system, the concentrations of these constituents increase. Very deep in the aquifer, the water is unusable and is dominated by a sodium-chloride composition from the original marine deposits.

The Alternative Plan submitted in 2016 evaluated temporal variations in concentrations of TDS, nitrate, iron, manganese, arsenic, and chloride at various locations. The water quality data for this evaluation were obtained from the Geotracker Ground-Water Ambient Monitoring and Assessment program (GAMA) website and subdivided by sampling date into six 3-year intervals. Beginning with 1998, two data periods are presented in **Table 2-D-1**; this table provides a summary of this evaluation. The database included numerous non-detects (ND) for nitrate, iron, manganese, and arsenic which were excluded from the evaluation.

Table 2-D-1: Groundwater Quality Median Concentrations at Specific Wells

Period	TDS (mg/L)	Chloride (mg/L)	Nitrate as N (mg/L)[1]	Iron (µg/L)	Manganese (µg/L)	Arsenic (µg/L)
1998-2000 Median	170	8	2.5	170	11	6.8
2013-2015 Median	210	12	3.2	270	14	9.8
Non-Detects			18-25%	41-79%	20-57%	10-36%

[1] Nitrate as NO_3 converted to Nitrate as N

The slightly increasing trends in the concentration of some of these naturally occurring constituents increased as the groundwater system became more dynamic during the last century of production, and due to wells drilled deeper to increase production capacity. While iron and manganese are known to be present in the deeper groundwater, some traces of arsenic have been occurring in shallow groundwater wells. Prior to the lowering of the public drinking water standard (primary MCL) from 50 ppb to 10 ppb, the occurrence of arsenic was not a significant regulatory issue. After the water standard was lowered, older public supply wells in Sacramento County Water Agency's (SCWA) Laguna service area were replaced with deeper wells designed for centralized treatment of iron and manganese. Additionally, private domestic well owners have been notified and encouraged through outreach to have their water tested once a year for nitrates and arsenic.

The GAMA has addressed conditions throughout much of California via a spatially-unbiased selection protocol for wells and a comprehensive suite of laboratory analyses. During a March to June 2005 study, 16 wells were sampled within the boundaries of the Subbasin and results were compared with selected Federal and State drinking-water standards (USGS, 2008). A summary of the USGS 2018 study, which updated the 2008 study results, is provided below:

- Thirteen out of the 16 wells within the SASb had one or more detections of a volatile organic compound; however, none of these concentrations were greater than an MCL or other threshold values. Their analysis of Tentatively Identified Organic Compounds (TIOCs) found cyclopentane in one well and sulfur dioxide in another well within the SASb area.
- Of the total of 129 pesticide compounds that USGS analyzed, eight were detected at least once within the SASb area, with the most frequently detected pesticide compounds being 2-chloro-4-isopropylamino-6-amino-s-triazine (deethylatrazine, a degradation of atrazine) and atrazine (general application herbicide). All of the detections were below regulatory threshold values for the corresponding pesticide.
- Among nutrients, orthophosphate and nitrate were detected at five and four wells within the SASb, respectively; nitrite was not detected in any well. Nitrate concentrations (as N) were all lower than the California Department of Health Services (CADHS) primary MCL of 10 mg/L.
- While there are no applicable health-based thresholds for the major ions, chloride and sulfate have secondary MCLs (SMCLs) set for aesthetic qualities. Concentrations of these naturally-occurring constituents were lower than the SMCL in all five wells where these constituents were detected within the Subbasin.
- USGS also analyzed 26 trace elements, including 18 trace elements with an MCL or other health-based thresholds in its study area. Three trace elements were detected at concentrations greater than the threshold: arsenic, barium, and boron. However, none of these detections were at wells within the SASb. While two naturally-occurring trace elements, iron and manganese, were detected at concentrations greater than an SMCL in the study unit, only manganese resulted in an exceedance of the SMCL (in one well) within the SASb.
- In the isotopes, radioactivity, and noble gases categories, USGS analyzed Tritium, deuterium, and oxygen-18, helium-3 to helium-4 ratio, helium-4, argon, neon, krypton, and xenon in the SASb area.

Assessment of Current and Historical Conditions

This section presents SASb groundwater quality information, including a discussion of numeric thresholds set by federal and state agencies, the processing of available water quality data, and results of water quality data analysis performed for the GSP.

This assessment focuses on the following water quality parameters that have been identified to be of interest in the Central Valley, generally, and in the SASb, specifically:

- Nitrate
- Total Dissolved Solids (TDS)
- Arsenic
- Hexavalent chromium
- PFAS compounds
- Chloride
- Iron
- Manganese

Additional wells and constituents that are not included in the Main Report's assessment are included in this Technical Appendix.

Regulatory Background

The overarching federal law regulating water quality in surface waters and wetlands is the Clean Water Act (CWA), passed in 1972. When the CWA was written, Congress explicitly left the regulation of discharges to groundwater to the states and to the United States Environmental Protection Agency (USEPA) under other statutory authorities. One of these federal statutory authorities is the federal Safe Drinking Water Act (SDWA), which applies to both surface and groundwater and provides protection to drinking water supplies. Under the SDWA, federal standards were established through USEPA in the form of primary maximum contaminant levels (1° MCLs or primary MCLs) to protect human health. Secondary maximum contaminant levels (2° MCLs or SMCLs) also were established at the federal level to address aesthetics of drinking water sources (i.e., taste, odor, or appearance) and are not federally enforceable. The State of California has its own SDWA that includes 1° MCLs and 2° MCLs which are, in some cases, more strict than those set at the federal level for select constituents. The California 1° and 2° MCLs are codified in Title 22 of the California Code of Regulations (CCR). Water quality standards to protect drinking water as established under the federal and state SDWAs are enforced through the State Water Resource Control Board's (SWRCB or State Water Board) Division of Drinking Water (DDW).

The California Porter-Cologne Water Quality Act, contained in California Water Code Division 7, applies to both groundwater and surface waters, designating responsibility for water quality and safe drinking water protection to the SWRCB and the nine Regional Water Quality Control Boards (RWQCB) in California. The Act requires RWQCBs to develop water quality control plans for the region over which it presides. These water quality control plans (Basin Plans) must include a list of the specific waterbodies and broad categories of waters (e.g., bays, estuaries, ocean waters, wetlands, and groundwaters) the RWQCB is charged with protecting, the beneficial uses designated for those waterbodies, and the water quality objectives used to protect those beneficial uses. These water quality objectives, defined for specific hydrologic regions and waterbodies, protect the quality of surface waters, groundwaters, and their designated beneficial uses.

In the SASb, the Sacramento-San Joaquin Water Quality Control Plan (Basin Plan) issued by the Central Valley Regional Water Quality Control Board (Central Valley Water Board) contains water quality objectives based on primary and secondary MCLs. Where available, these MCLs are used in the assessment of groundwater quality conditions in the SASb.

Groundwater Quality Data Processing

Groundwater quality data were downloaded from the Groundwater Ambient Monitoring and Assessment Program (GAMA) Groundwater Information System Data Download[1]. Data was downloaded for Sacramento County on May 22, 2020, and includes groundwater quality data from the following sources:

- Department of Pesticide Regulation (DPR)
- Department of Water Resources (DWR)
- Lawrence Livermore National Laboratory
- State and Regional Water Board Regulatory Programs (Electronic Deliverable Format (EDF) and Irrigated Agricultural Land Waiver (AGLAND))
- State Water Board, GAMA Program water quality data (GAMA, USGS)
- State Water Board, Division of Drinking Water public supply well water quality (DDW)
- U.S. Geological Survey (USGS)

Additional water quality data in the SASb were obtained directly from GEI Consultants Inc., which developed the Subbasin's 2016 Alternative Plan. All data were then compiled into a database for analysis. Data for nitrate, TDS, chloride, arsenic, iron, and manganese are from both the GAMA and GEI Consultants Inc., databases, while data for hexavalent chromium, and the larger family of per- and polyfluoroalkyl substances (PFAS) are solely from the GAMA database. Constituents were included in this analysis because they were cited in previous studies of the SASb, or they were discussed during public meetings as being of concern to stakeholders in the SASb. Analysis of chloride, iron, and manganese is included in this Technical Appendix and not the Main Report because these constituents are naturally occurring and will not likely be monitored or managed under the GSP.

Groundwater quality samples collected from less than 300 feet bgs were determined to be from the shallow zone, while samples collected from greater than 300 feet were determined to be from the deep zone. With the exception of PFAS, only measurements from wells located entirely in either the shallow zone or the deep zone are included in this analysis. Wells of all depths are analyzed for PFAS as monitoring data is sparse and less temporally extensive than the other constituents. The analysis presented in the Main Report omits State and Regional Water Board Regulatory Program (EDF) data that is included in the GAMA database because this monitoring data represents site specific conditions and is not indicative of regional groundwater conditions. Assessment of this data is included in this Technical Appendix for inclusiveness, and to present a more complete picture of all available data in the Subbasin.

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[1] http://geotracker.waterboards.ca.gov/gama/datadownload

All data, except the TDS dataset, include non-detect (ND) values, as well as estimated values (where the value was detected at a concentration below the reporting limit, but above the method detection limit). Estimated values are included in the box and whisker plots at their reporting limit, and the ND values are not included. Omission of the ND values increases the median, average, and overall statistics, and therefore results in an overestimation of these values.

Groundwater Quality Trends According to Available Historical Data

The following subsections present the temporal and spatial analysis of nitrate, TDS, arsenic, hexavalent chromium, PFAS, chloride, iron, and manganese. Variations of these constituents over time were plotted as “box and whisker” plots, where the box represents the concentration range for the middle 50 percent of the data (first quartile to third quartile, or interquartile range), the mean is represented as an ‘x’, and the median is shown as the line in the center of the box. The top whisker extends to the highest concentration that is less than or equal to the sum of the third quartile and 1.5 times the interquartile range; and the bottom whisker extends to the lowest concentration that is greater than or equal to the difference of the first quartile and 1.5 times the interquartile range. Regulatory limits are displayed as a dashed red line, and the concentration scale is displayed on the left side of each plot.

Figures of spatial groundwater quality data plot the location of wells where groundwater quality samples were collected, and indicate the maximum sampled concentration at each well for the entirety of the dataset. This representation was used in an initial screening to see where threshold values were exceeded, but should not be interpreted as a depiction of problem areas with regular concentrations above thresholds. With the exception of PFAS, individual maps are provided for samples collected from the shallow zone and the deep zone. Due to the scarcity of PFAS data, wells of all depths are included in one map.

Groundwater in the SASb is generally of good quality and meets local needs for municipal, domestic, and agricultural uses. Exceedances of constituent thresholds may be caused by localized conditions and may not be reflective of regional groundwater quality. In the analysis described below, groundwater data that includes monitoring well data from the GAMA data has been assessed. Also, an analysis that omits monitoring well data is presented. This distinction is important, because monitoring well data tends to be focused intensively at specific sites (e.g. remediation areas), and can bias statistical analysis of regional conditions.

Nitrate

Nitrate is an ion with the chemical formula NO_3. Salts containing this ion are called nitrates (e.g. ammonium nitrate, sodium nitrate, potassium nitrate, calcium nitrate, magnesium nitrate). Some forms of nitrates are naturally occurring. Nitrates are commonly found in groundwater as a result of the application of nitrate-containing fertilizers. Other nitrate sources include feedlot discharges, treated and untreated sewage, and emissions from food processing or industrial processes. At elevated levels, nitrates can affect human health. A primary MCL of 10 mg/L (milligrams per liter, or parts per million) exists for nitrate as nitrogen, applicable to drinking water supplies, to provide human health protection.

Nitrate data in wells in the SASb were extensive and spanned from 1951 to present. **Figure 2-D-1** illustrates variation in nitrate with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the primary MCL is displayed as a dashed red line (10 mg/L for Nitrate as N). As shown, nitrate concentrations in both the shallow and deep zone were relatively consistent throughout the period of record. Concentrations in the shallow zone increased slightly between the period 1991-95 and 1996-00; however, this increase was minor and not representative of an increasing trend. Nitrate concentrations in the deep zone have remained relatively stable throughout the period of record. It is noted that the elevated average and statistical distribution shown for the deep zone during the period 1986-90 is the result of one high estimated value (10 mg/L).

Nitrate data is plotted spatially for the shallow zone in **Figure 2-D-9** and the deep zone in **Figure 2-D-11**. **Figure 2-D-10** plots nitrate data for the shallow zone with data from monitoring wells included. The maps divide the wells into three categories: wells where all samples were below 50 percent of the MCL (indicated as a green point), wells where at least one sample was above 50 percent of the MCL (indicated as a yellow point), and wells where at least one sample was above the MCL (indicated as a red point). It is noted that not all wells analyzed are drinking water supply wells; also, a single exceedance of the MCL as indicated on the figures is not a violation of the limits as the SWRCB has set nitrate MCL compliance to be determined by a running annual average.

Figure 2-D-9 shows that the majority of shallow wells sampled for nitrate do not result in a concentration greater than 50 percent of the MCL. Analysis of wells where the maximum sampled concentration was greater than 50 percent of the MCL, or greater than the MCL, indicated that these wells are located in areas where municipal community water systems deliver domestic water supply, and that domestic well density is low. **Figure 2-D-11** shows that one deep well resulted in a concentration greater than the MCL, while no deep wells resulted in a concentration between 5 and 10 mg/L. **Figure 2-D-10** shows that when shallow monitoring wells are included in the analysis, more exceedances of the nitrate MCL occur. Also included in this figure is an inset map that focuses on the region of the Sacramento Regional Wastewater Treatment Plant (Regional San). This inset map and associated shallow water quality data (all shallow monitoring wells) highlight the fact that monitoring well data tends to be focused intensively at specific sites.

Total Dissolved Solids (TDS)

The salinity of freshwater is commonly measured either directly as the total concentration of all dissolved solids (organic and inorganic; TDS), or indirectly, as a water's ability to pass electrical flow (electrical conductivity, or EC). Conductance measured at – or normalized to – 25º Celsius is called specific conductance. Salts are both naturally occurring and man-made, and are persistent in nature. TDS levels in groundwater are often associated with agricultural irrigation, in combination with natural sources, where applied water is used by plants and water is lost in the process of evapotranspiration. Salts in the applied water remain in the root zone until they are leached out into the groundwater basin. Other sources of salts to groundwater may include municipal and industrial discharges.

TDS data in SASb wells were extensive and spanned from 1955 to present. TDS concentrations below the Recommended SMCL of 500 mg/L are desirable for a higher degree of consumer acceptance, while concentrations below the Upper SMCL of 1,000 mg/L are also deemed to be acceptable. **Figure 2-D-2** illustrates variation in TDS with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the

Recommended SMCL and Upper SMCL are displayed as dashed red lines. As illustrated, TDS concentrations measured in the deep zone were consistently below the SMCL value of 500 mg/L and remained relatively stable throughout the period of record. Concentrations in the shallow zone remained relatively stable from 1986 to 2005 and exhibit higher concentrations during the years 2006 to 2020; however, these elevated concentrations are still deemed acceptable.

TDS data is plotted spatially for the shallow zone in **Figure 2-D-12** and the deep zone in **Figure 2-D-14**. The maps divide the wells into four categories: wells where all samples were below 250 mg/L (indicated as a green point), wells where at least one sample was greater than 250 mg/L (indicated as a yellow point), wells where at least one sample was greater than 500 mg/L (indicated as an orange point), and wells where at least one sample was greater than 1,000 mg/L (indicated as a red point). **Figure 2-D-12** appears to show an increasing trend in shallow TDS values from the west of the subbasin to the east; however, the majority of shallow wells produced a maximum TDS concentration below the Recommended SMCL of 500 mg/L. **Figure 2-D-14** shows that no deep wells sampled for TDS resulted in a concentration greater than the Upper SMCL value of 1000 mg/L. **Figure 2-D-13** shows that when shallow monitoring wells are included in the analysis, higher concentrations of TDS are recorded. Also included in this figure is an inset map that focuses on monitoring near the Regional San wastewater treatment plant site. This inset map and associated shallow water quality data (all shallow monitoring wells) highlight the fact that monitoring well data tends to be focused intensively at specific sites.

Arsenic

Arsenic is a chemical element, naturally occurring in the earth's crust. It occurs naturally in many minerals and is naturally occurring in some groundwaters. Historically, it has been used in the production of semiconductors, pesticides and wood preservatives, and can be released during mining operations, smelting, and coal combustion. It is highly toxic in its inorganic form; a primary MCL for arsenic in drinking water is 10 μg/l (micrograms per liter, or parts per billion).

Arsenic data in SASb wells were extensive and spanned from 1982 to present. **Figure 2-D-3** illustrates variation in arsenic with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the MCL of 10 μg/L is displayed as a dashed red line. As shown, arsenic concentrations in the shallow zone have fluctuated over the period of analysis, with concentrations exhibiting slight increases during the 2006-10 and 2016-20 periods. Concentrations of arsenic in the deep zone appear elevated during the periods 1986-90 and 1991-95, and then decline below the MCL for the duration of analysis.

Arsenic data for the period 2005 – 2020 is plotted spatially for the shallow zone in **Figure 2-D-15** and the deep zone in **Figure 2-D-16**. The maps divide the wells into three categories: wells where all samples were below 50 percent of the MCL of 10 μg/L (indicated as a green point), wells where at least one sample was above 50 percent of the MCL (indicated as a yellow point), and wells where at least one sample was above the MCL (indicated as a red point).

Figure 2-D-15 shows that exceedances of arsenic occur in the shallow zone of the aquifer, with 25 of the 131 sampled wells experiencing one or more exceedances. Evaluation of wells where the maximum arsenic sampled concentration was greater than 50 percent of the MCL, or greater than the MCL, indicates that municipal community water systems deliver domestic water

supply to these areas, and that domestic well density is low. Within water system boundaries, monitoring and treatment should be available to protect beneficial users of groundwater. The boundary of municipal community water systems is shown in the figure. **Figure 2-D-16** shows that high arsenic values are less prevalent in the deep zone, with no wells exceeding the MCL.

It is noted that arsenic is a naturally occurring element in soils and rocks and has also been used in wood preservatives, animal feed, and pesticides. It can also be released into groundwater from mining. Because it is known to occur naturally in the aquifer sediments, some trace is expected to occur in shallow wells. Whether the arsenic is released from a geologic source into groundwater depends on the chemical form of the arsenic, the geochemical conditions in the aquifer, and the biogeochemical processes that occur. It is noted that recent groundwater pumping, observed through land subsidence, may result in increased arsenic aquifer concentrations (Smith et al., 2018). It is unclear if this is the cause of elevated arsenic in the Basin; regardless, increased land subsidence is not predicted, and therefore is not expected to result in increased arsenic concentrations in the shallow zone.

Hexavalent Chromium

Hexavalent chromium is one of the valence states of the element chromium. It is used in many industrial applications, including electroplating, welding and chromate painting. Hexavalent chromium is found in some groundwaters. A human health-based primary MCL of 50 µg/L exists in California; a proposed MCL of 10 µg/L is being considered by the State Water Board.

Hexavalent chromium data span from 2001 to present. **Figure 2-D-4** illustrates variation in hexavalent chromium with time for three intervals; the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells. The current MCL of 50 µg/L is displayed as a dashed red line, as well as the proposed MCL of 10 µg/L. As shown, hexavalent chromium concentrations in the subbasin are consistently below 10 µg/L in the deep zone for the duration of analyses. Concentrations in the shallow zone are consistently below the MCL of 50 µg/L, but are slightly elevated over the proposed MCL of 10 µg/L in some locations. As shown in the bottom plot concentrations in the shallow zone increase when data from monitoring wells is included in the analysis.

Hexavalent chromium data is plotted spatially for the shallow zone in **Figure 2-D-17**, and the deep zone in **Figure 2-D-18**. The maps divide the wells into three categories: wells where all samples were below 50 percent of the proposed MCL of 10 µg/L (indicated as a green point), wells where at least one sample was above 50 percent of the proposed MCL (indicated as a yellow point), and wells where at least one sample was above the proposed MCL (indicated as a red point). As shown, wells in the shallow zone produced a result above the proposed MCL of 10 µg/L, and no wells in the deep zone exhibited concentrations above 5 µg/L.

Polyfluoroalkyl substances (PFAS)

Per- and polyfluoroalkyl (PFAS) are a group of man-made chemicals, which numbers close to 5000, that have been manufactured since the 1940's. They are used in a variety of products, are commonly found in food, household products, in water supplies and in aquatic organisms, and characteristically are very persistent in the environment and in the human body. Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), which are no longer in production in the U.S., were the most extensively produced and have been the most extensively studied of the PFAS substances. At elevated levels, there is evidence of adverse human health effects associated with PFOA, PFOS and other PFAS substances. The State Water Board has established notification levels and response levels for PFOA (5.1 and 10 parts per trillion or ng/L) and PFOS (6.5 and 40 parts per trillion), respectively. The California Office of Environmental Health Hazard Assessment (OEHHA) is working to develop Public Health Goals (PHG) for PFOA and PFOS, a step in the development of MCLs by the State Water Board. OEHHA has recently released proposed PHGs of 0.007 ng/l for PFOA and 1 ng/l for PFOS, which will be considered in a public process prior to adoption.

Monitoring of PFAS has begun more recently, with data available beginning in 2017. **Figure 2-D-5** presents box and whisker plots for nine PFAS substances, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells. No MCL currently exists for PFAS substances, and the notification level for PFOA and PFAS is displayed as a dashed line. As shown, the notification levels of 5.1 and 6.5 ng/L have been regularly exceeded at wells for PFOA and PFOS, respectively. Additionally, it is noted that when data from monitoring wells are included in the plots, more substances are detected.

PFOA and PFAS data are plotted spatially in **Figure 2-D-19**, and indicate that 31 of 55 samples have PFOS concentrations greater than 6.5 ng/L, and 22 of 43 samples have PFOA concentrations greater than 5.1 ng/L. Data used to generate the maps includes EDF data, as the data was sparse.

Chloride

Chloride is an ion of the element chlorine. It is commonly associated with sodium as the salt sodium chloride. A SMCL of 250 mg/L exists for chloride to address taste issues in drinking water, while concentrations below the Upper limit of 500 mg/L are also deemed to be acceptable. Chloride data in the SASb were extensive and spanned from 1952 to present. **Figure 2-D-6** illustrates variation in chloride with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the SMCL is displayed as a dashed red line. As illustrated, chloride concentrations in the shallow and deep zone were consistently below the SMCL value of 250 mg/L. It is noted that the elevated average and statistical distribution shown for the deep a zone quifer during the period 1986-90 is the result of one high estimated value (250 mg/L).

Chloride data is plotted spatially for the shallow zone in **Figure 2-D-20** and the deep zone in **Figure 2-D-21**. The maps divide the wells into four categories: wells where all samples were below 50 percent of the Recommended MCL of 250 mg/L (indicated as a green point), wells where at least one sample was greater than 50 percent of the Recommended MCL (indicated as a yellow point), wells where at least one sample was greater than the Recommended MCL (indicated as an orange point), and wells where at least one sample was greater than the Upper limit of 500 mg/L (indicated as a red point). As shown, wells in the shallow zone are more likely to exceed the SMCL or Upper Limit in the western portion of the SASb; however, the vast majority of shallow wells have not resulted in a concentration above 125 mg/L. **Figure 2-D-21** shows that no wells in the deep zone exceeded the SMCL.

Iron

Iron is a chemical element, a metal, which is the most common element on Earth, by mass. Iron occurs naturally as a mineral in sediments and rocks and is commonly found in groundwater in its dissolved form. A SMCL of 300 µg/L exists for iron to address aesthetics (discoloration). Iron data in the SASb were extensive and spanned from 1958 to present. **Figure 2-D-6** illustrates variation in iron with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the SMCL is displayed as a dashed red line. As shown, when monitoring wells are omitted the average concentrations are consistently below the SMCL in both the shallow and deep zone. When monitoring wells are included in the analysis, concentrations increase for wells in the shallow zone during the period 2001 to present.

Iron data for the period 2005 – 2020 is plotted spatially for the shallow zone in **Figure 2-D-22** and the deep zone in **Figure 2-D-23**. The maps divide the wells into three categories: wells where all samples were below 50 percent of the SMCL of 300 µg/L (indicated as a green point), wells where at least one sample was above 50 percent of the SMCL (indicated as a yellow point), and wells where at least one sample was above the SMCL (indicated as a red point). **Figure 2-D-22** shows that exceedances of iron occur in the shallow zone of the aquifer. Evaluation of wells where the maximum iron sampled concentration was greater than 50 percent of the SMCL, or greater than the SMCL, indicates that municipal community water systems deliver domestic water supply to these areas, and that domestic well density is low. Within water system boundaries, monitoring and treatment should be available to protect beneficial users of groundwater. The boundary of municipal community water systems is shown in the figure. Data from the deep zone is more sparse than the shallow zone, and **Figure 2-D-23** shows that maximum sampled concentrations greater than the SMCL occur throughout the region of the deep zone sampled.

Manganese

Manganese is a chemical element often found in minerals associated with iron. Manganese is a metal which occurs naturally and is typically found in its dissolved form in groundwater. A SMCL of 50 µg/L exists for manganese to address aesthetics in drinking water supplies associated with discoloration. Manganese data in the SASb were extensive and spanned from 1958 to present. **Figure 2-D-8** illustrates variation in manganese with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the SMCL is displayed as a dashed red line. As shown in the top and bottom plot, average concentrations in the shallow and deep zone are often elevated above the SMCL. When monitoring wells are included in the analysis, the average and statistical distribution of wells in the shallow zone increase greatly from the period 2001 to present.

Manganese data for the period 2005 – 2020 is plotted spatially for the shallow zone in **Figure 2-D-24** and the deep zone in **Figure 2-D-25**. The maps divide the wells into three categories: wells where all samples were below 50 percent of the SMCL of 50 µg/L (indicated as a green point), wells where at least one sample was above 50 percent of the SMCL (indicated as a yellow point), and wells where at least one sample was above the SMCL (indicated as a red point). **Figure 2-D-24** shows that exceedances of manganese occur in the shallow zone of the aquifer. Evaluation of wells where the maximum manganese sampled concentration was greater than 50 percent of the SMCL, or greater than the SMCL, indicates that municipal community water systems deliver domestic water supply to these areas, and that domestic well density is low. Within water system boundaries, monitoring and treatment should be available to protect beneficial users of groundwater. The boundary of municipal community water systems is shown in the figure. Data from the deep zone is more sparse than the shallow zone, and **Figure 2-D-23** shows that maximum sampled concentrations greater than the SMCL occur throughout the region of the deep zone sampled.

Sustainable Management Criteria

As noted in Section 3, Sustainable Management Criteria (SMC) were developed for two of the constituents of concern in the Subbasin: nitrate and specific conductance. Although the evaluation of water quality in the Subbasin also identified elevated concentrations of arsenic, iron, and manganese, these constituents were not assigned SMCs because their presence is impacted significantly by natural processes and local geologic conditions that are not controllable by the GSAs through groundwater management processes. The GSP will monitor these constituents to track any potential mobilization of elevated concentration or exceedances of the MCLs or SMCLs. Monitoring for these constituents will be carried out as part of the GSP monitoring network that is discussed in **Section 3.5.2**, as well as the Volunteer Monitoring Program that is described in **Section 4.7.1**. The period of historical monitoring data for arsenic, iron, and manganese is presented for the upper aquifer zone in **Table 2-D-2**, and the lower aquifer zone in **Table 2-D-3**. New constituents of concern may be added with changing conditions and as new information becomes available.

Figure 2-D-1: Historical Range of Nitrate Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

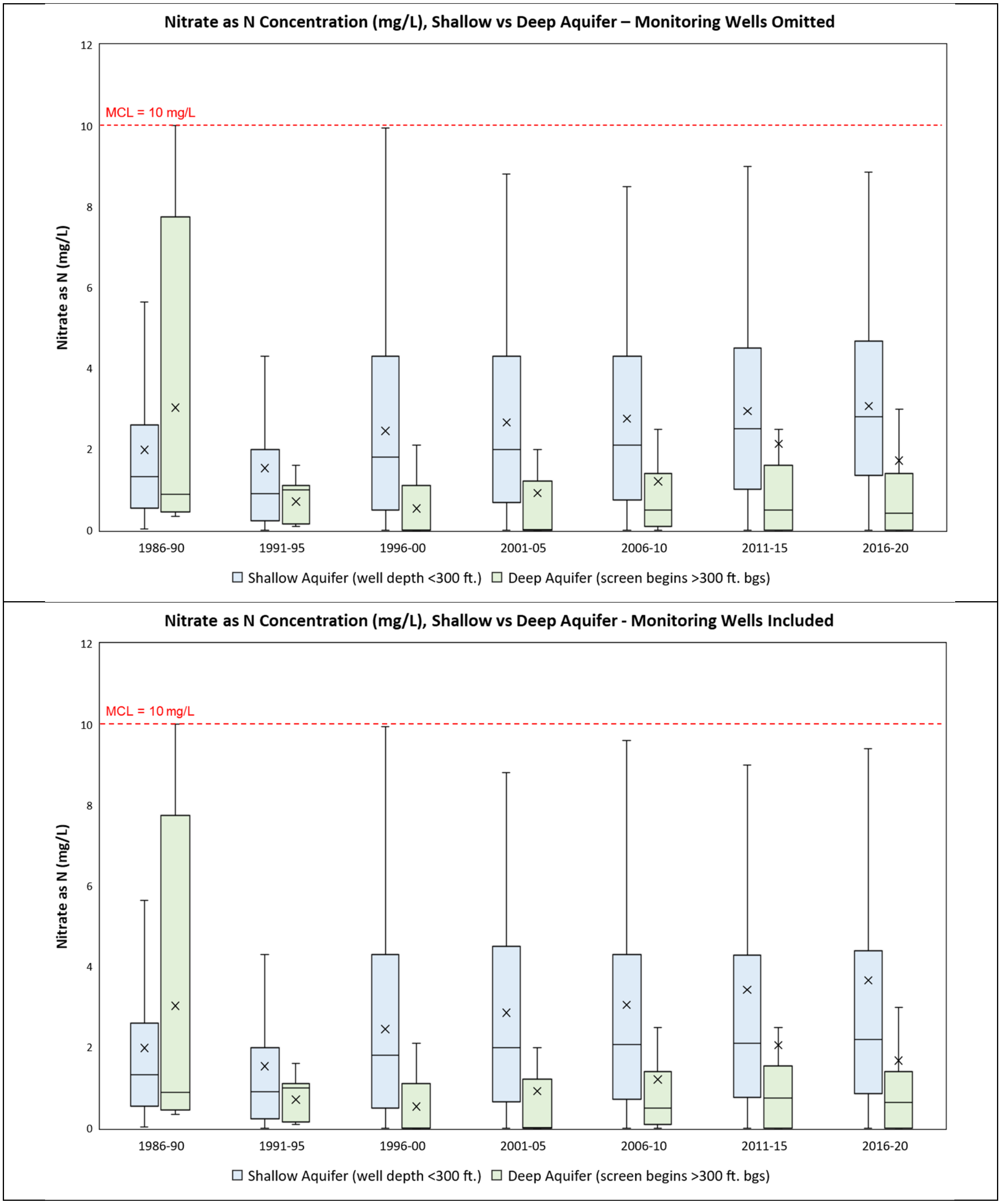


Figure 2-D-2: Historical Range of TDS Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

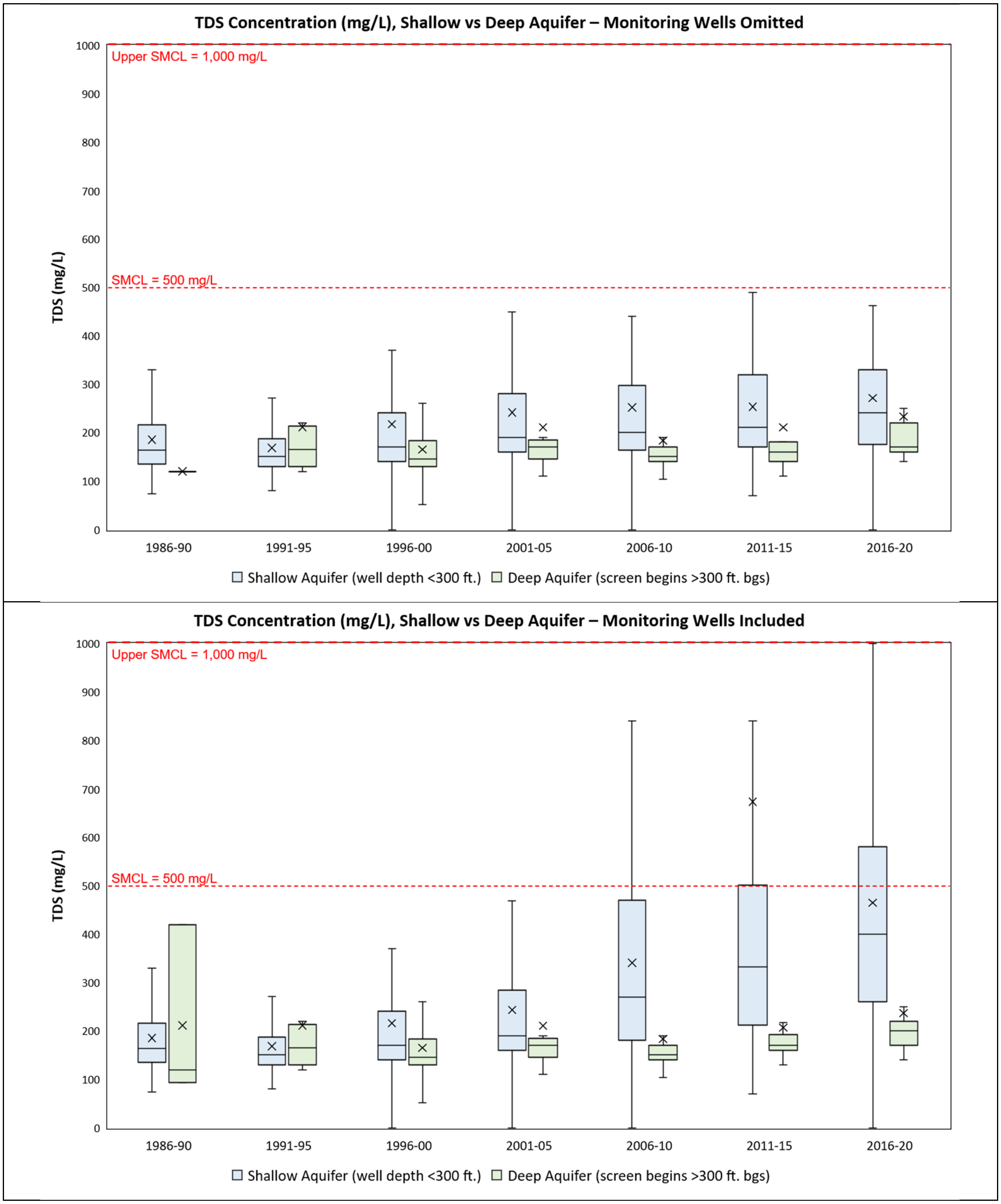
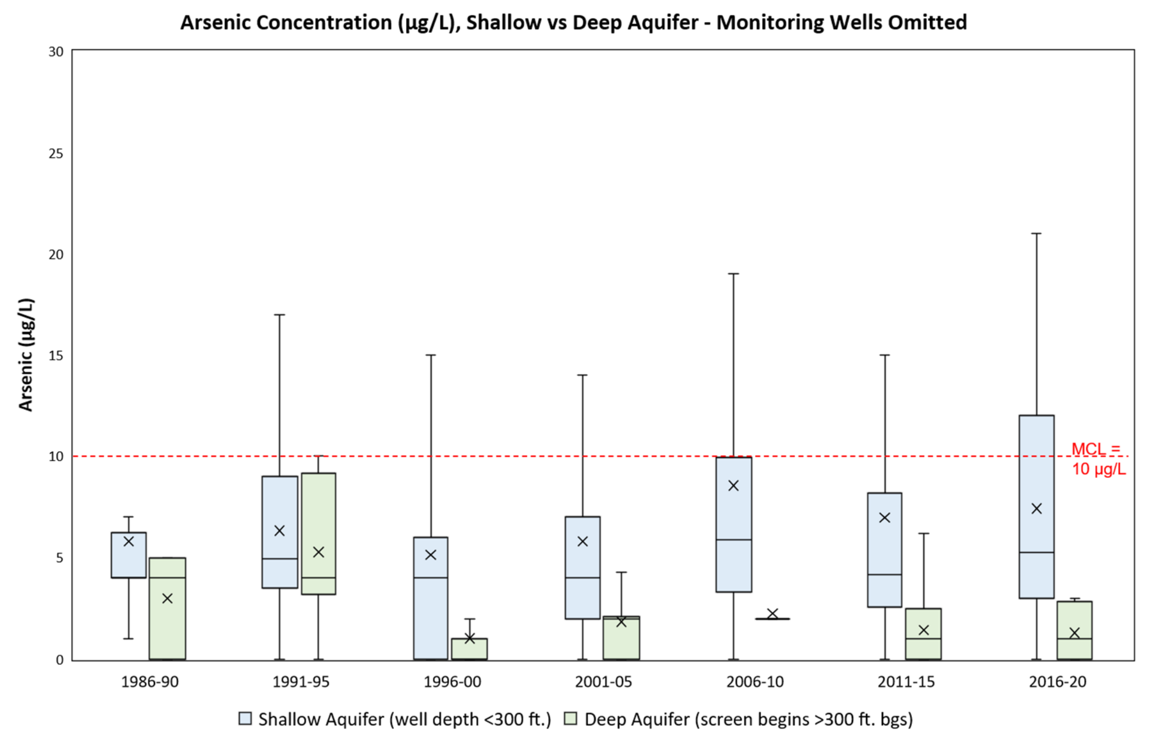


Figure 2-D-3: Historical Range of Arsenic Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)


Arsenic Concentration (µg/L), Shallow vs Deep Aquifer - Monitoring Wells Omitted

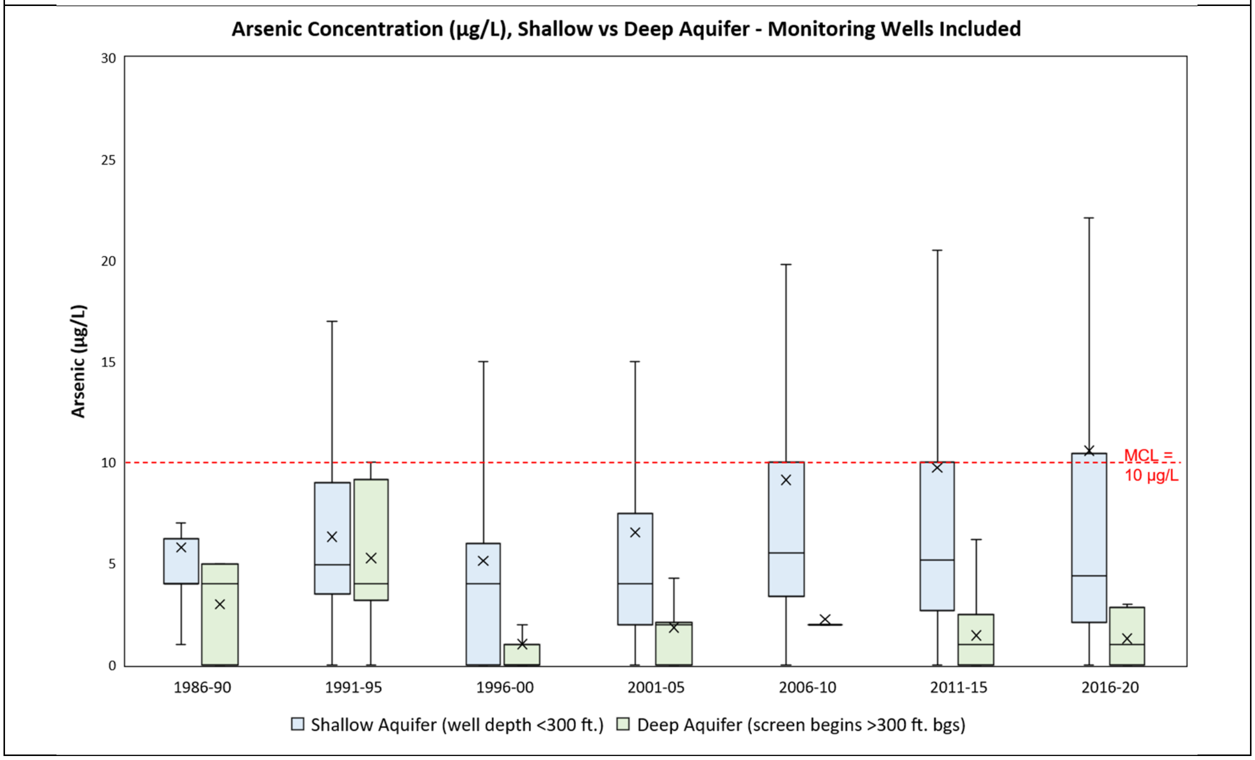

Arsenic Concentration (µg/L), Shallow vs Deep Aquifer - Monitoring Wells Included

Figure 2-D-4: Historical Range of Hexavalent Chromium Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

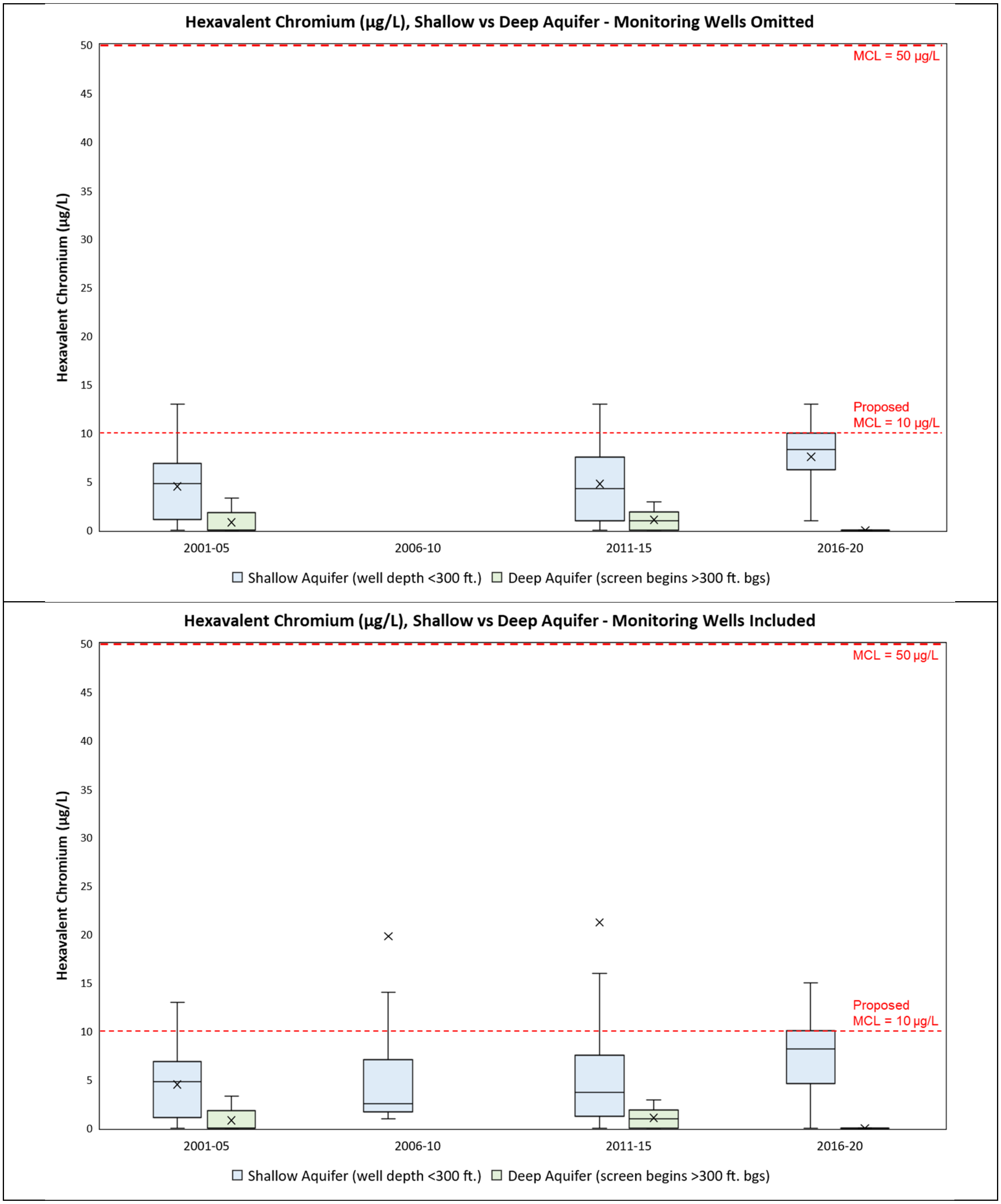


Figure 2-D-5: Range of PFAS Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

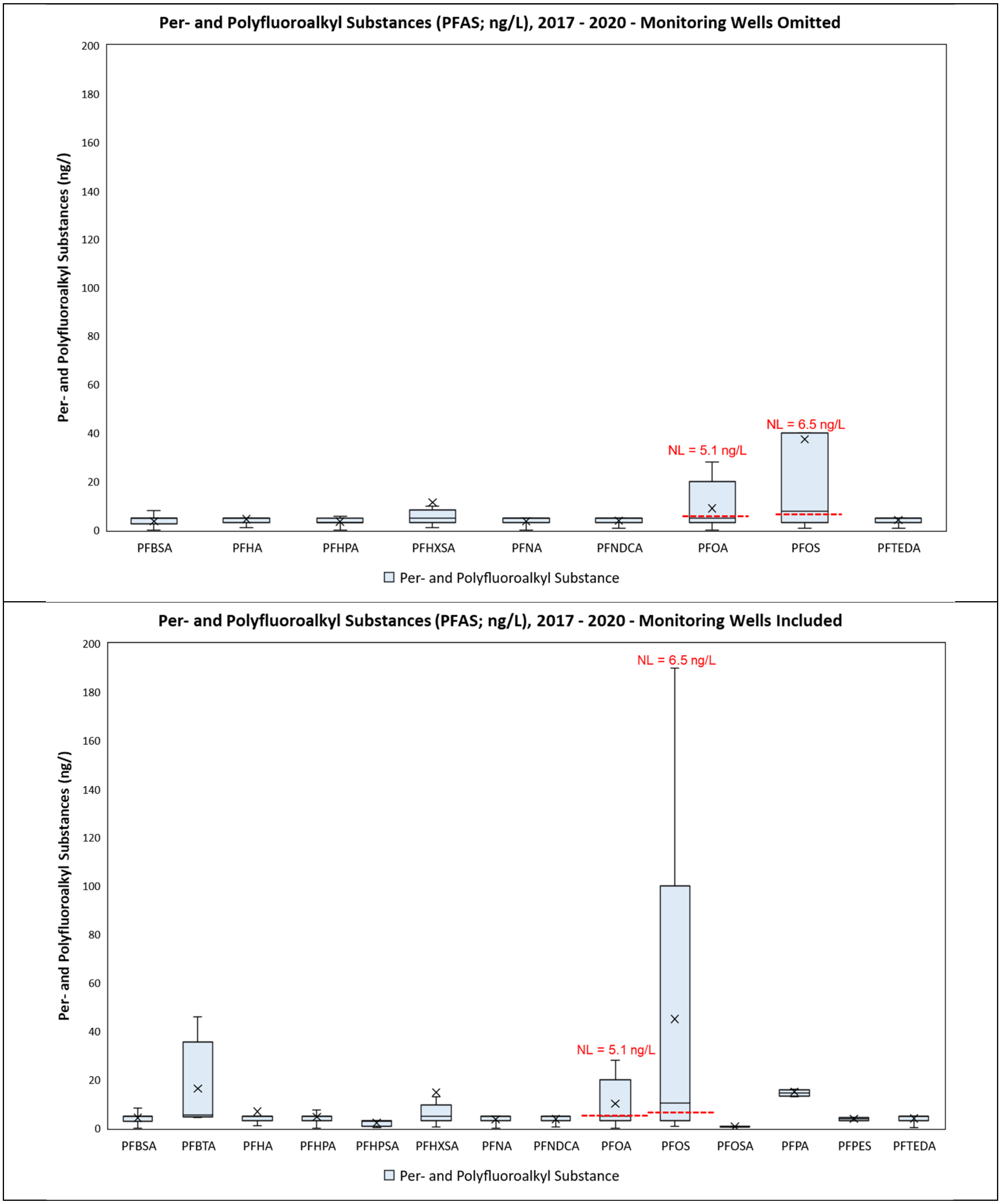


Figure 2-D-6: Historical Range of Chloride Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

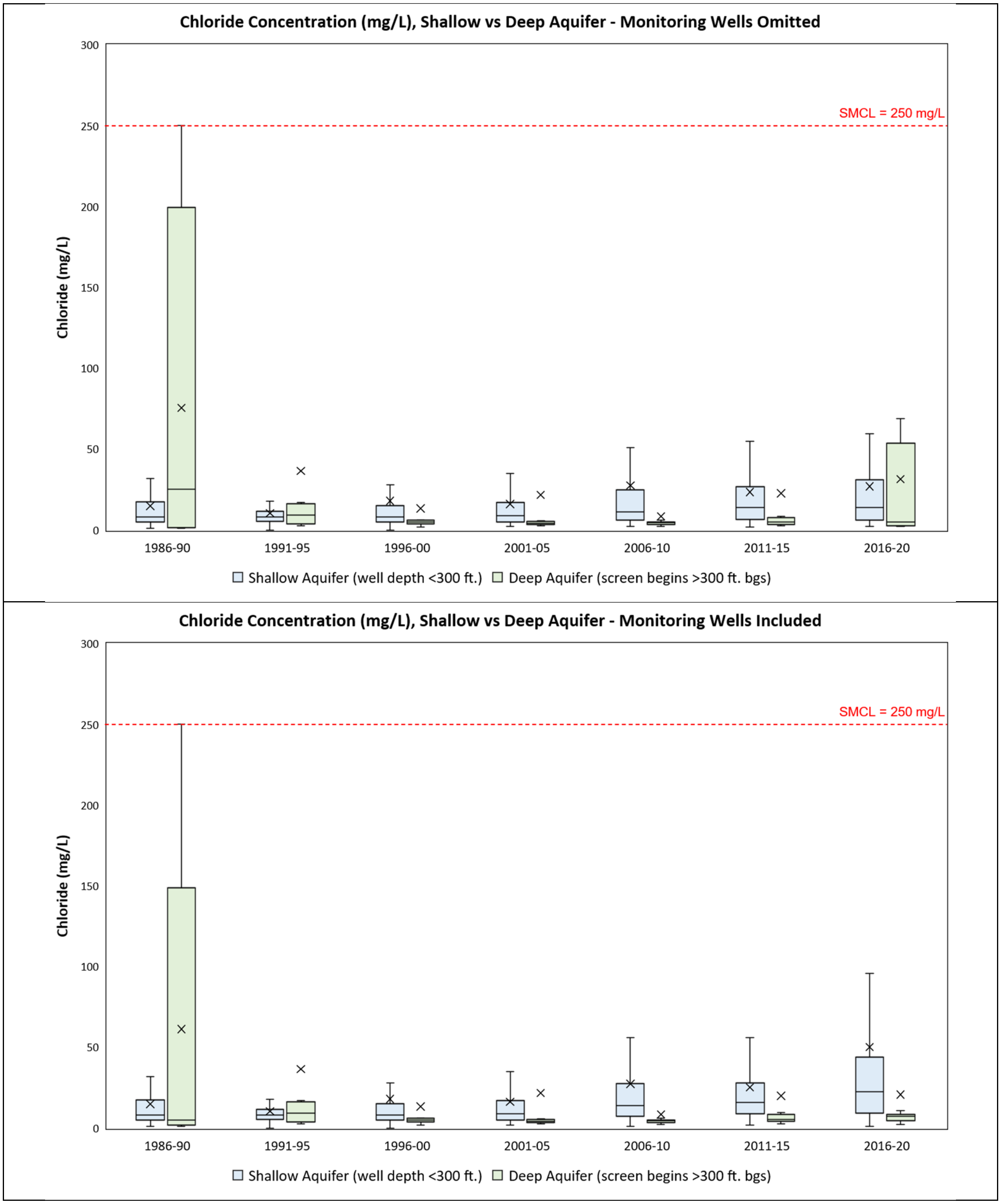


Figure 2-D-7: Range of Iron Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

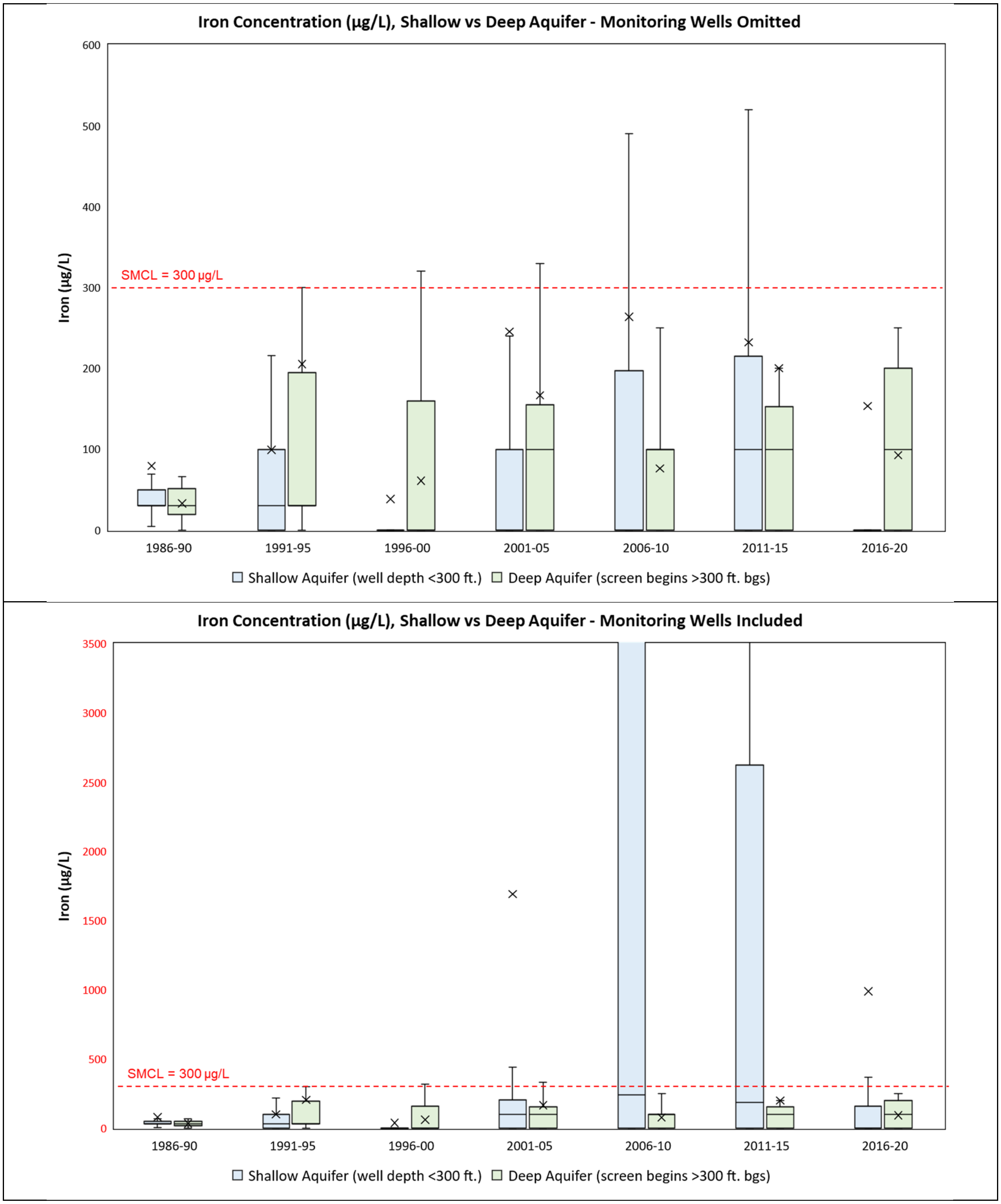


Figure 2-D-8: Range of Manganese Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

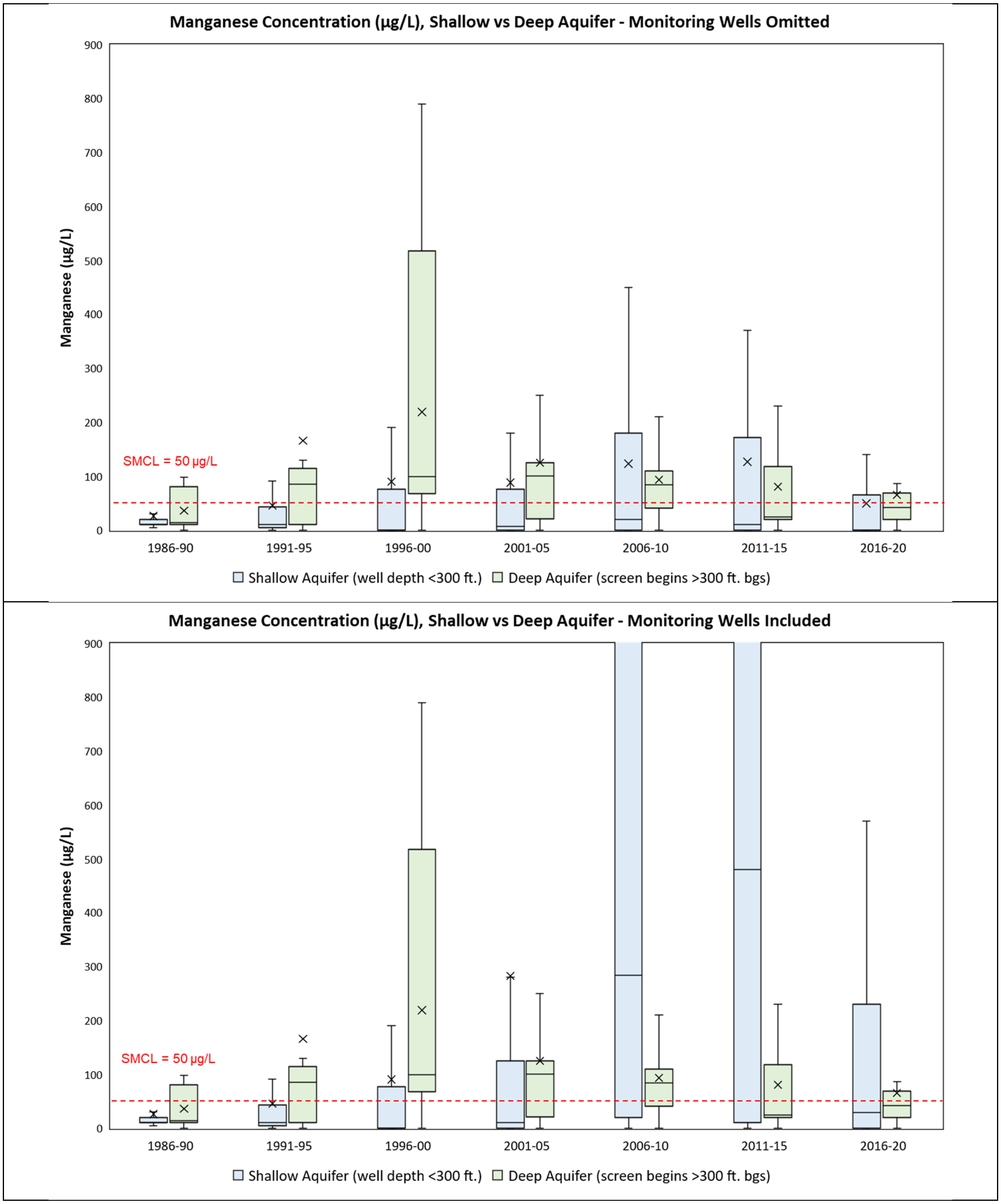


Figure 2-D-9: Nitrate Concentrations in the Shallow Zone, Monitoring Wells Omitted

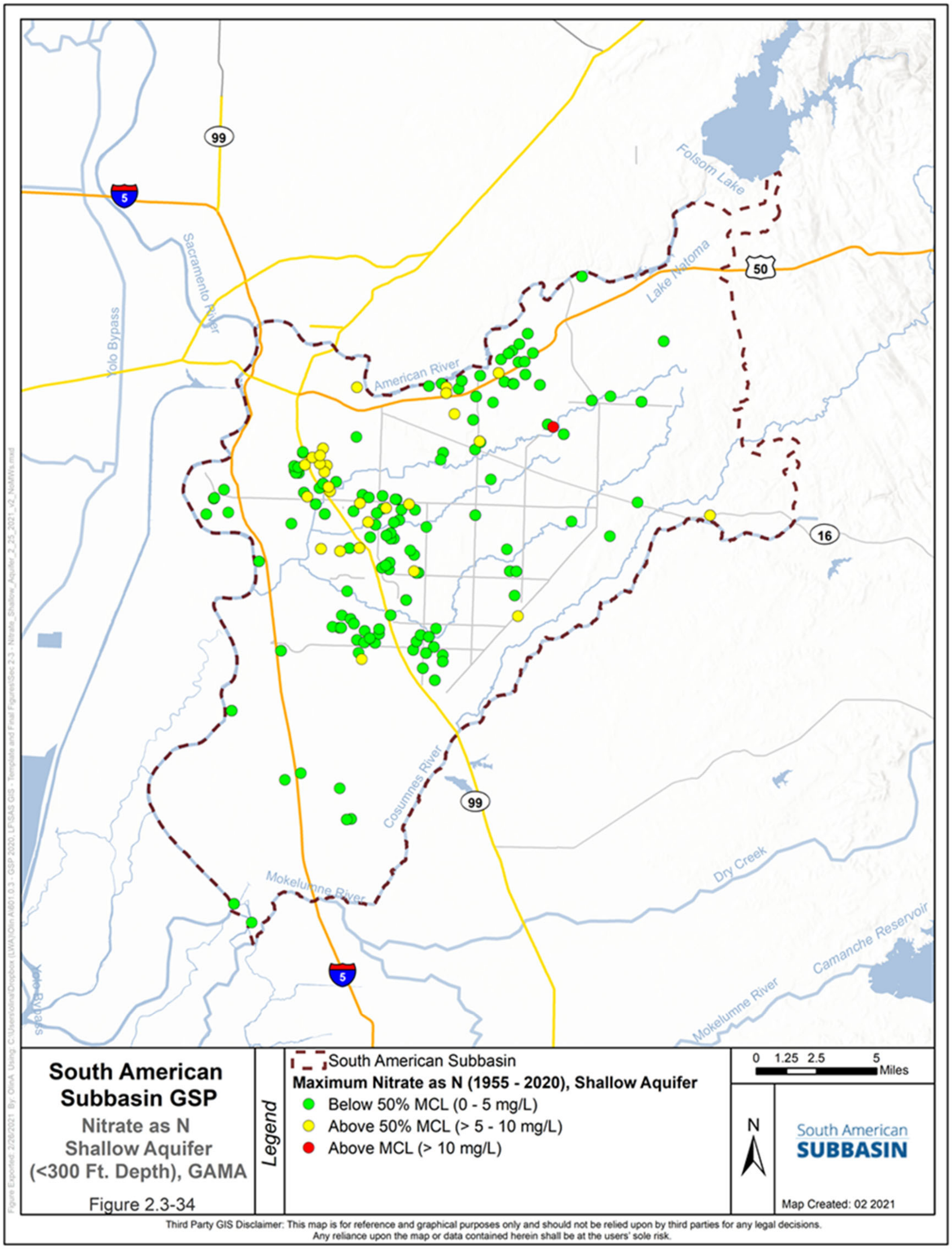


Figure 2-D-10: Nitrate Concentrations in the Shallow Zone, Monitoring Wells Included

