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TECHNICAL MEMORANDUM

DATE:	February 25, 2022
PROJECT #:	9150.0503
TO:	Bob Jaques, Technical Program Manager, Seaside Basin Watermaster
FROM:	Pascual Benito, Ph.D. and Georgina King, P.G, C.Hg.
PROJECT:	Seaside Basin Watermaster
SUBJECT:	Assessment of Potential Seawater Intrusion Travel Rates

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INTRODUCTION

The objective of this analysis is to estimate the velocities, time scales, and travel distances associated with potential seawater intrusion inland from locations along the coastline in the Northern Coastal Subarea of the Seaside basin. The analysis considers both current conditions and projected potential future conditions.

The modeling analyzes particles released along the entire extent of the coastline of the Seaside Subbasin and the portions of the neighboring Monterey Subbasin in the top 4 layers[1] of the Seaside Basin Watermaster's groundwater Model (the Model) and tracked inland throughout the simulation to look at how inland flow velocities vary spatially along the coastline of the basin and under different basin conditions. Groundwater travel velocity is very sensitive to the effective porosity of the aquifer; and since the effective porosity of the Paso Robles is not a calibrated parameter[2] from the Model, upper and lower bound estimates on the travel times are developed based on considering a reasonable range of aquifer effective porosities to provide a range of possible inland travel velocities. The maximum inland travel velocity is then used to provide estimates of travel times from the coastline to varying distances inland.

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[1] Layer 1 = Aromas Sands & Older Dune Deposits; Layer 2 = Upper Paso Robles, Layer 3 = Middle Paso Robles; Layer 4 = Lower Paso Robles

[2] During the Model calibration process (Hydrometrics LLC, 2009), aquifer parameters including hydraulic conductivity and storage coefficients, were adjusted iteratively to minimize the differences between observed historical water levels and simulated water levels. The effective porosity was not one of the parameters adjusted or used in the calibration of the Model to water levels.

This particle tracking analysis cannot tell us where the interface between fresh groundwater and saline groundwater, also referred to as the seawater interface, is located currently, or where it will be in the future. In un-intruded aquifers the seawater interface can be located at some distance offshore depending on the geometry of the aquifer and the magnitude of freshwater flux in the offshore direction, while the interface will be located at some distance inland for an intruded aquifer. The analysis can provide a range of potential groundwater travel rates from the coastline under different potential basin conditions, and as such can provide insights into the time scales and distances at which further inland intrusion could occur if early signs of seawater intrusion are detected in coastal monitoring wells.

ASSUMPTIONS FOR UPDATED BASELINE SIMULATION

In this Technical Memorandum the term "baseline simulation" refers to the simulation of future conditions assuming only operation of currently planned projects with no additional replenishment added. The updated baseline simulation represents recent conditions from water year (WY) 2018 through 2021 based on actual measured pumping, injection, and hydrology; and projected potential future conditions from WY 2022 through WY 2050 based on projected pumping, currently planned projects, and a repeated historical hydrology record.

The baseline simulation includes:

- A new extended hydrology period with 2 multi-year drought periods
- Projected mean sea level rise of up to 1.3 feet by 2050
- Seaside Aquifer Storage and Recovery (ASR) injection of Carmel River water, which is tied to the cycled hydrology and the assumption that planned upgrades to the Cal-AM Carmel Valley wellfield are completed by WY 2024
- Cal-Am's 25 year 700 AFY in-lieu replenishment begins in WY 2024
- Pure Water Monterey (PWM) Expansion project (tied to the new hydrology) begins in WY 2024
- Other planned projects including the City of Seaside's replacement of groundwater with recycled water for golf course irrigation in WY 2024 and the construction of the Security National Guaranty (SNG) and Campus Town developments in the City of Seaside occur
- No other sources of replenishment water are provided to the basin
- The assumption that no proposed Groundwater Sustainability Plan (GSP) projects are implemented in the neighboring coastal Monterey and 180/400 Foot Subbasins, such that groundwater levels along the northern boundary of the Model (located close to the

boundary between those two subbasins) remain unchanged as currently represented in the Model boundary conditions.

The updated baseline model simulates a 33-year period from October 2017 through the end of September 2050 (WY 2018–2050). The hydrology (rainfall, recharge, and streamflow) for WY 2018–2021 is based on measured values, while the hydrology for WY 2022 through 2050 is simulated by repeating the hydrology record from WY 1988 through 2016, as illustrated on Figure 1. Table 1 provides a listing of the simulated WY types, data sources, and major project events. A complete description of the baseline simulation assumptions and output is provided in the recent technical memorandum (M&A, 2022).

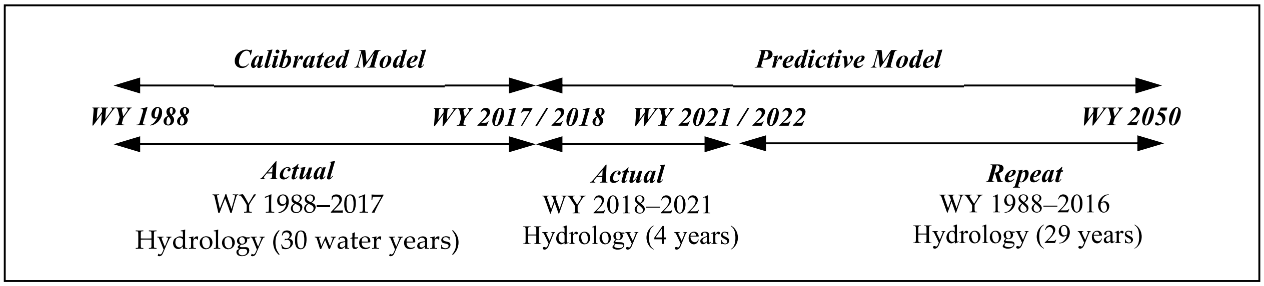

Figure 1: Repetition of Hydrology for Predictive Model

Table 1. Annual Summary of Updated Baseline Simulation Water Year Types, Data Sources, and Major Project Events

Sim Year	Water Year	Carmel River WY Type	Hydrology Source WY	Pumping & Injection	Cal-Am Repayment Period	Projects Timeline
1	2018	Below Normal	Actual	Actual		
2	2019	Extremely Wet	Actual	Actual		
3	2020	Normal	Actual	Actual		**PWM Base Project Begins (3,500 AF&)**
4	2021	Critically Dry	Actual	Actual		**Cal-Am ceases pumping in Laguna Seca**
5	2022	Critically Dry	1988	Projected		**PWM ramps up to 4,100 AFY**
6	2023	Critically Dry	1989	Projected		**Seaside Golf Courses shift to PWM water**, Campus Town starts up (100 AFY)
7	2024	Critically Dry	1990	Projected	1	**PWM Expansion Begins (5,750 AFY)**, Campus Town ramp up (130 AFY)
8	2025	Dry	1991	Projected	2	SNG starts up (25 AFY), Campus Town ramps up (215 AFY)
9	2026	Normal	1992	Projected	3	SNG ramps up (30 AFY), Campus Town full capacity (301 AFY)
10	2027	Wet	1993	Projected	4	SNG ramps up (50 AFY)
11	2028	Critically Dry	1994	Projected	5	SNG full Capacity (70 AFY)
12	2029	Extremely Wet	1995	Projected	6	
13	2030	Above Normal	1996	Projected	7	
14	2031	Above Normal	1997	Projected	8	
15	2032	Extremely Wet	1998	Projected	9	
16	2033	Normal	1999	Projected	10	
17	2034	Above Normal	2000	Projected	11	
18	2035	Normal	2001	Projected	12	
19	2036	Below Normal	2002	Projected	13	
20	2037	Normal	2003	Projected	14	
21	2038	Below Normal	2004	Projected	15	
22	2039	Wet	2005	Projected	16	
23	2040	Wet	2006	Projected	17	
24	2041	Critically Dry	2007	Projected	18	
25	2042	Normal	2008	Projected	19	
26	2043	Normal	2009	Projected	20	
27	2044	Above Normal	2010	Projected	21	
28	2045	Above Normal	2011	Projected	22	
29	2046	Dry	2012	Projected	23	
30	2047	Dry	2013	Projected	24	
31	2048	Critically Dry	2014	Projected	25	**Potential Final Year of Cal-Am Repayment Period (see footnote on page 6)**
32	2049	Dry	2015	Projected		
33	2050	Below Normal	2016	Projected		

