APPENDIX D

Pure Water Soquel Model Simulation Results

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TECHNICAL MEMORANDUM

To: Melanie Mow Schumacher

From: Cameron Tana

Date: June 22, 2018

Subject: Pure Water Soquel Groundwater Model Simulation Results

1. INTRODUCTION

This technical memorandum discusses model simulation groundwater levels, groundwater budget, and particle tracking results to support the Environmental Impact Report of the Pure Water Soquel project involving replenishment of advanced purified recycled water within Soquel Creek Water District's (SqCWD's) service area. Six model simulations have been run using the calibrated GSFLOW model for the Santa Cruz Mid-County Basin (the Basin) where SqCWD's service area is located. These simulations have different pumping and active replenishment distributions, as follows:

- Two Projected Existing Conditions (No Project) simulations with SqCWD's pumping distribution reflecting future demand without additional replenishment at proposed recharge wells.
- Two Project simulations with SqCWD's pumping distribution reflecting future demand and pumping re-distribution with the addition of replenishment at the Monterey and Cabrillo College Dr. sites (referred to as the Cabrillo-Monterey simulations). These simulations also represent potential replenishment at the Twin Lakes Church site instead of one of the two Cabrillo College Dr. sites. The Twin Lakes Church site is approximately 500-750 feet to the west of the Cabrillo College Dr. sites.
- Two Project simulations with the same pumping distribution as the Cabrillo-Monterey simulations, but with replenishment at the Monterey and Willowbrook sites (referred to as the Monterey-Willowbrook simulations).

Simulation groundwater levels are evaluated for the following effects:

- Comparison of groundwater levels at coastal monitoring wells to protective elevations estimated to prevent seawater intrusion from further occurring in groundwater supply aquifers.
- Groundwater levels in the recharge wells to assess whether model results are consistent with estimated capacities for the well, recognizing that site specific testing will be needed to confirm recharge well capacities.
- Groundwater levels at nearby wells to evaluate effects on operation of those municipal, private, and institutional wells.

Simulation groundwater budgets are evaluated for following effects:

- Flows entering and leaving the Basin, including flows to and from groundwater in storage and flows offshore to prevent seawater intrusion.
- Flows between groundwater and surface water.

This memo does not include results for a Cumulative simulation. Information from the City of Santa Cruz to define its Aquifer Storage and Recovery project to be cumulative with Pure Water Soquel is not available or developed at this time.

This memo includes results from particle tracking based on the above simulations performed to support the Salt and Nutrient Anti-degradation Study and permitting of the recharge wells. This involves particle tracking of simulated purified, replenishment water to evaluate the fate of the water as it travels in subsurface aquifers. Particle tracking is also used to evaluate travel times of purified, replenishment water, which requires refined analysis near the recharge wells. A scope to superimpose analytic element solutions for recharge and nearby extraction wells onto GSFLOW results to facilitate travel time calculations was approved by SqCWD Board December 18, 2017 and results should be forthcoming in July 2018.

2. CLIMATE SCENARIOS

As described in the August 15, 2017 memo with subject line *SqCWD Pumping Distributions for Pure Water Soquel Model Simulations – Revision* 2 (Attachment 1), two simulations were run for each pumping and managed recharge distribution because simulations were run under two climate scenarios based on historical data (Table 2). For each of the distributions, one simulation was run under historic climate from Water Years 1985-2015 used for calibration (Historic Climate scenario). The other scenario that was run for each simulation uses a representation of future climate change based on preferentially selecting warmer years from the catalog of historic years from Water Years 1909-2016 (HydroMetrics WRI, 2016, Attachment 2). Table 1 shows the difference in annual temperature and annual rainfall at the Santa Cruz Co-op Station for the two climate scenarios. The Catalog Climate scenario is warmer and drier than the Historic Climate scenario. Table 2 shows the climate classification by water year demonstrating the weighted selection of more Warm years in the Catalog Climate scenario resulting in a majority of years in the Catalog Climate scenario classified as historically warm and dry. Table 2 also shows which years are defined as critically dry based on San Lorenzo River flow below 29,000 acre-feet per year.

Table 1. Average Precipitation and Temperature at Santa Cruz Co-op Station for Climate Scenarios

Climate Scenario	Average Temperature (deg. F)	Annual Rainfall (in)
Historic Climate	57.9	29.0
Catalog Climate	59.0	26.0

The Catalog Climate scenario also includes sea level rise of 1.5 feet over the simulation period applied at the offshore general head boundary conditions. This sea level rise is based on National Research Council (2012) projections for sea level rise at San Francisco under the A1B emission scenario (average scenario).

Table 2. Water Years Used for Climate Scenarios

		Historic Climate Scenario Based on Water Years 1985-2015			Future Climate Scenario Based on Historic Catalog		
Model Water Year	Future Water Year Used for Pumping and Managed Recharge	Historic Water Year Used for Climate	Classification	San Lorenzo River Flow (AFY)	Historic Water Year Used for Climate	Classification	San Lorenzo River Flow (AFY)
				Critically Dry			Critically Dry
1	2016	2016	Warm & Wet	76,443	2016	Warm & Wet	76,443
2	2017	1985	Cooler & Wet	43,800	1992	Warm & Dry	48,421
3	2018	1986	Cooler & Wet	169,408	2015	Warm & Dry	31,637
4	2019	1987	Warm & Dry	23,963	2010	Cooler & Wet	94,840
5	2020	1988	Warm & Dry	20,254	2014	Warm & Dry	13,828
6	2021	1989	Cooler & Dry	24,398	2016	Warm & Wet	76,443
7	2022	1990	Warm & Dry	19,402	2004	Warm & Dry	84,283
8	2023	1991	Cooler & Dry	30,262	2003	Warm & Wet	77,102
9	2024	1992	Warm & Dry	48,421	2015	Warm & Dry	31,637
10	2025	1993	Warm & Wet	111,057	2013	Warm & Dry	53,284
11	2026	1994	Cooler & Dry	28,452	1990	Warm & Dry	19,402
12	2027	1995	Cooler & Wet	177,806	2015	Warm & Dry	31,637
13	2028	1996	Warm & Wet	125,952	1986	Cooler & Wet	169,408
14	2029	1997	Warm & Wet	142,694	1991	Cooler & Dry	30,262
15	2030	1998	Warm & Wet	204,303	1997	Warm & Wet	142,694
16	2031	1999	Cooler & Wet	86,876	2014	Warm & Dry	13,828
17	2032	2000	Cooler & Wet	112,232	1992	Warm & Dry	48,421
18	2033	2001	Cooler & Dry	48,868	2014	Warm & Dry	13,828
19	2034	2002	Cooler & Wet	67,763	1984	Warm & Dry	80,363
20	2035	2003	Warm & Wet	77,102	2015	Warm & Dry	31,637
21	2036	2004	Warm & Dry	84,283	2013	Warm & Dry	53,284
22	2037	2005	Cooler & Wet	119,599	2013	Warm & Dry	53,284
23	2038	2006	Cooler & Wet	198,295	1992	Warm & Dry	48,421
24	2039	2007	Cooler & Dry	28,524	1934	Warm & Dry	Estimated >29,000
25	2040	2008	Cooler & Dry	53,212	1983	Warm & Wet	283,216
26	2041	2009	Warm & Dry	45,465	1992	Warm & Dry	48,421
27	2042	2010	Cooler & Wet	94,840	2015	Warm & Dry	31,637
28	2043	2011	Cooler & Wet	123,002	2014	Warm & Dry	13,828
29	2044	2012	Cooler & Dry	46,751	1980	Cooler & Wet	135,825
30	2045	2013	Warm & Dry	53,284	2003	Warm & Wet	77,102
31	2046	2014	Warm & Dry	13,828	2006	Cooler & Wet	198,295
32	2047	2015	Warm & Dry	31,637	2015	Warm & Dry	31,637
33	2048				2013	Warm & Dry	53,284
34	2049				1958	Warm & Wet	205,389
35	2050				2016	Warm & Wet	76,443
36	2051				2009	Warm & Dry	45,465
37	2052				2015	Warm & Dry	31,637
38	2053				1999	Cooler & Wet	86,876
39	2054				2015	Warm & Dry	31,637
40	2055				2015	Warm & Dry	31,637
41	2056				1992	Warm & Dry	48,421
42	2057				2016	Warm & Wet	76,443
43	2058				2014	Warm & Dry	13,828
44	2059				1977	Cooler & Dry	9,556
45	2060				2015	Warm & Dry	31,637
46	2061				1992	Warm & Dry	48,421
47	2062				2014	Warm & Dry	13,828
48	2063				1998	Warm & Wet	204,303
49	2064				2013	Warm & Dry	53,284
50	2065				1992	Warm & Dry	48,421
51	2066				1992	Warm & Dry	48,421
52	2067				1989	Cooler & Dry	24,398
53	2068				2016	Warm & Wet	76,443
54	2069				1984	Warm & Dry	80,363

3. SUMMARY OF PUMPING DISTRIBUTIONS

The August 15, 2017 memo with subject line *SqCWD Pumping Distributions for Pure Water Soquel Model Simulations – Revision* 2 (Attachment 1) describes the pumping and replenishment distributions throughout the Basin in more detail, with the additional revisions described below. To summarize the August 15, 2017 memo, the Project (both Cabrillo-Monterey and Monterey-Willowbrook) pumping distributions are designed to increase pumping at SqCWD production wells near the proposed recharge wells to limit increases in groundwater levels near the proposed recharge wells and decrease pumping at SqCWD production wells away from the proposed recharge wells to recover groundwater levels throughout SqCWD's service area.

The Project pumping distributions are based on increases and decreases from the assumptions for SqCWD pumping in the Projected Existing Conditions simulations. SqCWD groundwater pumping in the Projected Existing Conditions simulations is based on demand projections in SqCWD's 2015 Urban Water Management Plan (Water Systems Consulting, 2016). The Urban Water Management Plan (UWMP) projects SqCWD demand to be 3,900 acre-feet per year in 2020 with decreases to 3,200 acre-feet per year by 2045. The maximum SqCWD pumping assumed in the Projected Existing Conditions simulation of 3,900 acre-feet per year is lower than historical pumping by SqCWD for all years from 1979 to Water Year 2014. SqCWD now anticipates additional water demands based on new regulations related to accessory dwelling units (ADUs), cannabis cultivation, and the housing crisis developed since release of the UWMP. The Projected Existing Conditions simulations also include an assumption of drought curtailment during critically dry years that are not assumed in Project simulations. The Projected Existing Conditions simulations do not assume continuation of Stage 3 drought curtailment in all years related to the groundwater emergency that SqCWD has declared. The Stage 3 drought curtailment is included in the Projected Existing Conditions simulations that serve as a baseline for effects from the Project because the curtailment is meant to be an interim measure while SqCWD develops new water sources such as the Project

Figure 1 shows the sites for proposed recharge wells: Monterey in the Purisima A unit and Cabrillo College, Twin Lakes Church, and Willowbrook in the Purisima BC and A units. Figure 1 shows the SqCWD production wells near the proposed recharge wells that have increased pumping with the Project: the Rosedale well screened in the Purisima A and AA units, the Tannery II and planned Cunnison Lane wells in the Purisima A unit, and the Estates well in the Purisima BC and A units. Project recharge will occur in the Purisima BC and A units. Figure 1 also shows the SqCWD production wells farther southeast of the proposed recharge wells that have reduced pumping with the Project: the Bonita, San Andreas, and Seascape wells screened in the Purisima F unit and Aromas Red Sands aquifer.

Figure 2 and Figure 3 show the time series of flow differences at SqCWD wells between the Project (both Cabrillo-Monterey and Monterey-Willowbrook) simulations and the Projected Existing Conditions simulations for Historic Climate and Catalog Climate, respectively. The positive flow differences represent active replenishment at the recharge well sites (solid bars) and also passive/in-lieu recharge due to reduced pumping at SqCWD production wells away from the recharge wells (dotted bars). The negative flow differences represent increased pumping near the recharge wells (hatched bars). The three lines shows net recharge (active replenishment plus pumping decrease minus pumping increase) for different areas of the Basin and aquifer units. The lines represent combined pumping so the orange dashed line on top is total net recharge resulting from the Project.

Total net recharge equals the amount of active replenishment in all years except critically dry years when the Projected Existing Conditions simulations used as baselines assumes drought curtailment. The amount of pumping decrease in the F unit and Aromas equals the amount of pumping increase in the Purisima AA, A, and BC units. Due to limits in extraction well capacities near the recharge wells, the annual quantities of active replenishment at the recharge well sites are more than two times the increases in nearby pumping. Likewise, the ability of the project to provide in-lieu/passive recharge in the F unit and Aromas is limited by the same Purisima AA, A, and BC unit extraction well capacities.

4. Revision of Pumping Distributions

Pumping distributions described in the August 16, 2017 memo (Attachment 1) assumed that the pilot transfer of City of Santa Cruz surface water is only available in non-critically dry years for Water Years 2019 and 2020, based on the current terms of the pilot surface water purchase agreement. This modeling input has been revised with the assumption that purchase of Pre-1914 surface water (also known as North Coast sources) is extended through a new agreement to provide the surface water to SqCWD in all non-critically dry years starting in Water Years 2019 for all simulations (Project Existing Conditions, Cabrillo-Monterey, Monterey-Willowbrook). Non-critically dry years occur when San Lorenzo River streamflow exceeds 29,000 acre-feet as shown in Table 2.

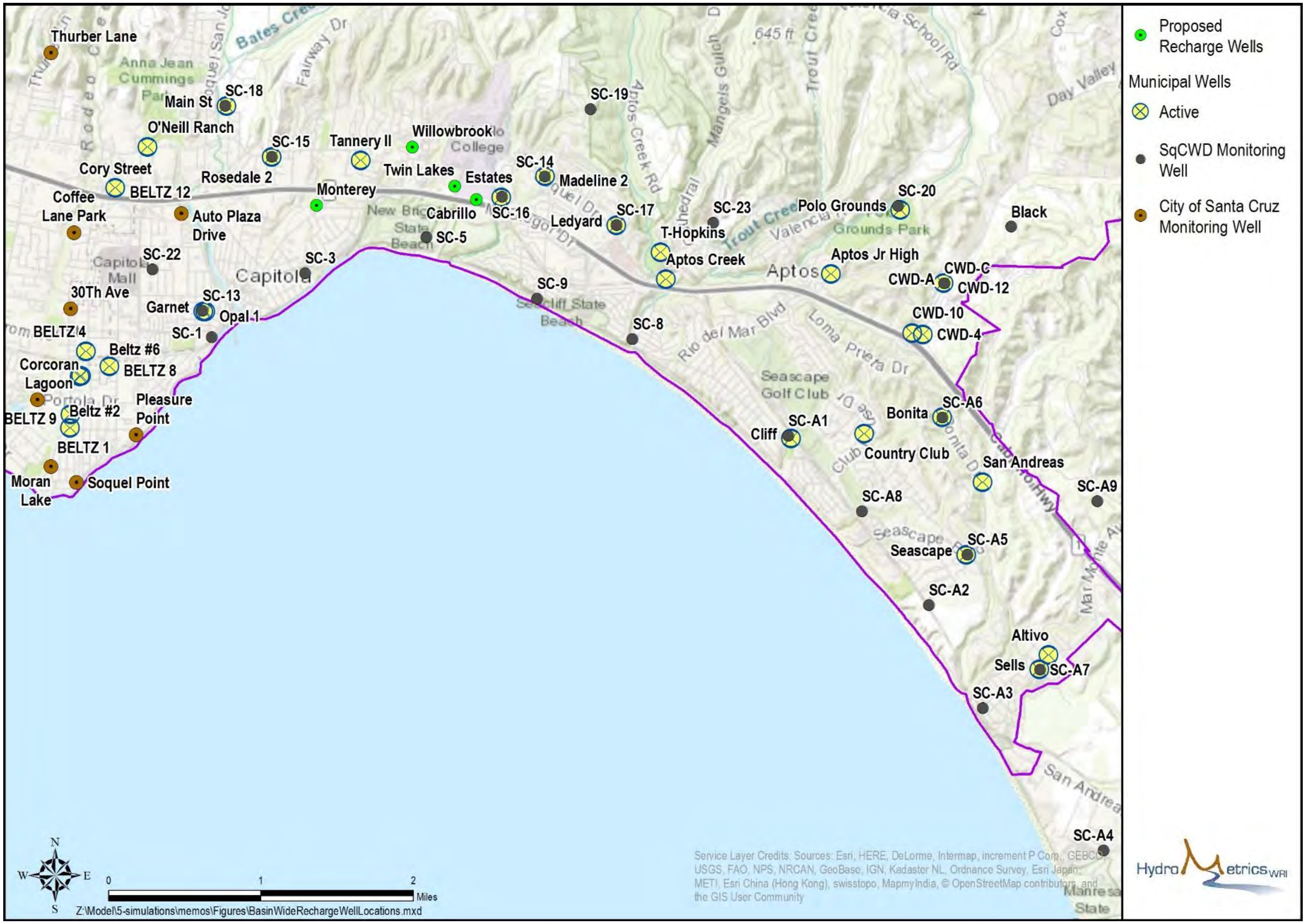

Figure 1. Proposed Recharge, Municipal, and Monitoring Well Locations

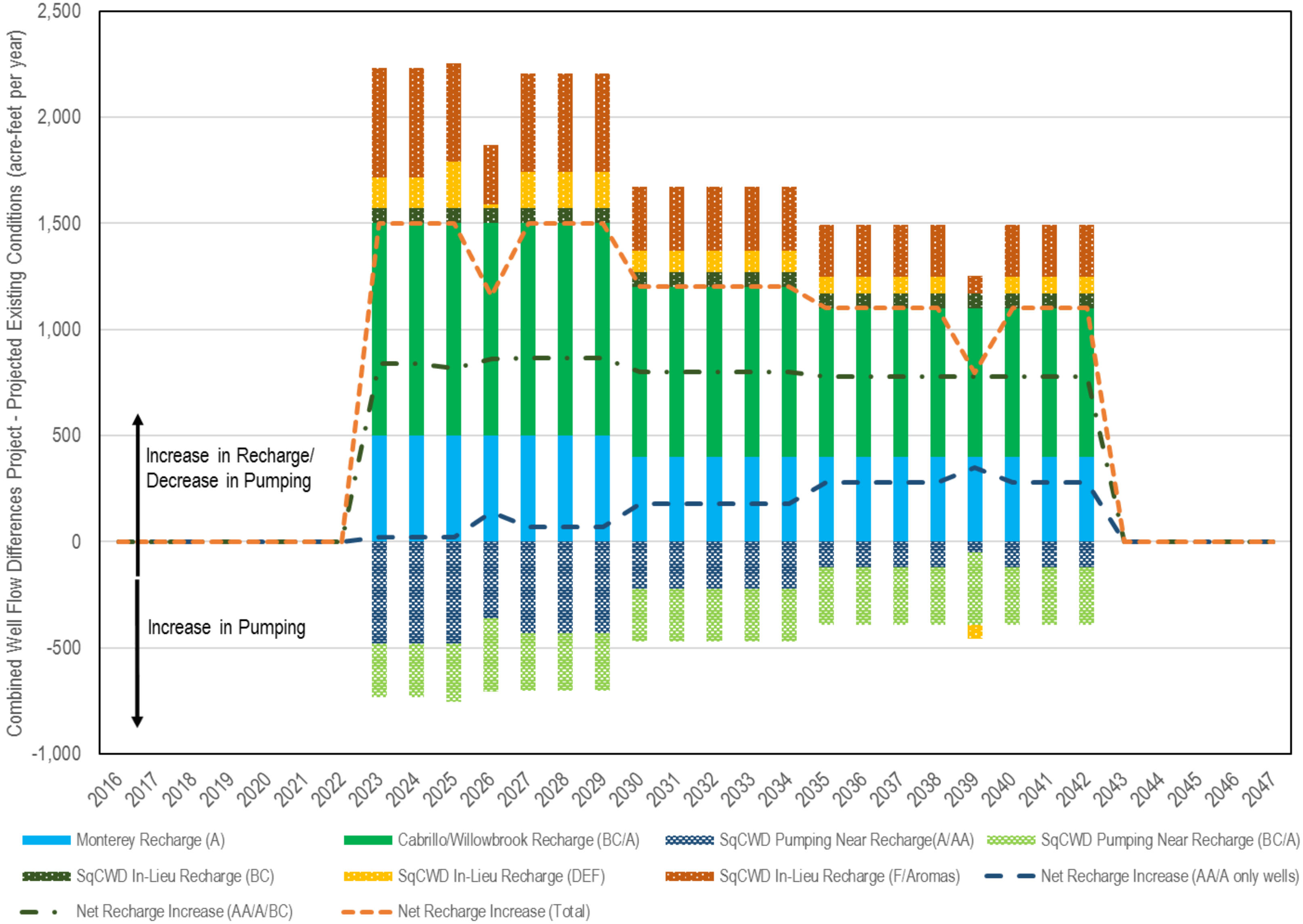

Figure 2. Project Simulation Well Flows Compared to Projected Existing Conditions for Historical Climate

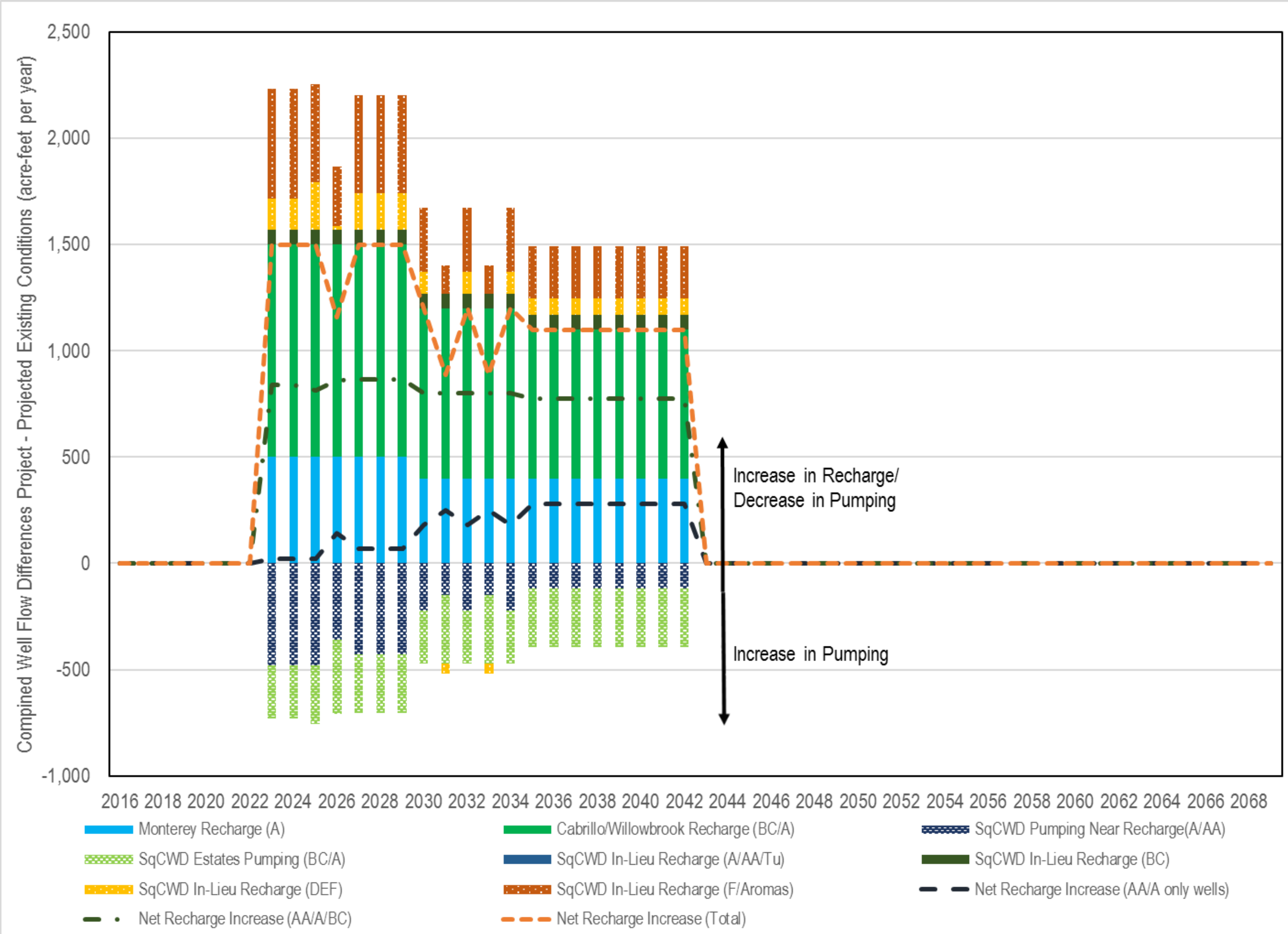

Figure 3. Project Simulation Well Flows Compared to Projected Existing Conditions for Historical Climate

The surface water purchase from the City of Santa Cruz reduces groundwater pumping by an equivalent amount for each month of purchase. As described in the August 16, 2017 memo (Attachment 1), the simulations assume a purchase amount of 215 acre-feet per year that is delivered to SqCWD service area I west of Soquel Creek from November-April of non-critically dry years. Therefore, the in-lieu recharge will take place by reducing pumping at the Garnet and O'Neill Ranch wells, the only two SqCWD wells west of Soquel Creek, from November through April, when pumping at the two wells during these six months is reduced by 86%. As a result, pumping at the Garnet well is reduced from 200 to 114 acre-feet per year and from 300 to 171 acre-feet per year at the O'Neill Ranch well in non-critically dry years; thus, the total reduction of pumping at these two wells is 215 acre-feet in all non-critically dry years starting in Water Year 2019. Table 1 shows the revised pumping distribution for the Projected Existing Conditions simulations. Table 2 shows the revised pumping distribution for the two sets of Project simulations (Cabrillo-Monterey and Monterey-Willowbrook).

Applying the 215 acre-feet per year surface water purchase to all non-critically dry years after Water Year 2019 reduces the difference in total SqCWD pumping between non-critically dry and critically dry years after Water Year 2019 under the Projected Existing Conditions simulations. The Projected Existing Conditions simulations assume SqCWD declares drought curtailment that achieves 15% reduction by SqCWD from April-September during critically dry years. Even with reduced pumping during non-critically dry years resulting from surface water purchase, total pumping during critically dry years is less than non-critically dry years in the Projected Existing Conditions simulation as a result of drought curtailment.

Conversely, the assumption applying the surface water purchase to all non-critically dry years after Water Year 2019 increases the difference in total SqCWD pumping between non-critically dry and critically dry years after Water Year 2019 under the Project simulations (both Cabrillo-Monterey and Monterey-Willowbrook). The Project simulations do not assume SqCWD declares drought curtailment with Pure Water Soquel implemented and providing replenishment in all years. Therefore, SqCWD groundwater pumping for the Project simulations equals its projected demand for all critically dry years and is 215 acre-feet less than SqCWD projected demand during non-critically dry years after Water Year 2019 when the surface water purchase is applied.

The pumping distributions are designed to have lower pumping in the Project simulations than the Projected Existing Conditions simulations in areas away from the recharge wells. Exceptions to this design results from the assumption that drought curtailment is not applied in critically dry years of the Project simulations like it is for the Projected Existing Conditions simulation results in a small increase in Project simulations' DEF pumping in critically dry years after 2030 when compared to the Projected Existing Conditions simulation (Figure 2 and Figure 3).

Well Name[1]	Service Area	Subarea	Instantaneous Pumping Rate (gpm)	Potential Production[2] 50% Operation (ac-ft/yr)		2016	2017-2024			2025 (pre-Cunnison)	2026-2029 (Cunnison on)		2030-2034		2035-2042		2043-2044		2045-end	
						Historic Climate	Non-Critically Dry Year	Critically Dry Year	Transfer from City (Climate Catalog 2019)	Non-Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year
						Recorded Pumping	Pre-Project/No-Project			No Project	No Project		No Project		No Project		Post Project		Post Project	
					Total Recharge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					Monterey	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					Willowbrook	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					Cabrillo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					Total Pumping	3,026	3,900	3,549	3,685	3,585	3,585	3,458	3,285	3,185	3,185	3,096	3,185	3,096	3,085	3,012
					Purisima	2,025	2,624	2,460	2,409	2,363	2,363	2,418	2,225	2,292	2,179	2,253	2,179	2,253	2,133	2,214
					Aromas	1,001	1,276	1,089	1,276	1,222	1,222	1,040	1,060	893	1,006	843	1,006	843	952	799
Garnet	I	Western Purisima CGMA	580	468	Garnet	219	200	100	114	114	114	100	114	100	114	100	114	100	114	100
O'Neill Ranch	I		580	468	O'Neill Ranch	273	300	300	171	171	171	300	171	300	171	300	171	300	171	300
Main Street	I		850	686	Main Street	519	650	680	650	650	650	680	650	680	650	680	650	680	650	680
Rosedale	I		800	645	Rosedale	102	510	580	510	510	510	580	510	580	510	580	510	580	510	580
Cunnison Lane	I	Eastern Service Area I	600	484	Cunnison Lane	0	0	0	0	0	170	170	170	170	170	170	170	170	170	170
Tannery II	I		800	645	Tannery II	558	290	290	290	290	170	170	170	170	170	170	170	170	170	170
Estates	II		530	427	Estates	164	258	181	258	236	236	161	169	100	147	80	147	80	124	61
Madeline	II	BC Unit	175	141	Madeline	0	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Ledyard	II		178	144	Ledyard	98	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Austrian Way	II		250	202	Austrian Way	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aptos Creek	II	Aptos Creek	400	323	Aptos Creek	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T. Hopkins	II		225	181	T. Hopkins	76	169	125	169	157	126	83	90	51	79	41	79	41	67	31
Granite Way	II		210	169	Granite Way	0	157	114	157	145	126	84	90	52	79	42	79	42	67	31
Aptos Jr. High	III	Valencia Creek	425	343	Aptos Jr. High	2	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Polo Grounds	III		260	210	Polo Grounds	177	210	210	210	210	210	210	210	210	210	210	210	210	210	210
Country Club	III		410	331	Country Club	185	190	190	190	190	190	190	190	190	190	190	190	190	190	190
Bonita	III	Future Cr VI plant	950	766	Bonita	205	267	187	267	244	244	166	175	103	152	82	152	82	129	63
San Andreas	III		992	800	San Andreas	432	313	220	313	286	286	195	205	121	178	97	178	97	151	74
Seascape	III		772	623	Seascape	0	46	32	46	42	42	29	30	18	26	14	26	14	22	11
Sells	IV	Service Area IV	529	427	Sells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Altivo	IV		614	495	Altivo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beltz #8		City of Santa Cruz			Beltz #8	98	73	179	73	73	73	179	73	179	73	179	73	179	73	179
Beltz #9					Beltz #9	203	189	213	189	189	189	213	189	213	189	213	189	213	189	213
Beltz #10					Beltz #10	91	149	128	149	149	149	128	149	128	149	128	149	128	149	128
Beltz #12					Beltz #12	59	110	125	110	110	110	125	110	125	110	125	110	125	110	125
CWD-4		Central Water District (Rob Roy only)			CWD-4	13	48	48	48	48	48	48	48	48	48	48	48	48	48	48
CWD-10					CWD-10	27	92	92	92	92	92	92	92	92	92	92	92	92	92	92
CWD-12					CWD-12	344	410	410	410	410	410	410	410	410	410	410	410	410	410	410
			TOTAL (ac-ft/yr)			3,026	3,900	3,549	3,685	3,585	3,585	3,458	3,285	3,185	3,185	3,096	3,185	3,096	3,085	3,012
			Subtotal Service Area I			1,671	1,950	1,950	1,735	1,735	1,785	2,000	1,785	2,000	1,785	2,000	1,785	2,000	1,785	2,000
			Subtotal Service Area II			354	674	510	674	628	578	418	440	292	394	253	394	253	348	214
			Subtotal Service Area III			1,001	1,276	1,089	1,276	1,222	1,222	1,040	1,060	893	1,006	843	1,006	843	952	799
			Subtotal Service Area IV			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Total Purisima Area			2,025	2,624	2,460	2,409	2,363	2,363	2,418	2,225	2,292	2,179	2,253	2,179	2,253	2,133	2,214
			Total Aromas Area			1,001	1,276	1,089	1,276	1,222	1,222	1,040	1,060	893	1,006	843	1,006	843	952	799
			Western Purisima Subarea		(1,660)	1,113	1,660	1,660	1,445	1,445	1,445	1,660	1,445	1,660	1,445	1,660	1,445	1,660	1,445	1,660
			Eastern Service Area I Subarea			558	290	290	290	290	340	340	340	340	340	340	340	340	340	340
			BC Subarea		(260)	98	90	90	90	90	90	90	90	90	90	90	90	90	90	90
			Aptos Creek Subarea		(470)	92	326	239	326	302	252	167	181	102	157	83	157	83	133	62
			Valencia Creek Subarea		(460)	179	460	460	460	460	460	460	460	460	460	460	460	460	460	460
			Chromium VI Treatment Plai		(1,600)	637	580	407	580	530	530	361	380	225	330	179	330	179	280	138
			City of Santa Cruz			450	520	645	520	520	520	645	520	645	520	645	520	645	520	645
			Central Water District			383	550	550	550	550	550	550	550	550	550	550	550	550	550	550

Notes:
[1] Wells proposed for installation shaded blue
Wells with increased pumping to support recharge shaded in yellow
[2] Annual production is rounded to nearest integer value for clarity

Table 3 SqCWD Pumping Distributions for Projected Existing Conditions Simulations

							2016	2017-2022			2023-2024	2025 (pre-Cunnison)	2026-2029 (Cunnison on)		2030-2034		2035-2042		2043-2044		2045-end	
							Historic Climate	Non-Critically Dry Year	Critically Dry Year	Transfer from City (Climate Catalog 2019)	Non-Critically Dry Year	Non-Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year
							Recorded Pumping	Pre-Project			Project	Project	Project		Project		Project		Post-Project		Post-Project	
						Total Recharge	0	0	0	0	1,500	1,500	1,500	1,500	1,200	1,200	1,100	1,100	0	0	0	0
						Monterey	0	0	0	0	500	500	500	500	400	400	400	400	0	0	0	0
						Willowbrook or Cabrillo	0	0	0	0	1,000	1,000	1,000	1,000	800	800	700	700	0	0	0	0
						Total Pumping	3,026	3,900	3,549	3,685	3,685	3,585	3,585	3,800	3,285	3,500	3,185	3,400	3,185	3,096	3,085	3,012
						Purisima	2,025	2,624	2,460	2,409	2,925	2,825	2,825	3,040	2,525	2,740	2,425	2,640	2,179	2,253	2,133	2,214
Well Name[1]	Service Area	Subarea	Instantaneous Pumping Rate (gpm)	Potential Production[2] 50% Operation (ac-ft/yr)	Wells Supporting Recharge Allow Increased Production[2] 60% Operation (ac-ft/yr)	Aromas	1,001	1,276	1,089	1,276	760	760	760	760	760	760	760	760	1,006	843	952	799
Garnet	I	Western Purisima CGMA	580	468		Garnet	219	200	100	114	114	114	114	100	114	100	114	100	114	100	114	100
O'Neill Ranch	I		580	468		O'Neill Ranch	273	300	300	171	171	171	171	300	171	300	171	300	171	300	171	300
Main Street	I		850	686		Main Street	519	650	680	650	650	650	650	680	650	680	650	680	650	680	650	680
Rosedale	I		800	645	774	Rosedale	102	510	580	510	640	640	510	510	510	510	510	510	510	580	510	580
Cunnison Lane	I	Eastern Service Area I	600	484	581	Cunnison Lane	0	0	0	0	0	0	385	385	280	280	230	230	170	170	170	170
Tannery II	I		800	645	774	Tannery II	558	290	290	290	640	640	385	385	280	280	230	230	170	170	170	170
Estates	II		530	427	513	Estates	164	258	181	258	510	510	510	510	420	420	420	420	147	80	124	61
Madeline	II	BC Unit	175	141		Madeline	0	40	40	40	10	10	10	10	10	10	10	10	40	40	40	40
Ledyard	II		178	144		Ledyard	98	50	50	50	10	10	10	10	10	10	10	10	50	50	50	50
Austrian Way	II		250	202		Austrian Way	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aptos Creek	II	Aptos Creek	400	323		Aptos Creek	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T. Hopkins	II		225	181		T. Hopkins	76	169	125	169	90	40	40	75	40	75	40	75	79	41	67	31
Granite Way	II		210	169		Granite Way	0	157	114	157	90	40	40	75	40	75	40	75	79	42	67	31
Aptos Jr. High	III	Valencia Creek	425	343		Aptos Jr. High	2	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Polo Grounds	III		260	210		Polo Grounds	177	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210
Country Club	III		410	331		Country Club	185	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190
Bonita	III	Future Cr VI plant	950	766		Bonita	205	267	187	267	50	50	50	50	50	50	50	50	152	82	129	63
San Andreas	III		992	800		San Andreas	432	313	220	313	50	50	50	50	50	50	50	50	178	97	151	74
Seascape	III		772	623		Seascape	0	46	32	46	10	10	10	10	10	10	10	10	26	14	22	11
Beltz #8		City of SC				Beltz #8	98	73	179	73	73	73	73	179	73	179	73	179	73	179	73	179
Beltz #9						Beltz #9	203	189	213	189	189	189	189	213	189	213	189	213	189	213	189	213
Beltz #10						Beltz #10	91	149	128	149	149	149	149	128	149	128	149	128	149	128	149	128
Beltz #12						Beltz #12	59	110	125	110	110	110	110	125	110	125	110	125	110	125	110	125
CWD-4		CWD				CWD-4	13	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
CWD-10						CWD-10	27	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92
CWD-12						CWD-12	344	410	410	410	410	410	410	410	410	410	410	410	410	410	410	410
Sells	IV	Service Area IV	529	427		Sells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Altivo	IV		614	495		Altivo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			TOTAL (ac-ft/yr)				3,026	3,900	3,549	3,685	3,685	3,585	3,585	3,800	3,285	3,500	3,185	3,400	3,185	3,096	3,085	3,012
			Subtotal Service Area I				1,671	1,950	1,950	1,735	2,215	2,215	2,215	2,360	2,005	2,150	1,905	2,050	1,785	2,000	1,785	2,000
			Subtotal Service Area II				354	674	510	674	710	610	610	680	520	590	520	590	394	253	348	214
			Subtotal Service Area III				1,001	1,276	1,089	1,276	760	760	760	760	760	760	760	760	1,006	843	952	799
			Subtotal Service Area IV				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Total Purisima Area				2,025	2,624	2,460	2,409	2,925	2,825	2,825	3,040	2,525	2,740	2,425	2,640	2,179	2,253	2,133	2,214
			Total Aromas Area				1,001	1,276	1,089	1,276	760	760	760	760	760	760	760	760	1,006	843	952	799
			Western Purisima Subarea			(1,660)	1,113	1,660	1,660	1,445	1,575	1,575	1,445	1,590	1,445	1,590	1,445	1,590	1,445	1,660	1,445	1,660
			Eastern Service Area I Subarea				558	290	290	290	640	640	770	770	560	560	460	460	340	340	340	340
			BC Subarea			(260)	98	90	90	90	20	20	20	20	20	20	20	20	90	90	90	90
			Aptos Creek Subarea			(470)	92	326	239	326	180	80	80	150	80	150	80	150	157	83	133	62
			Valencia Creek Subarea			(460)	179	460	460	460	460	460	460	460	460	460	460	460	460	460	460	460
			City of SC				450	520	645	520	520	520	520	645	520	645	520	645	520	645	520	645
			CWD				383	550	550	550	550	550	550	550	550	550	550	550	550	550	550	550
			Chromium VI Treatment Plant			(1,600)	637	580	407	580	100	100	100	100	100	100	100	100	330	179	280	138

Notes:
[1] Wells proposed for installation shaded blue
Wells with increased pumping to support recharge shaded in yellow
[2] Annual production is rounded to nearest integer value for clarity

Table 4. Municipal Pumping Distributions for Project (Cabrillo-Monterey and Monterey-Willowbrook) Simulations

5. Revision to Replenishment at Monterey-Willowbrook instead of Cabrillo-Willowbrook

The August 16, 2017 memo described an Alternative simulation as replenishment occurring at the Willowbrook and Cabrillo College sites. This simulation has been replaced by the second configuration of the Project simulation that evaluates replenishment occurring at the Monterey and Willowbrook sites. This Monterey-Willowbrook simulation assumes 500 acre-feet per year replenishment at the Monterey site, same as the Cabrillo-Monterey simulation. The Monterey-Willowbrook Simulation assumes 1,000 acre-feet per year replenishment at the Willowbrook site instead of the 1,000 acre-feet per year replenishment at the Cabrillo College site assumed by the Cabrillo-Monterey simulation. The pumping distribution is the same for both of the Cabrillo-Monterey and Monterey-Willowbrook configurations of Project simulations.