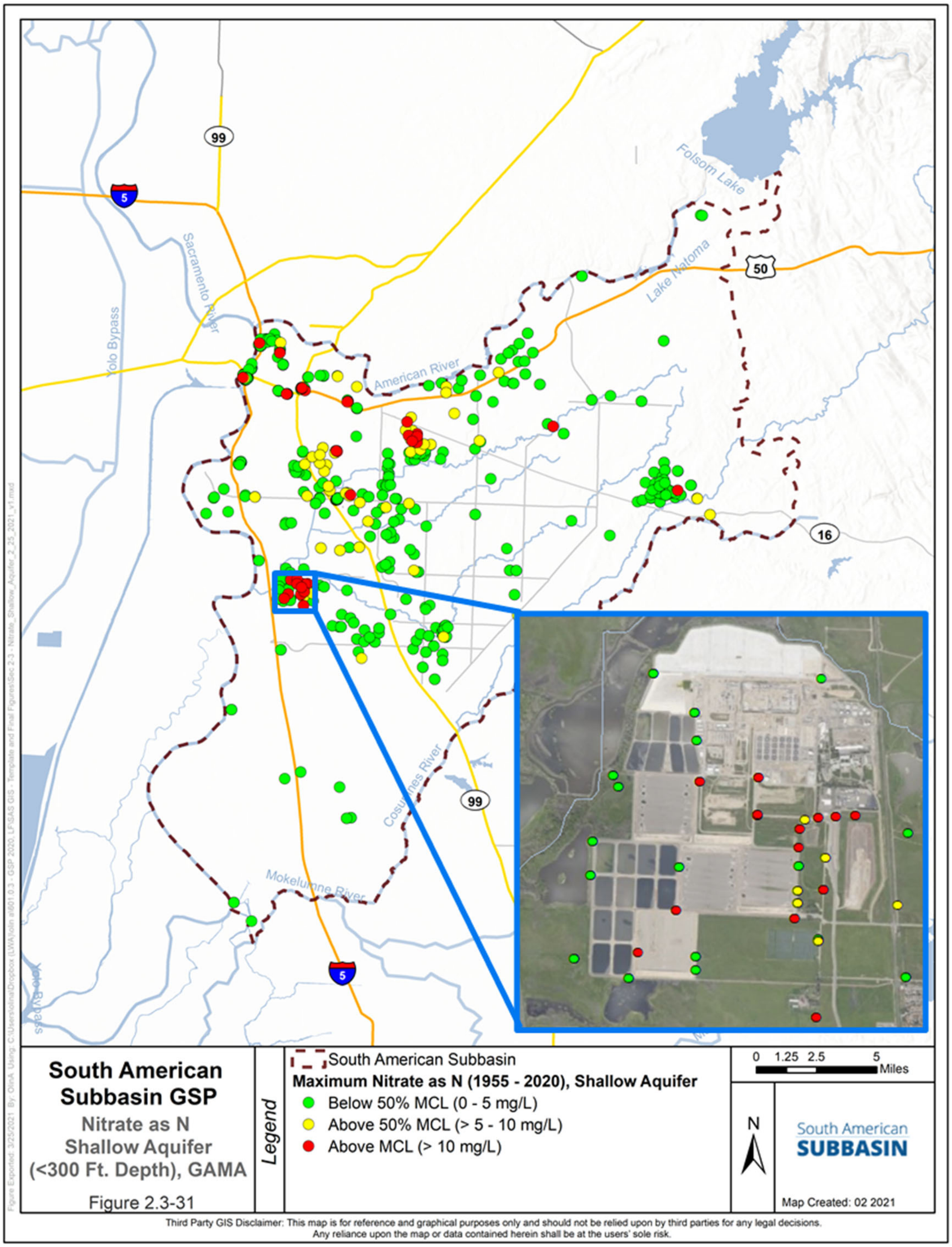


Figure 2-D-11: Nitrate Concentrations in the Deep Zone, Monitoring Wells Omitted

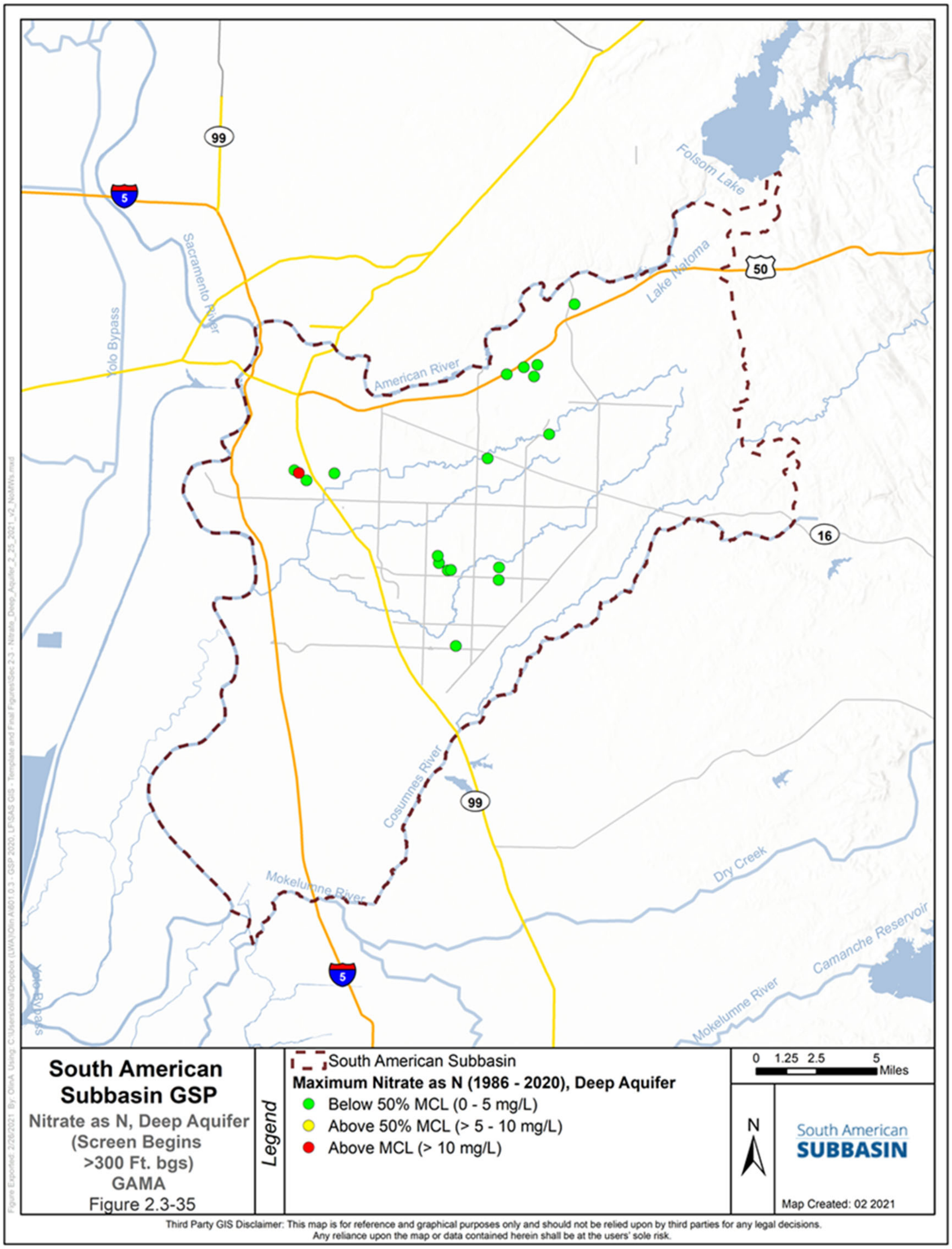
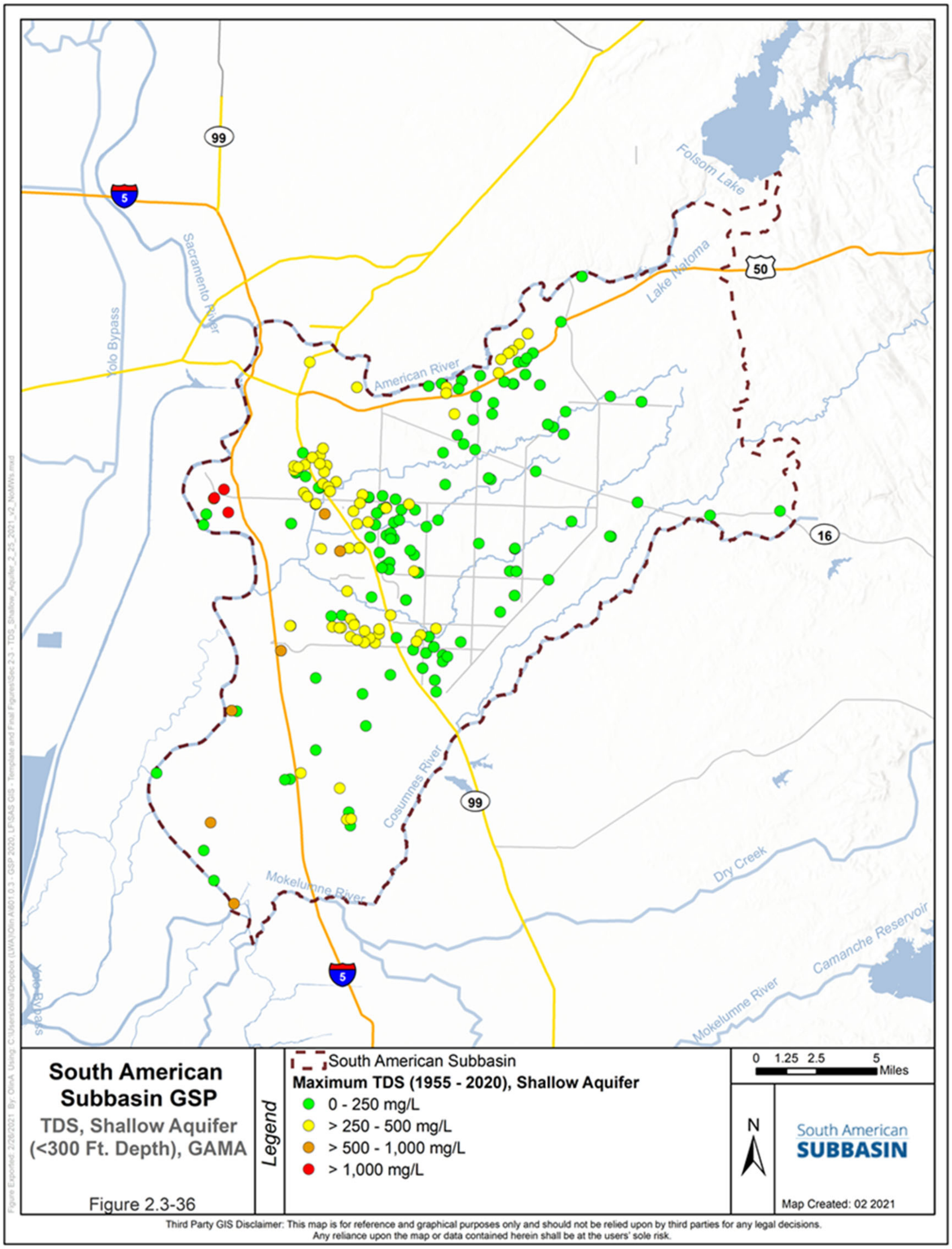


Figure 2-D-12: TDS Concentrations in the Shallow Zone, Monitoring Wells Omitted



South American Subbasin GSP

TDS, Shallow Aquifer (<300 Ft. Depth), GAMA

Figure 2.3-36

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the users' sole risk.

Figure 2-D-13: TDS Concentrations in the Shallow Zone, Monitoring Wells Included

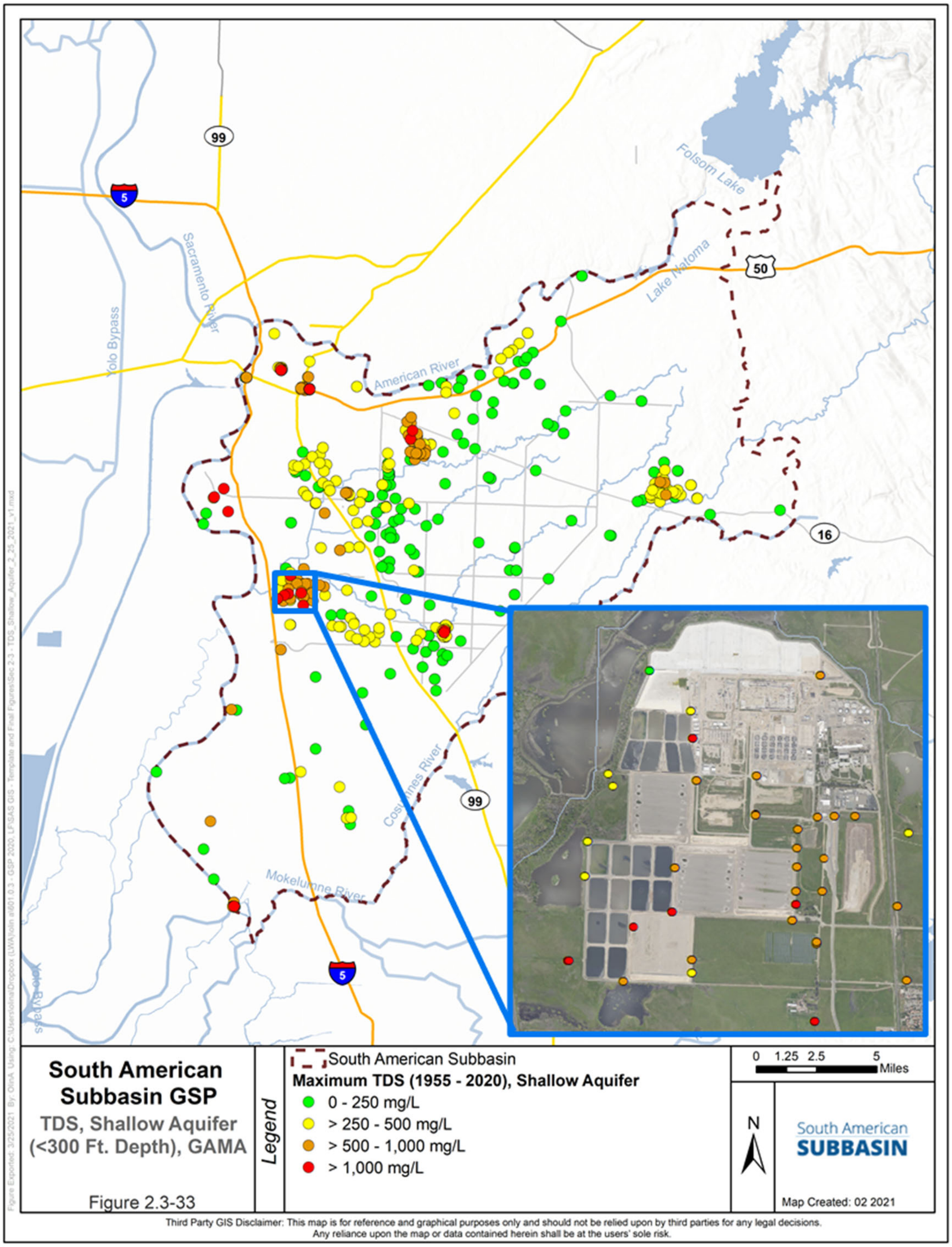
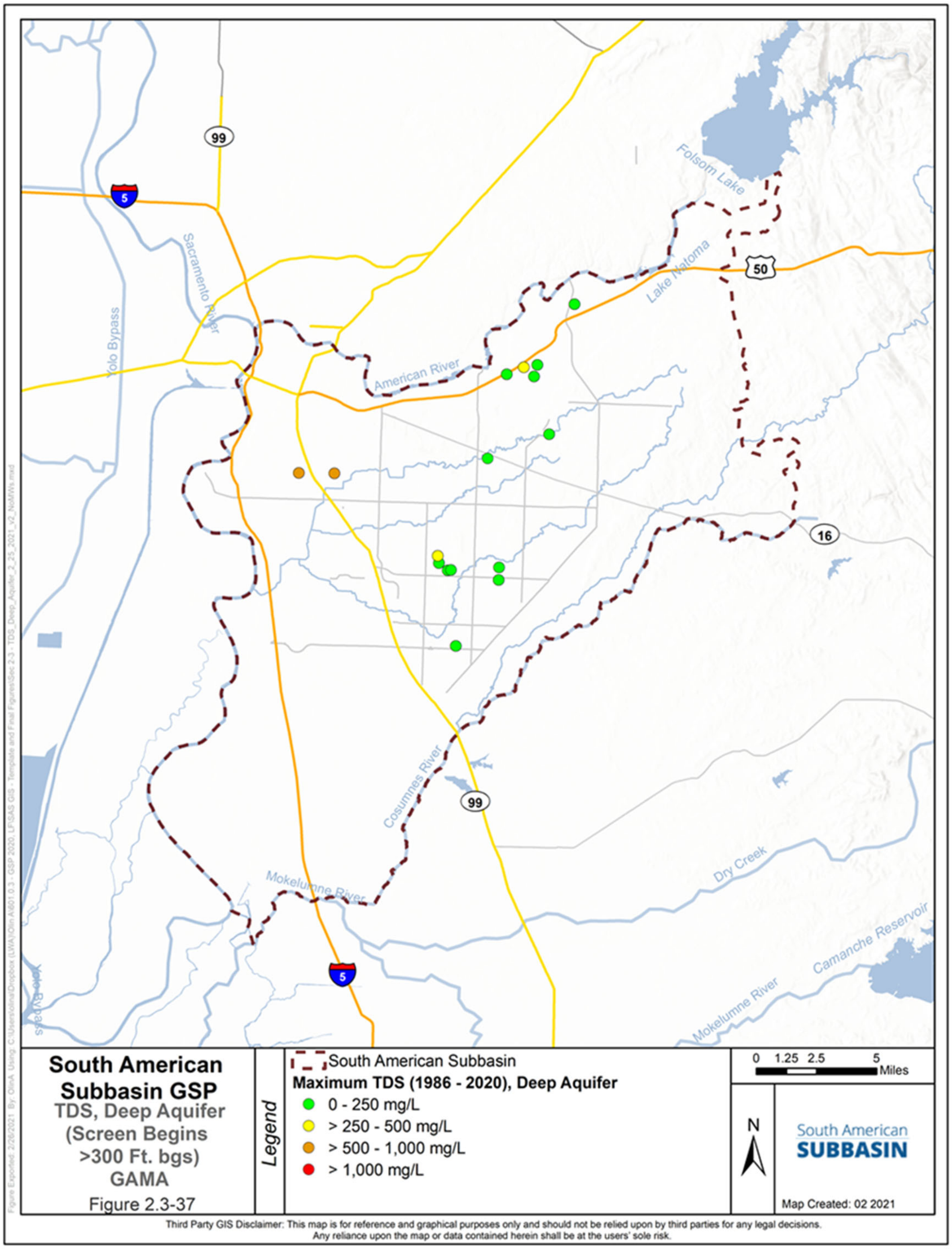


Figure 2-D-14: TDS Concentrations in the Deep Zone, Monitoring Wells Omitted



South American Subbasin GSP

TDS, Deep Aquifer (Screen Begins >300 Ft. bgs) GAMA

Figure 2.3-37

Legend

South American Subbasin

Maximum TDS (1986 - 2020), Deep Aquifer

- 🟢 0 - 250 mg/L
- 🟡 > 250 - 500 mg/L
- 🟠 > 500 - 1,000 mg/L
- 🔴 > 1,000 mg/L

Map Created: 02 2021

Figure 2-D-15: Arsenic Concentrations in the Shallow Zone, Monitoring Wells Omitted

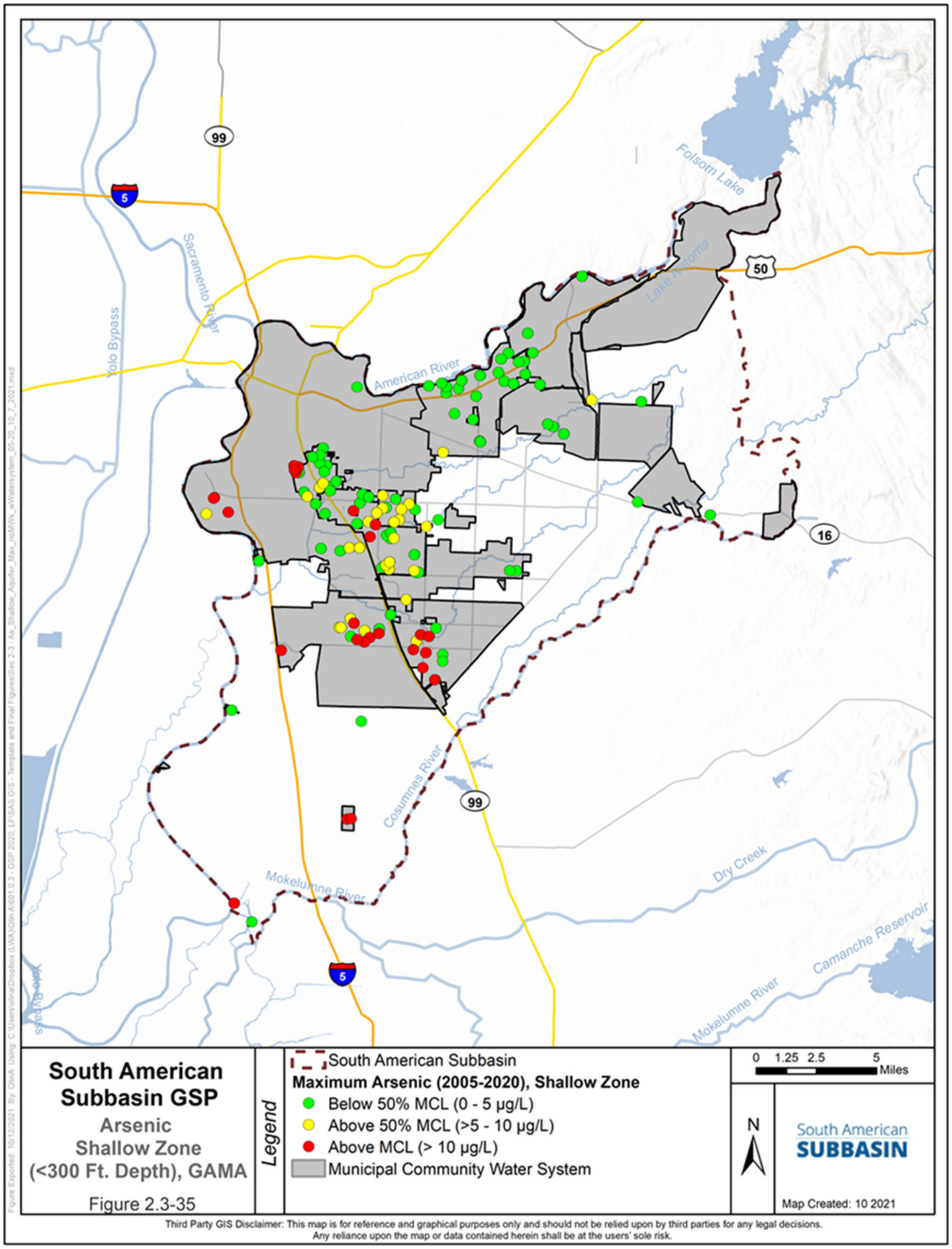


Figure 2-D-16: Arsenic Concentrations in the Deep Zone, Monitoring Wells Omitted

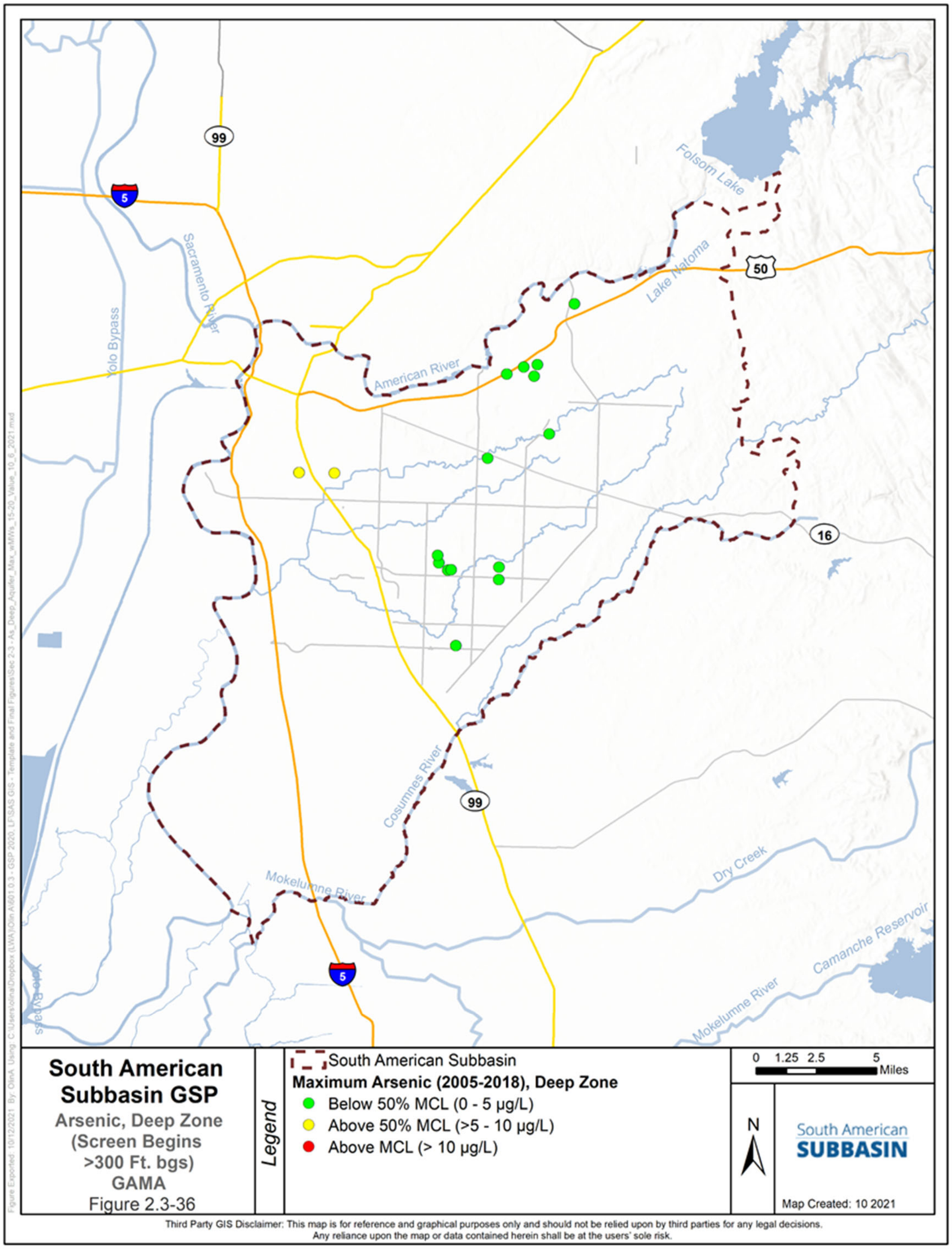


Figure 2-D-17: Hexavalent Chromium Concentrations in the Shallow Zone, Monitoring Wells Omitted

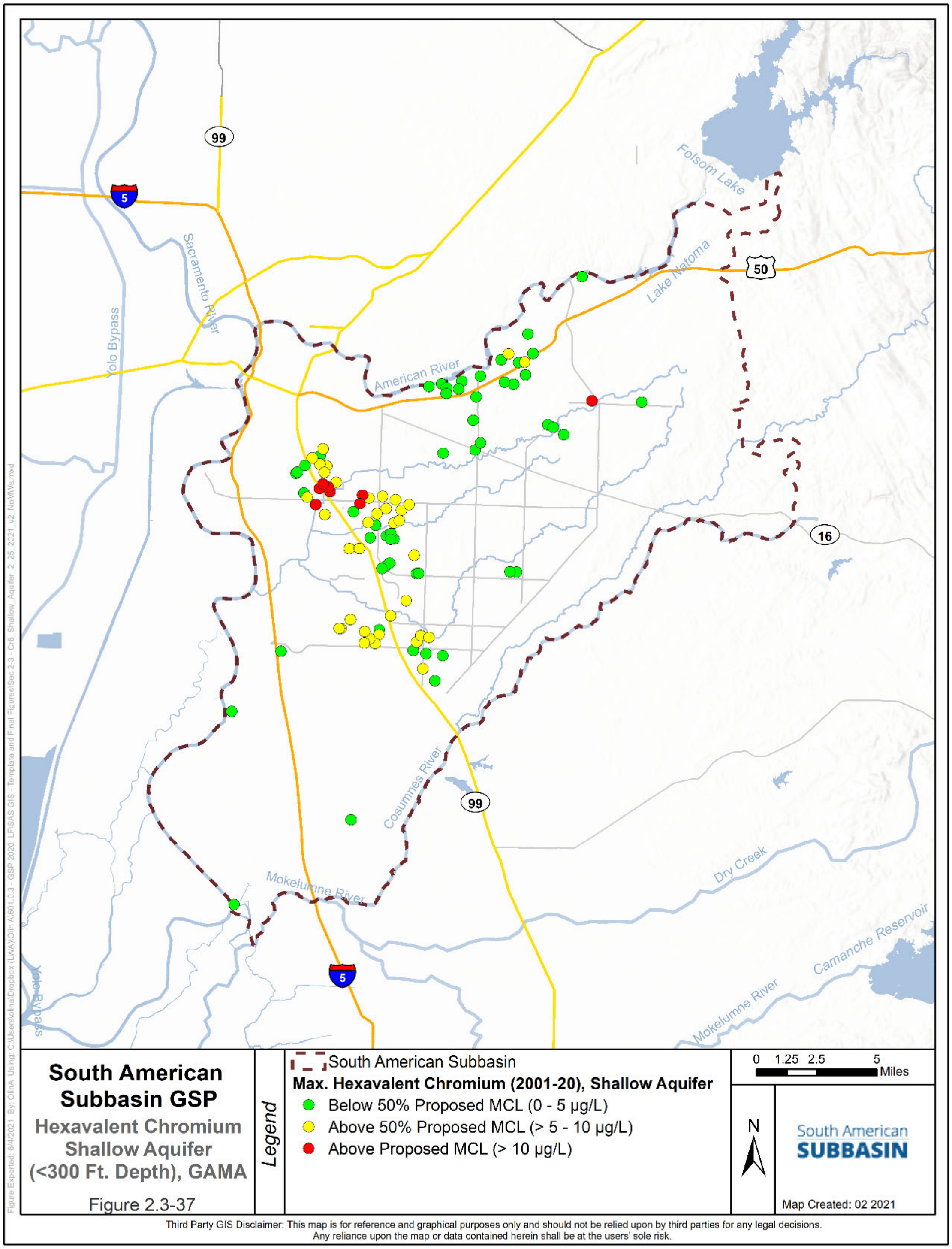


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Figure 2-D-18: Hexavalent Chromium Concentrations in the Deep Zone, Monitoring Wells Omitted

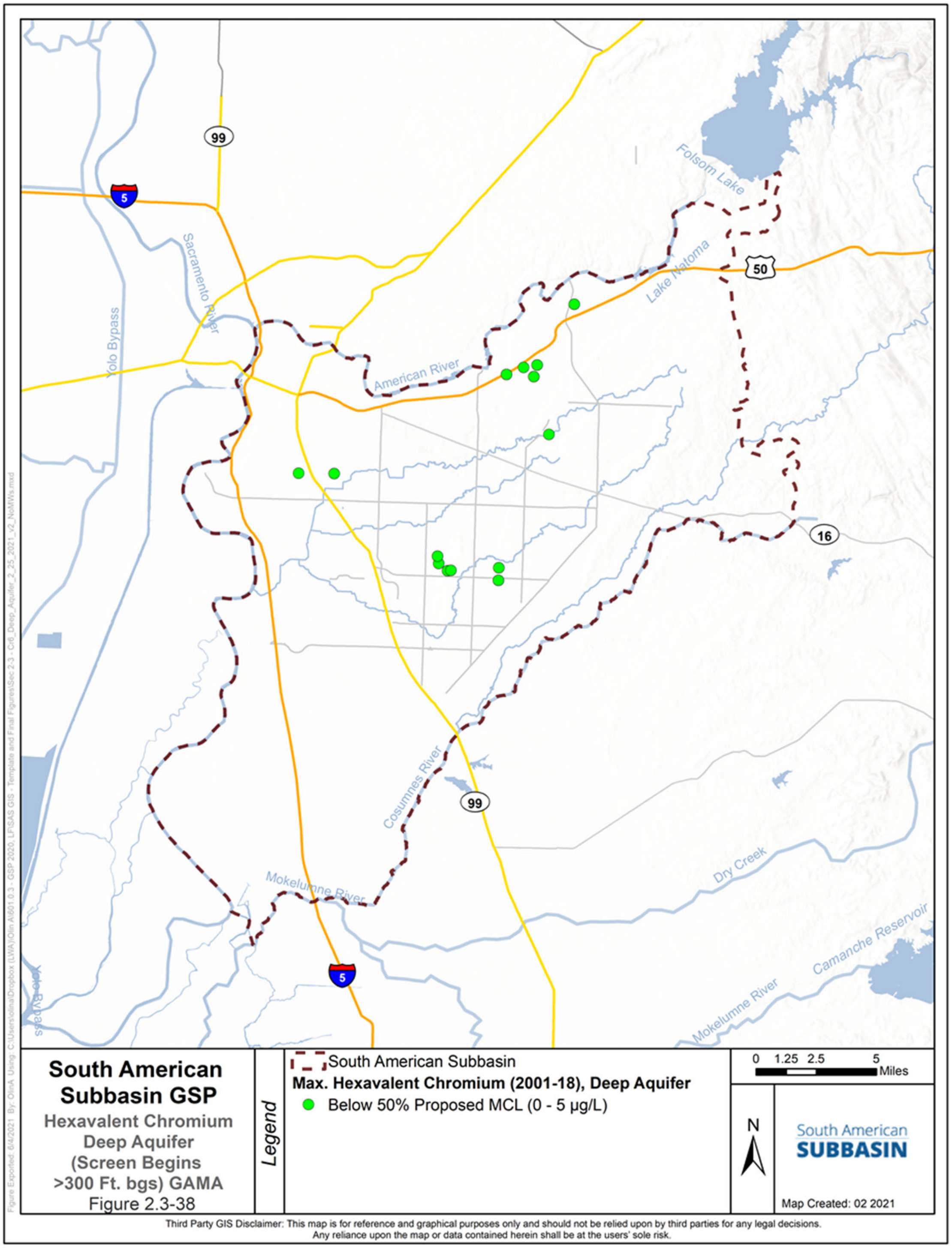

Figure 2-D-19: PFAS Concentrations in Groundwater, Monitoring Wells Included

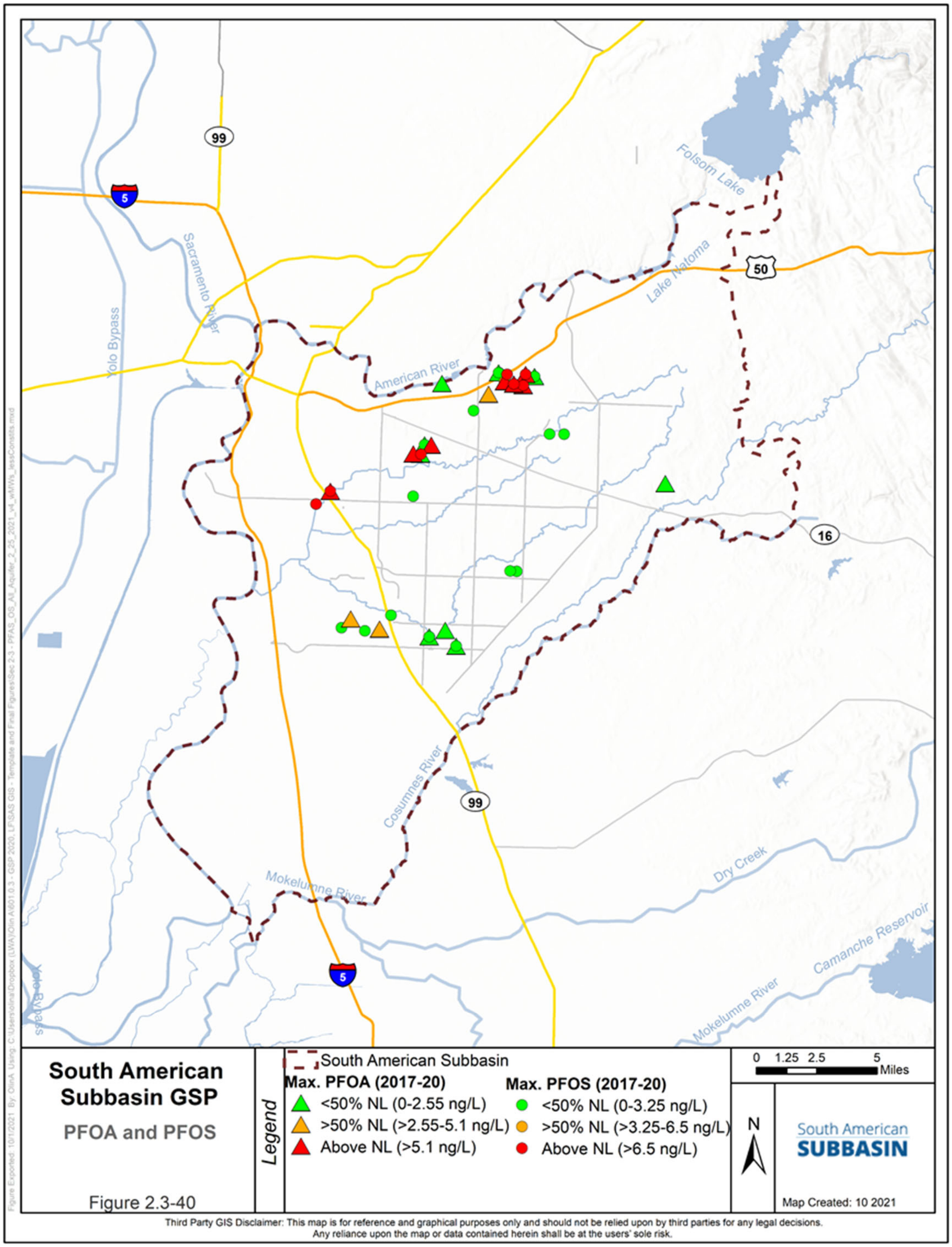

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Figure 2-D-20: Chloride Concentrations in the Shallow Zone, Monitoring Wells Omitted

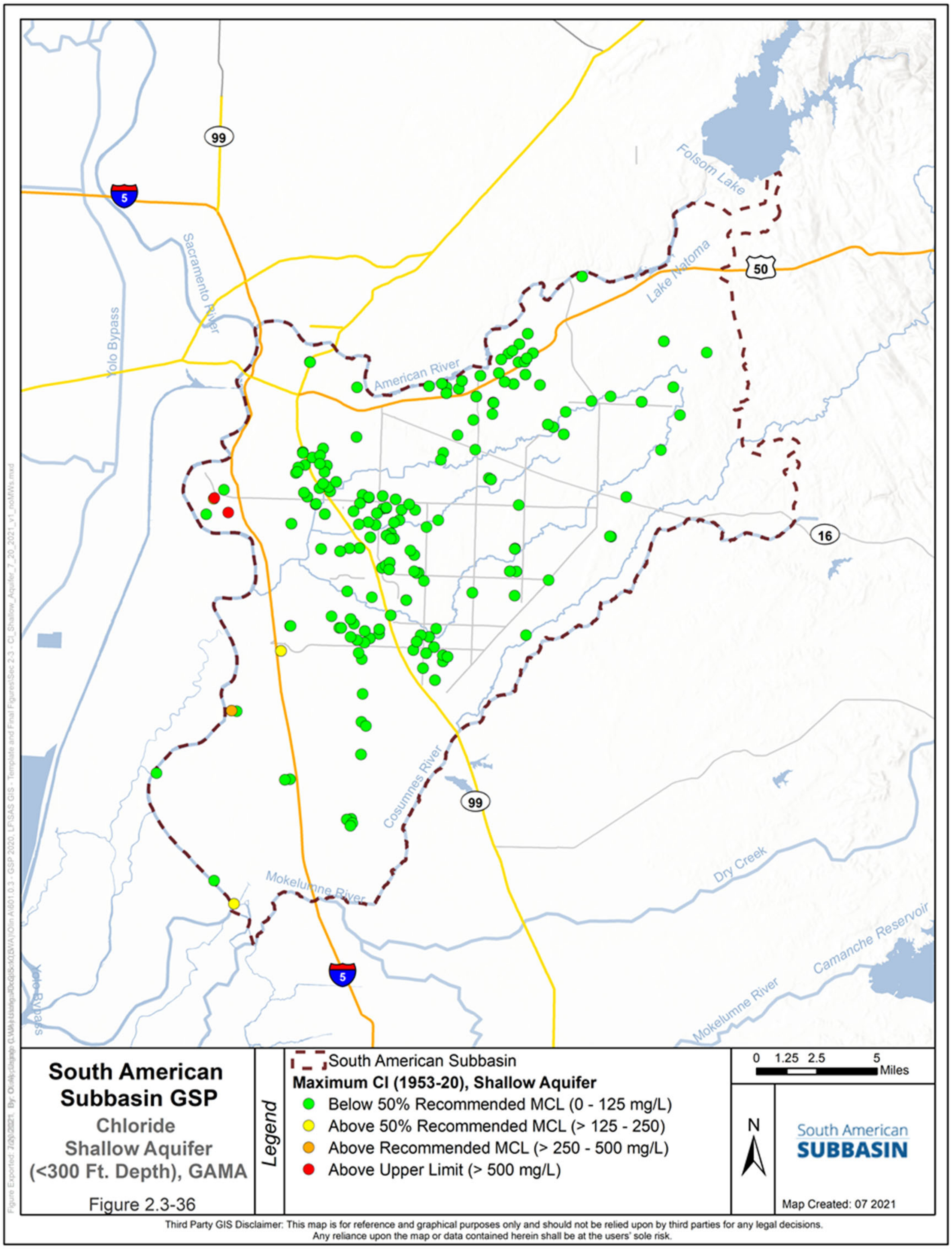

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Figure 2-D-21: Chloride Concentrations in the Deep Zone, Monitoring Wells Omitted

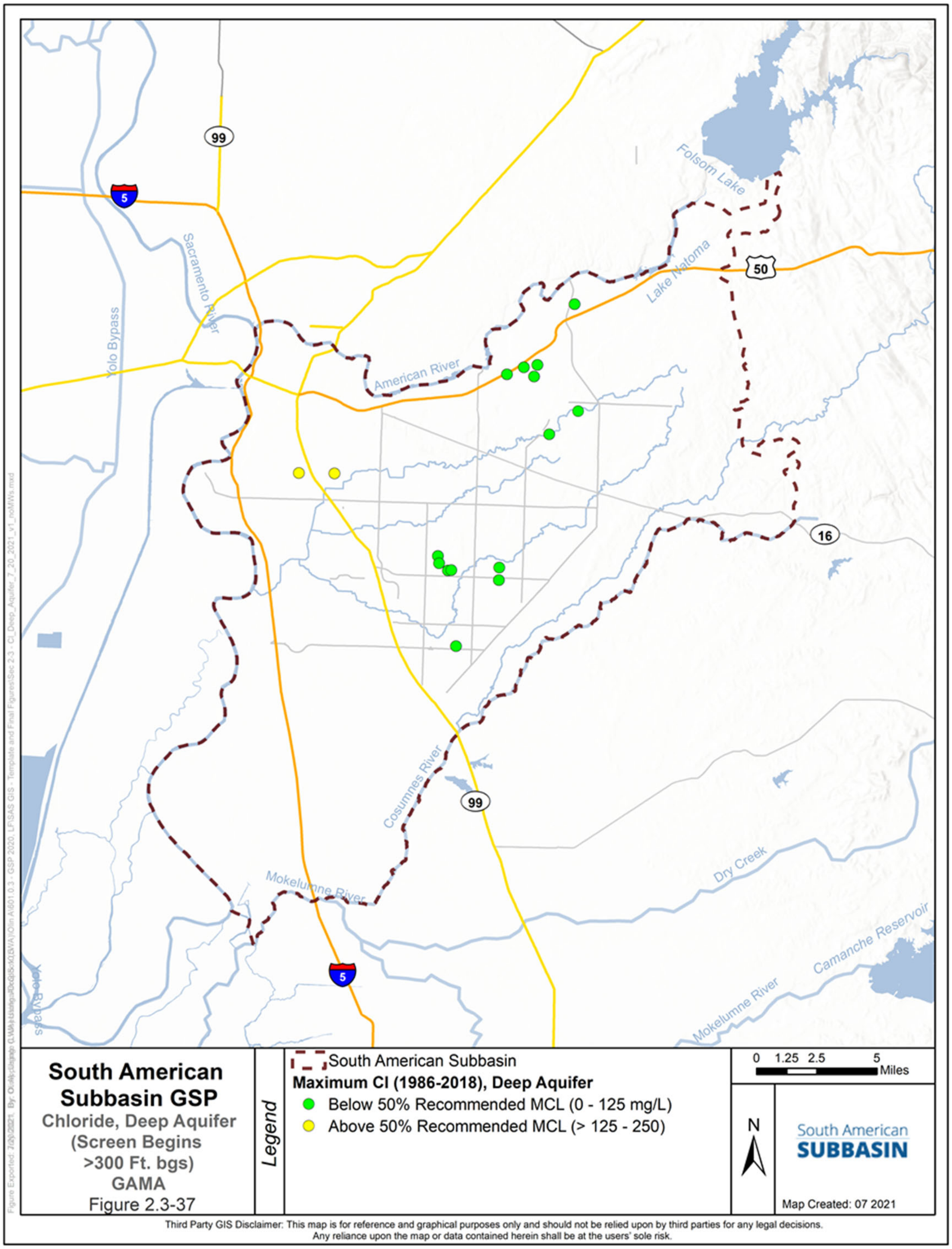

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Figure 2-D-22: Iron Concentrations in the Shallow Zone, Monitoring Wells Omitted

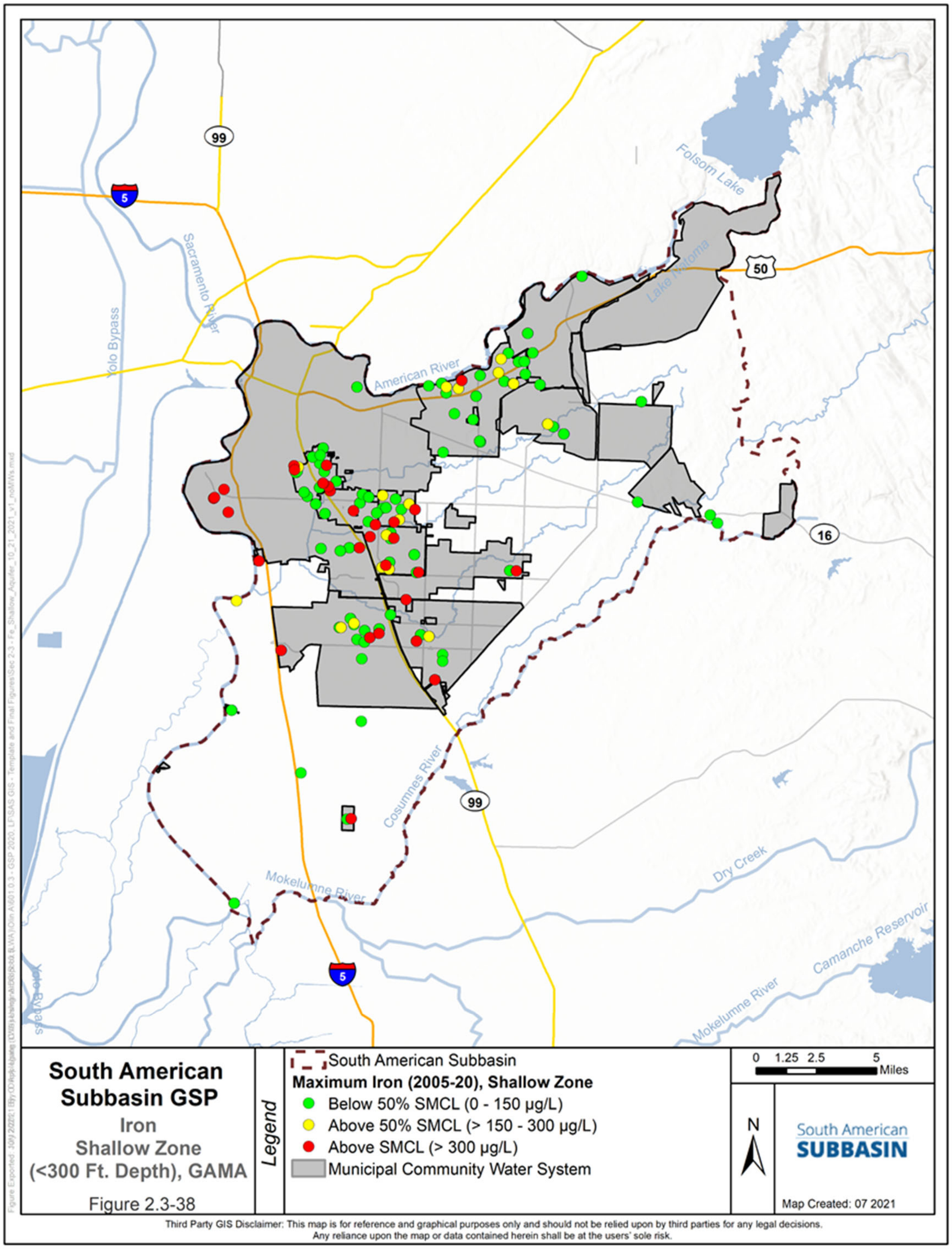

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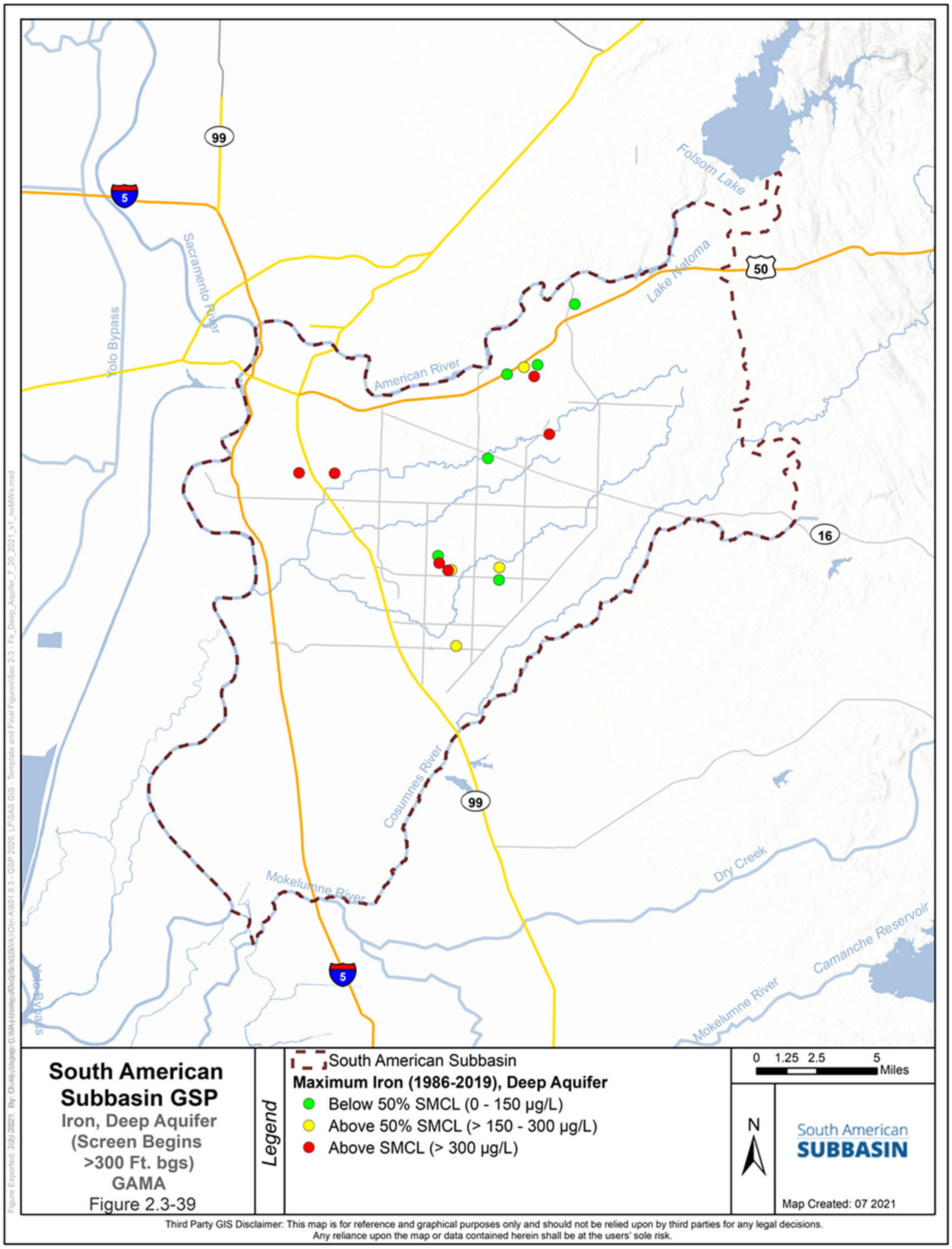
Figure 2-D-23: Iron Concentrations in the Deep Zone, Monitoring Wells Omitted



Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the users' sole risk.

Figure 2-D-24: Manganese Concentrations in the Shallow Zone, Monitoring Wells Omitted

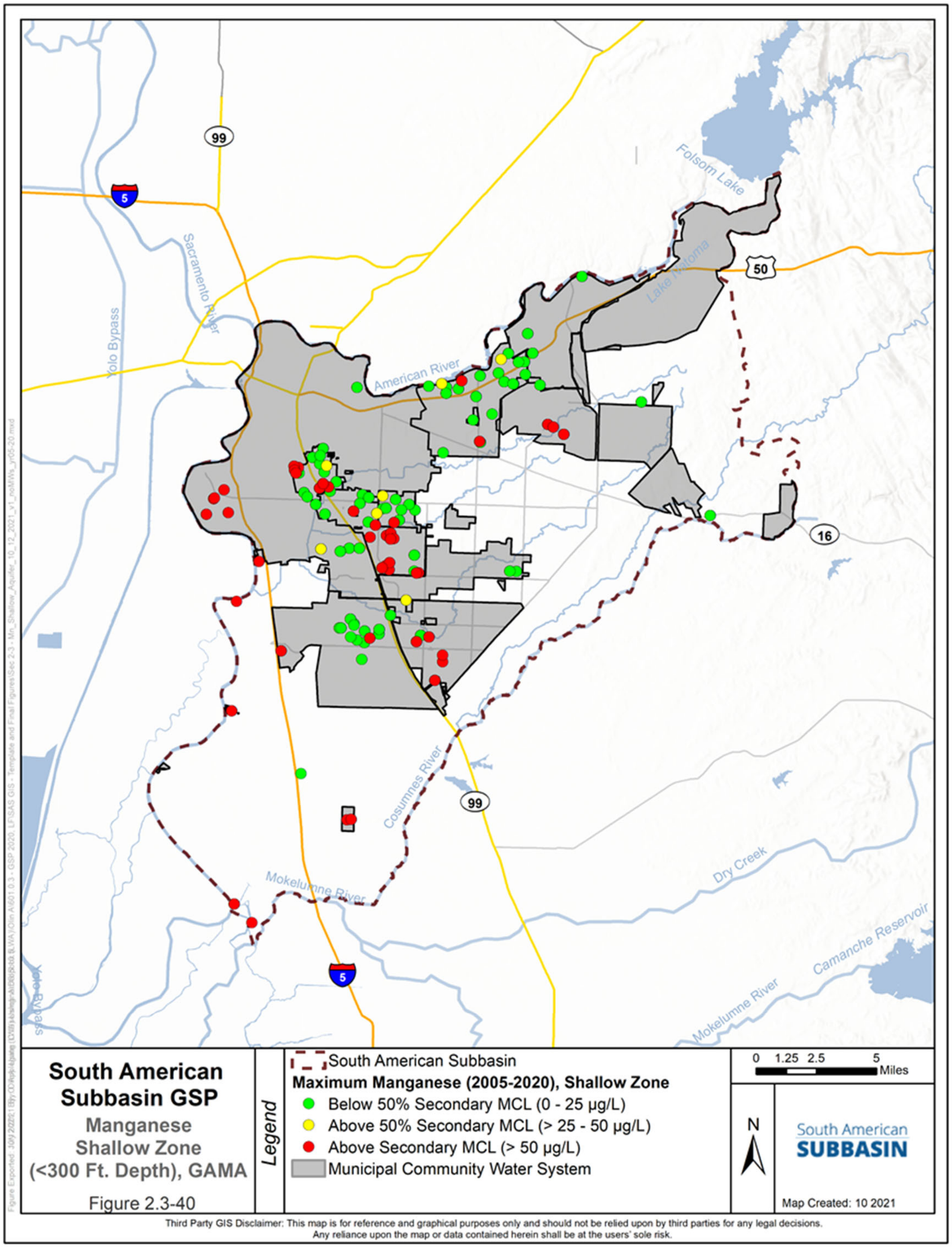


Figure 2-D-25: Manganese Concentrations in the Deep Zone, Monitoring Wells Omitted

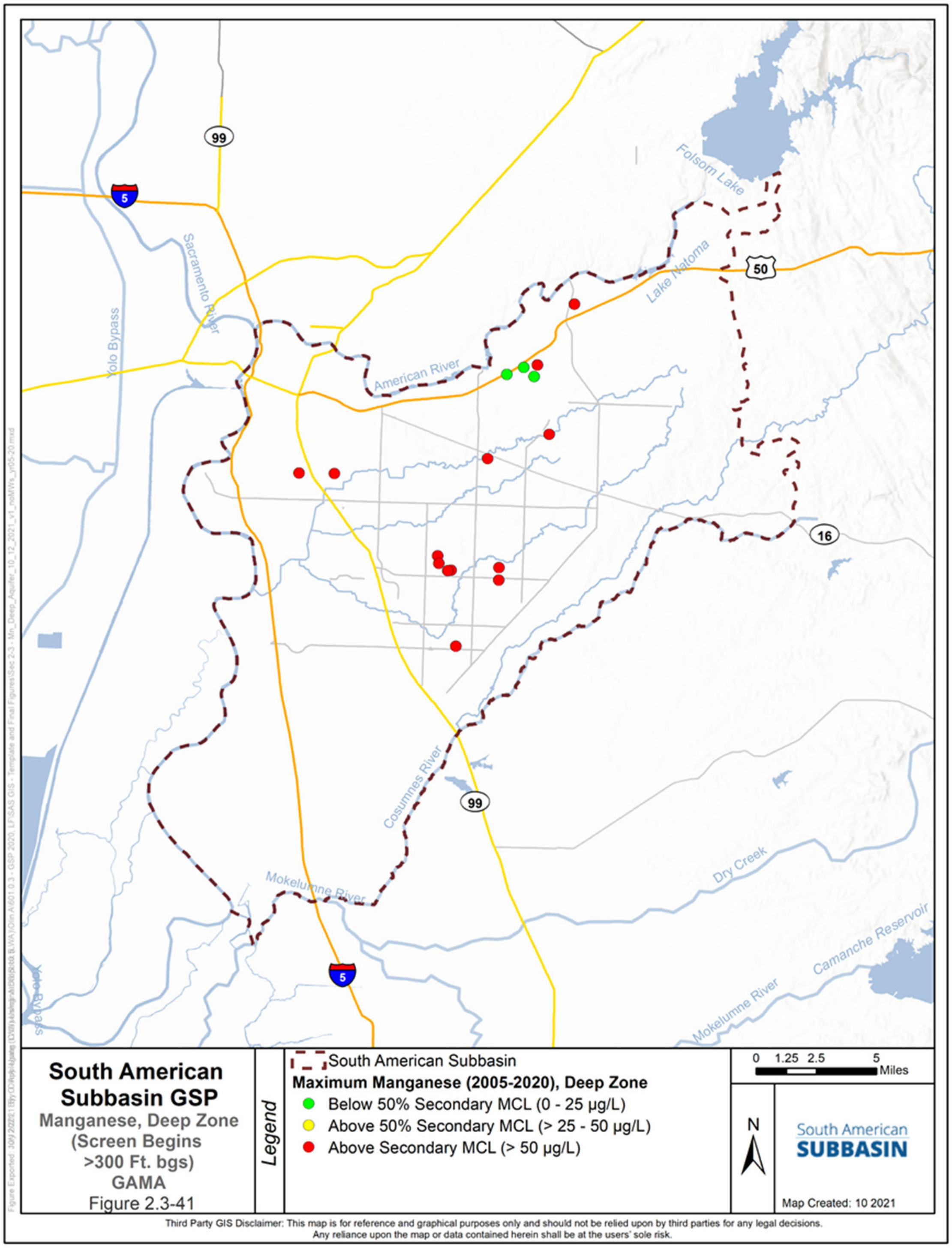


Table 2-D-2: Period of Record, Groundwater Quality Monitoring Wells in the Upper Aquifer Zone

	Arsenic Measurements			Iron Measurements			Manganese Measurements		
Well ID	From	To	# of records	From	To	# of records	From	To	# of records
3410020-009	11/16/88	5/9/17	13	11/16/88	2/4/20	13	11/16/88	2/4/20	13
3410029-002	2/21/91	2/6/17	11	7/27/89	2/13/20	15	7/27/89	2/13/20	16
3410029-016	7/1/88	2/10/20	10	7/1/88	2/10/20	13	7/1/88	2/18/14	12
3410029-029	10/25/01	2/18/14	7	10/25/01	2/18/14	6	10/25/01	2/13/20	7
3410033-006	7/13/90	12/12/13	8	5/8/87	6/13/19	12	5/8/87	6/13/19	12
L10005519750-MW-G(S)	N/A	N/A	0	10/23/17	10/23/17	1	5/20/15	5/20/15	1
L10008601447-MW-13	N/A	N/A	0	6/4/15	2/22/18	5	2/26/15	10/17/18	8
3400101-001	2/19/08	11/20/14	2	2/24/05	2/6/17	4	8/15/05	2/19/08	2
3410029-024	8/26/02	5/1/17	71	8/26/02	5/1/17	73	8/26/02	7/29/14	72
3410029-025	3/21/01	12/3/19	172	3/21/01	9/22/14	158	3/21/01	9/22/14	164
3901216-001	5/21/02	7/25/17	5	5/22/02	2/4/20	6	5/22/02	2/4/20	2

Table 2-D-3: Period of Record, Groundwater Quality Monitoring Wells in the Lower Aquifer Zone

	Arsenic Measurements			Iron Measurements			Manganese Measurements		
Well ID	From	To	# of records	From	To	# of records	From	To	# of records
3400375-001	5/5/05	6/8/12	2	5/5/05	6/8/12	2	5/5/05	6/8/12	2
3410015-020	5/27/86	1/14/14	11	5/27/86	2/28/17	14	5/27/86	2/28/17	14
3410015-022	5/19/93	5/25/17	8	5/19/93	1/14/14	10	5/19/93	10/8/19	83
3410023-015	2/15/91	1/8/15	6	7/18/89	1/8/15	23	7/18/89	1/8/15	23
3410029-015	7/1/88	5/23/18	10	7/1/88	5/23/18	16	7/1/88	5/13/15	19
3410029-026	10/25/01	5/11/17	9	10/25/01	2/18/14	10	10/25/01	5/11/17	16
3410029-027	11/19/03	8/18/11	5	11/19/03	2/5/19	8	11/19/03	2/5/19	11
3410704-001	4/30/92	5/20/14	6	4/30/92	5/11/17	8	4/30/92	5/20/14	11
L10007396297-MW-40B	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0
S7-SAC-SA10	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0

Land Subsidence

Land subsidence is the lowering of the ground surface elevation. This is often caused by pumping below thick clay layers. Land subsidence can be elastic or inelastic. Inelastic subsidence is generally irreversible. Elastic subsidence is small, reversible lowering and rising of the ground surface and can be cyclical with seasonal changes year to year. Land subsidence is not known to be historically or currently significant in South American Groundwater Subbasin.