SUMMARY OF SIMULATED BASELINE CONDITIONS

To provide context for the simulated basin conditions used for particle tracking analysis, a summary of the results of the baseline simulation are provided below, starting with an overview of simulated groundwater levels at coastal monitoring wells and following with a summary of simulated inland fluxes from the offshore portions of the aquifers.

Groundwater Levels at Coastal Monitoring Wells

Six monitoring wells have been used for establishing protective elevations against seawater intrusion in the basin (HydroMetrics LLC, 2009). These monitoring wells are: MSC Deep, MSC Shallow, PCA-West Deep, PCA-West Shallow, Sentinel Well 3 (also referred to as SBMW-3), and CDM MW-4 and are shown on Figure 2. Annually averaged hydrographs of groundwater levels in these coastal monitoring wells for the updated baseline simulation along with the simulated change in mean sea level are shown on Figure 3. Also overlain on the figure are the total annual replenishment volumes from ASR injection and PWM injection during the baseline simulation, as well as the periods and annual volumes when Cal-Am is projected to recover stored ("banked") ASR water. The right-hand vertical axis represents the groundwater level elevation and the left-hand vertical axis the annual recharge volumes.

At all the protective elevation monitoring wells, except for CDM MW-4[3], the annual average groundwater levels rise steadily starting in WY 2024 (when both the PWM Expansion and the Cal-AM replenishment repayment period begin) through WY 2033. After WY 2033 mean annual groundwater levels begin to either level off and/or drop to varying degrees in response to wetter and drier periods. During years when the Carmel River WY is classified as Below Normal, Dry, or Critically Dry (identified by dates with orange shading), the volumes of both ASR injection and Table 13 Carmel River diversions[4] to meet Cal-Am Monterey District demand are greatly reduced. Similarly, drought conditions in the Salinas Valley Castroville Seawater Intrusion Project (CSIP) service area result in a marked reduction in injected PWM water, as PWM source water is diverted to augment the CSIP agricultural irrigation supply and as Cal-Am recovers credited water from the banked drought reserve. Groundwater levels drop markedly in the last several years of the simulation period (WY 2046 through 2050) due to the impacts of a simulated

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[3] As has been observed in previous modeling, because of its very shallow depth and position in the Southern Coastal subarea of the basin, the groundwater levels at CDM MW-4 are largely insensitive changes in operations in the Northern subareas of the basin.

[4] Table 13 diversions refers to a streamflow-dependent water right that Cal-Am can use in its Carmel River well fields as identified in Table 13 of SWRCB Decision 1632 (1995). It is in addition to Cal-Am's entitled 3,376 AFY water right from the Carmel Valley basin with no streamflow restrictions.

multi-year drought period[5] during which both ASR and PWM injection are greatly reduced, and Cal-Am begins recovering banked ASR water credits to meet their system demand. The last 2 years of this period also coincides with the end of Cal-Am's repayment period[5], such that Cal-Am can exercise their full native groundwater rights from WY 2049 through 2050.

The direct correlation between drops in groundwater level and the Carmel River hydrology in terms of decreased Carmel River diversions for ASR and decreased PWM injection during these dry years and the sharp drops in groundwater level can be clearly seen in the overlay on Figure 3 of the total replenishment from ASR injection and PWM injection during the baseline simulation, as well as the periods and annual volumes when Cal-Am is projected to recover stored ASR water.

Change in Net Inflow to the Basin from Offshore

Figure 4 shows the results of a water budget analysis of the model and provides an estimate of the net annual inflow of groundwater into the Seaside Basin from the offshore portions of the aquifer for the updated baseline simulation. Positive values represent net inflow of groundwater moving from offshore across the coastline into the basin. Negative values represent net outflow of water from the onshore aquifers into the offshore region. The solid dark blue line represents the net inflow into the Northern Coastal subarea of the basin for the baseline simulation, and it shows that prior to the start of the repayment period in WY 2024 there is a net inflow of water from the offshore areas into the basin along the coastal boundary associated with the multi-year drought period and for conditions before future projects commence. While not necessarily implying seawater intrusion, because there may be freshwater stored offshore in the aquifer, this represents a condition that would increase the potential for seawater intrusion. In WY 2024 when both the PWM Expansion and the Cal-Am repayment period begins, groundwater levels in the basin begin to rise and simulated flows change to reflect a net outflow of groundwater from the basin in the offshore direction. The net outflow reaches a peak in WY 2033 following a series of above normal and extremely wet years (identified by dates with blue shading), and then begins to decrease in magnitude and remains relatively constant through WY 2045 before flow to the offshore areas decreases further during the final multi-year drought. Increased offshore groundwater flow minimizes the potential for seawater intrusion. The orange line represents the Southern Coastal subarea, which as would be expected appears to be insensitive to projects in the Northern subareas. This analysis considers the total net flow over the entire coastal boundary of each coastal subarea and for all the layers combined, however, and does not show differences in

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[5] The WY 2046–2050 drought is based on the repeated hydrology of the recent 2012–2015 drought

[5] Cal-Am's repayment period may extend to more than 25 years depending on the amount of water that needs to be repaid.

trends that could be spatially localized along the coast or within different model layers that could indicate risk for localized seawater intrusion. The layer-by-layer particle tracking results in the next section will provide a sense of the variability in offshore inflows by depth and location along the coastline.