Based on the Carollo feasibility study (November 2017), estimated replenishment capacity at Willowbrook is 700 gallons per minute, high enough to support 1,000 acre-feet per year. This capacity is based on information from the Tannery II well, which is screened only in the Purisima A unit. However, the Monterey-Willowbrook simulation assumes replenishment at Willowbrook is into both the Purisima BC and A units. Although the capacity is not based on data at a well screened in both the BC and A units, confined conditions in both the BC and A units that support replenishment are expected at the Willowbrook site and replenishment is more likely to achieve project goals if occurring in two aquifers. Evaluating site specific capacity for replenishment into the two units with a test well at Willowbrook would provide practical information if the Monterey-Willowbrook configuration for replenishment is selected.

6. Projected Existing Conditions Simulation Results

For most of the Basin, the Projected Existing Conditions simulations show groundwater levels rising over time for both Historical Climate and Catalog Climate, particularly at the coast because simulated pumping based on projected demand is lower than historical pumping. SqCWD pumping for the first year of the simulation is based on actual pumping for Water Year 2016 when SqCWD pumping was the lowest annual total since the 1970s. Simulated SqCWD pumping for Water Years 2017 and 2018 of 3,900 acre-feet per year is lower than all years from 1979 to Water Year 2014. With implementation of the surface water purchase from the City of Santa Cruz during non-critically dry years and drought curtailment during critically dry years, SqCWD pumping projections for Water Year 2019 and beyond are no higher than 3,685 acre-feet per year and decrease to less than 3,100 acre-feet per year by Water Year 2045. Since the

1970s, only the last three water years (2015-2017) have had less pumping than this simulated range.

Groundwater management objectives in the Basin focus on preventing seawater intrusion by recovering and maintaining groundwater levels to protective elevations at coastal monitoring wells.

Model Results for Projected Existing Conditions Under Historic Climate:

- The Projected Existing Conditions simulations (labeled Proj Ex Co in hydrographs) show recovery to long-term stable groundwater levels in SqCWD's Purisima coastal wells (Figure 4 and Figure 5), but do not achieve protective elevations at all coastal monitoring wells (SC-5A, SC-9C, and SC-8C).
- There is also a long-term rise in groundwater levels simulated at the City of Santa Cruz's coastal monitoring wells (Figure 6).
- In the Aromas coastal wells, reduced pumping from historical totals results in long-term recovery but groundwater levels respond to climatic changes and protective elevations are not met at all coastal monitoring wells (in Figure 7).
- The Projected Existing Conditions simulations show some inland groundwater levels declines over time near where pumping is increased in the pumping distributions relative to recent pumping. An example of a well with increased pumping is the Rosedale well where SC-15 is located (Figure 8).

Model Results for Projected Existing Conditions Under Catalog Climate

- A comparison of the Projected Existing Conditions simulations under the Historic Climate (labeled Hist in Figure 4 through Figure 9) and Catalog Climate show the effect of the warmer years used in Catalog Climate.
- Groundwater levels over the long term are lower under the Catalog Climate (labeled Cat in Figure 4 through Figure 9).
- Unless otherwise noted, evaluation focuses on results from the Catalog Climate simulations, which also have the benefit of projecting groundwater conditions to Water Year 2069 instead of Water Year 2047 for the Historic Climate, which is only four years after Pure Water Soquel replenishment ends.

7. Cabrillo-Monterey Simulation Results

7.1. Purisima A and BC Unit Groundwater Conditions During Project

Project simulations (labeled Mont/Cabr in hydrographs) show increases in groundwater levels in the Purisima A and BC units near the recharge wells at Monterey and Cabrillo College during the project period of Water Years 2023-2042 under both the Historical and Catalog Climate scenarios. This is a result of replenishment volumes that are greater than the increases in pumping at production wells near the recharge site which are due to limits on pumping capacities at the production wells.

At Purisima coastal monitoring wells SC-3A, and SC-5A in the Purisima A unit (Figure 4) and SC-9C and SC-8C in the Purisima BC unit (Figure 5), groundwater levels increase over 10 feet in the first year of replenishment and high groundwater levels well above protective elevations are maintained during the project period.

Farther to the west at Purisima coastal monitoring wells SC-1A (Figure 4) and the City of Santa Cruz's Pleasure Point well (Figure 6) in the Purisima A unit, groundwater level increases are more gradual and are less than 10 feet but would be sufficient to maintain groundwater levels above protective elevations during the project period. There is little effect simulated at the City of Santa Cruz's coastal Soquel Point and Moran Lake wells in the Purisima A unit (Figure 6).

During the project period in these Purisima units being replenished, there is little difference in results between Project simulations using the Historic Climate and Catalog Climate. Replenishment of these units is achieved regardless of the different climates simulated.

The groundwater level increases simulated in these aquifer units as a result of the Project will achieve and/or exceed protective levels fairly quickly upon implementation to prevent seawater intrusion during the project period. Groundwater levels near BC unit production wells such as Madeline and Ledyard (Figure 9) show increases caused by replenishment in the BC unit at Cabrillo College with assumed decreases pumping in the Project simulations. This indicates that revised pumping distributions with increased pumping at these wells could still meet provide groundwater management goals in this aquifer units while increasing groundwater management flexibility. Increasing pumping at these locations would increase potential for in-lieu recharge in aquifer units not directly receiving replenishment.

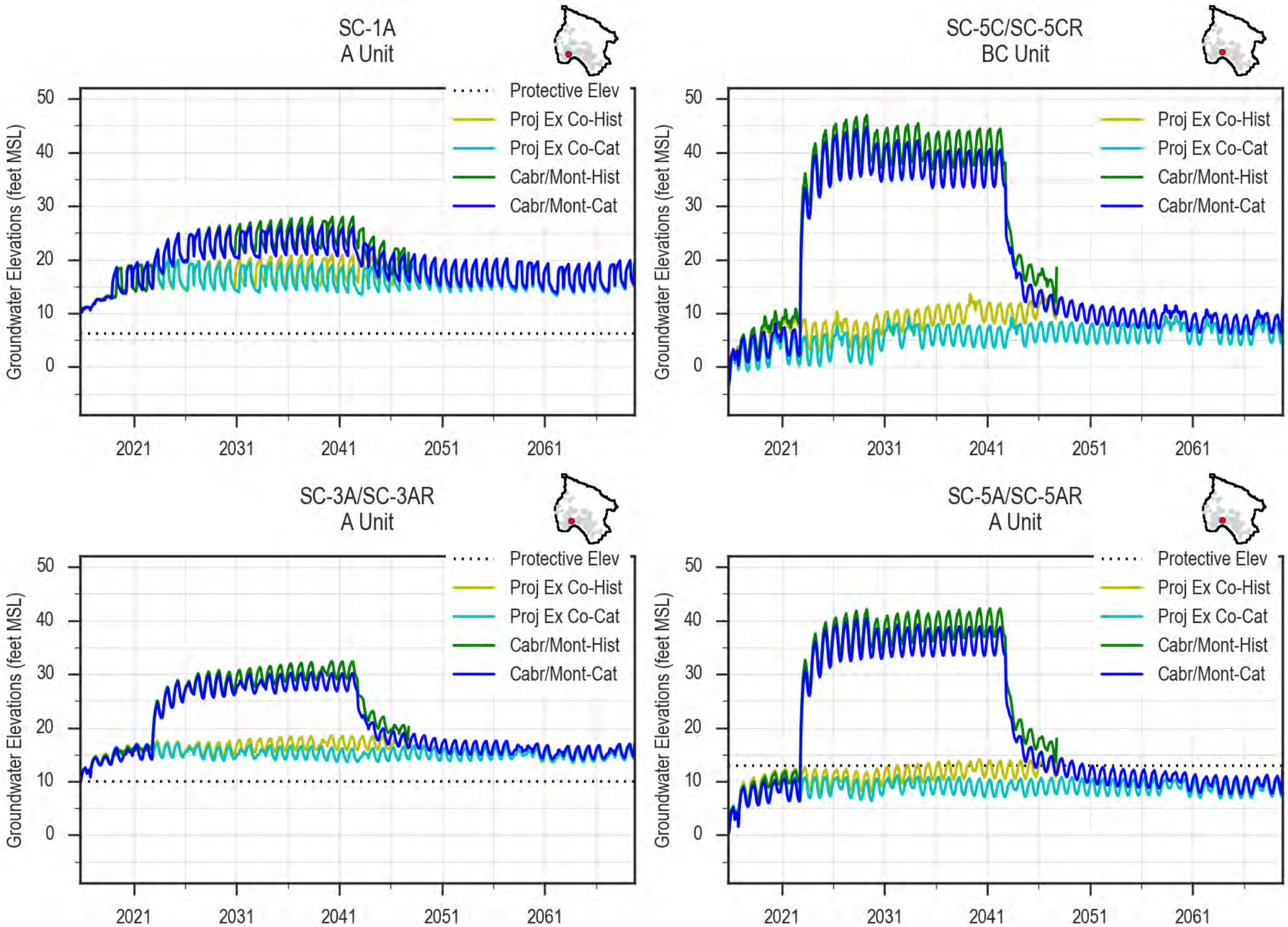

Figure 4. Simulated Project (Cabrillo-Monterey) and Projected Existing Conditions Coastal Groundwater Levels near SqCWD Purisima A Unit Pumping

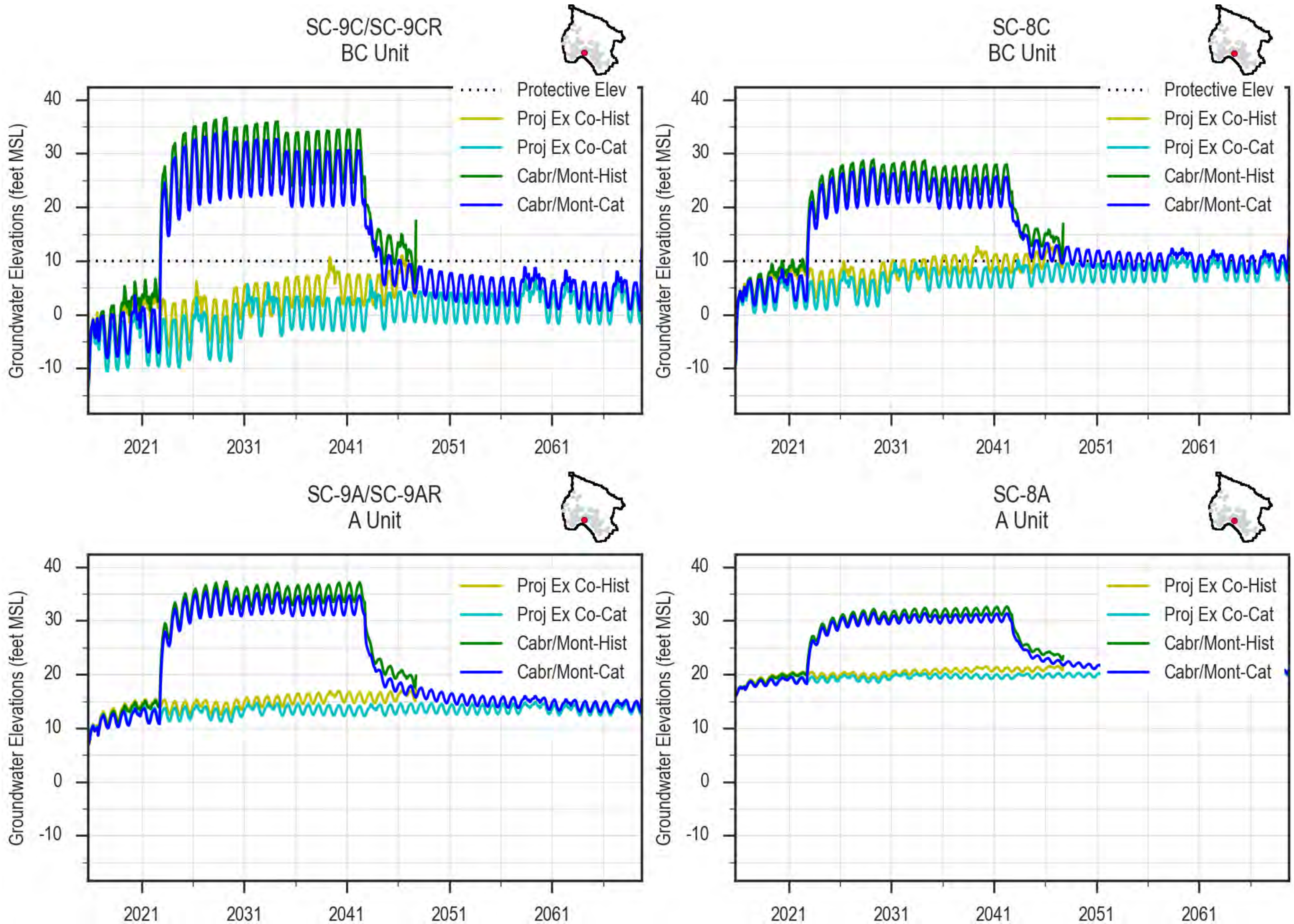

Figure 5. Simulated Project (Cabrillo-Monterey) and Projected Existing Conditions Coastal Groundwater Levels near SqCWD Purisima BC Unit Pumping

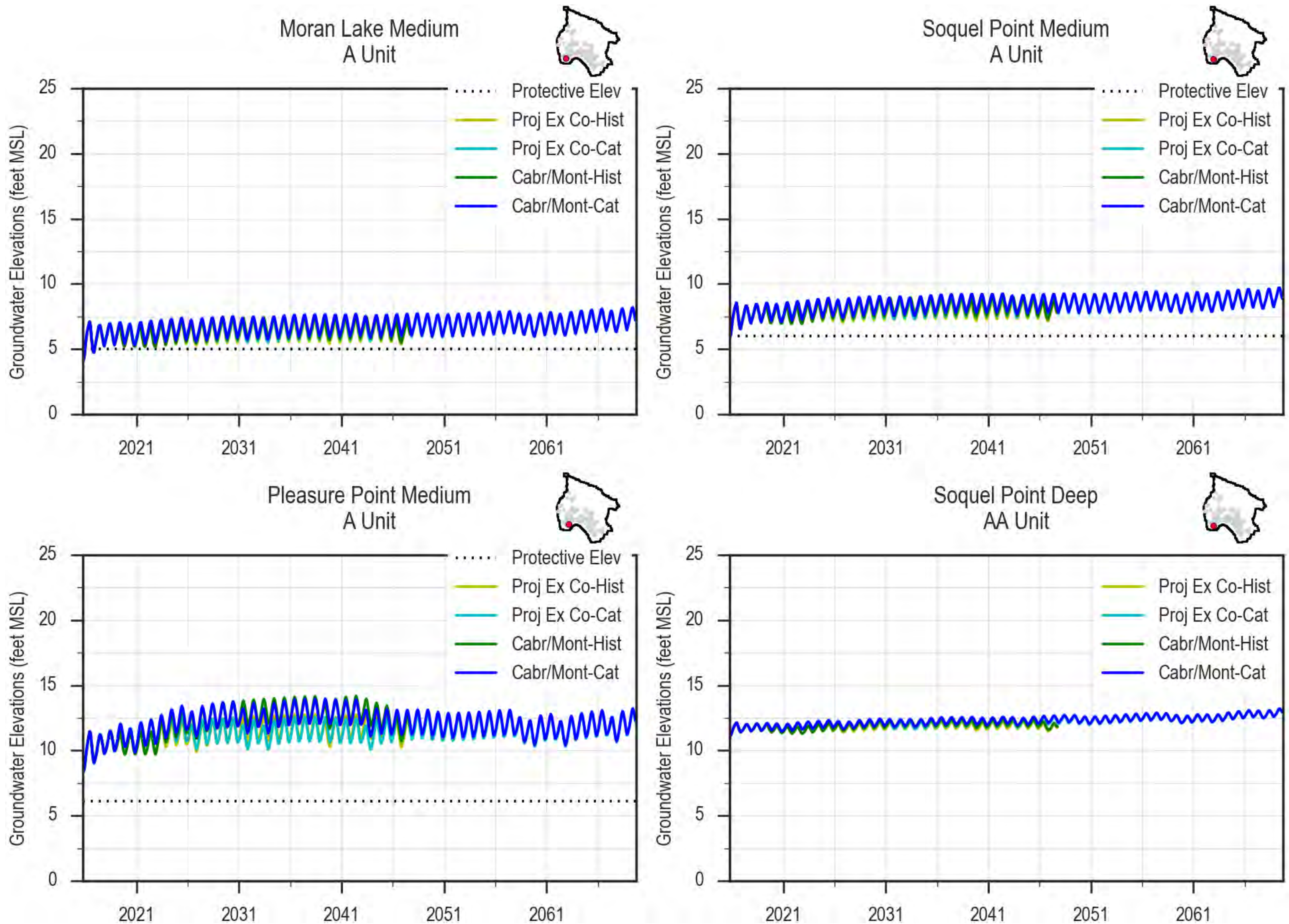

Figure 6. Simulated Project (Cabrillo-Monterey) and Projected Existing Conditions Coastal Groundwater Levels near City Purisima A and AA Unit Pumping

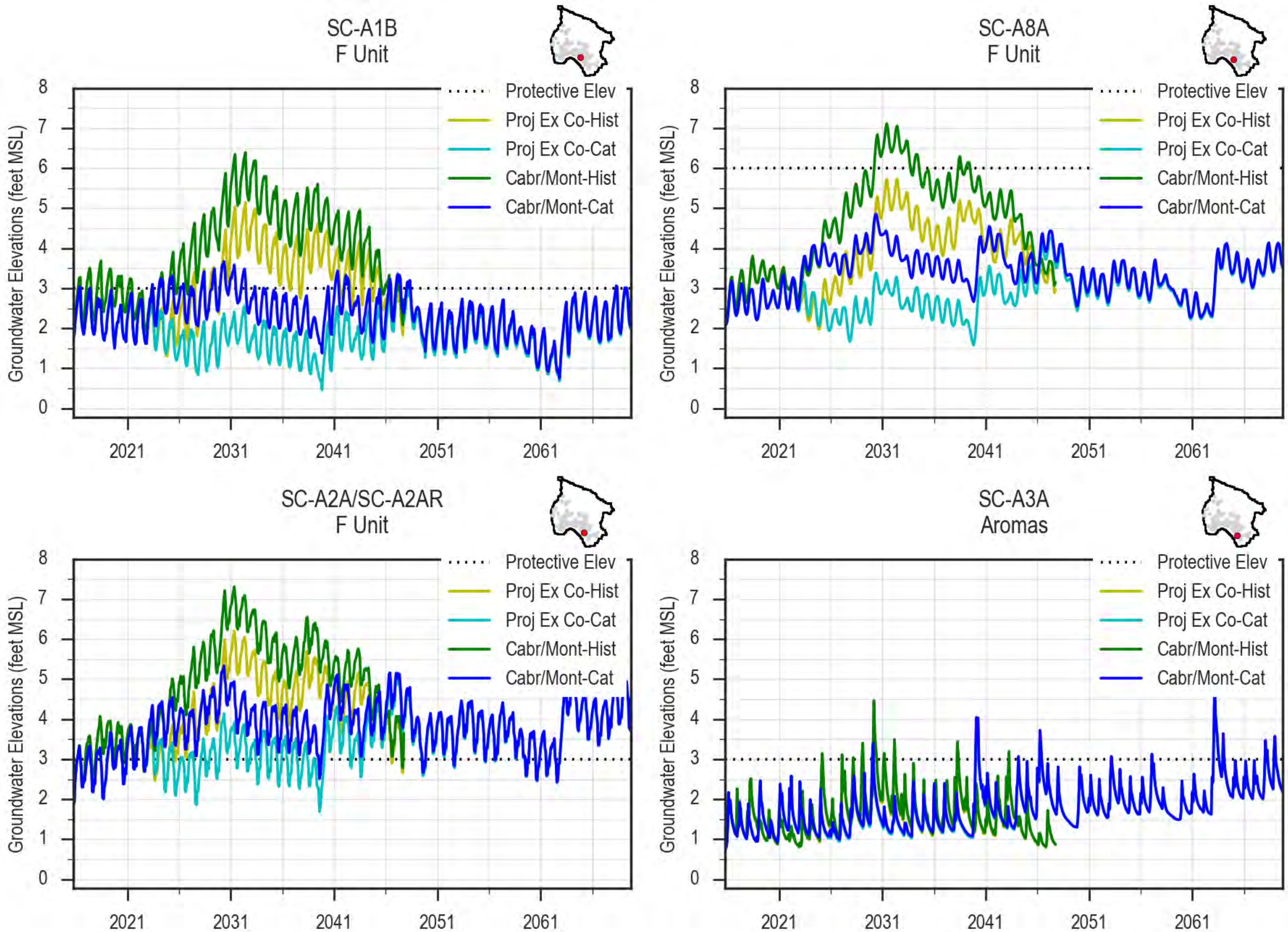

Figure 7. Simulated Project (Cabrillo-Monterey) and Projected Existing Conditions Coastal Groundwater Levels near SqCWD Purisma F Unit/Aromas Pumping

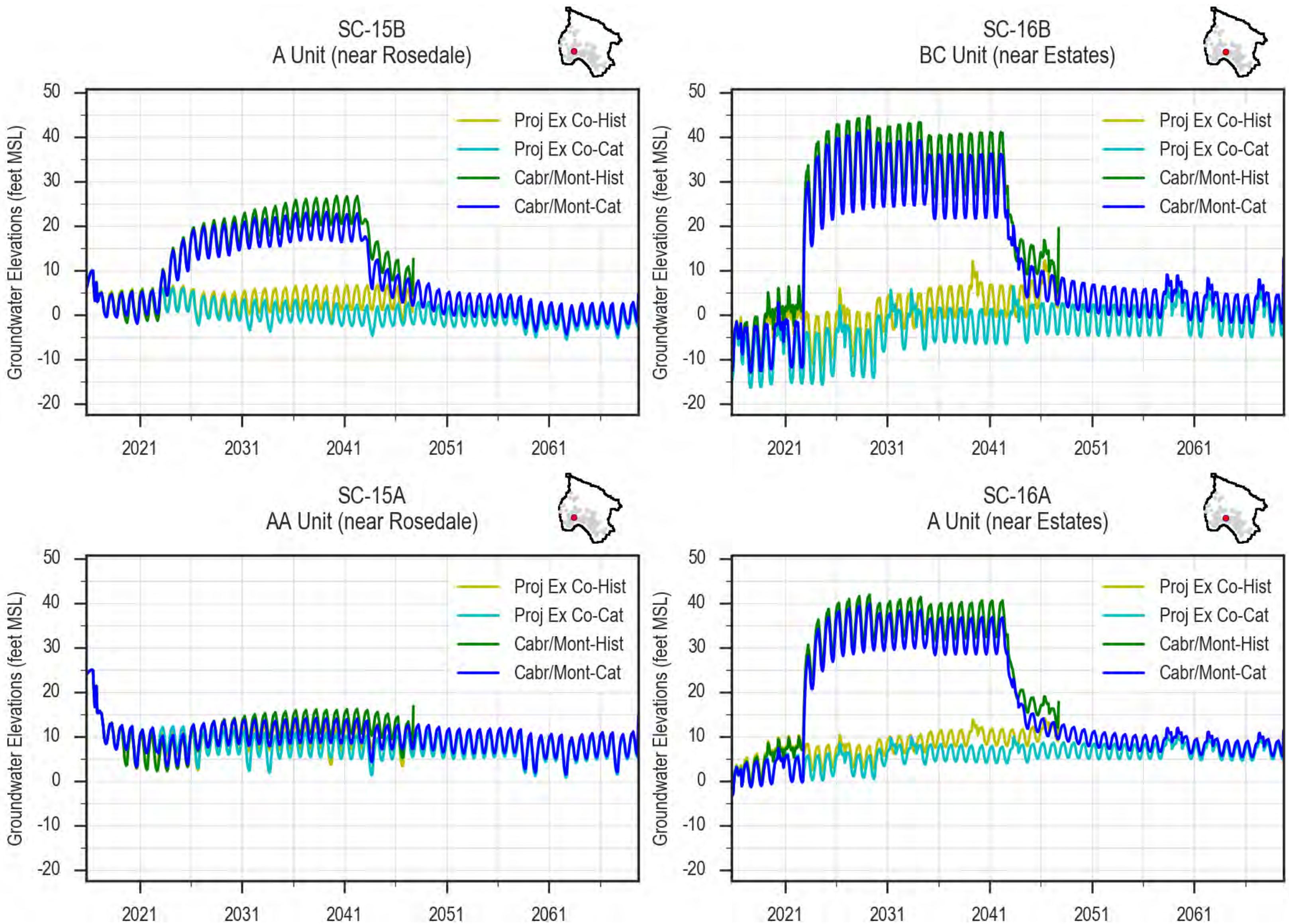

Figure 8. Simulated Project (Cabrillo-Monterey) and Projected Existing Conditions Groundwater Levels near SqCWD Extraction Wells near Recharge

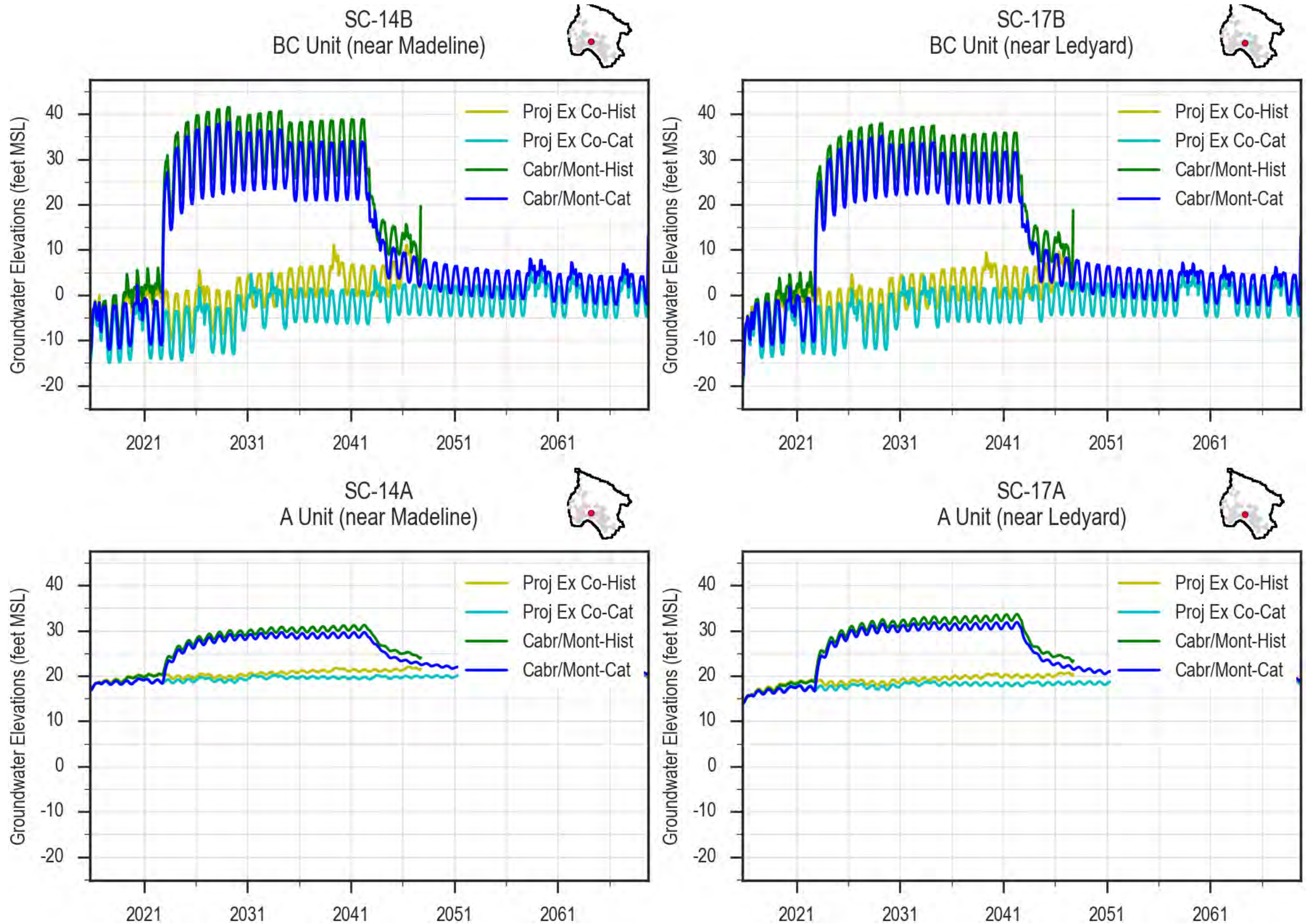

Figure 9. Simulated Project (Cabrillo-Monterey) and Projected Existing Conditions Groundwater Levels near SqCWD Purisima BC Unit Pumping Wells

Even with increasing pumping in the BC aquifer unit, lower replenishment quantities than assumed in the Cabrillo-Monterey simulation closer in magnitude to the quantities nearby SqCWD production wells have capacity to increase pumping (Figure 2 and Figure 3) could be sufficient to prevent seawater intrusion over the long term. The higher groundwater levels achieved by the Project based on replenishment simulated will have benefit of pushing out the salt water interface during the project period. The Santa Cruz Mid-County Groundwater Agency plans to enhance the GSFLOW model to evaluate movement of the salt water interface under different conditions.

7.2. Purisima A and BC Unit Groundwater Conditions After Project

The upper maps on Figure 10 and Figure 11 show groundwater level increases resulting from 20 years of replenishment at Monterey and Cabrillo College. After the project period ends in Water Year 2042, groundwater levels in the Purisima A and BC units drop rapidly in the first two years and more gradually over the following ten years (eg, Figure 4 and Figure 5). By the end of the Catalog Climate simulation extended through Water Year 2069, groundwater levels simulated for the Project are 1-2 feet higher at the coast than under the Projected Existing Conditions simulation (upper maps of Figure 12 and Figure 13).

Our conclusion based on the modeling simulations is that the long-term benefit to groundwater conditions in the Purisima A and BC Units from a limited duration operating the Project is minimal. It is likely that continued on-going operation of the Project will be necessary to maintain continued substantial benefits to groundwater conditions in the Basin.