Previous Land Subsidence Studies and Current Data Sources

Previous efforts to quantify land subsidence in the South American Subbasin have yielded results showing small-to-zero amounts of subsidence having occurred. Such efforts have mainly been through leveling profiles studied between 1947 and 1966, the 2006 GMP, a 2008 DWR and the US Bureau of Reclamation subsidence project throughout the Sacramento Valley using GPS technology (Frame Surveying & Mapping, 2008), and DWR's Sacramento Valley 2017 GPS Survey program (specific results are summarized in SCGA [2018]), all of which demonstrated that subsidence has been very minimal, not significant or unreasonable, across the Subbasin during the time period 2008-2017.

DWR published Interferometric Synthetic Aperture Radar (InSAR) satellite data on their SGMA Data Viewer web map in 2019 (with an additional update in 2020), providing an estimate of land subsidence covering the time period from June 2015 to September 2019 (see **Figure 2-D-1**). These data are processed by TRE Altamira and are made available by DWR as downloadable raster and point datasets for monthly time steps, updated annually.

The only current CGPS (Continuous GPS) data available within the Subbasin are from the UNAVCO CGPS station (# P274). The CGPS station data are available for the period from October 2005 to present (). The data from this station are used in estimating current land subsidence conditions in the area surrounding the CGPS station. The CGPS data are also planned for use by the GSA in estimating future land subsidence conditions in the Subbasin.

The DWR/TRE Altamira InSAR data are the only currently available subsidence-related dataset covering the whole Subbasin and provide high-resolution estimates of total vertical displacement, complementary to the CGPS station data. The CGPS and InSAR data are described in further detail below.

CGPS Data Analysis

The vertical displacement data available from the UNAVCO CGPS network station #P274 start in October 2005 and continue to the present. The record of this subsidence data product from October 2005 to December 2020 are shown in **Figure 2-D-2**Figure 2-D-2. The data suggest minimal land subsidence has occurred since measurement began in October 2005, equating to about -0.14 ft in total, or roughly -0.01 ft/year. The InSAR record of subsidence for the same area the CGPS station lies within compares similarly for the equivalent period of June 2015 to September 2019 (both recording about -0.03 ft of subsidence). This demonstrates the accuracy of InSAR to be approximate to the CGPS stations for purposes of tracking land subsidence according to SGMA needs.

InSAR Data Analysis

Using the TRE Altamira InSAR Dataset provided by DWR, it is observed that the majority of the vertical displacement values in South American Subbasin are very low to essentially zero, with minimal outliers and within the range of 0.0 to -0.14 ft (see **Figure 2-D-1**). These values are about the same to about one order of magnitude smaller than the combined data and raster conversion error. While there are areas of slight subsidence near and to the southwest of Elk Grove, these are noted by previous studies as being due to a persistent cone of depression from groundwater extraction due to pumping near Elk Grove (2006 GMP) and Delta area sediment-oxidation subsidence (DWR, 1995), respectively. The Subbasin overall reflects subsidence signals that are very low or are essentially noise in the data. Any actual signals at this level could be due to a number of possible activities, including land use change and/or agricultural or urban operational activities at the field scale, as well as sediment-oxidation induced subsidence. For perspective, during this same period (2015-2019), sections of the San Joaquin Valley in California's Central Valley experienced -3.5 ft of total vertical subsidence.

InSAR Data Quality

DWR has stated that the total vertical displacement measurement error for InSAR data are as follows:

1. The error between InSAR data and continuous GPS data is 0.052 ft (16 mm) with a 95% confidence level.
2. The measurement accuracy when converting from the raw InSAR data to the maps provided by DWR is 0.048 ft (15 mm) with 95% confidence level.

By simply adding the errors 1 and 2, the combined error is 0.1 ft (~30.5 mm) (B. Brezing, personal communication, February 27, 2020). While this is not a robust statistical analysis, it does provide an estimate of the potential error in the InSAR maps provided by DWR. A land surface change of less than 0.1 ft is therefore within the noise of the data and may not be indicative of subsidence in the basin. Additionally, the InSAR data provided by DWR reflects both elastic and inelastic subsidence. While it is difficult to compensate for elastic subsidence, visual inspection of monthly changes in ground elevations suggest that elastic subsidence is largely seasonal.

Figure 2-D-1: South American Subbasin InSAR Subsidence, June 2015 – September 2019

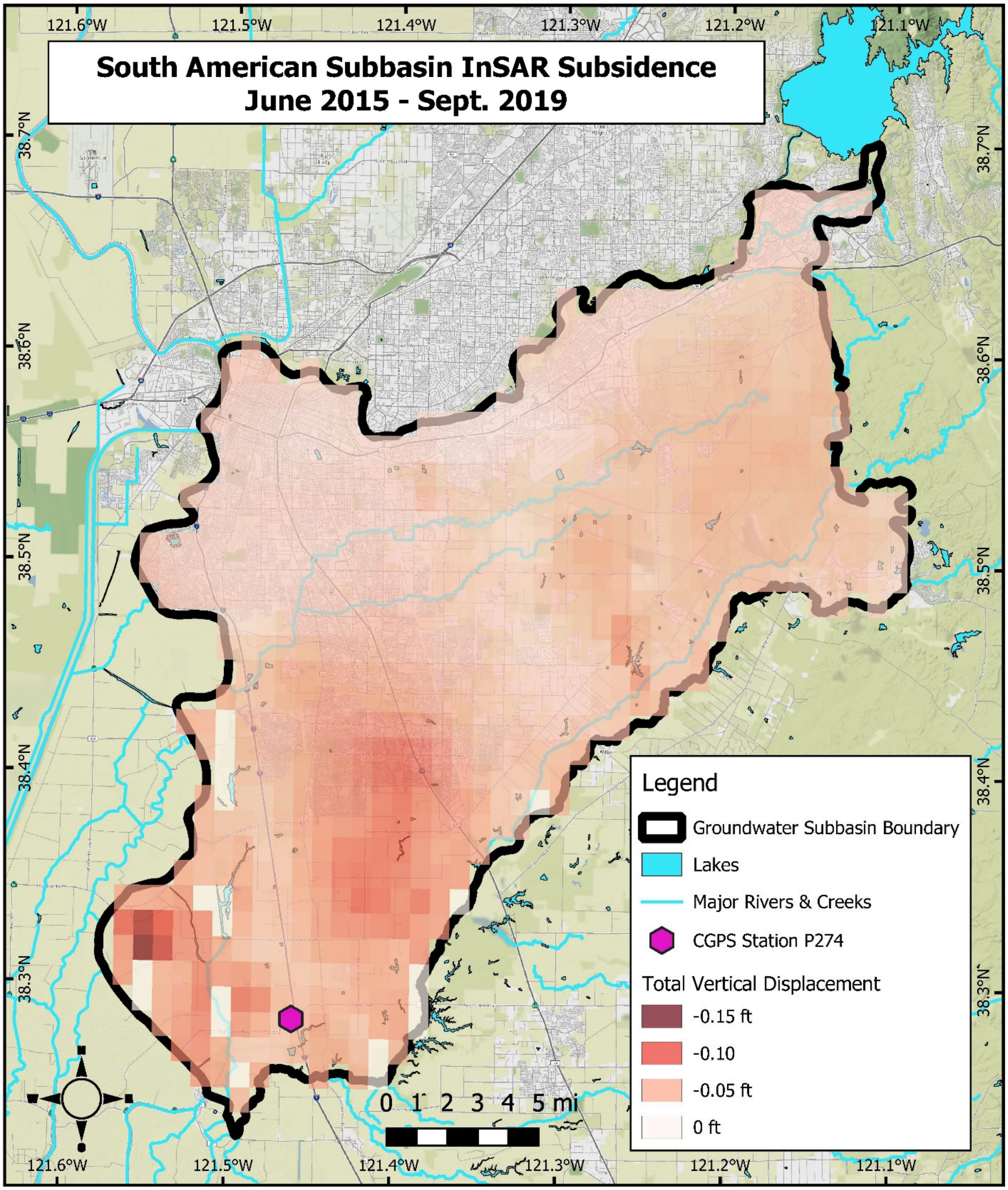
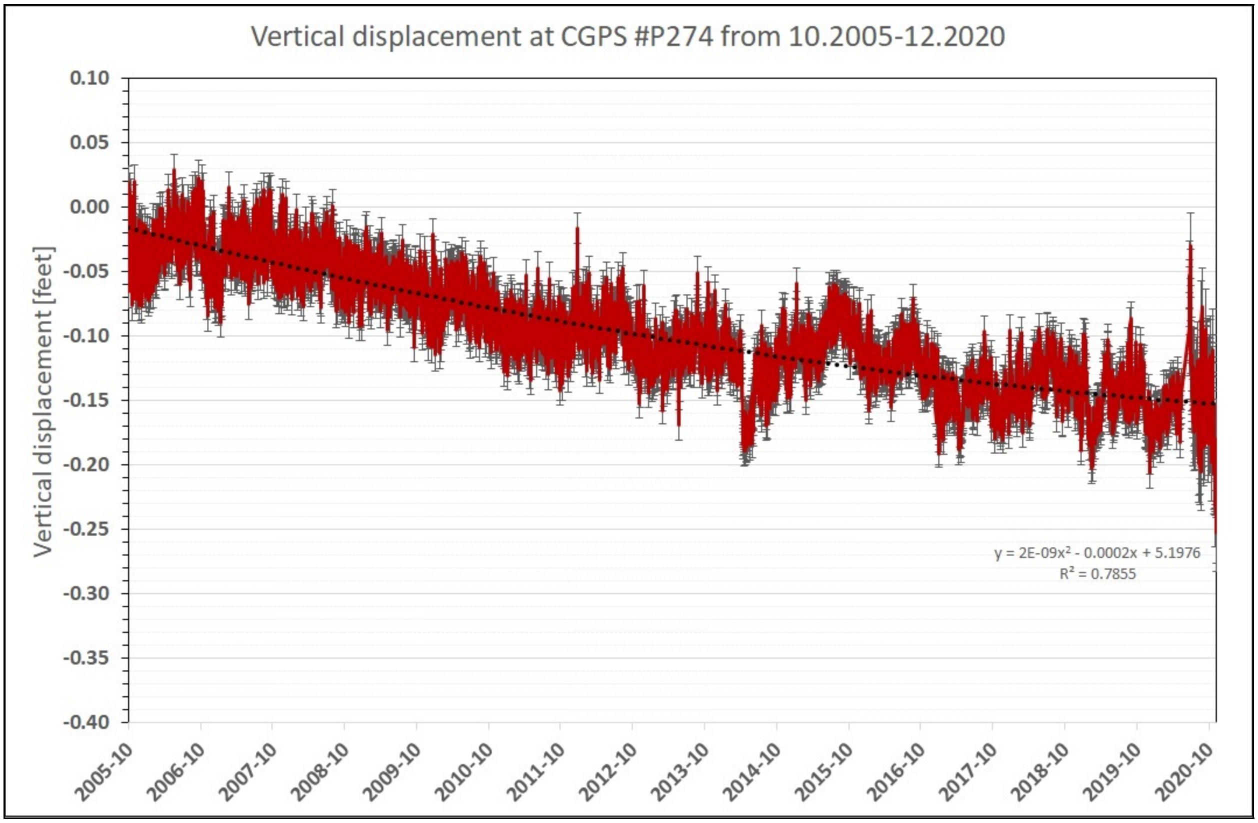


Figure 2-D-2: South American Subbasin CGPS Station (UNAVCO #P274) Subsidence, October 2005 – December 2020. Note: Trend line added solely for the purpose of added assistance with the interpretation of subsidence time series data. Trend line equation included for reference.



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Appendix 3-A

Interconnected Surface Water (ISW) in the South American Subbasin: Characterization of Historical and Present-day Conditions, and Approaches for Monitoring and Management (June 18, 2021)

Interconnected Surface Water (ISW) in the South American Subbasin: Characterization of Historical and Present-day Conditions, and Approaches for Monitoring and Management

Larry Walker Associates

2021-06-18

Table of Contents

1. Introduction

The South American Subbasin (SASb) is a medium priority groundwater basin in California's Central Valley. Groundwater pumping in the SASb provides water for municipal, agricultural, and domestic beneficial users, but has lowered groundwater elevations over time and lead to depletions of interconnected surface water (ISW), defined as:

> 23 CCR § 351(o): "Interconnected surface water" refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted.

The Sustainable Groundwater Management Act (SGMA) identifies "Depletions of Interconnected Surface Water" as an Undesirable Result (CWC § 10721(x)). Thus, ISW depletion requires the development of Sustainable Management Criteria (SMC) to quantify existing ISW depletion and plan for sustainable groundwater management that mitigates significant and unreasonable ISW depletion. Specifically, 23 CCR § 354.28. Minimum Thresholds states that the Minimum Threshold (MT) for Depletions of Interconnected Surface Water, "*shall be the rate or volume of surface water depletions caused by groundwater use that has adverse impacts on beneficial uses of the surface water and may lead to undesirable results*" and that developed MTs will be supported by:

A. The location, quantity, and timing of depletions of interconnected surface water.
B. A description of the groundwater and surface water model used to quantify surface water depletion.

Although numerous surface water bodies that support environmental flows and aquatic ecosystems are present in the SASb (i.e., Sacramento, American, and Cosumnes rivers, and minor creeks and streams in the basin's interior), seasonal and historical trends in the location and timing of ISW, as well as ISW volumetric depletion rates (quantity) remain poorly characterized. Herein, we report on long-term, recent groundwater level conditions (2005-2018) in the SASb, characterize the spatial location, timing, and quantity of ISW using output from the Cosana integrated hydrologic model, and recommend management actions that align ISW depletion with the mandates of SGMA.

Fundamentally, this memorandum shows that stream depletion is occurring in the SASb, and identifies ISW locations, timing, and quantity. Next, a management approach and sustainable management criteria (SMC) for groundwater level are recommended that arrest groundwater levels, which arrest hydraulic gradients, and finally, arrest streamflow depletion (Figure 1).

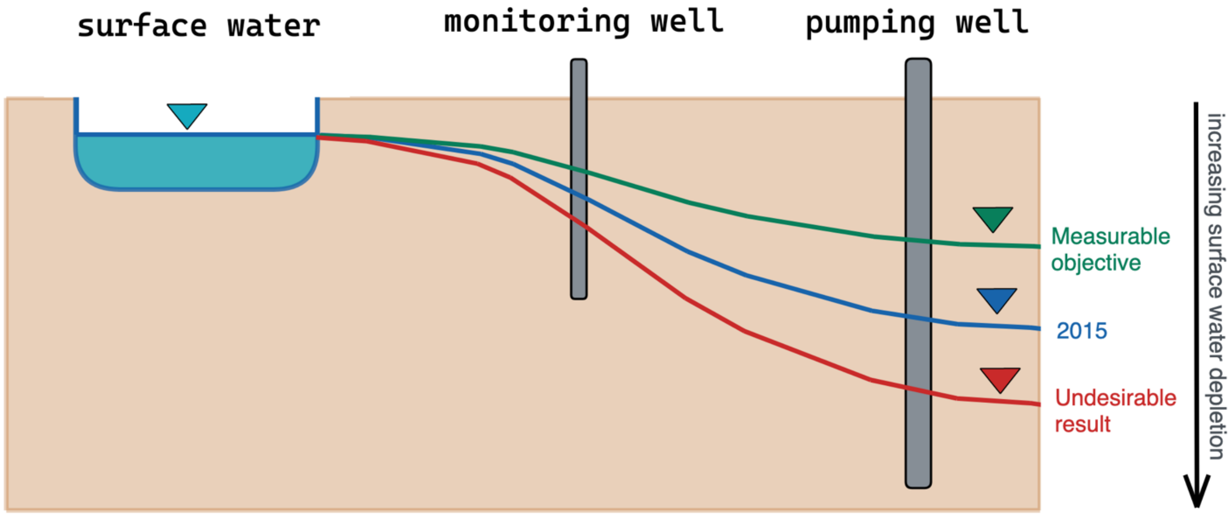

Figure 1: Surface water depletion can occur when adjacent groundwater elevation (green, blue, and red lines) falls below the stream stage elevation. As groundwater elevation declines, for example, due to groundwater pumping, the regional groundwater level falls, which steepens the gradient between surface and groundwater and increases the quantity of surface water depletion (black downwards-pointing arrow). In the figure above, the 2015 groundwater level is shown as a historic low groundwater elevation (blue line). Examples of an undesirable result (red line) and measurable objective (green line) are groundwater levels below and above this historic low, respectively.

This memorandum is outlined as follows. First, in Section 2, we briefly review study area and basin setting insofar as it is necessary to understand the subsequent material[1], then follow with an extensive review of major surface water features, special-status species, instream flow requirements, and surface and groundwater interactions in the SASb. Next, in Sections 3-4, we present the methods and results of analysis of historical and present-day groundwater level conditions. Groundwater level data and the numerical integrated surface and groundwater flow model Cosana are used to inform a characterization of ISW location, timing, and quantity in the SASb. We find persistently disconnected reaches, persistently connected reaches, and reaches that oscillate between connection and disconnection across seasons and water years. Gaining and losing reaches are identified and seepage values are quantified and discussed. Finally, in Sections 5-6 we discuss limitations of the study and propose management and monitoring actions.

Results inform a monitoring and management approach for ISW within the context of SGMA that arrests groundwater levels in ISW-adjacent representative groundwater monitoring wells. This ensures that hydraulic gradients are not increased beyond roughly present-day values plus reasonable hydrologic variability, which guarantees that ISW depletion remains within historic quantities, and that Undesirable Results to beneficial users and uses of ISW are avoided.

---

[1] An extensive review of study area and basin setting beyond the scope of the memo, and this information is readily accessible in existing documents. The key focus of this memorandum is to address the knowledge gap surrounding characteristics of surface waters and interconnected surface water in the SASb, and to develop a management plan for ISW consistent with requirements defined by SGMA.

2. Study Area and Setting

The SASb Groundwater Sustainability Plan (GSP) area (Figure 2) consists of five Groundwater Sustainability Agencies (GSAs), and is bordered on nearly all sides by major surface waters, including the Sacramento, American, Cosumnes and Mokelumne Rivers, which drain into the Bay Delta region – a complex aquatic ecosystem with species of concern, and a major surface water transfer point for beneficial users with appropriative surface water rights. The SASb is contained within Sacramento County and bordered by two medium priority basins: the North American subbasin to the north and the Cosumnes subbasin to the south. Interbasin coordination between adjacent basins is critical to address potential ISW depletion of the shared surface water resources that delineate basin boundaries.

Surface water in the SASb maintains aquatic ecosystems, provides recreation, and is distributed as urban water supply. At the time of writing, significant projects and management actions are in various stages of development to conjunctively manage surface and groundwater, which will bolster drought resilience and promote stable and sustainable groundwater storage and levels.

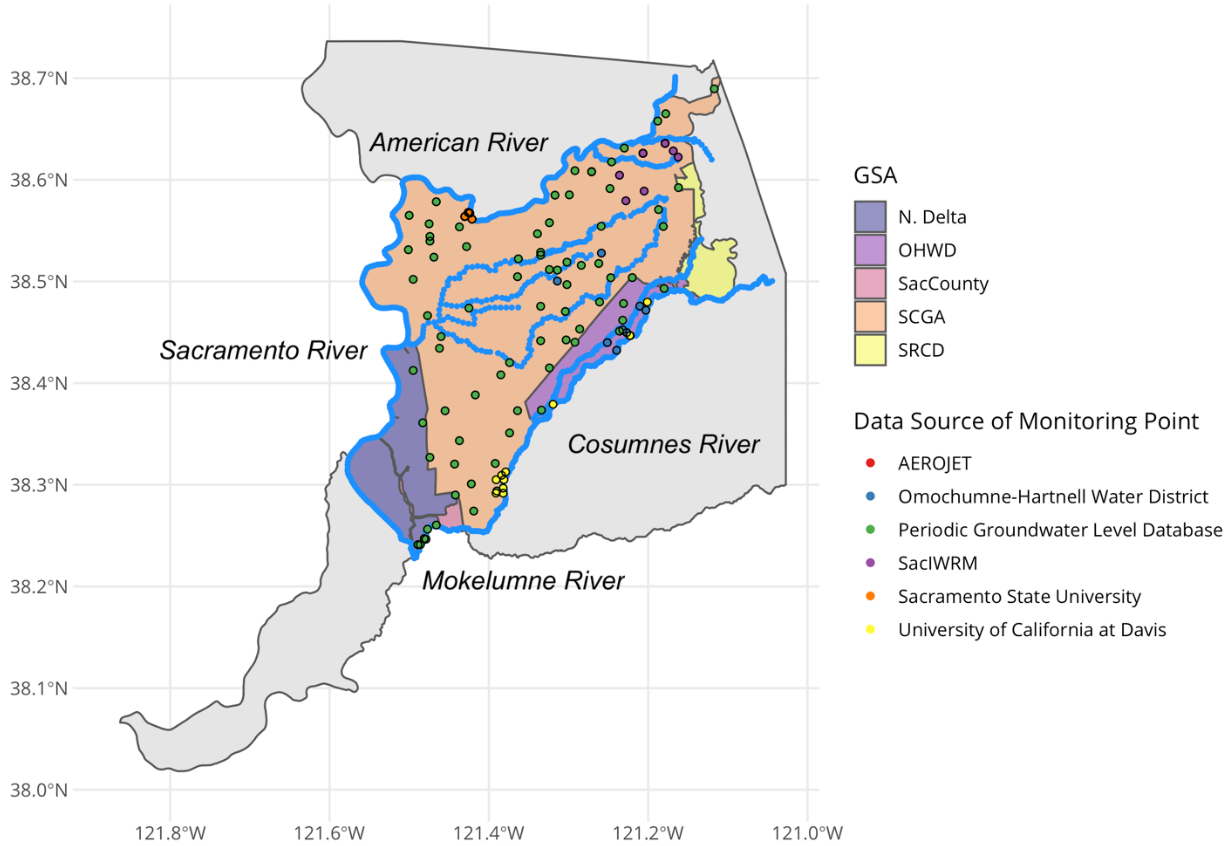

Figure 2. The South American Subbasin is an alluvial aquifer-aquitard system in California's Sacramento County (grey) housing 5 GSAs, and bordered by the American, Cosumnes, Mokelumne, and Sacramento Rivers on the north, east, south, and west boundaries respectively. Representation of these major surface water bodies in the Cosana integrated hydrologic model (including interior creeks) are shown in blue. Groundwater level monitoring

points are colored by the data source of the monitoring point. Monitoring points outside of the SASb which were used in the groundwater level interpolation are not shown.

The SASb subsurface geology is characterized by fluvial-alluvial clastic sedimentary deposits made of fines (silts and clays) and coarser, interconnecting aquifer material (sands and gavels). Long term water budgets in the SASb suggest generally stable groundwater storage conditions. The principal aquifer system primarily produces water for domestic, urban, and agricultural water supply, and interacts with major surface water bodies via baseflow and seepage[2].

Land use is characterized by the greater Sacramento urban area extending along the American and northern Sacramento Rivers. The Elk Grove urban area southeast of Sacramento is positioned at an urban-rural interface and reflects trends of urban expansion in the basin. Mixed agricultural-residential land is found along the Cosumnes River and extends north into the center of the basin. Northeastern foothills in the basin are contrasted by low-elevation wetlands in the southwest, which ultimately drain into the Sacramento-San Joaquin Delta.

It is in this diverse assemblage of GSAs in a basin bounded by surface waters and dependent on groundwater use that the sustainable management of ISW is to play out under SMGA. In the following subsections, we review characteristics of major surface waters, special-status species in these major surface waters, and instream flow requirements, and surface-groundwater interactions in the SASb.

2.1 Review of Major surface waters

Geographically, the SASb overlaps portions of the Sacramento river, American river, Cosumnes river, Mokelumne river, and San Joaquin Delta watersheds and supports a diverse assemblage of surface water bodies (Figure 3). The principal surface waters, the Sacramento, American, and Cosumnes rivers, define the basin’s western, northern, and southern boundaries, respectively. The Cosumnes river flows into the Mokelumne river which serves as the southwestern boundary of the basin. The major surface water bodies in the SASb can be further subdivided into 21 reaches (Figure 4). In the subsections that follow, the lower Sacramento, lower American, Cosumnes, and Mokelumne rivers and relevant tributaries are described.

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[2] For more information on the hydrogeologic conceptual model and a detailed history of groundwater conditions, please refer to the SASb GSP, section 2, “Plan Area and Basin Setting”.

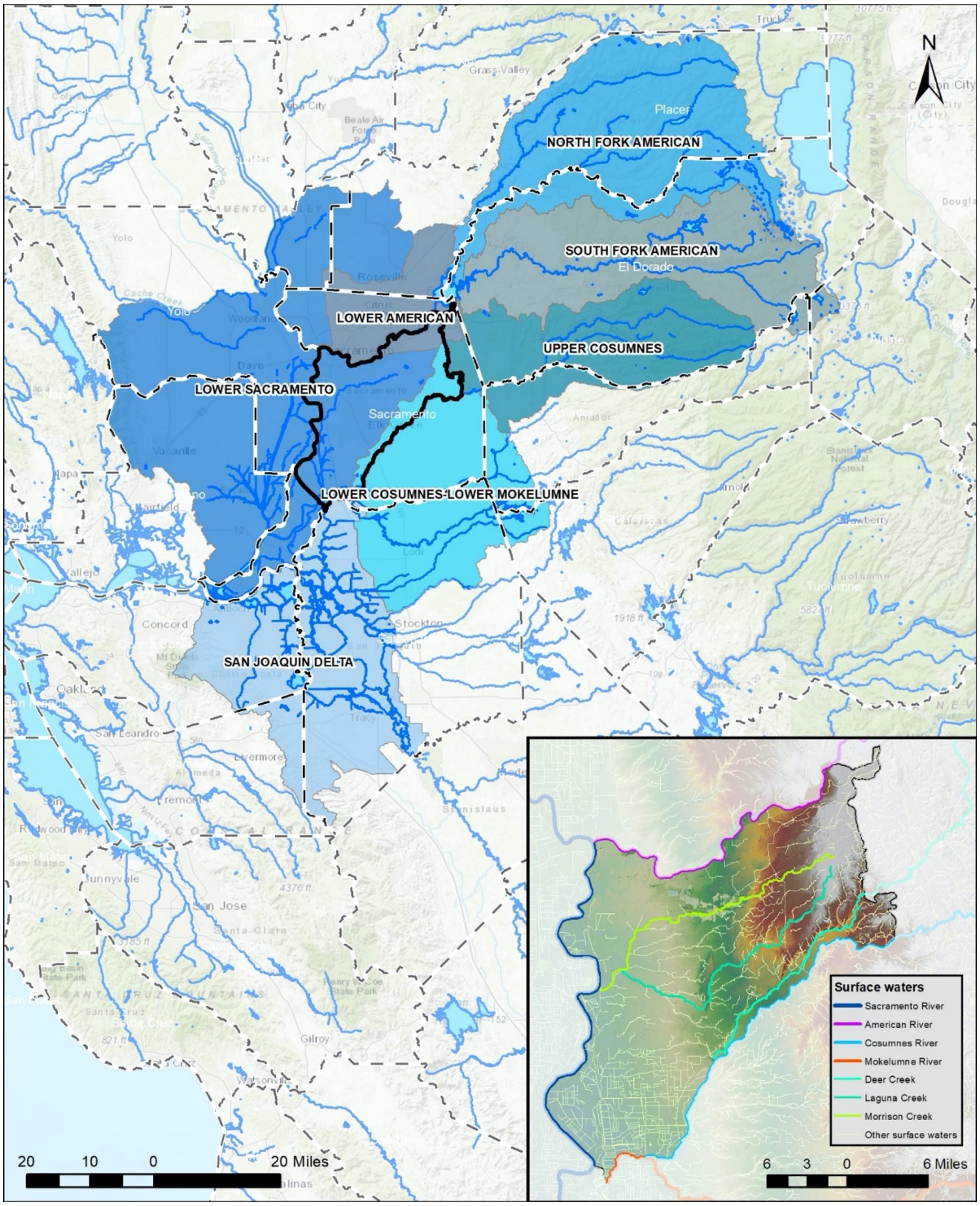

Figure 3. SASb watersheds and major surface water bodies.

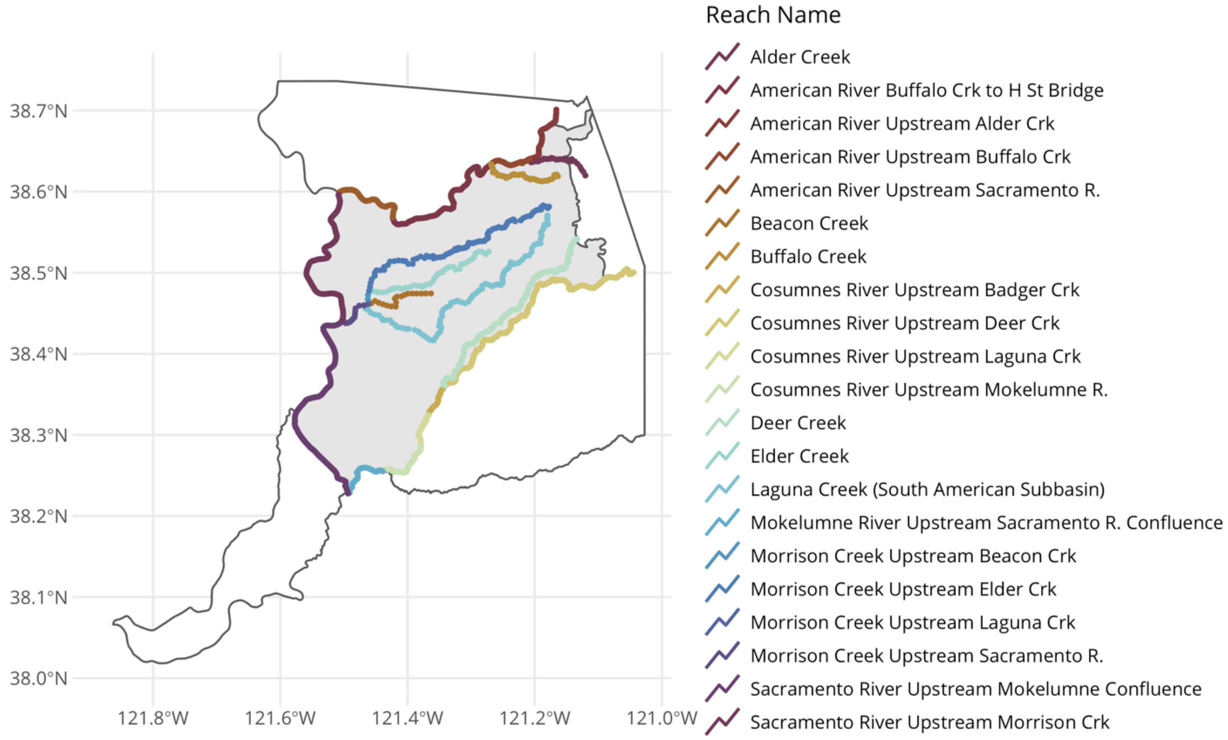

Figure 4. Major surface waters in the South American Subbasin are divided into 21 reaches, based on the surface water node representation in Cosana.

2.1.1 Lower Sacramento River

The Sacramento river watershed is the largest in the state, and drains a significant portion of Northern California. In the SASb the Sacramento river flows north-to-south along the basin's western margin from an elevation of approximately 10 feet above sea level at the northern inlet to nearly sea level at its southern outlet where it discharges out to the Sacramento-San Joaquin Delta. This portion of river is heavily modified with a system of levees present along both banks. River flows here are substantially altered compared to their natural flow regime due to a system of complex water management operations that provide societal benefits in addition to meeting environmental flow requirements.

Based on classification by Lane et al., (2018) the Sacramento river in the SASb is characterized as a 'High-Volume snowmelt and rain' (HSR) hydrologic regime. Key components of this bi-modal snow-rain driven hydrograph include a spring snowmelt pulse, high seasonality with large winter storm contributions, and high summer baseflows. Comparing dimensionless hydrographs for the HRS regime and flows recorded at the USGS gaging station at Freeport (Gage ID 11447650) illustrates the homogenizing influence of water management on river flows. While measured flows retain elements of the HRS regime there is a clear decrease in seasonality and depression of the snowmelt pulse (Figure 5).

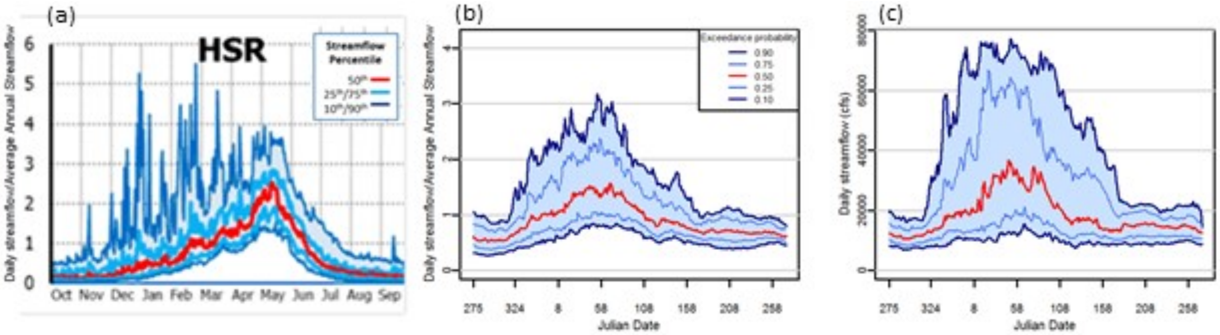

Figure 5. HSR non-dimensional hydrograph (a – modified from Figure 6 Lane et al., [2018]) and non-dimensional (b) and dimensional (c) hydrographs for Sacramento River at Freeport.

Average daily flow at the Freeport gage for the period of record between October 1, 1948 and September 30, 2015 was 22,923 cubic feet per second (cfs). Annual peak flows at Freeport over this same period ranged from 13,700 cfs in water year (WY) 1977 to 115,000 cfs in WY 1986. During high flow periods, a significant portion of flow from the Sacramento River Basin is diverted through the Yolo Bypass west of the Sacramento River and SASb. Notably, the entire SASb section of the Sacramento river is tidally influenced.

The Morrison creek watershed is the main system of tributaries that drain into the Sacramento river within the SASb. In addition to Morrison creek this system comprises a number of smaller creeks (e.g., Elder, Florin, and Stawberry creeks) which drain an approximately 192 square mile area of the central portion of the SASb. These drainages have been heavily modified, especially in the highly urbanized western portions of the basin near the City of Elk grove, and range in condition from semi-natural channels to concrete drainage canals. Morrison creek typically drains to the Sacramento River.

However, during high flow events, water may be directed to the Beach-Stone lakes basin including the Stone Lake National Wildlife Refuge and eventually to the Mokelumne River and Sacramento-San Joaquin Delta via Snodgrass Slough (Sacramento DWR, 2009). Hydrologically, flows in Morrison creek and its tributaries are driven by winter precipitation and stormwater runoff, but also receive discharge of treated groundwater. Daily average flows in Morrison creek were recorded from August 1, 1959 through November 27, 2017 at USGS gaging station ID # 11336580. These data show the flashy nature of the creek's response to storm events as well as prolonged periods of low flow (<5 cfs) during later spring and summer (e.g. May – October) (Figure 6). The average daily flow over this period was 21 cfs. Although measured flows at this location were rarely zero (< 0.1% of time) upstream portions of Morrison creek and associated tributaries have been described as intermittent or ephemeral and thus regularly do not flow in summer months (RWQCB, 2017; USFWS, 2007). While the flow records show the existence of interdecadal variability in average monthly flows, the lack of consistent monotypic trends between decades suggests flows have not experienced substantial statistical changes in bulk trends over the period of record. The peak discharge reported by the USGS gage over the period of record was 1,940 cfs during the winter of 1982.

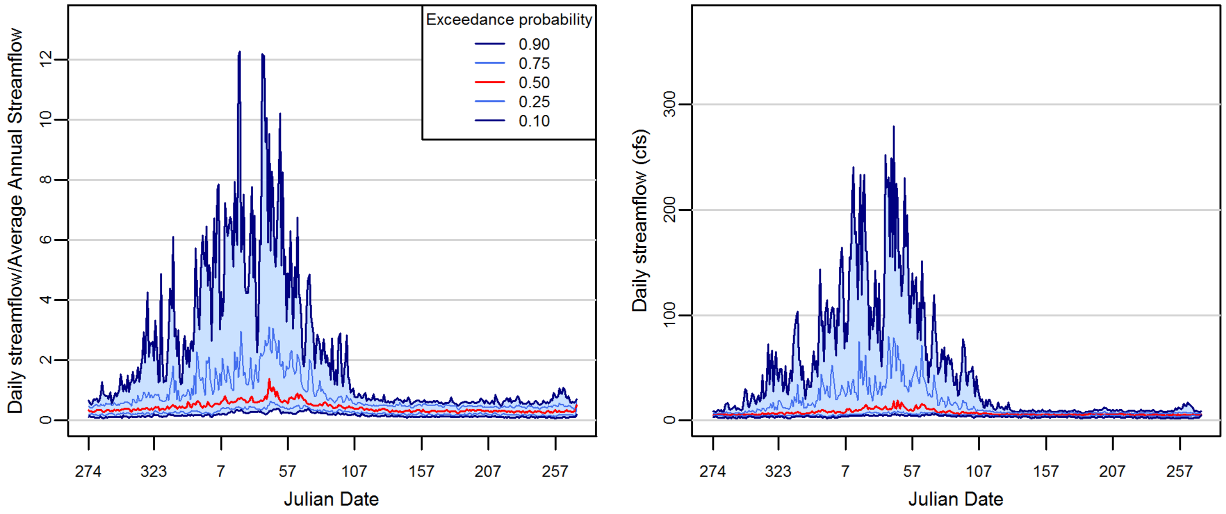

Figure 6. Non-dimensional and dimensional hydrographs for Morrison creek (USGS gage 11336580).

2.1.2 Lower American River

The American river watershed drains an area of approximately 2,155 mi^2 (5,581 km^2) ranging in elevation from over 10,000 feet in the headwaters in the Northern Sierra Nevada range to approximately 10 feet at the confluence with the Sacramento River. The lower American river defines the entirety of the northern boundary of the SASb. Like other basin surface waters the American river has been both physically modified (e.g., construction of levees, dams or other impoundments, and other in-channel infrastructure) and its flows are highly managed for water supply, flood control, and other societal and environmental benefits. Folsom reservoir, located just upstream outside of the SASb, is a critical component of the Central Valley Project (CVP) surface water storage and delivery system. The reservoir was established following completion of Folsom dam in 1955 and has a storage capacity of 976,000 acre-feet. Lake Natoma, located immediately downstream of Folsom reservoir on the northeast side of the SASb, serves as an afterbay that regulates Folsom flow releases to the American River.

Based on classification by Lane et al., (2018) the lower American river – like the lower Sacramento river – is characterized as a HSR hydrologic regime. Comparing lower American river flows recorded at the Fair Oaks USGS gaging station (Gage ID 11446500) with the HSR regime clearly reflects the influence of water management on river flows (Figure 7). This is exemplified by splitting the lower American river flow record to flows occurring prior to 1955 and those after (i.e., record split at October 1, 1954. For example, the pre-1995 hydrographs closely resemble the HSR regime, whereas post-1955 flows are much more homogenous. Average daily flows at the Fair Oaks gage for the periods between October 1, 1904 and September 30, 1954 and October 1, 1955 to March, 10 2021 were 3,752 and 3,686 cfs, respectively. Annual peak flows for the complete period of record ranged from 1,820 cfs in water year (WY) 1977 to 132,000 cfs in WY 1951, however flows as high as 318,000 cfs have been historically documented.

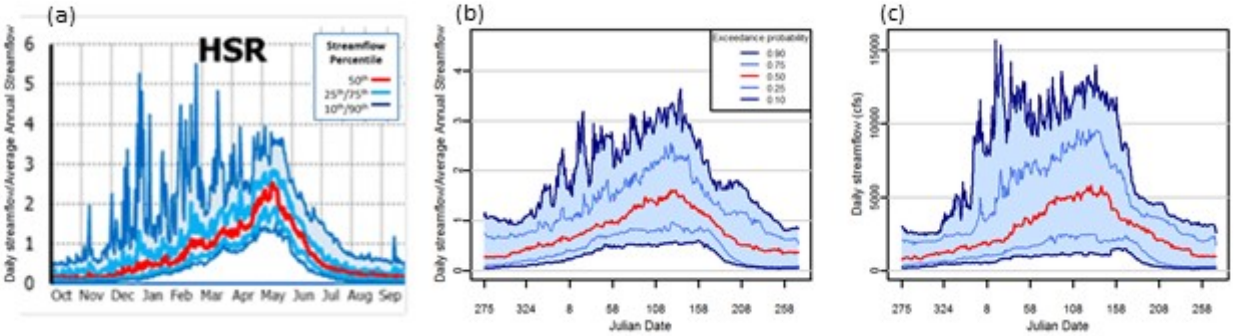

Figure 7. HSR non-dimensional hydrograph (a – modified from Figure 6 Lane et al., [2018]) and non-dimensional (b) and dimensional (c) hydrographs for American river at Fair Oaks.

2.1.3 Lower Cosumnes River

The Cosumnes river watershed drains an area of approximately 949 mi^2 ranging in elevation from 7,743 feet in the headwaters to near sea level at the confluence with the Mokelumne river. Annual rainfall in the watershed typically ranges from 22 inches in the lower portions of the watershed along the valley floor to upwards of 60 inches in the headwater portion of the watershed. Nearly all precipitation occurs between October and April, typical of the region's Mediterranean climate. The vast majority of the watershed (~84%) lies below the Sierran snow-level elevation of approximately 5,000 feet, meaning intense winter rainfall events primarily drive system flooding (Florsheim & Mount, 2002; Robertson-Bryan Inc., 2006a; Booth et al., 2006). Although snowmelt is not a large contributor to the annual streamflow volume, snowmelt and particularly rain-on-snow events influence flooding, the latter of which has been associated with peak flow events (Kleinschmidt Associates, 2008).

The Cosumnes river watershed is unique among the large-scale river systems draining the west side of California's Northern Sierra Nevada range. Unlike other major Sierran systems, the river remains relatively unregulated as it is free of high-head dams and significant surface water impoundments. This freedom allows river flows to retain a signature similar to their natural unimpaired flow regime. Detailed analysis of stream flows has been completed by several studies using data from the USGS Michigan Bar gage (ID 11335000), located approximately two miles upstream of the Highway 16 crossing, and the USGS McConnell gage (MCC) (ID 11336000), located approximately 20 miles downstream of the Michigan Bar gage (MHB) where the Cosumnes River crosses Highway 99) (e.g. Anderson et al., 2004; Fleckenstein et al., 2004; Mount et al., 2001; Robertson-Bryan Inc., 2006abc).

Of the river's natural flow regime, dry-season (May-October) baseflows at MCC appear to be the most likely altered (S. Yarnell, personal communication, January 2021). This is consistent with reports that flows at MHB are typically below 30 cfs between August and October. At this discharge, portions of the river from Highway 16 downstream to the tidal zone (RM 5-32.5) are generally dry due to seepage and evapotranspiration (Figure 8). This drying is more pronounced downstream of Wilton road (RM 17.3), where the river runs dry nearly every year (Robertson-Bryan Inc., 2006c). At the MCC gage (RM 11), the river is dry nearly 60 percent of the time in fall months (Ascent, 2014). Historical analysis suggests discharge in the lower reaches of the river decreased steadily from 1942 to 1982, as indicated by a linear increase in the number of days per year with flows below 10 cfs at MCC (Mount et al., 2001). These decreases coincide with periods of increased groundwater extraction and have been attributed to changes in surface water-groundwater (SW-GW) interactions. Dry-season baseflows are critical to upstream migration of fall-run Chinook salmon (Oncorhynchus tshawytscha) to their spawning grounds, and declines of Cosumnes salmon populations have been linked to changes in SW-GW interactions.

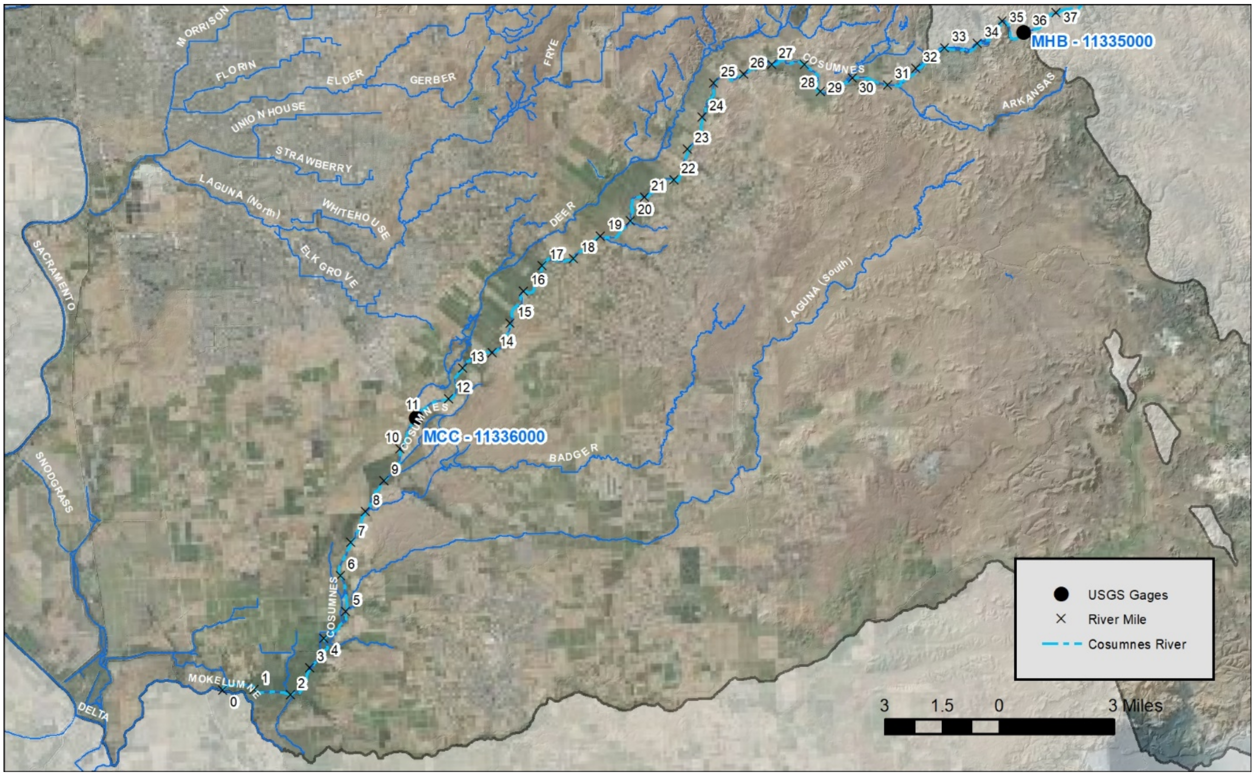

Figure 8. Lower Cosumnes river and river miles.

Based on classification by Lane et al., (2018) the Cosumnes river is mapped as having a ‘Rain and seasonal groundwater’ (RGW) hydrologic regime. This regime is characterized by winter storms and a low magnitude spring baseflow pulse. Waning snowmelt or groundwater contributions may result in ephemeral streamflow conditions. In general, flows at MHB and MCC coincide with the RGW regime (e.g., Figure 9). Average daily flow at the MHB for the period between October 1, 1907 and October 3, 2019 was 498 cfs, while average daily flow at MCC between October 1, 1941 and October 15, 1982 was 543 cfs. Annual peak flows at MHB for the complete period of record ranged from 134 cfs in water year (WY) 1977 to 61,600 cfs in WY 1997.

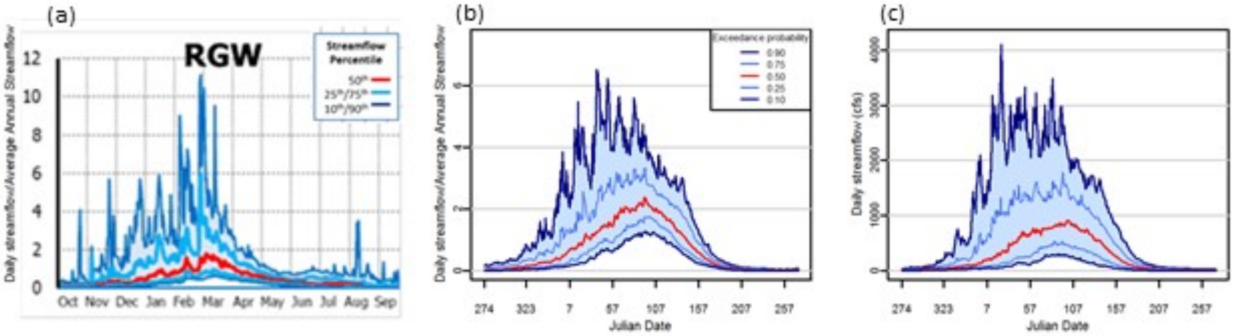

Figure 9. RGW non-dimensional hydrograph (a – modified from Figure 6 Lane et al., [2018]) and non-dimensional (b) and dimensional (c) hydrographs for Cosumnes River at Michigan bar.

The approximately 123 square mile Deer creek watershed is the main system of tributaries draining to the Cosumnes river in the SASb. Hydrologically, flows in Deer creek and its tributaries are driven by winter precipitation, stormwater runoff, irrigation runoff or return flows, and discharge of treated wastewater. Daily average flows in Deer creek were recorded from October 1, 1960 through September 29, 1977 at USGS gaging station ID # 11335700. These data show the flashy nature of the creeks response to storm events as well as prolonged periods of no or low flow (<5 cfs) during later spring and summer (e.g. May – October) (Figure 10). Overall, 45% of all days had zero flow, of which 100% of August and September measurement were zero. The average daily flow over this period was 25 cfs and the peak flow was 2,160 cfs.

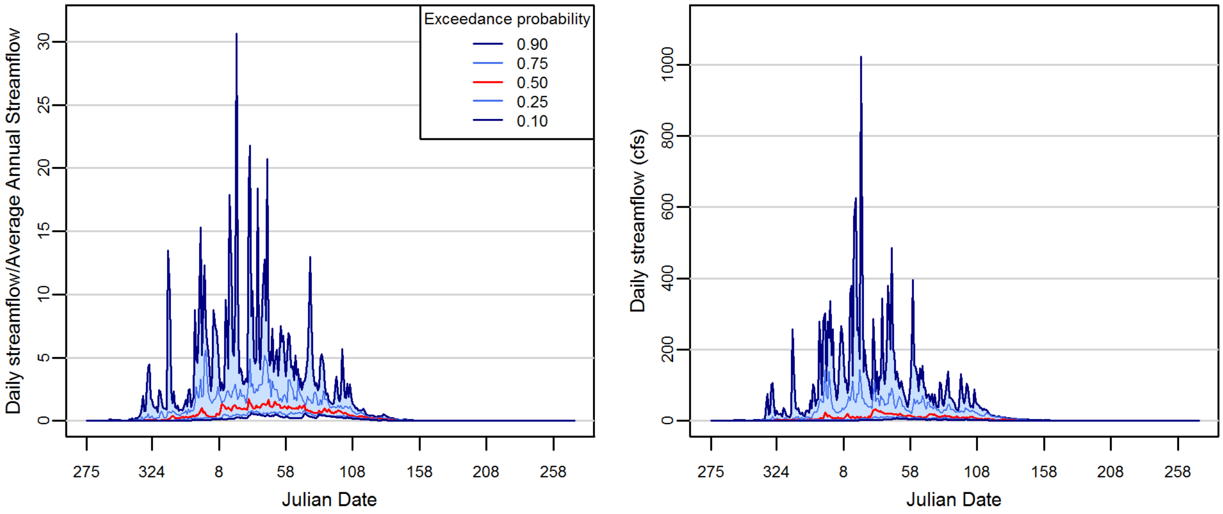

Figure 10. Non-dimensional and dimensional hydrographs for Deer creek (USGS gage 11335700).

2.1.4 Mokelumne River and Delta

The southwestern boundary of the SASb is defined by portions of the Delta cross-channel, Snodgrass slough, and the Mokelumne river. At the confluence with the Cosumnes the Mokelumne river watershed drains an area to the east of approximately 1085 mi^2 that overlaps with the Cosumnes subbasin. In addition to these areas the Mokelumne river also drains areas to the north that include Snodgrass slough, Stone Lakes National Wildlife refuge and Laguna Creek, which drains to the refuge system and Snodgrass slough via the lower portion of Morrison creek that does not discharge to the Sacramento River. Flows in Laguna creek and its tributaries are ephemeral.

Based on flow records at USGS gage 11336585 Laguna creek was dry 12% of the time from October 1, 1995 through October 21, 2018 and regularly experienced periods of zero or low flow throughout the year (USFWS, 2007). Downstream of Laguna creek water surface elevations in the Stone lakes system and Snodgrass slough depend on both flows from upstream and tidal influence from the delta but can be influenced by backwater from the Mokelumne River. These regions as well as the Sacramento river and the American river up to the I Street Bridge are all within the extent of the legal Delta established under the Delta Protection Act (Section 12220 of the Water Code) passed in 1959. The Delta consists of a mix of water from San Francisco Bay and tidally influenced fresh water from the Sacramento and San Joaquin River watersheds, with a land surface lower than the high river stage.

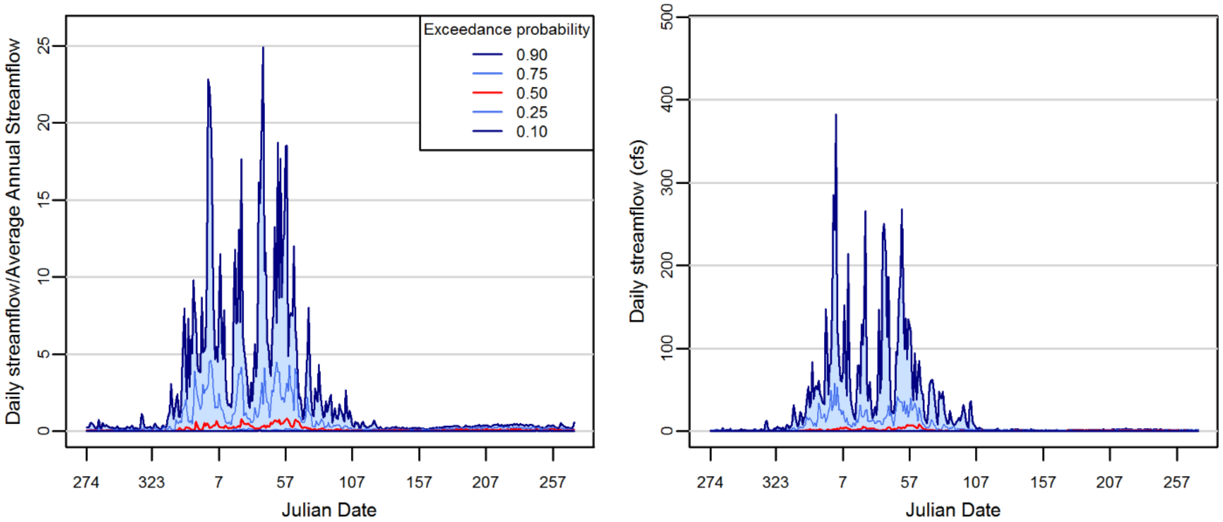

Figure 11. Non-dimensional and dimensional hydrographs for Laguna creek (USGS gage 11336585).

2.2 Special-status species

LWA conducted a review to identify potential sensitive biological features including target plant and wildlife species that have the potential to occur in the SASb. The review was initiated with a query of the most recent version of the CDFW California Natural Diversity Database (CNDDB) to identify reported occurrences of sensitive species within 1 mile of the SASb. In addition to the CNDDB query, USFWS species lists and critical habitat maps were reviewed. Existing environmental documents and reports were also reviewed to supplement these data sources (County of Sacremento et al., 2018; Moyle et al., 2015; Santos et al., 2014; SWRI, 2001; UC Davis, 1999). For the purposes of this report, special-status species are defined as follows:

- Plants and animals listed, proposed, or candidates for listing as threatened or endangered (including delisted species) under FESA.
- Plants and animals listed or proposed for listing by the State of California as threatened or endangered under CESA.
- Plants listed as rare under the California Native Plant Protection Act.
- Plants included in CNPS Ranks 1 and 2.
- California designated status:
    - Animal species that are fully protected in California; or,
    - Species of special concern (CSC) to the CDFW.

The list of special-status species was compiled and subset to only those species that occupy surface waters for at least part of their life-history. The final list includes 14 fish species and 2 reptile species (Table 1). Consideration of habitat requirements (e.g., physical and chemical conditions such as hydraulics [depth and velocity], substrate, and temperature) for these species often plays a large role in water management operations influencing SASb surface waters (Section 3).

Table 1. Special-status species occupying surface waters in the SASb

Scientific name	Common name	ESA status	CESA status	CDFW status	Principal Rivers[1]	Tributaries[2]
Acipenser medirostris	southern green sturgeon	Threatened	None	SSC	Sacramento is a migration corridor for adults and juveniles to and from upstream spawning grounds	low to no potential
Acipenser transmontanus	white sturgeon	None	None	SSC	Sacramento is a migration corridor for adults and juveniles to and from upstream spawning grounds	low to no potential
Archoplites interruptus	Sacramento perch	None	None	SSC	Transplanted populations in American and Sacramento and their tributaries	moderate potential
Cottus gulosus	riffle sculpin	None	None	SSC	Mokelumne, Sacramento, and Delta	low potential
Entosphenus tridentatus	pacific lamprey	None	None	SSC	All	low potential
Hypomesus transpacificus	delta smelt	Threatened	Endangered	SSC	Mokelumne, Sacramento, and Delta	no potential
Mylopharodon conocephalus	hardhead	None	None	SSC	Sacramento and American	moderate to high potential
Oncorhynchus mykiss irideus	steelhead - Central Valley DPS	Threatened	None		All life stages in American and Cosumnes; Sacramento is a migration corridor for adults and juveniles to and from upstream spawning grounds	low potential
Oncorhynchus tshawytscha	chinook salmon - Sacramento River winter-run ESU	Endangered	Threatened		Sacramento is a migration corridor for adults and juveniles to and from upstream spawning grounds	no potential

Scientific name	Common name	ESA status	CESA status	CDFW status	Principal Rivers[1]	Tributaries[2]
Oncorhynchus tshawytscha	chinook salmon - Central Valley spring-run ESU	Threatened	Threatened		Sacramento is a migration corridor for adults and juveniles to and from upstream spawning grounds	no potential
Oncorhynchus tshawytscha	chinook salmon - Central Valley fall & late fall-run ESU	None	None	SSC	All life stages in American and Cosumnes; Sacramento is a migration corridor for adults and juveniles to and from upstream spawning grounds	low to moderate potential
Pogonichthys macrolepidotus	Sacramento splittail	None	None	SSC	Delta	low potential
Spirinchus thaleichthys	longfin smelt	Candidate	Threatened	SSC	Sacramento and Delta	no potential
Emys marmorata	western pond turtle	None	None	SSC	moderate potential	moderate to high potential
Thamnophis gigas	giant garter snake	Threatened	Threatened		low potential	moderate to high potential

[1] Either brief description of occupancy within the SASb principal surface waters or potential for species to be present

[2] Potential for species to be present

2.3 Instream flow requirements

2.3.1 Lower Sacramento River

Many project-level and system-wide agreements or regulatory obligations dictate water management operations in the Sacramento river basin. Of the multitude of water management operation in the basin integrated operations of the CVP and State Water Project (SWP) aggregate to have the strongest influence on conditions downstream. A summary of several key CVP and SWP regulatory requirements are provided in Table 2 (see also reviews by NCWA, 2019; SWRI, 2001).