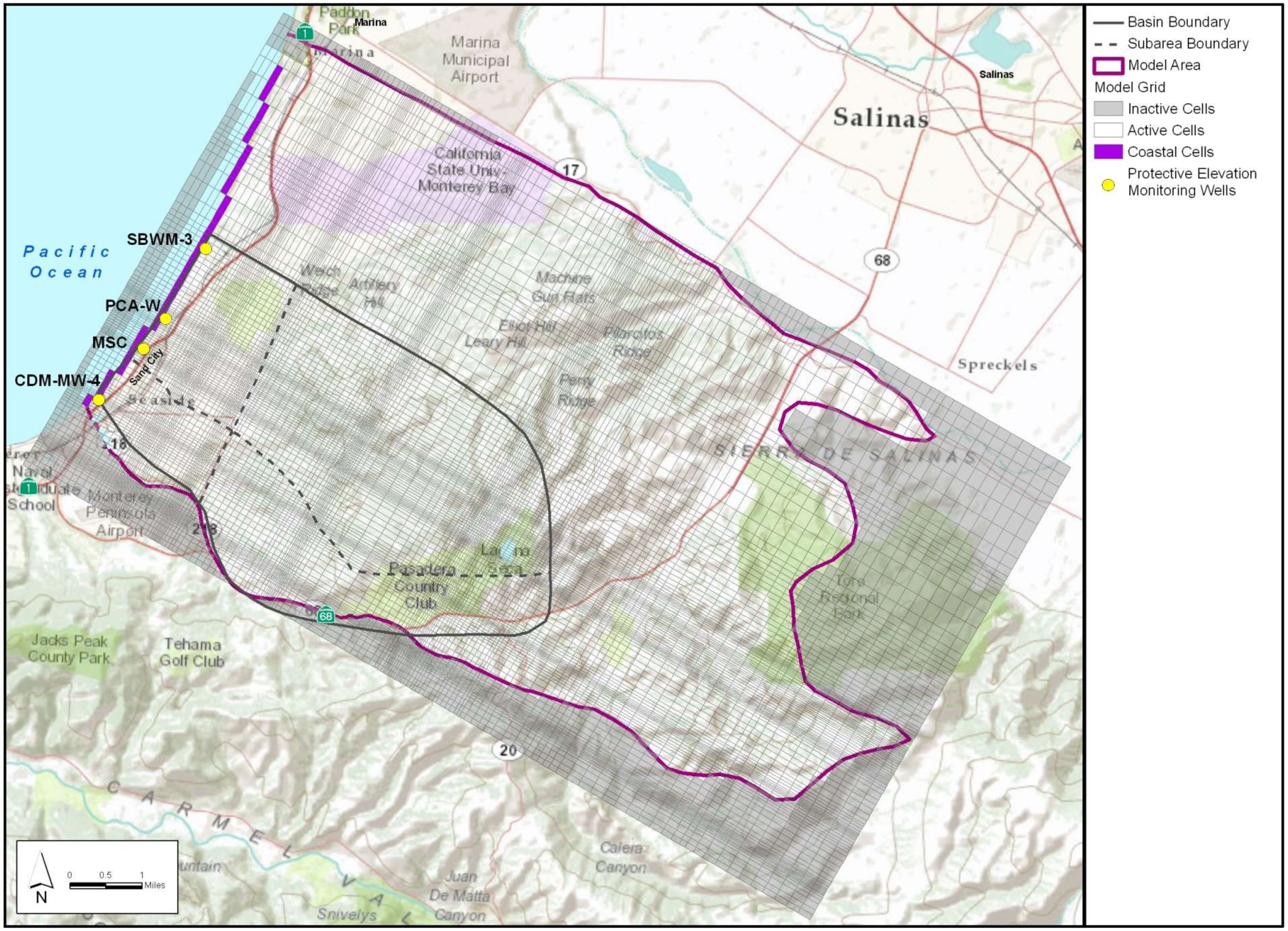

Figure 2. Location of Protective Elevation Monitoring Wells

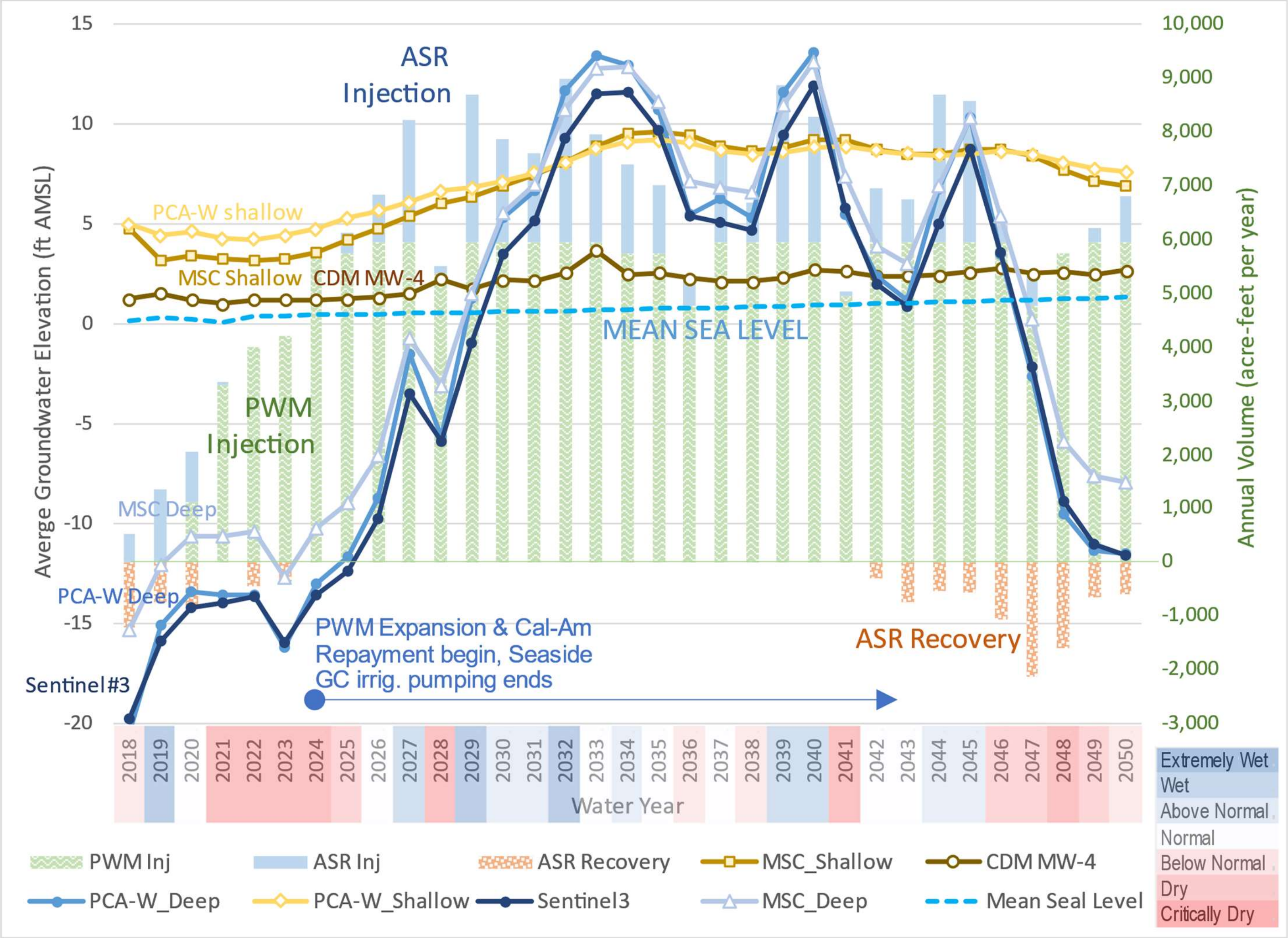

Figure 3. Annually Averaged Groundwater Elevations in Protective Elevation Wells Compared to PWM and ASR Injection and ASR Recovery (Right Axis) for the Baseline Simulation