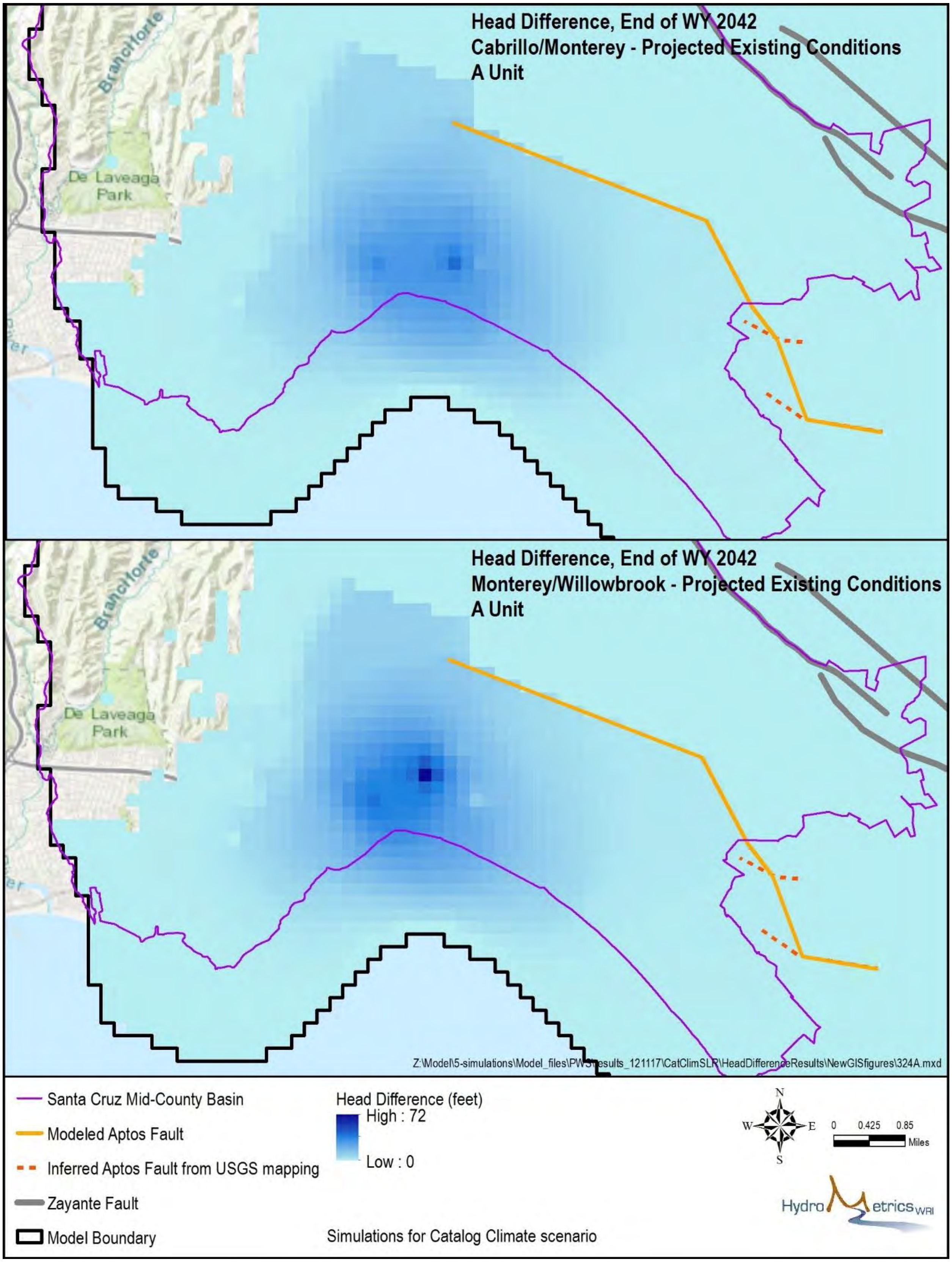

Figure 10. Purisima A Unit Groundwater Level Increases after 20 Years Replenishment

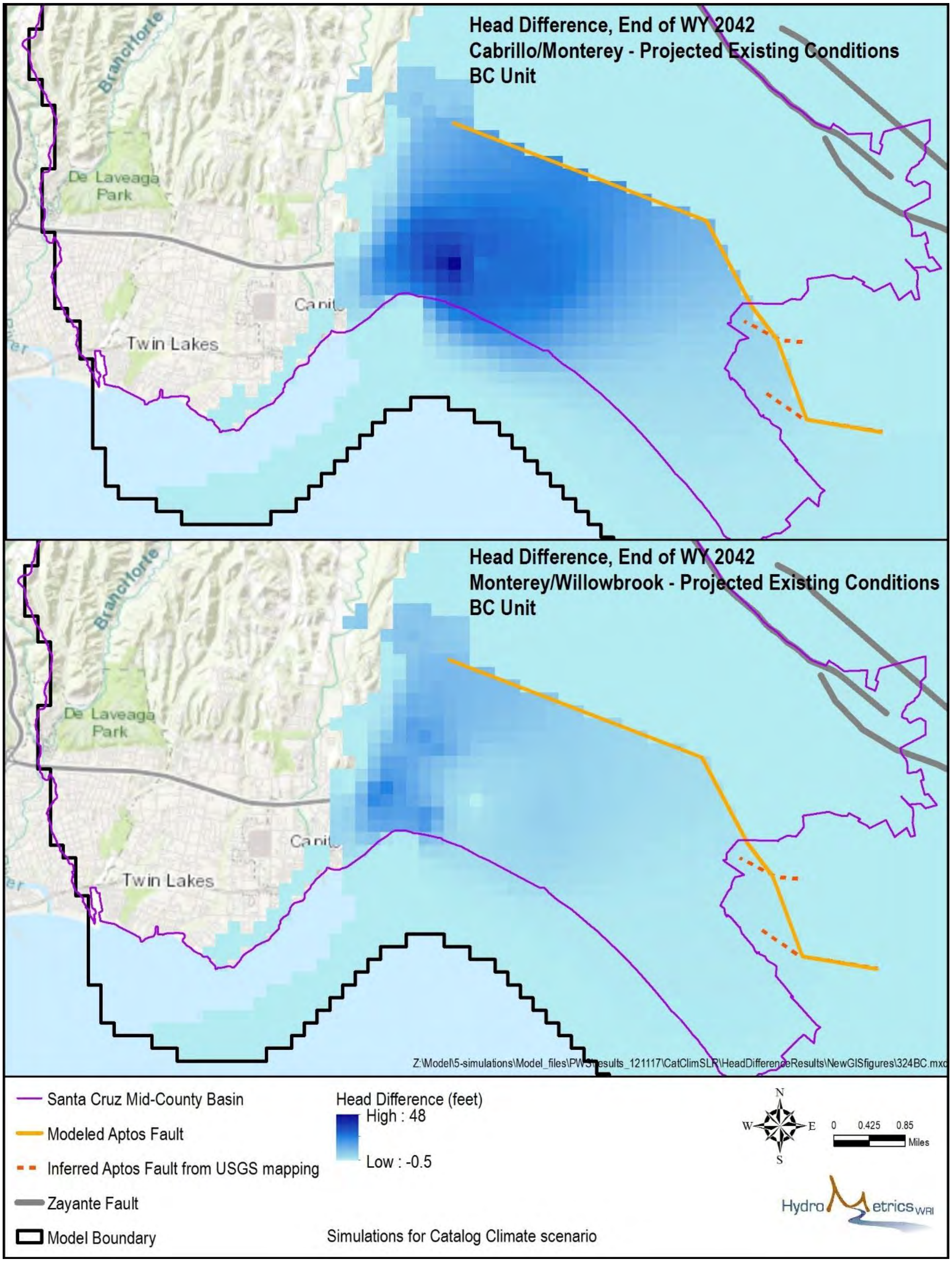

Figure 11. Purisima BC Unit Groundwater Level Increases after 20 Years Replenishment

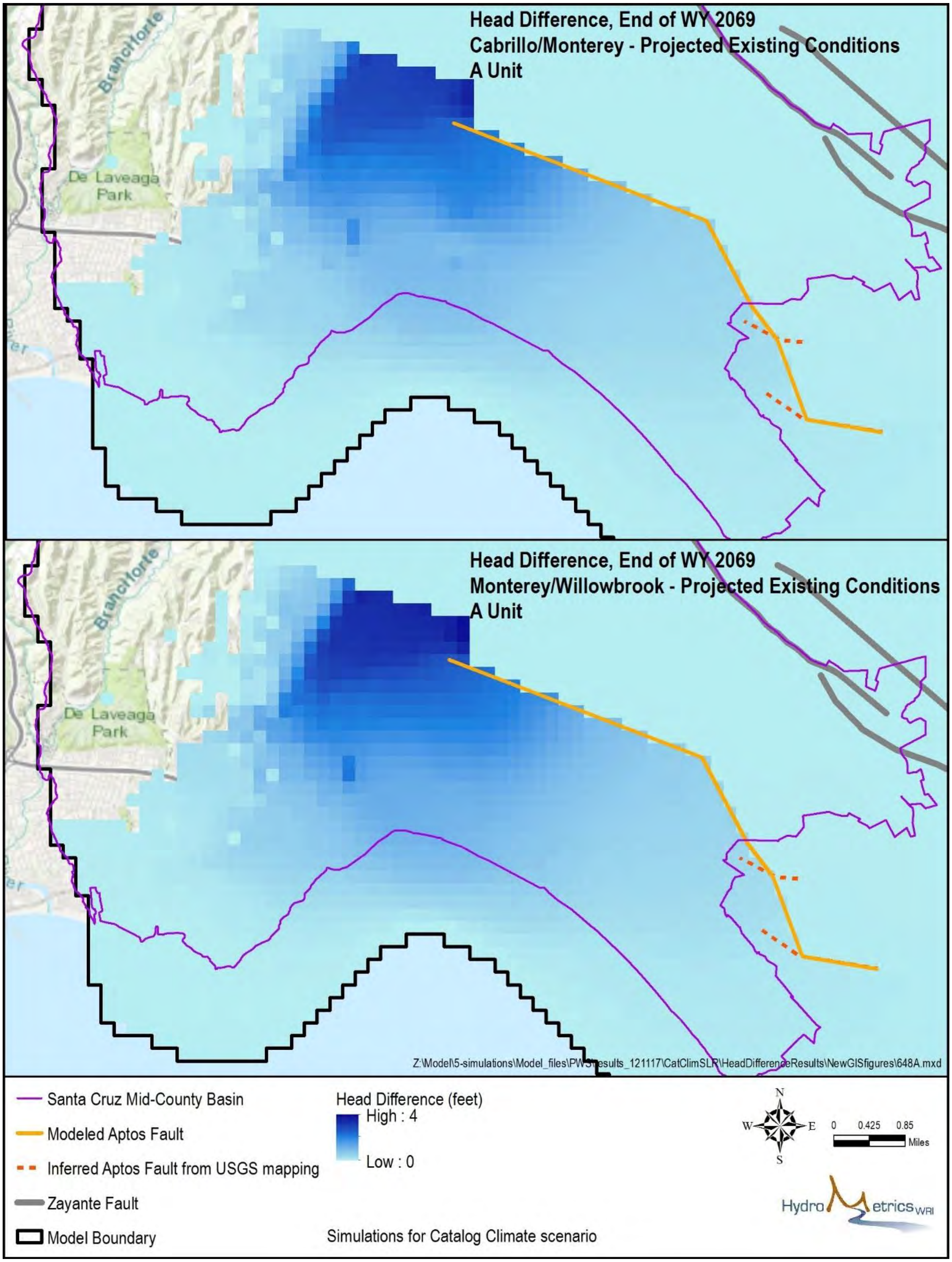

Figure 12. Purisima A Unit Groundwater Level Increases 27 Years after Replenishment

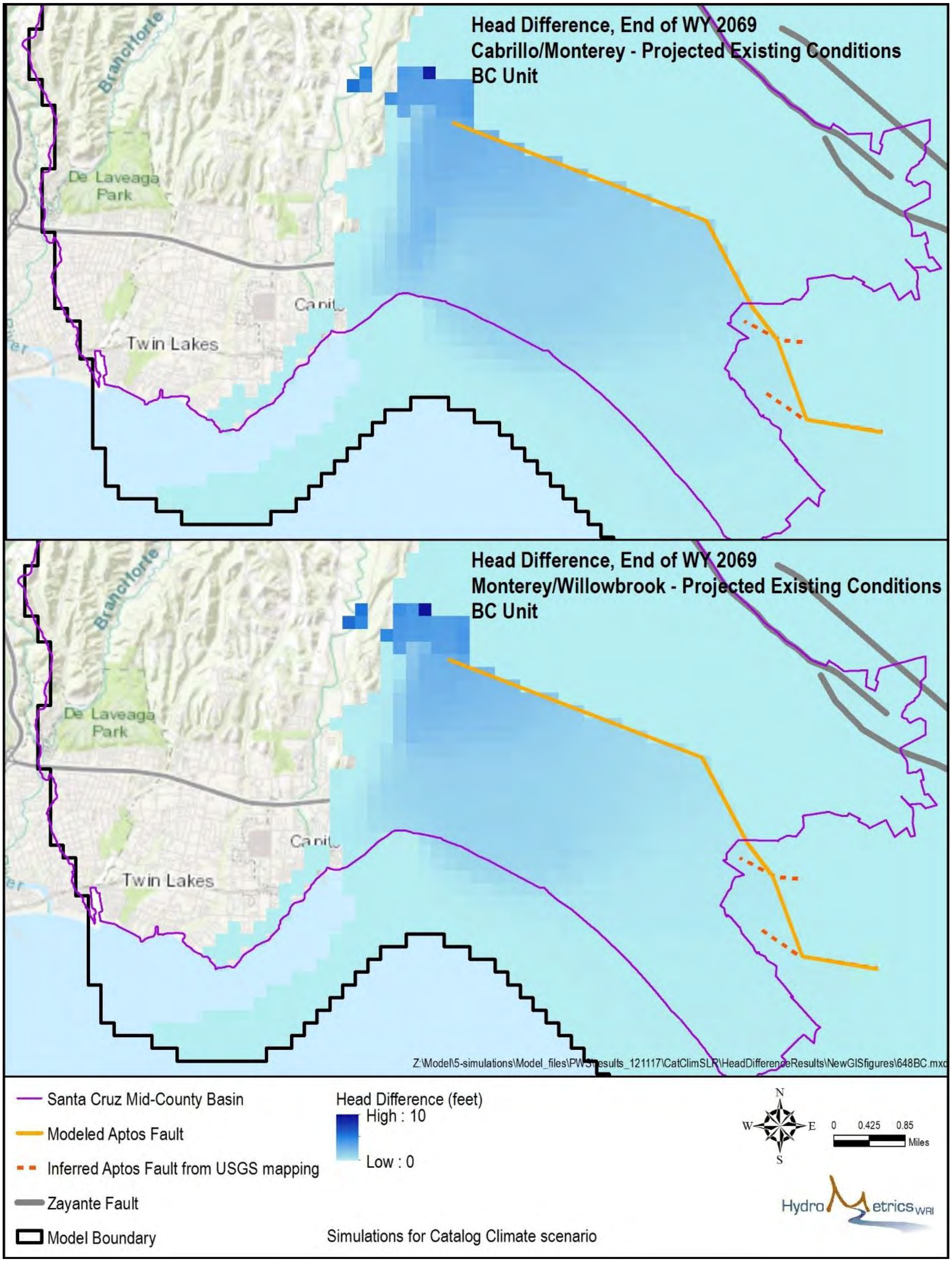

Figure 13. Purisima BC Unit Groundwater Level Increases 27 Years after Replenishment

7.3. Purisima F Unit (Aromas Area) Groundwater Conditions

Direct replenishment does not occur in the Aromas area. Instead, pumping in the Aromas area is reduced due to increases in the Purisima BC and A Units supported by replenishment. This provides passive/ in-lieu recharge for production wells extracting from the Purisima F Unit.

The reduction in pumping in the Aromas area does result in increases in simulated groundwater levels at coastal monitoring wells in the Purisima F Unit by 1-2 feet than contribute to recovery of groundwater levels to protective elevations (Figure 7 and top of Figure 14). The comparison of this effect to the difference between climate scenarios show that the Project has less effect than differences resulting from climate assumptions.

As with the Purisima A and BC Units, coastal groundwater level increases resulting from in-lieu recharge with the Project is virtually eliminated at the end of the simulations 27 years after in-lieu recharge with the Project ends (Figure 7 and top of Figure 14). Our conclusion based on the modeling simulations is that continued in-lieu recharge will be necessary to maintain the groundwater level benefits.

Pumping reductions at SqCWD production wells screened only in the Aromas Red Sands aquifer are not included in the Project simulation because the Altivo and Sells wells screened only in the Aromas Red Sands are currently inactive.

Evaluation of groundwater level effects from reducing pumping in the Purisima DEF aquifer unit (T. Hopkins and Granite Way wells) are not evaluated because model construction did not facilitate calibration for this aquifer unit.

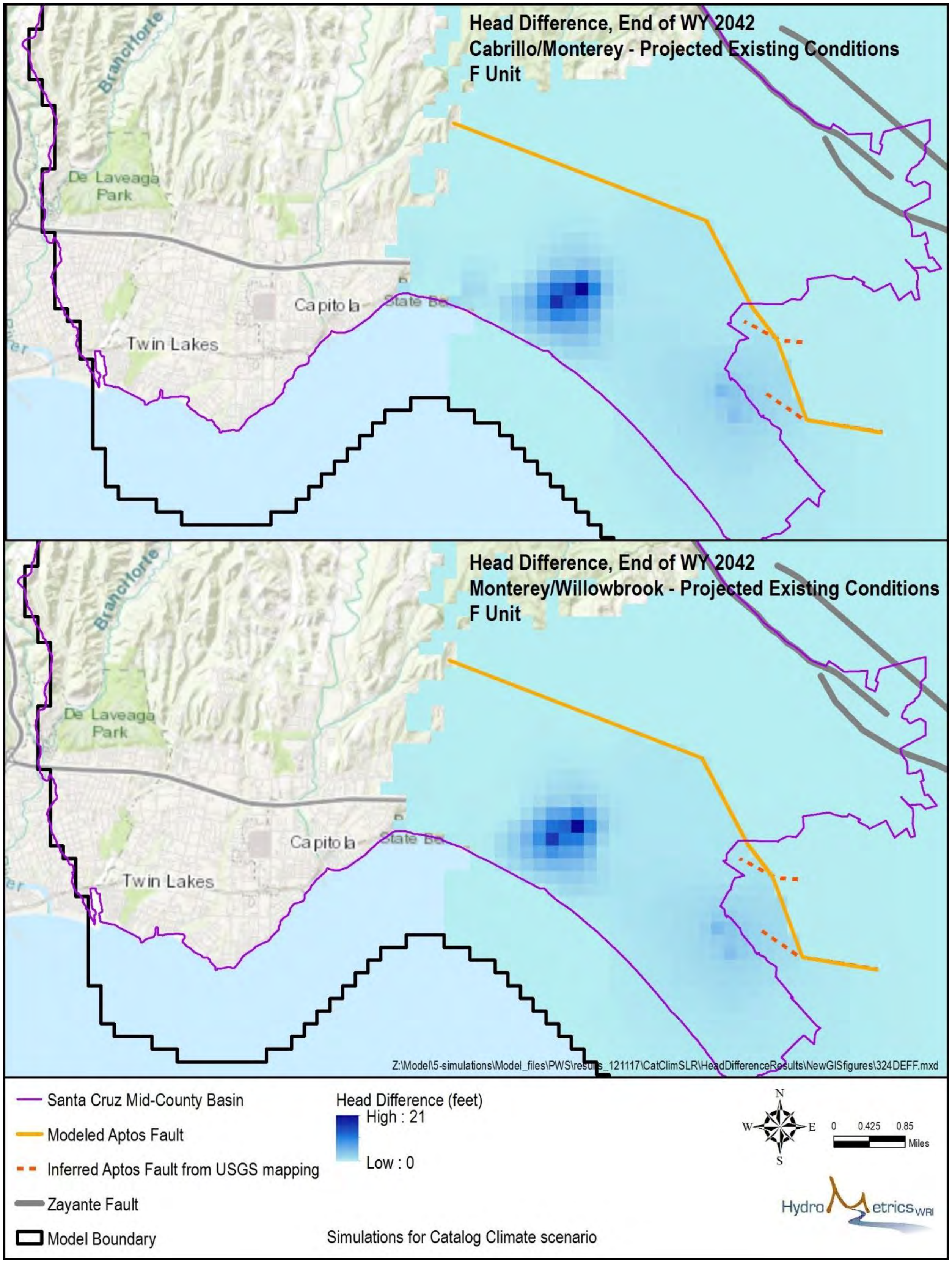

Figure 14. Purisima F Unit Groundwater Levels after 20 Years of In-Lieu Recharge

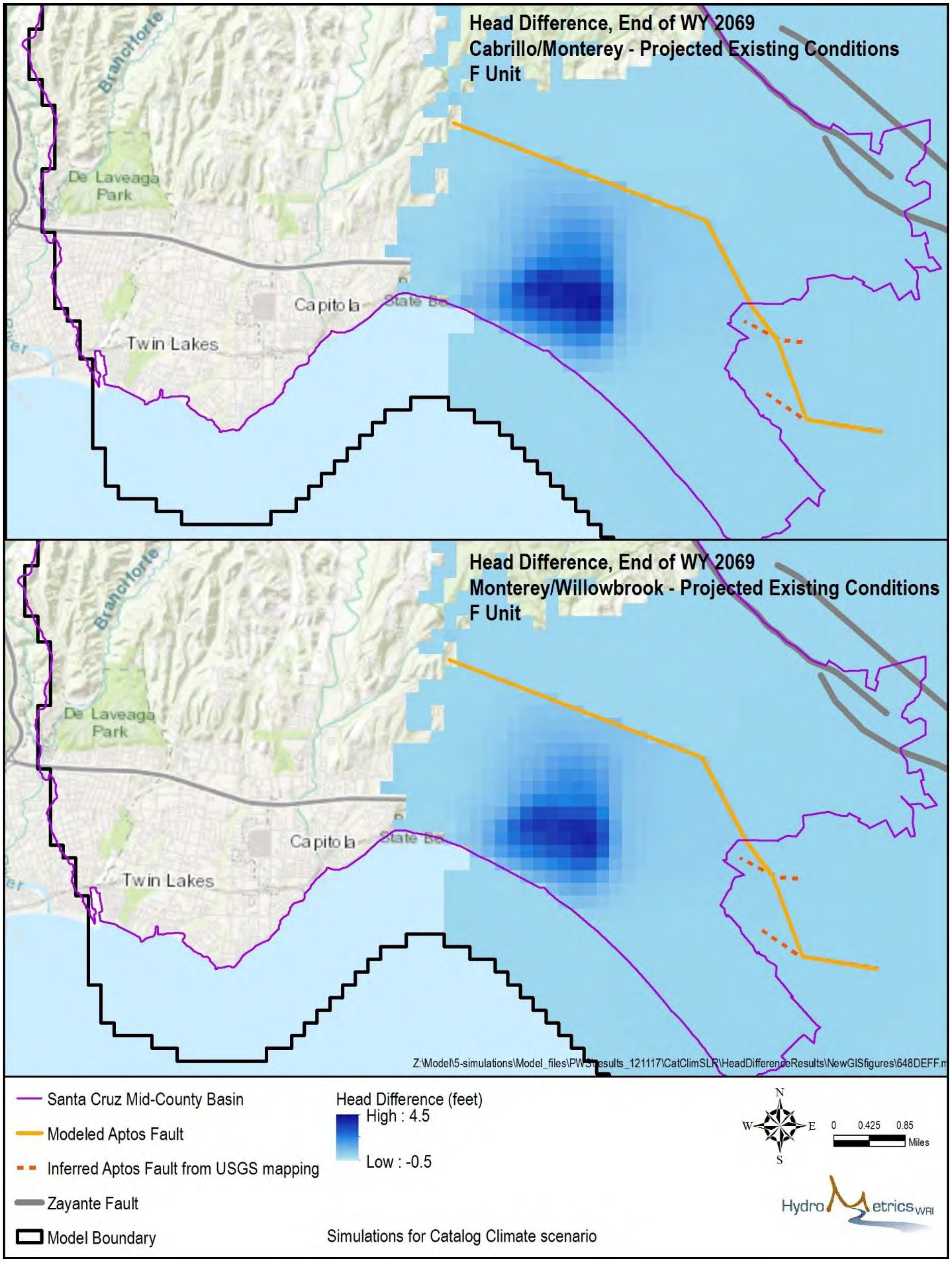

Figure 15. . Purisima F Unit Groundwater Levels 27 Years after In-Lieu Recharge Ends

7.4. Basin Groundwater Budget

Figure 16 shows the difference in Santa Cruz Mid-County Basin groundwater budget flows between the Projected Existing Conditions and Cabrillo-Monterey simulations. The budget is provided from the perspective of groundwater in the Basin. Positive flows are inflows to Basin groundwater and negative flows are outflows from Basin groundwater. By convention, flows that increase groundwater in storage are negative and flows that decrease groundwater in storage are positive.

The replenishment added by the Project to the Basin (positive values) by the Project primarily results in increases of groundwater in storage and offshore outflows from the Basin that help prevent seawater intrusion (negative values). Increasing groundwater in storage occurs when groundwater rises in the Project simulation relative to the Projected Existing Conditions simulation. The increases of groundwater in storage decline over time as groundwater levels stabilize. With this decline of increasing groundwater in storage, most of the additional replenishment results in added offshore outflows. An increase in offshore outflows by the Project relative to the Projected Existing Conditions simulation is necessary for the Project to provide benefits of preventing seawater intrusion. The Project simulation not only shows increase in offshore outflows to prevent seawater intrusion but this larger offshore outflows will likely also have the benefit of moving the saltwater interface farther offshore.

Less significant changes in the Basin groundwater budget include an increase in outflows to the Pajaro Valley Subbasin and a small decrease in inflows from stream alluvium. The increase in outflows to Pajaro Valley Subbasin (negative values) results from reduced pumping or in-lieu recharge by SqCWD in the Aromas area with the Project. The increase in outflows ranges from approximately 100 to 200 acre-feet per year during the Project replenishment period. The Project simulation shows a decrease in net flows from stream alluvium (negative values) of less than 100 acre-feet per year. The model uses cells representing overlying stream alluvium to connect streams with the stacked aquifer units (Purisima and Aromas Red Sands) of the Basin so these flow changes represent small reductions in stream losses to groundwater (which can also mean these reductions contribute to a small amount of increase in baseflows) during the Project replenishment period.

After the replenishment period, the Project simulation shows greater decreases of groundwater in storage than the Projected Existing Conditions simulation as groundwater levels are not maintained and drop with the Project towards Projected Existing Conditions levels. Greater offshore outflows also continue to exist with the Project compared with Projected Existing Conditions but the magnitudes of outflow decrease over time. Small quantities of greater outflows to the Pajaro Valley Subbasin are also maintained through the end of the simulation.

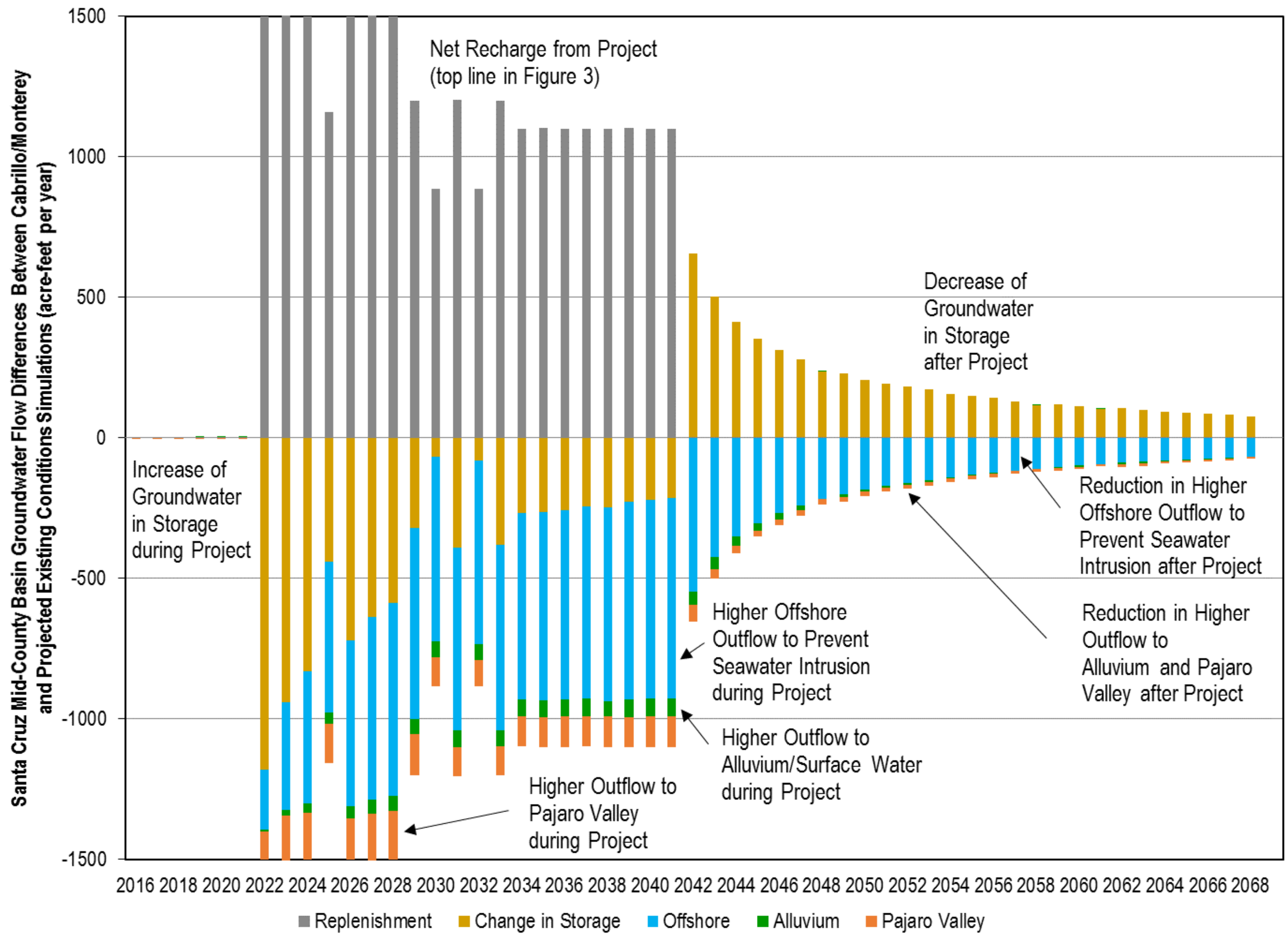

Figure 16. Santa Cruz Mid-County Basin Groundwater Flow Differences between Project and Projected Existing Conditions Simulations for Catalog Climate Scenario

7.5. Project Groundwater Effects on Recharge Wells

Groundwater levels at the recharge wells increase during the replenishment period. The GSFLOW model estimates groundwater levels in the recharge wells calculating losses between the well and model cell using the Thiem assumption. This calculation still underestimates the drawup at the well because local increases in groundwater levels are not calculated with the 800 foot model grid. Figure 17 is included to show the simulated drawup to demonstrate that assumed capacity of the recharge wells at Monterey and Cabrillo College are consistent with model results in that simulated drawup do not exceed ground surface elevations (dotted line on Figure 17). Figure 17 shows results for the Historic Climate simulation because that projects higher groundwater levels overall. Pilot testing would confirm actual capacity of the recharge wells.

Figure 18 shows that the Twin Lakes Church proposed recharge well location is in the same grid cell as the Cabrillo College recharge well location so the Cabrillo-Monterey simulations also represent simulations of replenishment at Twin Lakes Church instead of Cabrillo College.

7.6. Project Groundwater Effects on Nearby Extraction Wells

The Project increases groundwater levels at most nearby extraction wells, which provide a benefit to the groundwater supply at those wells. Adverse effects can occur if groundwater levels at the wells rise to the surface as shown by the dotted lines on Figure 19 through Figure 22. Simulated groundwater levels at nearby private and Cabrillo College extraction wells (Figure 18) show that these adverse effects are not projected to occur (Figure 19 through Figure 22) with replenishment at Monterey and Cabrillo College. It is important to note that private wells have been assumed and simulated in these model simulations and are not based on known wells. Rather, we have assumed private well extraction locations and water demands based on a water use analysis indicating private residences that are not served by SqCWD (HydroMetrics WRI, 2017b).

The Project increases pumping at nearby municipal wells so it is possible that there will be additional drawdown (or decrease in groundwater levels) at nearby wells during replenishment. Simulated results at District wells, Cunnison Lane (to be built in the future as part of the Well Master Plan to add extraction wells for groundwater management flexibility), Estates, and Tannery II wells (Figure 23) show that groundwater levels do not drop below the top of well screen elevation or rise to ground surface so model results are consistent with planned operation of these wells. Simulated results for the Rosedale well (Figure 23) shows groundwater levels dropping below the top of the screen with the Projected Existing Conditions as well as Project simulations so effects on operation with the Project are simulated to be consistent with operation without the project. The relatively small change in groundwater levels between the Project and Projected Existing Conditions simulations show the increase in pumping at Rosedale mostly balances out the effects of replenishment at the Rosedale location.

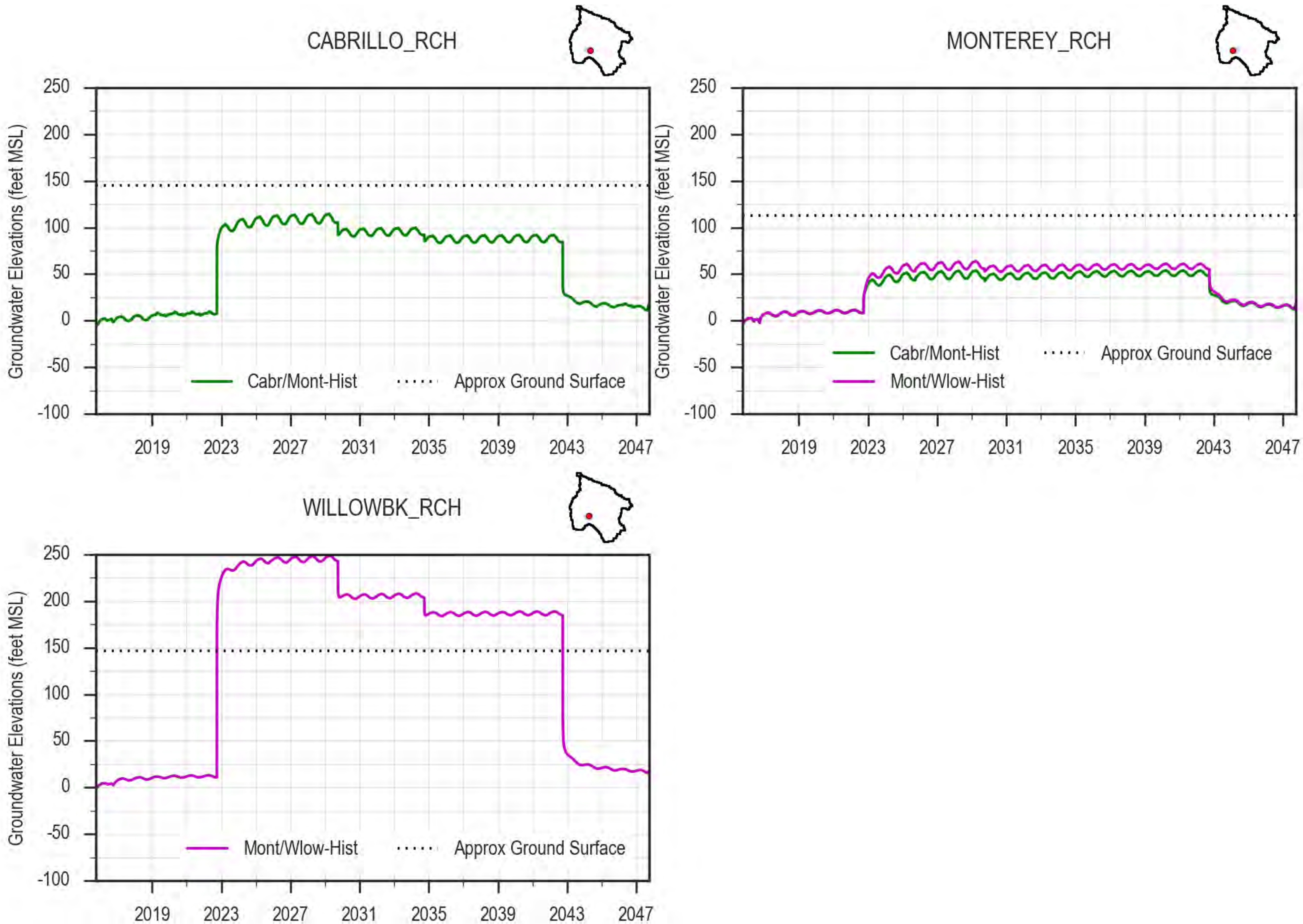

Figure 17. Simulated Groundwater Elevations at Recharge Wells for Project Simulations

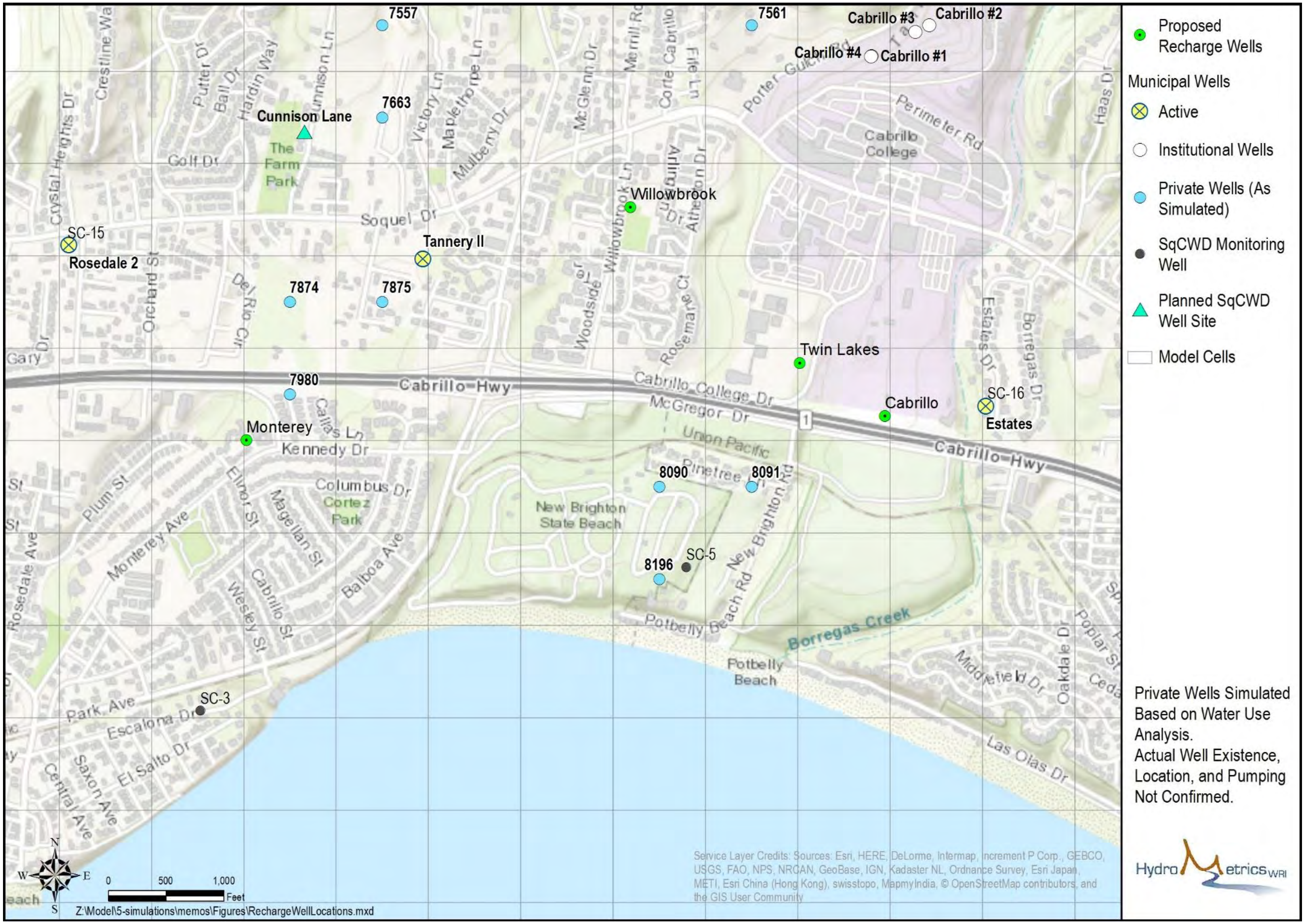

Figure 18. Simulated Extraction Wells near Recharge Wells

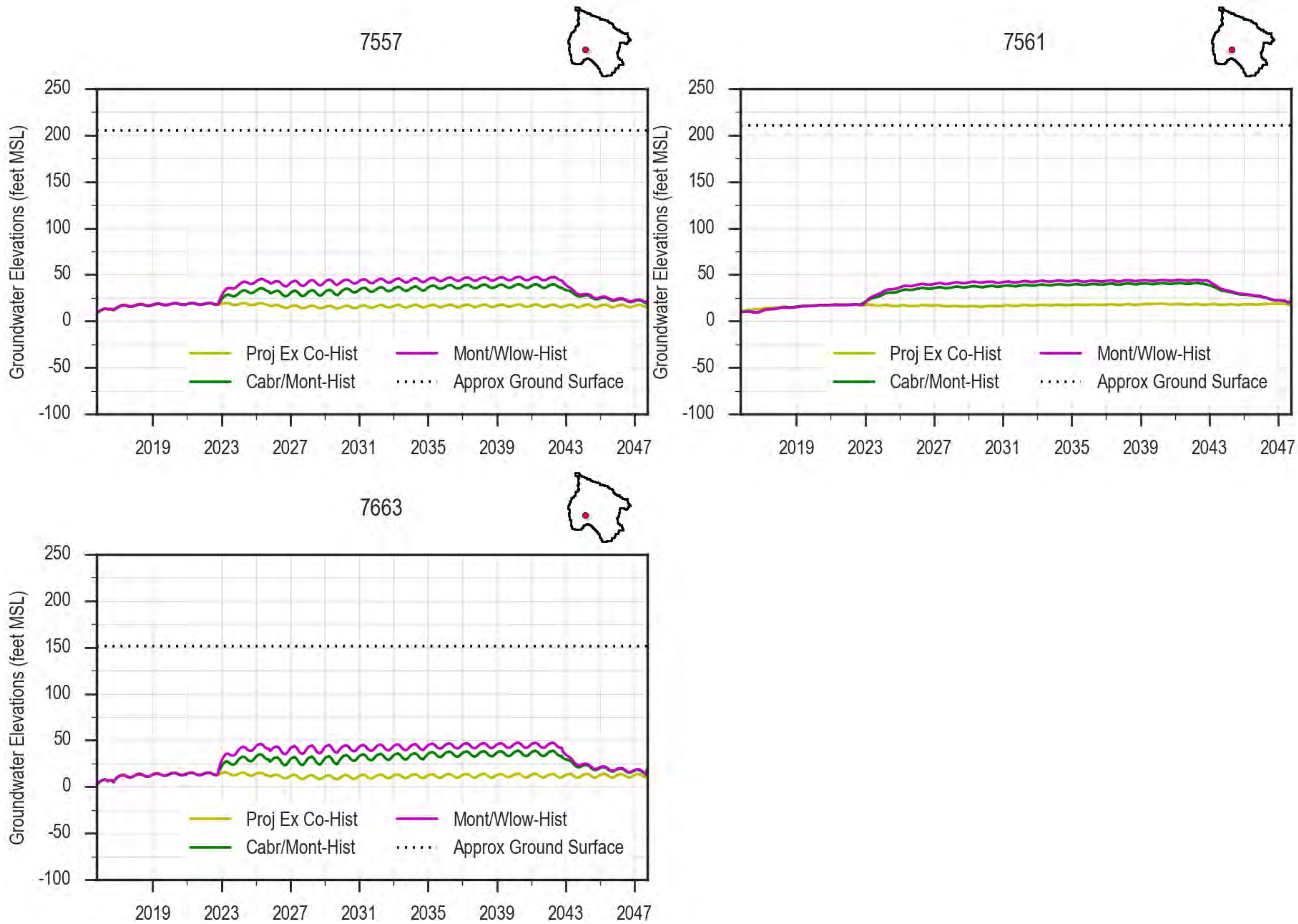

Figure 19. Simulated Groundwater Elevations at Possible Private Wells near Recharge Wells