Table 2. Key CVP and SWP regulatory requirement

Regulatory agreement/obligation	Date(s)	Description
SWRCB Water Rights Order 90-05 & 91-01	1990 & 1991	Establishes water right requirements on the U.S. Bureau of Reclamation's (Reclamation) operations of Keswick Dam, Shasta Dam, the Spring Creek Power Plant and the Trinity River Division related to temperature control in the Upper Sacramento River for the protection of fishery resources and requires monitoring and reporting to evaluate compliance with those requirements.
SWRCB Revised Water Right Decision 1641 (Water Rights Order 2000-02)	2000	Amended the water right license and permits for the CVP and SWP requiring them to meet certain flow objectives in the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (1995 Bay-Delta Plan). Specifically, places responsibility on the Department of Water Resources and the U.S. Bureau of Reclamation for measures to ensure that specified water quality objectives are met.
NMFS Biological Opinion for the Reinitiation of Consultation on the Long-Term Operation of the Central Valley Project and State Water Project	2019	Contain numerous terms and conditions for CVP and SWP operations including minimum flow requirements, temperature requirements, water quality standards, and entrainment controls.

2.3.2 Lower American River

Flow and temperature conditions in the lower American river results from complex interactions between hydrologic conditions, water management operations, and other decision-making regarding protection of environmental resources (SWRI, 2001). Folsom and Nimbus dams are part of the CVP and thus subject to some of the same requirements listed above for the lower Sacramento river. In addition to these requirements the U.S. Bureau of Reclamation who owns and operates the CVP has adopted instream flow requirements proposed by the Water Forum as outlined in the "Modified Flow Management Standard Proposed Water-Right Terms and Conditions, November 2017" (ARWA, 2017). The Water Forum is comprised of local business and agricultural leaders, citizen groups, environmentalists, water managers and local governments in the Sacramento region. The stated goals for the modified standards include "protecting anadromous salmonids, preserving recreational and aesthetic values, avoiding catastrophic water shortages in the basin and contributing to the Delta's ecological health downstream".

2.3.3 Lower Cosumnes River

To the best of our knowledge, at the time of writing, no overarching agreement or regulatory obligation exists for defining minimum instream flow requirements for the lower Cosumnes river. However, requirements for individual projects, diversions, and/or water rights exist on an ad hoc basis (see SWRCB, 2020 for example). Generally, such agreements are based on meeting flow requirements necessary to satisfy existing water rights (i.e., the State Water Resources Control Board [SWRCB] designation of the Cosumnes river as a 'fully appropriated stream' [FAS] from July 1st to October 31st, the South Fork Cosumnes river as a FAS from April 15th to October 31st, and Deer creek as a FAS from May 1st to October 31st [see SWRCB Order WR 98-08]). However, some instream flow agreements are based on environmental factors such as habitat and/or passage requirements for chinook salmon.

Cosumnes fall-run chinook salmon typically complete their spawning migration between October and December. During this period, they require flows that create conditions suitable for passage and spawning[3]. The majority of spawning in the river occurs in the 16 mile reach between Latrobe Falls (RM 41.5) downstream to Meiss Road (RM 25.5) with additional spawning occurring from Meiss to Wilton Roads (RM 25.5—17.3) (Robertson-Bryan Inc., 2006c). Historically, the Cosumnes supported large fall runs of Chinook salmon upwards of 17,000 fish. Over the past forty years, the fall run has declined to 0-5000 fish and is consistently less than 600 fish, with occasional higher returns in the last five years (USFWS, 1995; CDFW, 2020[4]).

Several studies provide estimates of what flow conditions are necessary for upstream fish passage. Most recently, hydraulic modeling by US Fish and Wildlife Service (USFWS) as part of an initial passage analysis identified 180 cfs as the minimum bypass flow condition for both the MCC and MHB locations. This estimate does not

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[3] Water depth and speed are common hydraulic factors considered though spawning success is influenced by many physical, chemical, and biological factors.

[4] See CDFW Grand Tab: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=84381&inline.

account for river seepage, which under current conditions would necessitate a larger flow requirement at MBH. Seepage estimates vary along the river but are generally in the range of 1 to 3.5 cfs/mile, suggesting flows upward of 266 cfs at MBH would be required. The effect of stream diversions between MHB and MCC at the time of passage must also be considered and added to recommended bypass flow requirements at MHB (see SWRCB, 2020 for example).

The USFWS passage estimates are larger than previous passage estimates for flows at MHB by Anderson et al. (2004), Fleckenstein et al., (2004), and Mount et al. (2001) which estimate flows of 32.8, 54.7, and between 40-45 cfs, respectively. These earlier predictions were each based on achieving a minimum flow depth of 0.6 feet at MCC using 1-D hydraulic modeling and accounting for seepage losses[5]. Observations by the Fisheries Foundation of California (FFC), note that fall (October-November) pulse flows on the order of 100 cfs may be required for a period of at least 10 days to provide and maintain passage conditions throughout the lower Cosumnes reach. FFC also report that stranding or delays can occur for higher pulse events of 200-400 cfs when flows last for less than a week and are followed by extended dry periods (FFC, 2004).

Several factors may explain the wide range of reported flows needed for fish passage. For one, river conditions (e.g., hydraulic geometry, slope, and substrate) are constantly changing. Second, passage criteria also evolve over time as understanding of species biological requirement improves. Although the passage criteria and date of physical conditions (e.g., river topography/bathymetry) used by USFWS in their evaluation are unknown, it is presumed their analysis reflects both updated river conditions and species requirements compared to those employed by Mount et al. (2001) and Anderson et al. (2004). In this manner, the more recent USFWS passage recommendation of 180 cfs is considered to more likely account for current river conditions and species biological requirements.

In addition to flow constraints, Cosumnes salmon must also navigate several in-stream structures during migration to their spawning grounds. These include a box culvert near RM 6.75, four low-head dams (RM 12.4, 16.25, 22.5, and 25), and two fish ladders at Granlees Dam (RM 34.5). All structures have been improved for fish passage in the last three decades, and current estimates by FFC suggest a minimum flow of 100 ft^3/s (2.83 m^3/s) is needed for fish navigability.

2.4 Surface water and Groundwater Interactions

In the most basic sense, the rate and direction of water movement from the channel bed to underlying porous media is controlled by the vertical hydraulic conductivity (K_v) of the riverbed, the geometry and thickness of the riverbed, and the hydraulic gradient (hydraulic head) between the river and the aquifer (Levy et al., 2018). In the case of a losing environment and all factors being equal, increases in K_v, a thinner channel bottom, and a stronger downward hydraulic gradient will intensify infiltration (seepage)

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[5] Slight variation in listed model parameters may explain differences in estimates.

into the aquifer. Alternately, when the head gradient is toward the stream, gaining conditions prevail and groundwater will discharge into the stream. Where the stream and groundwater are hydraulically disconnected (i.e., separated by an unsaturated zone), seepage is widely taken to not be influenced by the aquifer and becomes a function of streambed K_v, properties of the underlying aquifer materials, and water depth in the stream. The simplifying assumption that the underlying media is unsaturated is taken to be true in most cases due to more complicated flow dynamics under conditions of variably saturated flow (e.g., porous media is partially saturated and flow properties are highly non-linear) and that result from the presence of perched aquifers.

Complexities in even the simplest SW-GW flow systems begin to arise due to several factors. For one, it is difficult to quantify streambed K_v as well as aquifer hydraulic conductivities, which can range in value over more than 12-13 orders of magnitude. Hydraulic conductivities are also highly spatially heterogeneous, and K_v values vary temporally as bed sediment composition evolves (e.g., low flow clogging, bio-clogging, siltation, and high flow scour) (Barlow & Leake, 2002; Levy et al., 2008). Aquifer properties will also evolve under conditions of variably saturated flow. Where layers or lenses of low-permeability sediments exist, the presence of perched saturated zones can form. Such perched zones can reduce seepage and even reverse gradients to promote water discharge to the river (Niswonger & Fogg, 2008). Alternately, preferential flow via connected pathways of highly permeable materials can rapidly transmit immense seepage losses over small portions of the riverbed (Fleckenstein et al., 2006). In addition to these factors, consideration and inclusion of evapotranspiration may be equally important when quantifying SW-GW fluxes (Min et al., 2020; Niswonger, 2005). Cumulatively, these dynamical and heterogeneous conditions at the river-aquifer interface contribute to high spatial and temporal variability in SW-GW fluxes (Fleckenstein et al., 2006; Frei et al., 2009).

As noted above, near-river SW-GW interactions are strongly influenced by various scales of localized subsurface heterogeneity. Such heterogeneity is often described and stochastically represented by the arrangement of hydrofacies, which can be assigned variable conductivities amongst other physical properties. Spatial variability in hydrologic processes due to the organization of hydrofacies can result in localized mounding of GW or formation of perched water tables near the active channel bed and within the extent of paleochannels and associated floodplain surfaces (Niswonger & Fogg, 2008). These localized effects can serve to reduce or even reverse flow gradients between surface water and groundwater, and they have been documented to facilitate SW-GW interconnection in several Californian rivers thought to be disconnected from their regional GW tables (Fleckenstein et al., 2006; Niswonger 2005; Niswonger & Fogg, 2008).

A review of existing studies on SW-GW interactions in the SASb principal surface water bodies are described in the sections below.

2.4.1 Lower Sacramento River

Explicit study of SW-GW interactions along the Lower Sacramento River in the SASb has not been extensively evaluated. Limited analysis of spatial and temporal SW-GW interactions were investigated by TNC (2014) using results from C2VSim-FG model[6] historical simulation (1922-2009). Based on simulated annual groundwater flows, the researchers found the portion of the Lower Sacramento River in the SASb (e.g., defined as Reach E in their analysis) to be net losing at the beginning of the simulation period in the 1920's and found the losing trend to increase through time. Variable, but generally gaining conditions were simulated in Sacramento river reaches outside of the SASb upstream of Fremont. This finding corroborates other reports stating that while the Sacramento river may be hydraulically connected with the regional groundwater system it is a losing stream (MHW, 2006). The spatial extent of this possible hydraulic connection is not well constrained but studies support that it does not extend far from the river (RMC, 2015). For example, groundwater in the nearby Beach/Stone Lakes basin has been reported to have little exchange with the river and thus be considered hydrologically independent (Carollo Engineers, 2000).

2.4.2 Lower American River

Surface water and groundwater hydrology of the lower American river have been the subject of extensive documentation but studies explicitly focused on SW-GW interactions remain limited with the exception of focused studies centered on the Aerojet Superfund Site. Additional focus on this topic emerged as part of SWRCB review of a petition by Southern California Water Company to revise the Declaration of Fully Appropriated Streams adopted by SWRCB Order WR 98-05 in order to appropriate treated groundwater that was being discharges to the lower American river (SWRCB, 2003). Expert testimony and extensive evidentiary materials presented as part of the petition supported that circa 1980s to 2000s groundwater levels were typically at or above the bottom of the riverbed from Lake Natoma to approximately 3,000 feet downstream of Nimbus Dam and were close to riverbed for an additional 3,000 feet downstream (e.g., 3,000 to 6,000 feet downstream of the dam). Beyond the 6,000 foot mark, westward declining groundwater levels resulted in an increasingly large unsaturated zone between the river and groundwater table. Review of historic groundwater contours presented from the 1950s onward corroborated these findings consistent with the view that downstream portions of the lower American River are a losing stream. Further review indicated that prior to 1958 stream losses appeared to be at relatively steady state (e.g., groundwater withdrawals were in balance with river recharge). However, subsequent changes in head due to lowered groundwater levels resulted in increased river losses as it recharged groundwater. Although the potential exists it is unclear if higher groundwater levels in the region below lake Natoma result in groundwater discharge to the river and if so, what the magnitude of such discharges are.

In addition to materials associated with the SWRCB petition, investigation by TNC (2014) (see above) found, on average, the lower American river was annually gaining

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[6] See TNC (2014) for details of the C2VSim-FG integrated hydrologic model.

during the period from 1922 to 1930 but subsequently transitioned to a losing reach after the 1960s.

2.4.3 Lower Cosumnes River

Previous study of SW-GW interactions along the Lower Cosumnes River has primarily been addressed in two ways: (1) through data-driven approaches that include field measurement of streamflow, groundwater levels, seepage rates, sediment temperatures, soil moisture, and sedimentology; and (2) through numerical simulation. Combining review of historical field measurements with a numerical groundwater-surface water model (IGSM), Mount et al. (2001) concluded that it was likely that the entire study area was connected to the primary aquifer (i.e., shallow unconfined aquifer) before the early 1940s. Under this condition, groundwater would discharge to the system at least during certain portions of the year (see also Fleckenstein et al., 2004). This finding was based on back extrapolation of historic well data and model simulation of baseline conditions with groundwater pumping set to zero (see No Pumping [S0] scenario Figure 12), thus representing a “quasi-pristine or natural pre-development groundwater condition”. Both methods have uncertainty but provide a reasonable basis for the conclusion, especially in the absence of other historic records. Following the 1940s, increased groundwater production and declines of regional groundwater levels decoupled the river from saturated groundwater along much of the river. Increased groundwater pumping in subsequent decades has exacerbated this issue, resulting in continued lowering of regional water tables and increasing the saturated groundwater disconnection from the river. These groundwater declines are suggested by Mount et al. (2001) and others to be responsible for declines in fall streamflows and observed increases in low-flow and no-flow periods.

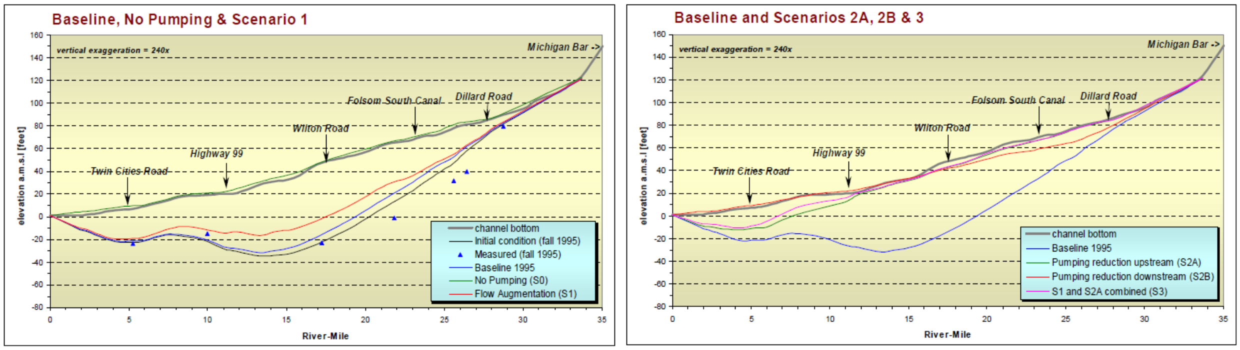

Figure 12. Measured, modeled, and simulated groundwater levels below river channel by Mount et al. (2001) (Figures 8 and 9). River miles may differ slightly from those used in this review.

Interestingly, in Mount’s no-pumping simulation, 12-years were required for the MBH-MCC reach to transition to a net gaining reach, and even at the end of the simulation, the reach was net losing during the fall. This determination simply reflects the period required to raise water levels from the fall 1995 groundwater elevations that were used for the model’s initial boundary condition. Over the 15-yr simulation period, the annualized water volumes necessary to overcome this deficit were estimated to be 166,000 acre-feet per year to partly reconnect the upper reaches of the river and ~250,000 acre-feet per year to reconnect the entire river. Gaining conditions were achieved more rapidly (6-years) between MCC (RM 0) and Twin Cities Bridge (RM 5.5).

Although the no-pumping scenario reduced seepage and thus improved fall conditions, that the river remained losing during this period highlights the seasonal nature of potential groundwater discharge and the importance of accurate representation of seepage processes.

Comparisons of measured and modeled groundwater levels with streambed elevations have been another effective method for spatial characterization of SW-GW interactions and have shown varying levels of disconnection between the Cosumnes riverbed and underlying principal aquifer. Using well data from April 2000 to 2001, Mount et al. (2001) recorded groundwater to be 7-20 feet below the channel near Dillard (RM 27.5), between 30-50 feet below the channel from Meiss to Highway 99 (RM 11-25.5), and between 3-15 feet below the channel from near Twin Cities Bridge (RM 5.5). Upstream of Dillard (RM 27.5-36), groundwater levels were within a few feet of the channel during the wet season, and levels were within 3-15 feet of the channel downstream of Twin Cities Bridge (RM 5.5) (Figure 12). In contrast to the well comparison, shallow piezometers installed downstream of Twin Cities Bridge documented groundwater levels at or above the ground surface, thus reflecting the spatial heterogeneity of water levels and potential limitations of this kind of comparative analysis.

Ultimately, Mount et al. (2001) concluded that reaches upstream of Dillard (RM 27.5) and downstream of Twin Cities Bridge (RM 5.5) were hydraulically connected to the primary aquifer and likely received seasonal groundwater discharge. These locations were demarcated as “sensitive transition areas” where further lowering of groundwater levels could result in increased stream flow depletions. The mechanisms driving these connections were not explicitly addressed in the study. The relatively intact connection of the river with its floodplains could be a primary driver for these observations. Further, depth to the bottom of the basin is higher (~400 feet below ground surface [bgs]) along the upstream portions of the river, and this area may receive higher relative quantities of mountain block recharge, which combined with connections to the floodplain could facilitate filling of the aquifer and thus more stable groundwater levels.

As discussed above, geologic complexity of the Cosumnes fluvial-riparian environment can induce high localized variability of groundwater conditions that may not be accurately represented with certain numerical models or groundwater measurements (such as those employed by Mount et al., 2001 and others [e.g., MHW, 2006; GEI Consultants, 2016]). Such uncertainty is exemplified when comparing the findings from these references with simulations that include higher resolution representations of aquifer heterogeneity (e.g., Fleckenstein et al. 2006; Niswonger, 2005[7]). For instance, conducting simulations with six different but equally likely geostatistical simulations of aquifer heterogeneity, Fleckenstein et al. (2006) identified spatially and temporally varying locations of local reconnection between the river bed and groundwater levels (Figure 13). Whether these connections were with the primary aquifer or due to formation of shallow perched aquifers is unclear. Although their simulated groundwater levels had large local variability between geologic realizations, most connections

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[7] Note information presented by Niswonger (2005) is similar in nature to what is contained in Niswonger and Fogg (2008).

occurred during the wet season, whereas dry-season connections generally occurred in similar locations to those identified by Mount et al., (2001). In addition to the up- and-downstream ends of the study area, wet season connections were clustered between Twin Cities Bridge and Wilton (RM 5.5-17.3) and were conjectured to even promote gaining conditions. These findings have been corroborated by physical observations of shallow local saturated zones below the river channel (Niswonger, 2005). Given the time period of SW-GW connections identified by Fleckenstein et al. (2006), as well as those discussed by Mount et al. (2001), it is unclear if groundwater discharge could contribute to dry-season flows, which is generally not supported by observed low-flow conditions. However, identification and better understanding of these connected zones is relevant due to their potential to reduce seepage losses, contribute to wet-season and possibly dry-season baseflow, and provide benefits for riparian vegetation and groundwater dependent ecosystems.

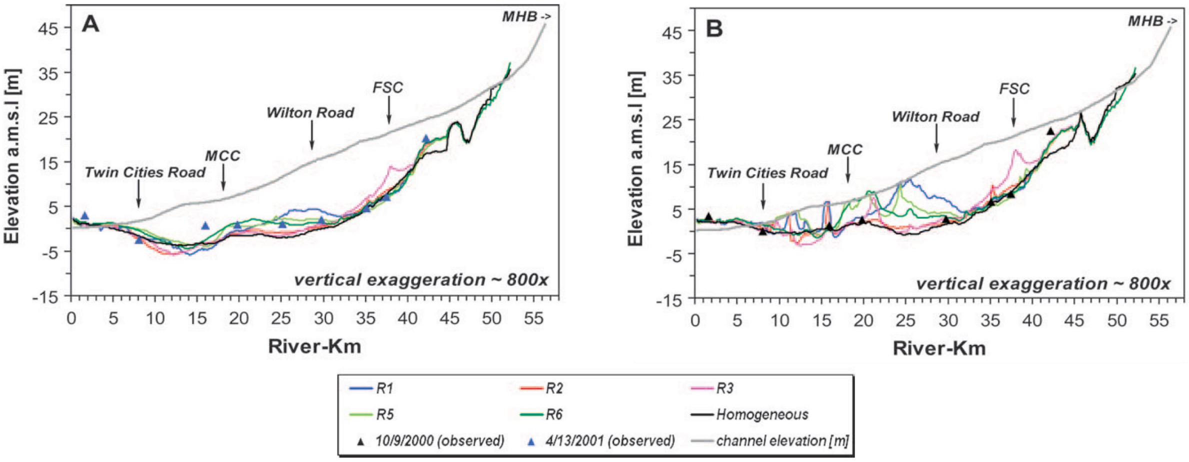

Figure 13. Simulated dry season (a) and wet season (b) groundwater levels of Fleckenstein et al., (2001) from different geologic realizations (Figure 11). River miles may differ slightly from those used in this review.

Lastly, no discussion of Cosumnes SW-GW interactions is complete without considering the influence of perched aquifers, which are covered in depth by the collective works of Niswonger (Niswonger, 2005; Niswonger & Fogg, 2008). Perched aquifer conditions occur where low conductivity sediments underlie higher conductivity sediments, and as discussed in the primer section, perched aquifers can diminish seepage losses and support gaining stream conditions. Where perched layers extend laterally from the stream corridor, perched water may also be vital to maintaining saturation of the riparian root zone. Even in the absence of providing groundwater discharge to the stream, hyporheic flows from perched aquifers can provide aeration of spawning habitats and drive biogeochemical cycling.

Under idealized circumstances, values reported by Niswonger show discharge from perched aquifers to streams could be as large as 1.5 ft^3/s per mile (0.04 m^3/s per mile), which are roughly proportional to estimates of Cosumnes seepage rates. However, the magnitude and duration of perched groundwater contributions is sensitive to properties of the streambed and underlying unsaturated porous media as well as geologic structure. Niswonger's studies show that a threshold condition for the ratio between the hydraulic conductivity of coarse streambed sediments to that of fine underlying sediments of 200 is required to create perching conditions capable of producing baseflows. Simulations in an idealized 2,000 m long stream segment based on the Cosumnes River near Highway 99 show that regardless of model parameters, dry-season perched groundwater discharges rapidly dissipate, often reducing to zero over a period of a few days to a few weeks. Larger baseflow contributions were found to be sustained for periods up to about 2-3 months after the cessation of bankfull-flows (e.g., mid-June) where, everything else being equal, coarse sediment hydraulic conductivity was higher. Even under these best-case scenarios, simulations show that discharges only on the order of 0.6 ft^3/s ($<0.02\ m^3/s$) would be expected during the first month after high flows, with even smaller contributions thereafter.

As shown by Niswonger and others, geologic heterogeneity strongly controls SW-GW interactions, such that perched aquifers and associated discharge in one region may seep into the subsurface downstream where perched layers are absent. Given the magnitude and spatially heterogeneous nature of these discharges, the total role of perched aquifer discharges in contributing to or potentially managing dry-season baseflows remains unclear. That said, perched aquifers undoubtedly provided benefits to the study areas through sustaining ephemeral pools, decreasing seepage losses, and contributing to wet-season baseflows.

3. Methods

In this section, we provide an overview of the data and models used in this study, the rationale behind groundwater flow simulation scenarios, and the classification system applied to ISW.

3.1 Data sources

3.1.1 Groundwater

Historic and present-day groundwater conditions were analyzed using all available data from six sources (Figure 2):

(1) California Department of Water Resources (DWR) Periodic Groundwater Level Database
(2) University of California at Davis (UCD) monitoring network
(3) Omochumne-Hartnell Water District (OHWD) monitoring network
(4) Sacramento State monitoring wells
(5) Aerojet
(6) Sac IWRM

Most groundwater level data is collected biannually in spring and fall and intended to capture seasonal variation – notably due to winter recharge and pumping and recharge during the dry growing season. In the South American Subbasin, periodic groundwater level data measurements peak in April and October (Figure 14) and suggest that future data collection should occur in these months to maximize data comparability across space and time.

Biannual seasonal groundwater level within the Sacramento Central Groundwater Authority (SCGA) jurisdictional boundary has been measured for decades; these measurements account for most of the spatial spread of groundwater level observations in the SASb and can be found in the DWR Periodic Groundwater Level Database [source (1) above]. Three additional networks, either established or maintained by UCD, OHWD, and Sacramento State all collect high-frequency, 15-minute interval groundwater elevation data. The UC Davis network (2) is situated on land owned by the Nature Conservancy and has collected data fall of 2012, the OHWD network (3) has collected data since fall of 2018, and the Sacramento State network (4) has collected data since spring of 2016. Aerojet monitoring wells (5) used in this study have been collecting data since 1982 and are actively monitored as part of on-site monitoring and remediation actions. Sac IWRM (6) is hydrologic model that includes the SASb and incorporates historic groundwater monitoring data; most of these data are included in (1). Duplicate measurements between data sources were reconciled by comparing monitoring site identification codes and position (latitude and longitude).

Modeled groundwater hydraulic head reflecting the transmissivity-weighted layer 2 and 3 (Laguna and Mehrten) heads from Cosana which represent average groundwater level in the production zone of the principal aquifer were compared against field-based monitoring groundwater level data[8].

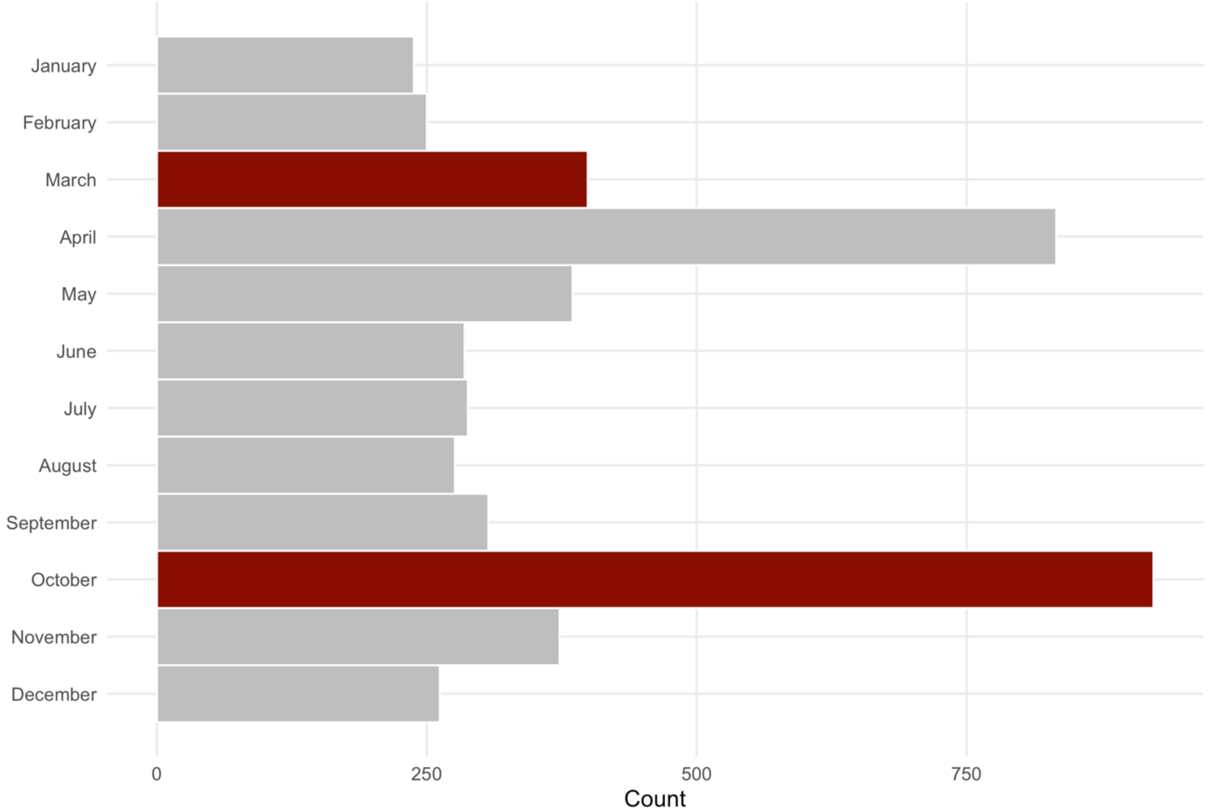

Figure 14: Periodic groundwater level measurements (2000-2021) reported by DWR in the South American Subbasin indicate peaks of seasonal data collection in April and October although DWR Best Management Practices indicate that monitoring wells should collect at least biannual measurements in spring (mid-March) and fall (mid-October) (CA-DWR, 2017). March and October are highlighted in the graph above, and roughly agree with historical data collection trends. It is especially important in dry years to monitor in mid-March, because pumping may begin as early as April; thus, a March measurement in a such a dry year provides a more accurate representation of ambient spring groundwater level. Consistent data collection in March and October ensures data comparability across years.

3.1.2 Surface Water

Surface water data considered in this analysis were designed to be consistent with the Cosana numerical groundwater flow model, and thus, the Cosana stream node representation (Figure *2* - *Figure 3*) was used. In particular, the vertical thalweg elevation, which represents the bottom of the streambed was used to ascertain the approximate vertical elevation at which various parts of streams may be reasonably connected to groundwater. This study uses 1,107 stream nodes. Soil thickness from the SSURGO soil database (Soil Survey Staff, NRCS, 2021) was taken to be a reasonable proxy for the clogging layer, a thin layer beneath streams, which is typically of lower conductivity than the surrounding sediment. Thus, at each stream node location, soil

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[8] As demonstrated in 3.2 Groundwater Level Interpolation, 99.4% of observations at wells occur within the Alluvium, Laguna, and Mehrten layers.

thickness[9] was extracted and subtracted from the thalweg elevation to define the elevation at which surface waters may be connected to groundwater.

Modeled nodal seepage at each of the Cosana stream nodes considered in this study were aggregated into reach-level (Figure 3) seasonal spring and fall seepages to assess historic variability in ISW depletion rates.

3.2 Groundwater Level Interpolation

Groundwater levels were assessed at biannual seasonal intervals during the period from spring 2005 to fall 2018 and encompass what can be considered "historic"[10] to approximately "present-day" seasonal conditions. This temporal range was selected because poor data density prior to spring 2005 and after fall 2018 prohibits meaningful analysis. "Spring" was defined as the months of March, April, and May and "fall" was defined as the months of August, September, and October.

At each monitoring location, the average groundwater level measured during spring and fall was computed by taking the grouped mean of observations in each spring and fall respectively. Next, to improve spatial data density and ascertain long-term regional trends, data were arranged in 4-year running seasonal means. For example, the 2005-2008 spring level is defined as the average spring groundwater elevation in 2005, 2006, 2007, and 2008. A four-year sliding window was applied to data from 2005 to 2018, resulting in 22 seasonally averaged groundwater elevation conditions (e.g., spring 2005-2009, fall 2005-2009, …, spring 2015-2018, fall 2015-2018). Windows of differing length (e.g., 1, 2, and 3-year long running means) were explored but resulted in larger groundwater level variance due to a lack of adequate spatial density, and hence, not used. By contrast, 4 year running means gave adequate regional spatial data density and were not so long in duration as to mute the impact of significant dry periods such as the 2012-2016 drought.

After data were grouped into seasonal 4-year windows, ordinary kriging[11] (Journel A.G. and Huijbregts, 1978) was applied to groundwater elevation measurements to generate groundwater level surfaces across the SASb at a 500 meter (0.31 mile) resolution. In order to minimize boundary effects, monitoring well data within a 20 kilometer (12.4 mile) buffer of the SASb were included, which effectively incorporates groundwater level data from the Cosumnes and North American subbasins, and Yolo county to the west of the Sacramento river (Figure *17*). Groundwater level measurements were screened to include data from wells shallower than 300 feet in total completed depth to reflect

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[9] According to SSURGO, soil thickness in the SASb ranges from 0 to about 170 centimeters.

[10] Importantly, this period contains the recent 2012-2016 drought.

[11] An exponential variogram model was used, and results did not appreciably differ from linear or spherical models. Stationarity across the unconfined to semiconfined aquifer is a reasonable assumption in the unconsolidated, alluvial aquifer-aquitard system that spans the South American subbasin and adjacent subbasins, which exhibit relatively continuous geology across borders. Data outliers were controlled by removing tails of the distribution above and below the 97.5th and 2.5th percentiles respectively. Groundwater elevations were approximately normal in distribution, thus log-transformation and exponentiation after kriging was not required.

conditions in the unconfined to semiconfined production aquifer, which are comparable to heads in layers 2-3 of Cosana. All monitoring points were further intersected with the Cosana model grid, and 99.4% of observations at wells occur within the Alluvium, Laguna, and Mehrten layers. 0.6% of observations occur in the Ione and Valley Springs.

3.3 Forward simulations of Projects and Management Actions and Climate Change

ISW depletions are characterized in terms of historical data and models of past hydrology (i.e., via Cosana), but also in terms of future, anticipated hydrology. Forward-simulated hydrologic conditions using the Cosana groundwater flow model were used to estimate the impact to ISW from:

- the combined effects of projected water use in the Basin;
- projects and management actions (PMA) already underway (Harvest Water, OHWD[12] recharge, and regional conjunctive use); and
- climate change.

Model outputs including future groundwater basin storage, groundwater level, seepage from streams, and streamflow were collectively used to analyze impacts to ISW.

In the presentation of results (Section 4), groundwater level conditions in the current conditions (baseline) are compared to groundwater level conditions in the scenarios evaluated. Five scenarios are compared:

- ***Baseline***: current conditions
- ***Projected***: projected groundwater use (i.e., business as usual with increased demand)
- ***Projected CC***: projected groundwater use with a median climate change warming scenario[13]
- ***Projected PMA***: projected groundwater use considering feasible, in-progress projects and management actions (Harvest Water, OHWD recharge, regional conjunctive use)
- ***Projected PMA CC***: projected groundwater use considering feasible, in-progress projects and management actions (Harvest Water, OHWD recharge, regional conjunctive use) and with a median climate change warming scenario

Differences in groundwater level, seepage, and streamflow between each of the scenarios and the “baseline” inform how ISW in the basin may respond to projected groundwater management. These differences are applied to observed data to translate model estimates of change to observed data. For example, to estimate the change in ISW location (and hence,

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[12] OHWD = Omochumne - Hartnell Water District

[13] Climate change (CC) scenarios are driven by changes in temperature and streamflow provided by the American River Basin Study (USBR, 2020) “central tendency” scenario, which reflect median temperature and precipitation outcomes.

change in ISW reach length) under each scenario, the groundwater level differences implied by each scenario at a Fall 2015 reference point were evaluated by the model, then this difference was applied to the measured and interpolated Fall 2015 level. Fall 2015 was chosen as a reference point because it represents a recent historical minimum in groundwater level across the basin.

3.4 Classification of ISW and Disconnected Surface Waters

The overarching goal of this analysis was to characterize the location, timing, and quantity of ISW in the SASb to inform the development of sustainable management criteria that avoid significant and unreasonable ISW depletion as defined by SGMA. Thus, it was important to classify all surface waters into "ISW" and "Disconnected" and explore how these classifications change over time. Groundwater and surface water data and modeled results were used to inform this classification.

As described in Section 2.4 Surface water and Groundwater Interactions, groundwater and surface water interact based on the relationship between the groundwater level and adjacent stream stage. Generally, if the groundwater level (also called the groundwater hydraulic head) exceeds the stream stage, a stream is interconnected and gaining. By contrast, if the stream stage exceeds the groundwater level, the stream is losing (Figure 15). However, a losing stream may still be ISW if the groundwater level intersects the clogging layer elevation; otherwise, if groundwater does not intersect the clogging layer, the stream can be considered disconnected. Importantly, a stream may be assessed along its entire reach to determine reaches characterized by connection and disconnection.

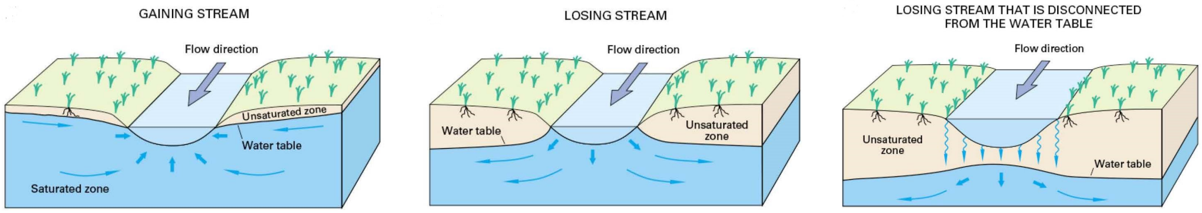

Figure 15: Surface water may be characterized as interconnected and gaining (left), interconnected and losing (center), or disconnected and losing (right). Figure modified from USGS.

This study uses a two-step system[14] to distinguish ***ISW*** and ***Disconnected*** surface water reaches described below and depicted in Figure 16. First, we determine interconnected and disconnected *stream nodes*:

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[14] Previous research has advanced similar classification schemes as the one put forward in this study. For instance, Brunner et al. (2009) devised a three-class surface water classification system (interconnected, transition, and disconnected), and defined the "transition" class based on a zone of capillary action between saturated groundwater and the streambed clogging layer which was determined via a 1D analytical model informed by geologic properties. In this study, we neglect the impacts of capillary action because the local-scale geologic information required to drive 1D modeling of capillary action are poorly constrained in the study site and difficult to obtain, but may represent a potential path for future scientific investigation.

- *Interconnected stream nodes*: groundwater elevation at the stream node in question is greater than or equal to the clogging layer elevation under the thalweg
- *Disconnected stream nodes*: groundwater elevation at the stream node in question is less than the clogging layer elevation under the thalweg

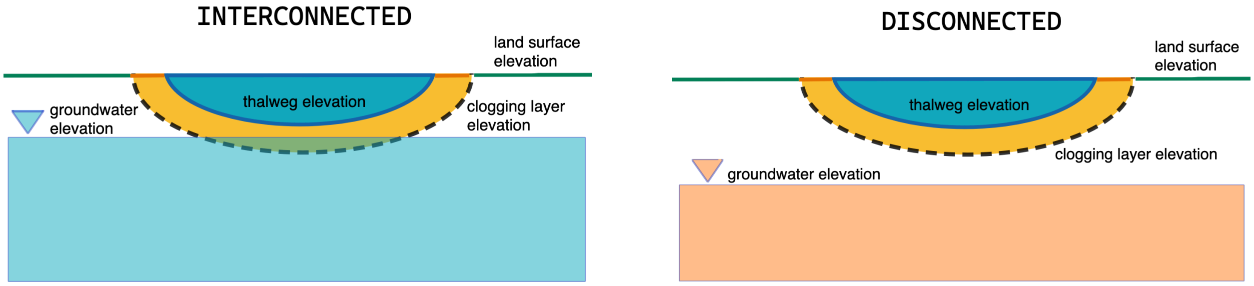

Figure 16: Classification of *Interconnected* Surface Water (ISW) and *Disconnected* stream nodes depends fundamentally on a comparison of the clogging layer elevation beneath the streambed and the groundwater elevation. If the groundwater elevation intersects the clogging layer, a stream node is considered ISW (right), otherwise, it is considered disconnected (left).

This classification is applied at each of the 1,107 stream nodes, and across the 22 seasonal groundwater level conditions from 2005-2018 (3.2 Groundwater Level Interpolation).

Second, looking across all reaches (Figure 4), we distinguish between *ISW and Disconnected* reaches (Figure 24).

- ***ISW:*** a majority of stream nodes are *Interconnected* for > 0% of all seasons evaluated in the historical period from 2005-2018.
- *Disconnected*: a majority of stream nodes are persistently *Disconnected* during all seasons from 2005-2018.

ISW and ***Disconnected*** categories thus represent reach- and seasonal-level summary statistics of *Probable ISW* and *Probable Disconnected* Cosana stream nodes, and are the final classifications used to inform GSP planning and SMC development. SMC and monitoring networks are developed for ***ISW*** reaches. Due to their persistent disconnection, ***Disconnected*** reaches are not considered within the requirements established by SGMA.

This classification is applied to historical groundwater level interpolations, and then across projected groundwater management in order to assess how expected groundwater use and climate change could affect ISW location.

3.5 Estimation of Depletion Volume at ISW Reaches

ISW depletion is extremely difficult to measure in the field, especially at the scale of an entire reach, and hence, numerical and analytical models are relied upon to estimate the magnitude and direction of stream-aquifer exchange. In accordance with SGMA, the Cosana groundwater flow model is used to estimate stream seepage along surface water reaches. The time period analyzed was 2005-2018 to maintain consistency with the previous groundwater level analysis. Cosana only runs through 2018.

Depletion volume is driven by the relative difference between aquifer and stream hydraulic head. Generally, if additional groundwater drawdown occurs adjacent to a connected, losing stream, increased surface water depletion is expected because the hydraulic gradient between the stream and aquifer also increases.

3.6 Location and Timing of Gaining and Losing Reaches

Gaining and losing reaches are defined by the direction of flow between surface and groundwater, which is itself controlled by the hydraulic gradient between these two systems. Gaining surface water reaches have a stage elevation lower than adjacent groundwater elevation; losing surface water reaches have a stage elevation higher than adjacent groundwater elevation (Figure 15). Gaining and losing conditions are examined by analysis of Cosana model results of stream-aquifer interaction captured by the seepage term. Positive seepage indicates gaining stream conditions, and negative seepage indicates losing stream conditions. Seepage was aggregated at the seasonal (spring and fall) and reach level for major surface water bodies (American, Sacramento, Mokelumne, and Cosumnes Rivers) in the SASb. Location and timing of gaining and losing reaches is examined by mapping and hydrogeologic interpretation of seepage timeseries.

3.7 Changes in ISW streamflow

A primary concern of projected groundwater management is the avoidance of groundwater pumping that causes significant decreases in groundwater baseflow to streams that reduces streamflow and causes damage to beneficial users of that streamflow. Thus, changes in streamflow along the American, Sacramento, and Cosumnes rivers resulting from projects and management actions and climate change were evaluated with Cosana and compared to best available estimates of streamflow requirements for fish migration (Section 2.3.3 Lower Cosumnes River). Flows are summarized by exceedance probability during October to December flows because this time frame aligns with salmonid spawning migration. Due to modeling constraints, flows are estimated at the downstream outlets of the Cosumnes and Sacramento Rivers in the model domain. American River flows are estimated at H Street Bridge.

3.8 Satellite Analysis of Wetting and Drying

Portions of the American Sacramento, and Mokelumne Rivers that border the SASb are perennial, but certain reaches along the Cosumnes River are ephemeral. High resolution remote sensing was assessed as a potential means to qualitatively describe important reaches along the Cosumnes River. “Drying” events along the Cosumnes River were assessed with 30-centimeter pan-sharpened resolution imagery provided by

Google Earth Pro in order to scope the feasibility of on-demand, reach-scale documentation of the timing location of “drying” events.

4. Results

4.1 Historic and Present-day Groundwater Conditions

4.1.1 Monitoring well hydrographs

Historic groundwater conditions were assessed via hydrographs at monitoring points in the SASb, and groundwater surfaces derived from these measurements (grouped by season over 4-year sliding windows as described in Section 3.2 Groundwater Level Interpolation). Monitoring well hydrographs[15] – depending on the temporal resolution available – can provide sub-seasonal insights into ambient groundwater level trends at specific monitoring locations and at particular screened interval depths. Taken together, the individual hydrographs in the SASb do not show one consistent trend, but rather, show decreasing, increasing, and stable groundwater elevations trends over time. This implies that groundwater pumping is localized and depth-dependent, a trend that is visible in the 120 hydrographs in *Appendix A: Hydrographs*, and the groundwater elevation surfaces discussed in the following section.

4.1.2 Groundwater elevation trends and flow direction

Groundwater elevation surfaces are statistical representations across the entire study area computed from monitoring well hydrographs. In this study, groundwater elevation surfaces were used to compare groundwater and surface water features over time to determine the location and timing of ISW.

Interpolation occurs at a larger spatial scale than the SASb to minimize boundary effects and allow for some interpretation of groundwater flow direction, thus interpolation results show Sacramento County-wide groundwater level estimates (Figure 17). Groundwater levels in the SASb (Figure 18) show oscillating seasonal trends, which are more easily visible when comparing the median and interquartile range of groundwater level across years and seasons (Figure 19). The difference between median fall and spring groundwater level in the SASb suggests a typical interannual fluctuation of around 3 to 10 feet. Moreover, median spring and fall groundwater levels show a consistent downwards trend from 2005 to the period ending in 2016, and an increasing trend thereafter. These regional groundwater level changes were caused by the historic 2012-2016 drought and demonstrate that prolonged drought conditions have an impact not only on fall lows, but also on the height of spring groundwater level recovery. Furthermore, trends in median groundwater levels also demonstrate that following drought, groundwater levels generally rebound to pre-drought levels. For instance, the

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[15] The 120 hydrographs considered in this study are presented in *Appendix A: Hydrographs*, although not all data shown in these hydrographs were used in the groundwater level interpolation due to the time period assessed in this study (2005-2018).

2015-2018 spring and fall median groundwater levels are roughly equivalent to the pre-drought 2005-2008 spring and fall levels.

Groundwater flow direction can be interpreted from groundwater elevation maps (Figure *17*, Figure *18*) which define the approximate subsurface “topography” of saturated groundwater in the principal aquifer given our best available data. Groundwater flows laterally from high to low groundwater elevation, along the lateral hydraulic gradient. Groundwater elevation mapping in the SASb indicates groundwater flow inwards towards the central and eastern SASb, coincident agricultural and rural areas which may pump more groundwater than urban areas. Urban areas near Sacramento, Rancho Cordova, and Folsom generally exhibit higher and more stable groundwater elevation trends, apart from notable groundwater drawdown near the Elk Grove urban-rural fringe. Higher groundwater elevations along the Sacramento and American river channels result from substantial seepage into groundwater causes groundwater to flow inwards to lower groundwater elevation sites in the SASb. Notably, the Cosumnes River channel does not show consistently higher groundwater elevation than interior groundwater elevation, perhaps due to seasonal wetting and drying of the river, and its closer proximity to groundwater pumping compared to the Sacramento and American rivers. Hence, groundwater in some seasons flows away from the Cosumnes towards the interior of the SASb, and in other seasons appears not to flow. North to south flow from the interior of the SASb towards the Cosumnes does not appear common in the period of record analyzed, consistent with a characterization of the Cosumnes as a stream experiencing active depletion.

A rigorous assessment of interbasin flow was outside of the scope of this study but should be conducted with the CoSANA model, or groundwater level measurements in all available datasets across the Cosumnes, South American, and North American basins. Nevertheless, Periodic Groundwater Level Measurements from the Department of Water Resources (see Section 3.1 Data sources) in the North American and Cosumnes basins provide some insight into general patterns of interbasin flow directions. Across years and seasons, lower groundwater elevations in the interior of each of these basins compared to groundwater elevations near major surface water channels suggests the presence of losing streams and active surface water depletion. This depletion moves along a hydraulic gradient from high groundwater elevation (near stream) to low groundwater elevation (basin interior). Therefore, interbasin coordination measures that arrest groundwater level decline (or increase groundwater levels) within zones of pumping inside the SASb, North American, and Cosumnes basins are critical to maintain surface water flows and preventing loss of ISW locations in the basin.

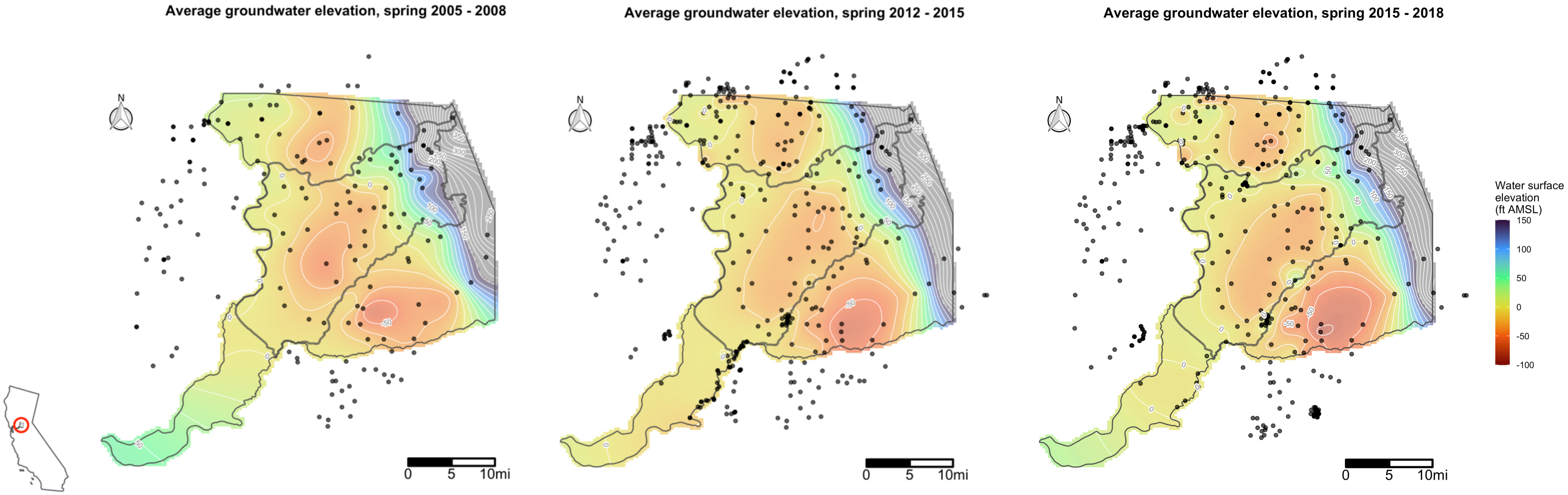

Figure 17: Spring groundwater elevation computed by ordinary kriging at three representative time steps (2005-2008, 2012-2015, and 2015-2018) demonstrate the presence of regional hydraulic gradients that contribute to inter-basin groundwater flow. Red indicates lower elevation and blue indicates higher elevation. Kriging is informed by groundwater level measurements taken at monitoring points (black dots), which are not constant across time steps. To best represent groundwater level in the SASb, monitoring points beyond the SASb boundary are incorporated into the analysis.

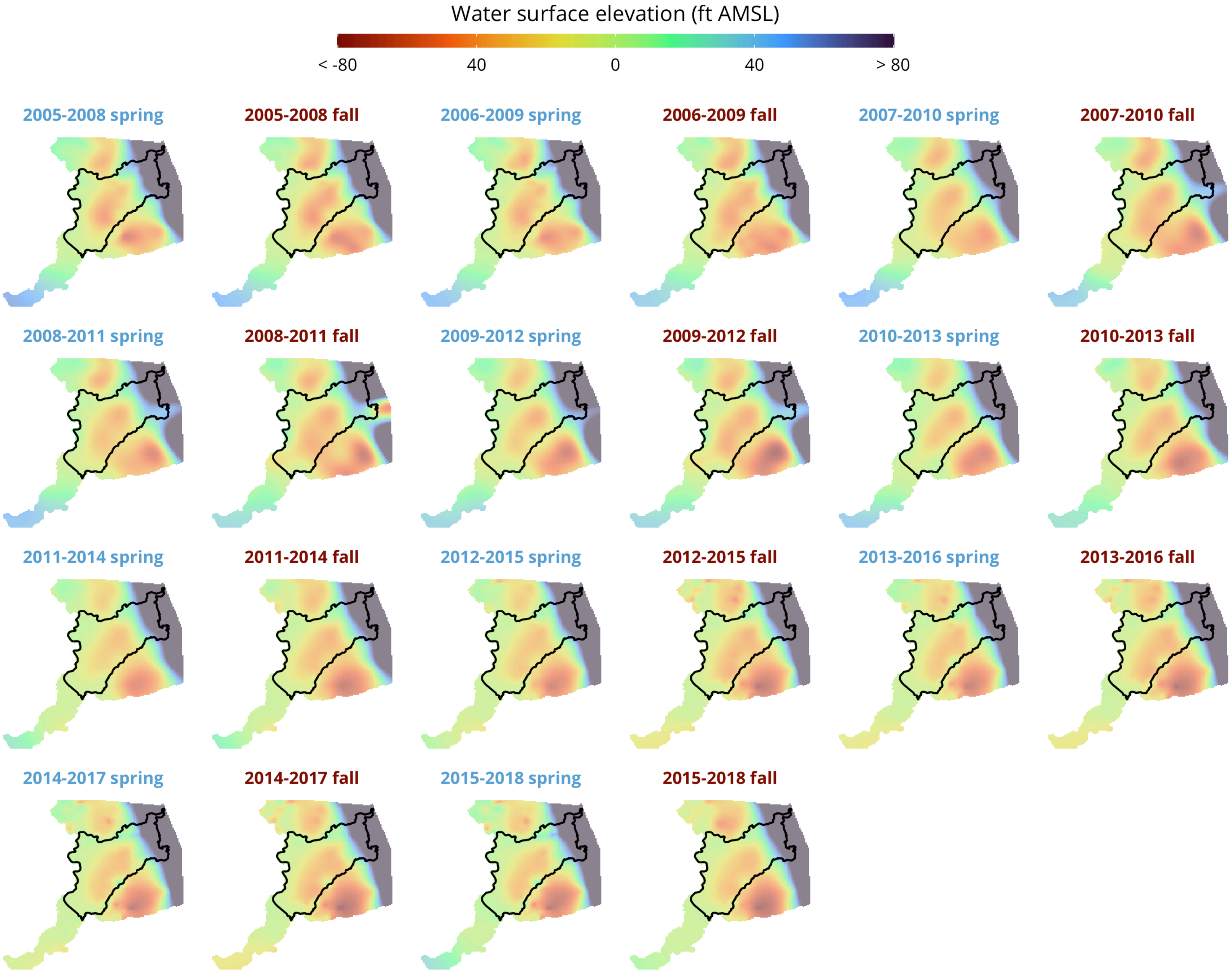

Figure 18: Seasonal, 4 year running mean interpolated groundwater elevations in the South American Subbasin from spring 2005 to fall 2018 show seasonal oscillation, with generally higher (blue) groundwater elevation in spring, and generally lower (red) groundwater elevation in the fall. Groundwater flows from areas of high (blue) to low (red) elevation groundwater elevation. Groundwater elevation mapping indicates groundwater flow inwards towards the center of the basin, coincident with areas of groundwater pumping.

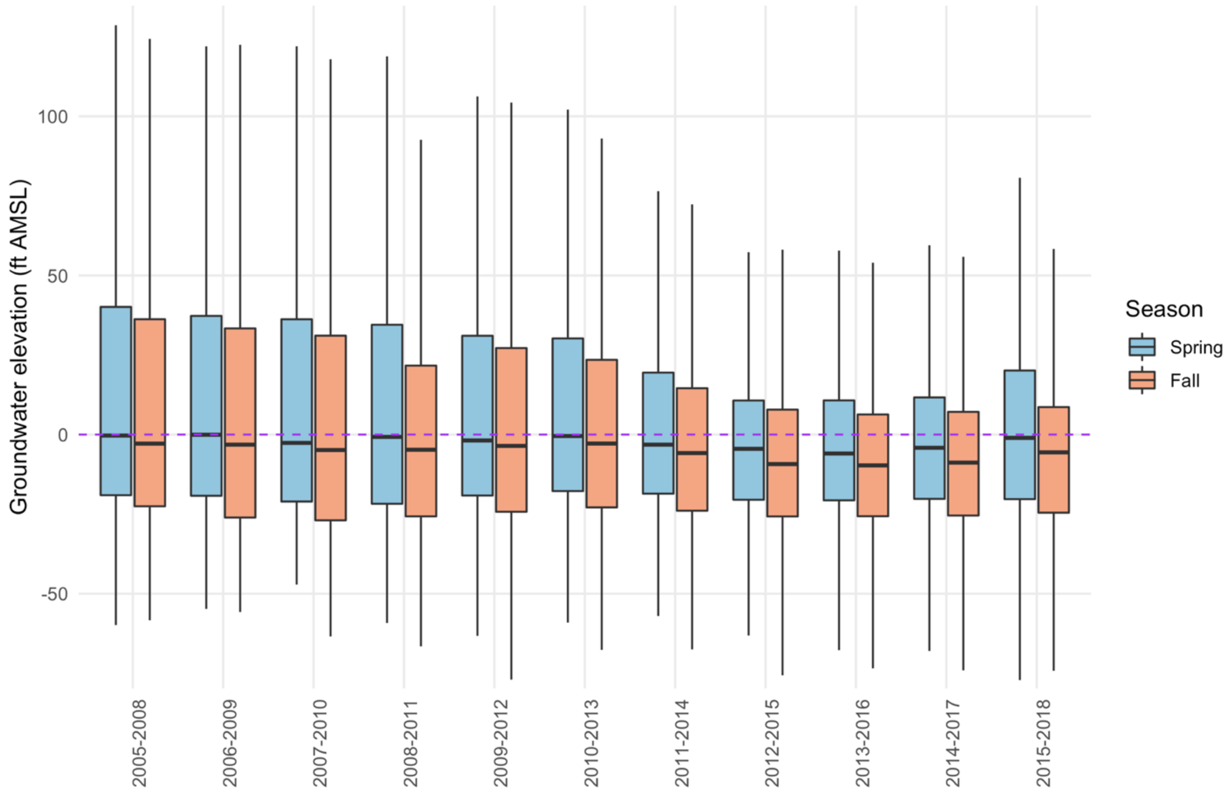

Figure 19: Seasonal summary of interpolated groundwater elevations in the SASb (Figure *18*) show oscillating seasonal medians, with consistently higher groundwater elevation in spring, and lower groundwater elevation in fall. Median fall groundwater elevation decreases over the period of record and reaches its lowest value during the average period of 2013-2016 due to the combined impact of 4 years of drought. After this minimum, spring and fall median groundwater levels trend upward. A purple, horizontal dashed line is shown at mean sea level elevation (0 feet) for reference.

4.1.3 Shallow groundwater locations

The depth to groundwater is calculated from seasonal groundwater elevations by subtracting the groundwater elevation from a digital elevation model. Estimated depth to groundwater (Figure 20) suggests that shallower groundwater is encountered moving from northeast to southwest in the SASb, from the foothills towards the Delta. Depths to groundwater are estimated at around 20-180 feet below land surface in the interior of the SASb[16], depending on the location considered. Areas of shallow groundwater occur along the southern Cosumnes River, along the American River above the Sacramento River confluence, along the Sacramento River, and within wetlands approaching the Delta. Moreover, relatively shallow depths to groundwater parallel the upper Cosumnes and American River channels, likely due to seepage from these major surface water bodies. Moving further away from these surface water channels, the depth to groundwater generally increases, which reflects the impact of groundwater pumping. Together, results suggest that ISW is more likely in regions with a shallower depth to

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[16] Poorly constrained data in the foothills (dark red eastern areas in Figure 20) prohibits meaningful estimates of groundwater elevation and hence, depth to groundwater. Thus, results in these areas should be interpreted with caution. Actual depths to groundwater are likely higher in the foothills. Incidentally, most groundwater pumping does not occur in these areas.

groundwater and are consistent with subsequent findings on the estimated location of ISW.

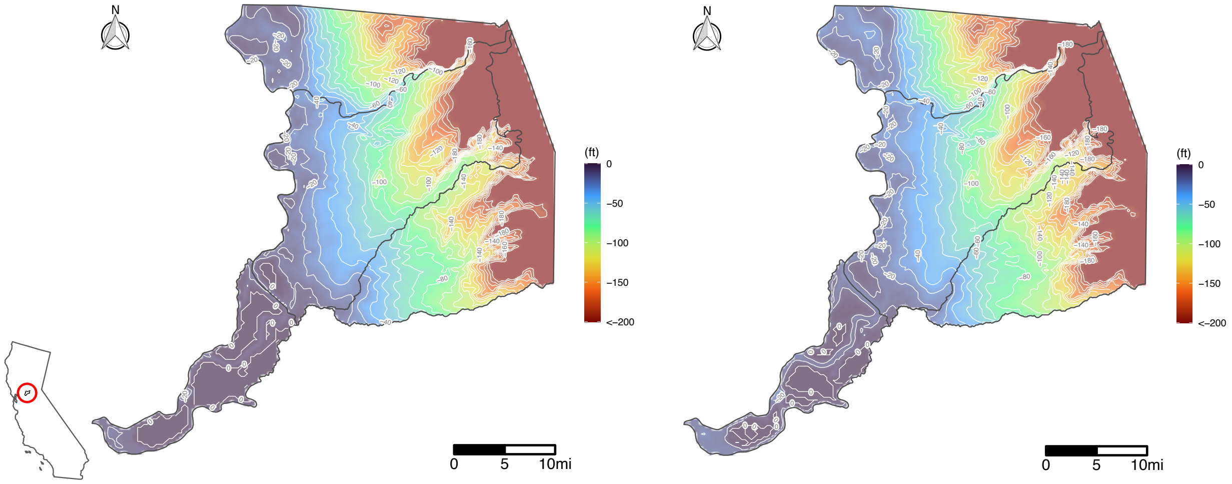

Figure 20: Depth to groundwater in the SASb for average spring (left) and fall (right) conditions across the entire period of record evaluated (2005-2018).

4.1.4 Projected groundwater levels

The impact of projected groundwater conditions including projects and management actions and climate change were evaluated with Cosana (see Section 3.3 Forward simulations of Projects and Management Actions and Climate Change).

Projected groundwater use assumes anticipated groundwater pumping on the part of water systems and GSAs across the SASb, the North American subbasin, and the Cosumnes subbasin. Results demonstrate that groundwater level declines around 15 to 20 feet or less are anticipated near Elk Grove and the Sacramento urban area respectively. Projects and management actions – including regional conjunctive use and recharge projects in Harvest Water and OHWD – lead to the mitigation of groundwater level declines near Elk Grove, and declines in the Sacramento region on the order of 15 feet or less. Groundwater level declines are estimated because of plans to exercise the basin, and declines are calculated between modeled scenarios and the current conditions baseline at the same time step (Fall 2015)[17].