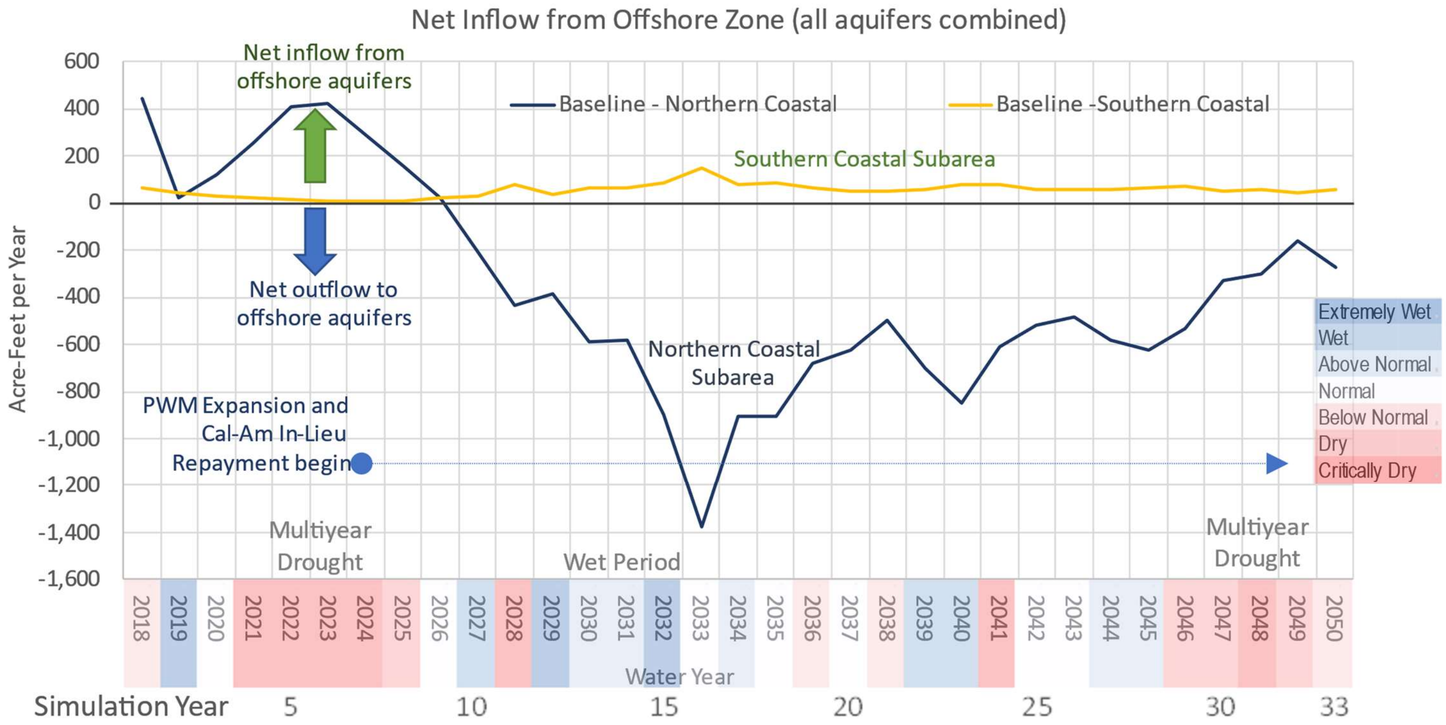

Figure 4. Net Groundwater Inflow to the Seaside Basin from Offshore for the Baseline and 1,000 AFY of Replenishment Water Scenario)

PARTICLE TRACKING OF INLAND FLOW ALONG COASTLINE

Particles are released every 500 feet along the entire coastline (as shown on Figure 5) at the mid-depth of model layers 1 through 4 (Aromas Sands & Older Dune Deposits, Upper, Middle, and Lower Paso Robles) at the start of the baseline simulation (October 2017) and their individual flow paths are tracked through the end of the 33-year baseline simulation (September 2050). Particles move with the groundwater and stop when they arrive at either a model boundary or a production well, or when the simulation ends.

Effective Porosity Parameter

The groundwater flow rate represented in Darcy's Law, which forms the basis for the groundwater flow equations used in the model, represents the groundwater velocity averaged over the total cross-sectional area of aquifer material. The actual travel velocity of a particle of water—or solute moving with the water—is greater, as the water flows through only the fraction of the cross-sectional area that represents the pore spaces between the solid grains. For this reason, the actual groundwater travel velocity is inversely dependent on the effective porosity of the aquifer material. The effective porosity represents the fraction of the total aquifer volume (both pore space and solid grains) through which water actually flows (i.e.*,* only the connected pore space). For the same volumetric flux, a higher effective porosity produces a slower particle travel velocity, and a smaller effective porosity produces faster travel velocity, because the same amount of flow is concentrated through a smaller cross-sectional area.

For a regional scale model, like the Seaside Model, where aquifers may be represented by a single model layer, the effective porosity parameter can also take on a surrogate role of accounting for depth intervals within an aquifer that are thinner than the total vertical layer thickness represented in the model, which are more permeable and through which a greater portion of the flow is concentrated In this case, in order to represent faster flow through this depth interval in the model, it may be necessary to use values of effective porosity that are lower than the effective porosity value that could be measured in the laboratory for the bulk aquifer material, or than would be needed if using multiple thinner model layers to represent the same single aquifer. For example, this has been found to be the case in recent and ongoing work analyzing and calibrating the Model to match the results of tracer studies recently conducted in the Santa Margarita formation for the Pure Water Monterey project (M&A, 2021). Spinner log vertical flow profiling in the ASR wells indicates that 70% of the flow in the well is occurring through only the lower 20% of the Santa Margarita formation (Padre, 2002; Pueblo, 2008). The result of this is that to match the faster observed tracer travel times resulting from preferential flow through only a portion of the total formation thickness, effective porosities as low as 7-8% have been needed to calibrate the particle tracking models (M&A, 2021)[6].

The Seaside model has been calibrated to groundwater levels but not to solute transport travel times, and as such the effective porosity of each aquifer is not currently a calibrated value in the model. For this reason, the particle tracking analysis evaluates a range of effective porosities to provide an upper and lower range estimate for potential inland travel times. A spatially uniform effective porosity of 8% is chosen to represent the higher range of potential travel velocities and an effective porosity of 16% to represent a lower velocity range. For comparison, previous estimates of average coastal influx rates used a higher effective porosity of 20% (Hydrometrics WRI, 2013).

It needs to be emphasized that particle tracking is not a substitute for full seawater intrusion modeling. Particle tracking represents the advective[7] transport of freshwater and does not account for the gradients due to density differences between saltwater and freshwater, or hydrodynamic dispersion and mixing, such as would be represented by using a density-dependent flow and transport model such as SEAWAT. The basin model has been spatially discretized[8] and calibrated specifically to evaluate changes in water levels and water fluxes at a basin subarea scale, and not specifically to evaluate solute transport travel times. As such, particle tracking based on the basin model will have limitations based on the vertical and horizontal model grid cell size. Particle tracking also does not tell us where the interface between freshwater and seawater is located currently or where it will be in the future. What particle tracking can provide is a range of potential groundwater travel rates from the coastline under different potential basin conditions, and as such can provide insights into the time scales and distances at which further inland intrusion could occur if early signs of seawater intrusion are detected in coastal monitoring wells.

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[6] Ongoing analysis of preliminary results from a more sensitive fluorescent dye tracer study suggest effective porosities as low as 5% may be needed.

[7] Advection refers to a solute being carried along with the bulk or average movement of groundwater, at the average local groundwater velocity, and does not include the additional spreading of solutes due to hydrodynamic dispersion that would lead to a lower concentration leading edge traveling faster than the average groundwater flow.