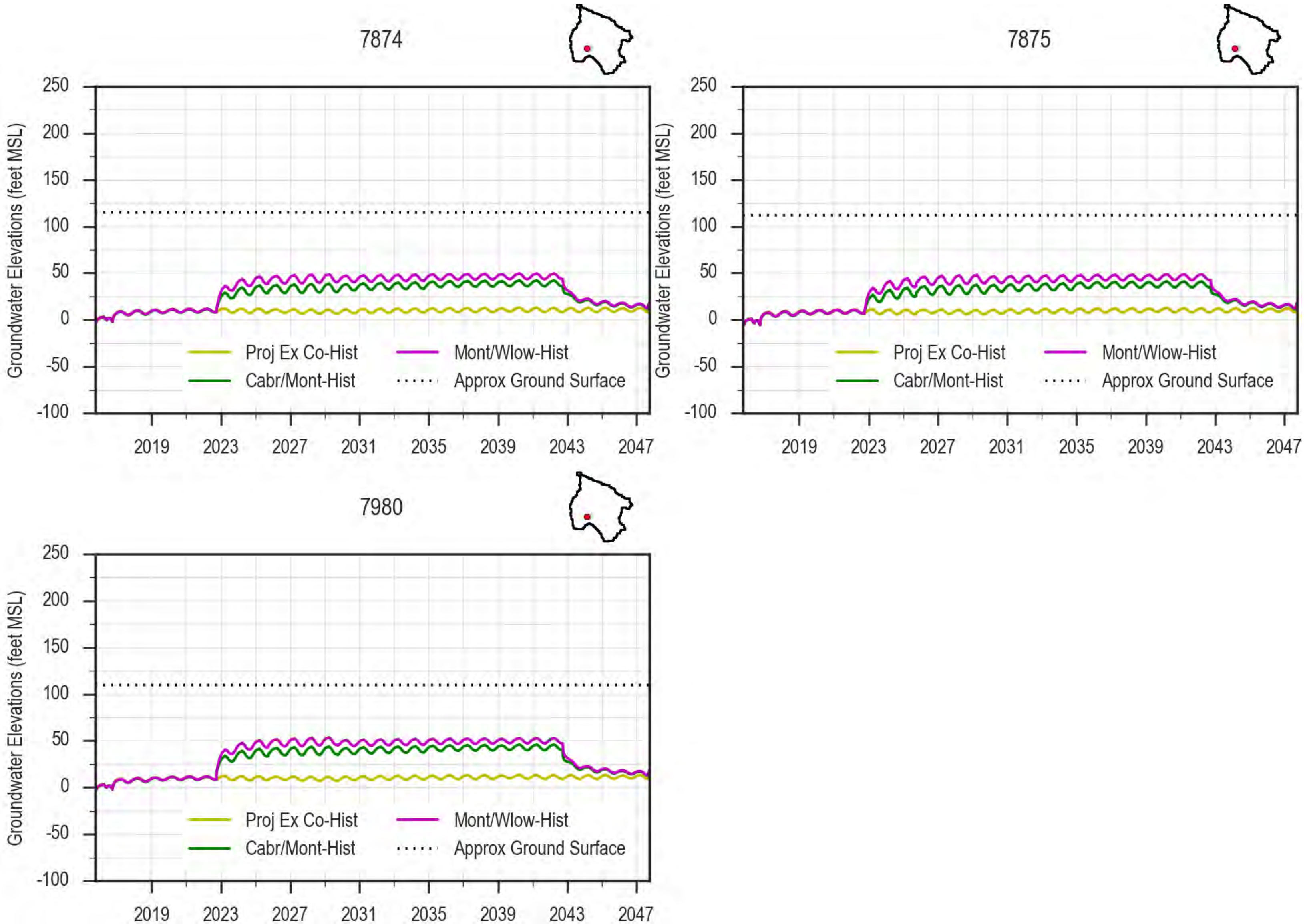

Figure 20. Simulated Groundwater Elevations at Possible Private Wells near Recharge Wells

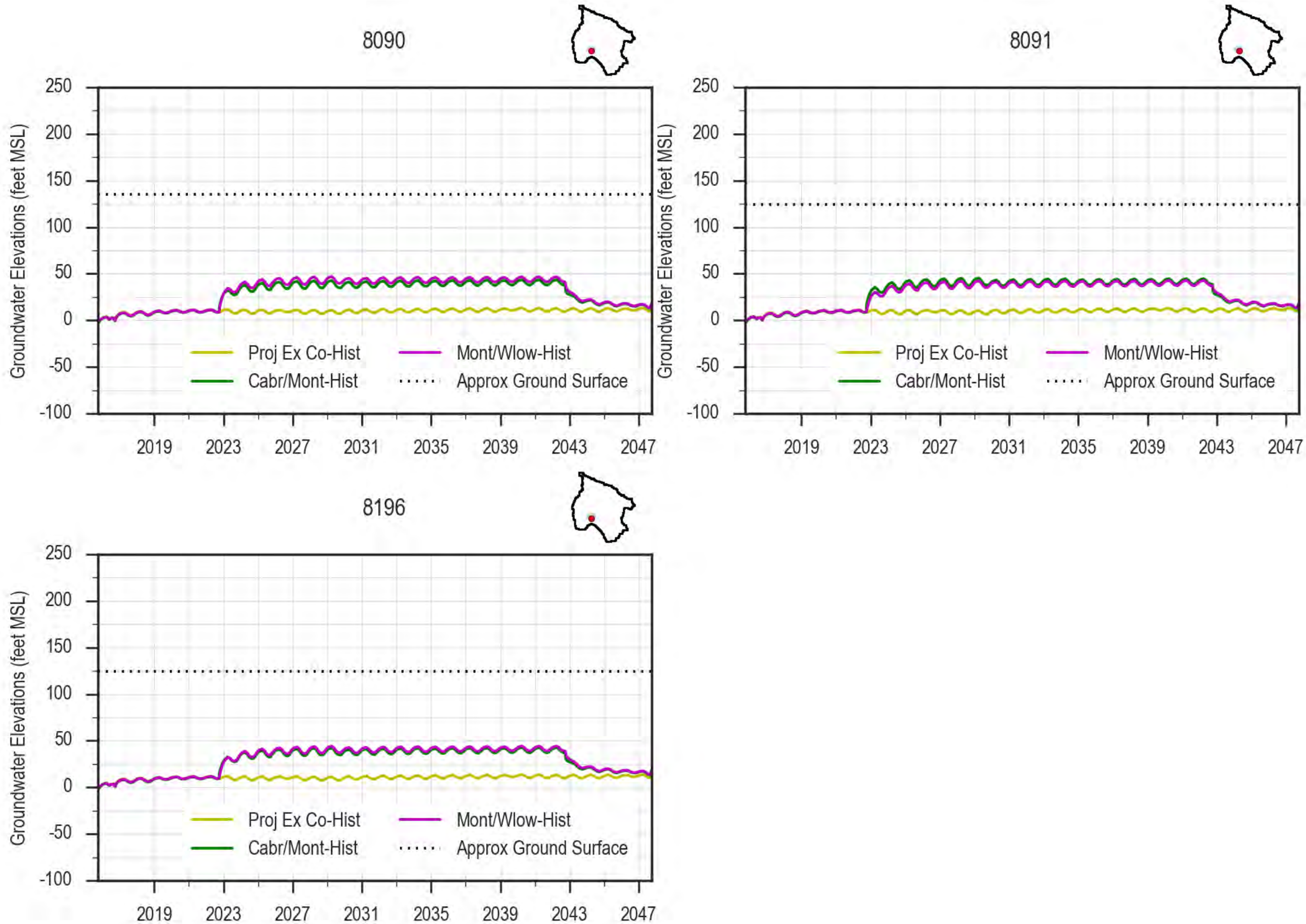

Figure 21. Simulated Groundwater Elevations at Possible Private Wells near Recharge Wells

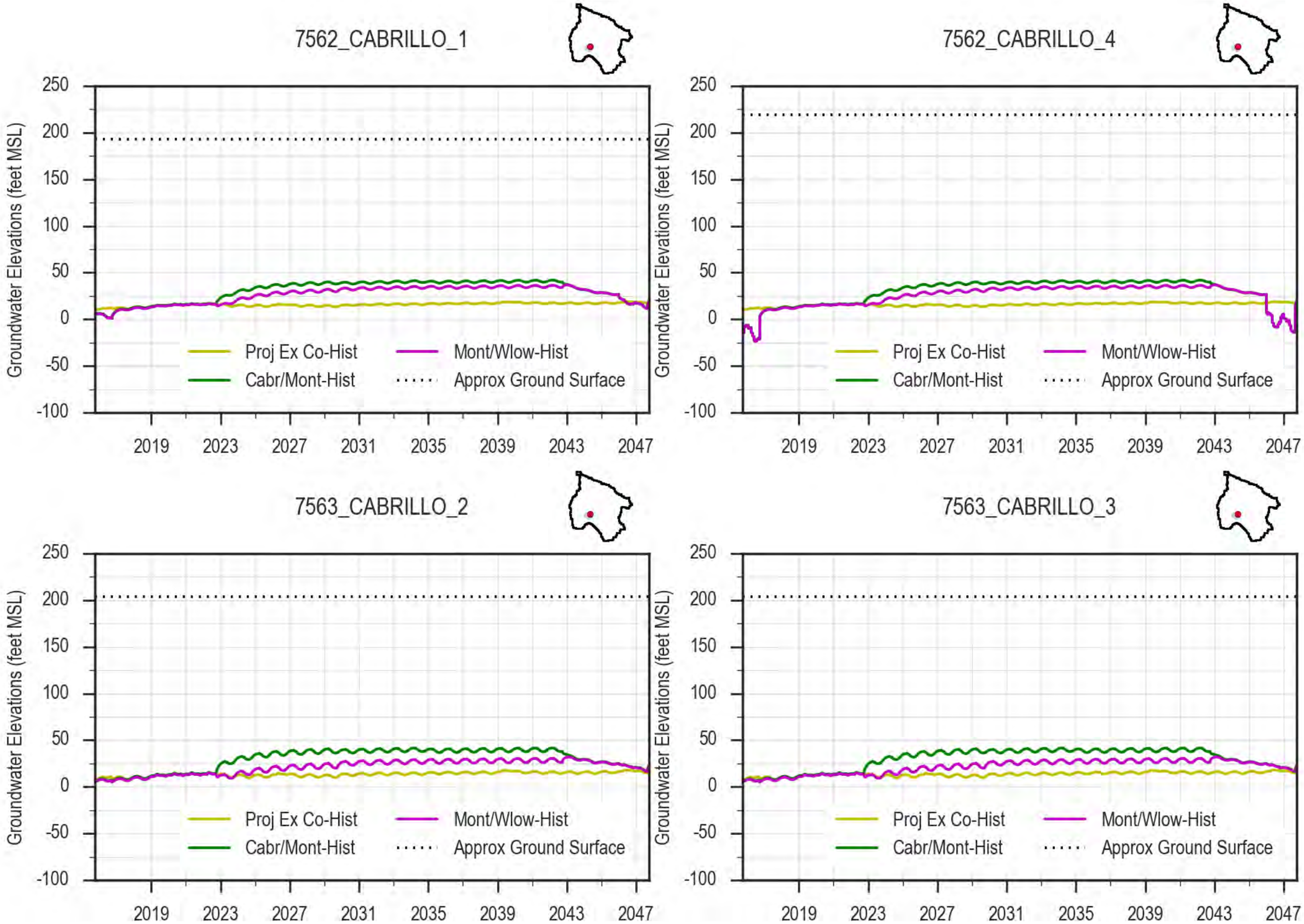

Figure 22. Simulated Groundwater Elevations at Cabrillo College Extraction Wells

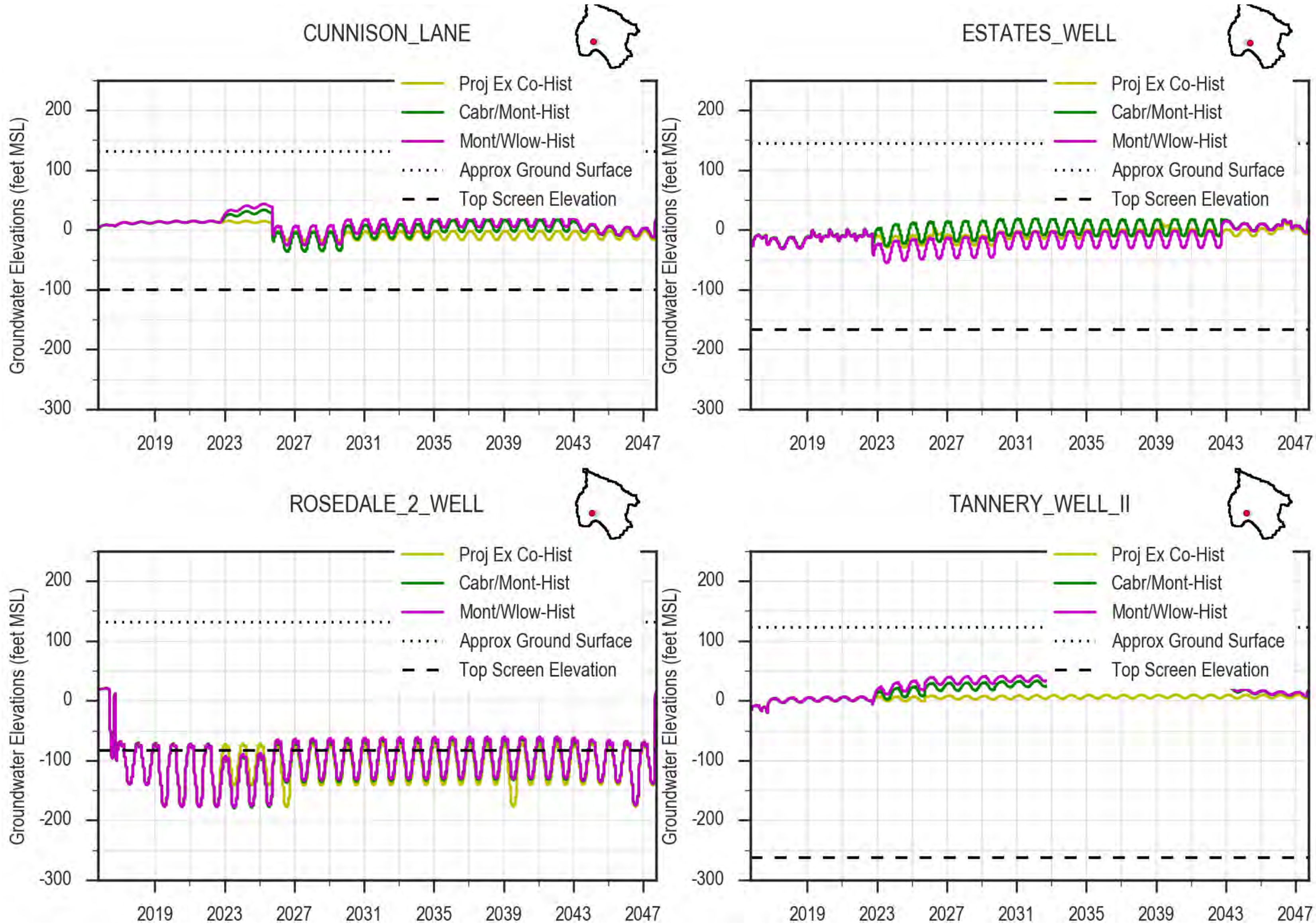

Figure 23. Simulated Groundwater Elevations at Municipal Wells near Recharge Wells

7.7. Long Term Fate of Replenishment Water for Cabrillo-Monterey Simulation

Particle tracking using the USGS MODPATH program was used to evaluate the long-term fate of replenishment water for the Cabrillo-Monterey simulation under the Catalog College Climate Scenario. Using MODPATH, particles are released from the simulated Cabrillo and Monterey recharge wells in every simulated month that recharge wells are in operation. MODPATH then uses the groundwater levels and flows simulated by GSFLOW for the Cabrillo-Monterey simulation to show where particles representing replenishment water travels to by specified times. The HydroMetrics WRI letter to Brown and Caldwell (June 19, 2018, Attachment 3) describes the methodology for particle tracking and complete results. The results can also be used to evaluate long term fate of replenishment water at Twin Lakes Church instead of Cabrillo College.

Figure 24 and Figure 25 show the location of replenishment water in 2047 in the A aquifer unit and BC aquifer unit respectively, five years following the conclusion of simulated replenishment by the Project. The colors indicate the time since particles representing replenishment were released. Most of the replenishment water travels toward SqCWD production wells.

Based on the MODPATH results, in 2047, 69% of replenishment water remains in the Basin in 2047, SqCWD production wells have captured approximately 29% of the replenishment water, and a simulated private well has captured 2% of the replenishment water. Simulated private wells are included in the model based on a water use analysis that indicate a parcel that is not served by SqCWD. Existence and location of as well as pumping rates for the well have not been confirmed.

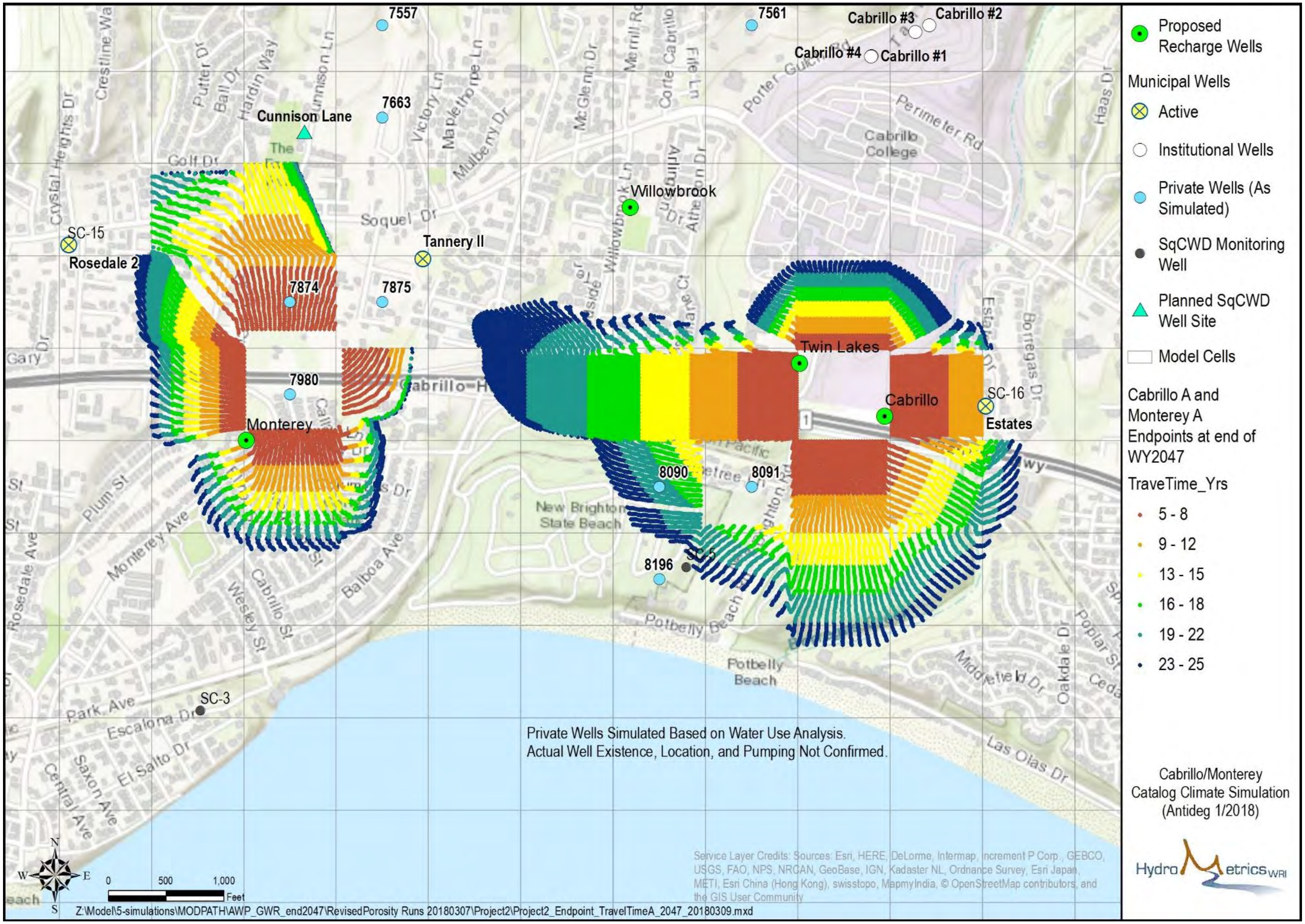

Figure 24. Locations of Replenishment Water Particles in the Purisima A Unit for the Cabrillo-Monterey Simulation

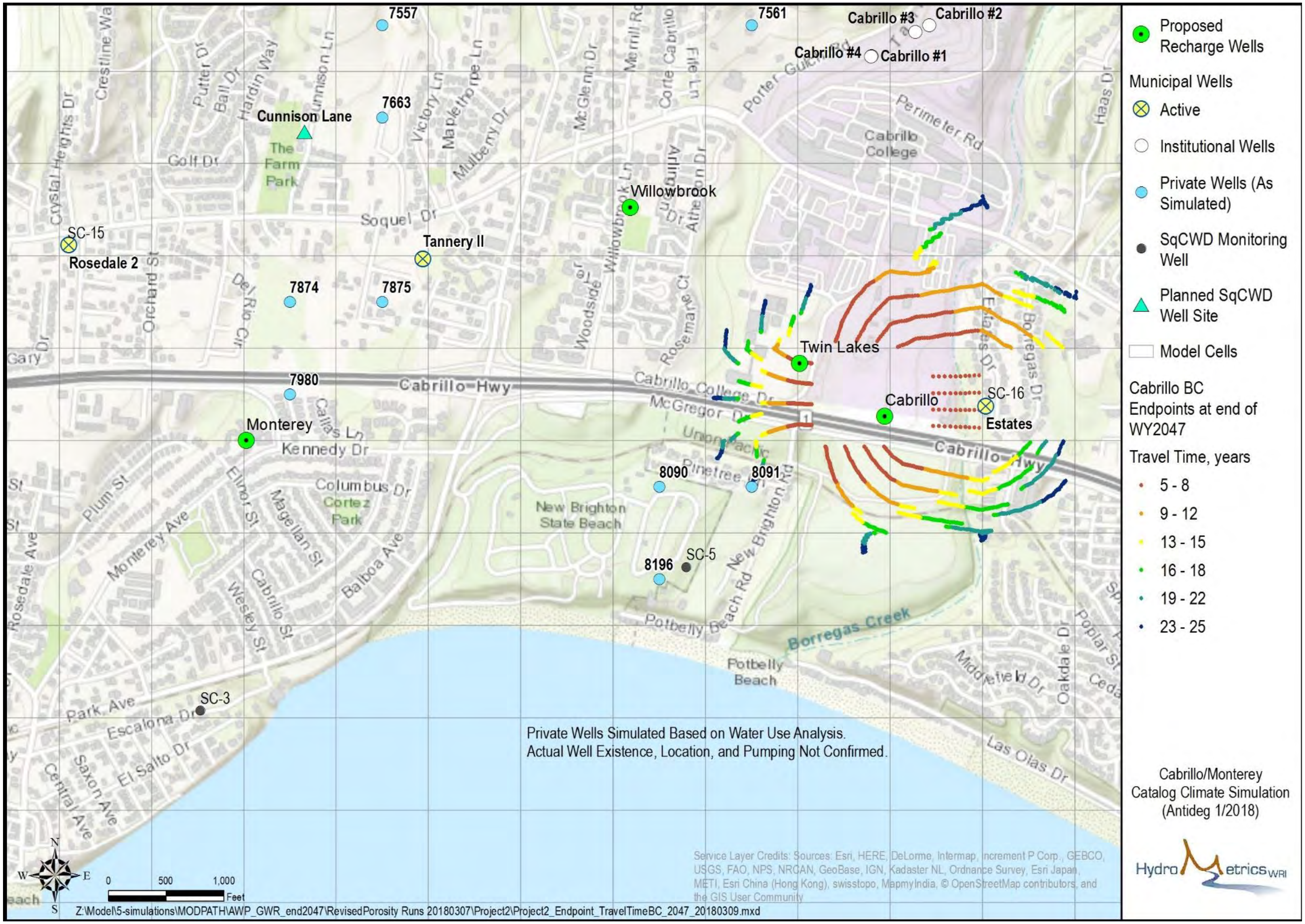

Figure 25. Locations of Replenishment Water Particles in the Purisima BC Unit for the Cabrillo-Monterey Simulation

8. Monterey-Willowbrook Simulation Results

8.1. Purisima A and BC Unit Groundwater Conditions During Project

The Monterey-Willowbrook simulations show substantial increases in groundwater levels in the Purisima A unit near the recharge wells at Monterey and Willowbrook (Mont/Wlow on Figure 26 through Figure 27) during the project period of Water Years 2023-2042 under both the Historical and Catalog Climate scenarios are slightly higher than the Cabrillo simulation as demonstrated by results from SC-1A, SC-3A, and SC-5A (Figure 26).

Monterey-Willowbrook simulations also show increases in groundwater levels in the Purisima BC unit near the recharge wells but substantially less than in the Cabrillo-Monterey simulations. This is a result of replenishment in the BC unit at Willowbrook being farther west from the more productive pumping areas of the BC unit. The difference between the Cabrillo-Monterey and Monterey-Willowbrook simulations for the BC unit are demonstrated by hydrographs at the SC-9C and SC-8C wells (Figure 27). Groundwater level increases in the BC unit with recharge at Willowbrook instead of Cabrillo College are between 5-10 feet as opposed to 20+ feet. Increases of 5-10 feet may not be sufficient to achieve protective elevations at these wells to prevent seawater intrusion. Replenishment of the BC unit at Willowbrook appears to be less effective than replenishment of the BC unit at Cabrillo College.

For replenishment at Willowbrook and Cabrillo College that occurs in both the BC and A aquifer units, the model apportions flows to groundwater based on relative transmissivity between the units. Less replenishment occurs in the BC unit at Willowbrook than it does at Cabrillo College because calibrated transmissivity is lower for the BC unit at Willowbrook. Confirmation of local site conditions with recharge wells either in operation or during a testing phase may provide different information about local transmissivities that would change the distribution of flow. Another possibility is to observe and implement replenishment into the BC and A units separately that will provide more control of replenishment volumes into each unit.

8.2. Purisima A and BC Unit Groundwater Conditions After Project

Under the Monterey-Willowbrook simulation, groundwater levels decline similarly to the Cabrillo-Monterey simulation with little difference between Project and Projected Existing Conditions by the end of 2069. In the BC unit, the groundwater level increase that is remaining at the end of 2069 is less for the Monterey-Willowbrook simulation (~1 foot at coast) than the Cabrillo-Monterey simulation (~1-2 feet near the coast). This decline between Water Years 2042 and 2069 is also shown in the bottom maps on Figure 10 through Figure 13.

8.3. Purisima F Unit (Aromas Area) Groundwater Conditions

There is minimal difference between Cabrillo-Monterey and Monterey-Willowbrook simulation results for the Purisima F unit (Figure 14 and Figure 15) because assumptions for reduced pumping and in-lieu recharge are the same for the two simulations.

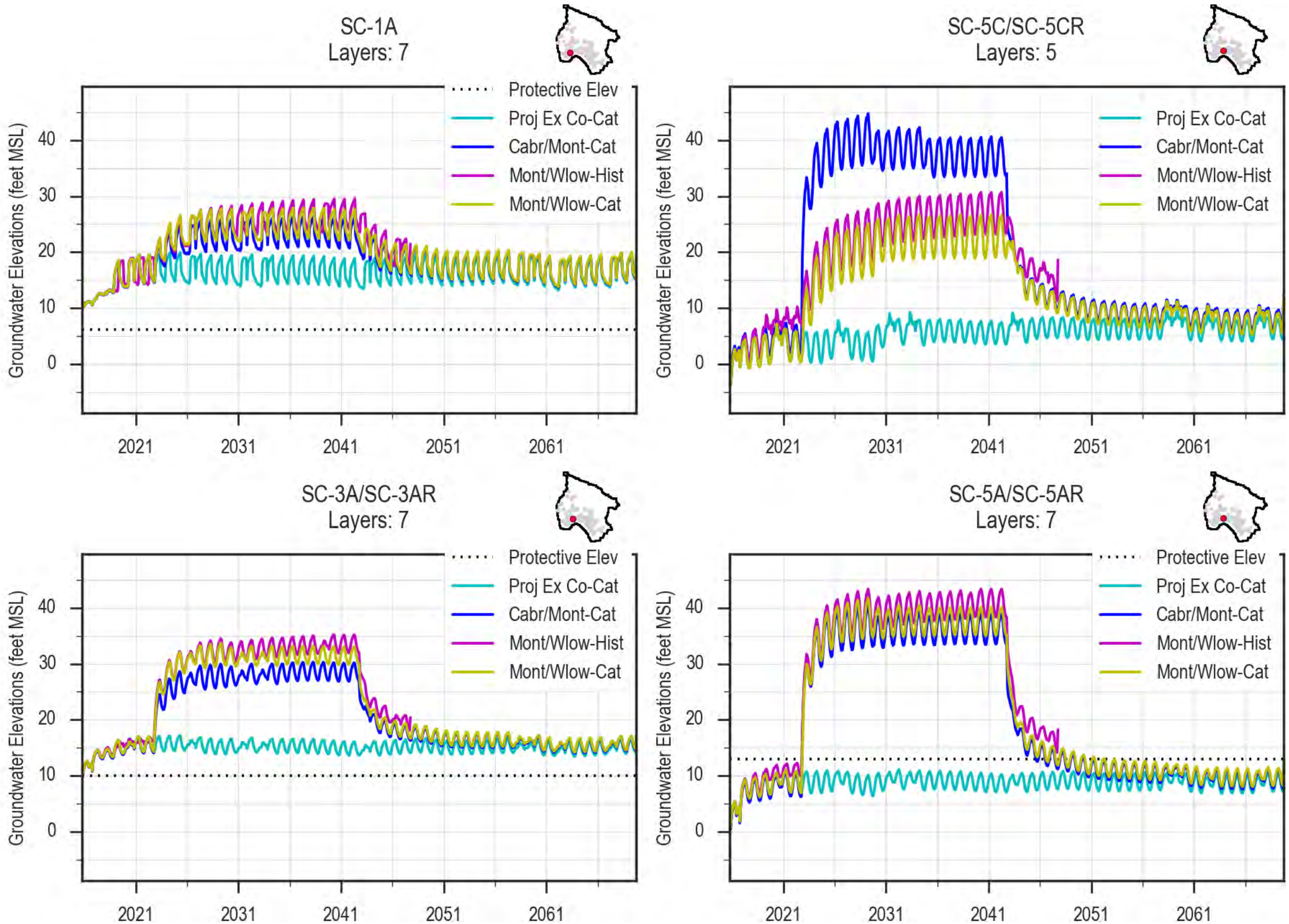

Figure 26. Simulated Monterey-Willowbrook Groundwater Levels at Coastal Monitoring Wells near SqCWD A Unit Pumping

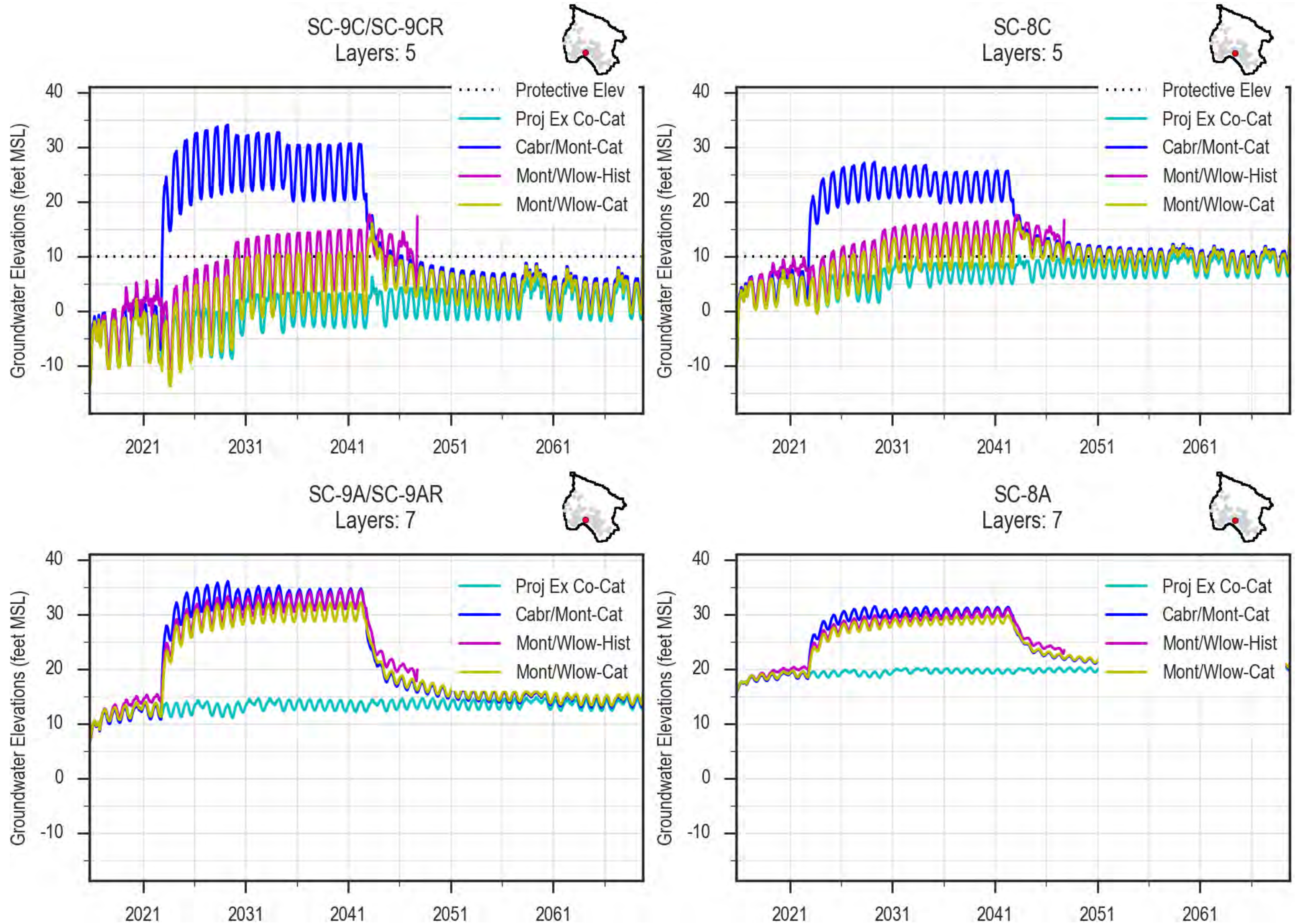

Figure 27. Simulated Monterey-Willowbrook Groundwater Levels at Coastal Monitoring Wells near SqCWD BC Unit Pumping

8.4. Basin Groundwater Budget

The Santa Cruz Mid-County groundwater budget for the Monterey-Willowbrook simulation is similar to the Cabrillo-Monterey simulation in that replenishment primarily results in increased flows to storage (by convention, negative values) and increased offshore outflows when compared to the Projected Existing Conditions simulation (Figure 28). The Monterey-Willowbrook simulation has greater flows to storage than the Project simulation (Figure 16). This is a result of a higher proportion of recharge at the Willowbrook well being simulated into the A unit versus the BC unit. Based on the modeling results, there is greater storage capacity in the A unit; thus, more of the replenishment flows to storage.