Importantly, groundwater level decline in and of itself is not inherently harmful to beneficial users. Rather, declines must be evaluated with respect to beneficial users to anticipate potential significant and unreasonable impacts. The following subsections will detail the results of such analyses. In particular, we evaluate projected groundwater management and climate change impacts to ISW reach length, seepage at ISW reaches, and ISW streamflow.

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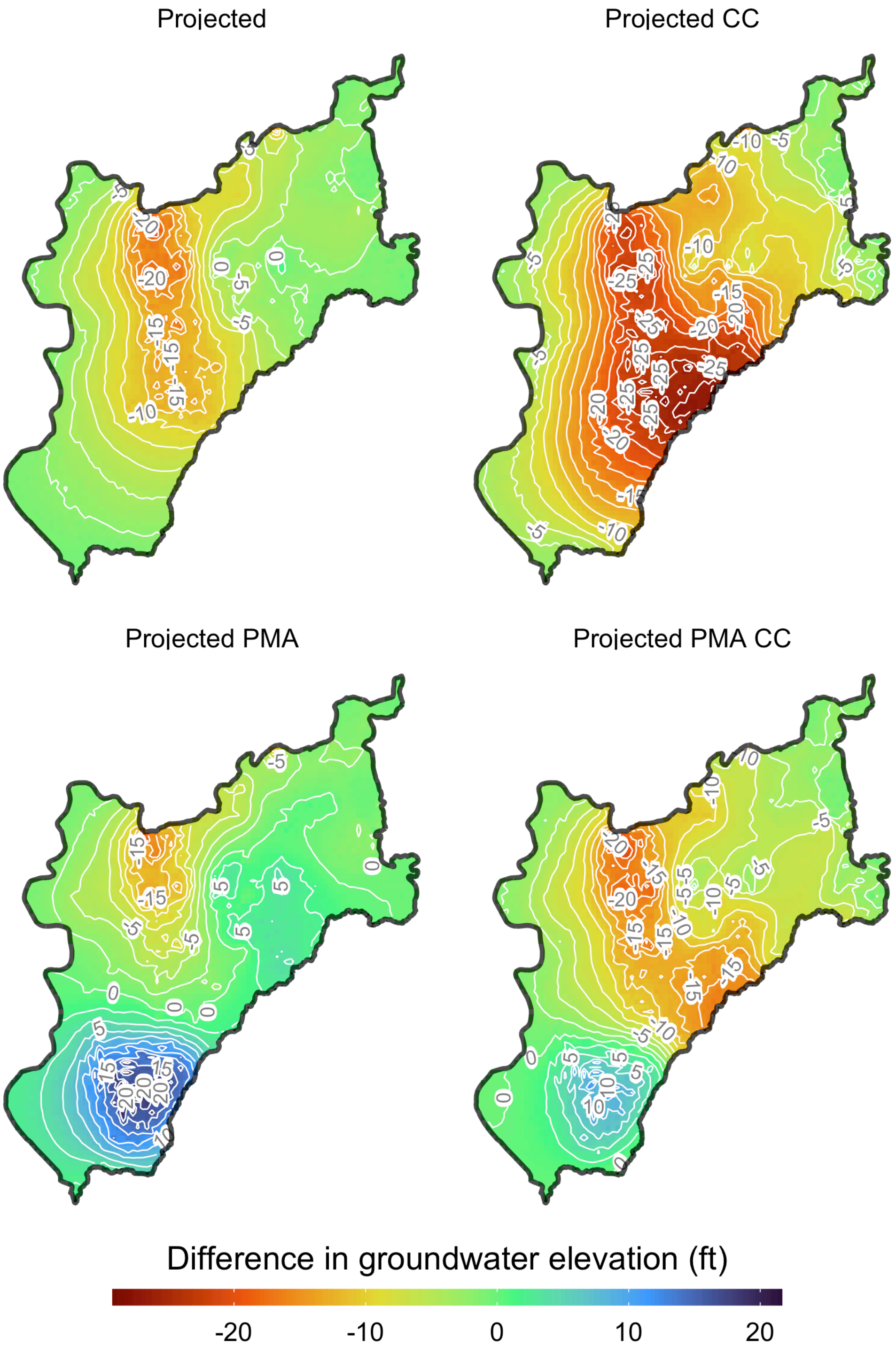
[17] In practice, another time step may be chosen as a benchmark (e.g., Spring 2018), however, groundwater level decline will be similar no matter what benchmark is chosen because groundwater levels in each scenario follow repeated hydrology as in the current conditions baseline scenario (see Figure 23).



Projected

Projected CC

Projected PMA

Projected PMA CC

Figure 21: Modeled difference in groundwater level between each of the scenarios and the current conditions baseline at a Fall 2015 benchmark. PMA lead to substantial increases in groundwater level that reduce seepage (e.g., improve baseflow) and increase streamflow at ISW reaches. Climate change projections lead to groundwater level declines, but assume no corrective action or land use change. In reality, climate change would require specialized adaptive management to avoid significant and unreasonable impacts to beneficial users of groundwater and ISW.

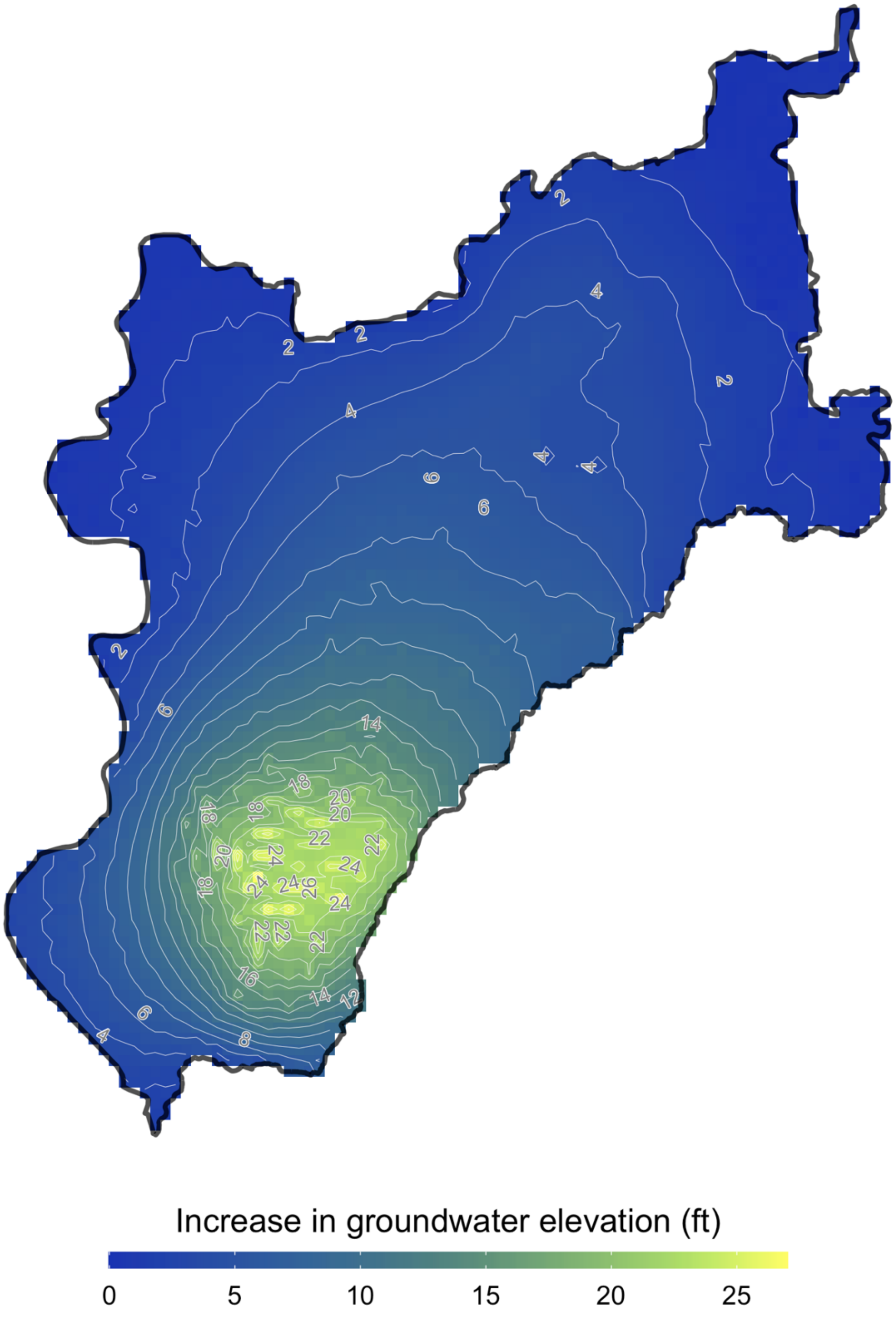


Figure 22: The difference in groundwater elevation between the "Projected PMA" and "Projected" scenarios shows the spatial distribution of groundwater level increases estimated to result from implementing PMA. Increases in groundwater level are observed across the basin, and concentrated near the Harvest Water recharge site.

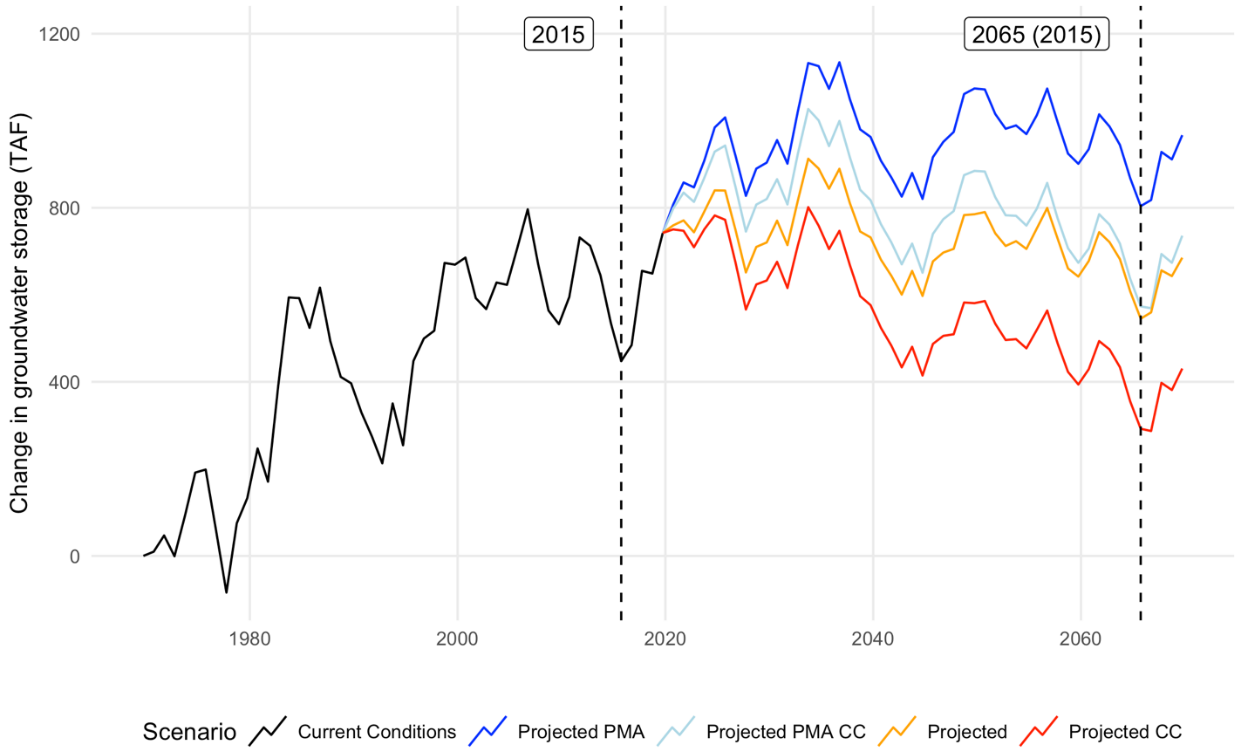


Figure 23: Cumulative change in groundwater storage under the current conditions baseline (black line), and the four scenarios (dark blue, light blue, orange, and red line). Importantly, projects and management actions (PMA) increase storage, and climate change (CC) reduces storage. A black dashed line shows where groundwater level differences are calculated between the projected scenarios and the current conditions baseline (Fall 2015) to maintain consistency.

4.2 Location and Timing of Interconnected Surface Waters

4.2.1 Historical data analysis

The location and timing of ISW was assessed by comparing each of the average seasonal groundwater level conditions presented above to the depth of the clogging layer of major surface water bodies (as described in 3.4 Classification of ISW and Disconnected Surface Waters). The proportion of seasons (across the 22 seasons evaluated in this study) that a stream node was classified as “Interconnected” to groundwater (3.4 Classification of ISW and Disconnected Surface Waters) was calculated at each stream node (Figure 24A), and used to inform a classification of “Interconnected” (ISW) and “Disconnected” stream nodes (Figure 24A) and reaches (Figure 24B).

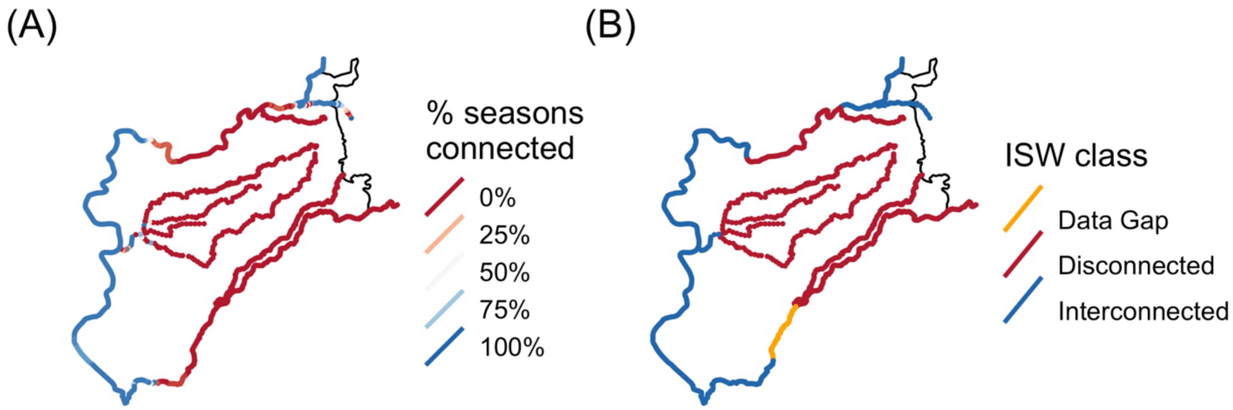


Figure 24: Interconnected and Disconnected stream nodes and reaches are defined by computing (A) the percentage of seasons evaluated from 2005 – 2018 where average groundwater elevation intersects the clogging layer of the streambed. (B) Disconnected stream reaches have a majority of stream nodes that are persistently disconnected from groundwater at all seasons evaluated, whereas Interconnected reaches are conservatively defined as having a majority of nodes connected for > 0% of all seasons evaluated. The Cosumnes River approximately between Deer Creek and Twin Cities Road is disconnected on a seasonal level, but some evidence of sub-seasonal connection exists, thus it is considered a data gap for planning purposes and more research is needed to understand stream-aquifer interactions in this region.

Final ISW classification results in a larger proportion of the Cosumnes River upstream of the Mokelumne River being classified as ISW. Due to relatively low groundwater levels in the basin's interior, most interior creeks are "Disconnected". ISW characterization is consistent with ISW characterization in The Nature Conservancy's ICONS web tool (TNC, 2021) and those in adjacent basins (North American and Cosumnes basins) that share boundaries with the South American Subbasin.

Results suggest that ISW locations over the period of record analyzed from 2005-2018 include:

- the entire Sacramento River;
- the American River upstream of the Sacramento River and downstream of the H Street Bridge;
- the American River upstream of Alder Creek and Buffalo Creek;
- Alder Creek and Morrison Creek upstream of the Sacramento River;
- the Mokelumne River; and
- the Cosumnes River upstream of the Mokelumne Confluence and downstream of the Laguna Creek confluence.

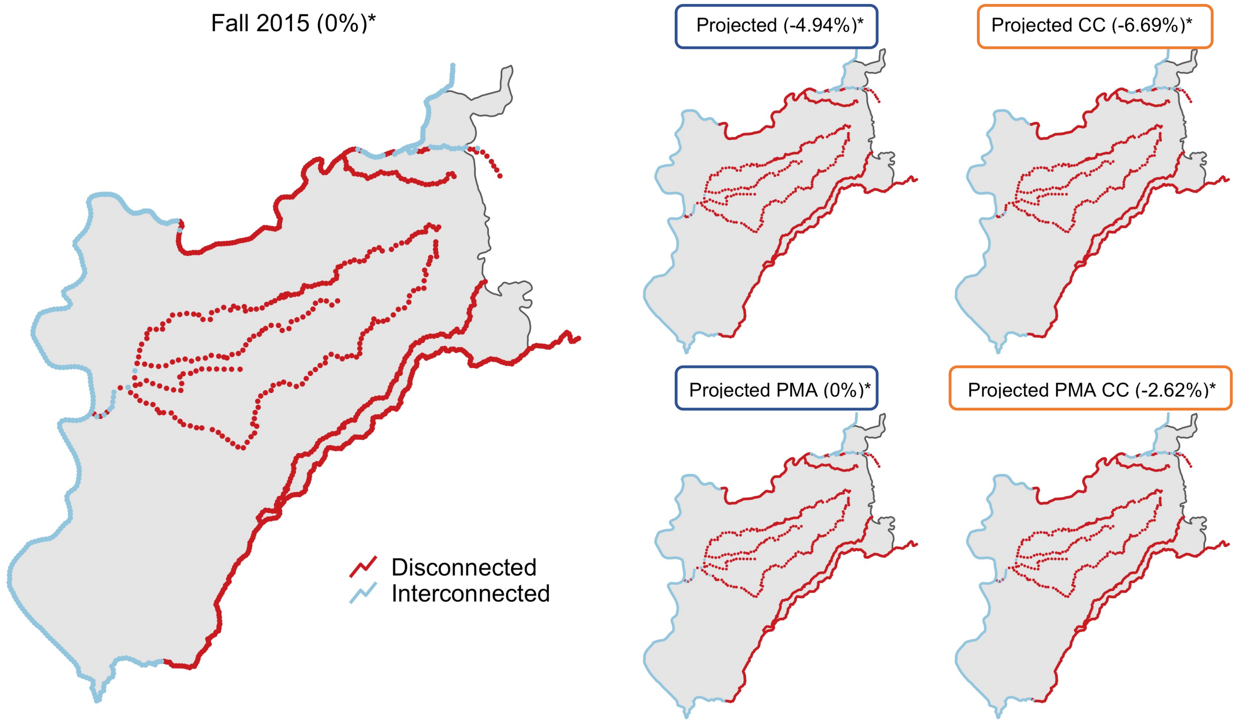
The actual location along the Cosumnes River where interconnection between surface and groundwater occurs should continue to be monitored and studied. Results suggest that seasonal average groundwater levels are not sufficiently high as to interconnect with streams, but some evidence of sub-seasonal connection exists, and this sub-seasonal connection may play a role in the maintenance of aquatic ecosystems. To better understand shorter-term interactions in this location, this region could be investigated with continuous groundwater and stream monitoring, which may improve understanding of sub-seasonal interconnection events and hydraulic gradients between surface and groundwater.

Figure 25: Probable ISW reaches by name, Disconnected reaches, and GSAs in the Basin. Monitoring points are assigned to nearby ISW reaches and are discussed in (SMC) *and Monitoring Approach*.

4.2.2 Impact of projected groundwater management on ISW reach length

The impact of projected groundwater conditions (including projects and management actions and climate change) on reach length were evaluated with Cosana (see Section 3.3 Forward simulations of Projects and Management Actions and Climate Change). Declines in the groundwater level may lead to disconnection events where previously interconnected stream nodes become disconnected, and conversely, increases in groundwater elevation may raise groundwater levels such that previously disconnected nodes become interconnected. Finally, the change in groundwater elevation may be such that connection or disconnection (relative to some historical benchmark) remains the same.

Results suggest that compared to a Fall 2015 baseline, projected conditions lead to a -4.94% decline in ISW reach length, and a 0% change if projects and management actions are implemented. The Harvest Water recharge project in the southern SASb substantially improves groundwater levels in and around the project area (Figure 22), resulting in a maintenance of ISW reach length. Decreases in reach length associated with climate change scenarios is attributable to increased temperatures and groundwater demand, but may be addressed with adaptative management.



*compared to the 'Fall 2015' scenario

Figure 26: Impact analysis of projected groundwater level scenarios (described in Section 3.3 Forward simulations of Projects and Management Actions and Climate Change) shows minimal impacts to ISW reach length across scenarios suggesting the avoidance of significant and unreasonable disconnection events. The "Projected" and "Projected PMA" scenarios (blue border) should be compared, and the "Projected CC" and "Projected PMA CC" scenarios (orange border) should be compared. In each pair of comparable scenarios, scenarios with PMA lead to a less than 5% reduction of ISW reach length compared to a 2015 baseline, and are generally more protective of ISW than scenarios without PMA.

4.3 Depletions of Interconnected Surface Waters

4.3.1 Comparison of current and projected seepage

Active ISW depletion is occurring in the SASb due to historical groundwater development and evidenced by the prevalence of disconnected surface water bodies and mostly losing stream reaches across the basin.

In practice, streamflow depletion is difficult to measure in the field, and varies considerably along a stream reach, thus it is almost always a modeled quantity. The

Cosana model simulates stream-aquifer exchange at stream nodes. The term that describes the flux of water between surface and groundwater bodies is called "Seepage". A negative seepage along a reach indicates losing stream conditions, and a positive seepage indicates gaining conditions (Figure 15). Cosana was used to simulate seepage under current conditions, as well as seepage under projected groundwater management and climate change (Figure 27) at ISW reaches identified above (Section 4.2 Location and Timing of Interconnected Surface Waters).

The primary driver of the direction and magnitude seepage is the relationship between groundwater elevation and the stream stage elevation. Generally speaking, water flows from areas of higher elevation to lower elevation as a result of potential energy and gravity, and thus changes in groundwater elevation (e.g., from pumping or recharge) and stream stage (e.g., from diversions or floods) change the relationship between groundwater and surface water elevations (Figure 1), and hence, the seepage. Overall, surface waters in the SASb exhibit seasonally and interannually variable stream depletion that results from the relationship between groundwater elevation and stream stage.

The magnitude of ISW depletion at interconnected stream reaches (Figure 27) is greatest along the Sacramento River due to its relatively larger stream geometry and larger volumetric flow compared to the American, Cosumnes, and Mokelumne Rivers. The American River is heavily managed and thus flows that are held back in Folsom reservoir generally decrease the magnitude of seepage along this river compared to what they may be in unmanaged conditions.

Projects and management actions generally reduce loss from losing streams and increase baseflow to gaining streams. Across all ISW reaches, all gaining and losing reaches remaining predominately gaining or losing reaches under all scenarios. A notable exception is Morrison Creek upstream of the Sacramento River, which is predominately losing assuming climate change and no PMA. Overall, projected management and PMA tend to either improve or maintain current conditions (Figure 27).

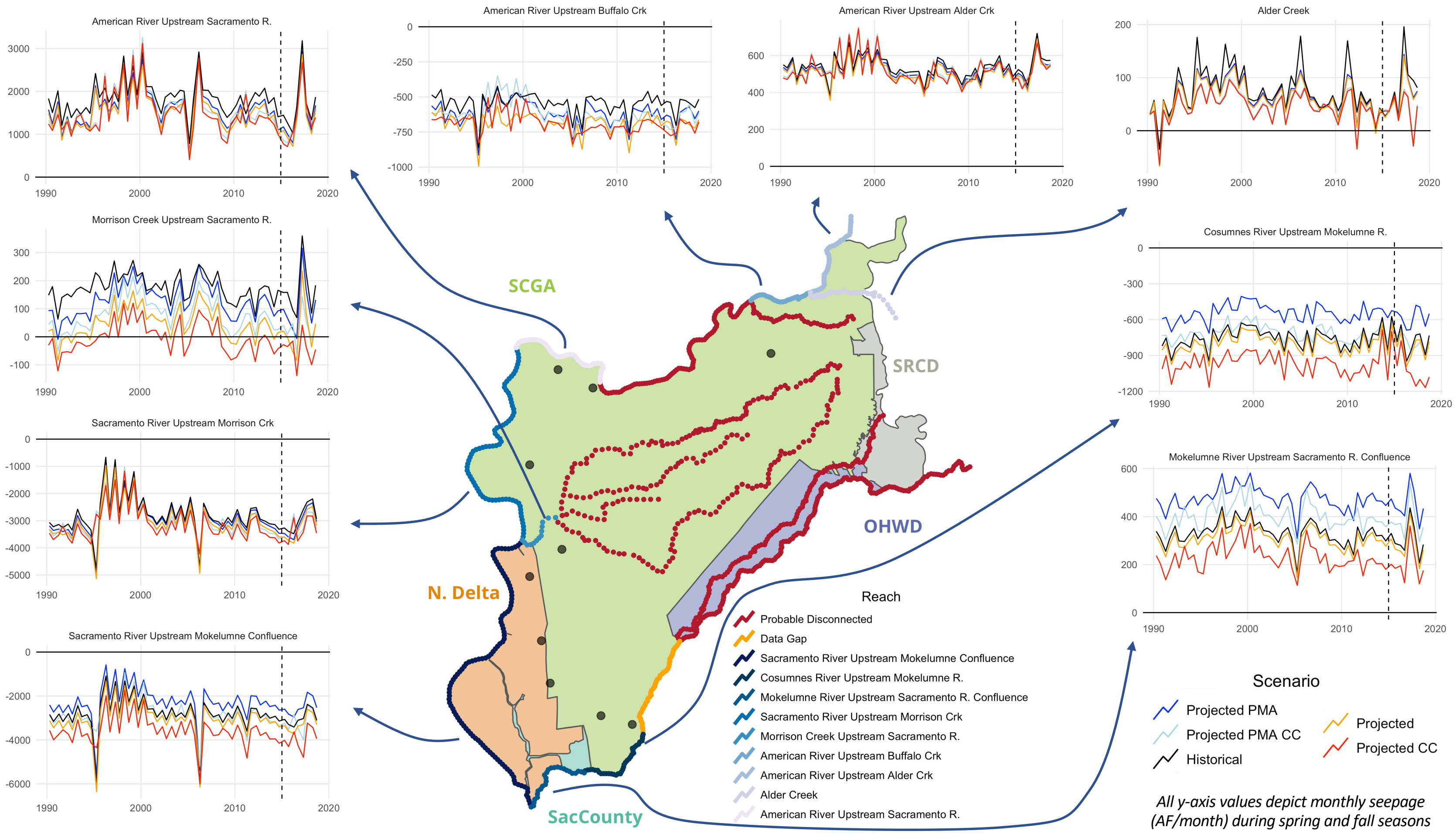


Figure 27: Seasonally averaged ISW depletion estimated by CoSANA at ISW designated reaches over the current conditions baseline model simulation is relatively constant. Negative numbers indicate losing stream conditions (stream loss to groundwater) and positive number indicate gaining stream conditions (stream gain from groundwater). Spring (February - April) and fall (August - October) depletion rates are averaged per month in each 3-month seasonal window. A black vertical dashed line at 2015-01-01 is drawn for reference, and a black solid horizontal line at y = 0 indicates the transition from gaining to losing conditions. Most scenarios have little impact on seepage. The Cosumnes and Mokelumne gain more under projected conditions, even with climate change. Morrison Creek loses more in all scenarios.

4.3.2 Dependence of seepage on water year type

Dry years tend to encourage groundwater pumping – this lowers groundwater level adjacent to streams, and hence, steepens the gradient between surface and groundwater bodies. A steeper hydraulic gradient between surface and groundwater[18], particularly in the losing streams found in the SASb, intensifies and increases depletion volumes.

Wet years sometimes lead to increased seepage from losing streams to groundwater due to excess water in stream channels that increases the hydraulic gradient. Increased seepage to groundwater during these wet years should not be interpreted as damaging aquatic habitats or ecosystem functions, but rather, as the result of floods and increased hydraulic head in rivers[19]. If the elevation of adjacent groundwater is relatively high and wet years have the effect of increasing groundwater level, the opposite effect can occur, and increased groundwater levels contribute to streamflow, observed in positive spikes in the seepage timeseries of the Mokelumne River upstream of the Sacramento River confluence.

Many factors influence seepage. Within the context of SGMA, it is important for management plans to evaluate how groundwater management may alter stream-aquifer interactions that lead to undesirable results for ISW or beneficial users of ISW. Measurable quantities that may be used in management plans include alterations to the reach length of identified ISW, changes in ISW seepage, and changes in critical flows for fish passage.

4.4 Location and Timing of Gaining and Losing Reaches

Although not directly managed by SGMA, an understanding of location and timing of gaining and losing streams is critical to anticipate how depletions of ISW may change under different water management scenarios. Importantly, a conceptual understanding of gaining and losing stream conditions may help identify *losing connected* and *gaining* reaches that should be maintained, to prevent the transition of ISW to losing disconnected reaches (Figure 15). Gaining and losing reaches according to Cosana are presented.

Seepage calculated by Cosana can be positive (stream gains from groundwater) or negative (stream loses to groundwater). The seasonal gaining and losing conditions for each reach (Figure 29) demonstrate consistent and mostly losing conditions (red) over

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[18] Hence, arresting the steepness of the hydraulic gradient between surface and groundwater is the management approach proposed in this memo, consistent with recommendations by Hall, Babbit, Saracino, and Leake (2018).

[19] Increased depletion during wet years along losing reaches that result from higher hydraulic head in streams (i.e., flood conditions) motivates sustainable management criteria based on groundwater levels rather than estimated depletion volume, because groundwater levels adjacent to streams represent the impact of groundwater management decisions that ultimately impact streams. Thus, SMC based on groundwater elevation more accurately target groundwater management.

time, apart from gaining reaches (blue) along the upper and lower American river, and the Mokelumne river. The average reach-level seepage across the period of record from 2005-2018 (Figure 28) does not appreciably differ between spring and fall.

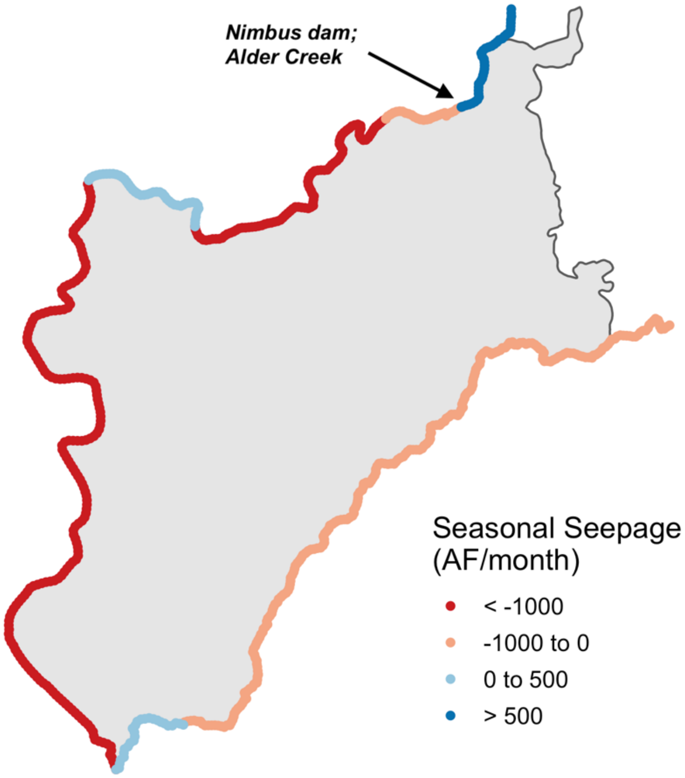

Figure 28: Average reach-level seasonal seepage from 2005-2018 computed by Cosana show gaining sections along the Mokelumne River, the lower American River downstream of the H Street bridge, and the American River upstream of Alder Creek (Nimbus dam), otherwise known as Lake Natoma. In this figure, spring and fall seasons are averaged because they do not appreciably differ.

Gaining and losing reach characterization is important insofar as it informs the hydrogeologic conceptual model of stream-aquifer interactions in the basin and provides a benchmark against which projected changes can be compared to. Future groundwater management planning should consider how projected groundwater use may impact gaining and losing systems. In particular, gaining and losing ISW that depend on minimum flows for fish migration may be sensitive to changes in seepage that deplete surface waters.

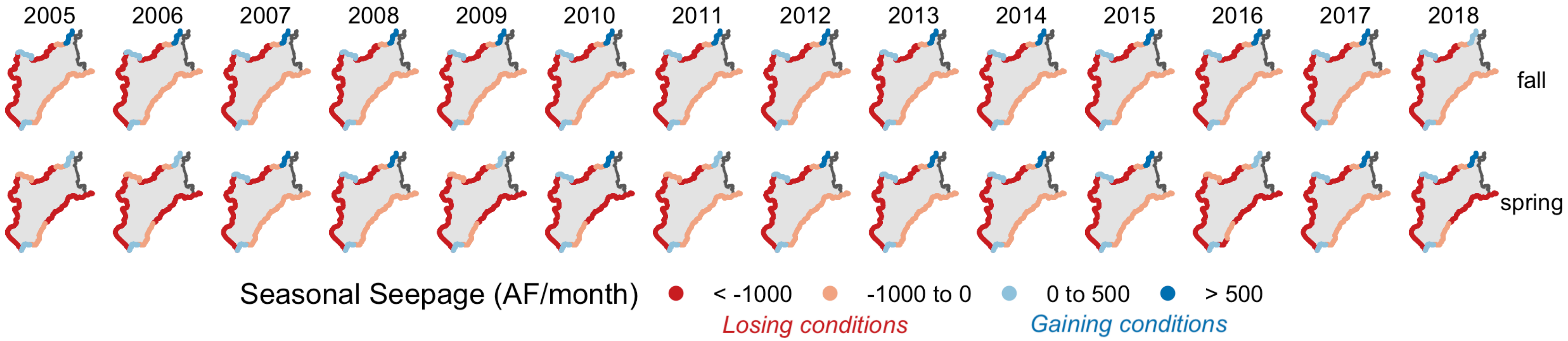

Figure 29: Major gaining and losing stream reaches from 2005-2018 in fall and spring according to the current conditions baseline. Average seasonal seepages show mostly losing (red) reaches.

4.5 Impacts to Streamflow

As in previous subsections, Cosana was used to compare the current conditions baseline scenario to projected management and climate change scenarios (3.3 Forward simulations of Projects and Management Actions and Climate Change). Streamflow exceedance probability at the outlets of the American, Cosumnes, and Sacramento rivers was compared across all scenarios. Exceedance probability represents the probability that a certain flow will be met or exceeded based on the hydrology observed during a period of record. The periods of record considered in this study are equivalent in length and based on monthly average streamflow values calculated by Cosana from 1990-2018 (and based on that hydrology). “Projected” and “Projected PMA” scenarios show increases in streamflow in the Sacramento and Cosumnes Rivers between 1-16%, and a negligible -1% decrease in the American River. Increases in flow, particularly in the Cosumnes River are attributable to increased groundwater elevations from the Harvest Water project and other regional conjunctive use projects (Figure 22), which increase local groundwater conditions upwards of 25 feet, thus reducing seepage from streams to groundwater along the losing Cosumnes River, and increasing baseflow to the gaining Mokelumne River (Figure 27).

Climate change scenarios cause outsized direct reduction in streamflow unrelated to groundwater management. Comparison of “Projected CC” and “Projected PMA CC” shows that across all ISW in the SASb, PMA dampen the impact of climate change on streamflow.

Table 3: October-December simulated streamflow for the American, Cosumnes, and Sacramento rivers under current conditions (Baseline), and projected scenarios (also see Figure 30)

River	Scenario	10th percentile (cfs)	25th percentile (cfs)	50th percentile (cfs)	75th percentile (cfs)	90th percentile (cfs)	% Difference in 50th percentile exceedance compared to Baseline
American	Baseline	4037	2714	2025.29	1283	914	0%
American	Projected PMA	4019	2699	2004.91	1266	892	-1%
American	Projected PMA CC	2346	2181	701.37	584	507	-65%
American	Projected	4020	2692	2000.04	1261	888	-1%
American	Projected CC	2337	2177	693.52	579	503	-66%
Cosumnes	Baseline	1662	523	153.77	47	35	0%
Cosumnes	Projected PMA	1695	564	177.93	59	45	16%
Cosumnes	Projected PMA CC	1752	462	142.91	52	37	-7%
Cosumnes	Projected	1679	537	163.59	52	40	6%
Cosumnes	Projected CC	1742	443	134.42	48	34	-13%
Sacramento	Baseline	36150	19323	13857.07	11294	8554	0%
Sacramento	Projected PMA	36441	19537	13969.06	11424	8672	1%
Sacramento	Projected PMA CC	24794	14612	11300.27	8206	6822	-18%
Sacramento	Projected	36421	19514	13943.24	11401	8648	1%
Sacramento	Projected CC	24763	14585	11270.08	8181	6797	-19%

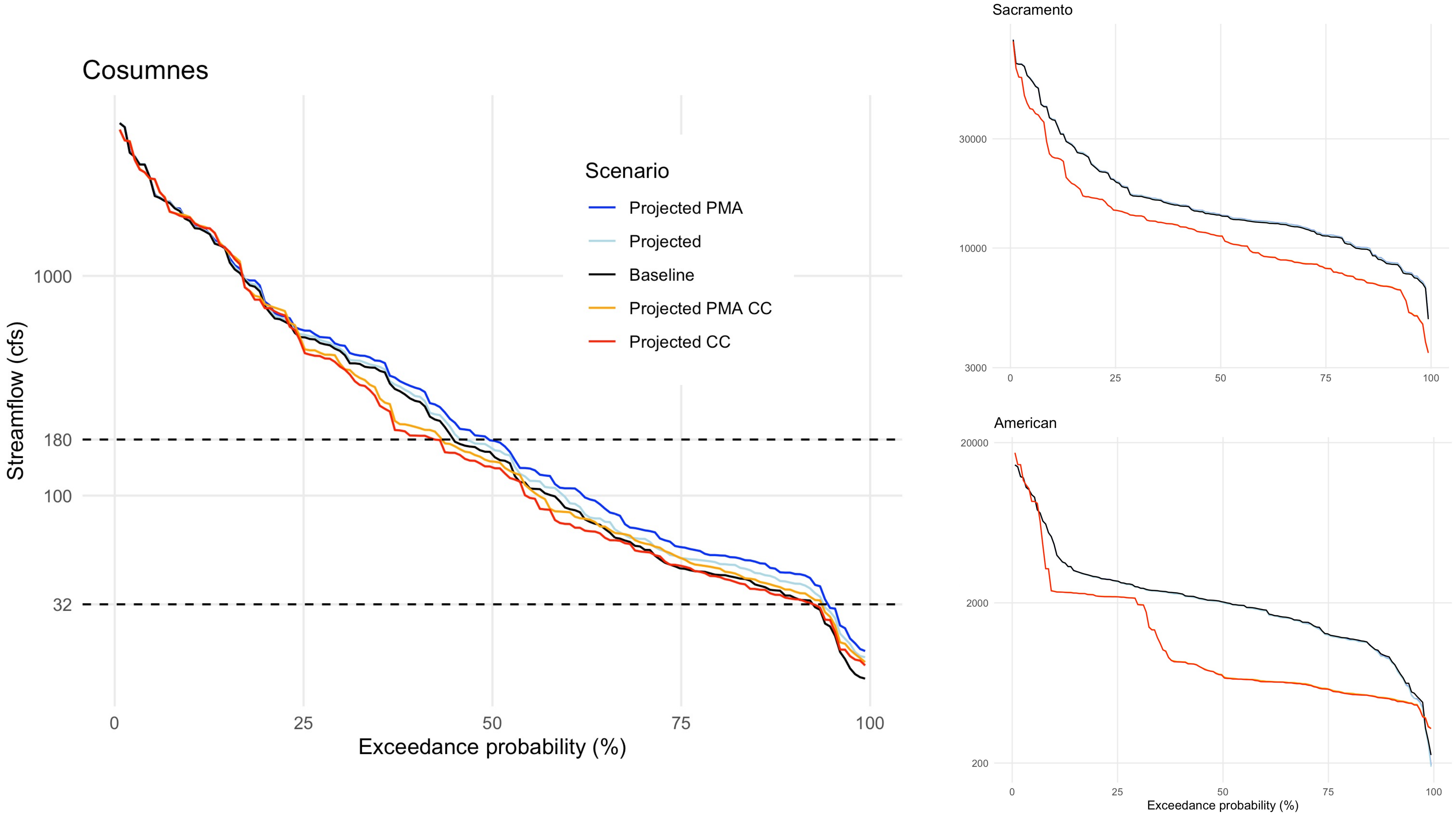

Figure 30: All projected scenarios show minimal impacts to October-December streamflow exceedance (Table 3) at ISW locations along the Cosumnes, Sacramento, and American rivers when compared to current conditions baseline flows (black solid line). American and Sacramento flows are only impacted by climate change and the absence of PMA (overlapping red and orange lines). In the Cosumnes, PMA introduction improves flow conditions, and projected management does not differ from current conditions. Black dashed horizonal lines on the leftmost plot indicate the envelope of flow target values reported by literature to support fish passage during low-flow October-December spawning months. The lower bound of this envelope (32 cfs) has a 90% exceedance probability across all scenarios which implies fish passage during spawning months. Due to modeling constraints, flows are estimated at the downstream outlets of the Cosumnes and Sacramento Rivers in the model domain. American River flows are estimated at H Street Bridge. Note the log-scale y-axis.

4.6 Satellite Analysis of Wetting and Drying

High spatial resolution, pan-sharpened, 30-centimeter satellite imagery from Google Earth Pro was used to qualitatively assess “drying” events along the ephemeral Cosumnes River. Results demonstrate the feasibility of commercial, on-demand imagery (e.g., Planet 50-centimeter satellite imagery) to assess drying events (Figure 31). True color composite images taken in the visible spectrum of light (380-750 nanometers) work best in cloud-free environments. Dry summer months when the Cosumnes is most likely to experience “drying” events co-occur with relatively cloud-free days with low atmospheric moisture, and thus the feasibility of using high resolution remote sensing to broadly assess ISW monitoring is promising.

Figure 31: Selected dates of 30-centimeter pan-sharpened true color images of a selected location along the Cosumnes River qualitatively demonstrate the effectiveness high-resolution satellite imagery in determining drying events.

Aerial images can only indicate if reaches have dried out or stranded some sections of river which may serve as critical fish passage and habitat. These images cannot, however, indicate if surface and groundwater become disconnected, and are thus not practical approaches for measurable strategies for sustainable groundwater management. Sustainable management criteria for groundwater based on the observation of dry streams in satellite imagery is thus misguided: ephemeral stream reaches are likely to dry out from upstream conditions (i.e., dry and critical years with little rainfall), which are completely unrelated to the impact of groundwater management (e.g., pumping). Thus, developed SMC in this memorandum rely on in-situ groundwater level observations to identify changes in groundwater level that would lead to increased ISW depletion. Nevertheless, remote sensing of the Cosumnes River presented in this study demonstrate the utility of remote sensing analysis towards improving regional understanding of drying events on surface water bodies.

Finally, coarser resolution, publicly accessible imagery from the Sentinel II satellite (10-meter spatial resolution) were assessed as a potential low-cost alternative to high resolution imagery, but it was determined that the features of interest are too coarse at

10-meter scale (Figure 32, Figure 33). This was unsurprising as some stream channels along the Cosumnes River can fit within less than one grid cell to a few grid cells.

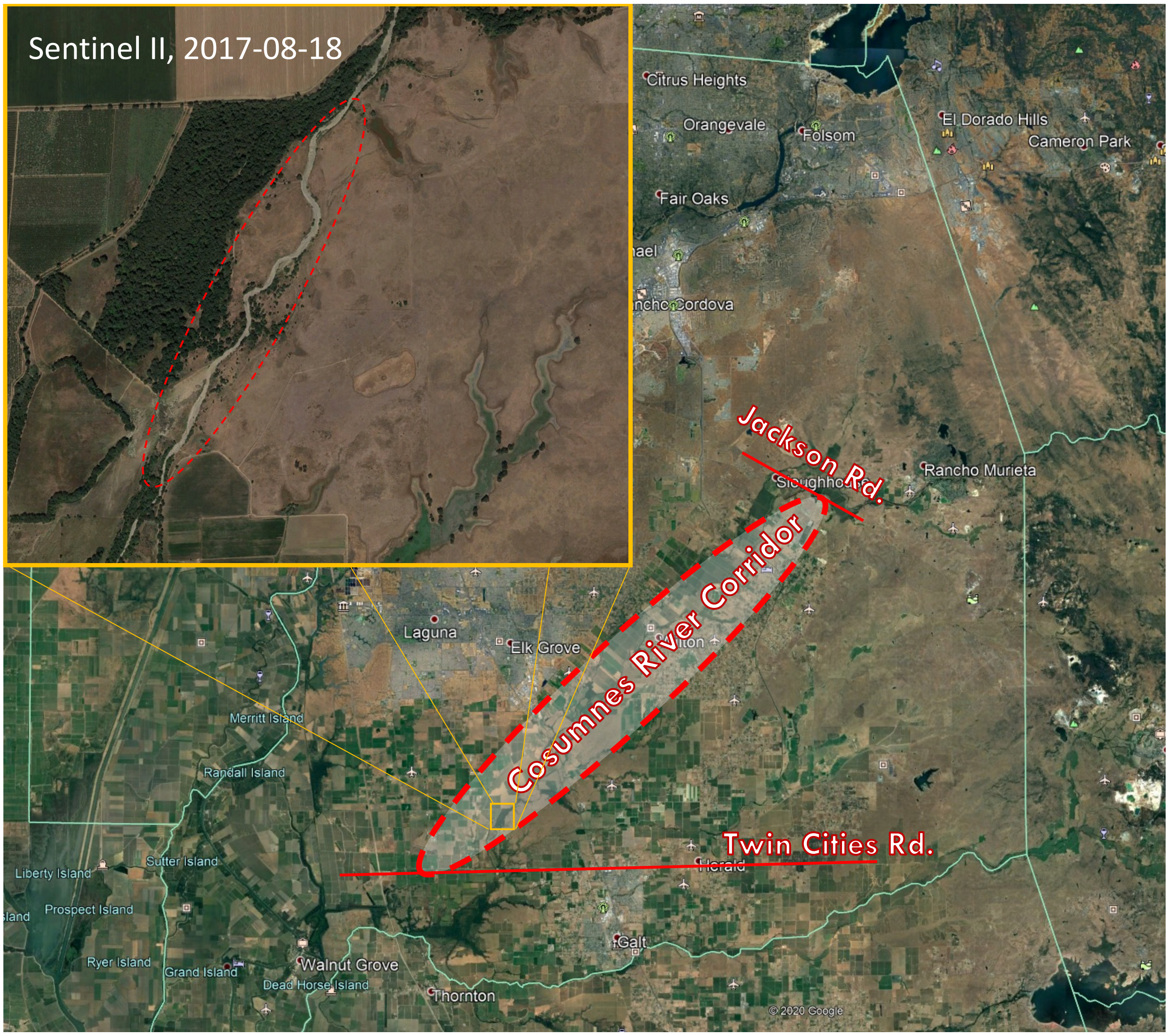

Figure 32: Sentinel II, which offers 10-meter resolution in the visible spectrum and regular flyovers of the SASb was investigated but did not offer appropriate spatial resolution for the task of qualitatively determining drying events.

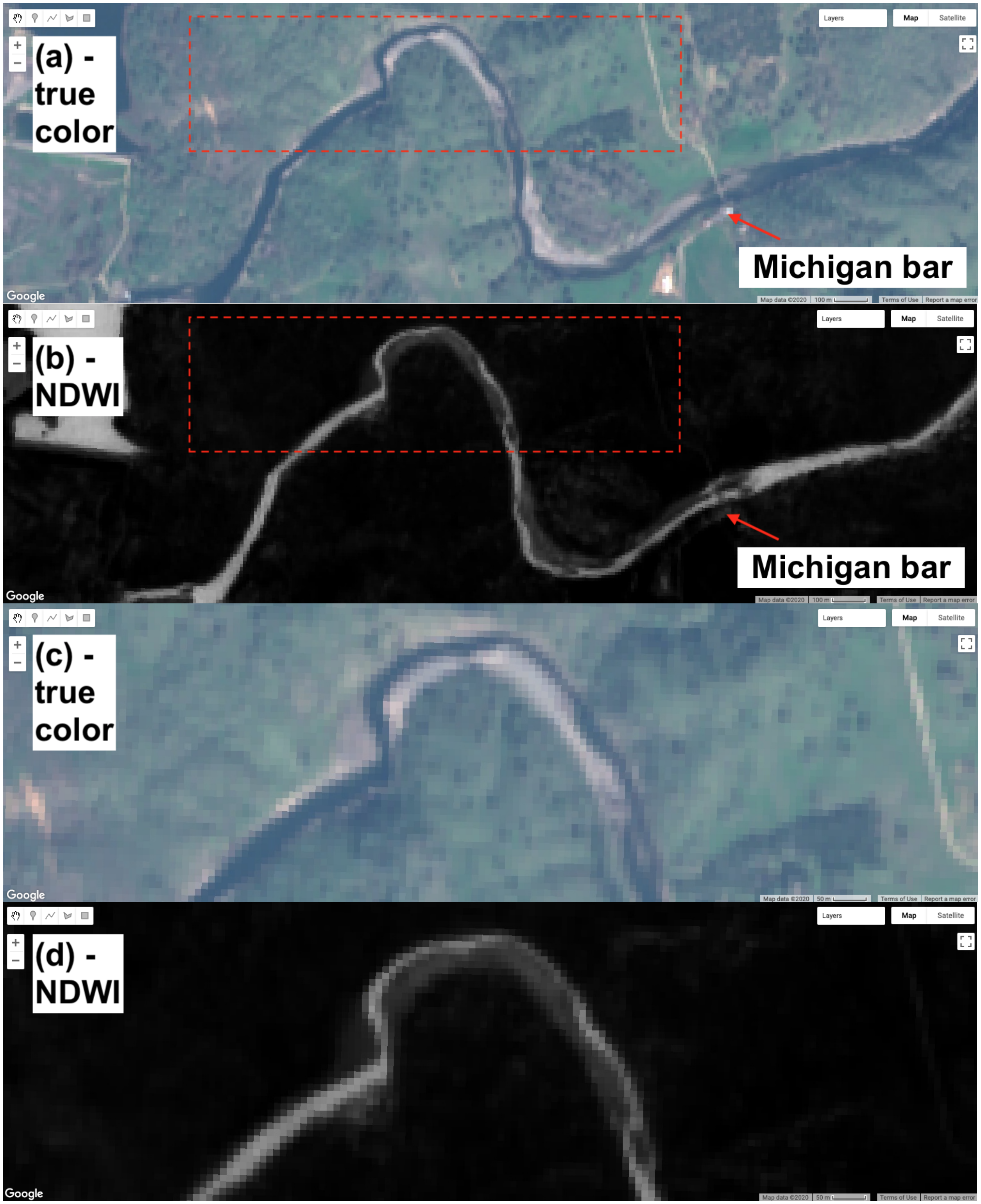

Figure 33: Sentinel-2 true color and NDWI near Michigan Bar on the Cosumnes River for the period from 2018-02-01 to 2018-03-3. Lower right scale bar is 100m in ***(a-b)****, and 50m in* ***(c-d)****. Dotted region in* ***(a-b)*** *is zoomed into in* ***(c-d)****.*

5. Limitations

Average regional, seasonal groundwater level cannot capture shorter-term connections between groundwater and surface water, or the impact of perched zones. Some studies suggest that on sub-monthly timescales, groundwater adjacent to streams may demonstrate higher hydraulic head than in the stream, consistent with gaining stream conditions. However, these trends often dissipate when looking at average conditions across the season. Therefore, the ISW mapping resulting from this study should be interpreted as regional and seasonal average conditions.

We ignore capillary action due to poorly constrained local-scale geologic data for the sediment underlying the streambed, but incorporation of these processes may allow in some cases for surface water to interconnect over a few more feet. To compensate for this effect, we conservatively consider an entire reach as connected if the majority of stream nodes within a reach are interconnected. This causes ISW classification to trend further upstream than what best available data suggest.

ISW connection estimates depend strongly on groundwater elevation data and thalweg elevation data, both of which always have room for improvement. Groundwater elevation data near streams is particularly important to refine ISW location estimates. Higher resolution thalweg elevation data may be obtained from local surveys and remote sensing (e.g., drones using LiDAR to acquire stream bathymetry data). The cost of these expeditions should be weighed against their ability to improve upon existing data, and the period of which the acquired data may become invalid (e.g., in the case of a large flood which scours channel geometry and changes the thalweg elevation).

6. Conclusion and Management Recommendations

In this section we summarize the main findings of the study and then advance management recommendations that pertain to SMC as defined by SGMA for the avoidance of Undesirable Results to beneficial users and users of ISW.
Data-driven analyses and modeling presented in this study show the location of ISW along the American, Sacramento, Mokelumne, and Cosumnes Rivers where ISW are located based on a historical (2005-2018)[20] analysis of seasonal groundwater elevation, thalweg elevation, and reach-level seepage. Modeled projected management and projects and management actions (PMA) generally improve ISW conditions compared to equivalent scenarios without PMA. Climate change has negative impacts of ISW streamflow, but these impacts are isolated from groundwater management actions.

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[20] Groundwater level analyses with data run from 2005-2018, and analyses of Cosana-calculated seepage runs from 2005-2018 because 2018 is the final year in which output is available at the time of writing.

Management actions should emphasize maintenance of ISW within reasonable margins, such that undesirable results to ISW are strictly defined. The strong dependence of threatened and endangered species on streamflow also suggests that SMC should emphasize similar quantitative criteria at which undesirable results are experienced. For example, the identification of undesirable results due to ISW depletion may include significant and unreasonable:

- percent decline in an ISW reach length
- percent decline in median exceedance probability at ISW reaches

Importantly, these metrics should be easy to measure over time to inform GSP implementation. Furthermore, the GSP should clearly link groundwater level declines to the above measurable outcomes so that groundwater level may be used as a proxy for ISW depletion.

6.1 Sustainable Management Criteria (SMC) and Monitoring Approach

SMC are monitored at representative monitoring points (RMPs), and it is critical that these RMPs are strategically sited to best represent changes in hydraulic gradient that indicate ISW depletion (Figure 34).

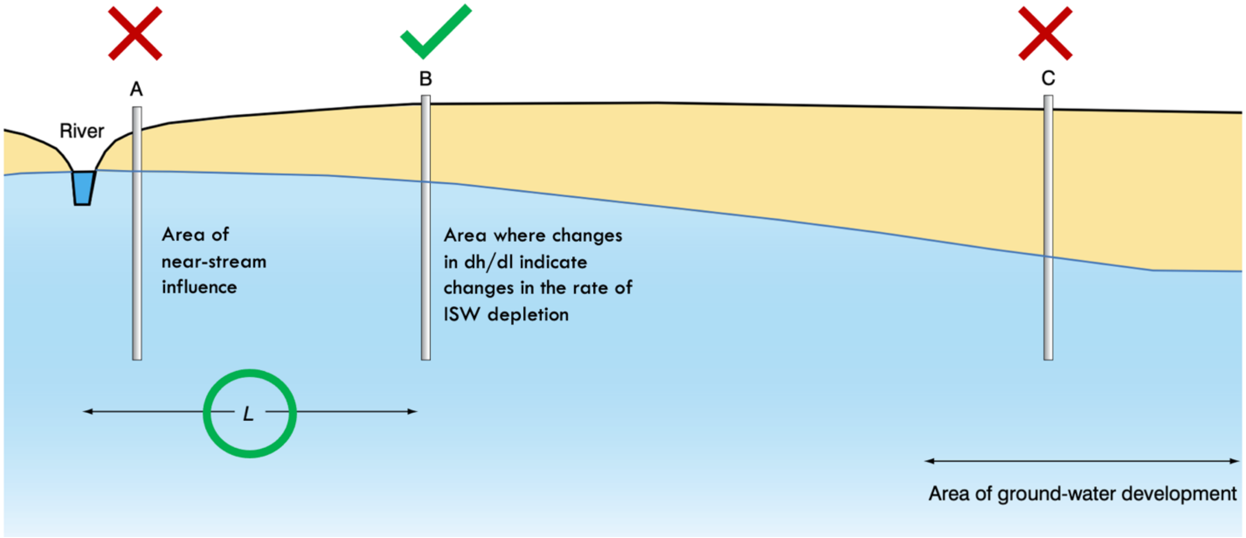

Figure 34: Monitoring wells for ISW depletion should be selected at a distance away from ISW such that areas of near-stream influence (A) and groundwater pumping (C) are avoided. Rather, groundwater levels should reflect the zone in which a propagating cone of depression has yet to reach the stream (B). In this way, monitoring reflects ambient groundwater conditions that may be impacted by overextraction, and anticipates ISW depletion. Modified from (EDF, 2018).

Analysis of hydraulic gradients along transects perpendicular to ISW demonstrated a buffer between 3000 and 9000 feet from ISW with relatively flat hydraulic gradients that appear to be unimpacted by near-stream influences or groundwater pumping. It is in this buffer that shallow monitoring wells were selected (Figure *27*). Whenever possible and appropriate, selected monitoring wells were drawn from the existing groundwater level network to minimize monitoring.

UC Davis and Sacramento State monitoring wells are situated in key locations and harbor valuable historical data, but the likelihood of these institutions supporting measurements over the GSP implementation timescale should not be taken for granted. It is recommended that the GSP monitoring effort coordinate with these entities to secure long-term monitoring, at least on a biannual basis.

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Appendix A: Hydrographs

Appendix 3-B

Table 1: RMP ID to SITE CODE key for groundwater level, storage, and ISW RMPs in the SASb

Appendix 3-B

Table 1: RMP ID to SITE CODE key for groundwater level, storage, and ISW RMPs in the SASb. This key is used to translate new RMP site IDs to older data tracking systems which may use DWR SITE CODEs identification numbers.

RMP ID	**SITE CODE**
RMP_01	382604N1214665W001
RMP_02	382939N1213904W001
RMP_03	MW_17
RMP_04	383009N1214224W001
RMP_05	MW_2
RMP_06	383270N1214736W001
RMP_07	383610N1214825W001
RMP_08	383728N1214548W001
RMP_09	MW_DR1
RMP_10	384125N1214946W001
RMP_11	384150N1213239W001
RMP_12	384202N1213738W001
RMP_13	ACR_13
RMP_14	384343N1214615W001
RMP_15	ACR_14
RMP_16	384425N1213031W001
RMP_17	384532N1212856W001
RMP_18	ACR_16
RMP_19	384738N1214249W001
RMP_20	384783N1212311W001
RMP_21	384798N1212614W001
RMP_22	384931N1211797W001
RMP_23	ACR_76
RMP_24	385021N1214948W001
RMP_25	385038N1212203W001
RMP_26	385190N1213015W001
RMP_27	385223N1213630W001
RMP_28	ACR_77
RMP_29	385343N1214280W001
RMP_30	385469N1213389W001
RMP_31	385543N1212592W001
RMP_32	385578N1213240W001

RMP_33	SS_MW1
RMP_34	SS_DWR2D
RMP_35	SS_DWR3D
RMP_36	385707N1211868W001
RMP_37	385784N1214655W001
RMP_38	385849N1213173W001
RMP_39	ARJ1256
RMP_40	385914N1212475W001
RMP_41	385923N1211621W001
RMP_42	ARJ188
RMP_43	ARJ3390
RMP_44	386578N1211879W001
RMP_45	386895N1211169W001

Appendix 3-C

Vulnerable well impact analysis in the South American Subbasin: well inventory, historical groundwater trends, and analysis to inform Sustainable Management Criteria (October 1, 2021)

Vulnerable well impact analysis in the South American Subbasin: well inventory, historical groundwater trends, and analysis to inform Sustainable Management Criteria

Larry Walker Associates

2021-10-01

Table of Contents

1. Executive Summary

Groundwater planning under the Sustainable Groundwater Management Act (SGMA) aims to curb the chronic lowering of groundwater levels, which may impacts shallow, vulnerable wells and cause dewatering or failure. Relatively shallow residential, agricultural, and public wells (henceforth “vulnerable wells”) in the South American Subbasin (SASb) are beneficial uses of groundwater identified by stakeholders in the SASb groundwater sustainability plan (GSP) working group. Residents and water users in the SASb that rely on drinking water obtained from private domestic wells are considered beneficial users of groundwater. The GSP aims to avoid chronic groundwater level decline that leads to significant and unreasonable impacts to vulnerable wells that hamper access to water for drinking, irrigation, and municipal use.

Although shallow wells in the SASb provide beneficial uses of groundwater, the SASb lacks a comprehensive well census (i.e., inventory) and understanding of how sustainable management criteria (SMC) may impact vulnerable wells in the SASb. These knowledge gaps motivate this memorandum, which aims to provide a well inventory based on best available data, and well protection analysis to inform critical decision-making in support of unstainable groundwater management in the SASb.

No wells in the SASb were reported dry during the past 2012-2016 drought. Herein, we assess potential impacts to vulnerable wells that may result during the SGMA planning and implementation period (2022-2042). First, we take inventory of wells in the SASb using publicly available, digitized well completion reports to describe the location and depths of different types of wells (e.g., domestic, public, agricultural). Next, we analyze historical groundwater elevation trends in the SASb from 2005-2018. Then, we combine well construction data and modeled groundwater levels to assess the count and location of impacted wells assuming different groundwater level scenarios (i.e., a return to the fall 2015 low, and 4 projected groundwater management and climate change scenarios). Finally, we estimate costs to rehabilitate impacted wells and advance recommended sustainable management criteria that mitigate impacts to vulnerable wells.