[8] Spatial discretization refers to the horizontal model grid cell size and model layer thicknesses selected to represent the groundwater basin by means of a numerical model. The finer the spatial discretization (e.g. smaller grid cells, thinner layers) that is chosen, the more detailed and refined the numerical representation can become, but at a tradeoff of increased computational complexity and data requirements. The degree of spatial resolution needed for accurately modeling solute transport is often greater than the spatial resolution needed to model average water levels and fluxes.

Particle Tracking Results

The results of the particle tracking simulations for model layers 1 (Aromas Sands & Older Dune Deposits) and layers 2 through 4 (Upper, Middle, and Lower Paso Robles) are presented on Figure 6 through Figure 9, focused on the Northern Coastal Subarea of the Seaside Subbasin. For each model layer, the figures show the path taken by each particle, after it is released at the coastline, over the entire 33-year baseline simulation period. The left-hand panel of each figure shows the results particle paths with an assumed layer effective porosity of 8%, while the right-hand panel shows the results for an assumed effective porosity of 16%. The particle paths are color-coded by travel time, with each color band representing a 5-year increment of time traveled since the particle was first released at the coastline at the start of the simulation. For example, the red color represents the position(s) of the particle in the first 5 years, orange represents the position in years 5 through 10, *etc*.

Note that only model layers 1 and 2 have active coastal grid cells across the entire shoreline in the Southern Coastal Subarea. Layers 3 through 5 pinch out just south of the boundary between the Southern and Northern Coastal Subareas where the Monterey Formation occurs at very shallow depths on the south side of the Seaside Fault. So, particles cannot be tracked from the Southern Coastal Subarea coastline in the deeper layers. In the 2 shallower layers, the flow is always in the offshore direction, consistent with the observations that water levels in the Southern Coastal Subarea are already at or above protective elevations. The particles tracks for Layer 1 and Layer 2 for the Southern Coastal Subarea are shown in Figure 10 and Figure 11.

Some general observations can be made by comparing the results for each layer

- For all model layers, the particles under the 8% effective porosity assumption travel significantly faster and further than under the 16% effective porosity assumption, as would be expected.
- As shown on Figure 6, for Layer 1 (Aromas Sands & Older Dune Deposits), the movement of particles (and the flow of water) in the basin is almost entirely in the offshore direction for the entire simulation except in the vicinity of Sentinel Well #3 along the subbasin boundary with the Monterey Subbasin. In the first 10 years of the simulation there is some movement of particles from the Monterey Subbasin into this area, but these appear to then move back toward the coast or toward the Monterey Subbasin as water levels in the Seaside Subbasin rise relative to the water levels in the Monterey Subbasin, reversing the flow gradients. Particles released along the coastline in the neighboring Monterey Subbasin appear to travel quickly large distances inland due to a combination of higher modeled hydraulic conductivities in this area and the inland gradients generated by the hydraulic heads assigned along the northern boundary of the

model. The portions of the Seaside Subbasin groundwater Model that represent areas outside of the boundaries of the Seaside Subbasin itself have not been the primary focus of model development and calibration, so the results in those areas have a greater degree of uncertainty than areas within the Seaside Subbasin itself.

- In Layer 2 (Upper Paso Robles), as shown on Figure 7, the movement of particles (and the flow of water) in the basin starts off in the first 5 years initially as moving very slowly in an inland direction in the northern half of the Northern Coastal Subarea, and moving offshore in the southern half, and then switches to almost entirely moving in the offshore direction as water levels rise. As in Layer 1, there is some inland crossflow at the boundary in the vicinity of Sentinel Well #3 along the subbasin boundary with the Monterey Subbasin. And similarly, particles released along the coastline in the neighboring Monterey Subbasin appear to travel quickly large distances inland due to a combination of higher modeled hydraulic conductivities in this area and the inland gradients generated by the hydraulic heads assigned along the northern boundary of the model.
- In Layer 3 (Middle Paso Robles), as shown on Figure 8, the movement of particles is initially inland at very slow rates, and then reverses to the offshore direction. The offshore flow is at very low rates in the northern and southern portions of the Northern Coastal Subarea, while in the central portion of the coastline, this offshore flow appears to be much faster, reflective of both higher hydraulic conductivities in this portion of the model, and because this area is directly downgradient from the PWM recharge areas. There is consistent inland flow in the vicinity of Sentinel #3 and the bordering areas of the Monterey Subbasin but at much smaller rates than simulated in Layers 1 and 2.
- As shown on Figure 9, the inland movement of particles in Layer 4 (Lower Paso Robles), is much greater than in the other layers. The movement of particles is initially inland at relatively high rates, penetrating almost half a mile in the first decade in the area around PCA-W and PCA-E before the flow gradients reverse to be in the offshore direction for some time. There is also significant and consistent inland flow in the vicinity of Sentinel #3 and the bordering areas of the Monterey Subbasin, though as simulated this flow appears to be directed further in the direction of the Marina area rather than further into the Seaside Subbasin. The greater inland flow rates and distances in Layer 4 as compared to Layers 1 through Layer 3 are a function both of the Model having higher calibrated hydraulic conductivities for the layer and of greater inland gradients. The area of fastest and greatest inland travel in the region of PCA-W lines up with the regional cone of depression resulting from several larger production wells that are partially screened across the Lower Paso Robles, such as Luzern, Ord Grove, Paralta, and Seaside Muni 4, and is also a zone where calibration of the model suggests higher hydraulic

> conductivities than the areas on either side. The modeling identifies this area of the Lower Paso Robles as having the highest risk of seawater intrusion.

The sequence of projected hydrologic conditions in the baseline simulation is based on the repetition of historical hydrologic data. A different sequence of wet and dry years, for example a greater number of dry years early on, would change the picture and could show much further inland penetration.