8.5. Monterey-Willowbrook Groundwater Effects on Recharge Wells

Groundwater levels at the recharge wells increase during the replenishment period. The GSFLOW model estimates groundwater levels in the recharge wells calculating losses between the well and model cell using the Thiem assumption. This calculation still underestimates the drawup at the well because local increases in groundwater levels are not calculated by the 800 foot model grid

Under the Monterey-Willowbrook simulation, groundwater levels at the Willowbrook well rise above ground surface (Figure 17) so the calibrated groundwater model indicates that the Willowbrook well does not have capacity to recharge up to 1,000 acre-feet per year. The model is not calibrated using local data around the Willowbrook site and testing during operations or pilot efforts could show that capacity is sufficient to implement the Monterey-Willowbrook. The pilot testing could also evaluate recharging into the Purisima A and BC aquifer units separately.

8.6. Monterey-Willowbrook Groundwater Effects on Nearby Extraction wells

The Monterey-Willowbrook simulation increases groundwater levels at and nearby extraction wells, which provide a benefit to the groundwater supply at those wells. Adverse effects can occur if groundwater levels at the wells rise to the surface. Simulated groundwater levels at municipal, institutional, and assumed private wells (Figure 19 through Figure 23) show that these adverse effects are not projected to occur with replenishment at Monterey and Willowbrook recharge wells.

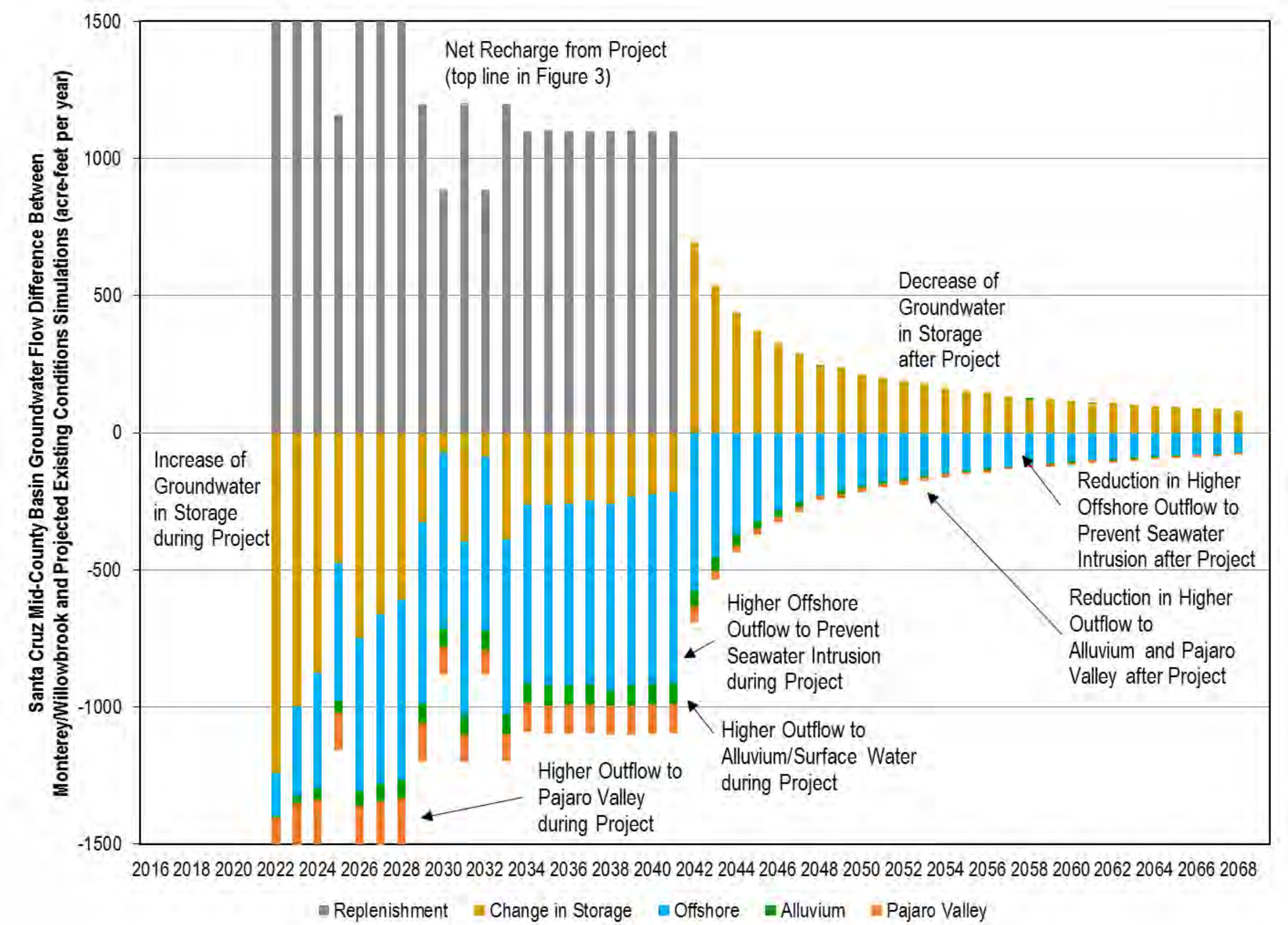

Figure 28. Santa Cruz Mid-County Basin Groundwater Flow Differences between Monterey-Willowbrook and Projected Existing Conditions Simulations

8.7. Long Term Fate of Replenishment Water for Willowbrook-Monterey Simulation

Particle tracking using the USGS MODPATH program was used to evaluate the long-term fate of replenishment water for the Monterey simulation under the Catalog College Climate Scenario. Using MODPATH, particles are released from the simulated Monterey and Willowbrook recharge wells in every simulated month that recharge wells are in operation. MODPATH then uses the groundwater levels and flows simulated by GSFLOW for the Monterey-Willowbrook simulation to show where particles representing replenishment water travels to at specified times. The HydroMetrics WRI letter to Brown and Caldwell (June 19, 2018, Attachment 3) describes the methodology for particle tracking and complete results. The results can also be used to evaluate long term fate of replenishment water at Twin Lakes Church instead of Cabrillo College.

Figure 29 shows the location of replenishment water in 2047 in the A aquifer unit five years following the conclusion of simulated replenishment by the Project. The colors indicate the time since particles representing replenishment were released. Most of the replenishment water travels toward SqCWD production wells.

Based on the MODPATH results, in 2047, 80% of replenishment water remains in the Basin, SqCWD production wells have captured approximately 18% of the replenishment water, a simulated private well has captured 2% of the replenishment water, and a Cabrillo College well capturing 0.02% of the replenishment water. Simulated private wells are included in the model based on a water use analysis that indicate a parcel that is not served by SqCWD. Existence and location of as well as pumping rates for the well have not been confirmed.

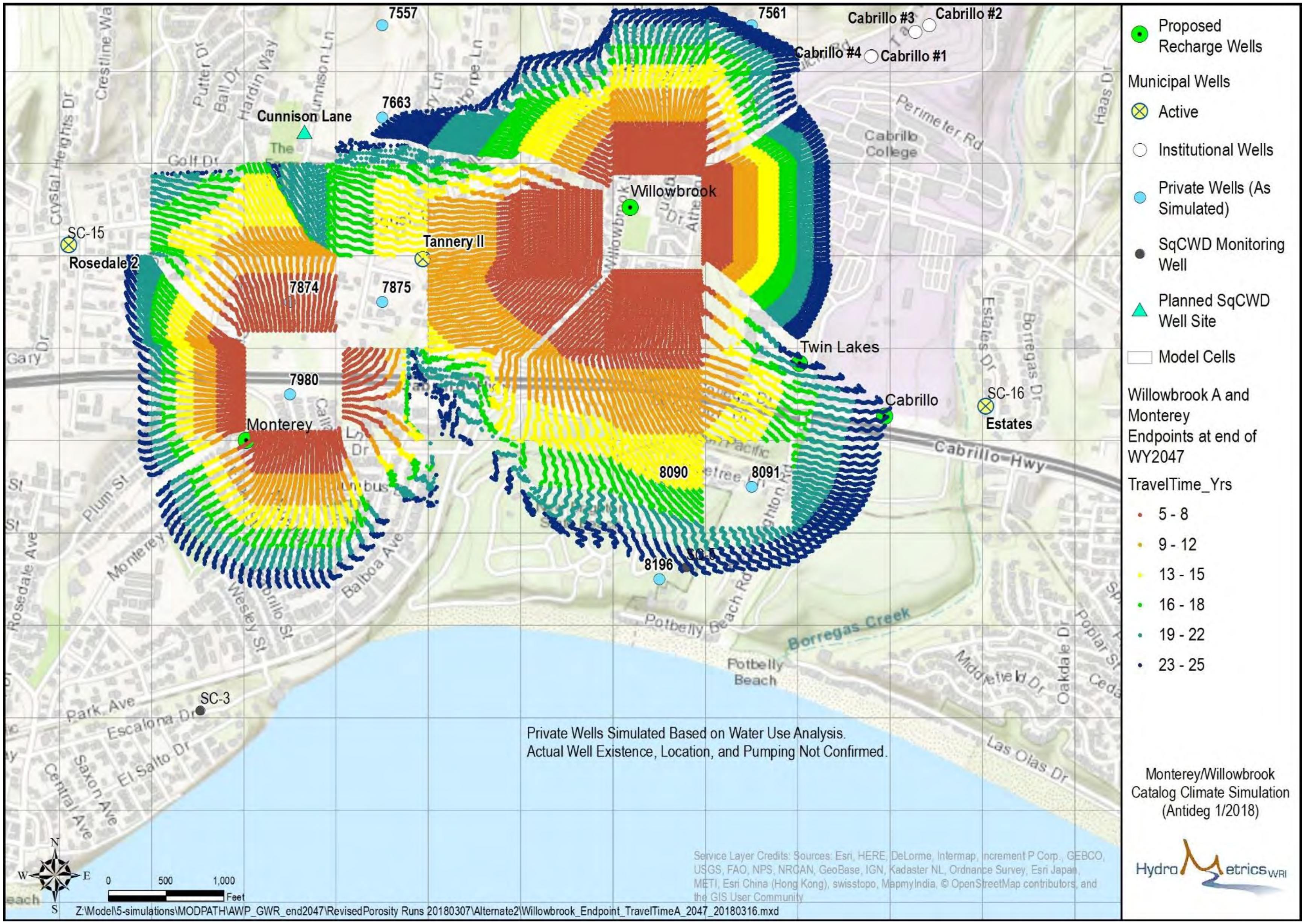

Figure 29. Locations of Replenishment Water Particles in the Purisima A Unit for the Monterey-Willowbrook Simulation

9. SUMMARY

Groundwater simulations under two climate scenarios show that the Pure Water Soquel project will provide benefits of raising groundwater levels in the Santa Cruz Mid-County Basin and reducing risk of seawater intrusion from moving farther inland. In the Purisima A and BC units where direct replenishment occurs, groundwater levels will rise substantially above protective elevations to prevent seawater intrusion and will likely be high enough to push the saltwater interface offshore. In the Aromas area's Purisima F unit, in-lieu recharge should increase groundwater levels. The Aromas area groundwater level increase resulting from the Project may not be enough to recover to protective elevations to prevent seawater intrusion as the overall groundwater level increase will likely also be dependent on other factors, such as climate and non-municipal pumping.

After the simulated replenishment period, groundwater levels drop down close to Projected Existing Conditions but a small groundwater level increase persists long term. Simulated groundwater levels greater than 10 feet above protective elevations in the Purisima A and BC units during the replenishment period reducing to 1-2 feet after the replenishment period. This indicates that the planned project duration of 20 years may not achieve basin management objectives to prevent seawater intrusion over the long-term and continued operations of the Project may be a more effective approach to protecting and sustaining the Basin's groundwater supply over the long-term.

Particle tracking shows that the majority of the replenishment water remains in the Basin's aquifer 5 years after Project replenishment is simulated to completed with nearly all of the remaining replenishment water being captured by SqCWD production wells.

Evaluation of the Monterey-Willowbrook simulation shows that recharging at Willowbrook is substantially less effective than recharging at Cabrillo College or Twin Lakes Church at raising groundwater levels in the Purisima BC unit. The calibrated model also indicates that recharge capacity at Willowbrook is less than Cabrillo College or Twin Lakes Church, but site specific tests could confirm capacity at either site.

The simulations also demonstrate that there is little control on proportions being recharged into the Purisima A and BC units by single wells at Cabrillo College, Twin Lakes Church or Willowbrook. Evaluation using pilot testing or during start-up of these recharge wells could evaluate replenishment capacity into the aquifer units separately by installing a filter pack seal between the units in the wells and using an inflatable packer during testing.

11. References

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HydroMetrics WRI. 2017a. *2017 Update to Pumping Distribution Plans for Current and Future Pumping Goals.* Technical Memorandum from C. Tana and S. Culkin to Taj Dufour, Soquel Creek Water District. March 1.

HydroMetrics WRI. 2017b. *Santa Cruz Mid-County Basin Groundwater Flow Model: Water Use Estimates and Return Flow Implementation (Task 2).* Technical Memorandum from G. King and C. Tana to John Ricker and Ron Duncan, Santa Cruz Mid-County Groundwater Agency. March 31.

HydroMetrics WRI. 2017c. *Santa Cruz Mid-County Basin Groundwater Management Biennial Review and Report Water Years 2015-2016.* MGA Board Draft prepared for Santa Cruz Mid-County Groundwater Agency. July.

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National Research Council (NRC). 2012. S*ea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future.* National Academy Press. Washington, D.C.

Water Systems Consulting. 2016. *2015 Urban Water Management Plan for the SqCWD.* Prepared for Soquel Creek Water District. June.

Attachment 1: Update to Pumping Distribution Plans for Current and Future Pumping Goals (HydroMetrics WRI, 2017a)

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TECHNICAL MEMORANDUM

To: Melanie Mow Schumacher

From: Cameron Tana

Date: August 15, 2017

Subject: SqCWD Pumping Distributions for Pure Water Soquel Model Simulations:

1. INTRODUCTION

This technical memorandum provides assumptions for annual pumping and managed recharge distributions in groundwater model simulations to be run to support the Environmental Impact Report and Salt and Nutrient Anti-degradation Study for the Pure Water Soquel project involving managed aquifer recharge of advanced purified recycled water within SqCWD's service area. Collectively, these pumping and managed recharge distributions will be applied to eight model simulations using the calibrated GSFLOW model for the Santa Cruz Mid-County Basin (the Basin). These simulations have different pumping and managed recharge distributions, as follows:

- Two No-Project Simulations with SqCWD's pumping distribution reflecting future demand without additional managed recharge at proposed recharge wells.
- Two Project Simulations with SqCWD's pumping distribution reflecting future demand and pumping re-distribution with the addition of managed aquifer recharge at the Monterey and Cabrillo College sites.
- Two Alternative Project Simulations with the same pumping distribution as the Project Simulations, but with managed recharge at the Cabrillo College and Willowbrook sites.
- Two Cumulative Project Simulations which will include the Pure Water Soquel project with managed recharge at the Monterey and Cabrillo College sites and a configuration of the City of Santa Cruz Aquifer Storage and Recovery project with additional changes to the pumping distribution. Development of this pumping and managed recharge distribution is pending information from the City of Santa Cruz's groundwater consultant.

Two simulations will be run for each pumping and managed recharge distribution because simulations will be run under two climate scenarios. For each of the distributions, one simulation will be run under historic climate from Water Years 1985-2015 used for calibration. The other simulation will be run using a representation of future climate change based on preferentially selecting warmer years from the catalog of historic years from Water Years 1909-2016 (HydroMetrics WRI, 2016). Table 1 shows the historic years used for climate under both climate scenarios.

Assumptions related to future pumping from the City of Santa Cruz, Central Water District, and non-municipal pumpers are also summarized in this document. Non-SqCWD pumping is the same between the No-Project, Project, and Alternate Project simulations for each climate scenario.

A pumping distribution for the Cumulative Simulation with Pure Water Soquel and City of Santa Cruz Aquifer Storage and Recovery will also be developed based on information provided by Pueblo Water Resources Inc. and City of Santa Cruz. This will include different pumping and managed recharge at both City of Santa Cruz and SqCWD wells from the distributions used in No-Project, Project, and Alternate Project Simulations.The attached Table 2 and Table 3 as well as the accompanying Excel workbook summarize the annual pumping distributions for these simulations (PWSPumpingForTables.xlsx). The model input time series is monthly and the monthly pumping distributions are summarized in the attached Excel workbook as pivot tables in sheets for the two No-Project Simulations (NoProject_HistClimate and NoProject_ClimateChange) and the two Project Simulations (Project_HistClimate and Project_ClimateChange).

2. Initial Conditions

The calibrated model run simulates Water Years 1985-2015. Initial conditions for all simulations are based on simulated results for the end of Water Year 2015 from the calibration run. Since there was substantial coastal groundwater level recovery in Water Year 2016 (HydroMetrics WRI, 2017c), actual climate and municipal pumping data are used to simulate Water Year 2016 as the first year of these future simulations. Rainfall in Water Year 2016 was above average at 32.6 inches for the Santa Cruz Co-op station. Municipal pumping within the Basin for Water Year 2016 of 3,928 acre-feet was the lowest annual total since 1977.

Table 1. Water Years Used for Climate Scenarios

		Historic Climate Scenario Based on Water Years 1985-2015			Future Climate Scenario Based on Historic Catalog		
Model Water Year	Future Water Year Used for Pumping and Managed Recharge	Historic Water Year Used for Climate	Classification	San Lorenzo River Flow (AFY) Critically Dry	Historic Water Year Used for Climate	Classification	San Lorenzo River Flow (AFY) Critically Dry
1	2016	2016	Warm & Wet	76,443	2016	Warm & Wet	76,443
2	2017	1985	Cooler & Wet	43,800	1992	Warm & Dry	48,421
3	2018	1986	Cooler & Wet	169,408	2015	Warm & Dry	31,637
4	2019	1987	Warm & Dry	23,963	2010	Cooler & Wet	94,840
5	2020	1988	Warm & Dry	20,254	2014	Warm & Dry	13,828
6	2021	1989	Cooler & Dry	24,398	2016	Warm & Wet	76,443
7	2022	1990	Warm & Dry	19,402	2004	Warm & Dry	84,283
8	2023	1991	Cooler & Dry	30,262	2003	Warm & Wet	77,102
9	2024	1992	Warm & Dry	48,421	2015	Warm & Dry	31,637
10	2025	1993	Warm & Wet	111,057	2013	Warm & Dry	53,284
11	2026	1994	Cooler & Dry	28,452	1990	Warm & Dry	19,402
12	2027	1995	Cooler & Wet	177,806	2015	Warm & Dry	31,637
13	2028	1996	Warm & Wet	125,952	1986	Cooler & Wet	169,408
14	2029	1997	Warm & Wet	142,694	1991	Cooler & Dry	30,262
15	2030	1998	Warm & Wet	204,303	1997	Warm & Wet	142,694
16	2031	1999	Cooler & Wet	86,876	2014	Warm & Dry	13,828
17	2032	2000	Cooler & Wet	112,232	1992	Warm & Dry	48,421
18	2033	2001	Cooler & Dry	48,868	2014	Warm & Dry	13,828
19	2034	2002	Cooler & Wet	67,763	1984	Warm & Dry	80,363
20	2035	2003	Warm & Wet	77,102	2015	Warm & Dry	31,637
21	2036	2004	Warm & Dry	84,283	2013	Warm & Dry	53,284
22	2037	2005	Cooler & Wet	119,599	2013	Warm & Dry	53,284
23	2038	2006	Cooler & Wet	198,295	1992	Warm & Dry	48,421
24	2039	2007	Cooler & Dry	28,524	1934	Warm & Dry	Estimated >29,000
25	2040	2008	Cooler & Dry	53,212	1983	Warm & Wet	283,216
26	2041	2009	Warm & Dry	45,465	1992	Warm & Dry	48,421
27	2042	2010	Cooler & Wet	94,840	2015	Warm & Dry	31,637
28	2043	2011	Cooler & Wet	123,002	2014	Warm & Dry	13,828
29	2044	2012	Cooler & Dry	46,751	1980	Cooler & Wet	135,825
30	2045	2013	Warm & Dry	53,284	2003	Warm & Wet	77,102
31	2046	2014	Warm & Dry	13,828	2006	Cooler & Wet	198,295
32	2047	2015	Warm & Dry	31,637	2015	Warm & Dry	31,637
33	2048				2013	Warm & Dry	53,284
34	2049				1958	Warm & Wet	205,389
35	2050				2016	Warm & Wet	76,443
36	2051				2009	Warm & Dry	45,465
37	2052				2015	Warm & Dry	31,637
38	2053				1999	Cooler & Wet	86,876
39	2054				2015	Warm & Dry	31,637
40	2055				2015	Warm & Dry	31,637
41	2056				1992	Warm & Dry	48,421
42	2057				2016	Warm & Wet	76,443
43	2058				2014	Warm & Dry	13,828
44	2059				1977	Cooler & Dry	9,556
45	2060				2015	Warm & Dry	31,637
46	2061				1992	Warm & Dry	48,421
47	2062				2014	Warm & Dry	13,828
48	2063				1998	Warm & Wet	204,303
49	2064				2013	Warm & Dry	53,284
50	2065				1992	Warm & Dry	48,421
51	2066				1992	Warm & Dry	48,421
52	2067				1989	Cooler & Dry	24,398
53	2068				2016	Warm & Wet	76,443
54	2069				1984	Warm & Dry	80,363

3. Critically Dry Years

Critically dry years are years are years when San Lorenzo River annual streamflow is less than 29,000 acre-feet. During the peak pumping season of April to September for these years, we assume City of Santa Cruz increases pumping and SqCWD adjusts pumping . For the No-Project Simulations, .SqCWD reduces pumping to meet a Stage II reduction of 15% and redistributes pumping from April to September. For the Project and Alternate Project Simulations, SqCWD only redistributes pumping during April to September of critically dry years. During the period with pilot transfer of surface water from City of Santa Cruz for in-lieu recharge, we assume surface water is only available during non-critically dry years.

4. No-Project Simulations

Pumping distributions for the No-Project Simulations are based on HydroMetrics WRI's *2017 Update to Pumping Distribution Plans for Current and Future Pumping Goals* provided to SqCWD March 1, 2017. Table 2 shows pumping distributions for the No-Project Simulations.

Total SqCWD demand is based on projected demand in the *2015 Urban Water Management Plan for the SqCWD* (Water Systems Consulting, 2016). With the exception of simulating years with the pilot transfer of surface water from City of Santa Cruz for in-lieu recharge, groundwater meets 100% of the projected demand.

Pumping distributions match annual demand to annual production totals as presented in the *2017 Update to Pumping Distribution Plans.* The non-critically dry year distributions incorporate assumptions about available infrastructure, wells with consistent pumping over time, and wells where pumping is reduced in response to lower demand.

4.1. Infrastructure Assumptions

The No-Project Simulations' pumping distribution incorporates the following assumptions about well use:

- The planned Cunnison Lane well (ESA, 2010) comes online in 2026.
- The planned Austrian Way well included in the *Well Master Plan* (ESA, 2010) is not constructed.
- The Aptos Creek well, currently offline due to geotechnical stability concerns for the well's pipeline, is not brought back online.

- The Sells and Altivo wells, currently offline due to water quality concerns, are not brought back online.

4.2. Wells with Consistent Pumping Over Time

Wells with consistent pumping over time in the No-Project Simulations include the following:

- Non-critically dry year pumping in the Western Purisima (Garnet, O'Neill Ranch, Main Street, Rosedale) is consistent over time assuming no pilot transfer of surface water from City of Santa Cruz. The consistent pumping rates are based on the cooperative agreement with City of Santa Cruz and because the Purisima A Unit is the most reliable aquifer unit in the Purisima Formation. The Garnet and O'Neill Ranch wells are on time clock and have consistent monthly pumping.
- Tannery II pumping is consistent over time until Cunnison Lane comes online in 2026, after which pumping at both wells is consistent and equal over time.
- Madeline and Ledyard pumping is consistently low over time as the Purisima BC unit has had the deepest groundwater depressions due to pumping. The Madeline well is on time clock and has consistent monthly pumping.
- Aptos Jr High and Polo Grounds pumping is consistent over time as this permanently shifts pumping away from the coast. The two wells are on time clock and have consistent monthly pumping.
- Country Club pumping is consistent over time in an area where there has not been seawater intrusion in the Aromas area. The well is on time clock and has consistent monthly pumping

4.3. Wells with Pumping Decreases Over Time

Wells where pumping decreases over time as demand declines in the No-Project Simulations include the following:

- Estates well in Purisima A and BC units;
- T. Hopkins and Granite Way wells in Purisima DEF unit;
- Bonita, San Andreas, and Seascape wells in Purisima F unit and Aromas Red Sands with Chromium VI treatment.

4.4. Pumping in Critically Dry Years (No Project)

The *2017 Update to Pumping Distribution Plans* assumed reduction of SqCWD's demand during drought years follow SqCWD initiating drought curtailment. For simplicity, we assume for No-Project Simulations that drought curtailment is only applied during critically dry years based on San Lorenzo River streamflow (Table 1). The No-Project Simulations incorporate the assumption that drought curtailment achieves 15% reduction in SqCWD from April-September during critically dry years after critically dry conditions are confirmed in the spring of that water year. The pumping decreases are applied at the Estates, T. Hopkins, Granite Way, Bonita, San Andreas, and Seascape wells.

As also included in the *2017 Update to Pumping Distribution Plans*, Garnet well pumping is reduced by 100 acre-feet per year, or 50%, during critically dry years. This pumping reduction is made in conjunction with pumping increases planned by the City of Santa Cruz for critically dry years when the City's surface water supplies are limited, as specified by the cooperative groundwater management agreement between the City and SqCWD. Although the reduction at the Garnet well is not required by the cooperative agreement, the Well Master Plan EIR (ESA, 2010) assumed a reduction of pumping at the Garnet well during critically dry years. The 50% pumping reduction is achieved by turning off the Garnet well from April to September in critically dry years.

Consistent with the *2017 Update to Pumping Distribution Plans*, SqCWD pumping is redistributed inland away from the City of Santa Cruz Beltz wells by increasing pumping at the Main Street and Rosedale wells by 30 acre-feet and 70 acre-feet, respectively, in critically dry years of the No-Project Simulations. These pumping increases occur during April to September in conjunction to reductions at the Garnet well.

4.5. Implementation of Pilot Transfer of City of Santa Cruz Surface Water

Pilot transfer of City of Santa Cruz surface water will be applied to model alternatives for Water Year 2019 and/or 2020 only in non-critically dry years, as it is assumed surface water will not be available in critically dry years. One of the two climate scenarios uses historical climate from 1985-2015 projected onto the future time period of each the simulation. Water Years 1986 and 1987 were critically dry years and climate from those years are used for Water Years 2019 and 2020 in the historical climate scenario. Therefore, the simulations of the historical climate scenario will not include the pilot transfer in any years. In the simulations of the future climate change based on the climate catalog, 2019 is not classified as a critically dry year while 2020 is classified as a critically dry year, so the pilot transfer will be simulated for that year only in the climate change scenario run of the No-Project Simulation.

The pilot transfer of 215 acre-feet per year will only be delivered to SqCWD service area I west of Soquel Creek from November-April of non-critically dry years. Therefore, the in-lieu recharge will take place by reducing pumping at the Garnet and O'Neill Ranch wells, the only two SqCWD wells west of Soquel Creek, from November-April, when pumping at the two wells during these six months is reduced by 86%. As a result, pumping at the Garnet well is reduced from 200 to 114 acre-feet per year and from 300 to 171 acre-feet per year at the O'Neill Ranch well to accomplish the 215 acre-feet pumping reduction during simulated year 2019 for simulations of the future climate change scenario. Production is not adjusted at any other well as a result of this transfer.

4.6. City of Santa Cruz Pumping

As specified in the cooperative groundwater management agreement between the City of Santa Cruz and SqCWD, the City plans to pump 520 acre-feet per year during the non-critically dry years and 645 acre-feet per year during critically dry years so this plan is implemented in the No-Project Simulations. The increase of 125 acre-feet per year of during critically dry years meets City demand when the City's surface water supply decreases with lower San Lorenzo River streamflow. The additional 125 acre-feet per year of pumping is supported by April-September pumping at the City's Beltz #12 well, which started operation in 2015. The total demand of 520 acre-feet per year in non-critically dry years is supported by four Beltz wells: Beltz #8,9,10 and 12. For non-critically dry years, pumping is distributed among these wells using the average pumping distribution from non-critically dry years 2015-2016 after Beltz #12 came online. For critically dry years, Beltz#12 pumping is set at 125 acre-feet per year based on the Beltz #12 EIR (Chambers, 2011). The remaining 520 acre-feet pumped in critically dry years is split between Beltz #8, 9 and 10 using the average pumping distribution in Water Years 2011-2014 prior to the Beltz #12 well coming online.

4.7. Central Water District Pumping

CWD is assumed to have a constant total demand of 550 acre-feet per year for all years in the No-Project Simulations approximately based on CWD's historical average pumping for Water Years 2005-2014. CWD pumping is supplied by three Rob Roy Wells: Rob Roy #4, #10 and #12 with Rob Roy #12 being the primary production well. The Cox wells are all assumed to be inactive through the future simulated period. Average historic monthly pumping distributions for the CWD wells in Water Years 2005-2014 is used as the basis for future CWD pumping. Since Cox #3 and Cox #5 were active during periods of years

2005-2014, any future pumping from those wells is transferred to Rob Roy #12 used for the simulations. The result of this approach is that 75% of the total CWD demand is supplied by Rob Roy 12 in the simulations. Rob Roy 10 and Rob Roy 4 supply 17% and 9% of the total demand, respectively, in the simulations.

4.8. Non-Municipal Pumping

Non-municipal pumping is estimated using the same approach as was used for the calibration run (HydroMetrics WRI, 2017b). The water use factor for water use by residences not served by municipal supply is assumed to be 0.35 acre-feet per year, except for the Pajaro Valley Subbasin where 0.59 acre-feet per year is used, based on the water use factors for 2013 used in the calibration run. We use these water use factors because this represents water use habits before the most recent droughts, when significant reductions in water use occurred due to high awareness of drought conditions. The number of residences are projected to increase based on an estimated of population growth of 4.2% per year for 2017-2035 (AMBAG, 2014) and a 50% reduction in growth rate to 2.1% per year for years after 2035, based on the average Santa Cruz County forecasted population change after 2035 (CA Dept. of Finance, 2017). Monthly pumping distributions change annually based on the climate simulated for that year and its associated effect on irrigation demand.

Using the same methodology as the calibration run (HydroMetrics WRI, 2017b), institutional irrigation and agricultural pumping is based on simulated climate and evapotranspiration demand (potential evapotranspiration minus actual evapotranspiration) simulated by the PRMS watershed model simulating historical climate and future climate change scenarios.

4.9. Return Flow

Return flow from municipal water use is based on projected future pumping for SqCWD and CWD, and the estimated water use within the model area for the Cities of Santa Cruz and Watsonville.

Water use within the model for Santa Cruz is estimated as a proportion of each use type that is estimated to fall within the model. Future water use for non-critically dry years is based on projected water demand from the 2015 UWMP (Table 4-3 of the UWMP; City of Santa Cruz Water Department, 2016) adjusted for proportion of use falling within the model. For critically dry years, a reduction of approximately 15%,representing Stage II of the Water Shortage Contingency Plan (Table ES-3 of the plan; City of Santa Cruz Water Department, 2009) is applied to the non-critically dry year water use projections. For

Water Years 2017 through 2019, an increase of 25% of 2016's water use is assumed to account for an increase in usage due to the drought being over.

For the areas of the City of Watsonville within the model, water use is estimated from a projected building count multiplied by a constant water use factor of 0.59. Population projections from Watsonville's 2015 Urban Water Management Plan (Table 3-1 of the UWMP; City of Watsonville Public Works and Utilities, 2016) are used to determine an 0.91% annual increase in projected population from Water Year 2017 through 2035. For years after Water Year 2035, an annual population increase of 0.51% is assumed. Similar to the estimation of water use for the calibration period, the ratio of each year's population to 2014 population is used to adjust the building counts within in the model area.

As with the calibration run (HydroMetrics WRI, 2017b), we calculate return flow for each service area based on system loss percentage of 4%-7.5% depending on the system, assumed outdoor use of 30%, irrigation efficiency of 90%, estimated septic use for the service area, assuming 90% of indoor use becomes wastewater, and sewer loss percentage of 7%. As with the calibration run (HydroMetrics WRI, 2017b), return flow is added to the MODFLOW UZF package as flow to the shallowest layer with groundwater.

Return flow for institutional irrigation and agricultural pumping is based on estimated water use and an irrigation efficiency of 90%.

5. PURE WATER SOQUEL SIMULATIONS

The Project Simulations simulating Pure Water Soquel managed active recharge involve increased SqCWD pumping relative to the No-Project Simulations at existing or planned production wells near the Pure Water Soquel managed recharge sites. This increased pumping supports decreased pumping at wells farther away from the recharge wells, therefore increasing potential for recovery of recharged groundwater and reduced seawater intrusion risk in a large portion of the Santa Cruz Mid-County Basin, while keeping overall production similar to the No-Project Simulations.

The pumping distribution is based on potential managed recharge of up to 500 acre-feet per year at the Monterey site and up to 1,000 acre-feet per year at the Cabrillo College site. As SqCWD's projected demand drops below 3,800 acre-feet per year after 2029, total managed recharge is reduced such that net extraction remains at 2,300 acre-feet per year. Managed recharge at the Monterey site will replenish the Purisima A unit, while managed recharge at the Cabrillo College site will replenish the Purisima A and BC units.

SqCWD wells near managed recharge sites where pumping is increased are the Rosedale, Cunnison Lane (planned to come online in 2026), Tannery II, and Estates wells. The Rosedale, Cunnison Lane, and Tannery II wells will extract primarily from the Purisima A unit, while the Estates well will extract from both the Purisima A and BC units.

The *2017 Update to Pumping Distribution Plans* limits pumping wells to 50% runtime operation over the year as a conservative measure for well maintenance. As discussed in Appendix G of the *Groundwater Replenishment Feasibility Study* (Carollo, 2016), increasing runtime operation to 60% may be necessary to maximize benefit of managed recharge throughout the Basin. However, the distributions projected in these scenarios continue to limit pumping at the Rosedale, Cunnison Lane, and Tannery II wells to 50% runtime operation. Since all three of these wells extract primarily from the Purisima A unit, higher runtime operation for any one of these three wells is less likely to be needed. Runtime operation up to 60% at the Estates well is allowed in these simulations as this is the only nearby well that extracts from both the Purisima BC unit and the A unit, the recharge units for the Cabrillo College well.

Pumping distributions for the Project Scenario are also adjusted to reflect both decreases in overall demand as well as the Cunnison Lane well coming online in 2026. Total groundwater pumping will meet the total demand projected in the *Urban Water Management Plan* with no planned reduction in critically dry years. However, there will be some pumping re-distribution during critically dry years. The following describes the distributions for the Project Scenario with Pure Water Soquel managed recharge in operation during different projected periods of time. Table 3 show the managed recharge and pumping distributions for the Project Simulations.

5.1. Pumping Consistent with No-Project Simulations

For the Pure Water Soquel Project Simulations, pumping distributions in pre-project (2017-2022) and post-project (2043-end) periods are identical to the No-Project Simulations for each of the climate scenarios. Western Purisima pumping (Garnet, O'Neill Ranch, and Main Street wells) with the exception of the Rosedale well is consistent with the No-Project Simulations and the cooperative agreement with the City of Santa Cruz. Nearby coastal groundwater levels at monitoring well SC-1A have also been above protective elevations for preventing seawater intrusion during recent years (HydroMetrics WRI, 2017c), so additional recovery should not be needed in this area. Increasing pumping at the Rosedale well may require revision of the cooperative agreement with the City of Santa Cruz as that agreement sets pumping goals for the Western Purisima area at amounts that equal the area total in the No-Project Simulations and the agreement does not account for possibility of managed recharge. Critically dry years during pre-project and post-project periods are also consistent with corresponding years of the No-Project Simulations.