Results suggest that the most common well types with direct beneficial uses are domestic (n = 2,600), agricultural (n = 532), and public (n = 237) wells[1], although the actual number of “active” wells today is likely less due to ageing and well retirement. Assuming 31 to 40 year retirement ages (based on Pauloo et al, 2020), and that wells with pumps above initial groundwater level conditions are inactive, the number of

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[1] At the time of writing (2021-06-18), these are the well counts provided by the online well completion report database. Note that public wells are “municipal” wells, and domestic wells are private residential wells.

assumed active wells in the SASb is much lower: domestic (n = 372 - 709), agricultural (n = 72 - 99), and public (n = 62 - 101). An ongoing well "census" would be supersede these data, but in its absence, this approach provides a reasonable approximation of the count and location of active wells.

During fall of 2015, groundwater levels reach a [modern] historical low in the SASb after four consecutive years of drought and excess pumping to augment lost surface water supply. Data from the DWR and Cal OPR suggests that during this time, no wells in the SASb were reported dry, in contrast to more than two thousand wells reported dry across California (Pauloo et al, 2020)[2]. Thus, a return to Fall 2015 groundwater level lows is unlikely to result in catastrophic and widespread well impacts, which we confirm via modeling described in this memorandum.

Working group input indicated significant and undesirable results to include 5% or more of impacted wells of any type (domestic, agricultural, public). Thus, well impact analysis under projected groundwater level conditions was evaluated to assess impacts assuming a return to historic Fall 2015 lows, and projected groundwater management and climate change scenarios. Results suggest that even assuming a worst-case climate change scenario with no projects and management actions (PMA) – which is unlikely as PMA are already underway – all well types are unlikely to impacted at the 5% undesirable result threshold.

Well protection analysis thus informed the creation of minimum thresholds (MTs) which avoid significant and unreasonable impacts to wells in the basin. Well rehabilitation costs for impacted wells over the implementation horizon, assuming all MTs are reached at all representative monitoring points (RMPs), were estimated at around $300,000 - $700,000 following the cost structure of Pauloo et al. (2021), EKI (2020), and Gailey (2019), but would likely be less, as significant and unreasonable impacts occur when 25% of RMPs exceed MTs.

Possible well protection measures may include a combination of regional groundwater supply and demand management (e.g., managed aquifer recharge and pumping curtailments that increase or maintain groundwater levels); well protection funds to internalize well refurbishment and replacement costs; domestic supply management, (e.g., connecting rural households to more reliable municipal water systems); and proactive community-based monitoring that acts as an early warning systems to anticipate impacts at the level of individual wells.

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[2] Outage data analyzed by Pauloo et al (2020) was provided via an agreement between Cal OPR and the authors, but has since been released by the DWR at MyDryWaterSupply: https://mydrywatersupply.water.ca.gov/report/publicpage.

2. Introduction

Around 1.5 million Californians depend on private domestic wells for drinking water, about one third of which live in the Central Valley (Johnson and Belitz 2016). Even fewer reside in the South American Subbasin (SASb), and these wells tend to be in mixed agricultural-residential land. Private domestic wells are more numerous than other types of wells (e.g., public or agricultural), and tend to be shallower and have smaller pumping capacities, which makes them more vulnerable to groundwater level decline (Theis 1935; Theis 1940; Sophocleous 2020; Greene 2020; Perrone and Jasechko 2019). During previous droughts in California, increased demand for water has led to well drilling and groundwater pumping to replace lost surface water supplies (Hanak et al 2011; Medellín-Azuara et al 2016). Increased pumping lowers groundwater levels and may partially dewater wells or cause them to go dry (fail) altogether. During the 2012–2016 drought, 2,027 private domestic drinking water wells in California's Central Valley were reported dry (Cal OPR 2018). Notably, zero dry wells were reported in the SASb, which suggests a combination of relatively stable groundwater levels and more favorable well construction properties (e.g., deeper wells and pump locations). Moreover, this observation implies that a return to 2015 low groundwater levels is unlikely to cause widespread and catastrophic well failure in the SASb.

Until recently, few solutions and data products existed that addressed the vulnerability of shallow wells to drought and unsustainable groundwater management (Mitchell et al. 2017; Feinstein et al. 2017). A lack of well failure research and modeling approaches can largely be attributed to the fact that well location and construction data (well completion reports, or WCRs) were only made public only in 2017. Released digitized WCRs span over one hundred years in California drilling history and informed the first estimates of domestic well spatial distribution and count in the state (Johnson and Belitz 2015; Johnson and Belitz 2017). Since then, these WCRs, provided in the California Online State Well Completion Report Database (CA-DWR 2018), have been used to estimate failing well locations and counts (Perrone and Jasechko 2017), and domestic well water supply interruptions during the 2012–2016 drought due to overpumping and the costs to replenish lost domestic water well supplies (Gailey et al 2019). A regional aquifer scale domestic well failure model for the Central Valley was developed by Pauloo et al (2020) that simulated the impact of drought and various groundwater management regimes on domestic well failure. More recently, Bostic and Pauloo et al (2020), EKI (2020), and Pauloo et al (2021), estimated the impact of reported groundwater level minimum thresholds in critical priority basins on domestic wells across California's Central Valley and found that thousands of domestic wells were potentially vulnerable.

California's snowpack is forecasted to decline by as much as 79.3% by the year 2100 (Rhoades et al 2018). Drought frequency in parts of California's Central Valley may increase by more than 100% (Swain et al 2018). A drier and warmer climate (Diffenbaugh 2015; Cook 2015) with more frequent heat waves and extended droughts (Tebaldi et al 2006; Lobell et al 2011) will coincide with urban development and population growth, land use change, conjunctive use projects, and implementation of the Sustainable Groundwater Management Act (SGMA 2014), in which groundwater sustainability plans (GSPs) will specify groundwater level minimum thresholds (MTs) that among other outcomes, protect vulnerable wells.

In this technical memorandum, we analyze how projected hydrologic conditions, projects and management actions (PMA), and climate change may impact vulnerable wells in the SASb. In Section 3, the methodology is explained, followed by the results in Section 4, and a discussion of the results in terms of how they impact sustainable groundwater management in Section 5. This memorandum closes with a discussion of future actions and SGMA management recommendations.

3. Methods

Key data that inform this analysis include seasonal groundwater level measurements taken by various state-level and local sources, and well completion reports (WCRs) from the California Department of Water Resources (CA-DWR 2018).

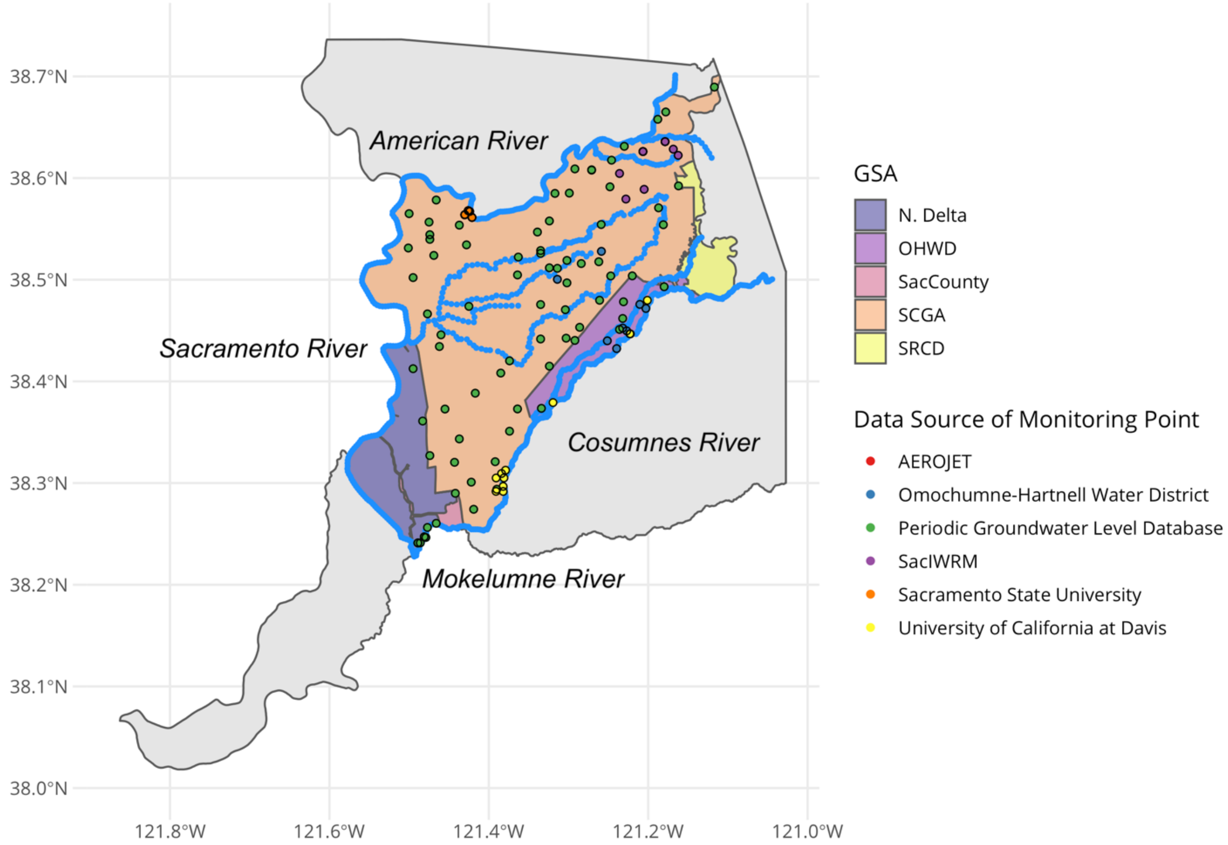

Figure 1. The South American Subbasin is an alluvial aquifer-aquitard system in California's Sacramento County (grey) housing 5 GSAs, and bordered by the American, Cosumnes, Mokelumne, and Sacramento Rivers on the north, east, south, and west boundaries respectively. Representation of these major surface water bodies in the Cosana integrated hydrologic model (including interior creeks) are shown in blue. Groundwater level monitoring points are colored by the data source of the monitoring point. Monitoring points outside of the SASb which were used in the groundwater level interpolation are not shown.

3.1 Groundwater level

Historic and present-day groundwater conditions were analyzed using all available data from six sources (Figure *1*):

(1) California Department of Water Resources (DWR) Periodic Groundwater Level Database
(2) University of California at Davis (UCD) monitoring network
(3) Omochumne-Hartnell Water District (OHWD) monitoring network
(4) Sacramento State monitoring wells
(5) Aerojet
(6) Sac IWRM

Most groundwater level data is collected biannually in spring and fall and intended to capture seasonal variation – notably due to winter recharge and pumping and recharge during the dry growing season. In the SASb, periodic groundwater level data measurements peak in April and October (Figure 2).

Biannual seasonal groundwater level within the Sacramento Central Groundwater Authority (SCGA) jurisdictional boundary has been measured for decades; these measurements account for most of the spatial spread of groundwater level observations in the SASb and can be found in the DWR Periodic Groundwater Level Database [source (1) above]. Three additional networks, either established or maintained by UCD, OHWD, and Sacramento State all collect high-frequency, 15-minute interval groundwater elevation data. The UC Davis network (2) is situated on land owned by the Nature Conservancy and has collected data fall of 2012, the OHWD network (3) has collected data since fall of 2018, and the Sacramento State network (4) has collected data since spring of 2016. Aerojet monitoring wells (5) used in this study have been collecting data since 1982 and are actively monitored as part of on-site monitoring and remediation actions. Sac IWRM (6) is hydrologic model that includes the SASb and incorporates historic groundwater monitoring data; most of these data are included in (1). Duplicate measurements between data sources were reconciled by comparing monitoring site identification codes and position (latitude and longitude).

Groundwater levels were assessed at biannual seasonal intervals during the period from spring 2005 to fall 2018 and encompass what can be considered “historic”[3] to approximately “present-day” seasonal conditions. This temporal range was selected because poor data density prior to spring 2005 and after fall 2018 prohibits meaningful analysis. “Spring” was defined as the months of March, April, and May and “fall” was defined as the months of August, September, and October.

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[3] Importantly, this period contains the recent 2012-2016 drought.

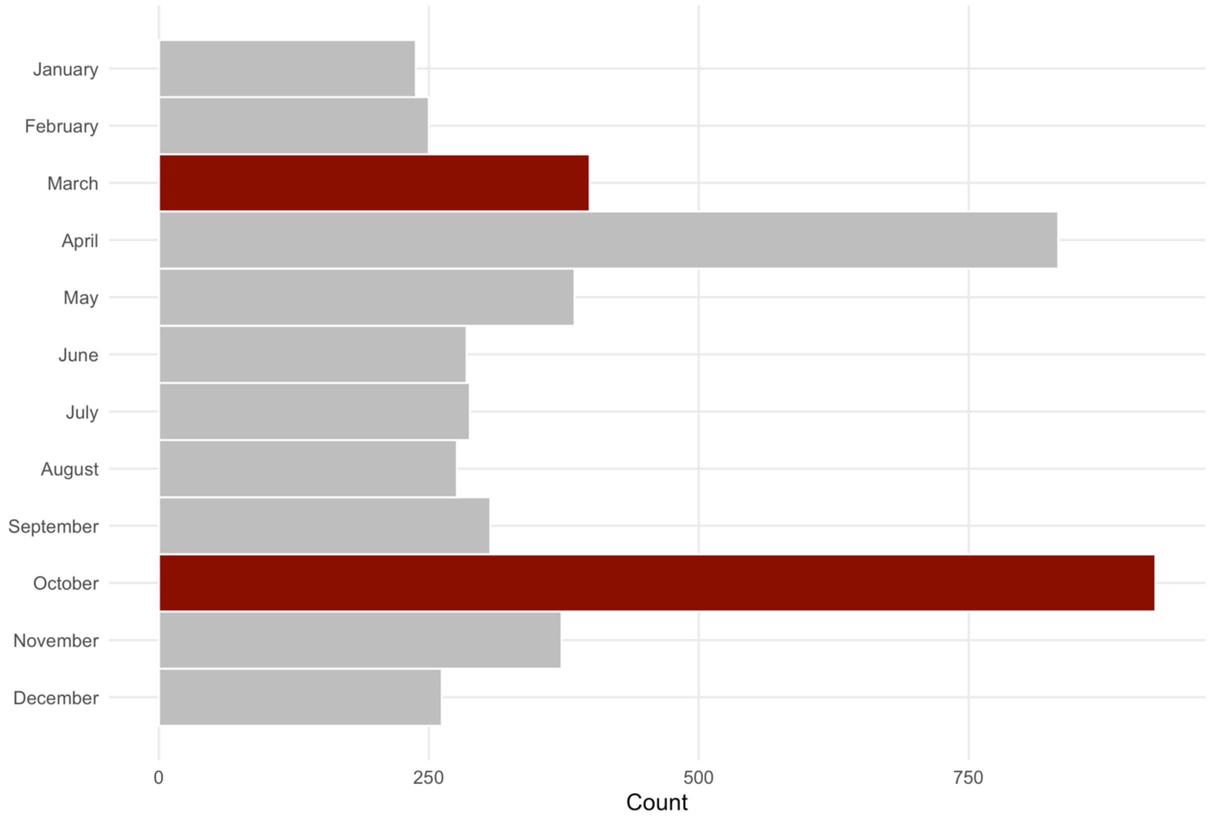

Figure 2: Periodic groundwater level measurements (2000-2021) reported by DWR in the South American Subbasin indicate peaks of seasonal data collection in April and October although DWR Best Management Practices indicate that monitoring wells should collect at least biannual measurements in spring (mid-March) and fall (mid-October) (CA-DWR, 2017). March and October are highlighted in the graph above, and roughly agree with historical data collection trends. It is especially important in dry years to monitor in mid-March, because pumping may begin as early as April; thus, a March measurement in a such a dry year provides a more accurate representation of ambient spring groundwater level. Consistent data collection in March and October ensures data comparability across years.

At each monitoring location, the average groundwater level measured during spring and fall was computed by taking the grouped mean of observations in each spring and fall respectively. Next, to improve spatial data density and ascertain long-term regional trends, data were arranged in 4-year running seasonal means. For example, the 2005-2008 spring level is defined as the average spring groundwater elevation in 2005, 2006, 2007, and 2008. A four-year sliding window was applied to data from 2005 to 2018, resulting in 22 seasonally averaged groundwater elevation conditions (e.g., spring 2005-2009, fall 2005-2009, …, spring 2015-2018, fall 2015-2018). Windows of differing length (e.g., 1, 2, and 3-year long running means) were explored but resulted in larger groundwater level variance due to a lack of adequate spatial density, and hence, not used. By contrast, 4 year running means gave adequate regional spatial data density and were not so long in duration as to dampen the impact of significant dry periods such as the 2012-2016 drought.

After data were grouped into seasonal 4-year windows, ordinary kriging[4] (Journel A.G. and Huijbregts, 1978) was applied to groundwater elevation measurements to generate groundwater level surfaces across the SASb at a 500 meter (0.31 mile) resolution. In order to minimize boundary effects, monitoring well data within a 20 kilometer (12.4 mile) buffer of the SASb were included, which effectively incorporates groundwater level data from the Cosumnes and North American subbasins, and Yolo county to the west of the Sacramento river. Groundwater level measurements were screened to include data from wells shallower than 300 feet in total completed depth to reflect conditions in the unconfined to semiconfined production aquifer, which are comparable to heads in layers 2-3 of Cosana. All monitoring points were further intersected with the Cosana model grid, and 99.4% of observations at wells occur within the Alluvium, Laguna, and Mehrten layers. 0.6% of observations occur in the Ione and Valley Springs.

3.2 Well Completion Reports (WCRs)

The well completion report database (CA-DWR, 2020) was used to filter and clean WCRs within the SASb. Similar well types were grouped into categories (e.g., “domestic”, “private residential”, and “residential” were all grouped together) to enable analysis of wells by type. The majority of wells are accurate to the centroid of the nearest section in the PLSS Survey system (1 square mile grid cells). All wells reviewed in the SASb had a total completed depth.

3.4 Projected groundwater management and climate change

Well impacts are characterized in terms of historical data but also in terms of future, anticipated hydrology. Forward-simulated hydrologic conditions using the Cosana groundwater flow model were used to estimate the impact to vulnerable wells from:

- the combined effects of projected water use in the Basin;
- projects and management actions (PMA) already underway (Harvest Water, OHWD[5] recharge, and regional conjunctive use); and
- climate change.

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[4] An exponential variogram model was used, and results did not appreciably differ from linear or spherical models. Stationarity across the unconfined to semiconfined aquifer is a reasonable assumption in the unconsolidated, alluvial aquifer-aquitard system that spans the South American subbasin and adjacent subbasins, which exhibit relatively continuous geology across borders. Data outliers were controlled by removing tails of the distribution above and below the 97.5th and 2.5th percentiles respectively. Groundwater elevations were approximately normal in distribution, thus log-transformation and exponentiation after kriging was not required.

[5] OHWD = Omochumne - Hartnell Water District

Key model outputs include future groundwater basin storage and groundwater level. Storage provides a big picture overview of the change in available groundwater in the basin, and groundwater level shows the spatially distributed result of management actions, which are then used to evaluate well impacts.

In the presentation of results (Section **Error! Reference source not found.**), groundwater level conditions in the current conditions (baseline) are compared to groundwater level conditions in the scenarios evaluated. Five scenarios are compared:

- ***Baseline***: current conditions
- ***Projected***: projected groundwater use (i.e., business as usual with increased demand)
- ***Projected CC***: projected groundwater use with a median climate change warming scenario[6]
- ***Projected PMA***: projected groundwater use considering feasible, in-progress projects and management actions (Harvest Water, OHWD recharge, regional conjunctive use)
- ***Projected PMA CC***: projected groundwater use considering feasible, in-progress projects and management actions (Harvest Water, OHWD recharge, regional conjunctive use) and with a median climate change warming scenario

Differences in groundwater level between each of the scenarios and the "baseline" inform how wells in the basin may respond to projected groundwater management and climate change. These differences are applied to observed data to translate model estimates of change to observed data. For example, to estimate the change in vulnerable well impacts under each scenario, the groundwater level differences implied by each scenario at a Fall 2015 reference point were evaluated by the model, then this difference was applied to the measured and interpolated Fall 2015 level. Fall 2015 was chosen as a reference point because it represents a recent historical minimum in groundwater level across the basin.

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[6] Climate change (CC) scenarios are driven by changes in temperature and streamflow provided by the American River Basin Study (USBR, 2020) "central tendency" scenario, which reflect median temperature and precipitation outcomes.

3.3 Classification of failing wells and cost estimate

The initial set of wells to consider are a subset of all domestic wells in the WCR database. Wells are removed based on the year in which they were constructed[7], and their estimated pump location relative to the initial groundwater level condition prior to impact analysis. In other words, wells that are likely to be inactive, or already dry at the initial condition are not considered, and do not count towards the well impact count.

Next, we assign a "critical datum"[8] to each well, equal to 30 feet above the total completed depth, roughly 3 times the height of water column required to prevent decreased well function and cavitation as calculated by Pauloo et al 2020 using standard assumptions of pumping rate, net positive suction head, barometric pressure head, vapor pressure, and frictional losses (see Pauloo et al 2020, SI Appendix Section S2.3). If groundwater level scenarios imply a groundwater elevation below this critical datum, the well is considered "impacted" and may require pump lowering or well deepening to rehabilitate it (Figure 3).

In reality, wells dewater and experience reduced yield when the groundwater level approaches the level of the pump. However, for the purposes of this study, we assumed wells maintain the net positive suction head (Tullis 1989) required to provide uninterrupted flow until groundwater falls below the critical datum. At this point, we assume the well needs replacement (i.e., a well deepening event). Therefore, the well impact estimates provided in this study should be interpreted as a worse-case scenario wherein wells can no longer access reliable groundwater and are deepened. In most cases, pumps will be able to be lowered into the 30 foot operating margin prior to a deepening event – this is more affordable than a well deepening, so the cost estimate is conservative in this sense.

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[7] Two previous studies estimate well retirement ages at 28 years in the Central Valley (Pauloo et al 2020), and 33 years in Tulare county (Gailey et al 2019), thus, we use the average of these two studies and remove wells older than a retirement age of 31 years. To account for uncertainty in the well retirement age, we also consider another well retirement age of 40 years. Importantly, these numbers reflect mean retirement ages in the retirement age distribution. Although some wells in the population may be active for longer than 31 or 40 years, some will also retire before 31 or 40 years. Thus, results should be interpreted as an average estimate of well impacts.

[8] A standard approach for the choice of a critical datum is not well established. Other studies (e.g., Gailey et al, 2019; Pauloo et al, 2020; Bostic and Pauloo et al, 2020; Pauloo et al, 2021) estimate pump locations in different ways. Since considerable uncertainty exists in estimating pumps at a local scale, but WCR data for total completed depth is present and reliable for nearly all wells in the dataset, it is favored. An operating margin of 30 feet added to the bottom of each well's total completed depth is a reasonable column of water necessary for the well to properly function, although wells with greater pumping capacities may require a longer water column.

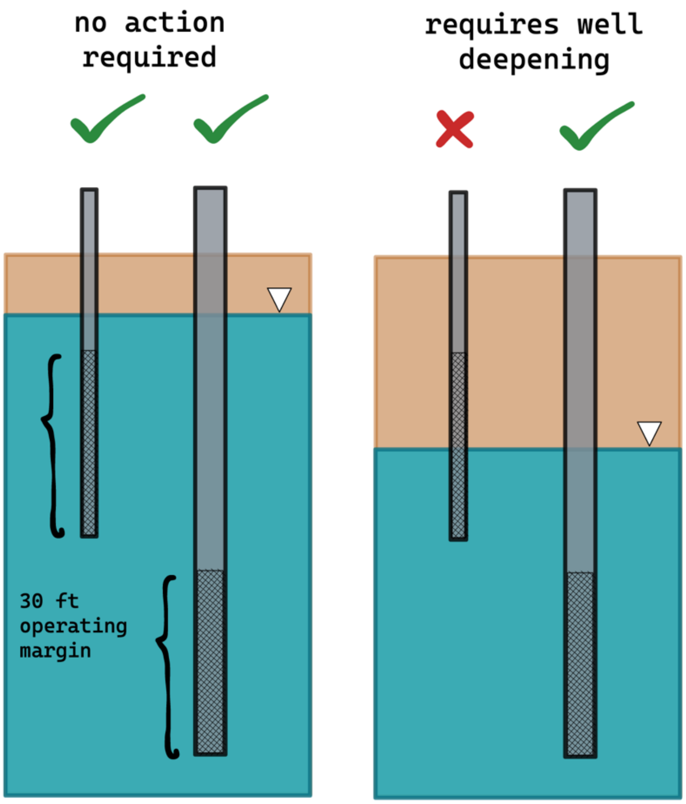

Figure 3: Wells are assigned a 30 foot operating margin above the total competed depth. When groundwater levels are above this "critical datum" at a well, the well is active (left), and the well is impacted when the groundwater falls below the critical datum, which triggers a well deepening event. Note that in reality, cones of depression form around active pumping wells, but are not shown in the figure above for simplicity.

To compute rehabilitation costs, it is assumed that if the groundwater level falls below the total completed depth of the well plus an operating margin of 30 ft, a well deepening rehabilitation event is assumed to take place. Well deepening is estaimted at $21,500 per domestic well, and $100,000 per agricultural and public well. We neglect costs associated with increased lift, as these constitute around 1% of total costs estimated by EKI, 2020. We also neglect costs associated with screen cleaning, as this action is unlikely to yield significant additional water when groundwater levels have fallen below the critical datum.

4. Results

4.1 Groundwater levels

Groundwater level analysis in this memorandum is consistent with that conducted in another technical memorandum attached to Section 3 of the SASb GSP. A detailed treatment of groundwater level results is provided in Appendix C: Interconnected Surface Water (ISW) Section 4.1, and a summary is provided here.

Groundwater elevations show seasonal oscillation (Figure 4, Figure 5) and increasing depth to groundwater in the northeast direction away from the Bay Delta (Figure 6).

Key groundwater levels include the initial condition (spring 2018), and 5 boundary conditions at which well impacts are evaluated. The first boundary condition is the Fall 2015 low, and the remaining four boundary conditions are defined by differences in groundwater elevation projected by the Cosana groundwater level scenarios (see Section 3.4 Projected groundwater management and climate change and Figure 7). The impact of projects and management actions (PMA) on groundwater levels is substantial: Harvest Water accounts for upwards of 25 feet of projected increase in groundwater level in the center of the project area (Figure 8). Importantly, to scope the severity of well impacts at potential MTs, for each scenario and at each location in the SASb, the lower of the Fall 2015 groundwater level and the projected scenario was used as a boundary condition.

Change in basin groundwater storage (Figure 9) indicates that projected management and projected management with PMA increase basin storage over the SGMA implementation horizon, whereas climate change reduces groundwater levels (assuming constant land use and ET commensurate with increased temperature).

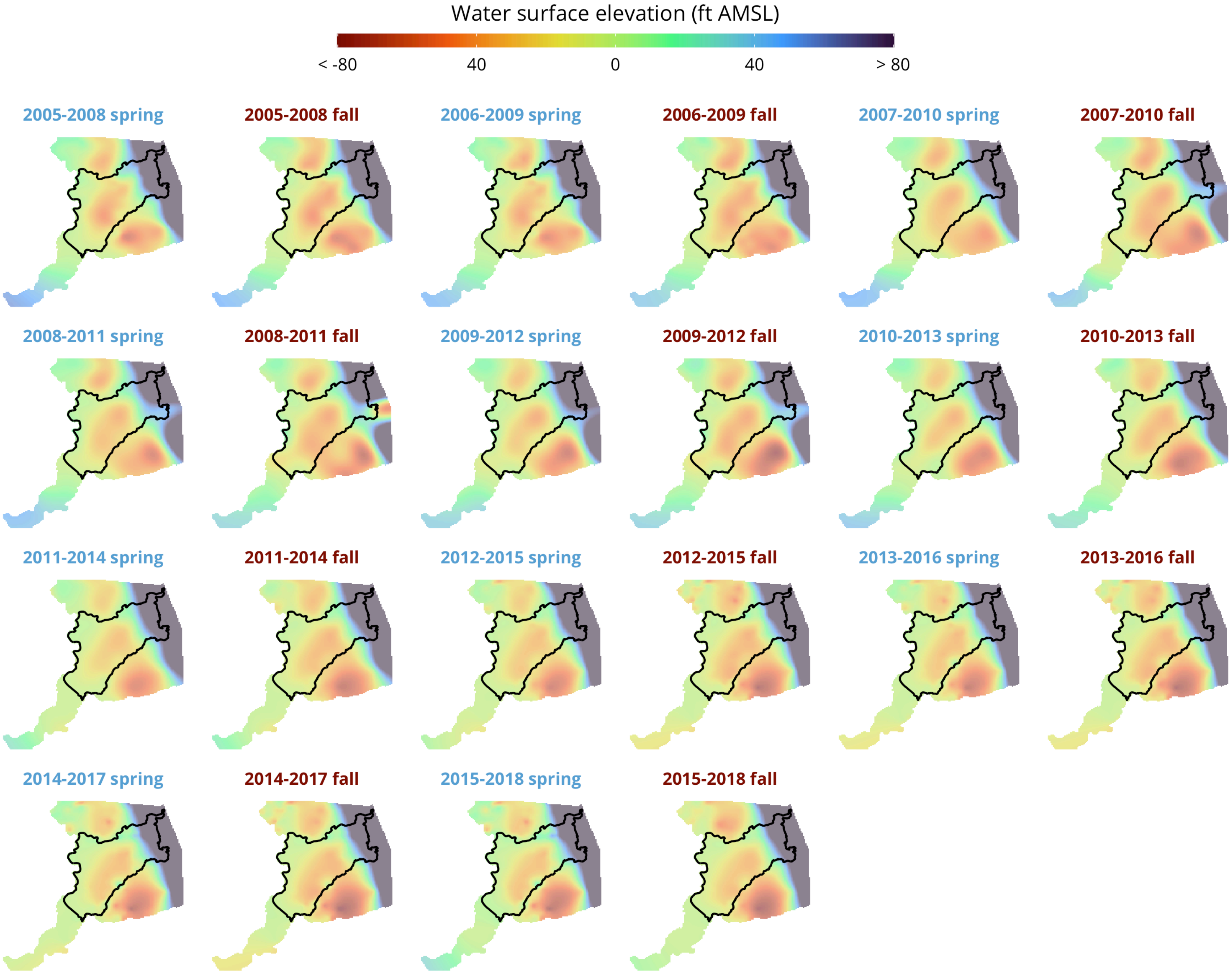
Water surface elevation (ft AMSL)
< -80
40
0
40
> 80
2005-2008 spring
2005-2008 fall
2006-2009 spring
2006-2009 fall
2007-2010 spring
2007-2010 fall
2008-2011 spring
2008-2011 fall
2009-2012 spring
2009-2012 fall
2010-2013 spring
2010-2013 fall
2011-2014 spring
2011-2014 fall
2012-2015 spring
2012-2015 fall
2013-2016 spring
2013-2016 fall
2014-2017 spring
2014-2017 fall
2015-2018 spring
2015-2018 fall

Figure 4: Seasonal, 4 year running mean interpolated groundwater elevations in the South American Subbasin from spring 2005 to fall 2018 show seasonal oscillation, with generally higher (blue) groundwater elevation in spring, and generally lower (red) groundwater elevation in the fall. Groundwater flows from areas of high (blue) to low (red) elevation groundwater elevation. Groundwater elevation mapping indicates groundwater flow inwards towards the center of the basin, coincident with areas of groundwater pumping.

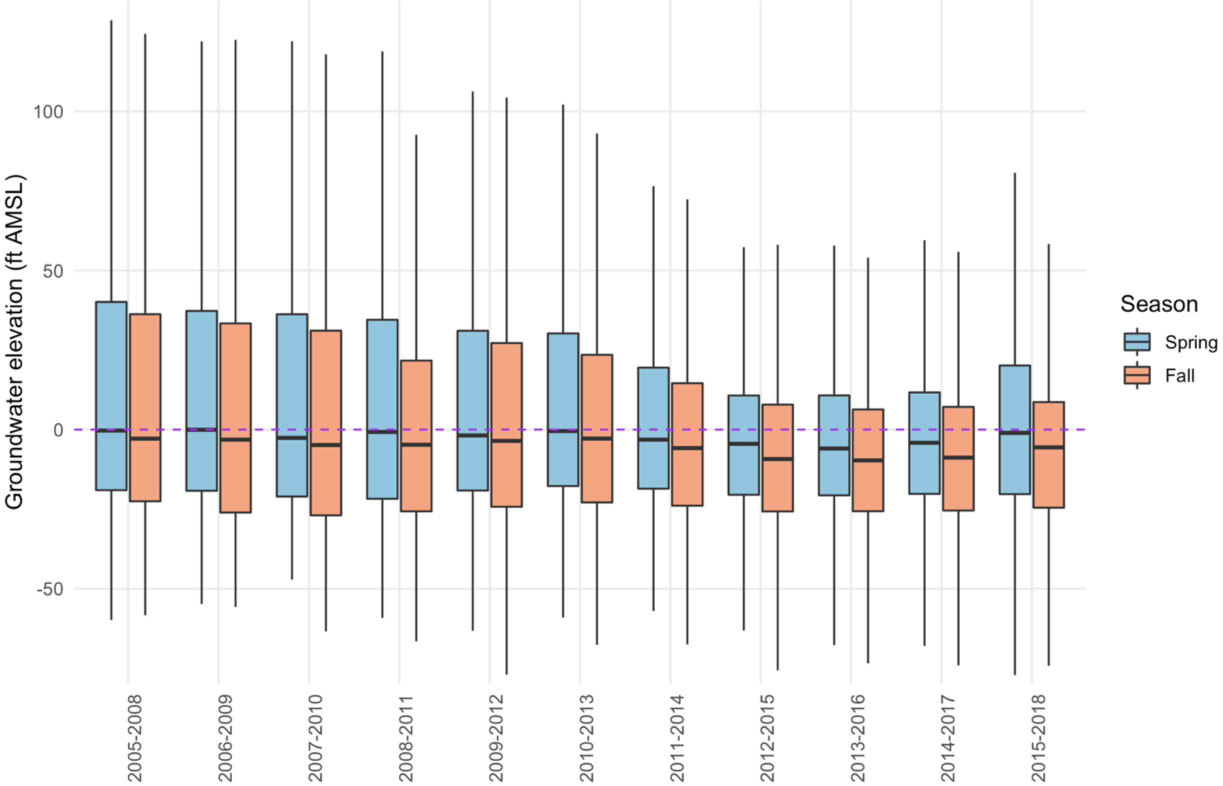

Figure 5: Seasonal summary of interpolated groundwater elevations in the SASb (Figure 4) show oscillating seasonal medians, with consistently higher groundwater elevation in spring, and lower groundwater elevation in fall. Median fall groundwater elevation decreases over the period of record and reaches its lowest value during the average period of 2013-2016 due to the combined impact of 4 years of drought. After this minimum, spring and fall median groundwater levels trend upward. A purple, horizontal dashed line is shown at mean sea level elevation (0 feet) for reference.

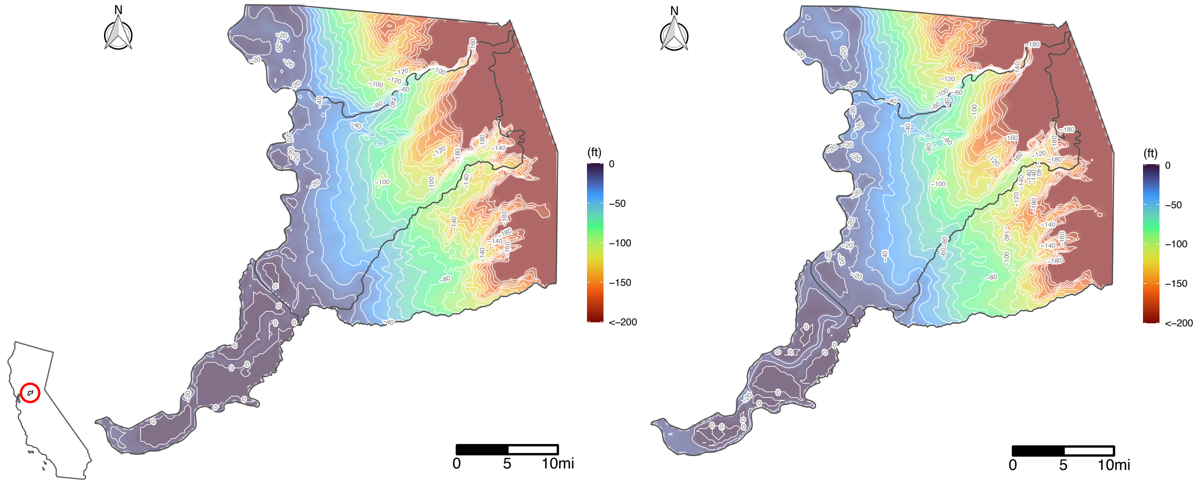

Figure 6: Depth to groundwater in the SASb for average spring (left) and fall (right) conditions across the entire period of record evaluated (2005-2018).

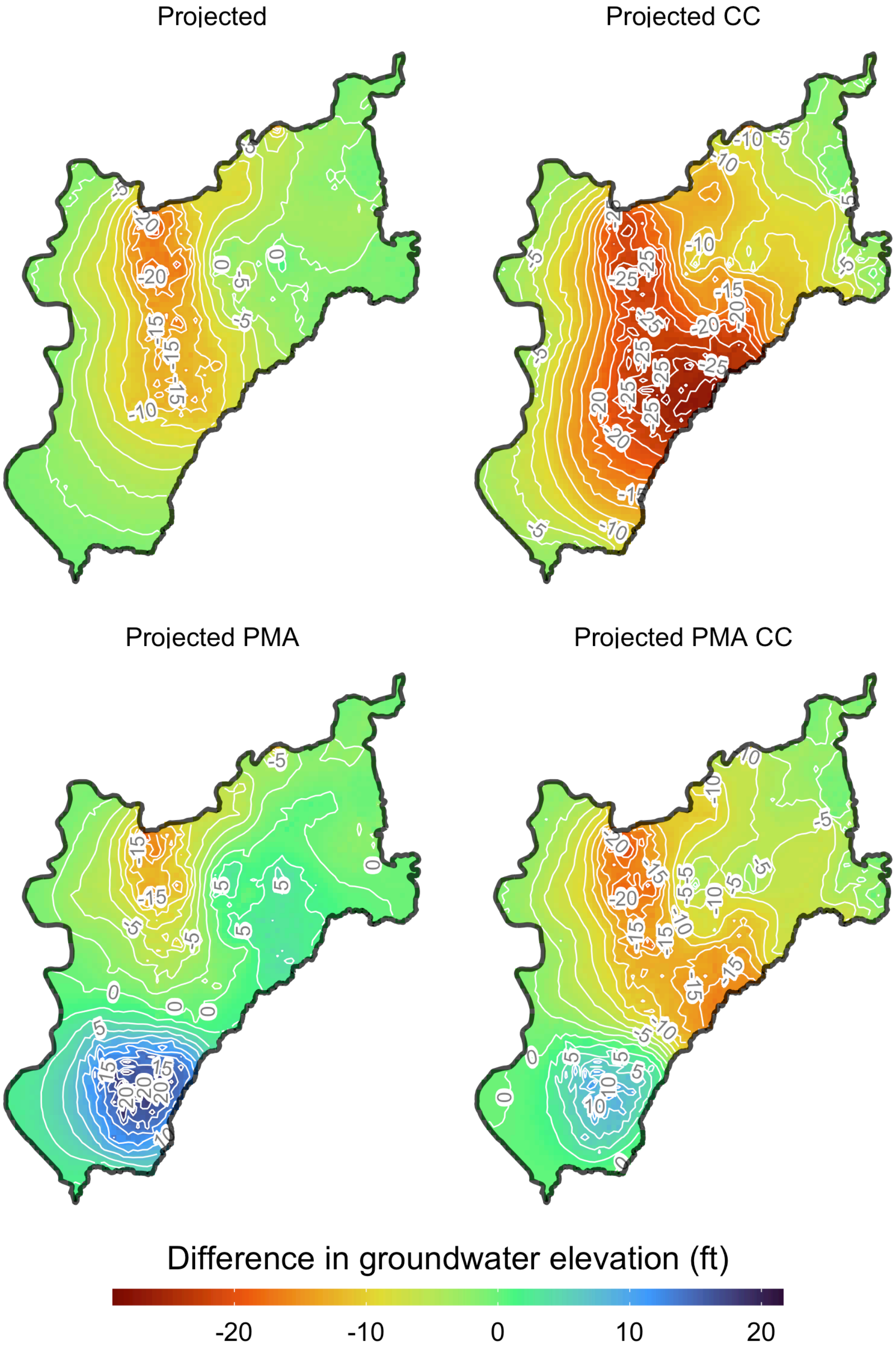

Figure 7: Modeled difference in groundwater level between each of the scenarios and the current conditions baseline at a Fall 2015 benchmark. PMA lead to substantial increases in groundwater level. Climate change projections lead to groundwater level declines, but assume no corrective action or land use change. In reality, climate change would require specialized adaptive management to avoid significant and unreasonable impacts to beneficial users, particularly ISW.

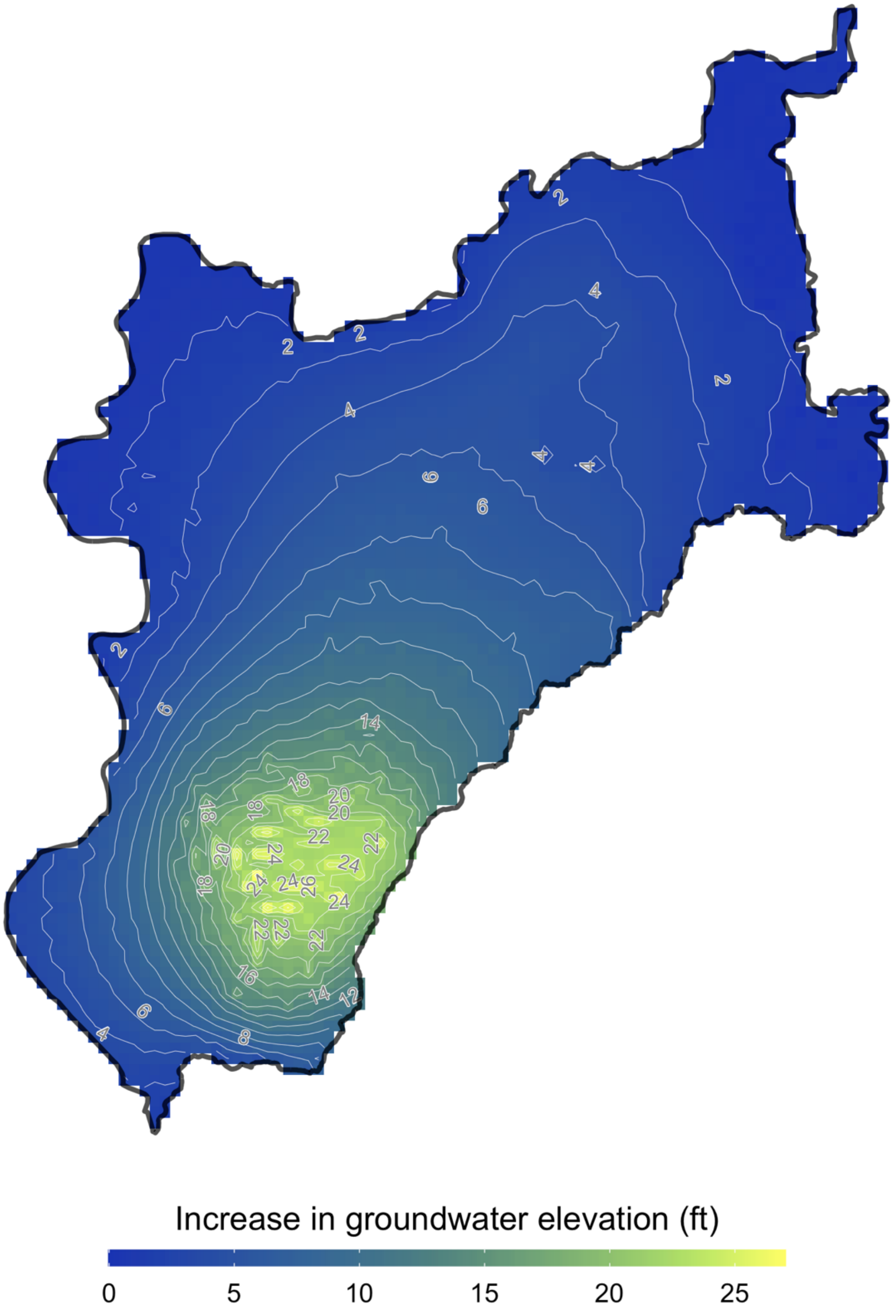

Figure 8: The difference in groundwater elevation between the "Projected PMA" and "Projected" scenarios shows the spatial distribution of groundwater level increases estimated to result from implementing PMA. Increases in groundwater level are observed across the basin and concentrated near the Harvest Water recharge site.

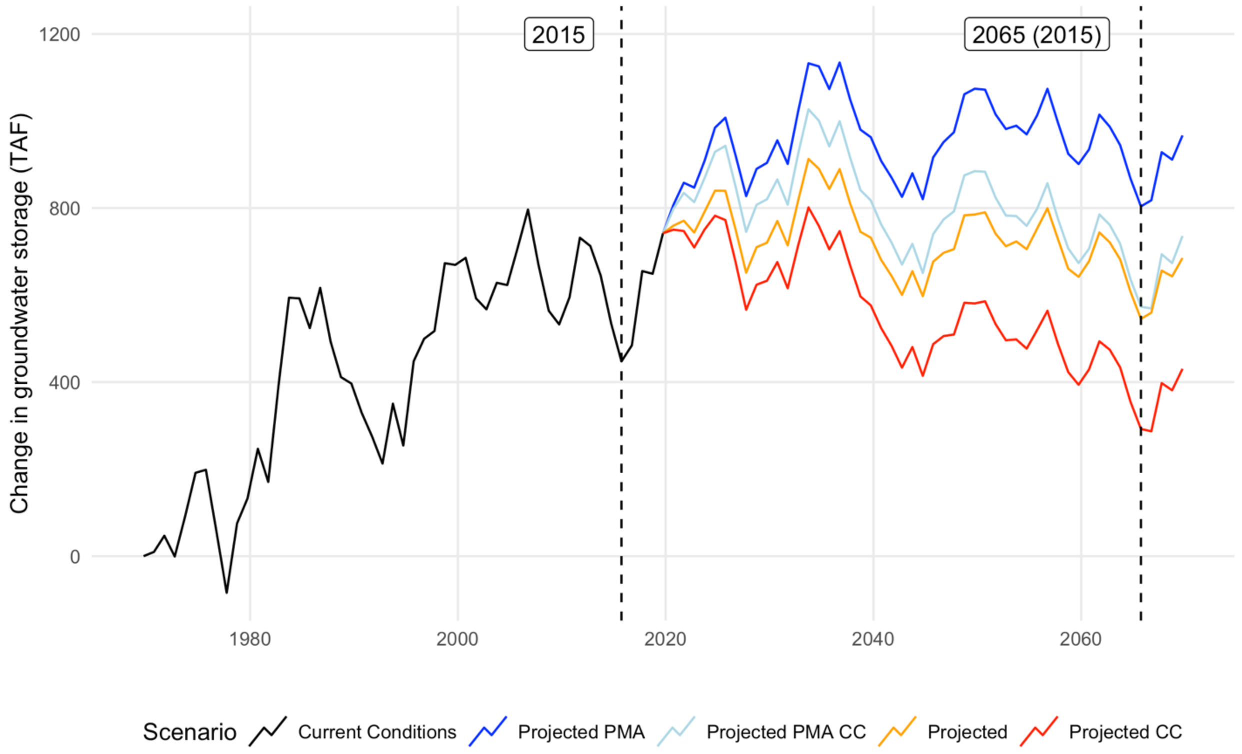

Figure 9: Cumulative change in groundwater storage under the current conditions baseline (black line), and the four scenarios (dark blue, light blue, orange, and red line). Importantly, projects and management actions (PMA) increase storage, and climate change (CC) reduces storage. A black dashed line shows where groundwater level differences are calculated between the projected scenarios and the current conditions baseline (Fall 2015) to maintain consistency.

4.2 Well inventory and characteristics

Results suggest that the most common well types (

Figure 10) with direct beneficial uses are domestic (n = 2,600), agricultural (n = 532), and public (n = 237) wells[9], although the actual number of "active" wells today is likely less due to ageing and well retirement. Assuming 31 to 40 year retirement ages (Figure 11), and that wells with pumps above initial groundwater level conditions are inactive, the number of assumed active wells in the SASb is much lower: domestic (n = 372 - 709), agricultural (n = 72 - 99), and public (n = 62 - 101). Most wells that provide beneficial uses (public, agricultural, domestic) bottom out in the Laguna and Mehrten formations (Figure 12), which constitute a principal aquifer from which transmissivity-weighted heads are extracted from the Cosana model and used to evaluate changes in groundwater level.

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[9] At the time of writing (2021-06-18), these are the well counts provided by the online well completion report database. Note that public wells are "municipal" wells, and domestic wells are private residential wells.

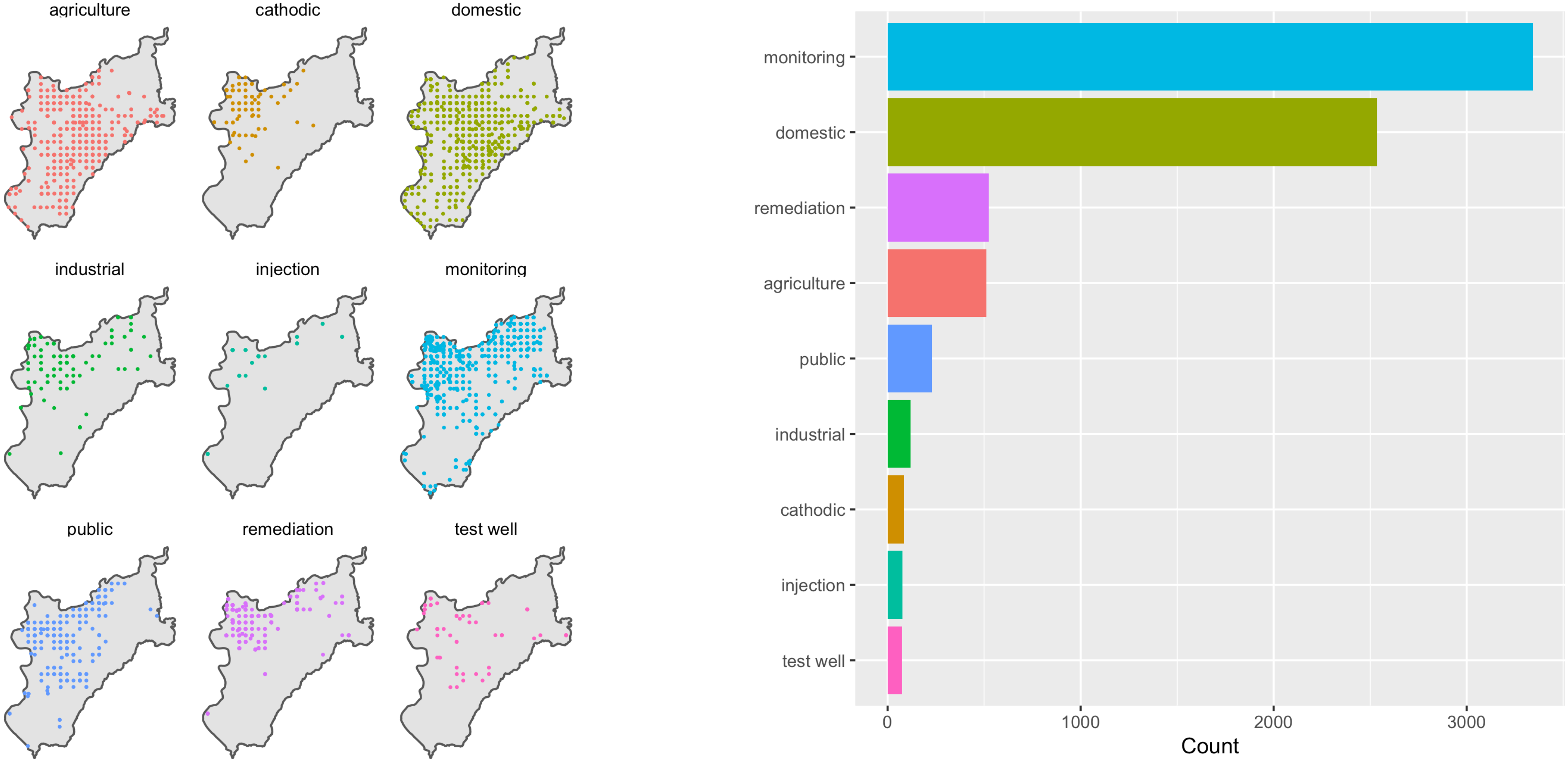


Figure 10: Well inventory of the SASb. Locations and counts do not consider retirement age, thus these wells do not reflect the location and count of active wells, but rather, all wells ever drilled for which records exist. Notice that agricultural, public, and domestic wells are collocated, and that domestic wells outnumber agricultural and public wells. Well locations appear in a grid like pattern because the accuracy of most wells is to the nearest PLSS section (1 square mile grid).

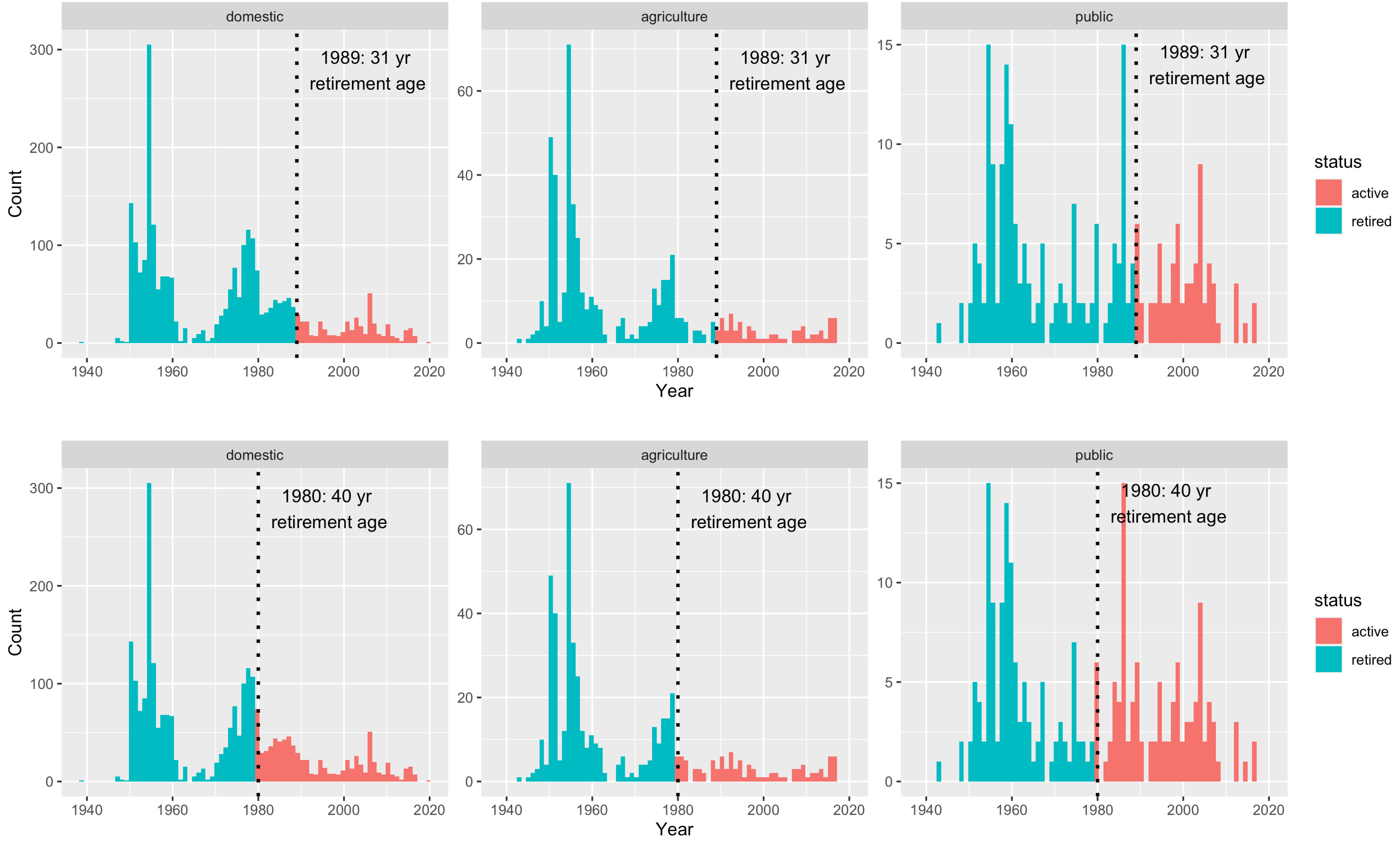
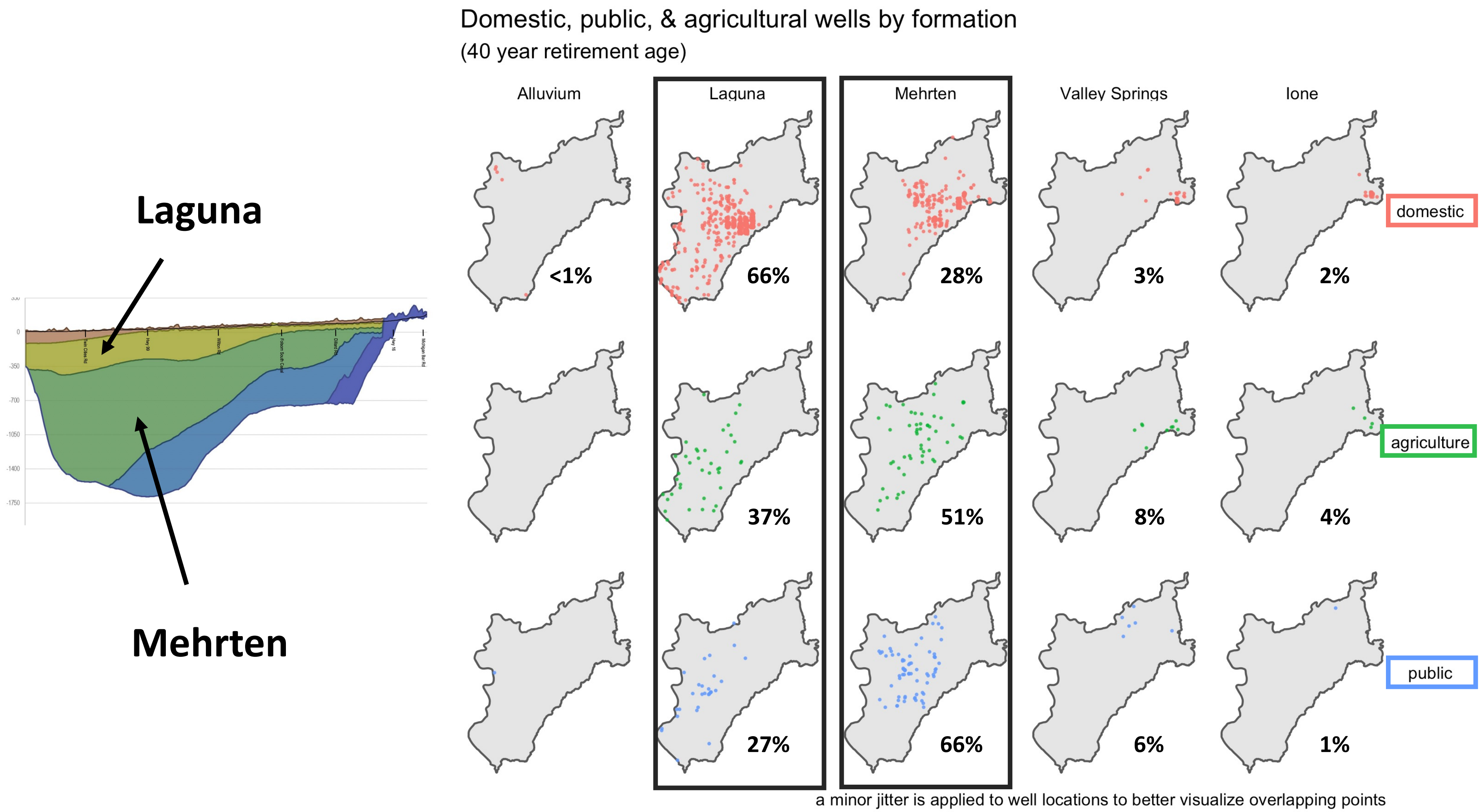


Figure 11: Not all wells drilled are active. Assuming a 31 year (top) and 40 year (bottom) retirement age, different numbers of wells are active.



a minor jitter is applied to well locations to better visualize overlapping points

Figure 12: Most wells that provide beneficial uses bottom out in the Laguna or Mehrten, thus transmissivity-weighted heads from these layers (the principal aquifer) are used to evaluate differences in groundwater elevation implied by the projected scenarios.

Most wells are deeper than long-term average depths to groundwater in the SASb, which suggests a buffer against potential well impacts from declining groundwater levels (Figure 13). Finally, wells tend to be drilled deeper over time (Figure 14), driven by improvements in drilling technology and the need for deeper groundwater unimpacted by surface contaminants and with sufficient transmissivity to support well yield targets.