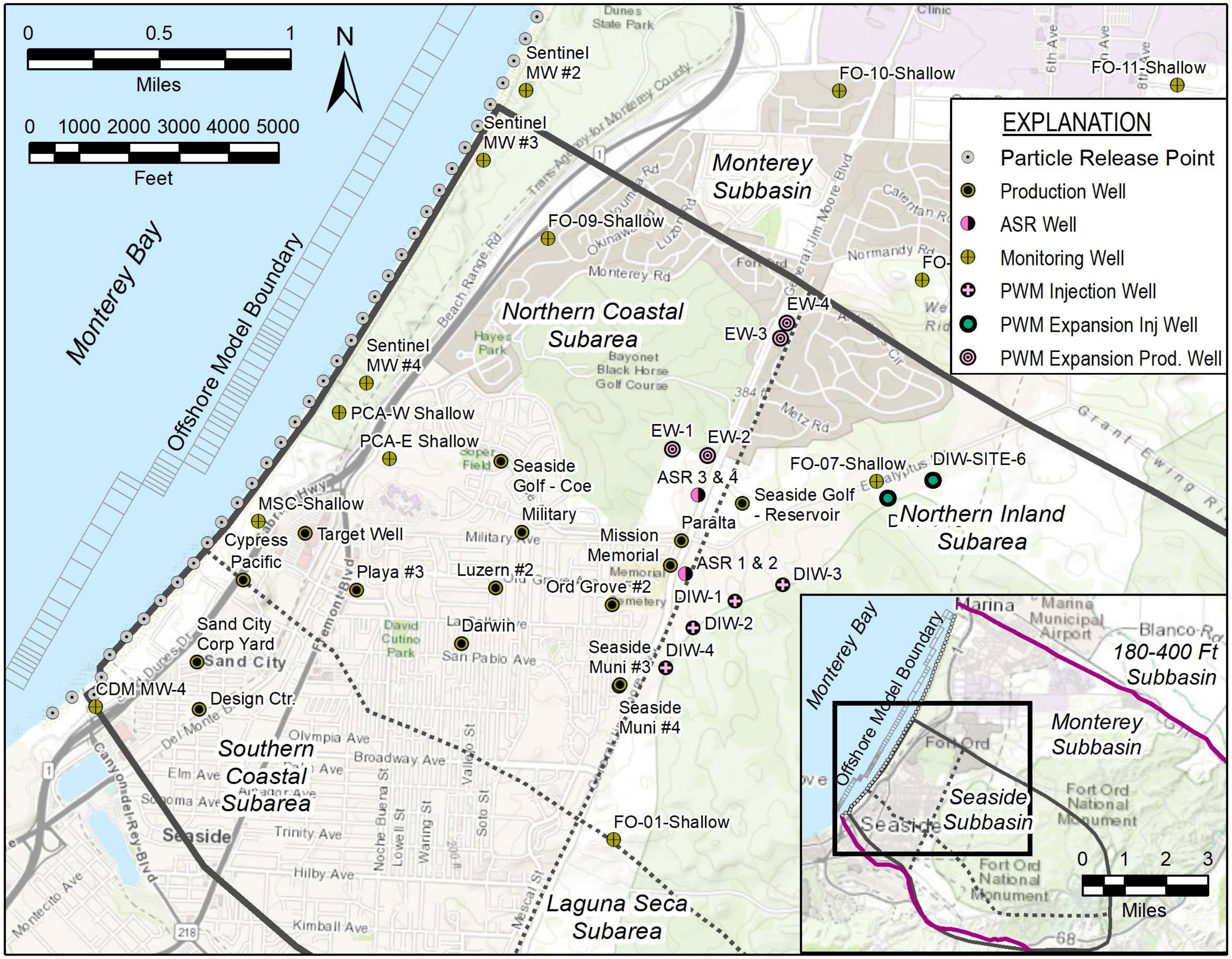

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Figure 5. Particle Release Points Along the Coastline

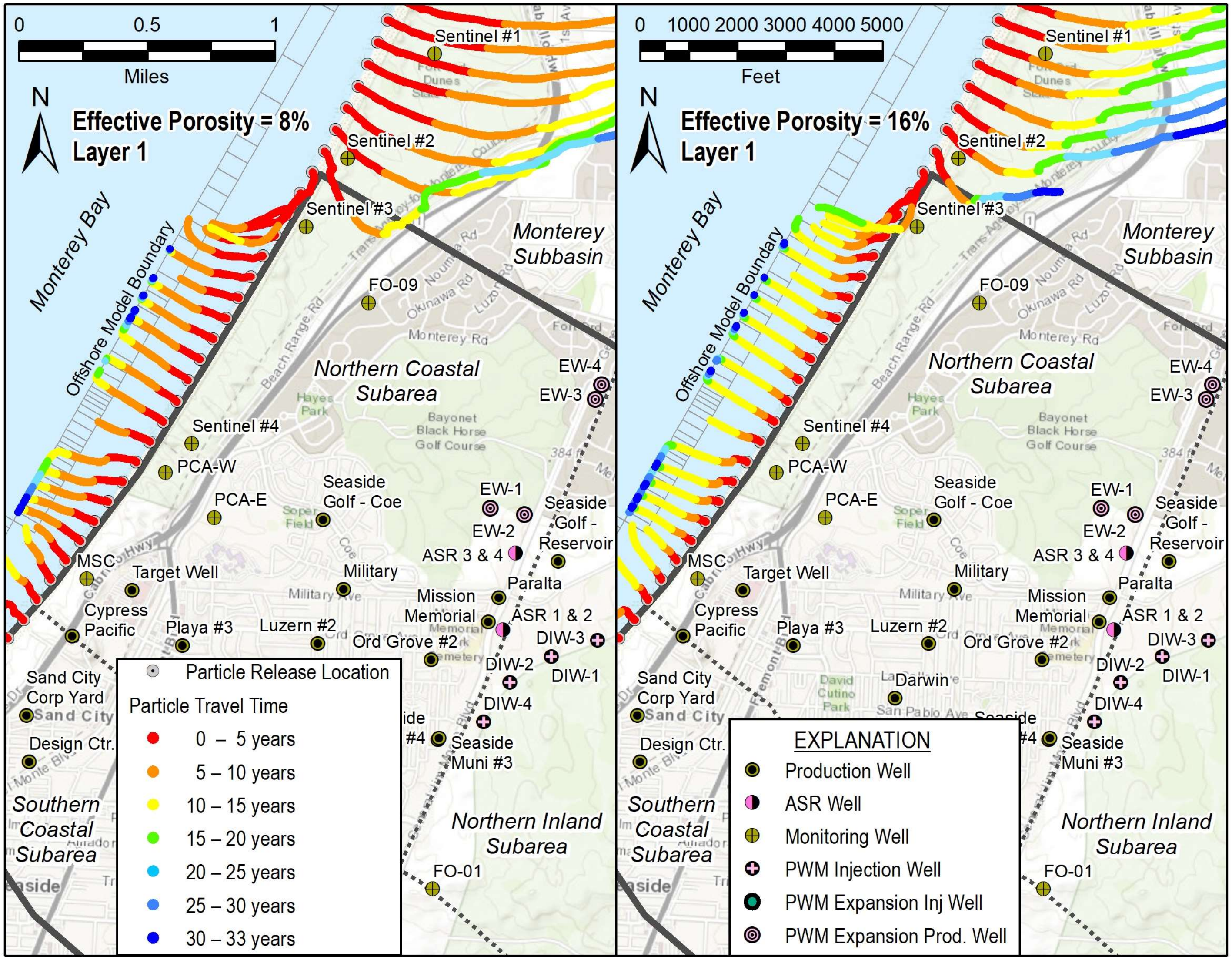

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Figure 6. Particle Tracks in Layer 1 (Aromas Sands & Older Dune Deposits) for 8% and 16% Assumed Effective Porosity