The pumping distribution for the Project Simulation in 2019 under the future climate change scenario is consistent with the future climate change No-Project Simulation. We assume that 215 acre-feet per year of surface water is transferred from the City of Santa Cruz to SqCWD to the west of Soquel Creek during November-April of 2019 under the future climate change scenario. As a result of this surface water transfer, pumping is reduced by a total of 215 acre-feet during these months at the Garnet and Main Street wells.

Pumping for the Project Simulations in the western end of Service Area III, at the Aptos Jr. High, Polo Grounds and Country Club wells, is also consistent with the No-Project Simulations. Aptos Jr High and Polo Grounds operation has recently been added to shift pumping away from the coast. Country Club pumping is in an area within Service Area III where there has not been seawater intrusion and nearby coastal groundwater levels at monitoring well SC-A1 have been above protective elevations for preventing seawater intrusion (Hydrometrics WRI, 2017c). As a result, additional recovery should also not be needed in this area.

The Project Simulations distribute pumping by City of Santa Cruz, CWD, and non-municipal water users in the same way as the No-Project Simulations.

5.2. 2023-2025 Projected Demand before Cunnison Lane

With a total projected demand of 3,800-3,900 acre-feet per year, managed recharge at Cabrillo College and Monterey is assumed to be 1,000 acre-feet per year and 500 acre-feet per year, respectively during 2023-2025. Prior to the Cunnison Lane well coming online, Rosedale and Tannery II wells pump at 50% runtime operation and the Estates well pumps at 60% runtime operation to support managed recharge at the Monterey and Cabrillo College sites.

The pumping increase near managed recharge sites supports decreased pumping throughout Service Areas II and III. Pumping is reduced at T. Hopkins, Granite Way, Bonita, and San Andreas wells. Pumping is limited to approximately 1 hour per day at the Ledyard and Madeline wells in the BC unit where pumping depressions have been observed to be the deepest depressions in the Basin. Pumping is limited to approximately 1 hour per week at the Seascape well, the closest well to the coast. In 2025, when total projected demand steps down from 3,900 to 3,800 acre-feet per year, pumping at the T. Hopkins and Granite Way wells are reduced 100 acre-feet per year from 2024.

5.3. 2026-2029 Projected Demand with Cunnison Lane

With a total projected demand of 3,800 acre-feet per year, managed recharge at Cabrillo College and Monterey continues at 1,000 acre-feet per year and 500 acre-feet per year, respectively from 2026-2029. With the Cunnison Lane well online, the Rosedale and Tannery II, and Cunnison Lane wells pump below 50% daily operation. The Estates well continues to pump at 60% daily operation to support managed recharge in the BC unit. Pumping at wells throughout the rest of Service Areas II and Service Area III continue at the same reduced rates as in the 2023-2025 period.

5.4. 2030-2042 Projected Demand with Cunnison Lane

With total projected demand reduced to 3,400-3,500 acre-feet per year, managed recharge is reduced to 1,100-1,200 acre-feet during 2030-2042. Managed recharge at Cabrillo College and Monterey is reduced to 800 and 400 acre-feet per year, respectively after 2029. An additional reduction of managed recharge at Cabrillo College to 700 acre-feet per year is implemented in 2035. Further reductions at Monterey are not implemented due to greater excess pumping capacity near the Monterey recharge site.

With the reduced managed recharge, the Estates well is reduced to pump at the preferred 50% runtime operation, while the other three wells near managed recharge, Rosedale, Tannery II, and Cunnison Lane, pump at below 50% runtime operation. Pumping at wells throughout the rest of Service Area II and Service Area III continue at the same reduced rates as in the 2023-2025 period.

5.5. Pumping in Critically Dry Years During Project

During the project period (WY 2023-2042), managed recharge at recharge wells and pumping at wells near managed recharge sites do not change during critically dry years compared to non-critically dry years. However, Garnet well pumping is still reduced during this time period by 100 acre-feet per year, or 50%, during critically dry years as with the No-Project Simulations as part of implementation of the cooperative groundwater management agreement between the City and SqCWD. Unlike the No-Project Simulations, 70 acre-feet per year is not redistributed to the Rosedale well because during the project period Rosedale pumping is already increased to or near its daily runtime goal of 50% to support managed recharge at the Monterey site. Instead, pumping is increased by 35 acre-feet per year each at the T. Hopkins and Granite Way wells during critically dry years in the project period. As with the No-Project Simulations, pumping at the Main Street well is increased 30 acre-feet per year during critically dry years.

5.6. Return Flow During Project

The Project Simulations include return flow from City of Santa Cruz, CWD, and non-municipal water users with the same assumption as in the No-Project Simulations. Return flow from SqCWD during the project period is based on SqCWD pumping distribution for the No-Project Simulations during non-critically dry years. Although pumping is increased near managed recharge wells in the Project Simulations to facilitate reductions of pumping elsewhere, the areal distribution of water use is assumed to be the same as the No-Project Simulations. There is no reduction in pumping during critically dry years in the project period so non-critically dry year pumping from the No-Project Simulations should be used for all years in the project period.

5.7. Alternative Managed Recharge Distribution

Separate Pure Water Soquel project simulations, referred to as the Alternative Project Simulations, will be developed where managed recharge occurs at both the Willowbrook and Cabrillo College sites. Managed recharge scheduled for the Monterey site for the Project Simulations described above will occur at the Willowbrook site instead, replenishing the A aquifer unit to the east of the Monterey site and closer to the Cabrillo College site. Managed recharge capacity at the Willowbrook site is estimated to be similar to the Monterey site.

All pumping and return flow for the Alternative Project Simulations is assumed to be the same as the Project Simulations with managed recharge at Monterey and Cabrillo College. The four wells with pumping increases in pumping to support managed recharge are the four wells closest to managed recharge even with the shift from Monterey to Willowbrook. Table 3 also represents the managed recharge and pumping distributions for the Alternative Project Simulations.

6. Next Steps

We appreciate feedback on these annual and monthly distributions. We will develop distributions for the cumulative alternative based on scenarios from the City of Santa Cruz's consultant Pueblo Water Resources Inc. for the City's ASR project.

7. References

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Table 2. SqCWD Pumping Distributions for No-Project Simulations

Well Name[1]	Service Area	Subarea	Instantaneous Pumping Rate (gpm)	Potential Production[2] 50% Operation (ac-ft/yr)		2016	2017-2024			2025 (pre-Cunnison)	2026-2029 (Cunnison on)		2030-2034		2035-2042		2043-2044		2045-end	
						Historic Climate	Non-Critically Dry Year	Critically Dry Year	Transfer from City (Climate Catalog 2019)	Non-Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year
						Recorded Pumping	Pre-Project/No-Project			No Project	No Project		No Project		No Project		Post Project		Post Project	
					Total Recharge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					Monterey	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					Willowbrook	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					Cabrillo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					Total Pumping	3,026	3,900	3,549	3,685	3,800	3,800	3,458	3,500	3,185	3,400	3,096	3,400	3,096	3,300	3,012
					Purisima	2,025	2,624	2,460	2,409	2,578	2,578	2,418	2,440	2,292	2,394	2,253	2,394	2,253	2,348	2,214
					Aromas	1,001	1,276	1,089	1,276	1,222	1,222	1,040	1,060	893	1,006	843	1,006	843	952	799
Garnet	I	Western Purisima CGMA	580	468	Garnet	219	200	100	114	200	200	100	200	100	200	100	200	100	200	100
O'Neill Ranch	I		580	468	O'Neill Ranch	273	300	300	171	300	300	300	300	300	300	300	300	300	300	300
Main Street	I		850	686	Main Street	519	650	680	650	650	650	680	650	680	650	680	650	680	650	680
Rosedale	I		800	645	Rosedale	102	510	580	510	510	510	580	510	580	510	580	510	580	510	580
Cunnison Lane	I	Eastern Service Area I	600	484	Cunnison Lane	0	0	0	0	0	170	170	170	170	170	170	170	170	170	170
Tannery II	I		800	645	Tannery II	558	290	290	290	290	170	170	170	170	170	170	170	170	170	170
Estates	II		530	427	Estates	164	258	181	258	236	236	161	169	100	147	80	147	80	124	61
Madeline	II	BC Unit	175	141	Madeline	0	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Ledyard	II		178	144	Ledyard	98	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Austrian Way	II		250	202	Austrian Way	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aptos Creek	II	Aptos Creek	400	323	Aptos Creek	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T. Hopkins	II		225	181	T. Hopkins	76	169	125	169	157	126	83	90	51	79	41	79	41	67	31
Granite Way	II		210	169	Granite Way	0	157	114	157	145	126	84	90	52	79	42	79	42	67	31
Aptos Jr. High	III	Valencia Creek	425	343	Aptos Jr. High	2	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Polo Grounds	III		260	210	Polo Grounds	177	210	210	210	210	210	210	210	210	210	210	210	210	210	210
Country Club	III		410	331	Country Club	185	190	190	190	190	190	190	190	190	190	190	190	190	190	190
Bonita	III	1000 gpm Cr VI plant	950	766	Bonita	205	267	187	267	244	244	166	175	103	152	82	152	82	129	63
San Andreas	III		992	800	San Andreas	432	313	220	313	286	286	195	205	121	178	97	178	97	151	74
Seascape	III		772	623	Seascape	0	46	32	46	42	42	29	30	18	26	14	26	14	22	11
Sells	IV	Service Area IV	529	427	Sells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Altivo	IV		614	495	Altivo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beltz #8		City of Santa Cruz			Beltz #8	98	73	179	73	73	73	179	73	179	73	179	73	179	73	179
Beltz #9					Beltz #9	203	189	213	189	189	189	213	189	213	189	213	189	213	189	213
Beltz #10					Beltz #10	91	149	128	149	149	149	128	149	128	149	128	149	128	149	128
Beltz #12					Beltz #12	59	110	125	110	110	110	125	110	125	110	125	110	125	110	125
CWD-4		Central Water District (Rob Roy only)			CWD-4	13	48	48	48	48	48	48	48	48	0	0	48	48	48	48
CWD-10					CWD-10	27	92	92	92	92	92	92	92	92	92	92	92	92	92	92
CWD-12					CWD-12	344	410	410	410	410	410	410	410	410	410	410	410	410	410	410
			TOTAL (ac-ft/yr)			3,026	3,900	3,549	3,685	3,800	3,800	3,458	3,500	3,185	3,400	3,096	3,400	3,096	3,300	3,012
			Subtotal Service Area I			1,671	1,950	1,950	1,735	1,950	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
			Subtotal Service Area II			354	674	510	674	628	578	418	440	292	394	253	394	253	348	214
			Subtotal Service Area III			1,001	1,276	1,089	1,276	1,222	1,222	1,040	1,060	893	1,006	843	1,006	843	952	799
			Subtotal Service Area IV			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Total Purisima Area			2,025	2,624	2,460	2,409	2,578	2,578	2,418	2,440	2,292	2,394	2,253	2,394	2,253	2,348	2,214
			Total Aromas Area			1,001	1,276	1,089	1,276	1,222	1,222	1,040	1,060	893	1,006	843	1,006	843	952	799
			Western Purisima Subarea		(1,660)	1,113	1,660	1,660	1,445	1,660	1,660	1,660	1,660	1,660	1,660	1,660	1,660	1660	1,660	1660
			Eastern Service Area I Subarea			558	290	290	290	290	340	340	340	340	340	340	340	340	340	340
			BC Subarea		(260)	98	90	90	90	90	90	90	90	90	90	90	90	90	90	90
			Aptos Creek Subarea		(470)	92	326	239	326	302	252	167	181	102	157	83	157	83	133	62
			Valencia Creek Subarea		(460)	179	460	460	460	460	460	460	460	460	460	460	460	460	460	460
			Chromium VI Treatment Plai		(1,600)	637	580	407	580	530	530	361	380	225	330	179	330	179	280	138
			City of Santa Cruz			450	520	645	520	520	520	645	520	645	520	645	520	645	520	645
			Central Water District			383	550	550	550	550	550	550	550	550	502	502	550	550	550	550

Notes:
[1] Wells proposed for installation shaded blue
Wells with increased pumping to support recharge shaded in yellow
[2] Annual production is rounded to nearest integer value for clarity

Table 3. SqCWD Managed Recharge and Pumping Distributions for Project and Alternative Project Simulations

Well Name[1]	Service Area	Subarea	Instantaneous Pumping Rate (gpm)	Potential Production[2] 50% Operation (ac-ft/yr)	Wells Supporting Recharge Allow Increased Production[2] 60% Operation (ac-ft/yr)		2016	2017-2022			2023-2024	2025 (pre-Cunnison)	2026-2029 (Cunnison on)		2030-2034		2035-2042		2043-2044		2045-end	
							Historic Climate	Non-Critically Dry Year	Critically Dry Year	Transfer from City (Climate Catalog 2019)	Non-Critically Dry Year	Non-Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year	Non-Critically Dry Year	Critically Dry Year
							Recorded Pumping	Pre-Project			Project	Project	Project		Project		Project		Post-Project		Post-Project	
						Total Recharge	0	0	0	0	1,500	1,500	1,500	1,500	0	1,200	0	1,100	0	0	0	0
						Monterey or Willowbrook	0	0	0	0	500	500	500	500	0	400	0	400	0	0	0	0
						Cabrillo	0	0	0	0	1,000	1,000	1,000	1,000	0	800	0	700	0	0	0	0
						Total Pumping	3,026	3,900	3,549	3,685	3,900	3,800	3,800	3,800	3,500	3,500	3,400	3,400	3,400	3,096	3,300	3,012
						Purisima	2,025	2,624	2,460	2,409	3,140	3,040	3,040	3,040	2,740	2,740	2,640	2,640	2,394	2,253	2,348	2,214
						Aromas	1,001	1,276	1,089	1,276	760	760	760	760	760	760	760	760	1,006	843	952	799
Garnet	I	Western Purisima CGMA	580	468		Garnet	219	200	100	114	200	200	200	100	200	100	200	100	200	100	200	100
O'Neill Ranch	I		580	468		O'Neill Ranch	273	300	300	171	300	300	300	300	300	300	300	300	300	300	300	300
Main Street	I		850	686		Main Street	519	650	680	650	650	650	650	680	650	680	650	680	650	680	650	680
Rosedale	I		800	645	774	Rosedale	102	510	580	510	640	640	510	510	510	510	510	510	510	580	510	580
Cunnison Lane	I	Eastern Service Area I	600	484	581	Cunnison Lane	0	0	0	0	0	0	385	385	280	280	230	230	170	170	170	170
Tannery II	I		800	645	774	Tannery II	558	290	290	290	640	640	385	385	280	280	230	230	170	170	170	170
Estates	II		530	427	513	Estates	164	258	181	258	510	510	510	510	420	420	420	420	147	80	124	61
Madeline	II	BC Unit	175	141		Madeline	0	40	40	40	10	10	10	10	10	10	10	10	40	40	40	40
Ledyard	II		178	144		Ledyard	98	50	50	50	10	10	10	10	10	10	10	10	50	50	50	50
Austrian Way	II		250	202		Austrian Way	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aptos Creek	II	Aptos Creek	400	323		Aptos Creek	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T. Hopkins	II		225	181		T. Hopkins	76	169	125	169	90	40	40	75	40	75	40	75	79	41	67	31
Granite Way	II		210	169		Granite Way	0	157	114	157	90	40	40	75	40	75	40	75	79	42	67	31
Aptos Jr. High	III	Valencia Creek	425	343		Aptos Jr. High	2	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Polo Grounds	III		260	210		Polo Grounds	177	210	210	210	210	210	210	210	210	210	210	210	210	210	210	210
Country Club	III		410	331		Country Club	185	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190
Bonita	III	1000 gpm Cr VI plant	950	766		Bonita	205	267	187	267	50	50	50	50	50	50	50	50	152	82	129	63
San Andreas	III		992	800		San Andreas	432	313	220	313	50	50	50	50	50	50	50	50	178	97	151	74
Seascape	III		772	623		Seascape	0	46	32	46	10	10	10	10	10	10	10	10	26	14	22	11
Beltz #8		City of SC				Beltz #8	98	73	179	73	73	73	73	179	73	179	73	179	73	179	73	179
Beltz #9						Beltz #9	203	189	213	189	189	189	189	213	189	213	189	213	189	213	189	213
Beltz #10						Beltz #10	91	149	128	149	149	149	149	128	149	128	149	128	149	128	149	128
Beltz #12						Beltz #12	59	110	125	110	110	110	110	125	110	125	110	125	110	125	110	125
CWD-4		CWD				CWD-4	13	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
CWD-10						CWD-10	27	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92
CWD-12						CWD-12	344	410	410	410	410	410	410	410	410	410	410	410	410	410	410	410
Sells	IV	Service Area IV	529	427		Sells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Altivo	IV		614	495		Altivo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			TOTAL (ac-ft/yr)				3,026	3,900	3,549	3,685	3,900	3,800	3,800	3,800	3,500	3,500	3,400	3,400	3,400	3,096	3,300	3,012
			Subtotal Service Area I				1,671	1,950	1,950	1,735	2,430	2,430	2,430	2,360	2,220	2,150	2,120	2,050	2,000	2,000	2,000	2,000
			Subtotal Service Area II				354	674	510	674	710	610	610	680	520	590	520	590	394	253	348	214
			Subtotal Service Area III				1,001	1,276	1,089	1,276	760	760	760	760	760	760	760	760	1,006	843	952	799
			Subtotal Service Area IV				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Total Purisima Area				2,025	2,624	2,460	2,409	3,140	3,040	3,040	3,040	2,740	2,740	2,640	2,640	2,394	2,253	2,348	2,214
			Total Aromas Area				1,001	1,276	1,089	1,276	760	760	760	760	760	760	760	760	1,006	843	952	799
			Western Purisima Subarea			(1,660)	1,113	1,660	1,660	1,445	1,790	1,790	1,660	1,590	1,660	1,590	1,660	1,590	1,660	1660	1,660	1660
			Eastern Service Area I Subarea				558	290	290	290	640	640	770	770	560	560	460	460	340	340	340	340
			BC Subarea			(260)	98	90	90	90	20	20	20	20	20	20	20	20	90	90	90	90
			Aptos Creek Subarea			(470)	92	326	239	326	180	80	80	150	80	150	80	150	157	83	133	62
			Valencia Creek Subarea			(460)	179	460	460	460	460	460	460	460	460	460	460	460	460	460	460	460
			City of SC				450	520	645	520	520	520	520	645	520	645	520	645	520	645	520	645
			CWD				383	550	550	550	550	550	550	550	550	550	550	550	550	550	550	550
			Chromium VI Treatment Plant			(1,600)	637	580	407	580	100	100	100	100	100	100	100	100	330	179	280	138

Notes:
[1] Wells proposed for installation shaded blue
Wells with increased pumping to support recharge shaded in yellow
[2] Annual production is rounded to nearest integer value for clarity

Attachment 2: Santa Cruz Mid-County Basin Groundwater Flow Model: Future Climate for Model Simulations (Task 5) (HydroMetrics WRI, 2016)

1814 Franklin St, Suite 501
Oakland, CA 94612

TECHNICAL MEMORANDUM

To: Mid-County Groundwater Agency Executive Staff

From: Georgina King and Cameron Tana

Date: August 17, 2017

Subject: Santa Cruz Mid-County Basin Groundwater Flow Model: Future Climate for Model Simulations (Task 5)

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Appendix A: Santa Cruz Coop Station Exceedance Probabilities with Year Type Classification

Appendix B: Proposed Climate Scenarios

1.0 INTRODUCTION

This technical memorandum documents our approach for developing an initial future climate scenario to be implemented with simulations using the GSFLOW model of the Santa Cruz Mid-County Groundwater Basin currently under development, and presents two proposed climate scenarios. Climate data used in GSFLOW includes minimum and maximum temperature, and precipitation at the Santa Cruz Co-op and Watsonville Waterworks stations.

The objective of this subtask is to develop a reasonable climate scenario that adequately represents the warmer temperatures that are being predicted due to global climate change. At the August 24, 2016 TAC meeting, Prof. Andrew Fisher suggested using a catalog of historical annual climate instead of one of the multitude of General Circulation Models (GCM) available for future climate scenarios. The premise of this approach is that we use actual historical climate data representing the warmest years on record and not modeled climate data such as GCM. This approach is appropriate because to retain integrity of the climate data, the future climate scenario must have temperature data that corresponds to precipitation data, which is ensured by using historical data. A similar approach using historical data instead of using future climate predictions is used by Metropolitan Water District of Southern California to evaluate its region's future water supply reliability (MWD, 2016).

As discussed in our revised scope of work for fiscal year 2016-2017 approved by the MGA Board, downscaling one or more GCM scenarios to develop additional climate change scenarios has been re-prioritized for implementation in 2017. This is still recommended because the GCMs predict temperatures warmer than even the warmest years on record.

2.0 CLIMATE DATASETS

2.1 SANTA CRUZ CO-OP STATION

The Santa Cruz Co-op station has climate data available from January 1893 through present. Figure 1 shows the average annual temperature ranges and overall average for Water Years 1894 through 2016. It is visually evident that minimum temperatures have been higher since 1977. Maximum temperatures do not show the same trend, perhaps because of the moderating influence of the ocean. Expectedly, average annual temperatures also show an increase but of a lower magnitude than the minimum temperature increase due to more stable maximum temperatures. Water Years 2013 through 2016 have four of the five hottest average annual temperatures in the record. Table 1 illustrates that post-1977, average annual temperatures at the Santa Cruz Co-op station are 1.3° F warmer than before 1977. The 1985-2015 average for the model calibration period is also shown.

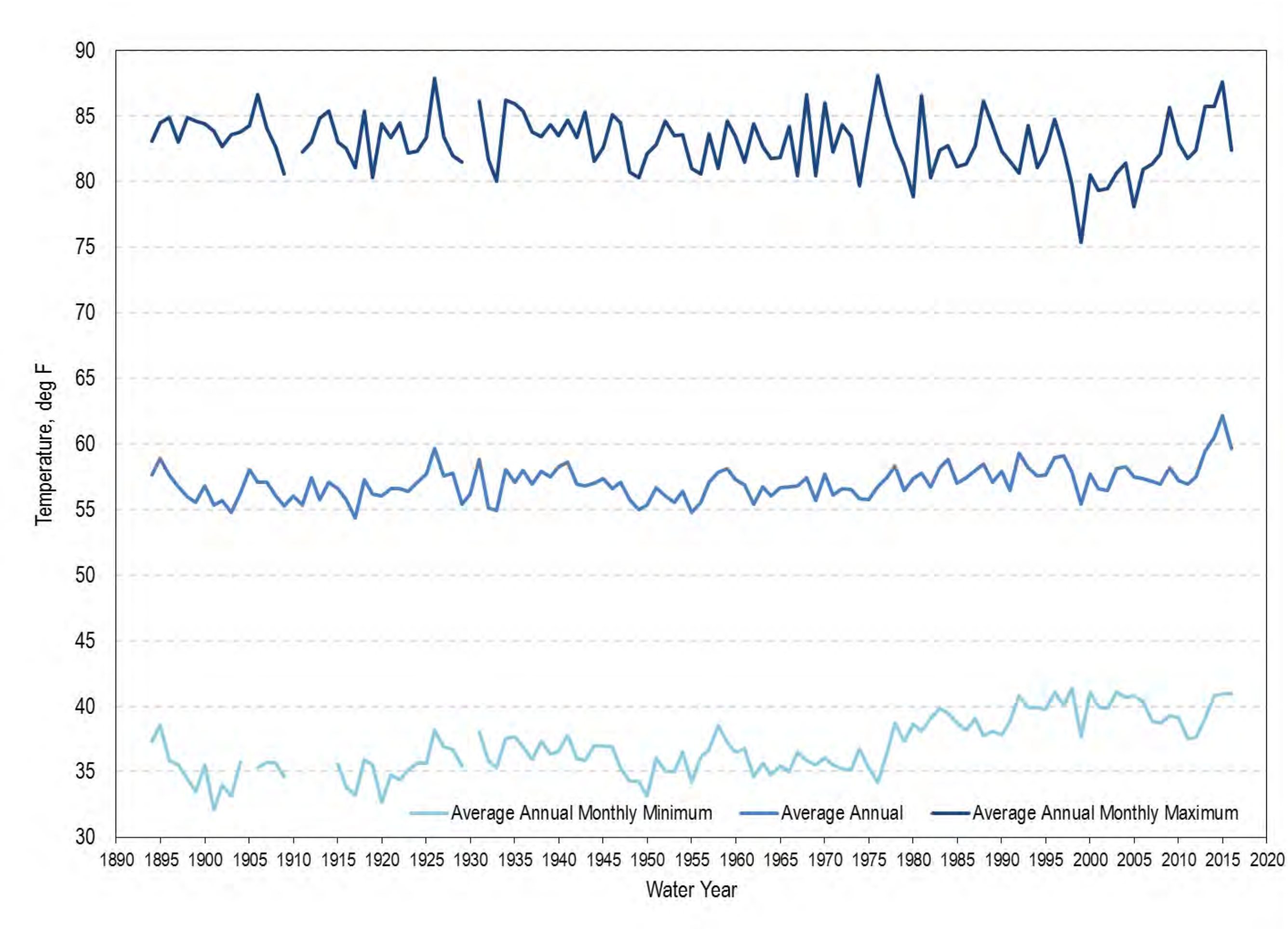


Figure 1: Measured Minimum, Maximum, and Average Annual Temperatures at the Santa Cruz Co-op Station

Table 1: Santa Cruz Co-op Station Average Annual Temperatures for Selected Periods

Annual Temperature, °F	
1985-2015 Average	57.9
1977-2016 Average	57.9
Pre-1977 Average	56.6
1894-2016 Average	57.0

Figure 2 presents the annual precipitation recorded at the Santa Cruz Co-op station. The average annual precipitation for various periods of interest are provided in Table 2. Although the chart on Figure 2 does not show any discernible trends, the averages in Table 2 indicate that pre-1977 precipitation was very slightly lower than that experienced from 1977 onwards. In general however, the data do not show a trend that is visually evident like temperature.

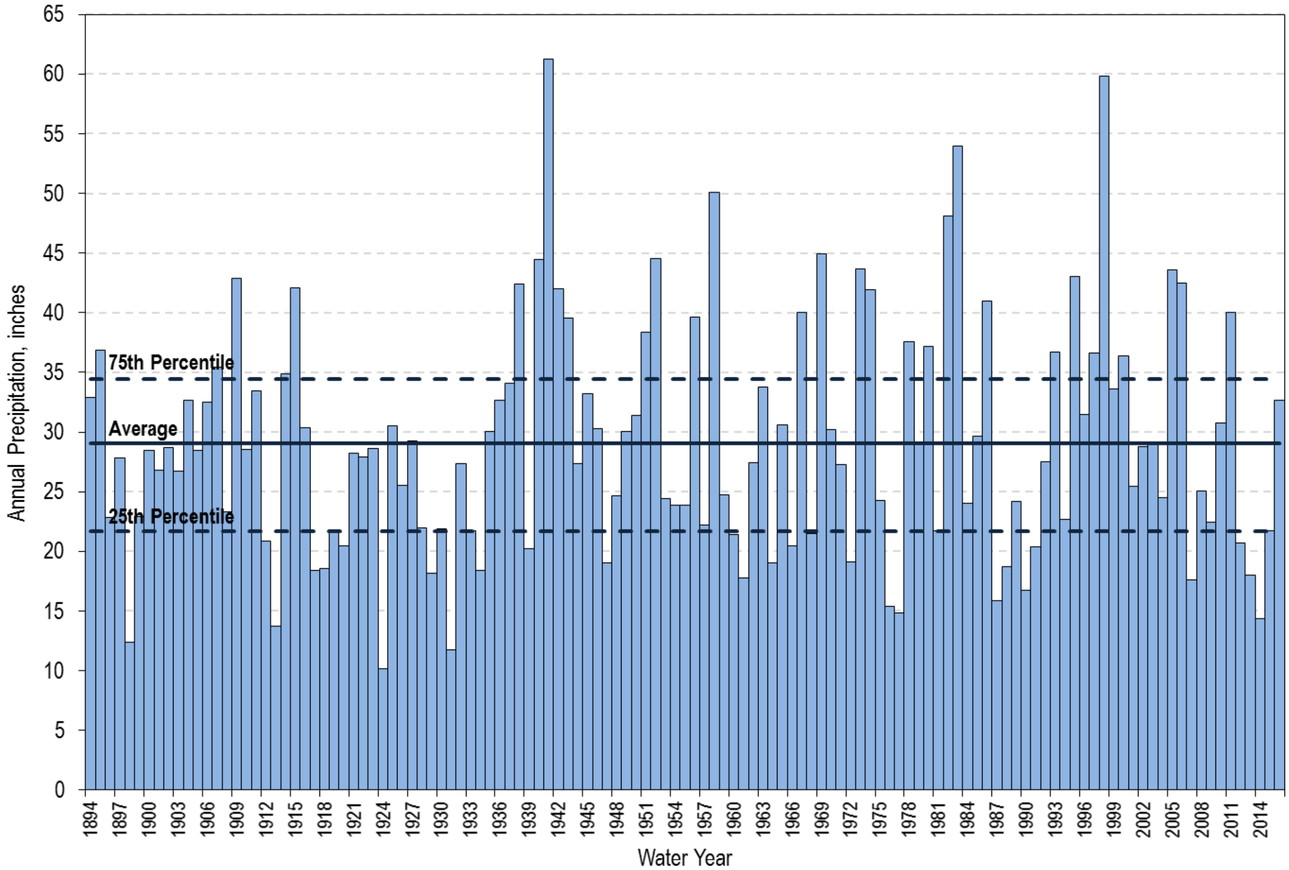


Figure 2: Annual Precipitation at the Santa Cruz Co-op Station

Table 2: Santa Cruz Co-op Station Average Precipitation for Selected Periods

Annual Precipitation, inches	
1985-2015 Average	29.0
1977-2016 Average	30.0
Pre-1977 Average	28.7
1894-2016 Average	29.1

2.2 WATSONVILLE WATERWORKS STATION

The Watsonville Waterworks station has climate data available from January 1908 through present. Figure 3 shows average annual temperature ranges and overall average for Water Years 1909 through 2016; note there were a number of missing records in the monthly data used to generate the annual averages; therefore those years are not included on the chart. The line showing minimum temperatures has a clear increasing trend over the period of record, with a slight jump in temperatures from 1977 onwards where minimum temperatures mostly remain consistently above pre-1977 temperatures. At this station, maximum temperatures also show an increasing trend like minimum temperatures but they are more muted. The Watsonville Waterworks station is 4.5 miles from the ocean compared to the Santa Cruz Co-op station which is two miles from the ocean, and has less effects from the ocean. Average annual temperatures also show a noticeable increase after 1977. Table 4 illustrates that post-1977, average annual temperatures at the Watsonville Waterworks station are 1.7 °F warmer than before 1977.

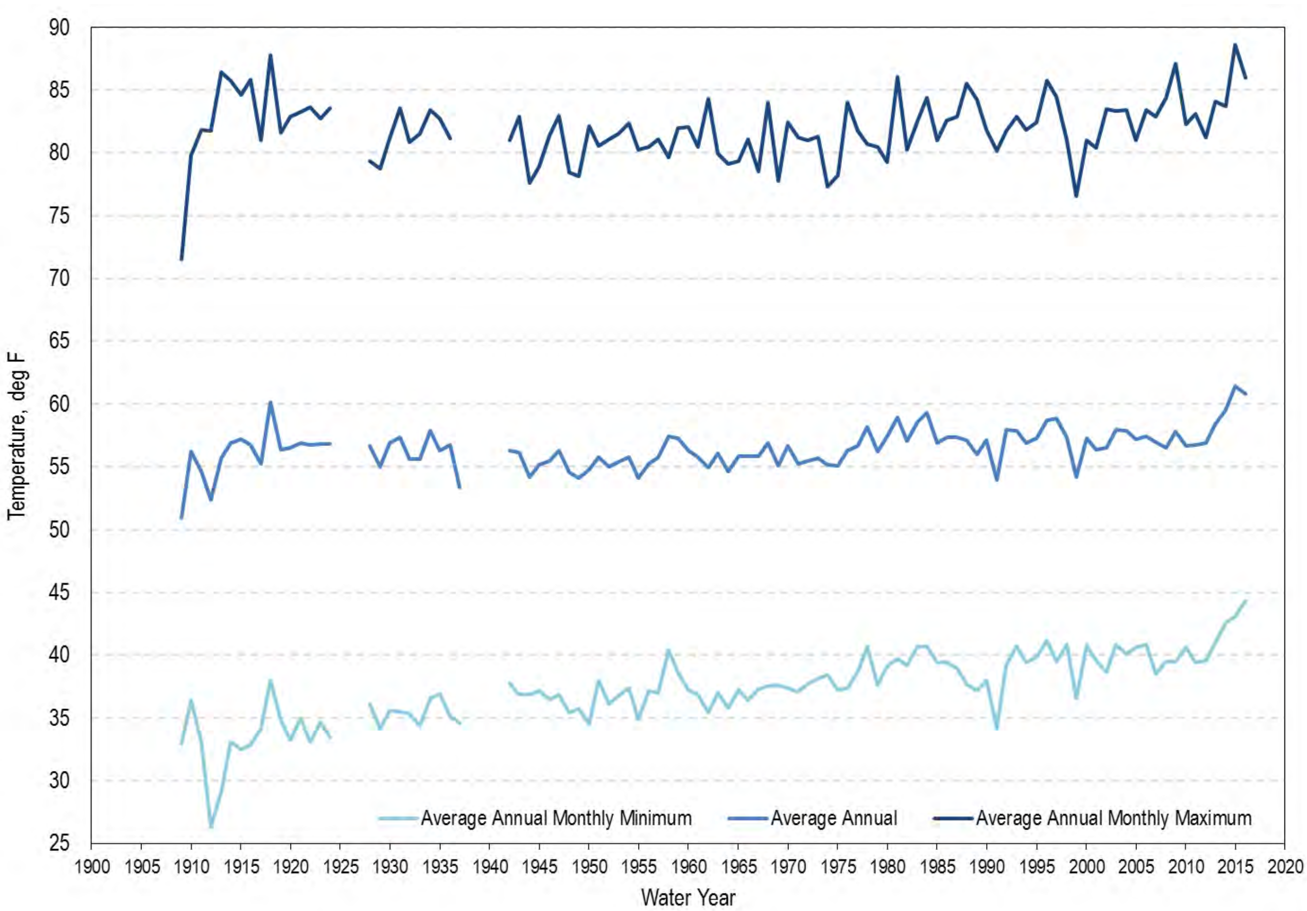


Figure 3: Measured Minimum, Maximum, and Average Annual Temperatures at the Watsonville Waterworks Station

Table 3: Watsonville Waterworks Station Average Annual Temperatures for Selected Periods

Annual Temperature, °F	
1985-2015 Average	57.3
1977-2016 Average	57.5
Pre-1977 Average	55.8
1894-2016 Average	56.5

Figure 4 presents the annual precipitation recorded at the Watsonville Waterworks station. The average annual precipitation for various periods of interest are provided in Table 4. The data suggest that since the 1980s, there has been an increase in the amount of precipitation at this station. This is confirmed in Table 4 where post-1977 precipitation is 2.8 inches more than before 1977.