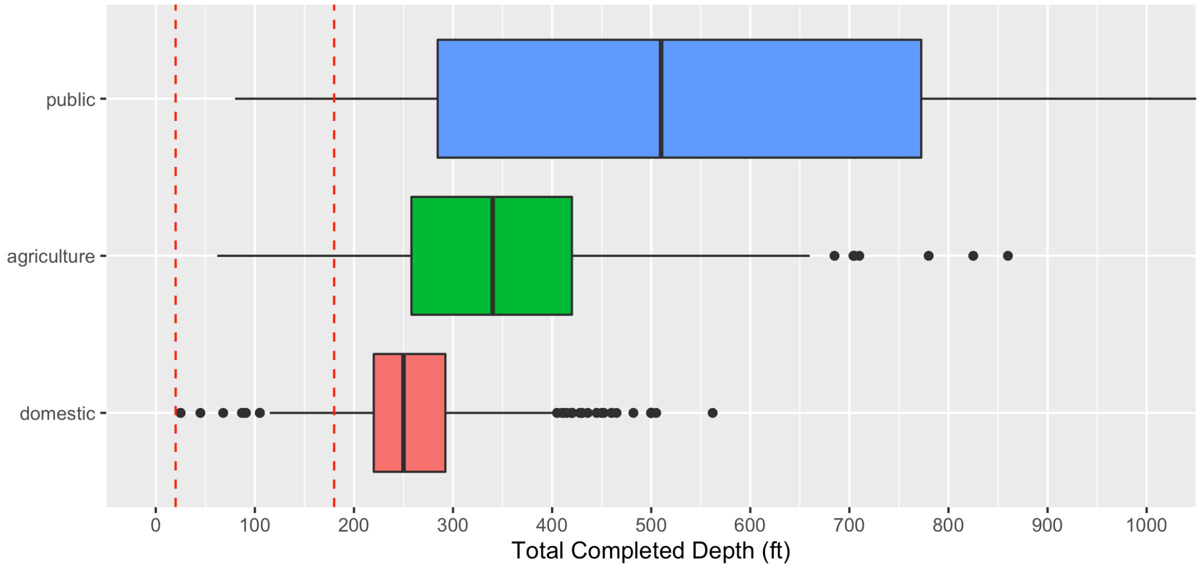


Figure 13: Relative depth distributions of domestic, agricultural, and public wells indicates increasing depth. Red dashed vertical lines are shown at 20 and 180 feet below land surface, which are the approximate modern, long-term depths to groundwater in the SASb (Figure 6)). The 25th percentile of all well depths falls outside of the 20-180 foot envelope, suggesting that many wells are deeper than present day depths to groundwater.

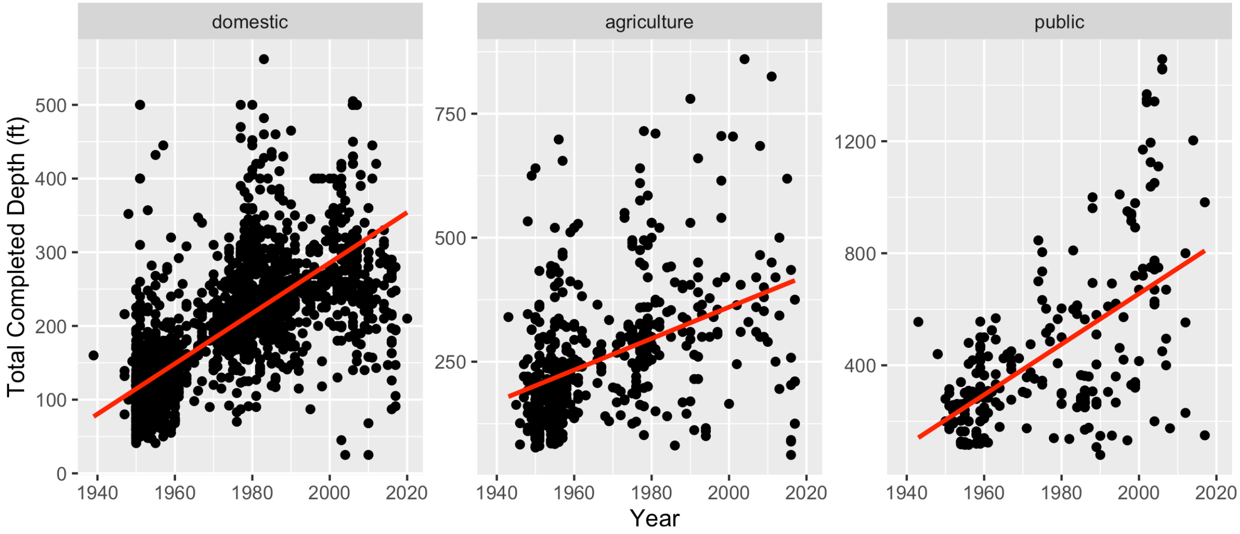


Figure 14: Since 1950, average domestic well depths increased by around 3x; agricultural and public well depths increased by around 2x and 4x respectively.

4.3 Well impacts: location, count, and cost

Fall 2015 groundwater level lows are around 12 feet lower on average compared to near present day groundwater levels. A return to these levels, as well as those implied by projected management, PMA, and climate change show little appreciable difference on well impacts (Figure 15).

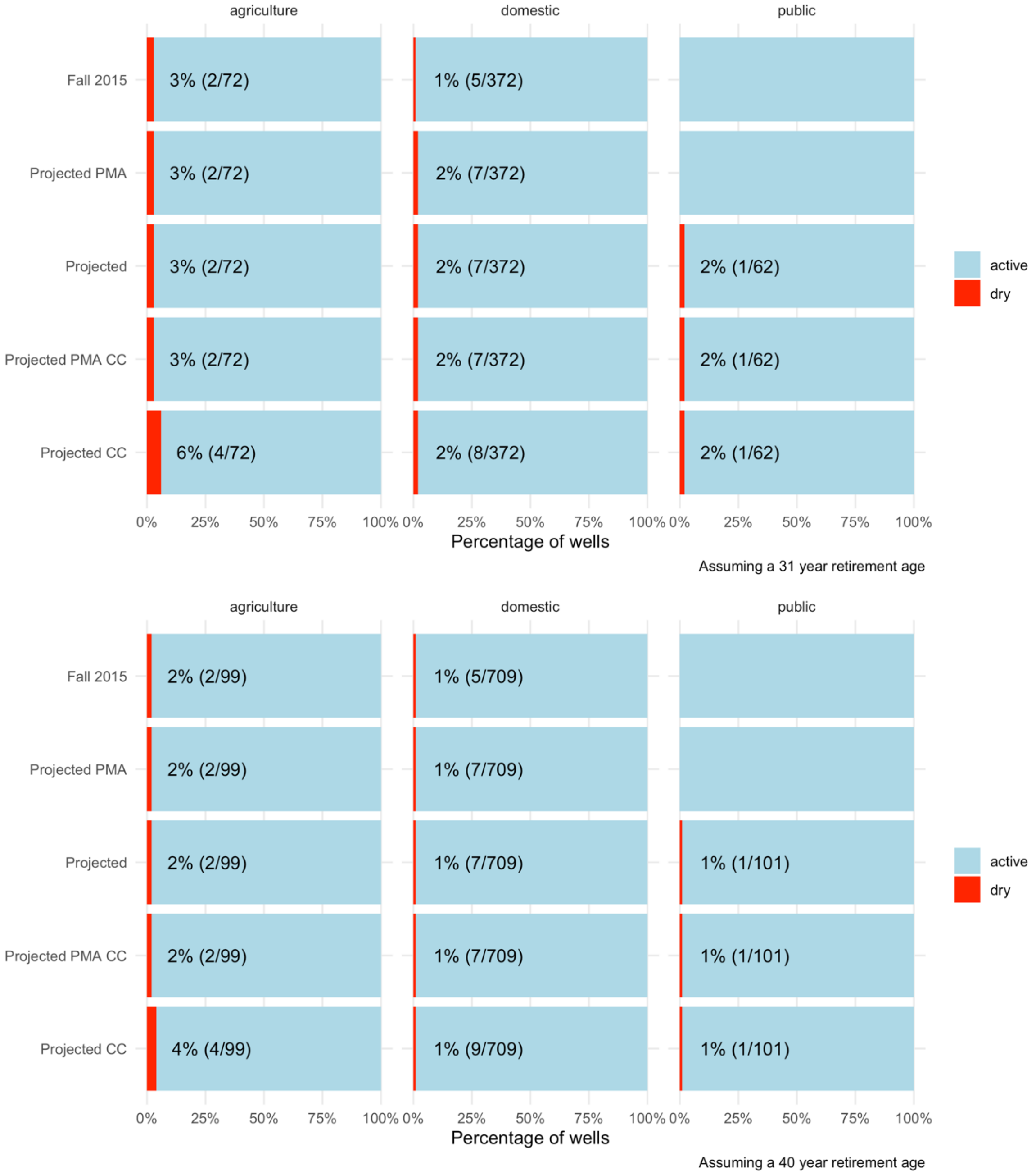


Figure 15: Vulnerable well impact analysis of a Fall 2015 baseline and 4 projected management conditions show little appreciable difference, even when accounting for a 31-year (left) and 40-year (right) well retirement age. Projected = Projected water use in the Basin. PMA = projects and management actions including Harvest Water, OHWD recharge, and regional conjunctive use. CC = climate change. Bar plots show well impact summary statistics for all scenarios and well types. Maps show results for the "Projected PMA CC" scenario on which groundwater level MTs are based.

Consequently, the point patterns of estimated active and dry wells do not appreciably differ among the five scenarios, thus only the most severe case scenario is shown (Figure 16).

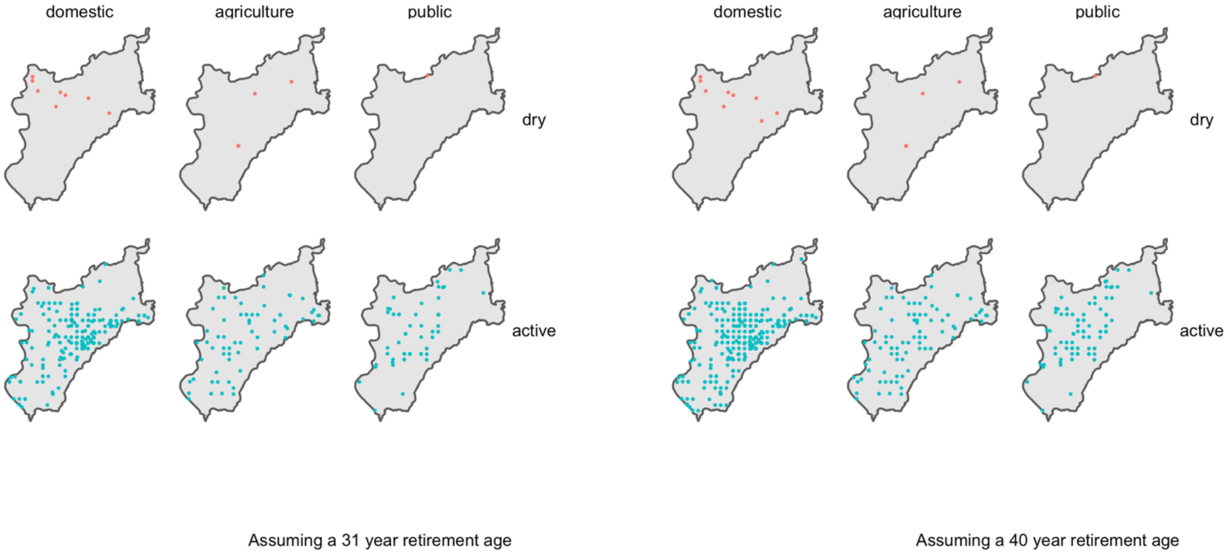


Figure 16: Of the five scenarios evaluated in this study, the Projected Conditions with climate change (and no PMA) result in the most severe well impacts (Figure 15), which are still minimal and close to a 5% impact range in agricultural wells, when accounting for uncertainty in well retirement age.

These results are unsurprising, as well depths are relatively deep compared to groundwater elevations, and the lower of Fall 2015 lows and projected groundwater head conditions do not begin to approach depths that intersect the critical datum of most wells.

4.4 Estimated cost

Costs are estimated informed by the costs put forward by Gailey et al (2019), EKI (2020), and Pauloo et al (2021), which assume well deepening events occur in intervals of 100 feet. For simplicity, domestic wells were assumed to cost $21,500 USD per well replacement, and agricultural and public wells were assumed to cost $100,000 USD per well replacement.

Results across all scenarios evaluated suggest a range of 7-15 wells would be impacted under 31-year and 40-year retirement ages, and accounting for uncertainty in projected management and climate change (Figure 15). For a conservative estimate of PMA with climate change, impacted well count is around 2-3% of domestic wells and 1-2% of public wells, and 1-2% of agricultural wells, primarily near the greater Sacramento urban area. This is explained by groundwater level simulations that indicate drawdown in these areas – areas which are also far away from the agriculture-rural interface where most vulnerable domestic wells are located. These well impact percentages align with GSA-driven definitions of unreasonable results to vulnerable wells.

Further, unacceptable well impacts are defined as dewatering or lost access to groundwater at a well that requires well deepening. Well rehabilitation costs for impacted wells, assuming a return to the MT at all RMPs, were estimated at around \$300,000 - \$700,000 following the cost structure of Pauloo et al. (2021), EKI (2020), and Gailey (2019), but would likely be less, as significant and unreasonable impacts occur when 25% of RMPs exceed MTs, and less expensive rehabilitation costs such as pump lowering may be more appropriate in some situations (e.g., when operating margin exists).

5. Discussion

Vulnerable wells in the SASb tend to be privately owned and adjacent to or within areas of concentrated groundwater extraction for agricultural and municipal use. Due to their relatively shallow depth, these wells are vulnerable when water levels decline due to drought or unsustainable management. With the passage of the Sustainable Groundwater Management Act, local groundwater sustainability agencies will develop sustainable management criteria including minimum thresholds and objectives, measured at monitoring networks that will chart progress towards, or deviance from, sustainability goals. Sustainable management criteria should identify vulnerable wells as beneficial users of groundwater, and hence, identify the quantitative thresholds at which they will be impacted by declining groundwater levels, and the percentages (or count) of impacts above which, local agencies deem significant and unreasonable. The GSP should then set groundwater level MTs according to these thresholds and manage groundwater levels above them to ensure that at MTs, significant and unreasonable impacts occur, and that at MOs, significant and unreasonable impacts are avoided.

Data from the DWR and Cal OPR suggests that during Fall 2015, no wells in the SASb were reported dry, even though this period represents a [modern] historic groundwater level low. Results are consistent with this observation and suggest that a return to Fall 2015 groundwater level lows is unlikely to result in catastrophic and widespread impacts to wells. Moreover, additional declines anticipated under projected management result in negligible impacts to wells, largely owing to the relatively deep total completed depth of wells compared to present day groundwater levels, and minimal to no groundwater level decline in most parts of the basin. The percentage of wells impacted in the worst-case scenario assuming climate change and no PMA results in only one of the well types (agricultural) impacted at 4-6% (accounting for uncertainty in well retirement age). In all other scenarios (many of which are more likely), well impacts for all well types remain below 5%.

Well protection analysis thus informs the creation of minimum thresholds (MTs) which avoid significant and unreasonable impacts to wells in the basin and allow the basin to achieve projected growth targets within a framework of regional conjunctive use and PMA. Well rehabilitation costs for impacted wells, assuming all MTs are reached at all representative monitoring points (RMPs), were estimated at around \$300,000 -

$700,000, but would likely be less, as significant and unreasonable impacts occur when 25% of RMPs exceed MTs, and if operational space remains in the well, a less costly pump lowering may take place.

6. Conclusion

Well completion reports, and historical and forecasted groundwater levels (using Cosana) were analyzed to estimate groundwater thresholds at which different well types in the SASb reach levels of impact deemed significant and unreasonable. Results suggest that projected groundwater management with PMAs and climate change will not lead to widespread catastrophic well failure in the SASb, and thus groundwater level MTs should be designed according to these levels.

It is advisable therefore, that MTs are based on the lower of the observed fall 2015 groundwater level and any additional decline anticipated under the projected PMA with CC scenario since this represents a likely, but conservative groundwater level scenario with an estimated 1-3% well impact across well types that also fits within the significant and unreasonable 5% impact threshold.

Well impact analyses depend on reliable data to determine the set of active wells to consider, and their critical datum (the vertical elevation at which a well is estimated to be impacted by declining groundwater levels). Reasonable assumptions are made for modeling purposes, but are not accurate to every well across the basin. Results are sensitive to well retirement age. A “well census” may improve understanding of well retirement and well vulnerability more generally. Such a census, if performed, should take place at the county level; results of the census may be attached to the parcel database used to better inform well protection and rates and fee schedules.

Top-down approaches like the analysis provided herein should be combined with bottom-up approaches. Localized, volunteer-based vulnerable well monitoring may empower point-of-use crowdsourced data and facilitate an early warning system to prioritize well rehabilitation measures before wells go dry. Truly, the best indication of well vulnerability will come from measurements at point-of-use wells. SGMA does not require this level of monitoring or provide guidance on how to achieve it, but GSAs may consider local monitoring programs outside of GSP RMP network to improve communication with well owners and take corrective actions as needed.

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Appendix 3-D

Groundwater Dependent Ecosystems in the South American Subbasin
(April 21, 2021)

THE FRESHWATER TRUST™

700 SW Taylor Street, Suite 200
Portland, OR 97205
www.thefreshwatertrust.org

Groundwater Dependent Ecosystems in the South American Subbasin

April 21, 2021

SUMMARY

The Sustainable Groundwater Management Act (SGMA) requires Groundwater Sustainability Plans (GSPs) to identify and consider impacts to Groundwater Dependent Ecosystems (GDEs). GDEs are complex ecosystems that rely on a connection to groundwater to sustain their health and function. GDEs provide various ecosystem services (e.g., supporting habitat for life stages of State and federal special status species, providing habitat for migratory fish), and recreational amenities (e.g., parks and waterways). Groundwater Sustainability Agencies (GSAs) are required to manage GDEs and their associated beneficial uses and users consistent with the strategies outlined in the GSP to avoid "undesirable effects" resulting from unsustainable groundwater management. Despite the significant presence of GDEs in the South American Subbasin (SASb)[1] and the ecological value they provide to beneficial users of groundwater, they remain poorly understood. To support these valuable ecosystems, they must be considered in terms of scale and spatial distribution, the plant and animal communities that rely on them, best practices to monitor their condition, and how their functions may be supported through groundwater management.

The SASb's extensive vegetation communities and natural features associated with both surface and groundwater expressions were identified and classified as to their potential GDE status using a multi-faceted approach. First, potential GDEs were identified using available datasets in a geographic information system (GIS). Next, an analysis was carried out to determine if the most deeply rooted local species could reasonably reach groundwater throughout the historical period from 2005 to 2019 which contains wet, above normal, below normal, dry, and critical water year types. Then, surface vegetation health was evaluated with satellite imagery to assess the possibility of broad, rapid, and cost-effective characterization of GDE health. Finally, results were synthesized into quantitative metrics that may be monitored within the SGMA framework, and which provide reasonable assurance that undesirable results to GDEs in the SASb are avoided.

In following sections present: a brief background on GDEs in SGMA; methods used to classify and map GDEs via groundwater level and satellite imagery; management approaches (including definition and identification of Undesirable Results, and Measurable Objectives); a discussion of GDE-associated beneficial users; a discussion of study limitations; and a discussion of potential projects and management actions that may interact with GDEs in the SASb.

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[1] The South American Subbasin is defined by Bulletin 118.

SGMA requires consideration of the interests of all beneficial uses and users of groundwater in the development and implementation of GSPs (CAL. WATER CODE § 10723.2). These interests explicitly include environmental users. As a result, ecosystems dependent on groundwater must be evaluated in GSPs. The identification and subsequent management of GDEs is closely related to two SGMA sustainability indicators: lowering of groundwater levels and depletion of interconnected surface waters (CAL. WATER CODE § 10721(x)).[2] Thus, SGMA requires that GSPs consider GDEs, which are a beneficial user of both groundwater and interconnected surface water.

SGMA defines GDEs as "ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface" (CAL. CODE REGS. tit. 23 § 351(m)). Hence, GDEs are habitats and populations of species whose health relies on access to groundwater. SGMA details the specific conditions and considerations that every GSP must address. These include identifying GDEs within the basin as well as evaluating the potential for adverse impacts to interconnected surface waters (ISW) (CAL. CODE REGS. tit. 23 §§ 354.8(5), .16(g), .28(6)). The ISW analysis for the SASb is presented separately in an accompanying technical memo: "Interconnected Surface Water in the South American Subbasin: Historical and Present-day Characterization, and Approaches for Monitoring and Management." SGMA requires the GSP to define an approach to monitor and manage significant and unreasonable impacts to GDEs. The identification of GDEs is based on the "best available science" and requires "the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, that is consistent with scientific and engineering professional standards of practice" (CAL. CODE REGS. tit. 23 § 351(h)). The following effort has been designed and undertaken in accordance with these requirements and standards in order to provide a thorough and reliable analysis of GDEs in the SASb.

METHODS

Classes of GDEs

Applying legal standards defined by statutes, this analysis considers GDEs as ecosystems that meet the scientific framework for classification based on data available at the subbasin scale, including depth to groundwater or the presence or absence of an associated mapped vegetation community. Scientific literature identifies three GDE classes (Eamus 2006; Eamus & Froend 2006; Eamus et al. 2006, 2015):

- Class 1: Underground aquifer and cave systems hosting stygofauna (species adapted to living in underground water)
- Class 2: Ecosystems that rely on surface expressions of groundwater, including springs, perennial wetlands, and rivers whose flow is augmented by groundwater
- Class 3: Ecosystems that rely on sub-surface groundwater, including phreatophytes (Greek for "well plant", or plants with roots that reach into saturated groundwater)

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[2] GDEs may or may not be reliant on the "primary aquifer" but this does not change the definition for GSP purposes.

In the SASb, only class 2 and 3 ecosystems are present (see Section 2 of the GSP, Plan Area), and hence, in this memo, references to “GDEs” indicate both class 2 and 3 GDEs.

Within GDEs, microbial and invertebrate communities that could interact with surface water systems can reside at groundwater depths to 230 ft (White 1993; Kawanishi 2013; Sorensen 2013; Korbel 2017). According to California’s Bulletin 118, this hyporheic zone consists of the fully saturated sediments beneath and beside the active channel, which contains a proportion of surface water that was part of the flow in the surface channel that went back underground where it mixed with groundwater (California DWR 2003). The hyporheic zone links surface and groundwater to integrate and modulate stream ecological processes, and thereby serves as a refuge and habitat for a diverse range of aquatic organisms, from bacteria to invertebrates to aquatic worms. It also can influence river water quality due to substantial surface area contact with microbial communities and the gradient from oxygenated to unoxygenated waters that can transform and trap nutrients and organic compounds. A conceptual diagram of a hyporheic zone in a gaining stream reach where groundwater is contributing to surface water flows is presented in Figure 1. Note that although a gaining stream is shown in the conceptual diagram, a hyporheic zone also exists in losing (but still interconnected) streams where stream-aquifer interaction is present.

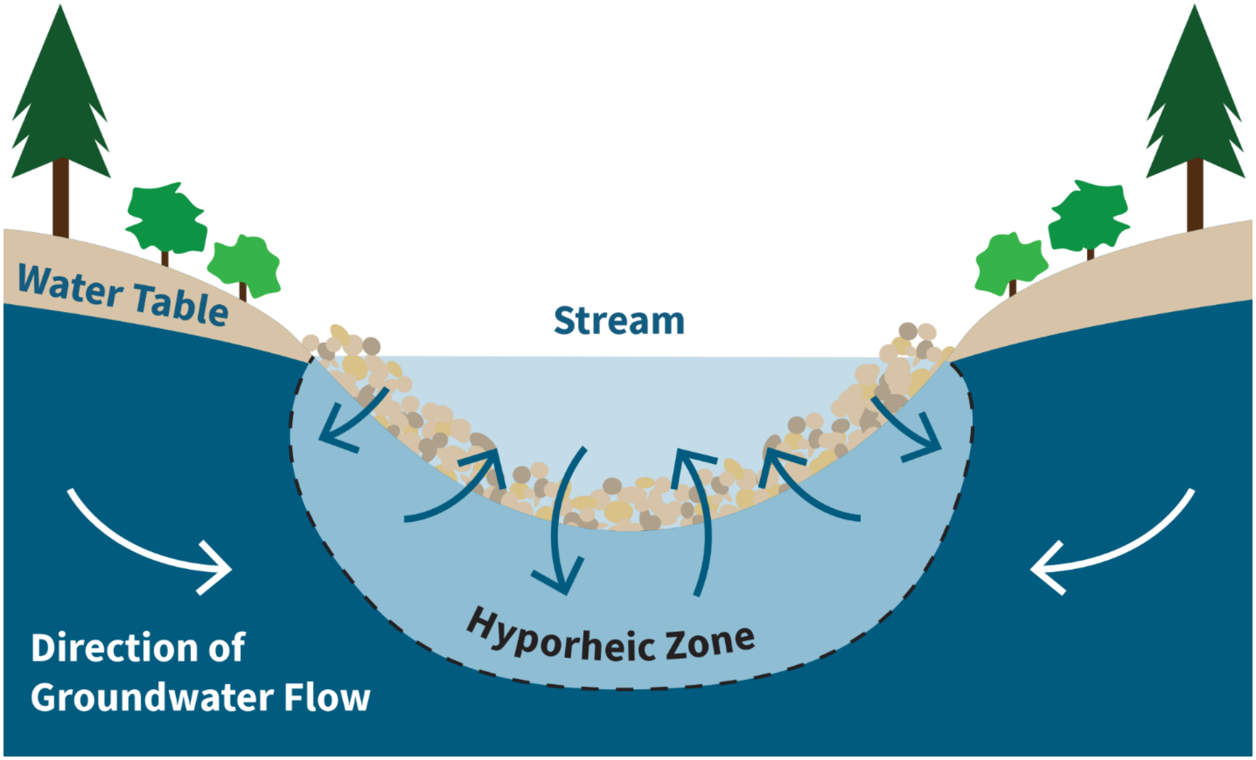

Figure 1: Conceptual Diagram of a Saturated Hyporheic Zone Surrounding a Surface Water Channel for a Graining Reach

The hyporheic zone may connect surface and groundwater when groundwater elevations are sufficiently high enough to intersect the subsurface streambed, and thus constitute ISWs. SGMA regulations define an ISW as "surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted." (CAL. CODE REGS. tit. 23 § 351(o)). Accordingly, the presence of an ISW implies high water levels which may support fish passage by adding water to the stream via baseflow. Moreover, an ISW allows for the transfer of nutrients dissolved in groundwater to the stream. Both GDEs and ISWs are connected to groundwater over some vertical extent: for ISW, the streambed clogging layer must reach into saturated groundwater in order to be interconnected, and for GDEs, the rooting depth must reach into saturated groundwater to be "groundwater-dependent" (CAL. CODE REGS. tit. 23 § 354.16).

Identifying Mapped Potential GDEs

A series of geospatial datasets were used to identify potential GDEs in this analysis. These datasets and the geospatial processing steps used to translate them into an integrated representation of mapped potential GDEs within the SASb are presented in this section.

Class 1 - Aquifer Cave Systems

Aquifer cave systems are typically found in karstic limestone formations, where mineral dissolution creates caves that fill with groundwater. These systems are included here for completeness, but do not exist in the fluvial-alluvial clastic sedimentary deposits of California's Central Valley, as defined in the SASb's Hydrogeologic Conceptual Model (Chapter 2 of the GSP, Plan Area), and therefore are not identified or mapped in this study.

Class 2 - Wetlands

The second class of GDEs, referred to here as wetlands, are those ecosystems that rely on a surface expression of groundwater, such as natural springs, perennial wetlands, and rivers supplemented by groundwater. Three datasets were combined to create a representation of assumed mapped potential wetland GDE polygons including the:

- National Wetlands Inventory (NWI) developed and distributed by US Fish & Wildlife;[3]
- California Aquatic Resource Inventory (CARI) developed and distributed by the San Francisco Estuary Institute;[4] and
- Natural Communities Commonly Associated with Groundwater Wetlands (NCCAG-W) dataset developed by a working group comprised of California Department of Water Resources (DWR), California Department of Fish and Wildlife (CDFW), and The Nature Conservancy (TNC) distributed by California DWR.[5]

The NCCAG-W and CARI datasets incorporated the NWI during their development, yielding a number of mapped potential wetland GDEs identified by more than one dataset. The NWI dataset was included in this analysis for completeness. The CARI dataset incorporates the U.S. Geological Survey (USGS) National Hydrography Dataset as well as Sacramento County wetland and stream mapping from the U.S. Army

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[3] *Available at* https://www.fws.gov/wetlands/Data/Data-Download.html.

[4] *Available at* https://www.sfei.org/cari.

[5] *Available at* https://data.cnra.ca.gov/dataset/natural-communities-commonly-associated-with-groundwater.

Corps of Engineers.[6] A summary of the areas of mapped potential wetland GDEs identified by each dataset and combination of datasets is presented in Table 1 with spatial distribution of each class presented in Figure 2. A series of four figures presenting the spatial distribution of mapped potential wetland GDEs at a zoomed in extent are presented in Appendix A. Geospatial processing ensured that overlapping areas were not double or triple counted in summaries.

Table 1. Mapped Potential Wetland GDEs Identified by Data Source and Combination of Data Sources in the South American Subbasin

Data Source[7]	Area (acres)	% of Mapped Potential Wetland GDE Area (Total)
NWI* + CARI** (overlap)	6,005	28.8%
CARI ** (no overlap)	5,959	28.6%
NCCAG-W* + CARI** + NWI*** (overlap)	4,693	22.5%
NWI* (no overlap)	3,153	15.1%
NCCAG-W* + NWI*** (overlap)	1,051	5.0%
NCCAG-W*** (no overlap)	0	0.0%
NCCAG-W* + CARI**** (overlap)	0	0.0%
Total	20,861	100%

*National Wetland Inventory (NWI) (total acres; 14,902)

** California Aquatic Resource Inventory (CARI) (total acres; 16,657)

*** Natural Communities Commonly Associated with Groundwater– Wetlands (NCCAG-W) (total acres; 5,744)

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[6] *Available at* https://www.sfei.org/projects/six-county-aquatic-resource-inventory.

[7] "Overlap" indicates the intersection of two datasets for purposes of analysis that are not additive in acreage; "no overlap" indicates there is no intersection between datasets.

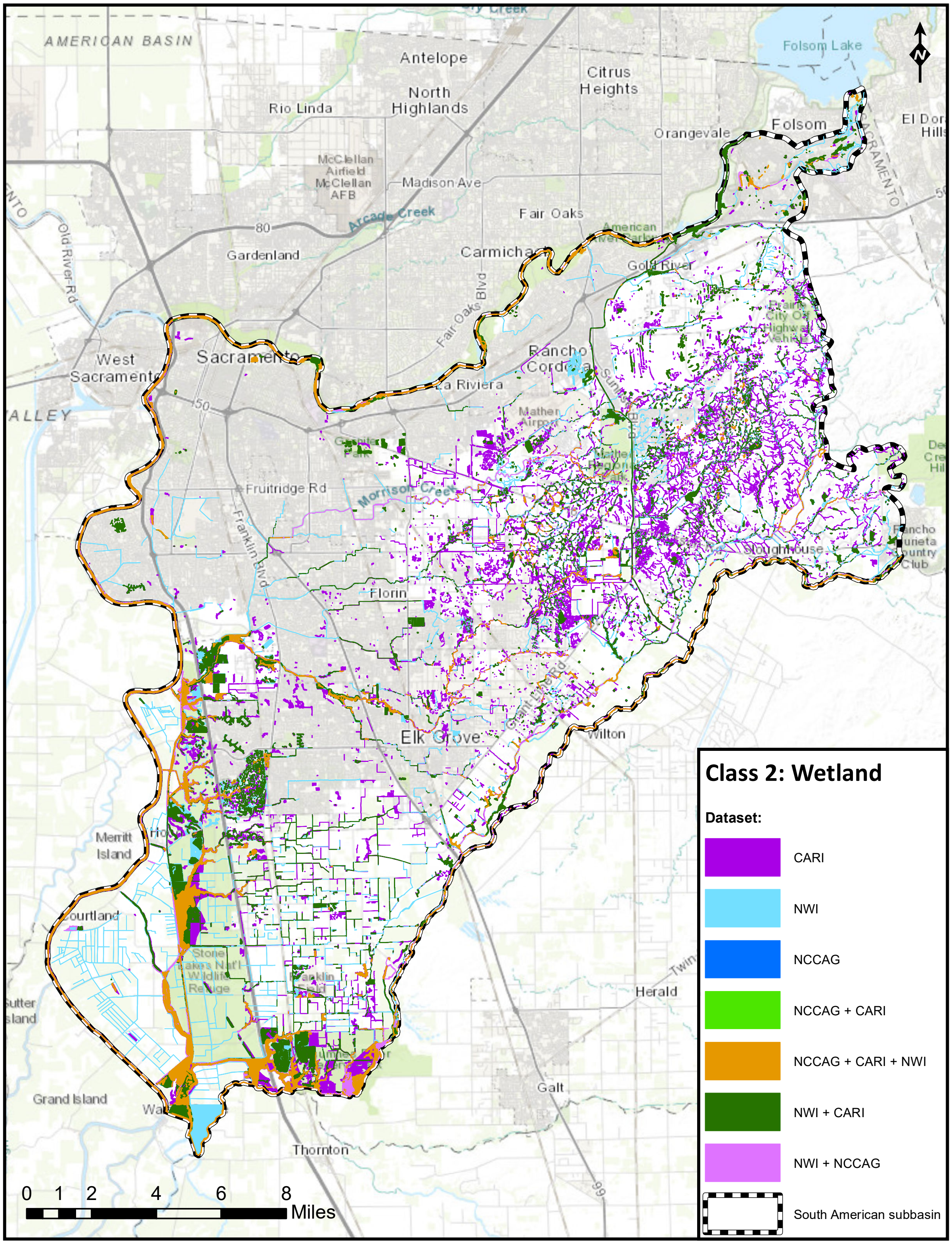

Figure 2: Mapped Potential Wetland GDEs Identified by Data Source and Combination of Data Sources in the South American Subbasin

Class 3 – Non-Wetland Vegetation

The third class of GDEs are non-wetland vegetation that rely on at least temporary connection to groundwater. Three datasets were combined to create a representation of assumed mapped potential non-wetland GDEs polygons including the:

- Natural Communities Commonly Associated with Groundwater Vegetation (NCCAG-V) developed by a working group comprised of California Department of Water Resources (DWR), California Department of Fish and Wildlife (CDFW), and The Nature Conservancy (TNC) distributed by California DWR;[8]
- South Sacramento Habitat Conservation Plan (SSHCP) landcover,[9] and
- CDFW Vegetation augmented with project-based mapping for a landscape management scenario analysis.[10]

A summary of the areas of mapped potential wetland GDEs identified by each dataset and combination of datasets is presented in Table 2 with spatial distribution of each class presented in Figure 3. A series of four figures presenting the spatial distribution of mapped potential non-wetland GDEs at a zoomed in extent are presented in Appendix B. There is notable overlap between these datasets and distinct polygons from each source. Notably, the SSHCP/Underwood dataset incorporates many more stands of isolated trees.[11] The relative acreage of those mapped GDE features demonstrates that riparian species occupy double the area of underwood species. For the purpose of this analysis, the presence of a non-wetland potential mapped GDE polygon was considered to be an initial indicator of the presence of this class of GDE. The absence of vegetation in otherwise appropriate locations in near contact with shallow groundwater does not preclude classification as a GDE if additional evidence indicates the existence of a GDE.

Table 2. Mapped Potential Non-Wetland GDEs Identified by Data Source in the South American Subbasin

Data Source[12]	Area (acres)	% of Mapped Potential Non-Wetland GDE Area (Total)
NCCAG-V* (no overlap)	4,166	40.2%
SSHCP/Underwood** (overlap)	2,033	19.6%
NCCAG-V & SSHCP (overlap)	4,168	40.2%
Total	10,367	100%

*Natural Communities Commonly Associated with Groundwater – Vegetation (total acres; 8,334)
**South Sacramento Habitat Conservation Plan (total acres; 6,201)

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[8] *Available at* https://data.cnra.ca.gov/dataset/natural-communities-commonly-associated-with-groundwater.

[9] This dataset is referred to as SSHCP/Underwood as the data was provided by E. Underwood and R. Hutchinson. *Available at* https://escholarship.org/uc/item/8700x95f.

[10] *Available at* https://wildlife.ca.gov/Data/VegCAMP.

[11] This is perhaps due to the focus of the landscape management planning on carbon storage and 16 local bird species.

[12] "Overlap" indicates the intersection of two datasets for purposes of analysis that are not additive in acreage; "no overlap" indicates there is no intersection between datasets.

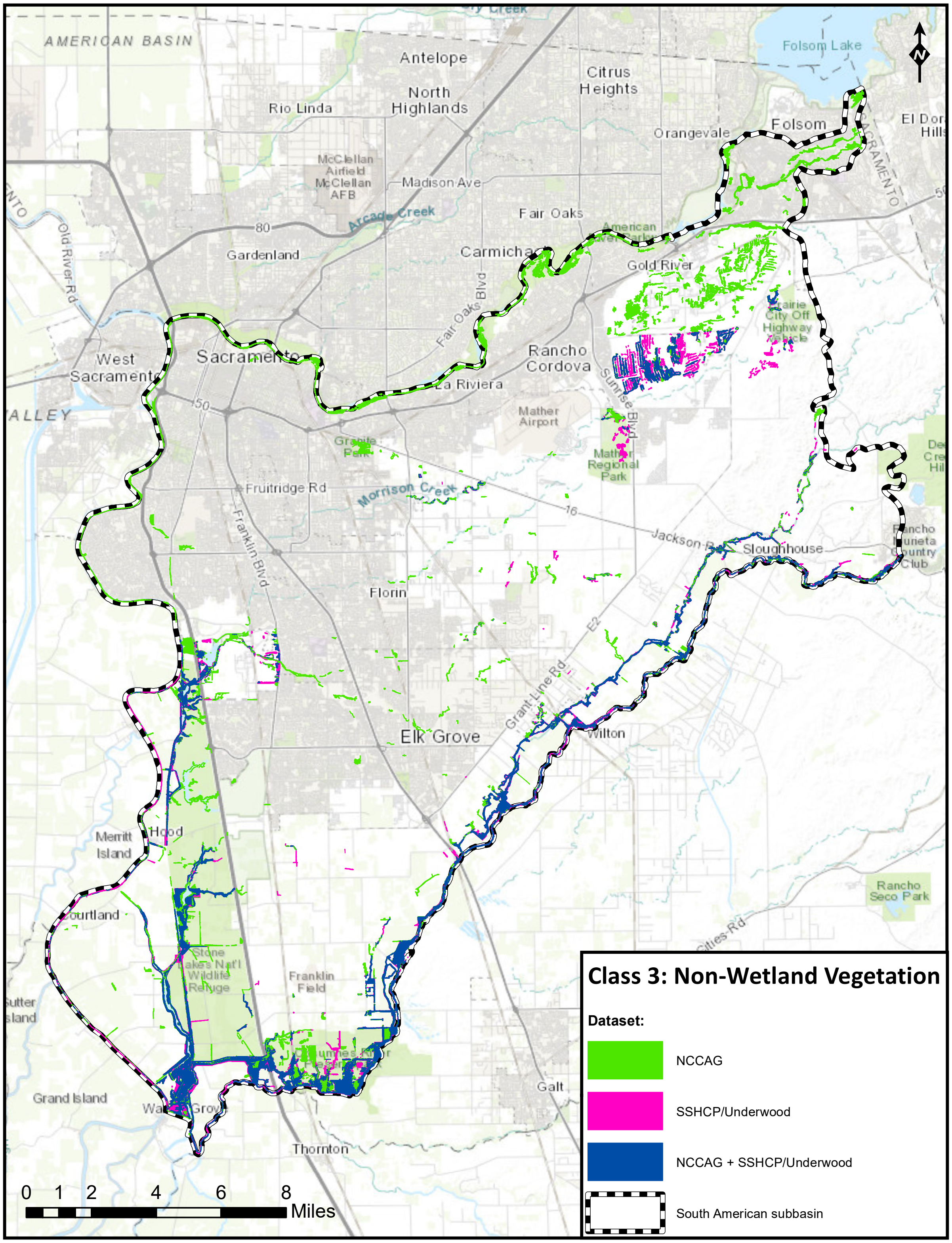

Figure 3: Mapped Potential Non-Wetland GDEs Identified by Data Source in the South American Subbasin

Rooting Zone Depth Threshold

Roots and rooting depths help plants maintain access to water. Although the rooting depths of mature vegetation may be relatively static, groundwater level fluctuations caused by pumping may temporarily or permanently disconnect roots from saturated groundwater, which may impact plant health. The California Department of Fish and Wildlife (CDFW), in collaboration with other entities, has collected data from a variety of sources to create a comprehensive list of phreatophytes, or plants that require significant contact with the groundwater table, and assigned maximum rooting zone depths by species based on available literature. This State-wide CDFW dataset was revised to more effectively reflect the vegetative communities within the SASb and is presented in Appendix C. Deeply rooted species not typically found in the region (e.g., desert species) and species that lacked rooting depth data were excluded. Plants were included if found locally, if they were native, and if their plant family or *Genus* had a reported rooting depth.

The maximum reported rooting depths of the plant species found in the SASb range from near-surface for grasses like creeping wildrye (3.84 feet) to deep-rooted trees like the Valley Oak (24.31 feet). Rooting depths of species within the SASb were evaluated, and the Valley Oak (*Quercus lobata*) was found to exhibit the largest rooting depth[13]. Because plants can extract moisture from pore spaces away from the roots themselves, a threshold depth of 30 feet was used as a cutoff for the maximum depth of groundwater that could reasonably be accessed by a GDE within the SASb. Areas within the SASb where depth to groundwater is consistently greater than 30 feet are therefore assumed incapable of supporting non-wetland GDE communities and by extension, any GDEs. In the context of identifying GDEs, this 30-foot depth threshold is very conservative and overly inclusive as shallower groundwater is likely required to support a broader array of healthy GDEs in most circumstances.

Depth to Groundwater

Available groundwater monitoring datasets were used to develop statistical representations of groundwater elevation for 12 four-year running periods for both spring and fall between 2005 and 2008 (e.g., spring 2005, 2006, 2007, and 2008 representing spring 2005 – 2008). These groundwater elevations[14] were developed by interpolating mean observed groundwater for each season with ordinary kriging. Seasonal, four-year running mean interpolated groundwater elevations in the SASb from spring 2005 to fall 2019 (Figure 4) show seasonal oscillation, with generally higher (blue) groundwater elevation in spring, and generally lower (red) groundwater elevation in the fall. Groundwater flows from areas of high (blue) to low (red) groundwater elevation. Groundwater elevation mapping indicates groundwater flow inwards towards the center of the basin, coincident with areas of groundwater pumping.

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[13] Coast Live Oak (*Querus agrifolia*) is also present in the SASb and has an average maximum rooting depth of 35.1 feet, however, it occupies 2.3 acres, and is thus neglected. By comparison, Valley Oak (*Quercus lobata*) has an area of 2937.0 acres, thus we use the Valley Oak to set the upper bound of maximum rooting depth expected in the SASb.

[14] The full methodology for groundwater level interpolation is discussed in the accompanying technical memo, “Interconnected Surface Water in the South American Subbasin: Historical and Present-day Characterization, and Approaches for Monitoring and Management” and a brief summary is presented here.

The seasonal summary of interpolated groundwater elevations (Figure 5) shows oscillating seasonal medians, with consistently higher groundwater elevations in spring, and lower groundwater elevation in fall. Median fall groundwater elevation decreases over the period of record and reaches its lowest value during the average period of 2013-2016 due to the combined impact of four years of drought. After this minimum, spring and fall median groundwater levels trend upward.

Groundwater elevations were translated into depth to water by subtracting kriged groundwater elevations from the elevation of the land surface represented by Sacramento County's one-foot resolution digital elevation model (DEM).

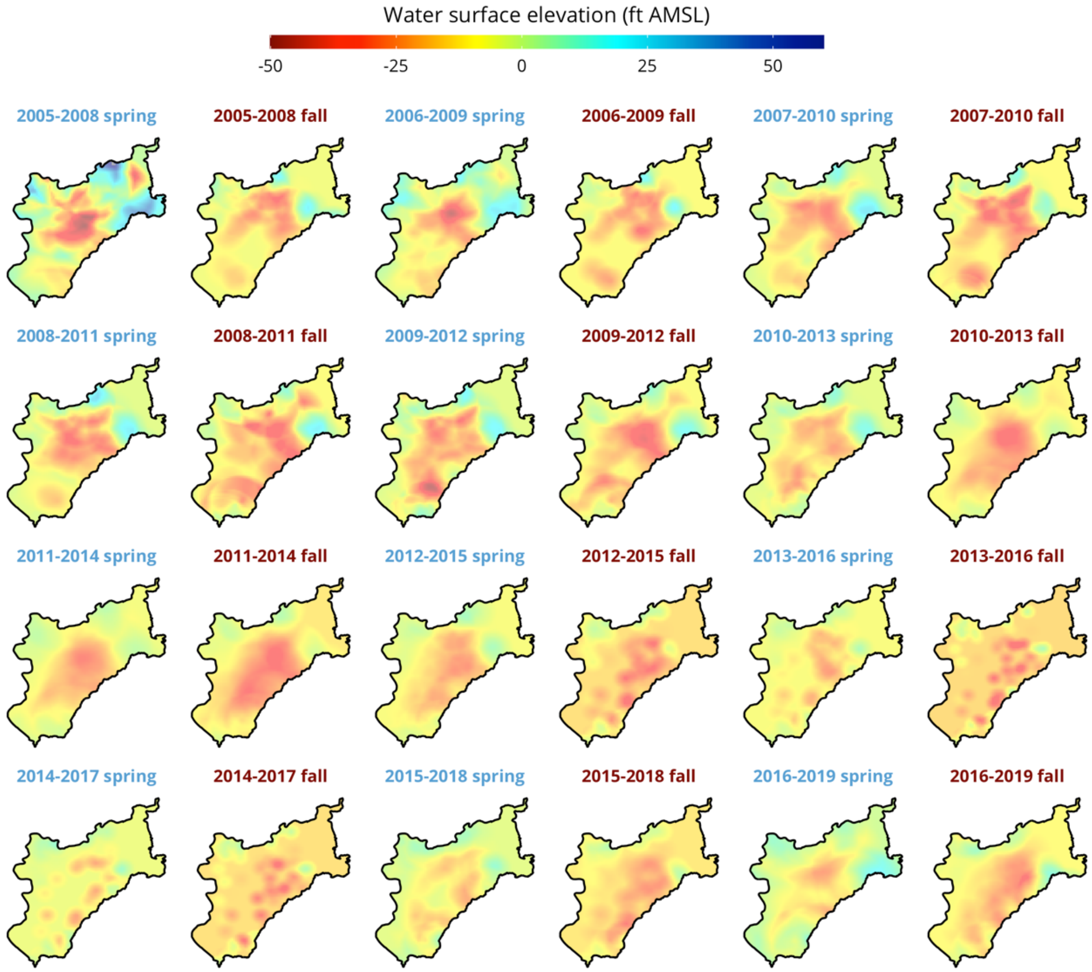

Figure 4. Groundwater Elevation (feet above mean sea level) for Four-Year Running Seasonal Groundwater Level Mean in the South American Subbasin

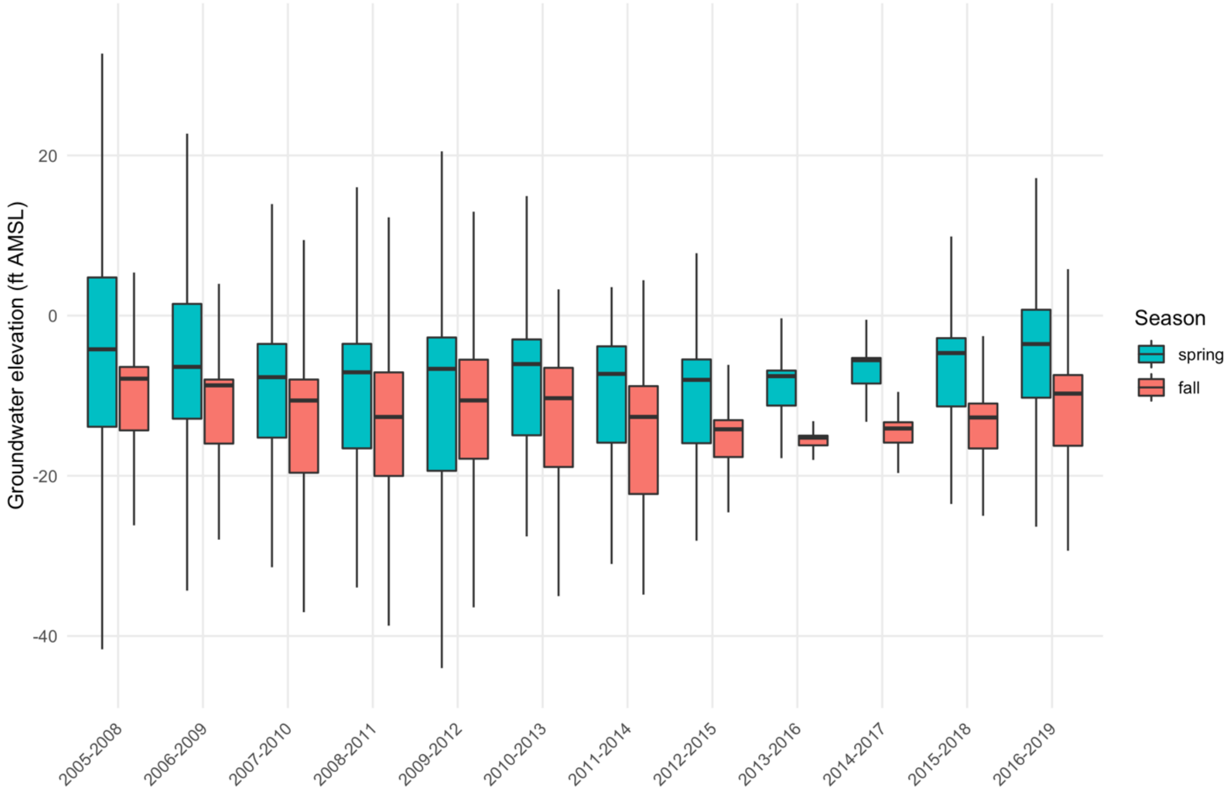

Figure 5. Box Plot Summary of Groundwater Elevations for Four-Year Running Mean Values by Season for the South American Subbasin

Mapped Potential GDE Classification

The maximum assumed extent of all mapped potential GDEs was established by combining class 2 mapped potential wetland GDEs (Figure 2) and class 3 mapped potential non-wetland GDEs (Figure 3). A two-tier classification approach (Figure 6) was developed and applied to classify GDE based on assumed access to groundwater.

The first-tier classification involved computing an area-weighted statistical representation of depth to groundwater for each mapped potential vegetative GDE area using the zonal statistics function available in many GIS programs. This zonal statistics function identifies what cells of the depth to groundwater grid or raster dataset fall within the bounds of each mapped potential GDE and then computes an area-weighted average for that area. The 30-foot depth to groundwater threshold discussed in the Rooting Zone section above was applied to each of the 24 four-year running depth to groundwater rasters for fall and spring independently to separate mapped potential GDEs into two classes: “Assumed GDE” and “Assumed Not GDE.” Areas where the area-weighted depth to groundwater was less than or equal to 30 feet were classified as “Assumed GDE” for that single four-year running representation of groundwater conditions. Conversely, areas where the area-weighted depth to groundwater was greater than 30 feet were classified as “Assumed Not GDE” for that single representation of groundwater conditions. A box plot summarizing the proportion of mapped potential GDEs split into “Assumed GDE” and “Assumed Not GDE” classes for each seasonal four-year running depth to groundwater raster or grid is presented in

Figure 7. Figures showing the spatial distribution of the classification of mapped potential GDEs into “Assumed GDE” and “Assumed Not GDE” classes for each of the four-year running depth to groundwater rasters or grids are presented in Appendix D. The difference in spring (blue) and fall (red) GDE proportion ranges from 0.4 – 7.3% (hovering text boxes) and represents natural historic seasonal and interannual variance across the period of record evaluated. The largest differences in the seasonal range occur during running means that contain years within the 2012 – 2016 drought and suggest that dry conditions may cause desiccation of mapped potential GDEs. Over the period of record evaluated, the area classified as “Assumed GDE” ranges, at a maximum, from around 44% to 54%.

The second tier of the assessment further classifies “Assumed GDE” and “Assumed Not GDE” polygons into GDE likelihood classes based on how often groundwater was within 30 feet of the polygon during the 2005-2019 record examined (**Error! Reference source not found.**). A tabular summary of GDE likelihood classes is presented in Table 4 and the spatial distribution of each category presented in Figure 8. The key difference between the Tier 1 and Tier 2 classification is that multiple representations of depth to groundwater are incorporated into the second tier of the analysis to evaluate longer term trends or persistent conditions.

Table 3. GDE Likelihood Class Descriptions

Class	Definition
GDE	Areas classified as “Assumed GDE” for 100% of groundwater conditions from 2005-2019
Potential GDE - Likely	Areas classified as “Assumed GDE” for more than 50% of groundwater conditions from 2005-2019
Potential GDE - Unlikely	Areas classified as “Assumed GDE” for less than or equal to 50% of groundwater conditions from 2005-2019
Not GDE	Areas classified as “Assumed Not GDE” for 100 % of groundwater conditions from 2005-2019

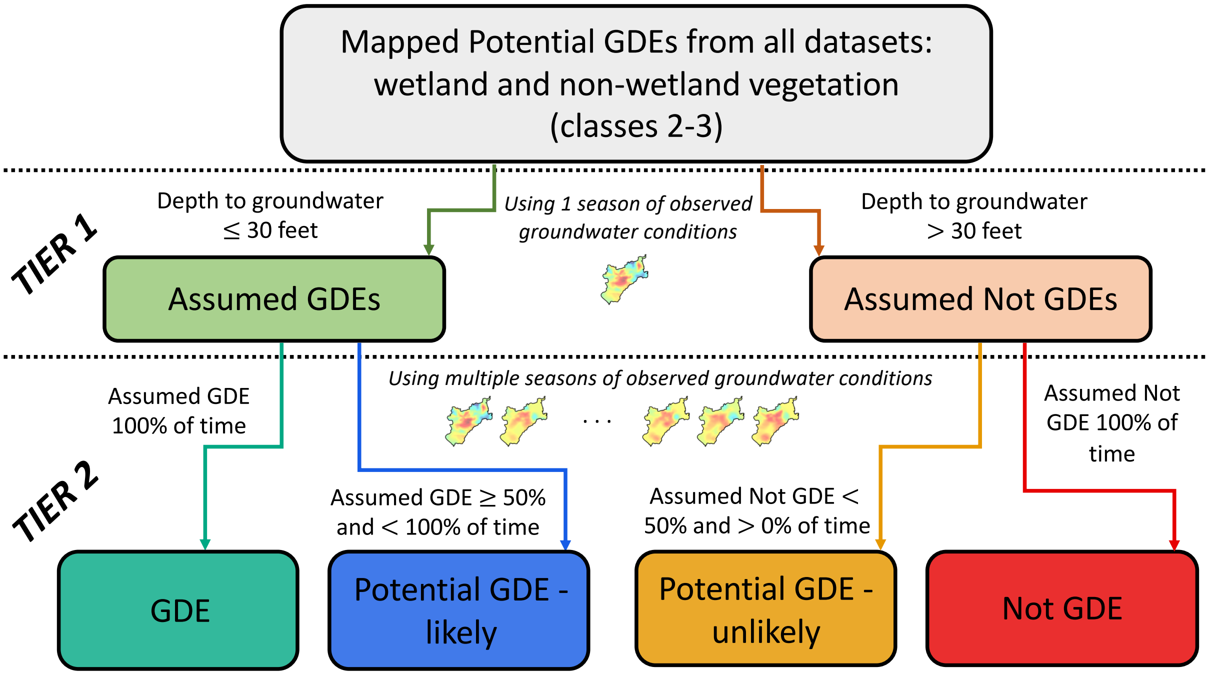

Figure 6. Conceptual Diagram Showing the Two-Tier GDE Classification Process

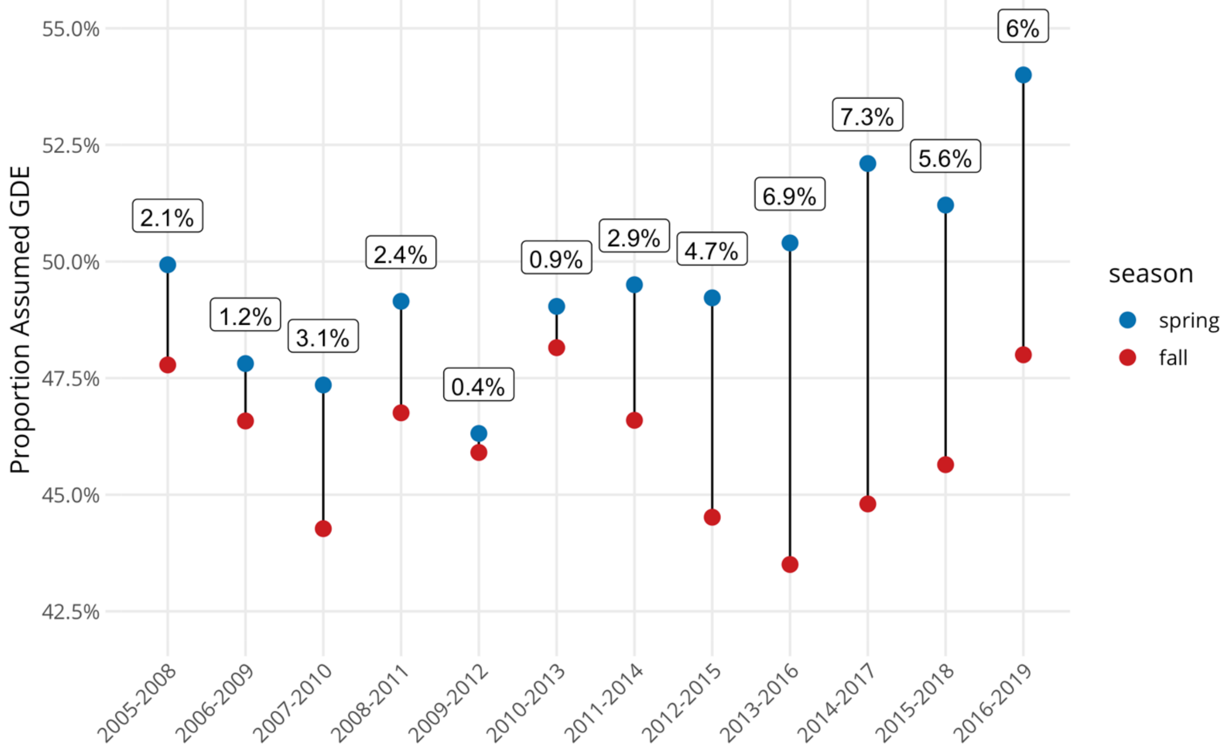

Figure 7. GDE Classification Based on the Application of a 30 ft. Depth to Groundwater Threshold on Mapped Potential GDEs

Table 4. GDE Likelihood Categorization Based All 4-year Groundwater Elevations from 2005-2019

Category	Area (acres)	% of Mapped Potential GDE Area
GDE	11,340	43.2%
Potential GDE - Likely	1,695	6.5%
Potential GDE - Unlikely	914	3.5%
Not GDE	12,296	46.9%
Total	26,245	100%

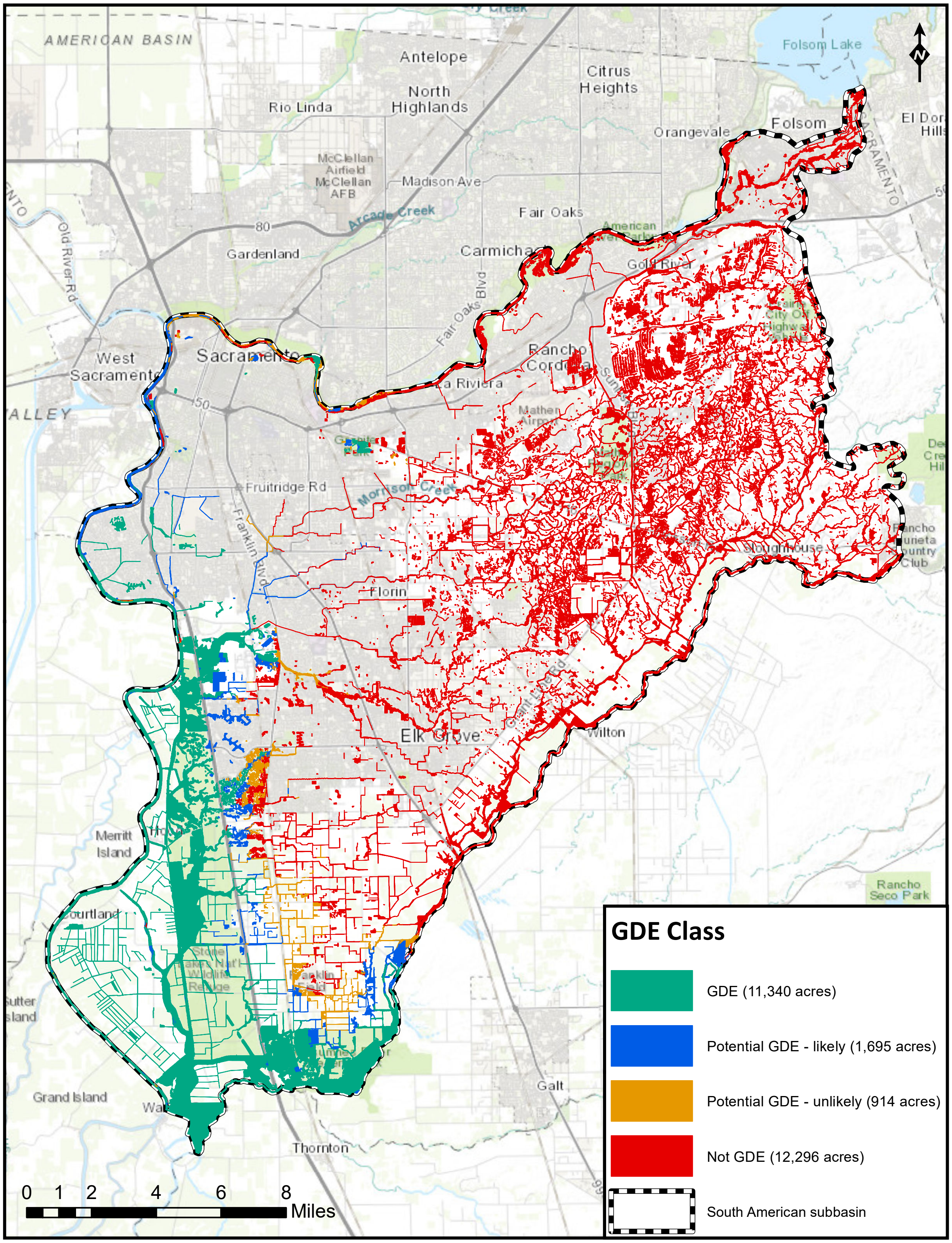

Figure 8. GDE Likelihood Classification of all Mapped Potential GDEs Over the Entire Period of Record (2005-2019)

GDE Categorization Through Aerial Imagery

An additional evaluation using aerial imagery and remote sensing techniques was carried out to validate, to the extent feasible, the Tier 2 GDE likelihood classification driven by the relationship of mapped potential GDE polygons to groundwater conditions. As previously discussed, the 30-foot depth to groundwater threshold is conservatively inclusive of GDE areas. In the SASb, only the Valley Oak would reasonably access groundwater close to 30 feet below ground surface. Thus the 30-foot threshold is most effective in identifying "Assumed Not GDE" areas based on SASb-scale representation of groundwater levels. A secondary evaluation of the classification of mapped potential GDEs into "GDE", "Potential GDE - Likely", "Potential GDE - Unlikely", and "Not GDE" classes was therefore required to account for the complex relationship between vegetation rooting depth and dynamic groundwater conditions.