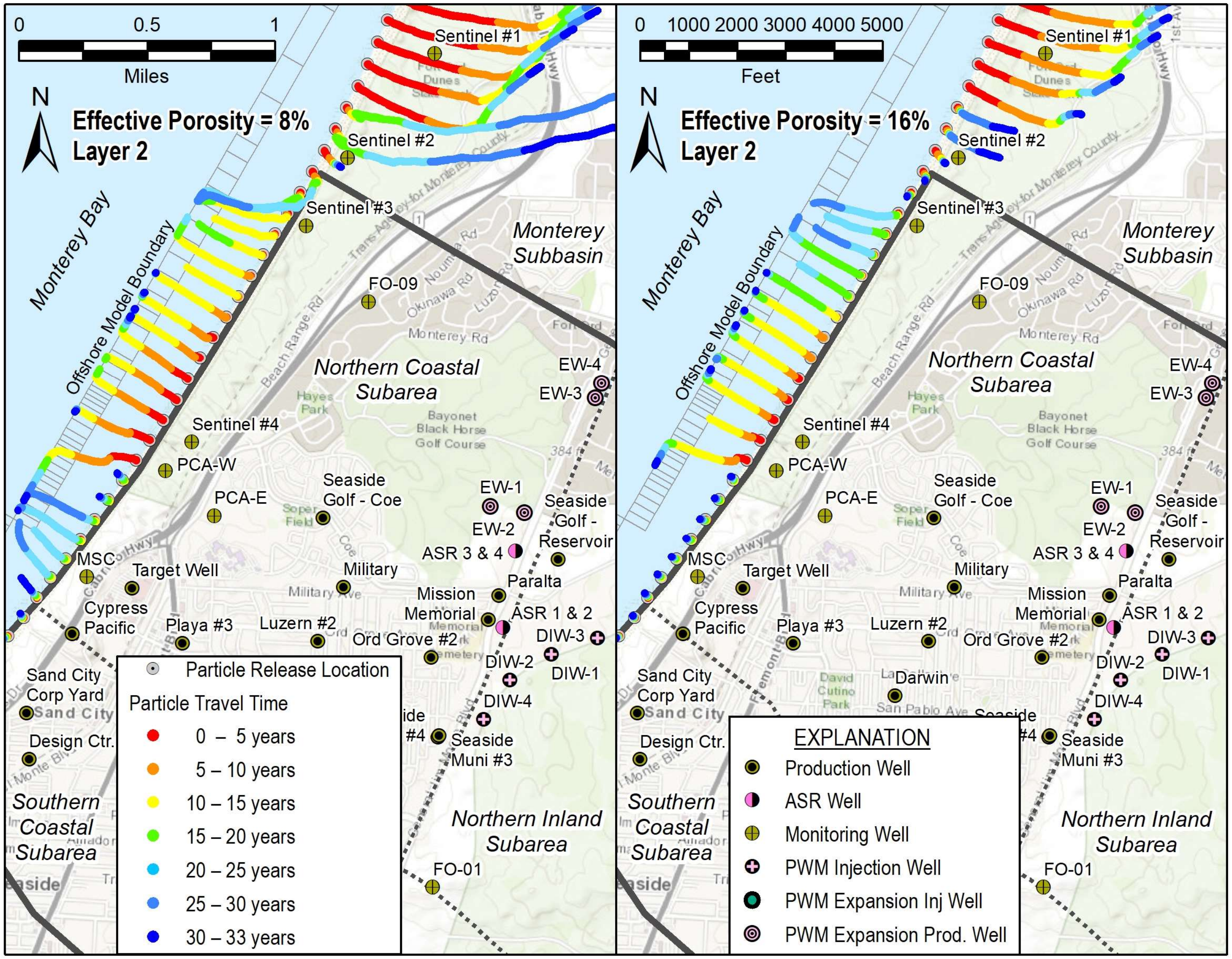

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Figure 7. Particle Tracks in Layer 2 (Upper Paso Robles) for Assumed 8% Effective Porosity

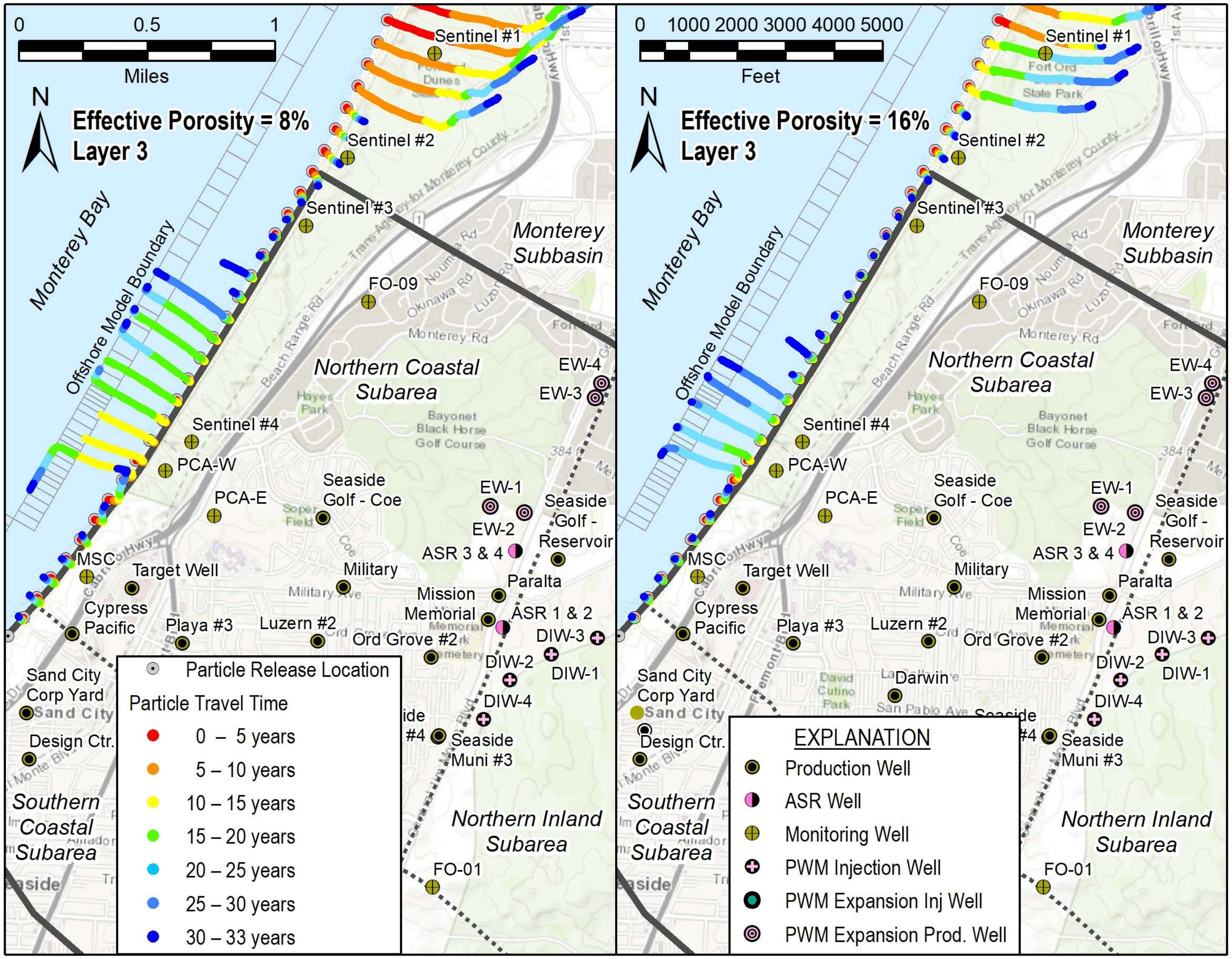

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Figure 8. Particle Tracks in Layer 3 (Middle Paso Robles) for Assumed 8% Effective Porosity