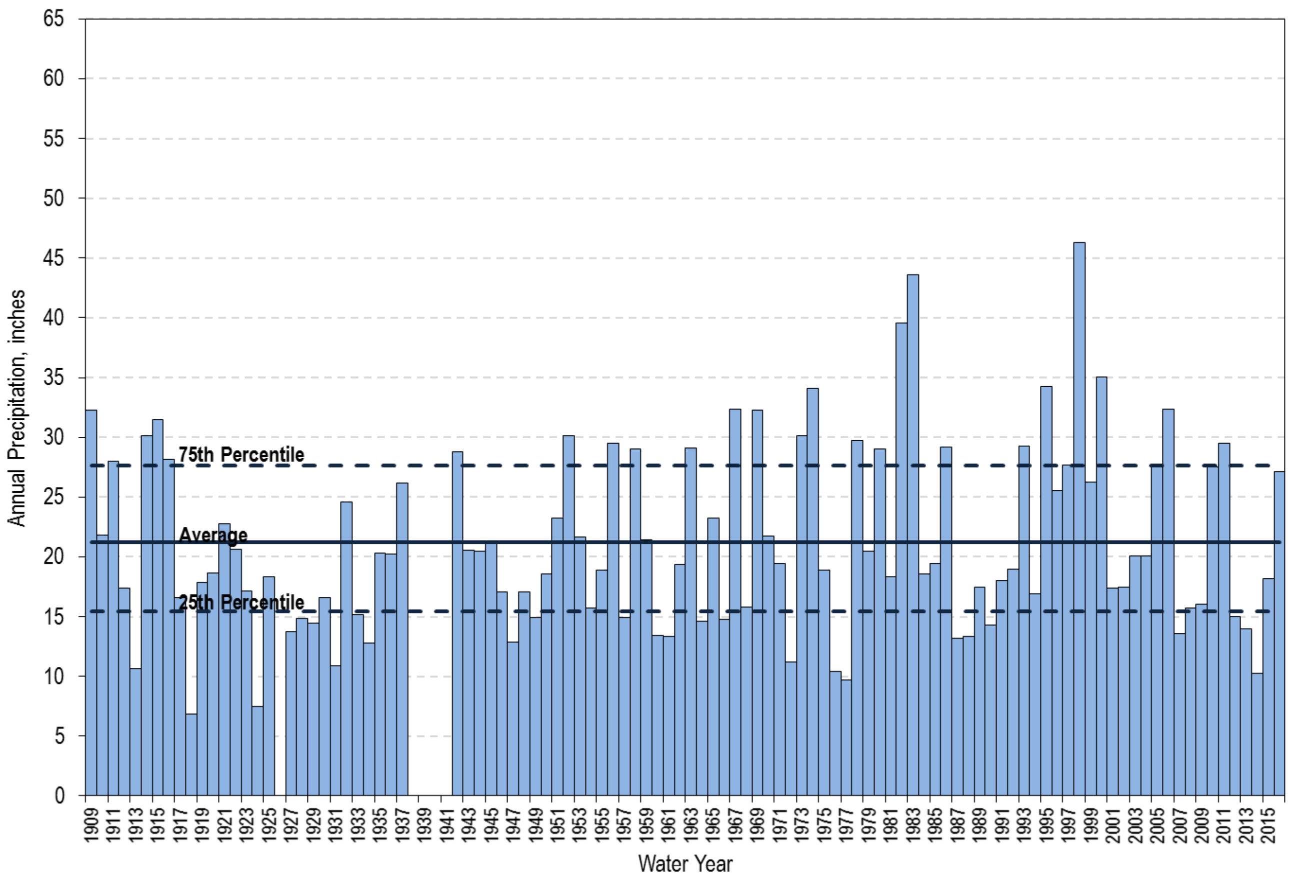


Figure 4: Annual Precipitation at the Watsonville Waterworks Station

Table 4: Watsonville Waterworks Station Average Precipitation for Selected Periods

Annual Precipitation, inches	
1985-2015 Average	21.9
1977-2015 Average	22.9
Pre-1977 Average	20.1
1909-2015 Average	21.2

3.0 APPROACH

3.1 CLIMATE CATALOG

Using the general method for creating a catalog of each historical year suggested by Prof. Andrew Fisher (Young, 2016), exceedance probabilities (p) for both temperature and precipitation are calculated using the following equation for the full dataset on record for the climate station:

$$p = \frac{m}{n+1}$$

where m is the rank based on total precipitation or temperature (from largest to smallest), and n is the total number of years in the dataset. A chart of exceedance probabilities for temperature and precipitation at the Santa Cruz Co-op station is provided on Figure 5. The catalog is based on the Santa Cruz Co-op station because the majority of model cells are assigned to it for rainfall distribution in PRMS, the watershed component of the GSFLOW model.

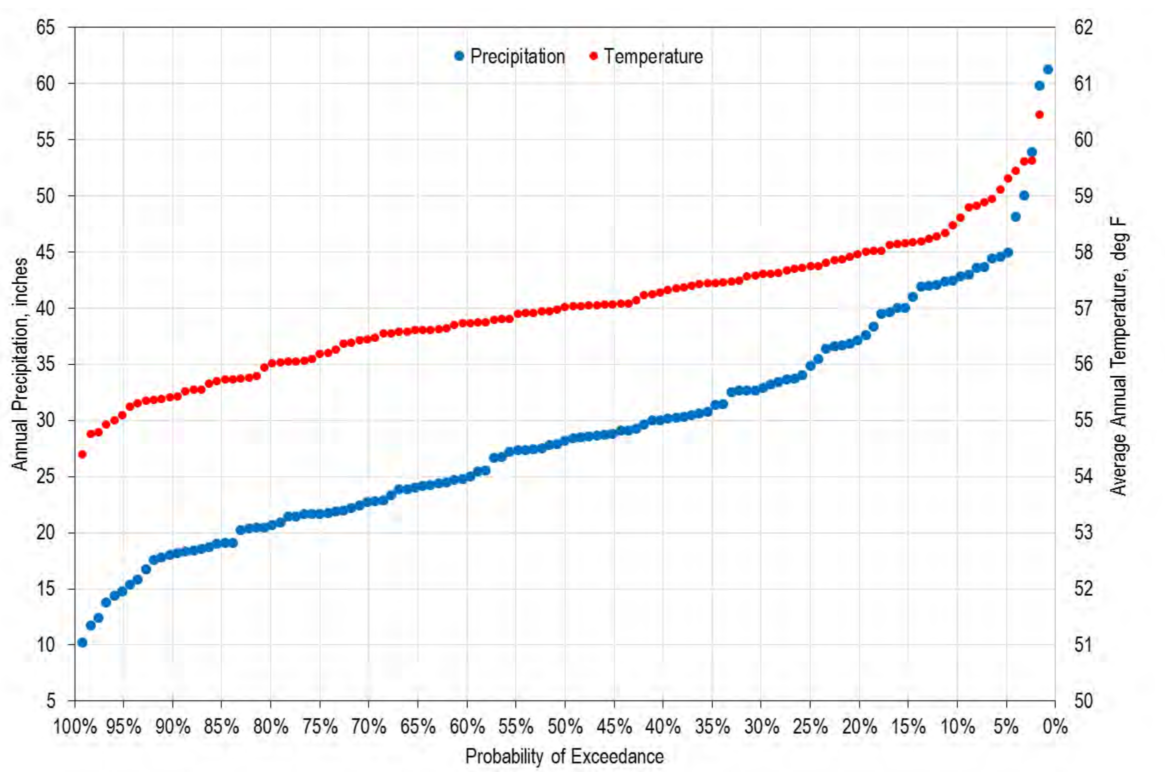


Figure 5: Probability of Exceedance for Annual Precipitation and Average Annual Temperature, Santa Cruz Co-op Station

Figure 6 and Figure 7 graphically show consecutive water years' probabilities of exceedance for temperature and precipitation at the Santa Cruz Co-op Station, respectively. Figure 6, similar to Figure 1, shows that since 1977, there has been an increased number of years that have less than a 50% probability of exceedance, i.e., warmer than the rest of the record. Figure 7 shows no visual trend towards either decreasing or increasing precipitation over time like temperature does.

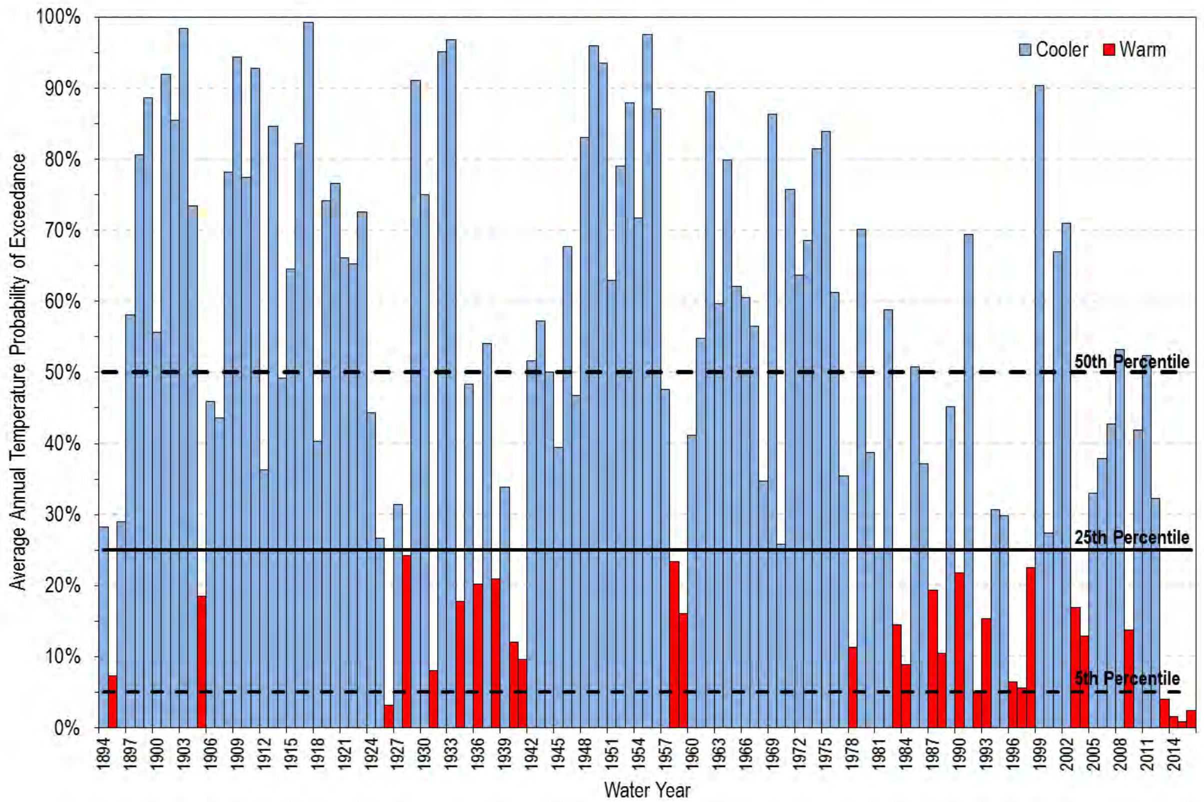


Figure 6: Average Annual Temperature Probability of Exceedance for the Santa Cruz Co-op Station

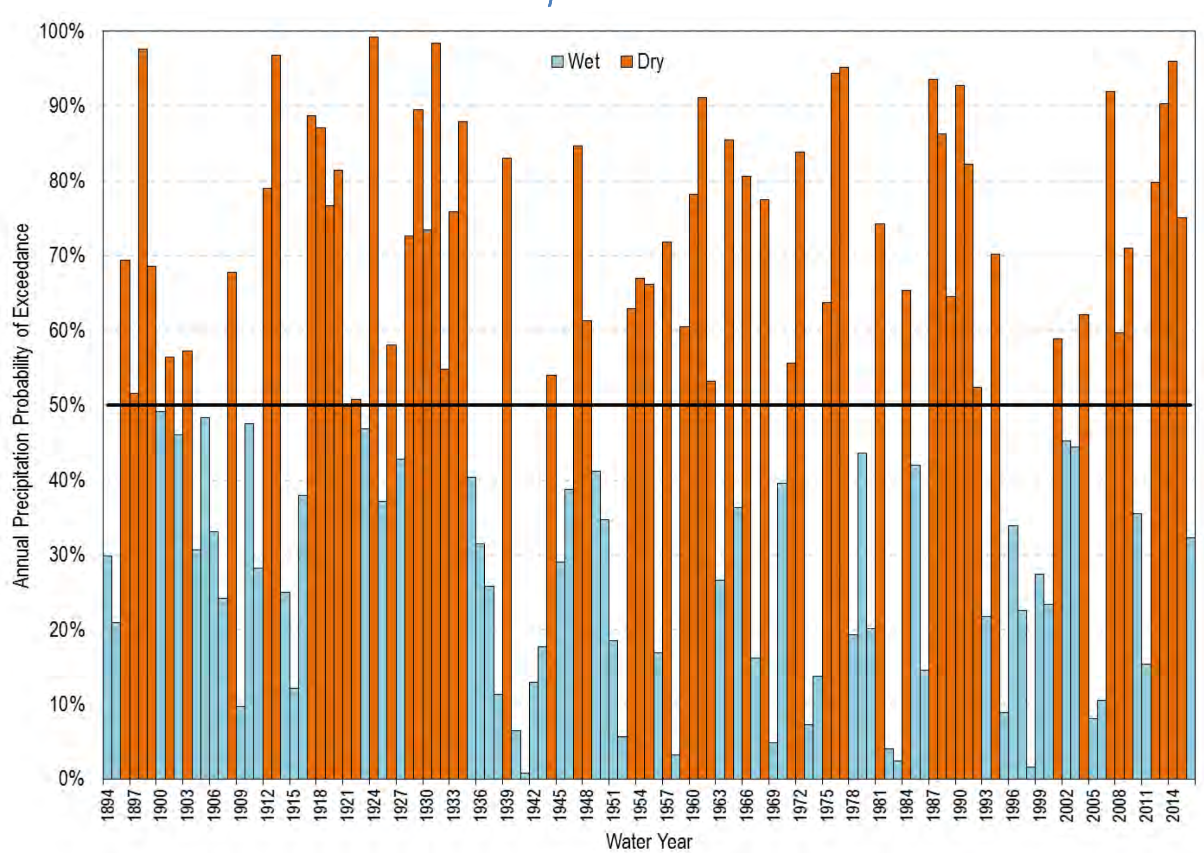


Figure 7: Annual Precipitation Probability of Exceedance for the Santa Cruz Co-op Station

Another way to visualize the climate data based on probabilities of exceedance is to classify each water year according to a combination of temperature and precipitation probabilities shown in Table 5. Appendix A provides the probabilities for all water years on record for the Santa Cruz Co-op Station, and Figure 8 presents the historical data color-coded by classification plotted against precipitation.

Table 5: Classification of Probabilities

Probability of Exceedance		Category
Precipitation	Average Temperature	
>= 50%	< 25%	Warm and Dry
< 50%	< 25%	Warm and Wet
< 50%	>= 25%	Cooler and Wet
>= 50%	>= 25%	Cooler and Dry

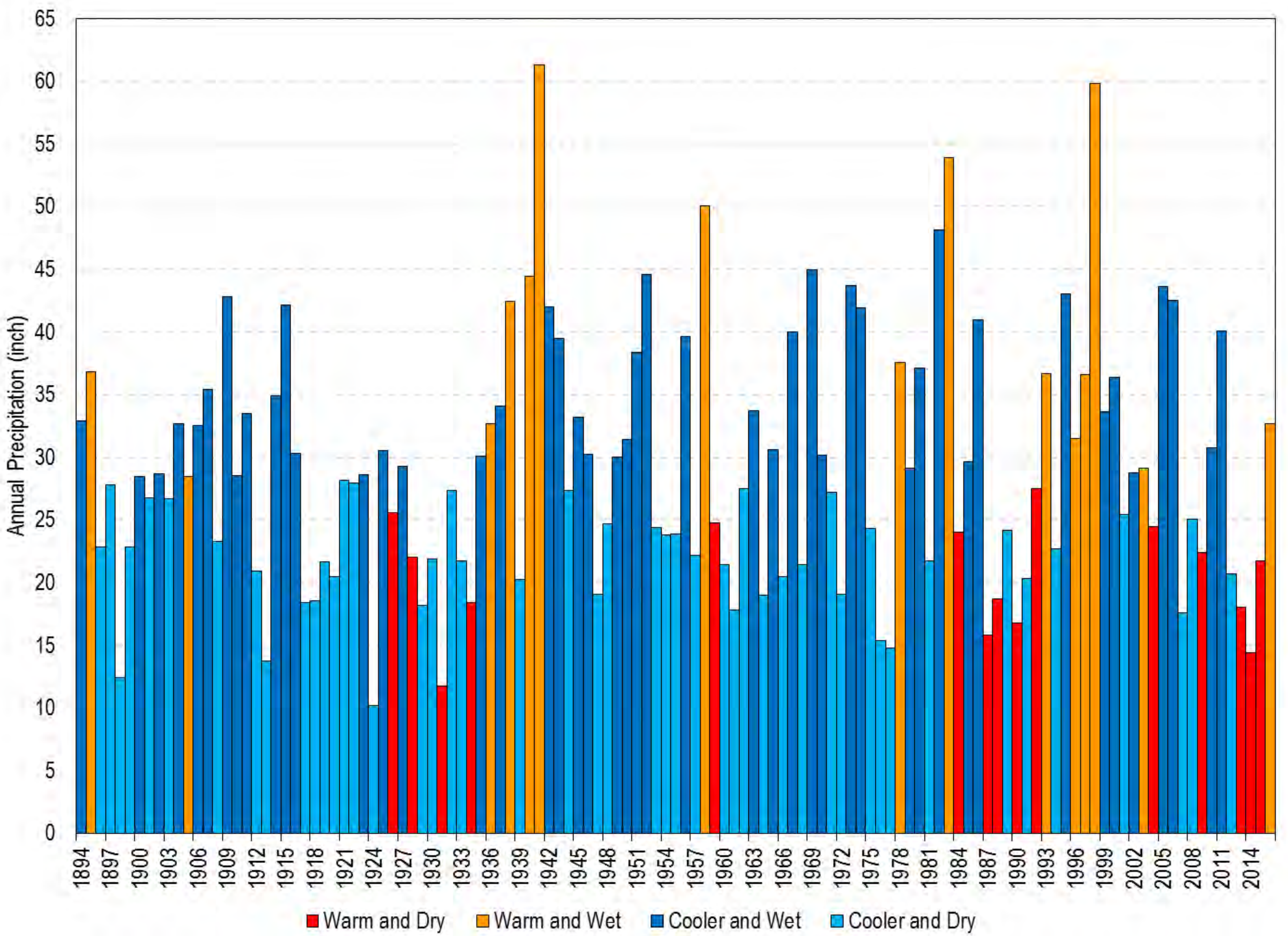


Figure 8: Santa Cruz Co-op Station Classification of Historical Water Years

3.2 Future Climate Scenario Generation

The future climate scenario will cover Water Years 2016-2069. This time span is selected to meet the requirement in California Department of Water Resources regulations for Groundwater Sustainability Plans (GSP) to evaluate sustainability for future climate over fifty years. Fifty years after the 2020 GSP deadline for the critically overdrafted Santa Cruz Mid-County Groundwater Basin goes through Water Year 2069. Water Year 2016 will be simulated based on recorded climate data using initial conditions from the end of the calibrated model run of Water Years 1985-2015. The 53 water years 2017-2069 will be simulated using the approach described below.

As temperature shows a much more evident trend than precipitation, the catalog of annual average temperature at the Santa Cruz Co-op station is used to generate one future climate scenario. First, a subset of historic climate is selected to form a catalog from which to generate the future climate scenario. The catalog of years selected are all the years from 1977 to 2016 representing the most recent period where warming has been observed, plus six additional years from 1909[1] to 1977 that have a temperature probability of exceedance of 25% or less, i.e., the warmest years and that don't have entire months of missing temperature data in the Watsonville Waterworks station record. See bold records in Appendix A for those years included in the catalog.

The catalog is then randomly ordered using the Random Number Generator in Excel to generate the scenario. The Random Number Generator uses weights applied to each water year to ensure a pre-determined distribution of temperature exceedance probabilities results from the process. Weights are assigned by categories of exceedance probabilities for temperature shown in Table 6. For example, the warmest category (<5% exceedance probability) is given a 50% weight and includes Water Years 1992, and 2013-2016. Warmer years are given greater weights than cooler years to ensure an overall warmer scenario is generated.

[1] Water Year 1909 was selected because this is the first water year for the Watsonville Waterworks station climate records. If we used prior years, there would be no climate data for the Watsonville Waterworks station for the future climate scenario for those years.

Table 6: Weights Assigned to Catalog of Water Years Based on Temperature Exceedance Probabilities

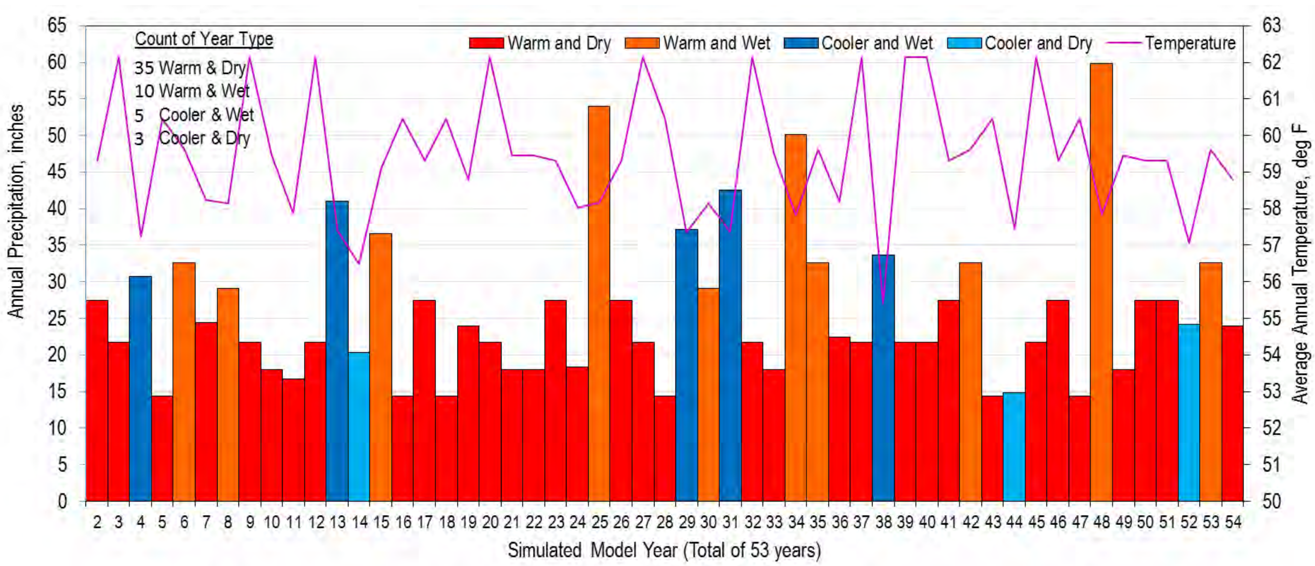
Exceedance Probability Category	Weight
< 5%	0.5
5 – 25%	0.3
>=25 – 50%	0.1
> = 50%	0.1

After the water year sequence is selected based on the Santa Cruz Co-op temperature data, climate data for the future climate scenario for the Watsonville Waterworks station is selected based on the same water year sequence. Climate data for both the Santa Cruz Co-op and Watsonville Waterworks stations are input into the GSFLOW model.

4.0 PROPOSED CLIMATE SCENARIOS

4.1 TEMPERATURE WEIGHTED

The first scenario is generated using the temperature weights shown in Table 6 and the Random Number Generator to arrive at a sequence of 53 water years with an average temperature that is as high as we could get without manually selecting the warmest years. Figure 9 shows the color-coded distribution of water years for the Santa Cruz Co-op station representing a potential future climate scenario that is on average 2.4 °F warmer than the long-term average and 1.6 °F warmer than the average annual temperature from 1977-2016. The scenario also has 3.1 inches less precipitation per year than the long-term historical average as 4 of the 5 hottest years used for 50% of the scenario are dry years. Appendix B provides a list of the randomly selected historic years generated for this scenario.

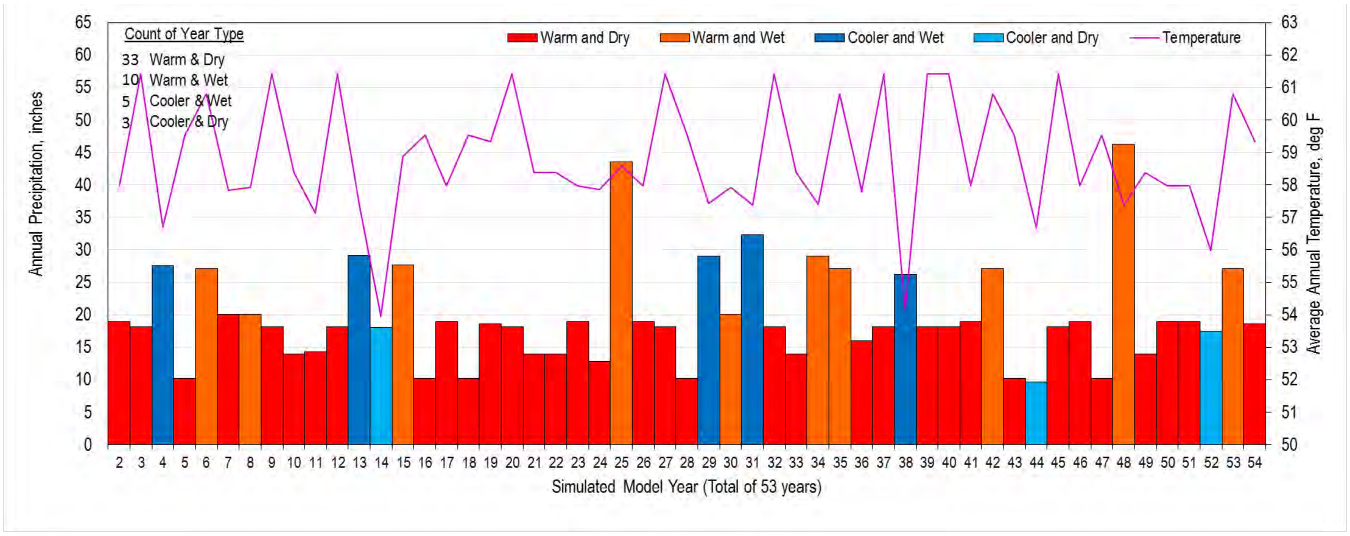


Annual Temperature, deg F	
Scenario Average	59.4
1985-2015 Average	57.9
1977-2016 Average	57.8
Pre-1977 Average	56.6
1894-2016 Average	57.0

Annual Precipitation, inches	
Scenario Average	26.0
1985-2015 Average	29.0
1977-2016 Average	29.9
Pre-1977 Average	28.7
1894-2016 Average	29.1

Figure 9: Temperature Weighted Climate Scenario for Santa Cruz Co-op Station

Using the same sequence of 53 water years used for the Santa Cruz Co-op station temperature weighted climate scenario. Figure 10 shows a potential future climate scenario for the Watsonville Waterworks station that is on average 2.4 °F warmer than the long-term average and 1.4°F warmer than the average annual temperature from 1977-2016. The scenario also has 1.3 inches less precipitation per year than the long-term historical average.



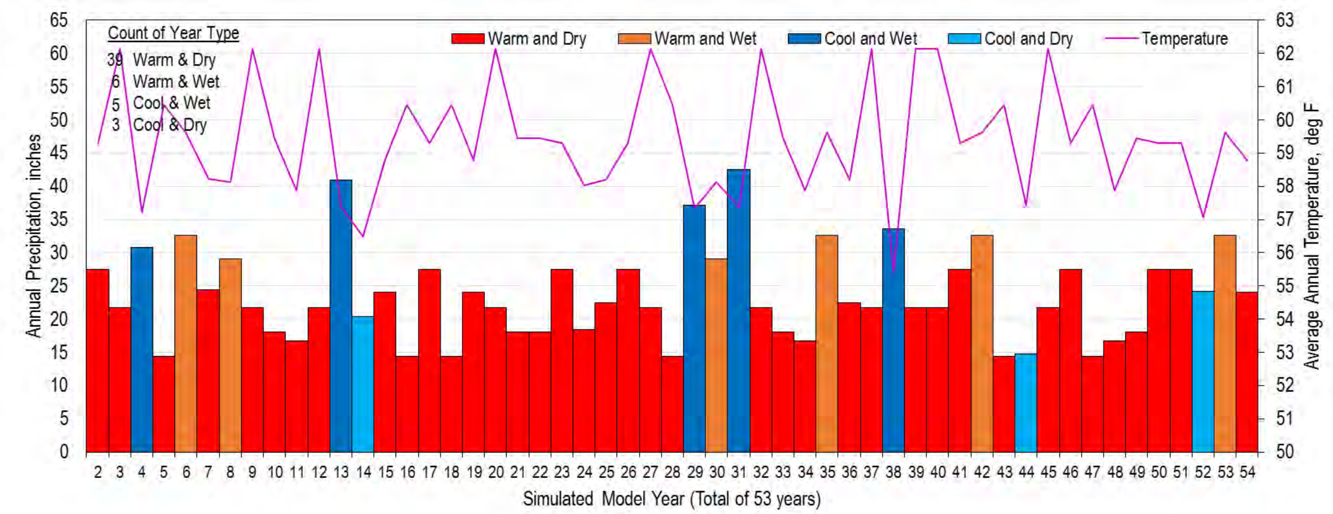
Annual Temperature, deg F	
Scenario Average	58.8
1985-2015 Average	57.3
1977-2016 Average	57.4
Pre-1977 Average	55.8
1894-2016 Average	56.4

Annual Precipitation, inches	
Scenario Average	19.8
1985-2015 Average	21.9
1977-2016 Average	22.8
Pre-1977 Average	20.1
1894-2016 Average	21.1

Figure 10: Temperature Weighted Climate Scenario for Watsonville Waterworks Station

4.2 TEMPERATURE WEIGHTED AND PRECIPITATION ADJUSTED

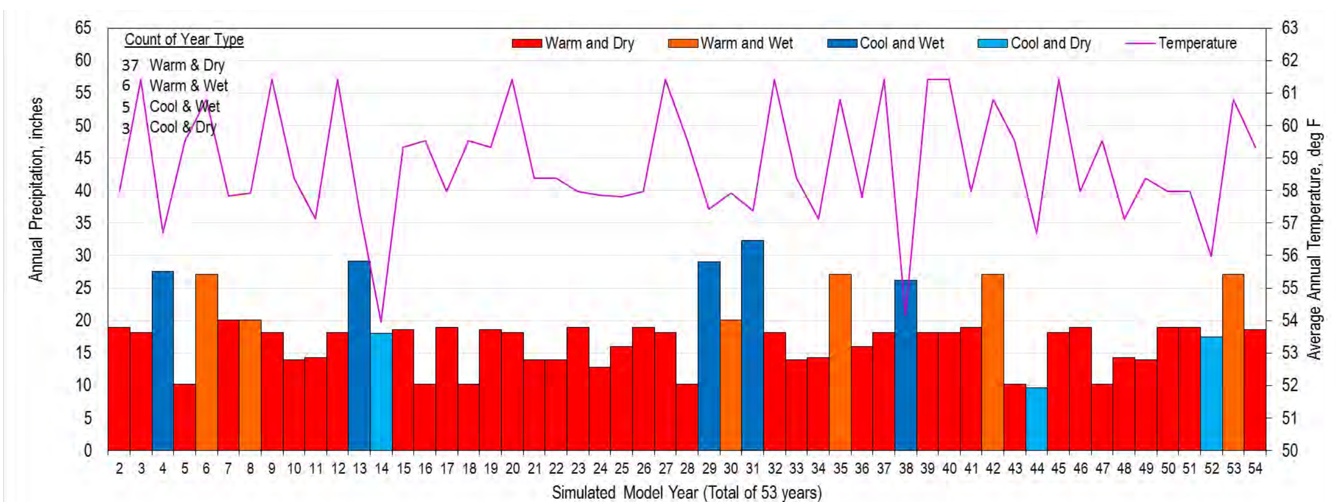
Although there is no trend of decreased precipitation in the Santa Cruz area, a drier scenario than that generated by weighting temperature only is also generated for consideration. We avoided randomly generating a new dataset based on both temperature and precipitation weights as we want a scenario that we can compare with the temperature weighted climate scenario. To arrive at this scenario, we start with the temperature weighted scenario and then adjust the four wettest "Warm and Wet" years to "Warm and Dry" by substituting the "Warm and Wet" years with "Warm and Dry" years with similar temperatures but less precipitation. Figure 11 shows the color-coded distribution of water years for the Santa Cruz Co-op station representing a potential future climate scenario that has the same average temperature as the temperature weighted scenario but has 5.4 inches less precipitation per year than the long-term average. Appendix B provides a list of the randomly selected historic years generated for this scenario. Figure 12 shows this potential future climate scenario applied to the Watsonville Waterworks station that results in the same average temperature as the temperature weighted scenario but has 2.9 inches less precipitation per year than the long-term average.



Annual Temperature, deg F	
Scenario Average	59.4
1985-2015 Average	57.9
1977-2016 Average	57.8
Pre-1977 Average	56.6
1894-2016 Average	57.0

Annual Precipitation, inches	
Scenario Average	23.7
1985-2015 Average	29.0
1977-2016 Average	29.9
Pre-1977 Average	28.7
1894-2016 Average	29.1

Figure 11: Temperature Weighted Climate Scenario for Santa Cruz Co-op Station with Decreased Precipitation Adjustment



Annual Temperature, deg F	
Scenario Average	58.8
1985-2015 Average	57.3
1977-2016 Average	57.4
Pre-1977 Average	55.8
1894-2016 Average	56.4

Annual Precipitation, inches	
Scenario Average	18.2
1985-2015 Average	21.9
1977-2016 Average	22.8
Pre-1977 Average	20.1
1894-2016 Average	21.1

Figure 12: Temperature Weighted Climate Scenario for Watsonville Waterworks with Decreased Precipitation Adjustment

5.0 DISCUSSION AND LIMITATIONS

One of the two scenarios presented in this memo will be selected to run simulations using the GSFLOW model. The selection will be made based on input from MGA member agency staff, the model Technical Advisory Committee, and possibly the MGA Board.

This approach of using historical climate allows us to generate climate scenarios that are warmer than the past 40 years but it does not increase temperatures to the degree that some of the GCMs predict global warming. For example, GCMs (Flint and Flint, 2014) have been downscaled to the San Lorenzo-Soquel Basin, which includes the Santa Cruz Mid-County Groundwater Basin. The downscaled predictions include warming of up to 4.1 °F (GFDL A2, a moderately warmer, drier future) and 6.2°F (MIROC-esm RCP 8.5, the warmest, driest future) over our simulated model period (54 years from Water Year 2016 – 2069). It is important to note that these GCM predicted temperatures are for minimum temperatures which, as shown above, tend to have a greater increase than average temperatures. We used average temperature in our analysis. Additionally, the GCM downscaled predictions are for the entire San Lorenzo-Soquel Basin which extends much farther inland than the Santa Cruz Co-op and Watsonville Waterworks stations.

Assigning lower weights to the “Cooler and dry” and “Cooler and wet” classifications will raise the scenario’s average temperature slightly but still not as high as those in the GCMs described above because the hottest years in the historical record are not as hot as what is projected by the GCMs.

Simulating GCM projections will require downscaling GCM results to the Santa Cruz Co-op and Watsonville Waterworks stations for distribution to the model grid by the PRMS watershed component of GSFLOW. The USGS has recommended that the Jensen-Haise formulation for potential evapotranspiration used in the model be changed to Priestly-Taylor or Penman-Monteith when using hotter GCM projections. The Priestly-Taylor and Penman-Monteith evapotranspiration formulations have only recently been added to PRMS so will take additional work to implement with the likelihood of issues implementing new capabilities. Therefore, we will use one of the scenarios described in this memo to represent future climate to perform the initial evaluation of groundwater management alternatives. Implementation of downscaled GCM projections has been re-prioritized to 2017.

This approach also does not project trends for temporal precipitation patterns as previously evaluated by Daniels (2014)[2]. Daniels identified long-term trends in storm intensity, duration, and pauses between storms and assessed effects on groundwater recharge and streamflow of those trends projected into the future. Since those projections are not part of the historical record, they are not part of the climate scenario described in this memo. However, 83% of historical years randomly selected for the future climate scenario in this memo are from 1990-2016, so the historical trends for these patterns are reflected in the scenario.

[2] Dr. Bruce Daniels is Board President of Soquel Creek Water District, a member of the Santa Cruz Mid-County Agency that is funding development of this GSFLOW model. Dr. Daniels also serves on the Technical Advisory Committee for this model.

6.0 References

Daniels, B.K. 2014. *Hydrologic response to climate change in California: observational and modeling studies.* Ph.D. dissertation, University of California, Santa Cruz. December.

Flint L.E. and A.L. Flint. 2014. *California basin characterization model: a dataset of historical and future hydrologic response to climate change*, U.S. Geological Survey Data Release, doi:10.5066/F76T0JPB

Metropolitan Water District of Southern California (MWD). 2016. *Integrated Water Resources Plan, 2015 Update*. Report No. 1518. January.

Young, K. 2016. *A high-resolution, regional-scale analysis of stormwater runoff in the San Lorenzo river basin for managed aquifer recharge decision making*. Masters of Science Thesis, University of California, Santa Cruz. June.