Rooting depths for species vary over time as plants grow. Cottonwoods are a salient local example of the complex relationship between dynamic rooting zones and groundwater conditions because they are a relatively long-lived, deep-rooted and well-studied species commonly found in the SASb. Cottonwood seedlings require contact with moisture to sprout and elongate their roots rapidly to meet the groundwater or to follow it as water tables decline following floods. Mahoney and Rood (1992) identified that the maximum rate of root elongation was 0.47 inches per day (12 mm/day) for cottonwoods, with a 3.94 inch per day (10 cm/day) decline in experimental conditions, which matched field analysis on the cottonwood species (*P. fremontii*) found in this part of California. In other words, as groundwater levels fall, roots respond by elongating. Moreover, roots can access water through capillary action in soils with more fines (e.g., sand and smaller) and can be cut off more quickly in well-drained cobbles and boulder soils, highlighting the dependence of subsurface geology on root access to groundwater. The complexity of the root-water interface challenges measurable and scalable management criteria, thus we assume that above-ground differences in plant health (measured by plant "greenness" discussed below) are a reasonable proxy for unseen, below-ground processes. With all else being equal, greener plants presumably have greater access to groundwater, and drier plants have less access to groundwater.

An aerial imagery analysis was performed to evaluate the difference in Normalized Difference Vegetation Index (NDVI)[15] values between GDE likelihood classes. NDVI is a dimensionless measure of how surface vegetation reflects light in the visible and near-infrared parts of the electromagnetic spectrum and is a popular approach to estimate plant and community health at scale. The chlorophyll present in healthy plants absorbs visible light while the cellular structure of vibrant vegetation cover such as leaves strongly reflects near-infrared light. Healthy vegetation reflects more near infrared light and dry, unhealthy vegetation reflects more visible red light. NDVI exploits this material property of plants and is used to measure the relative health of vegetation in the SASb. Importantly, NDVI may be zero or negative for soil and water land cover classes, and NDVI can only be calculated at the scale of the pixel. Mixed pixels which contain vegetation, soil, and water have lower NDVI because soil and water do

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[15] NDVI is calculated as (NIR-Red) / (NIR + Red), where NIR is reflectance measured in the near infrared portion of the electromagnetic spectrum (750 - 1400 nanometers), and Red is red visible light (625-740 nanometers).

not reflect as strongly in the near infrared; these pixels were included in this analysis, and a spectral unmixing analysis was not performed.

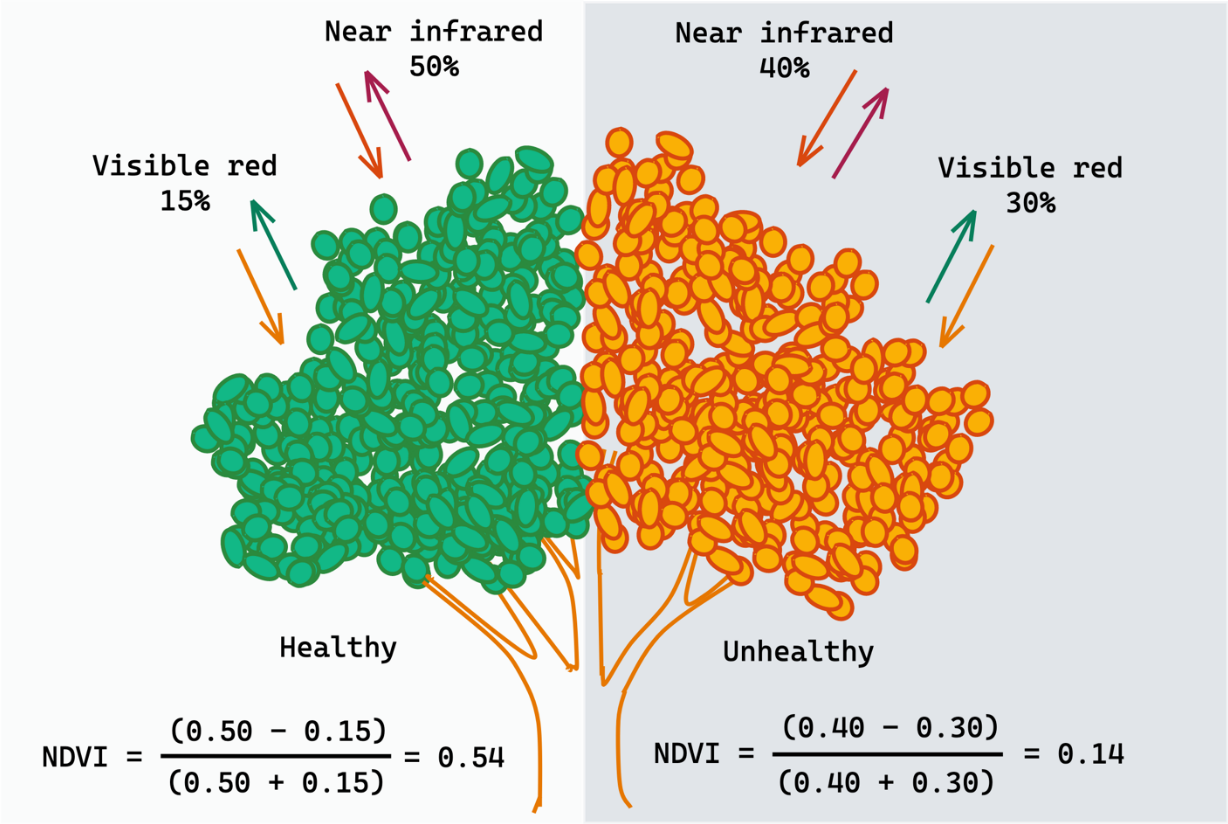

Figure 9: Normalized Difference Vegetation Index (NDVI) is higher for healthy vegetation and can be zero or less than zero for soil and water, and occurs when reflected red light exceeds reflected near infrared light.

Imagery from U.S. Department of Agriculture's (USDA) National Agriculture Imagery Program (NAIP) was obtained for summer dates from 2009-2020 when available (Table 5). NAIP imagery is generally available for a given area for one day a year during the growing season and was typically collected between late June and mid-July in the SASb. The previously discussed zonal statistics function within a GIS was used to compute grid-level NDVI values for each mapped potential GDE. NDVI values were summarized by GDE likelihood class for each NAIP imagery date (Figure 10). The NDVI distribution for areas classified as "GDE" consistently exhibit higher median NDVI compared to all other classes. Moreover, the "Potential GDE - likely" class tends to have the widest interquartile range across the years evaluated, which is unsurprising as this class is assumed to reflect vegetation where depth to groundwater is less than 30 feet in more than 50% of representations of groundwater conditions. The NDVI classification generally shows that areas assumed to have access to groundwater based on the Tier two GDE likelihood classification ("GDE" areas) have higher median and 75th percentile NDVI values (i.e., healthier vegetation) than other categories. This demonstrates that GDE can be used to separate Tier two "GDE" areas from other Tier two categories. Conversely, areas assumed to have limited or no access to groundwater based on the Tier two GDE likelihood classification such as "Not GDE", "Potential GDE -

Unlikely", "Potential GDE - Likely" classes are associated with lower median NDVI values and therefore are reasonably assumed to have less coverage, or less healthy vegetation. Moreover, class are relatively inseparable based solely on NDVI within these three non "GDE" Tier two classes.

Table 5. National Agriculture Imagery Program (NAIP) Image Dates used in this study

Calendar Year	Date
2009	June 21
2012	June 28
2014	June 5
2016	June 21
2018	July 14
2020	July 7

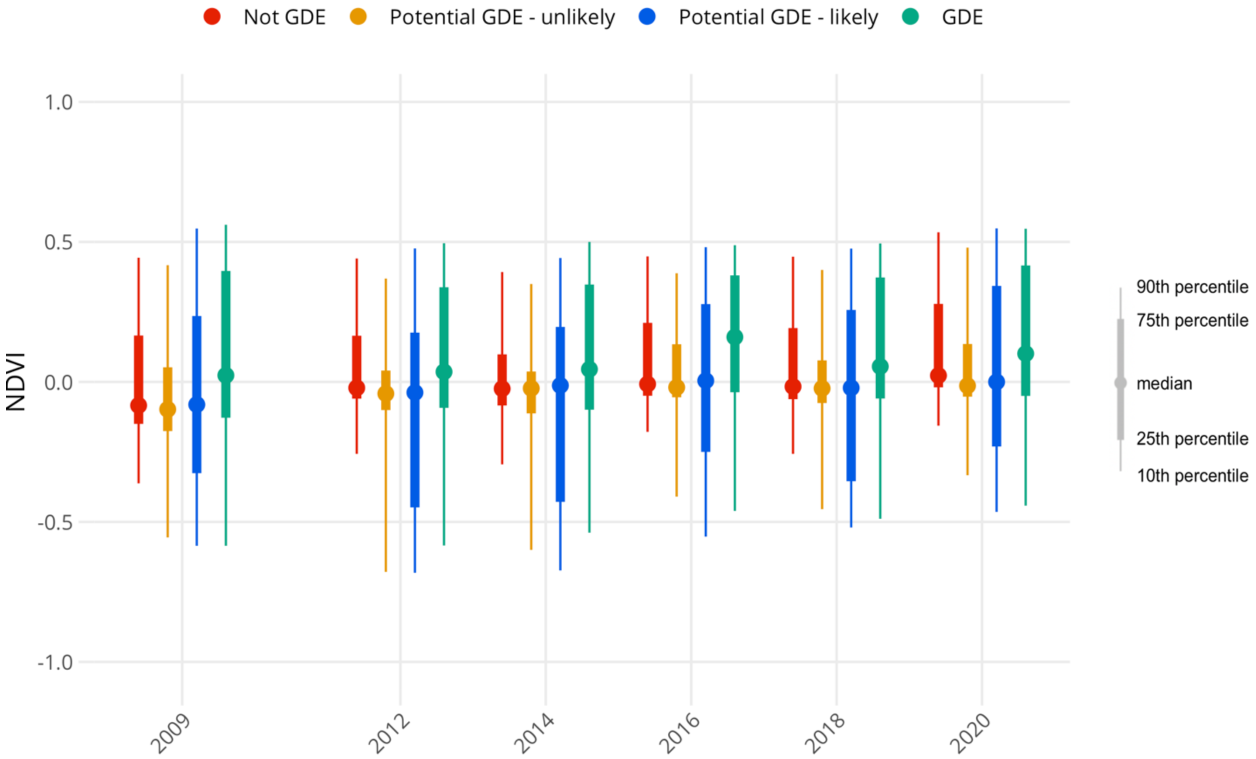

Figure 10. Distribution of Normalized Difference Vegetation Index (NDVI) Values by Tier two GDE Likelihood Class for Each National Agriculture Imagery Program (NAIP) Imagery Date

MANAGING GDEs

Wetland and non-wetland GDEs within the SASb are assumed to depend on shallow groundwater to support mature vegetation and seedling establishment (Rood et al., 2003). Shallow groundwater level decline may result in reduced plant growth and, in more severe cases, lead to plant mortality (Shafroth et al., 2000). Moreover, groundwater extraction can impact the shallow groundwater levels that support hydrophilic vegetation (Rood et al., 2003; Scott et al., 1999; Shafroth et al., 2000). For instance, Stromberg and colleagues (1996) found that mature cottonwood and willow trees required mean depths to groundwater in the range of nearly five feet and moderate, persistent reductions in groundwater level jeopardized the species' fitness. Moreover, seasonal fluctuations in groundwater levels are normal and once established, riparian species can survive periodic declines (Stromberg & Patten, 1992). Management of GDEs will therefore focus on defining Undesirable Results and setting measurable objectives (MOs) that account for the natural variability in depth to groundwater and surface vegetation composition represented by NDVI across the SASb. The governing philosophy of the proposed management criteria is to avoid previously un-observed conditions (defined by historical variability in groundwater and GDEs) – these criteria are measured in terms of groundwater level and NDVI.

Definition of Undesirable Results

Establishing a clear definition of Undesirable Results and the quantitative criteria by which these results are identified is a key outcome of the GDE management plan within the context of SGMA.

Undesirable Results for GDEs in the SASb are experienced when GDE area or plant health falls below 2015 minima, which indicate impacts to GDEs in excess of natural variability.

Bear in mind, the "natural variability" included in this contemporary historical range includes the impacts of the 2012-2016 drought, and pre-SGMA groundwater management.

Identification of Undesirable Results

The identification of Undesirable Results is based on how depth to groundwater and NDVI relate to historical Tier 1 and Tier 2 GDE classifications (Figure 6): if Tier 1 "Assumed GDE" area or Tier 2 "GDE" health declines below historically observed (2005-2019) natural variability, Undesirable Results occur. If either of the following criteria occur for three consecutive years during the implementation horizon, Undesirable Results are identified:

- **Criteria A (based on Tier 1 classification):** The proportion of Tier 1 "Assumed GDE" class falls below 44% (the lowest historically observed proportion of "Assumed GDE" occurring in fall 2013-2016)
- **Criteria B (based on Tier 2 classification):** Median June NDVI across the Tier 2 "GDE" class falls below 0.023 (the lowest historical median NDVI value, observed in June 2009). The Tier 2 "GDE" class is computed using observed groundwater conditions from the previous five fall seasons.

Criteria A was defined by reviewing the GDE likelihood categorization based on the relationship between area-weighted depth to groundwater value and the 30-foot threshold. The fall seasonal depth to groundwater from 2013-2016 represented the lowest proportion of historically observed Tier 1 "Assumed GDE" and "Assumed Not GDE" classes, with 44% of mapped potential GDEs falling into the "Assumed GDE" category. Thus, this criterion stipulates that Undesirable Results are identified if the proportion of the area in the "Assumed GDE" class falls to levels roughly observed during the 2012-2016 drought and remains there for three consecutive years.

Criteria B was defined by identifying the lowest historical median NDVI value (0.023) for the Tier 2 "GDE" class observed in the June 2009 NAIP imagery (Figure 10). Notably, this date precedes the 2012-2016 drought and represents an NDVI minimum based on natural variability in GDE vegetation. If the median "GDE" NDVI falls below the historically observed median "GDE" NDVI (0.023) this equates to a reduction in median plant health previously unobserved in the SASb. The Tier 2 "GDE" class is computed using the previous five fall groundwater level conditions, to represent a running five-year window of relatively recent groundwater conditions. Using the entire historical record (2005 - present) was considered, but it was determined that a running five-year window would be more representative of present-day conditions during the implementation horizon.

Collectively, Criteria A and B are based on Tier one and two GDE classification, and measure changes to GDE area and health, respectively. Thus, during an implementation year, even if GDE area may appear constant according to Criteria A, Criteria B will provide a lens into GDE conditions. Similarly, if GDE conditions are constant according to Criteria B, Criteria A will provide a lens into how GDE area has changed.

Median NDVI close to zero may be misinterpreted as indicating unhealthy vegetation. In fact, NDVI values form a distribution. In the year with the lowest median NDVI (2009), half of NDVI values in areas identified as "GDE" exceed 0.023, and half fall below this value. These Tier two GDE areas (groundwater within 30 feet of land surface in 100% of times evaluated) include vegetated areas (NDVI > 0), non-vegetated areas like water and soil (NDVI $\leq$ 0), and mixed pixels that contain vegetation, soil, water, and other materials (NDVI $\leq$ 0, and sometimes > 0). Median NDVI in Tier two GDE areas that falls below 0.023 during the implementation time period indicates the areas which are consistently within 30 feet of groundwater have become less photosynthetic as a whole, which indicates loss of healthy vegetation in excess of historically observed natural variability in NDVI. If this criteria is observed, it should be considered alongside Criteria A, and change in NDVI maps should inform strategic field-based monitoring.

Table 6. Quantitative Definition of Undesirable Results

Identification of Undesirable Result	Historical minimum observed	Quantitative Metric
Criteria A: Proportion of Mapped Potential GDE Classified as "Assumed GDE" in Tier 1 GDE Likelihood Analysis	2013-2016 Fall	44%
Criteria B: Lowest Median NDVI for "GDE" in Tier 2 GDE Likelihood Analysis	June 2009	0.023

Both criteria to identify Undesirable Results use metrics based on evolving representations of mapped potential GDE areas and hence allow for the future addition or removal of mapped potential GDE areas as the composition of surface vegetation within the SASb is more comprehensively understood. Furthermore, future iterations of this GDE analysis can be carried out and compared to the period or dates associated with the quantitative definitions of Criteria A and B. In subsequent implementation years, a dataset representing the current understanding of the spatial distribution of class 2 wetland and class 3 non-wetland mapped potential GDEs will be developed and set the extent of the GDE analysis.

Mapped potential GDEs will be undergo Tier 1 classification into "Assumed GDE" and "Assumed Not GDE" classes by applying the 30-foot threshold based on the current representation of depth to groundwater (Figure 6). If the proportion of mapped potential GDEs classified as "Assumed GDE" in Tier 1 is less than 44% for 3 consecutive years, an Undesirable Result is observed. A comparison of "Assumed

GDE" Tier 1 class for the current year and the 2013-2016 Fall period will reveal areas where changes in groundwater conditions have moved areas into the "Assumed Not GDE" Tier 1 class.

Areas will then be further classified consistent with the Tier 2 criteria into GDE likelihood classes (**Error! Reference source not found.**). NDVI summary statistics will be computed for each Tier 2 GDE likelihood class based on groundwater conditions for five fall seasons (the year of the evaluation and the previous four years). If the median NDVI for areas that fall into the Tier 2 "GDE" class is less than 0.023, an Undesirable Result is observed. A map showing pixel NDVI change between the NDVI for the year in question with the June 2009 date used to establish the Undesired Result metric will show what areas have experienced vegetative condition change.

Measurable Objectives

Measurable objectives (MOs) are sustainable management targets to reach within the implementation horizon. The clear relationship between Tier 2 GDE likelihood classes based on depth to groundwater and NDVI (Figure 10) suggest that sustainable management criteria for groundwater which maintain groundwater levels within 30 feet of land surface in existing GDE areas will support GDE health.

Like the identification of Undesirable Results, MOs for GDE health are based on maintaining or exceeding the average historically observed GDE area proportion and NDVI. GDE MOs for the implementation horizon are summarized as follows:

- Tier 1 "Assumed GDE" class remains at 48% or higher (mean of GDE area proportion from 2005-2019)
- Median five-year running June NDVI for the Tier 2 "GDE" class remains at or above 0.07 (average median June NDVI over NAIP period of record evaluated in this study)

Stabilization at these levels implies GDE area and plant health consistent with average historical conditions.

GDE-ASSOCIATED BENEFICIAL USES & USERS

There are a variety of aquatic, amphibious and riparian species that may be associated with GDEs in the SASb. In order to better understand these users and their uses of aquatic and riparian habitat, the analysis includes a report from CDFW's Biogeographic Information and Observation System (BIOS), a database that provides a comprehensive list of special status species and some of their habitat in Sacramento County.[16] The database does not allow querying by Bulletin 118 subbasins. As such, it contains more species than are found in the SASb, as well as some species that are found in the general watershed but have not been identified as occupying this region. The complete list and an annotated list of those species and habitats that have known or likely relationships to GDEs are included in Appendix E. These environmental beneficial users have the potential to be impacted through chronic or acute lowering of water tables.

LIMITATIONS

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[16] *Available at* https://wildlife.ca.gov/Data/BIOS.

The approach developed and carried out to identify and evaluate GDEs within the SASb represents a conservative application of best available science through the application of reasonable assumptions. Representations of mapped potential GDEs were developed based on available geospatial datasets, though these resources cannot be assumed to be definitive. The vegetation classes present in the datasets outlined in the Mapped Potential GDEs section above are broad and could reasonably represent a broad array of vegetation types precluding the reasonable and defensible assignment of assumed rooting zone depths. Groundwater conditions were represented by the interpolation of observed conditions in the Subbasin’s well network. These interpolated groundwater elevations may not reflect smaller scale variations in conditions both in space (less than 500 meters) and time (sub-seasonal). Because the groundwater elevations used herein represent regional, seasonal trends, they cannot capture the impact of perched aquifers on GDE health. Moreover, regional groundwater models such as CoSANA were not incorporated into the analysis.

Notably, GDEs are not necessarily static and can vary in time and space depending on water year type and other environmental conditions. As such, this analysis is not intended to be a definitive cataloging of each class of GDE, but rather a survey of the maximum possible extent of above-ground, vegetated GDEs in the SASb. A physical determination of GDEs must show that roots are connected to groundwater, which would require an infeasible subsurface geophysical survey across the SASb.

NDVI analysis included data from 2009, 2012, 2014, 2016, 2018, and 2020. These 6 years are a sample of water year types and GDE conditions and may not reflect the entire range of natural variation in NDVI across the SASb. SGMA implementation will require the re-calculation of this metric, and over time, a better understanding of the variance in NDVI in Tier two GDE areas will be reached.

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Appendix 3-E

Table A-1: Groundwater Quality Monitoring Wells Within the South American Subbasin that Measure Both Nitrogen and TDS

Appendix 3-E

Table A-1: Groundwater quality monitoring wells within the South American Subbasin that measure both nitrate and TDS.

WELL ID	Facility or Water System Name	GSA	Well Depth	Formation	Nitrate Measurements			TDS Measurements		
					From	To	# of records	From	To	# of records
3400101-001	Hood Water Maintenance Dist	ND	60	Alluvium	3/21/2001	11/13/2018	9	2/19/2008	2/11/2020	3
3400173-001	Northgate 880 (SWS)	ND	284	Laguna	7/26/2001	2/3/2020	15	5/24/2001	2/27/2007	3
3410020-009	City of Sacramento Main	SCGA	91	Laguna	11/16/1988	2/4/2020	23	11/16/1988	2/4/2020	13
3410029-002	SCWA - Laguna/Vineyard	SCGA	176	Laguna	2/21/1991	2/13/2020	26	2/21/1991	2/13/2020	9
3410029-016	SCWA - Laguna/Vineyard	SCGA	150	Laguna	7/1/1988	2/10/2020	24	7/1/1988	2/10/2020	9
3410029-024	SCWA - Laguna/Vineyard	SCGA	232	Laguna	8/26/2002	5/10/2018	16	8/26/2002	5/22/2014	5
3410029-025	SCWA - Laguna/Vineyard	SCGA	252	Laguna	3/21/2001	5/14/2019	17	3/21/2001	5/22/2014	6
3410029-029	SCWA - Laguna/Vineyard	SCGA	153	Laguna	10/25/2001	2/13/2020	17	10/25/2001	2/13/2020	7
3410033-006	Florin County Water District	SCGA	127	Laguna	7/13/1990	3/19/2019	48	7/13/1990	6/13/2019	10
3901216-001	Unknown	ND	292	Laguna	5/22/2002	2/12/2018	9	5/22/2002	2/16/2017	4
L10004137499-MW-11	L &D Landfill	SCGA	136	Laguna	11/11/2009	8/20/2019	14	5/13/2009	8/20/2019	16
L10004137499-MW-19	L &D Landfill	SCGA	100	Laguna	12/14/2010	11/6/2019	8	5/12/2009	11/6/2019	17
L10004137499-MW-21	L &D Landfill	SCGA	100	Laguna	5/12/2009	8/19/2019	18	5/9/2011	8/19/2019	11
L10004137499-MW-23	L &D Landfill	SCGA	100	Laguna	5/12/2009	5/21/2019	15	5/5/2010	8/19/2019	17
L10004137499-MW-24	L &D Landfill	SCGA	100	Laguna	5/13/2009	5/21/2019	14	5/14/2012	11/7/2019	10
L10004137499-MW-29	L &D Landfill	SCGA	90	Laguna	5/6/2010	11/6/2019	7	5/15/2012	5/22/2019	5

WELL ID	Facility or Water System Name	GSA	Well Depth	Formation	Nitrate Measurements			TDS Measurements		
					From	To	# of records	From	To	# of records
L10004137499-MW-5	L &D Landfill	SCGA	91	Laguna	5/7/2010	5/24/2019	12	5/15/2009	11/8/2019	17
L10004137499-MW-8	L &D Landfill	SCGA	120	Laguna	5/7/2010	11/6/2019	7	5/7/2010	5/22/2019	9
L10005519750-MW-D	Unknown	SCGA	48	Laguna	5/5/2014	12/10/2019	8	5/5/2014	12/10/2019	7
L10005519750-MW-E	Unknown	SCGA	60	Laguna	5/5/2014	12/10/2019	5	5/5/2014	12/10/2019	5
L10005519750-MW-G(S)	Unknown	SCGA	59	Laguna	5/6/2014	12/10/2019	7	5/6/2014	12/10/2019	9
L10008601447-EW-1	Elk Grove Class III Landfill	SCGA	75	Laguna	8/6/2013	6/7/2019	9	10/28/2014	6/7/2019	6
L10008601447-EW-4	Elk Grove Class III Landfill	SCGA	120	Laguna	8/28/2013	9/17/2019	11	6/11/2014	6/6/2019	5
L10008601447-MW-12	Elk Grove Class III Landfill	SCGA	122	Laguna	5/2/2013	9/17/2019	8	6/11/2014	9/17/2019	7
L10008601447-MW-13	Elk Grove Class III Landfill	SCGA	130	Laguna	9/25/2014	9/19/2019	13	9/25/2014	9/19/2019	12
L10008601447-MW-2	Elk Grove Class III Landfill	SCGA	134	Laguna	5/6/2013	6/5/2019	7	9/5/2013	9/19/2019	12
L10008601447-MW-3	Elk Grove Class III Landfill	SCGA	125	Laguna	2/22/2013	9/18/2019	9	2/22/2013	9/18/2019	9
L10008601447-MW-6	Elk Grove Class III Landfill	SCGA	121	Laguna	5/2/2013	6/10/2019	7	5/2/2013	9/17/2019	10
L10008601447-MW-8	Elk Grove Class III Landfill	SCGA	125	Laguna	5/2/2013	9/16/2019	9	5/2/2013	9/16/2019	6
L10008601447-MW-9	Elk Grove Class III Landfill	SCGA	176	Laguna	5/2/2013	7/10/2019	6	9/17/2013	6/5/2019	5
3400125-001	Freeport Marina	SCGA	0	-	3/13/2001	3/14/2019	19	7/14/2005	3/14/2019	5
3400375-001	Slavic Missionary Church Inc	SCGA	300	Mehrten	7/9/2003	3/8/2019	14	6/8/2012	6/8/2012	1
3410010-002	Cal Am - Suburban Rosemont	SCGA	350	Mehrten	2/13/1991	9/12/2013	23	2/13/1991	8/17/2006	6
3410010-021	Cal Am - Suburban Rosemont	SCGA	366	Mehrten	1/21/1997	8/13/2018	22	1/21/1997	8/13/2018	8

WELL ID	Facility or Water System Name	GSA	Well Depth	Formation	Nitrate Measurements			TDS Measurements		
					From	To	# of records	From	To	# of records
3410015-020	Golden State Water Co. - Cordova	SCGA	363	Mehrten	5/27/1986	1/8/2019	32	5/27/1986	1/14/2014	11
3410015-022	Golden State Water Co. - Cordova	SCGA	430	Mehrten	5/19/1993	1/15/2019	24	5/19/1993	5/25/2017	11
3410015-029	Golden State Water Co. - Cordova	SCGA	510	Mehrten	5/18/1998	1/8/2019	20	5/18/1998	1/14/2014	7
3410023-015	Cal Am Fruitridge Vista	SCGA	340	Mehrten	2/15/1991	1/19/2017	29	2/15/1991	1/11/2018	7
3410029-015	SCWA - Laguna/Vineyard	SCGA	744	Mehrten	7/1/1988	5/7/2019	22	7/1/1988	5/23/2018	9
3410029-017	SCWA - Laguna/Vineyard	SCGA	0	-	2/1/1995	2/10/2020	24	8/20/1989	2/10/2020	10
3410029-018	SCWA - Laguna/Vineyard	SCGA	780	Mehrten	2/1/1995	5/7/2019	19	2/10/1998	5/22/2014	9
3410029-020	SCWA - Laguna/Vineyard	SCGA	950	Mehrten	2/23/2000	8/21/2018	16	2/23/2000	8/16/2017	7
3410029-021	SCWA - Laguna/Vineyard	SCGA	303	Mehrten	10/19/1999	8/23/2017	17	10/19/1999	8/20/2014	7
3410029-022	SCWA - Laguna/Vineyard	SCGA	366	Mehrten	10/26/2000	8/16/2018	20	10/26/2000	8/16/2017	9
3410029-026	SCWA - Laguna/Vineyard	SCGA	979	Mehrten	10/25/2001	8/15/2019	17	10/25/2001	5/11/2017	8
3410029-027	SCWA - Laguna/Vineyard	SCGA	720	Mehrten	11/19/2003	5/22/2018	15	11/19/2003	2/5/2019	5
3410704-001	SCWA Mather-Sunrise	SCGA	300	Mehrten	10/25/1999	5/6/2019	18	8/27/2002	6/4/2014	5
L10007396297-MW-12A	Kiefer Landfill	SCGA	60	Mehrten	9/15/2015	10/8/2019	5	9/15/2015	4/10/2019	5
L10007396297-MW-12B	Kiefer Landfill	SCGA	120	Mehrten	9/12/2016	10/2/2019	5	5/20/2014	10/2/2019	8
L10007396297-MW-16A	Kiefer Landfill	SCGA	114	Mehrten	9/29/2015	10/3/2019	5	11/5/2013	10/3/2019	8
L10007396297-MW-17A	Kiefer Landfill	SCGA	65	Mehrten	9/4/2014	10/7/2019	11	9/22/2015	4/10/2019	5
L10007396297-MW-20C	Kiefer Landfill	SCGA	336	Mehrten	5/12/2015	4/18/2019	4	6/2/2014	4/18/2019	6

WELL ID	Facility or Water System Name	GSA	Well Depth	Formation	Nitrate Measurements			TDS Measurements		
					From	To	# of records	From	To	# of records
L10007396297-MW-22B	Kiefer Landfill	SCGA	196	Mehrten	5/27/2014	4/17/2019	7	5/27/2014	9/30/2019	5
L10007396297-MW-27A	Kiefer Landfill	SCGA	126	Mehrten	9/21/2015	9/27/2019	7	6/2/2014	9/27/2019	5
L10007396297-MW-2C	Kiefer Landfill	SCGA	314	Mehrten	5/29/2014	4/16/2019	5	10/17/2013	4/16/2019	2
L10007396297-MW-37C	Kiefer Landfill	SCGA	350	Mehrten	10/13/2015	4/16/2019	2	6/4/2014	4/16/2019	6
L10007396297-MW-38B	Kiefer Landfill	SCGA	170	Mehrten	6/30/2014	10/3/2019	8	9/26/2014	4/18/2019	9
L10007396297-MW-40B	Kiefer Landfill	SCGA	300	Mehrten	5/7/2014	4/24/2019	5	9/2/2014	4/24/2019	8
L10007396297-MW-43A	Kiefer Landfill	SCGA	150	Mehrten	5/20/2015	10/8/2019	6	5/20/2015	10/8/2019	6
L10007396297-MW-5A	Kiefer Landfill	SCGA	114	Mehrten	5/5/2014	9/30/2019	8	5/5/2014	9/30/2019	6
L10007396297-MW-5B	Kiefer Landfill	SCGA	176	Mehrten	5/27/2014	10/4/2019	5	11/3/2015	10/4/2019	5
L10007396297-MW-6A1	Kiefer Landfill	SCGA	117	Mehrten	9/3/2014	10/8/2019	8	5/29/2014	10/8/2019	10
L10007396297-MW-7AR	Kiefer Landfill	SCGA	190	Mehrten	5/22/2014	10/4/2019	7	5/22/2014	4/26/2019	6
S7-SAC-SA10	Unknown	SCGA	480	Mehrten	11/2/2017	11/2/2017	1	11/2/2017	11/2/2017	1

Appendix 4-A

Projects and Management Actions

Appendix 4-A: Projects and Management Actions

No.	Project and Management Action Type	Project Name	Organization	Status
Structural				
1	Recharge Enhancement	Laguna Creek and Whitehouse Creek Multi-Functional Corridor Enhancement Project	City of Elk Grove	In Progress
2	Recharge Enhancement	Alder Creek Watershed Open Space/Conservation Easement Catalog	City of Folsom	In Progress
3	Recharge Enhancement	Alder Creek Watershed Tree Planting Program	City of Folsom	In Progress
4	Recharge Enhancement	American River Parkway Cordova Creek Naturalization	County of Sacramento	In Progress
5	Recharge Enhancement	Lower American River Berm Restoration	Sacramento Area Flood Control Agency	In Progress
6	Recharge Enhancement	Lower American River Gravel Augmentation and Side Channel Enhancement	Water Forum	In Progress
7	Recharge Enhancement	Carmichael Creek Restoration Project	Water Forum	
8	Recharge Enhancement	Alder Creek Channel and Floodplain Restoration	City of Folsom	Not Started
9	Recharge Enhancement	Alder Creek Watershed Coordinator Position	City of Folsom	Not Started
10	Recharge Enhancement	Alder Creek Watershed Invasive Weed Removal Strategy	City of Folsom	Not Started
11	Recharge Enhancement	Cosumnes River Preserve Wetland Units	Ducks Unlimited	Not Started
12	Recharge Enhancement	Bushy Lake Enhancement	Sacramento Area Flood Control Agency	Not Started
13	Recharge Enhancement	Cordova Creek Phase II	Water Forum	Not Started
14	Recharge Enhancement	Revolving Power Bypass Fund	Water Forum	Not Started
15	Recharge Enhancement	Gardenland Flood Management, Habitat Restoration, and Recreation Project	Sacramento Area Flood Control Agency	
16	Flood/Stormwater Management	Strawberry Creek Detention Basin Retrofit	City of Elk Grove	Not Started
17	Flood/Stormwater Management	Natomas Company Dam/Alder Reservoir Management	City of Folsom	Not Started
18	Water Quality	Abandoned Wells Program (AWP)	County of Sacramento	In Progress
19	Water Quality	Franklin Septic Conversion Project	Sacramento Area Sewer District	In Progress
20	Water Quality	Hood Community Septic Conversion Project	Sacramento Area Sewer District	In Progress

No.	Project and Management Action Type	Project Name	Organization	Status
21	Water Quality	SRCSD Biological Nutrient Removal Project	Sacramento Regional County Sanitation District	In Progress
22	Water Quality	SRCSD Disinfection System Project	Sacramento Regional County Sanitation District	In Progress
23	Water Quality	SRCSD Granular Media Filtration System Project	Sacramento Regional County Sanitation District	In Progress
24	Water Quality	Alder Pond Restoration and Management	City of Folsom	Not Started
25	Water Quality	Broadway Green Infrastructure Project	City of Sacramento	Not Started
26	Water Quality	Department of Utilities River Friendly Landscape and Water Efficient Irrigation System Demonstration Project	City of Sacramento	Not Started
27	Water Quality	Stormwater Pollution Reduction at Riverfront Parks: Sand Cove Park, Miller Park, Garcia Bend Park, Chicory Bend Park	City of Sacramento	Not Started
28	Water Quality	SW Pollution Reduction at Riverfront Parks: Del Paso Regional Park	City of Sacramento	Not Started
29	Water Quality	SW Pollution Reduction at Riverfront Parks: Glen Hall Park	City of Sacramento	Not Started
30	Water Quality	SW Pollution Reduction at Riverfront Parks: Tiscornia Park	City of Sacramento	Not Started
31	Flood/Stormwater Management	Alder Creek Watershed Stormwater Detention Basin Management	City of Folsom	In Progress
32	Flood/Stormwater Management	Basin 26 Drainage Project	City of Sacramento	In Progress
33	Flood/Stormwater Management	The Upper Laguna Creek Open Space Preserve	County of Sacramento	In Progress
34	Flood/Stormwater Management	Florin Creek Multi-Use Basin	Sacramento Area Flood Control Agency	In Progress
35	Flood/Stormwater Management	Lower Sacramento River Regional Project	Sacramento Area Flood Control Agency	In Progress
36	Flood/Stormwater Management	Pocket Area Levee Underseepage Repair	Sacramento Area Flood Control Agency	In Progress
37	Flood/Stormwater Management	Regional Integration with Central Valley Flood Protection Plan	Sacramento Area Flood Control Agency	In Progress
38	Flood/Stormwater Management	Multi-Functional Drainage Corridor for Shed C	City of Elk Grove	
39	Flood/Stormwater Management	Combined Sewer Green Infrastructure Pilot Projects	City of Sacramento	Not Started
40	Flood/Stormwater Management	Folsom Dam Raise	Sacramento Area Flood Control Agency	Not Started

No.	Project and Management Action Type	Project Name	Organization	Status
41	Flood/Stormwater Management	South Sacramento Streams Group Flood Management	Sacramento Area Flood Control Agency	
42	Water Quality	Elk Grove Green Street Project: Repurposing Urban Runoff with Green Instructure Technologies	City of Elk Grove	Not Started
43	Water Quality	City of Sacramento 16th Street Greenscape	City of Sacramento	In Progress
44	Water Quality	Elk Grove Creek Watershed Storm Water Detention Groundwater Recharge, Habitat Restoration and LID Project	City of Elk Grove	Not Started
45	Supply Augmentation	Sacramento Railyards Stormwater Stewardship and Groundwater Protection Project	City of Sacramento	In Progress
46	Supply Augmentation	Harvest Water Dilutant Stormwater Project	Sacramento Regional County Sanitation District	Not Started
47	Flood/Stormwater Management	Mather Field Road Rehabilitation	City of Rancho Cordova	Not Started
48	Flood/Stormwater Management	Monier Circle Detention and Water Quality Retrofit Project	City of Rancho Cordova	Not Started
49	Flood/Stormwater Management	Rockingham Drive Rehabilitation	City of Rancho Cordova	Not Started
50	Flood/Stormwater Management	Sunrise Blvd Rehabilitation - Phase II	City of Rancho Cordova	Not Started
51	Flood/Stormwater Management	Sunrise Blvd. Rehabilitation - Phase III	City of Rancho Cordova	Not Started
52	Flood/Stormwater Management	Sunrise Blvd. Rehabilitation Phase I	City of Rancho Cordova	Not Started
53	Flood/Stormwater Management	White Rock Road Rehabilitation	City of Rancho Cordova	Not Started
54	Recharge Enhancement	Groundwater Recharge/Swainson's Hawk Habitat Project	American River Conservancy	In Progress
55	Recharge Enhancement	Franklin Groundwater Treatment Plant - Recycled Water Storage Tank & Booster Pump Station	Sacramento County Water Agency	In Progress
56	Recharge Enhancement	Cosumnes River Area Conjunctive Use	The Nature Conservancy	Not Started
57	Recharge Enhancement	Phase II Recycled Water Project	Sacramento County Water Agency	
58	Water Quality	Iron/Manganese Removal Treatment Plant for Town of Hood	Sacramento County Water Agency	In Progress
59	Water Quality	Water Treatment Plants Rehabilitation Project	City of Sacramento	
60	Supply Augmentation	City of Folsom Turf Removal and Landscape Irrigation Upgrades	City of Folsom	In Progress
61	Supply Augmentation	E. A. Fairbairn Groundwater Well	City of Sacramento	In Progress
62	Supply Augmentation	Groundwater Well Recharge Improvements	City of Sacramento	In Progress

No.	Project and Management Action Type	Project Name	Organization	Status
63	Supply Augmentation	River Friendly Retrofit Program	City of Sacramento	In Progress
64	Supply Augmentation	FWTP Improvements and Pumpback Pipeline	City of Sacramento	In Progress
65	Supply Augmentation	City of Sacramento Conjunctive Use - Well 167	City of Sacramento	In Progress
66	Supply Augmentation	Sacramento Regional Weather Based Controller Irrigation Efficiency Incentives Project	City of Sacramento	In Progress
67	Supply Augmentation	Folsom Lake Raw Water Pump Station Replacement	El Dorado Irrigation District	In Progress
68	Supply Augmentation	Regional Leak Detection and Repair	Regional Water Authority	In Progress
69	Supply Augmentation	Water Loss Control Program	Regional Water Authority	In Progress
70	Supply Augmentation	Cordova Hills Storage Tanks & Booster Pump Station	Sacramento County Water Agency	In Progress
71	Supply Augmentation	Franklin Intertie Project	Sacramento County Water Agency	In Progress
72	Supply Augmentation	Hood Distribution Upgrades	Sacramento County Water Agency	In Progress
73	Supply Augmentation	Meter Retrofit Project for Tower Reads	Sacramento County Water Agency	In Progress
74	Supply Augmentation	North Service Area Pipeline - Phase 2	Sacramento County Water Agency	In Progress
75	Supply Augmentation	North Service Area Terminal Tanks & Booster Pump Station - Phase 1	Sacramento County Water Agency	In Progress
76	Supply Augmentation	Harvest Water Project	Sacramento Regional County Sanitation District	In Progress
77	Supply Augmentation	SRCSD/City of Sacramento Recycled Water Phase 2 Project	Sacramento Regional County Sanitation District	In Progress
78	Supply Augmentation	SRCSD/City of Sacramento Recycled Water Phase 3 Project	Sacramento Regional County Sanitation District	In Progress
79	Supply Augmentation	SRCSD/SPA Recycled Water Project	Sacramento Regional County Sanitation District	In Progress
80	Supply Augmentation	City of Sacramento/Commercial, Industrial and Institutional Expanded Water Conservation Program	City of Sacramento	N/A

No.	Project and Management Action Type	Project Name	Organization	Status
81	Supply Augmentation	GSWC/Cal-Am Interconnection Upgrade	Golden State Water Company	N/A
82	Supply Augmentation	City of Sacramento Conjunctive Use - Well 168	City of Sacramento	Not Started
83	Supply Augmentation	City of Sacramento Conjunctive Use - Well 169	City of Sacramento	Not Started
84	Supply Augmentation	City of Sacramento Conjunctive Use and Pressure Augmentation - New Pressure Zone	City of Sacramento	Not Started
85	Supply Augmentation	River Bend Park Water Supply Enhancement Project	County of Sacramento	Not Started
86	Supply Augmentation	Automatic Meter Infrastructure (AMI)	Elk Grove Water District	Not Started
87	Supply Augmentation	Railroad Corridor Water Line	Elk Grove Water District	Not Started
88	Supply Augmentation	American River South Interconnection Pipeline	Fair Oaks Water District	Not Started
89	Supply Augmentation	FOWD/CWD Interconnection Pipeline & Booster Facility	Fair Oaks Water District	Not Started
90	Supply Augmentation	Omochumne Hartnell Water District Off Season Irrigation Project Expansion	Omochumne Hartnell Water District	Not Started
91	Supply Augmentation	Franklin Groundwater Treatment Plant	Sacramento County Water Agency	Not Started
92	Supply Augmentation	Laguna Ridge (Whitelock) Groundwater Treatment and Storage Facility Plant	Sacramento County Water Agency	Not Started
93	Supply Augmentation	North Vineyard Storage and Booster Pump Facility	Sacramento County Water Agency	Not Started
94	Supply Augmentation	Poppy Ridge Groundwater Treatment and Storage Facility Plant - Phase 2	Sacramento County Water Agency	Not Started
95	Supply Augmentation	Power Inn Road Transmission Main - Calvine Road to Geneva Pointe Drive	Sacramento County Water Agency	Not Started
96	Supply Augmentation	Sunrise Douglas (Suncreek) Groundwater Treatment Plant	Sacramento County Water Agency	Not Started
97	Supply Augmentation	Walnut Grove Distribution Upgrades	Sacramento County Water Agency	Not Started
98	Supply Augmentation	SSWD-City of Sacramento Enterprise Intertie	Sacramento Suburban Water District	Not Started
99	Supply Augmentation	Booster pump for Northgate service area	City of Sacramento	
100	Supply Augmentation	River Arc completion	Placer County Water Agency	
101	Supply Augmentation	California-American Water Company Parkway well system (6 wells)	California-American Water Company	

No.	Project and Management Action Type	Project Name	Organization	Status
102	Supply Augmentation	California-American Water Company Rosemont well system (3 wells)	California-American Water Company	
103	Supply Augmentation	City of Sacramento groundwater well drilling (up to 24 wells)	City of Sacramento	
104	Supply Augmentation	Groundwater well construction (1)	Rancho Murieta Community Services District	
105	Supply Augmentation	City of Sacramento groundwater well flexible pump install (12 wells)	City of Sacramento	
106	Supply Augmentation	California-American Water Company and SCWA Intertie (Mather Air Force Base)	California-American Water Company	
107	Supply Augmentation	Golden State Water Company - City of Folsom Intertie	City of Folsom	
108	Supply Augmentation	Folsom South Canal pipeline	City of Folsom	
109	Supply Augmentation	Folsom-EID intertie	City of Folsom	
110	Supply Augmentation	Folsom-FOWD intertie	City of Folsom	
111	Supply Augmentation	City of Sacramento - SSWD intertie	City of Sacramento	
112	Supply Augmentation	City of West Sacramento-City of Sacramento intertie	City of Sacramento	
113	Supply Augmentation	Valve replacement at Franklin Road	City of Sacramento	
114	Supply Augmentation	American River South Interconnection Pipeline	Fair Oaks Water District	
115	Supply Augmentation	Golden State Water Company - Cordova booster pump station	Golden State Water Company	
116	Supply Augmentation	SCWA Zone 40 Pipeline improvement (P-17)	Sacramento County Water Agency	
117	Supply Augmentation	SCWA Zone 40 Pipeline improvement (P-19)	Sacramento County Water Agency	
118	Supply Augmentation	Folsom scalping plant	City of Folsom	
119	Supply Augmentation	Recycled water use expansion	Rancho Murieta Community Services District	
120	Supply Augmentation	Clementia and Bass Lake watershed stormwater capture and reuse	Rancho Murieta Community Services District	
121	Supply Augmentation	CoGen project and conveyance expansion	Sacramento Regional County Sanitation District	

No.	Project and Management Action Type	Project Name	Organization	Status
122	Supply Augmentation	Explore GSWC, OVWC, and CWD recycled water opportunities	Sacramento Regional County Sanitation District	
123	Supply Augmentation	Harvest Water groundwater pumping offset	Sacramento Regional County Sanitation District	Not Started
124	Supply Augmentation	Alder Creek Reservoir and diversion points	El Dorado County Water Agency	
125	Supply Augmentation	Calero Dam raising	Rancho Murieta Community Services District	
Non-Structural				
126	Demand Management	City of Sacramento Demand Management Projects	City of Sacramento	
127	Demand Management	Golden State Water Company Demand Management Projects	Golden State Water Company	
128	Demand Management	California American Water Company Demand Management Projects	California American Water Company	
129	Community Stewardship	Cordova Creek & River Viewing Chamber	City of Rancho Cordova	In Progress
130	Community Stewardship	American River Basin Creek Week	Sacramento Area Creeks Council	In Progress
131	Community Stewardship	Nimbus Hatchery Visitors Center	Water Forum / California Department of Fish and Wildlife	In Progress
132	Community Stewardship	Effie Yeaw Nature Center -- Education Program	Water Forum / Effie Yeaw Nature Center	In Progress
133	Community Stewardship	Alder Creek Watershed Stewardship program	City of Folsom	In Progress
134	Community Stewardship	Alder Creek Watershed Water Use Efficiency Outreach and Education	City of Folsom	In Progress
135	Community Stewardship	Promote River Friendly Landscaping in the Alder Creek Watershed	City of Folsom	In Progress
136	Demand Management	Regional Joint Water Energy Rebate Program	Regional Water Authority	In Progress
137	Demand Management	Advancing Water Efficiency in the Sacramento Region	Regional Water Authority	Not Started
138	Demand Management	Water Efficiency on Large Landscapes (WELL) project	Sacramento Central Groundwater Authority	
139	Community Stewardship	Citizen Science Program	Water Forum / Effie Yeaw Nature Center	Not Started
140	Recharge Enhancement	Alder Creek Watershed Monitoring Program	City of Folsom	In Progress

No.	Project and Management Action Type	Project Name	Organization	Status
141	Recharge Enhancement	Cordova Creek Maintenance	Water Forum	In Progress
142	Recharge Enhancement	Cosumnes River Water Quality Monitoring Program	American River Conservancy	Not Started
143	Water Quality	Sacramento-San Joaquin Delta Watershed Models for Water Supply /Water Quality	Sacramento Regional County Sanitation District	In Progress
144	Conjunctive Use	Examine and expand groundwater monitoring	Sacramento Central Groundwater Authority	
145	Conjunctive Use	Groundwater Accounting Program	Sacramento Central Groundwater Authority	
146	Conjunctive Use	PUC Groundwater Sales Improvement	California-American Water Company	
147	Conjunctive Use	Regional groundwater bank	various	
148	Conjunctive Use	Long-Term Water Supply Contracts with Reclamation	various	
149	Conjunctive Use	Reclamation Modified Flow Management Standard	various	
150	Conjunctive Use	CVP American River Division accelerated water transfer program	various	
151	Conjunctive Use	Clarification of Reclamation drought documents and policies	various	
152	Conjunctive Use	City of Sacramento surface water economic study	City of Sacramento	
153	Conjunctive Use	Fluoridation practice consistency	various	
154	Conjunctive Use	City of Sacramento POU expansion	City of Sacramento	
155	Conjunctive Use	City of Sacramento POU expansion	City of Sacramento	
156	Conjunctive Use	City of Sacramento Hodge Flow study	City of Sacramento	
157	Conjunctive Use	Folsom - Golden State Water Company emergency water agreement	City of Folsom	
158	Conjunctive Use	Folsom - Fair Oaks Water District emergency water agreement	City of Folsom	
159	Conjunctive Use	Golden State Water Company - SCWA agreement	Golden State Water Company	
160	Conjunctive Use	Long-term partnership agreements with SCWA, City of Sacramento, and/or others	Sacramento Suburban Water District	
161	Conjunctive Use	City of Sacramento - SCWA Southwest track agreement	Sacramento County Water Agency	
162	Community Stewardship	Morrison Creek Revitalization Plan	Environmental Justice Coalition for Water	In Progress

No.	Project and Management Action Type	Project Name	Organization	Status
163	Community Stewardship	Alder Creek Watershed Connected Creek Trails, Open Space and Interpretive Signage	City of Folsom	In Progress
164	Community Stewardship	American River Basin Collaborative for Watersheds	Valley Foothill Watersheds Collaborative	In Progress
165	Recharge Enhancement	Lower American River Ecosystem Enhancement Decision Support Tool	Water Forum	In Progress
166	Recharge Enhancement	Lake Natoma Warming Study	Water Forum	Not Started
167	Recharge Enhancement	Stormwater Quality and Groundwater Recharge Study Using Flood Detention Basins and Local Creeks/Streams	Sacramento County Water Agency	
168	Conjunctive Use	Maintain and Update HydroDMS	Sacramento Central Groundwater Authority	
169	Conjunctive Use	Sacramento Area Integrated Water Resource Model Hydrologic Model	Sacramento Central Groundwater Authority	

Sources:

1. American River Basin Integrated Water Management Plan, 2018. Regional Water Authority.
2. SCGA Basin Management Report 2013-2014, 2017. Sacramento Central Groundwater Authority.
3. City of Sacramento - 2015 Urban Water Management Plan, 2016. City of Sacramento.
4. 2015 Urban Water Management Plan, Northern Division - Sacramento District, 2016. California American Water.
5. Regional Water Reliability Plan, 2019. Regional Water Authority
6. 2015 Urban Water Management Plan, Cordova, 2016. Golden State Water Company.
7. Personal communication, Dave Ocenosak, Regional San.
8. Personal communication, Terrie Mitchell, Regional San.

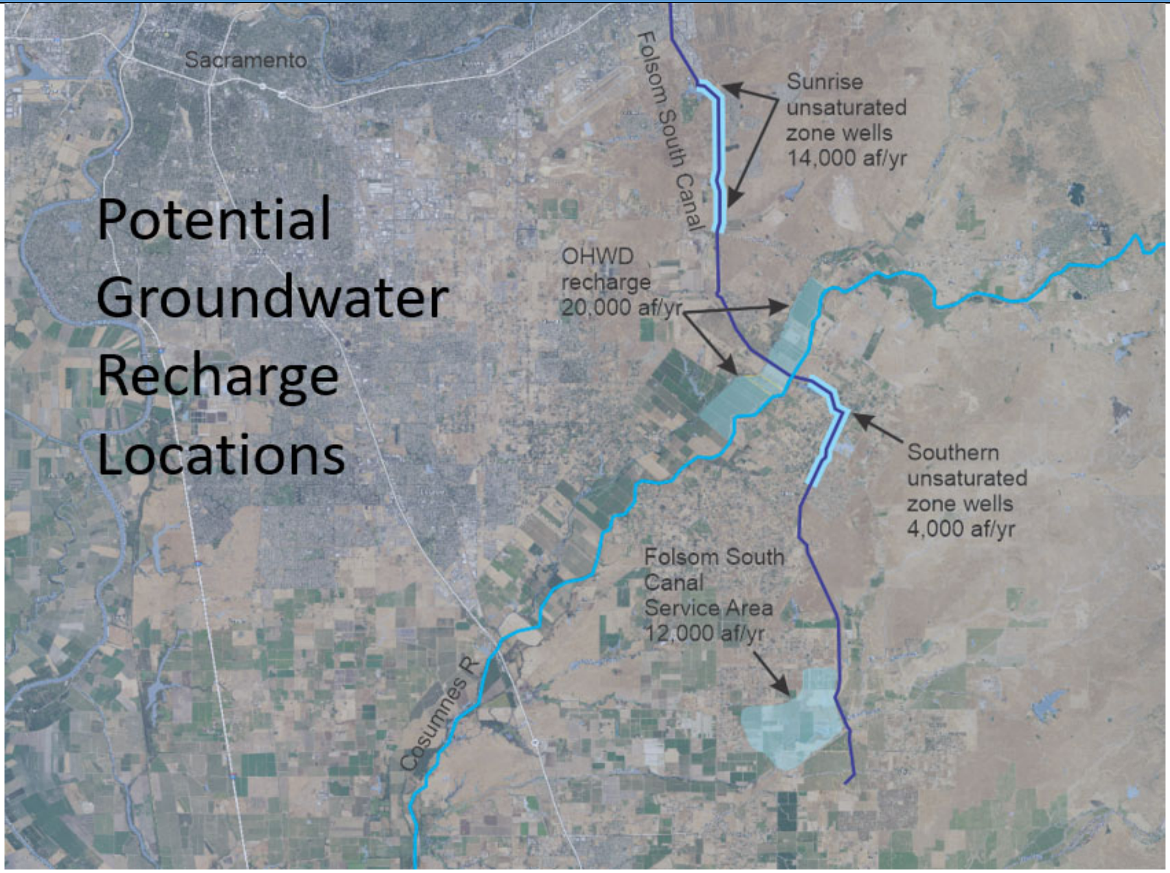
Appendix 4-B

Project Descriptions

Appendix 4-B: Project Descriptions

SAFCA FLOOD-MAR

PROJECTS & MANAGEMENT ACTIONS	
Date	**4/14/21**
Project Title	**SAFCA Flood-MAR Project**
PROJECT PROPONENT	
Agency Name	Sacramento Area Flood Control Agency
Key Contact	Timothy Washburn
Email	washburnt@SacCounty.NET
Phone	

PROJECT LOCATION	
Map	
PROJECT DESCRIPTION	
Description of Project Elements	This project will consist of modifications to Hell Hole, French Meadows, and Union Valley Reservoirs to enable forecast informed operations, changes in operations in Folsom Lake, the use of the Folsom South Canal, and the creation of recharge zones along the FSC alignment using unsaturated zone wells and spreading basins.

Actions	This project will utilize storage in the Middle and South Forks of the American River Basin as well as Folsom Reservoir to capture flood flows that would otherwise flow down the American River. These flows will then be diverted into the Folsom South Canal for recharge at 4 locations (see Figure) located in the South American and Cosumnes Subbasins.			
Project Goals	Recharge up to 125,000 AF/year in four of ten years into aquifers in South American and Cosumnes Subbasins.			
Project Benefits	• Increased groundwater recharge. • Improve flows and temperature conditions along the American and Cosumnes Rivers • Sustain agricultural productivity in South Sacramento County • Meet urban water needs in drought conditions			
Project Impacts	Enhanced capture and use of flood flows.			
Project Costs/Financing	The cost of the infrastructure necessary to support the program (recharge pipes, pumps, infiltration wells, recovery wells, etc.) will be provided largely by state and federal grant funds. Annual operation and maintenance costs will be provided principally through the banking and sale of fallowed water by the GSAs to an urban water purveyor for dry year augmentation.			
PROJECT STATUS				
Concept ☒	**Planned** ☐	**In-Design** ☐	**Under Construction** ☐	**Completed** ☐
Project Schedule				

Fruitridge Vista Main Replacement and Meter Retrofit

PROJECTS & MANAGEMENT ACTIONS	
Date	**March 15, 2021**
Project Title	**Fruitridge Vista Main Replacement and Meter Retrofit**
PROJECT PROPONENT	
Agency Name	California American Water
Key Contact	Evan Jacobs
Email	Evan.jacobs@amwater.com
Phone	916 568-4252
PROJECT LOCATION	
Map	

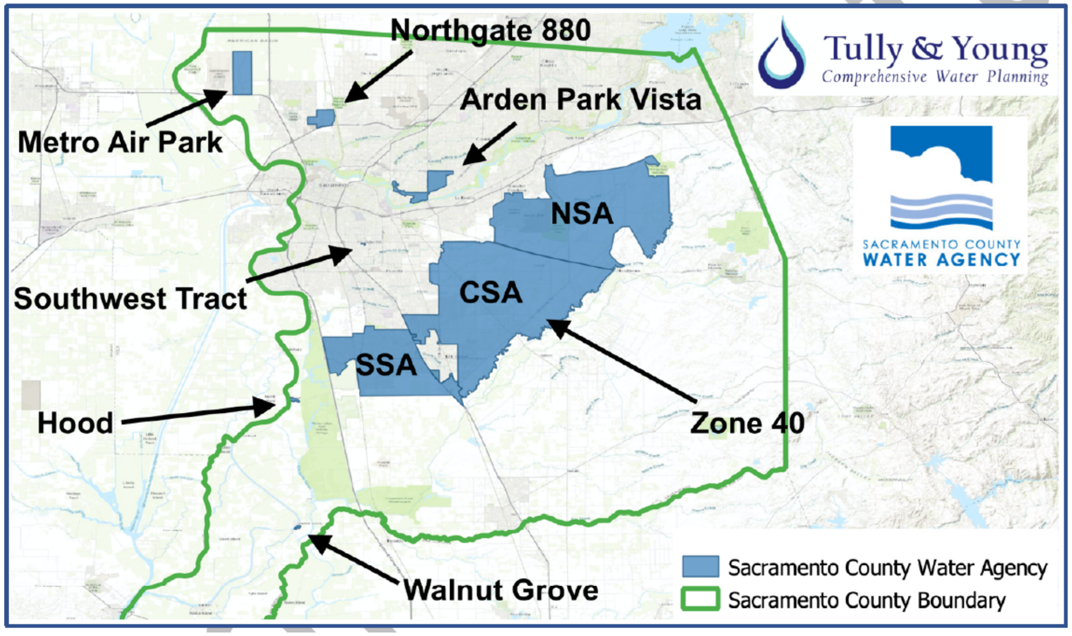
PROJECT DESCRIPTION	
Description of Project Elements	CAW acquired the Fruitridge Vista Water Company in south Sacramento in February 2020. There are several projects needed to comply with state law requiring meter installation and address aging steel mains that were installed in the 1950s and 60s.
Actions	California American Water plans to install approximately 81,382 linear feet of aging water mains in the Fruitridge Vista service area - $26 million project and install 2396 meters - $11 million project
Project Goals	The combination of metering and tiered rate design, conservation services, and replacing mains that are known to frequently leak/break is expected to reduce current demand (usually all groundwater pumped from the basin) by 241,159 thousand gallons
Project Benefits	Comply with state law, reduce leaks and main breaks, improve service for the Fruitridge Vista Community
Project Impacts	
Project Costs/Financing	$26 million in main replacement and $11 million for meter retrofit

PROJECT STATUS				
Concept ☐	**Planned ☐**	**In-Design ☐**	**Under Construction ☒**	**Completed ☐**

Project Schedule	All work done by 2025

Sacramento County Water Agency New Surface Water Supply

PROJECTS & MANAGEMENT ACTIONS	
Date	**4/12/2021**
Project Title	**New Surface Water Supply**
PROJECT PROPONENT	
Agency Name	Sacramento County Water Agency
Key Contact	Mike Huot
Email	huotm@saccounty.net
Phone	916-875-6947

PROJECT LOCATION	
Map	
PROJECT DESCRIPTION	
Description of Project Elements	Procurement of new surface water supplies to bolster surface water portfolio in dry year types.
Actions	Increase the use of surface water by procuring new surface water supplies to bolster availability of surface water in dry year types.
Project Goals	Maximize the ability to use surface water, improve SCWA’s conjunctive use water portfolio, and enhance the reliability SCWA’s water supplies.

Project Benefits	Additional groundwater could be left in the basin, which could provide both environmental benefits as well as provide long-term water reliability for the water agencies. • Increases regional and state water supply reliability through groundwater storage and conjunctive use • Improves water quality by restoring groundwater levels and increasing in-stream flows in the Cosumnes River • Provides reliable water supplies, enhanced groundwater storage opportunities, and drought resiliency			
Project Impacts	Significant Financial Investment			
Project Costs/Financing	• Currently unknown			
PROJECT STATUS				
Concept ☒	**Planned ☐**	**In-Design ☐**	**Under Construction ☐**	**Completed ☐**
Project Schedule	Anticipated Completion Years: Currently unknown, concept only.			

Contact Information

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