Appendix A

Santa Cruz Co-op Station Exceedance Probabilities with Year Type Classification

Water Year	Temperature			Precipitation			Classification 1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet
	Average (°F)	Rank	Probability of Exceedance	Total (inches)	Rank	Probability of Exceedance	
1894	57.6	35	28.2%	32.9	37	29.8%	3
1895	58.9	9	7.3%	36.8	26	21.0%	2
1896	57.6	36	29.0%	22.9	86	69.4%	4
1897	56.8	72	58.1%	27.8	64	51.6%	4
1898	55.9	100	80.6%	12.4	121	97.6%	4
1899	55.5	110	88.7%	22.9	85	68.5%	4
1900	56.8	69	55.6%	28.4	61	49.2%	3
1901	55.4	114	91.9%	26.8	70	56.5%	4
1902	55.7	106	85.5%	28.7	57	46.0%	3
1903	54.8	122	98.4%	26.7	71	57.3%	4
1904	56.3	91	73.4%	32.7	38	30.6%	3
1905	58.0	23	18.5%	28.5	60	48.4%	2
1906	57.1	57	46.0%	32.5	41	33.1%	3
1907	57.1	54	43.5%	35.5	30	24.2%	3
1908	56.0	97	78.2%	23.3	84	67.7%	4
1909	55.2	117	94.4%	42.9	12	9.7%	3
1910	56.1	96	77.4%	28.6	59	47.6%	3
1911	55.3	115	92.7%	33.5	35	28.2%	3
1912	57.4	45	36.3%	20.9	98	79.0%	4
1913	55.7	105	84.7%	13.8	120	96.8%	4
1914	57.0	61	49.2%	34.9	31	25.0%	3
1915	56.6	80	64.5%	42.1	15	12.1%	3
1916	55.8	102	82.3%	30.4	47	37.9%	3
1917	54.4	123	99.2%	18.4	110	88.7%	4
1918	57.3	50	40.3%	18.6	108	87.1%	4
1919	56.2	92	74.2%	21.7	95	76.6%	4
1920	56.1	95	76.6%	20.5	101	81.5%	4
1921	56.6	82	66.1%	28.2	62	50.0%	4
1922	56.6	81	65.3%	27.9	63	50.8%	4
1923	56.4	90	72.6%	28.6	58	46.8%	3
1924	57.1	55	44.4%	10.2	123	99.2%	4
1925	57.7	33	26.6%	30.5	46	37.1%	3
1926	59.6	4	3.2%	25.6	72	58.1%	1
1927	57.6	39	31.5%	29.3	53	42.7%	3

Water Year	Temperature			Precipitation			Classification
	Average (°F)	Rank	Probability of Exceedance	Total (inches)	Rank	Probability of Exceedance	1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet
1928	**57.8**	**30**	**24.2%**	**22.0**	**90**	**72.6%**	1
1929	55.4	113	91.1%	18.2	111	89.5%	4
1930	56.2	93	75.0%	21.9	91	73.4%	4
1931	**58.8**	**10**	**8.1%**	**11.7**	**122**	**98.4%**	1
1932	55.1	118	95.2%	27.4	68	54.8%	4
1933	54.9	120	96.8%	21.7	94	75.8%	4
1934	**58.0**	**22**	**17.7%**	**18.4**	**109**	**87.9%**	1
1935	57.0	60	48.4%	30.1	50	40.3%	3
1936	**58.0**	**25**	**20.2%**	**32.7**	**39**	**31.5%**	2
1937	56.9	67	54.0%	34.1	32	25.8%	3
1938	57.9	26	21.0%	42.4	14	11.3%	2
1939	57.5	42	33.9%	20.2	103	83.1%	4
1940	58.3	15	12.1%	44.5	8	6.5%	2
1941	58.6	12	9.7%	61.3	1	0.8%	2
1942	57.0	64	51.6%	42.0	16	12.9%	3
1943	56.8	71	57.3%	39.5	22	17.7%	3
1944	57.0	62	50.0%	27.4	67	54.0%	4
1945	57.3	49	39.5%	33.2	36	29.0%	3
1946	56.6	84	67.7%	30.3	48	38.7%	3
1947	57.1	58	46.8%	19.1	105	84.7%	4
1948	55.7	103	83.1%	24.7	76	61.3%	4
1949	55.0	119	96.0%	30.0	51	41.1%	3
1950	55.3	116	93.5%	31.4	43	34.7%	3
1951	56.6	78	62.9%	38.4	23	18.5%	3
1952	56.0	98	79.0%	44.6	7	5.6%	3
1953	55.6	109	87.9%	24.4	78	62.9%	4
1954	56.4	89	71.8%	23.8	83	66.9%	4
1955	54.8	121	97.6%	23.9	82	66.1%	4
1956	55.6	108	87.1%	39.7	21	16.9%	3
1957	57.0	59	47.6%	22.2	89	71.8%	4
1958	**57.8**	**29**	**23.4%**	**50.1**	**4**	**3.2%**	2
1959	**58.1**	**20**	**16.1%**	**24.8**	**75**	**60.5%**	1
1960	57.3	51	41.1%	21.4	97	78.2%	4
1961	56.9	68	54.8%	17.8	113	91.1%	4
1962	55.4	111	89.5%	27.5	66	53.2%	4
1963	56.7	74	59.7%	33.7	33	26.6%	3
1964	56.0	99	79.8%	19.0	106	85.5%	4
1965	56.6	77	62.1%	30.6	45	36.3%	3
1966	56.7	75	60.5%	20.5	100	80.6%	4
1967	56.8	70	56.5%	40.0	20	16.1%	3

Water Year	Temperature Average (°F)	Temperature Rank	Temperature Probability of Exceedance	Precipitation Total (inches)	Precipitation Rank	Precipitation Probability of Exceedance	Classification 1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet
1968	57.4	43	34.7%	21.5	96	77.4%	4
1969	55.7	107	86.3%	44.9	6	4.8%	3
1970	57.7	32	25.8%	30.2	49	39.5%	3
1971	56.1	94	75.8%	27.2	69	55.6%	4
1972	56.6	79	63.7%	19.1	104	83.9%	4
1973	56.5	85	68.5%	43.7	9	7.3%	3
1974	55.8	101	81.5%	42.0	17	13.7%	3
1975	55.7	104	83.9%	24.3	79	63.7%	4
1976	56.7	76	61.3%	15.4	117	94.4%	4
1977	**57.4**	**44**	**35.5%**	**14.8**	**118**	**95.2%**	**4**
1978	**58.3**	**14**	**11.3%**	**37.6**	**24**	**19.4%**	**2**
1979	**56.5**	**87**	**70.2%**	**29.2**	**54**	**43.5%**	**3**
1980	**57.4**	**48**	**38.7%**	**37.1**	**25**	**20.2%**	**3**
1981	**57.7**	**31**	**25.0%**	**21.7**	**92**	**74.2%**	**4**
1982	**56.7**	**73**	**58.9%**	**48.1**	**5**	**4.0%**	**3**
1983	**58.2**	**18**	**14.5%**	**53.9**	**3**	**2.4%**	**2**
1984	**58.8**	**11**	**8.9%**	**24.0**	**81**	**65.3%**	**1**
1985	**57.0**	**63**	**50.8%**	**29.7**	**52**	**41.9%**	**3**
1986	**57.4**	**46**	**37.1%**	**41.0**	**18**	**14.5%**	**3**
1987	**58.0**	**24**	**19.4%**	**15.9**	**116**	**93.5%**	**1**
1988	**58.5**	**13**	**10.5%**	**18.7**	**107**	**86.3%**	**1**
1989	**57.1**	**56**	**45.2%**	**24.2**	**80**	**64.5%**	**4**
1990	**57.9**	**27**	**21.8%**	**16.8**	**115**	**92.7%**	**1**
1991	**56.5**	**86**	**69.4%**	**20.4**	**102**	**82.3%**	**4**
1992	**59.3**	**6**	**4.8%**	**27.5**	**65**	**52.4%**	**1**
1993	**58.2**	**19**	**15.3%**	**36.7**	**27**	**21.8%**	**2**
1994	**57.6**	**38**	**30.6%**	**22.7**	**87**	**70.2%**	**4**
1995	**57.6**	**37**	**29.8%**	**43.0**	**11**	**8.9%**	**3**
1996	**59.0**	**8**	**6.5%**	**31.5**	**42**	**33.9%**	**2**
1997	**59.1**	**7**	**5.6%**	**36.6**	**28**	**22.6%**	**2**
1998	**57.9**	**28**	**22.6%**	**59.8**	**2**	**1.6%**	**2**
1999	**55.4**	**112**	**90.3%**	**33.7**	**34**	**27.4%**	**3**
2000	**57.7**	**34**	**27.4%**	**36.4**	**29**	**23.4%**	**3**
2001	**56.6**	**83**	**66.9%**	**25.5**	**73**	**58.9%**	**4**
2002	**56.4**	**88**	**71.0%**	**28.8**	**56**	**45.2%**	**3**
2003	**58.1**	**21**	**16.9%**	**29.1**	**55**	**44.4%**	**2**
2004	**58.2**	**16**	**12.9%**	**24.5**	**77**	**62.1%**	**1**
2005	**57.5**	**41**	**33.1%**	**43.6**	**10**	**8.1%**	**3**
2006	**57.4**	**47**	**37.9%**	**42.5**	**13**	**10.5%**	**3**
2007	**57.1**	**53**	**42.7%**	**17.6**	**114**	**91.9%**	**4**

Water Year	Temperature			Precipitation			Classification 1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet
	Average (°F)	Rank	Probability of Exceedance	Total (inches)	Rank	Probability of Exceedance	
2008	**56.9**	**66**	**53.2%**	**25.0**	**74**	**59.7%**	**4**
2009	**58.2**	**17**	**13.7%**	**22.4**	**88**	**71.0%**	**1**
2010	**57.2**	**52**	**41.9%**	**30.8**	**44**	**35.5%**	**3**
2011	**57.0**	**65**	**52.4%**	**40.1**	**19**	**15.3%**	**3**
2012	**57.5**	**40**	**32.3%**	**20.7**	**99**	**79.8%**	**4**
2013	**59.4**	**5**	**4.0%**	**18.0**	**112**	**90.3%**	**1**
2014	**60.5**	**2**	**1.6%**	**14.4**	**119**	**96.0%**	**1**
2015	**62.2**	**1**	**0.8%**	**21.7**	**93**	**75.0%**	**1**
2016	**59.6**	**3**	**2.4%**	**32.6**	**40**	**32.3%**	**2**

Bold records denote water years included in the catalog for future climate scenario generation

Appendix B

Proposed Climate Scenarios

The Weighted Temperature Scenario with Precipitation Adjustment columns only show those water years where records are manually adjusted to be drier. For the remaining years, data from the Weighted Temperature Scenario apply.

Model Water Year	Weighted Temperature Scenario					Weighted Temperature Scenario with Precipitation Adjustment (Drier)				
		Temperature		Precipitation			Temperature		Precipitation	
	Historic Water Year	Average (°F)	Probability of Exceedance	Average (inches)	Probability of Exceedance	Historic Year if changed	Average (°F)	Probability of Exceedance	Average (inches)	Probability of Exceedance
1	2016	59.6	2.4%	32.6	32.3%					
2	1992	59.3	4.8%	27.5	52.4%					
3	2015	62.2	0.8%	21.7	75.0%					
4	2010	57.2	41.9%	30.8	35.5%					
5	2014	60.5	1.6%	14.4	96.0%					
6	2016	59.6	2.4%	32.6	32.3%					
7	2004	58.2	12.9%	24.5	62.1%					
8	2003	58.1	16.9%	29.1	44.4%					
9	2015	62.2	0.8%	21.7	75.0%					
10	2013	59.4	4.0%	18.0	90.3%					
11	1990	57.9	21.8%	16.8	92.7%					
12	2015	62.2	0.8%	21.7	75.0%					
13	1986	57.4	37.1%	41.0	14.5%					
14	1991	56.5	69.4%	20.4	82.3%					
15	1997	59.1	5.6%	36.6	22.6%	1984	58.8	8.9%	24.0	65.3%
16	2014	60.5	1.6%	14.4	96.0%					
17	1992	59.3	4.8%	27.5	52.4%					
18	2014	60.5	1.6%	14.4	96.0%					
19	1984	58.8	8.9%	24.0	65.3%					
20	2015	62.2	0.8%	21.7	75.0%					
21	2013	59.4	4.0%	18.0	90.3%					
22	2013	59.4	4.0%	18.0	90.3%					
23	1992	59.3	4.8%	27.5	52.4%					
24	1934	58.0	17.7%	18.4	87.9%					
25	1983	58.2	14.5%	53.9	2.4%	2009	58.2	13.7%	22.4	71.0%
26	1992	59.3	4.8%	27.5	52.4%					
27	2015	62.2	0.8%	21.7	75.0%					
28	2014	60.5	1.6%	14.4	96.0%					

	Weighted Temperature Scenario					Weighted Temperature Scenario with Precipitation Adjustment (Drier)				
		Temperature		Precipitation			Temperature		Precipitation	
Model Water Year	Historic Water Year	Average (°F)	Probability of Exceedance	Average (inches)	Probability of Exceedance	Historic Year if changed	Average (°F)	Probability of Exceedance	Average (inches)	Probability of Exceedance
29	1980	57.4	38.7%	37.1	20.2%					
30	2003	58.1	16.9%	29.1	44.4%					
31	2006	57.4	37.9%	42.5	10.5%					
32	2015	62.2	0.8%	21.7	75.0%					
33	2013	59.4	4.0%	18.0	90.3%					
34	1958	57.8	23.4%	50.1	3.2%	1990	57.9	21.8%	16.8	92.7%
35	2016	59.6	2.4%	32.6	32.3%					
36	2009	58.2	13.7%	22.4	71.0%					
37	2015	62.2	0.8%	21.7	75.0%					
38	1999	55.4	90.3%	33.7	27.4%					
39	2015	62.2	0.8%	21.7	75.0%					
40	2015	62.2	0.8%	21.7	75.0%					
41	1992	59.3	4.8%	27.5	52.4%					
42	2016	59.6	2.4%	32.6	32.3%					
43	2014	60.5	1.6%	14.4	96.0%					
44	1977	57.4	35.5%	14.8	95.2%					
45	2015	62.2	0.8%	21.7	75.0%					
46	1992	59.3	4.8%	27.5	52.4%					
47	2014	60.5	1.6%	14.4	96.0%					
48	1998	57.9	22.6%	59.8	1.6%	1990	57.9	21.8%	16.8	92.7%
49	2013	59.4	4.0%	18.0	90.3%					
50	1992	59.3	4.8%	27.5	52.4%					
51	1992	59.3	4.8%	27.5	52.4%					
52	1989	57.1	45.2%	24.2	64.5%					
53	2016	59.6	2.4%	32.6	32.3%					
54	1984	58.8	8.9%	24.0	65.3%					

Attachment 3: Pure Water Soquel Anti-Degradation Analysis – Particle Tracking Model Results (HydroMetrics WRI, 2018)

1814 Franklin St., Suite 501
Oakland, CA 94612

Mr. Robert Beggs
1590 Drew Ave.
Suite 210
Davis, CA 95618

June 21, 2018

Subject: Pure Water Soquel Anti-Degradation Analysis – Particle Tracking Model Results

Dear Mr. Beggs:

HydroMetrics WRI is pleased to present these particle tracking modeling results of simulated groundwater recharge for the Pure Water Soquel project using the calibrated GSFLOW model of the Santa Cruz Mid-County Groundwater model. Particle tracking was performed based on the Project simulations (Cabrillo-Monterey and Monterey-Willowbrook) under the Catalog Climate scenario documented in the draft technical memorandum to Soquel Creek Water District December 13, 2017.

RECHARGE WELL SIMULATION DESCRIPTION

Cabrillo-Monterey Pumping Simulation

Recharge was simulated with the Cabrillo-Monterey pumping simulation using the calibrated Santa Cruz Mid-County groundwater model. This predictive model was used to simulate potential recharge and pumping conditions between water years 2016 and 2069. Particle tracking, with the USGS' MODPATH program, is used to assess the extent of recharged water in the various aquifers at the end of water year 2047, five years after the end of Project injection.

Particles are released from the simulated Cabrillo and Monterey recharge wells in every simulated month that recharge wells are in operation. Recharge is grouped into three periods corresponding to three recharge rates. The three time periods are water years 2023 to 2029; 2030 to 2034; 2035 to 2042.

The number of particles released from each well is proportional to the recharge flow rate. This was done to approximately equate the number of particles to the amount of recharged mass: doubling the flow rate at a constant concentration effectively doubles the amount of mass being recharged to the aquifers. We therefore release twice the number of particles if the flow rate is doubled.

The Monterey well recharges only into the A aquifer. The Cabrillo well recharges into both the A and BC aquifers. For the Cabrillo well, recharge flow was initially assumed to be proportioned between the A and BC aquifers in a 9:1 ratio, corresponding to the estimated transmissivity ratio between the A and BC units at the Cabrillo site in a preliminary version of the model. The simulated recharge flowrates for each recharge location are shown in Table 1.

Table 1: Simulated Recharge Flowrates for Cabrillo-Monterey Simulation

		Recharge Flowrates (Acre-Feet/year)		
Water Years	**Recharge Time Period**	**Cabrillo BC**	**Cabrillo A**	**Monterey A**
2016-2022	Pre-Project	0	0	0
2023-2029	1	100	900	500
2030-2034	2	80	720	400
2035-2042	3	70	630	400
2043-2047	Post-Project	0	0	0

The number of particles assigned to each recharge well at each time period was calculated from the data in Table 1. As mentioned earlier, the number of particles is proportional to the estimated recharge flowrates of the recharge wells. Table 2 shows the number of particles released monthly from each well during each recharge period. Each particle is given a unique name, and the prefix of the name (Group prefix) corresponds to the release location and release time.

Table 2: Number of Released Particles per Well per Month for Cabrillo-Monterey Simulation

Recharge Period	Group Prefix	Group	Number of particles
2023-2029	CabrilloBC-1	1	72
	CabrilloA-2	2	624
	MontereyA-3	3	348
2030-2034	CabrilloBC-4	4	60
	CabrilloA-5	5	504
	MontereyA-6	6	276
2035-2042	CabrilloBC-7	7	48
	CabrilloA-8	8	432
	MontereyA-9	9	276

Monterey-Willowbrook Pumping Simulation

Recharge was also simulated with the Monterey-Willowbrook pumping simulation, under the same conditions as the Cabrillo-Monterey simulation. The Monterey and Willowbrook wells both recharge into the A aquifer. The simulated recharge flowrates for each recharge location are shown in Table 3.

Table 3: Recharge Flowrates for Monterey-Willowbrook Simulation

		Recharge Flowrates (Acre-Feet/year)	
Water Years	Recharge Time Period	Willowbrook A	Monterey A
2016-2022	Pre-Project	0	0
2023-2029	1	1,000	500
2030-2034	2	800	400
2035-2042	3	700	400
2043-2047	Post-Project	0	0

The number of particles assigned to the Willowbrook well at each time period is identical to that assigned to Cabrillo A in the Cabrillo-Monterey simulation. The number of particles assigned to the Monterey well at each time period is the same as in the Cabrillo-Monterey simulation. Table 4 shows the number of particles released monthly from each well during each recharge period.

Table 4: Number of Released Particles per Well per Month for Monterey-Willowbrook Simulation

Water Years	Group Prefix	Group	Number of particles
2023-2029	WillowbrookA-2	1	624
	MontereyA-3	2	348
2030-2034	WillowbrookA-5	3	504
	MontereyA-6	4	276
2035-2042	WillowbrookA-8	5	432
	MontereyA-9	6	276

SIMULATION RESULTS

Excel Spreadsheet

The accompanying Excel workbooks, named "Project_Recharge_Results _0p9_0p13.xlsx" and "Alternate_Recharge_Results_0p9_0p13.xlsx", provide the final locations of the particles released from the two simulated recharge wells for Cabrillo-Monterey and Monterey-Willowbrook simulations, respectively. The first sheet of both workbooks, "Results", includes the following data:

- Column A: the particle group number as defined in Table 2 or Table 4.
- Column B: the particle release point (well and aquifer)
- Column C: the unique particle ID number
- Column D: the particle release time, in days elapsed from the model start time of 10/1/2015.
- Column E: the last time the particle was in the aquifer, days elapsed from the model start time of 10/1/2015.
- Column F: the aquifer into which the particles are initially released.
- Column G, H, and I: the particle release coordinates. X and Y coordinates are given in state plane (feet) units. The Z coordinate is the elevation of the particle with respect to the model datum (mean sea level).
- Column J: the aquifer that the particle is in at the time shown in column E.
- Columns K,L, and M: the final particle coordinates. X and Y coordinates are given in state plane (feet) units. The Z coordinate is the elevation of the particle with respect to the model datum (mean sea level).
- Columns N and O: the ending status of each particle. The two columns include a status code, followed by the status descriptor. Table 5 provides a summary

description of the Status Codes. The particles released in the simulation are assigned either an "Active Status" (Status Code=1) or "Normally Terminated" (Status Code =2) at the end of the particle tracking period (end of WY 2047).

Table 5: Particle Status Codes

Status Code	Status Category	Description
1	Active	Particles that are actively moving in the flow system and have not yet reached a termination location
2	Normally Terminated	Particles that have terminated at a boundary or internally at a cell with an internal source/sink. These particles may have exited the model through a pumping well or a boundary such as the ocean, or were located in the same cell as a recharge well after recharge turns off.

Endpoint Location Maps: Project

The following maps show the final location of the particles released at the simulated recharge well locations. Figure 1 shows the final location of the particles released in the simulated A Aquifer model layer. The dots show the final locations of the particles released from the CabrilloA and MontereyA sites, and are colored by travel time, which is the time elapsed since particle release. MODPATH assumes that once a particle reaches a model cell containing a large pumping well, the particle is removed from the system by the well. Therefore, the particles are removed at the cell boundary, and the model cells show no particles within the cell. The map shows that particles reaching the cells containing the Cunnison Lane, Rosedale 2, Tannery 2, and Estates municipal wells and simulated private well 8091 were terminated and removed from the system at the cell boundary. There are no active particles in the cells containing these wells.

Figure 1 shows active particles in the cells containing private wells 7874, 7980, 8090, and 8196. Flow rates in these wells are low compared to the wells at which particles are captured. The cells containing these wells are classified as weak sinks, and MODPATH assumes that particles are not removed from the system in these cells. Private well 7875 is also a weak sink and is in the same cell as Tannery 2. All particles terminated in this cell are assumed to be captured by Tannery 2.

Note that the simulated private wells are based on identification of residential parcels that do not receive municipal supply and do not represent actual well locations, depths or pumping rates. It is assumed that there is a private well to meet the water demand of residential parcels that do not receive municipal supply within the model cell but the existence of a well has not been confirmed. The figures show the wells located in the center of the cell.

Figure 2 shows the final location of the particles released in the simulated BC Aquifer layer. The number of particles released in the BC Aquifer is small compared to the particles released in the A Aquifer, proportional to the anticipated lower recharge rate in that formation. The dots show the final locations of the particles released from the CabrilloBC site; there are no particles released at the Monterey recharge site in the BC Aquifer. The particles released in the BC Aquifer are only captured in the Estates well.

There were no particles captured at the Cunnison Lane well, Rosedale 2 well, Tannery 2 well, or private well 8091 due to their relative distance from the Cabrillo recharge well site.

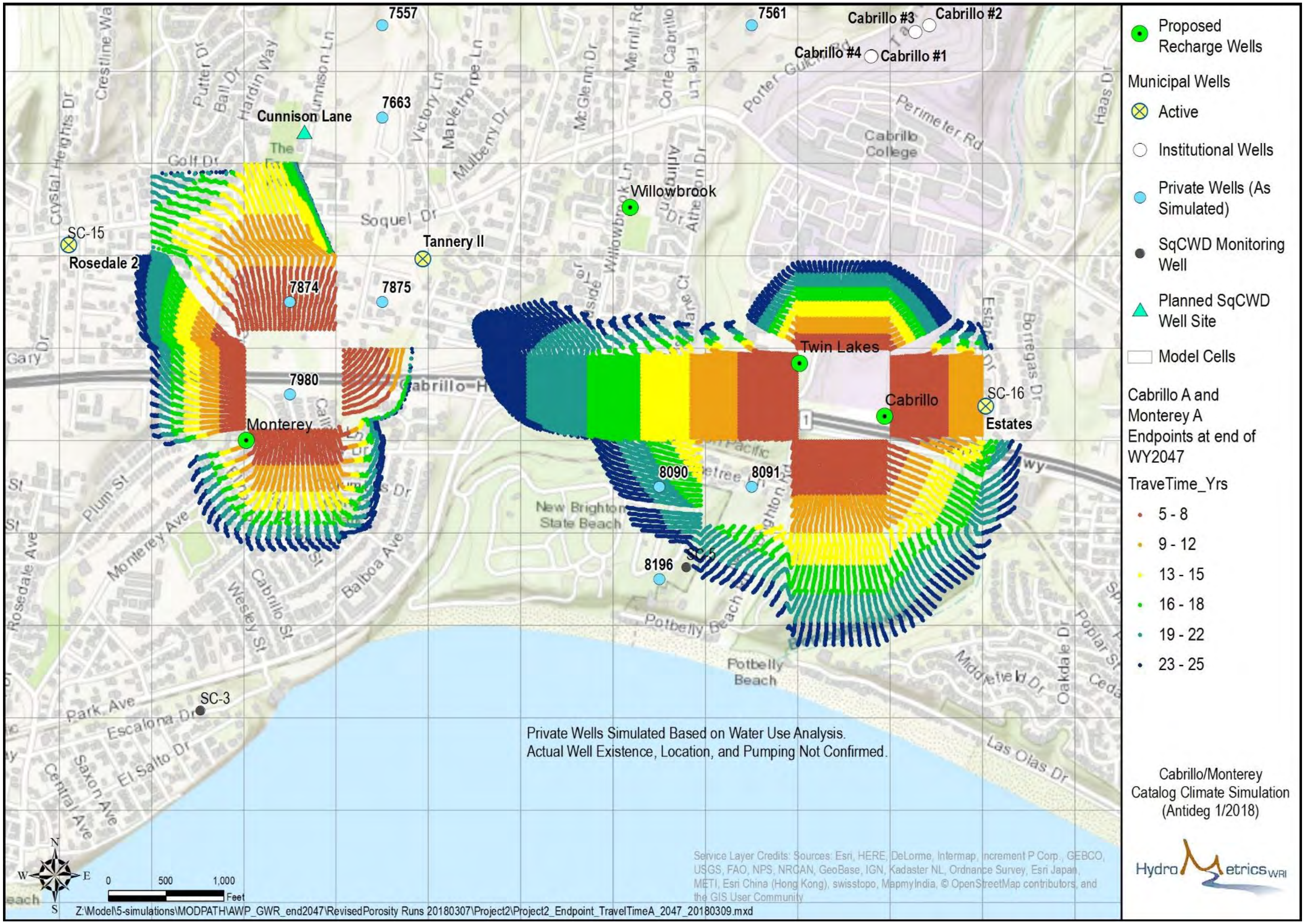


Figure 1: Particle End Points Released at the A Aquifer for Cabrillo-Monterey Simulation

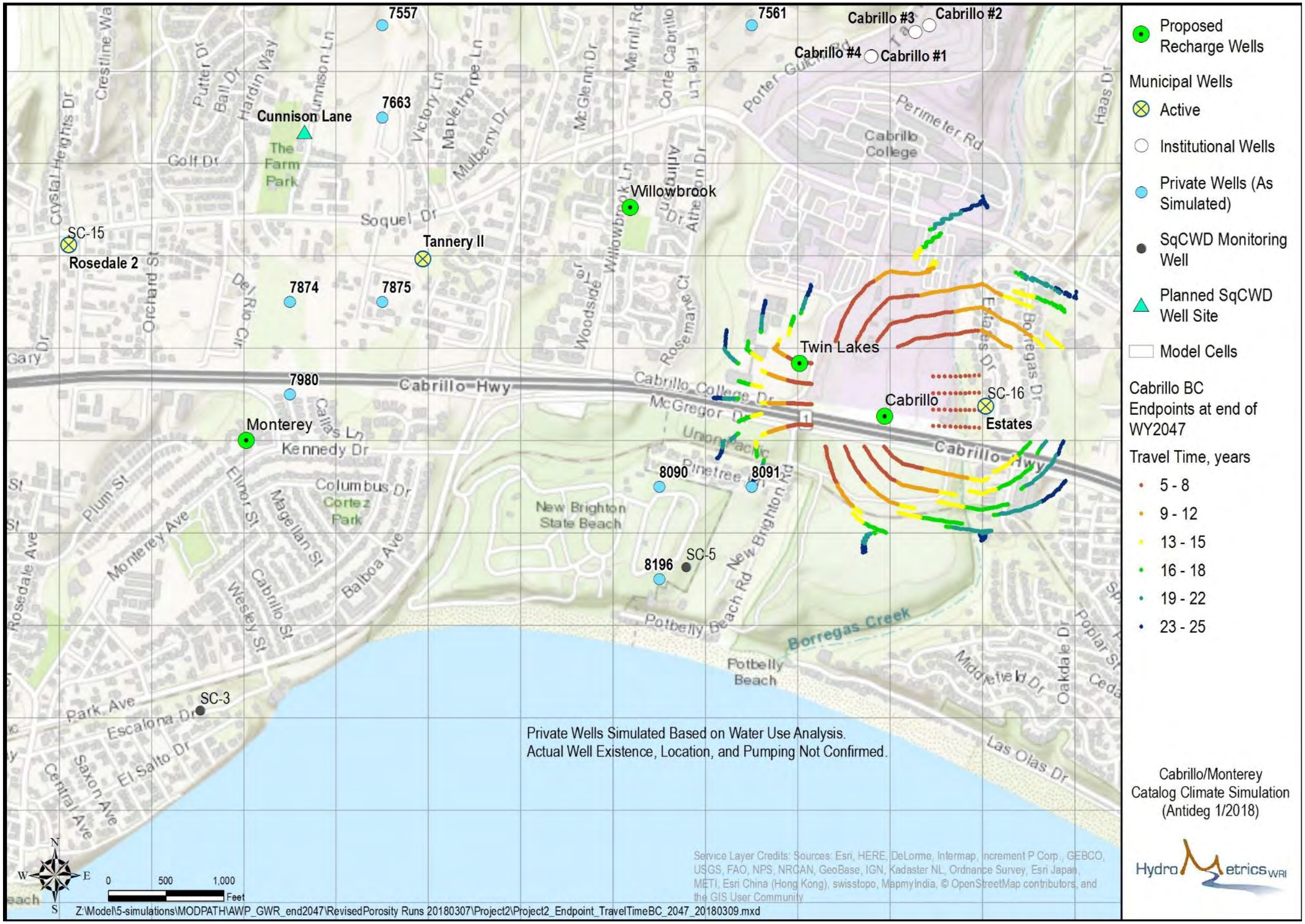


Figure 2: Particle End Points Released at the BC Aquifer for Cabrillo-Monterey Simulation

Summary of Particles Final Status Adjusted by Simulated Flow Rates: Project

As outlined in the Recharge Well Simulation Description, the relative numbers of particles released at the CabrilloA and CabrilloBC sites were based on the assumption that recharge flow to the A aquifer is nine times that to the BC aquifer. Simulation flow results indicate that average Cabrillo well recharge flow to the A aquifer is approximately 1.4 times that to the BC aquifer during the Project. Therefore, we calculated an adjustment to number of particles to better represent recharge water mass added to the system by the model.

Table 6 provides a summary of the particles captured at each well, adjusted for the simulated flow rates between the A and BC aquifers at the Cabrillo recharge well. The number of particles released at CabrilloBC is held constant. The number of particles released at CabrilloA is reduced to 1.4 times the number released at CabrilloBC. The number of particles released at MontereyA is reduced to maintain the ratio of number of particles released at Cabrillo to number released at Monterey, which is set by the recharge flow rates in Table 1. Table 7 provides a summary of active particles at the end of water year 2047 with the same adjustment. The adjustment calculations are provided in the second sheet of Project_Recharge_Results_0p9_0p13.xlsx, "Particle Fate."

A small number of particles are shown in Project_Recharge_Results_0p9_0p13.xlsx as terminated in the Cabrillo recharge well cell in the A aquifer. These particles comprise the ~1% of total adjusted particles released. These particles were released near or at the end of the Project and remained in the cell until the end of the simulation. MODPATH assumes that particles are removed from cells containing internal sources, but we add it to Table 7 as being active at the end of Water Year 2047.

Table 6: Particles Captured by Wells for Cabrillo-Monterey Simulation, adjusted for Cabrillo recharge rates

Well	Adjusted Number of Captured Particles	Percentage of Total Adjusted Particles Released
Cunnison Lane	2,946	5.6%
Rosedale 2	848	1.6%
Tannery 2	2,387	4.5%
Estates	9,193	17%
8091	892	1.6%
Total Captured	16,266	31%

Table 7: Active Particles at End of Water Year 2047 for Cabrillo-Monterey Simulation, adjusted for Cabrillo recharge rates

Aquifer	Adjusted Number of Active Particles	Percentage of Total Adjusted Particles Released
BC	8,496	16%
A	27,784	53%
Total Active	36,208	69%

Endpoint Location Maps: Monterey-Willowbrook

Figure 3 shows the final location of the particles released in the simulated A Aquifer model layer. The dots show the final locations of the particles released from the WillowbrookA and MontereyA sites, and are colored by travel time. The map shows that particles reaching the cells containing the Cunnison Lane, Rosedale 2, and Tannery 2 municipal wells and private well 8091 were terminated and removed from the system at the cell boundary. No particles were captured at the Estates well.

Figure 3 shows active particles in the cells containing private wells 7874, 7980, 8090, 7663, and 7561, which are classified as weak sinks. As with the Cabrillo-Monterey simulation, private well 7875 is also a weak sink; all particles terminated in the cell it shares with Tannery 2 are assumed to be captured by Tannery 2.

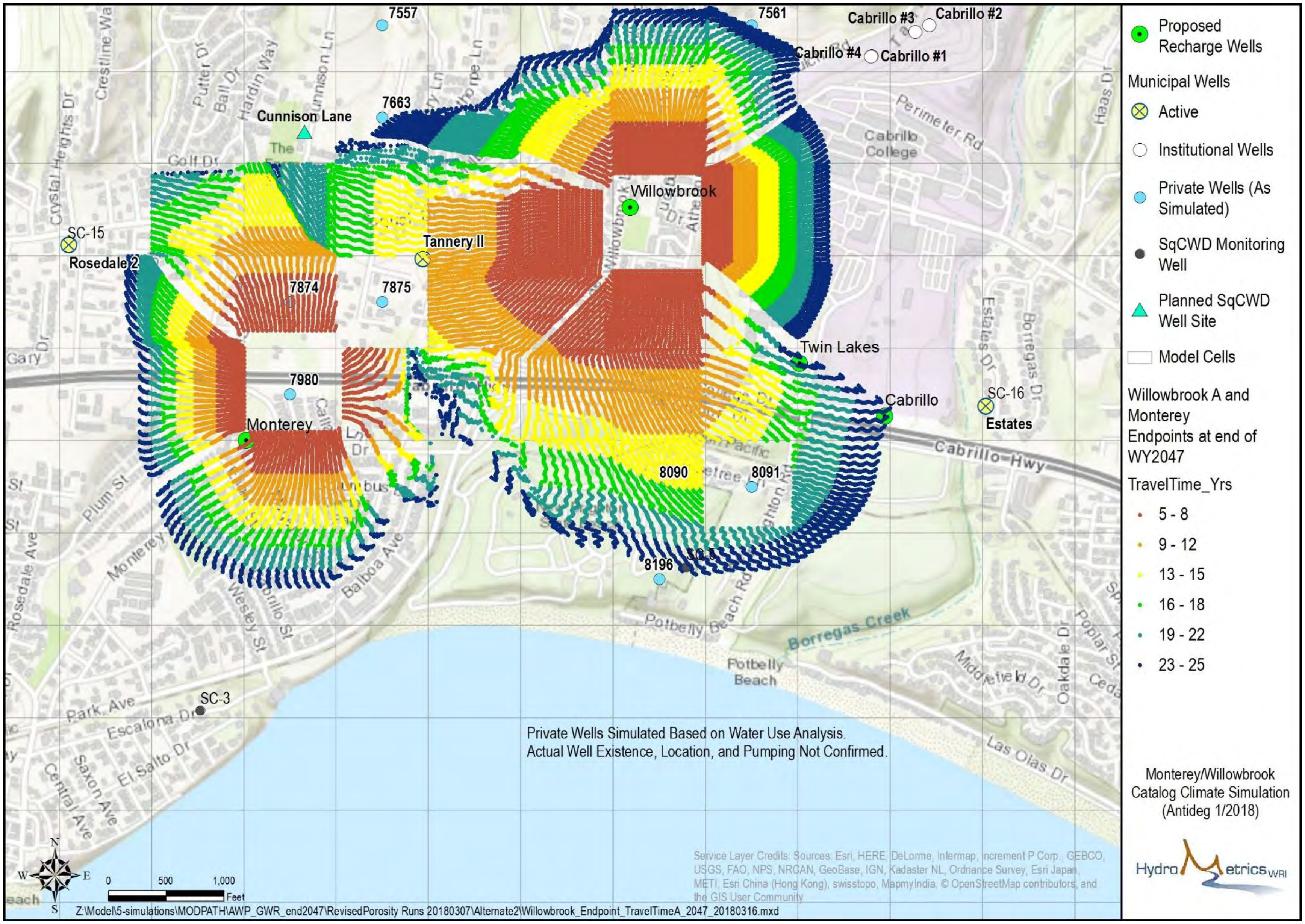


Figure 3: Particle End Points Released in A Aquifer for Monterey-Willowbrook Simulation

Summary of Particles Final Status Adjusted by Simulated Flow Rates: Monterey-Willowbrook

Table 8 provides a summary of the particles captured at each well, adjusted to be consistent with adjusted Cabrillo-Monterey particle numbers. The number of Monterey-Willowbrook particles released at MontereyA is reduced to match the adjusted number of MontereyA Project particles. The number of particles released at Willowbrook is then adjusted so the ratio of number of particles released at Willowbrook to number released at Monterey is consistent with the recharge flow rates in Table 3. Table 9 provides a summary of active particles at the end of water year 2047 with the same adjustment. The adjustment calculations are provided in the second sheet of Alternate_Recharge_Results _0p9_0p13y.xlsx, "Particle Fate."

Table 8: Particles Captured by Wells for Monterey-Willowbrook Simulation, adjusted to Cabrillo-Monterey Simulation releases

Well	Adjusted Number of Captured Particles	Percentage of Total Adjusted Particles Released
Cunnison Lane	2,336	4.5%
Rosedale 2	1,087	2.0%
Tannery 2	5,991	11.4%
Estates	0	0%
8091	1,091	2.1%
Cabrillo #4	11	0.02%
Total Captured	10,516	20%

Table 9: Particles Active at End of Water Year 2047 for Monterey-Willowbrook Simulation, adjusted to Cabrillo-Monterey Simulation releases

Aquifer	Adjusted Number of Active Particles	Percentage of Total Adjusted Particles Released
A	42,035	80%
Total Active	42,035	80%

If you have any questions about our results, do not hesitate to contact us.

Sincerely,

Cameron Tana, VicePresident
HydroMetrics Water Resources Inc.