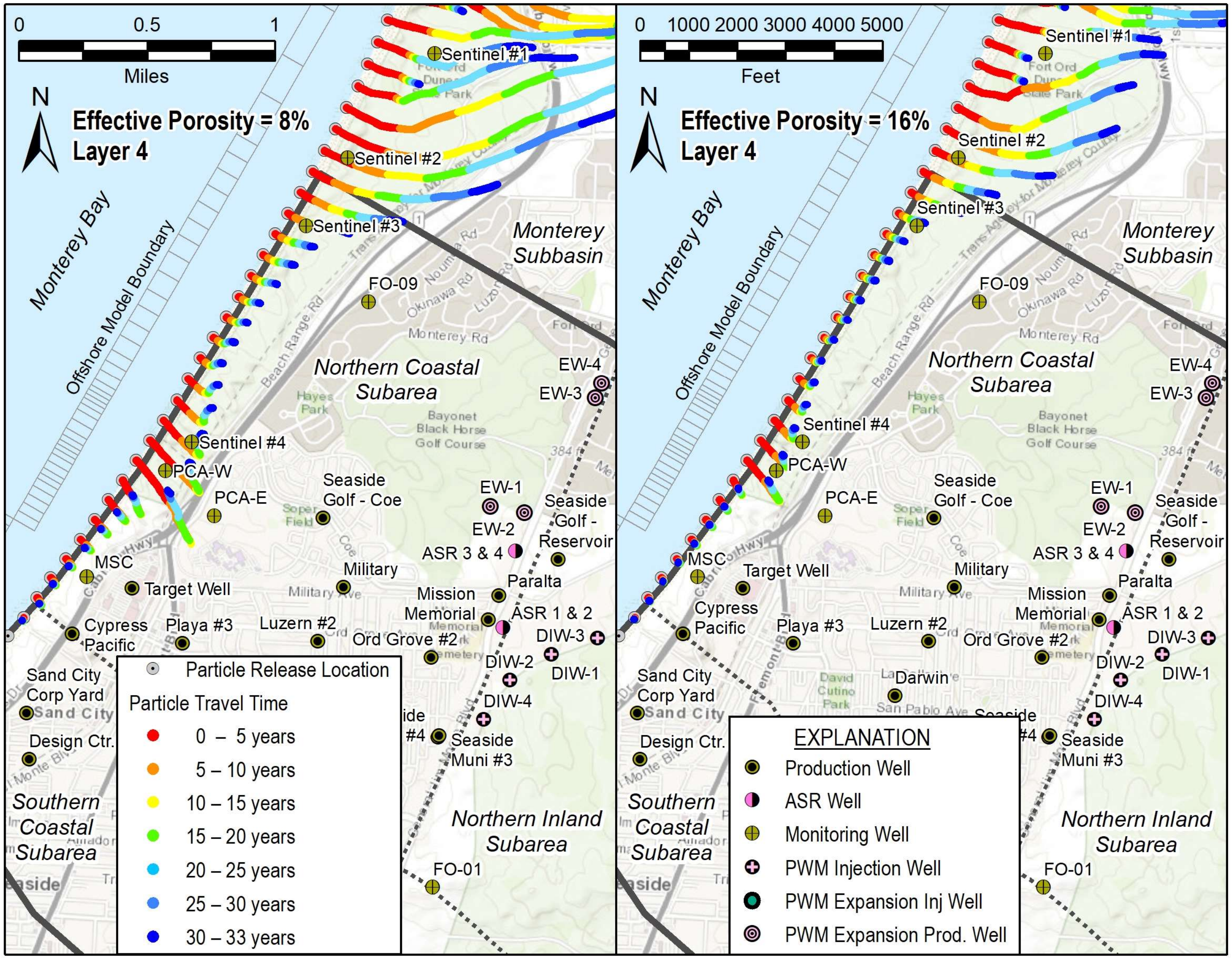

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Figure 9. Particle Tracks in Layer 4 (Lower Paso Robles) for Assumed 8% Effective Porosity

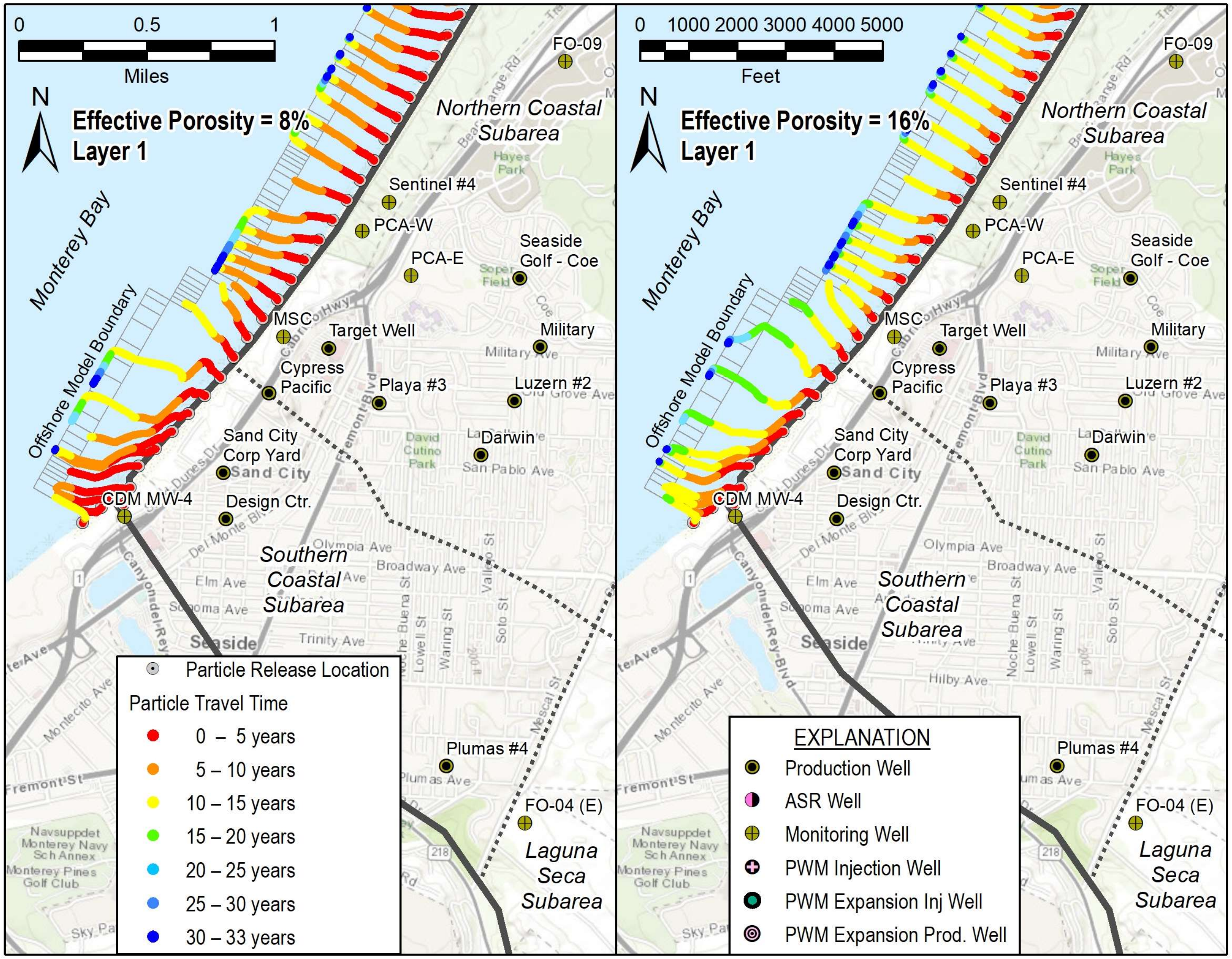

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Figure 10. Particle Tracks in Southern Coastal Subarea Layer 1 (Lower Paso Robles) for Assumed 8% Effective Porosity

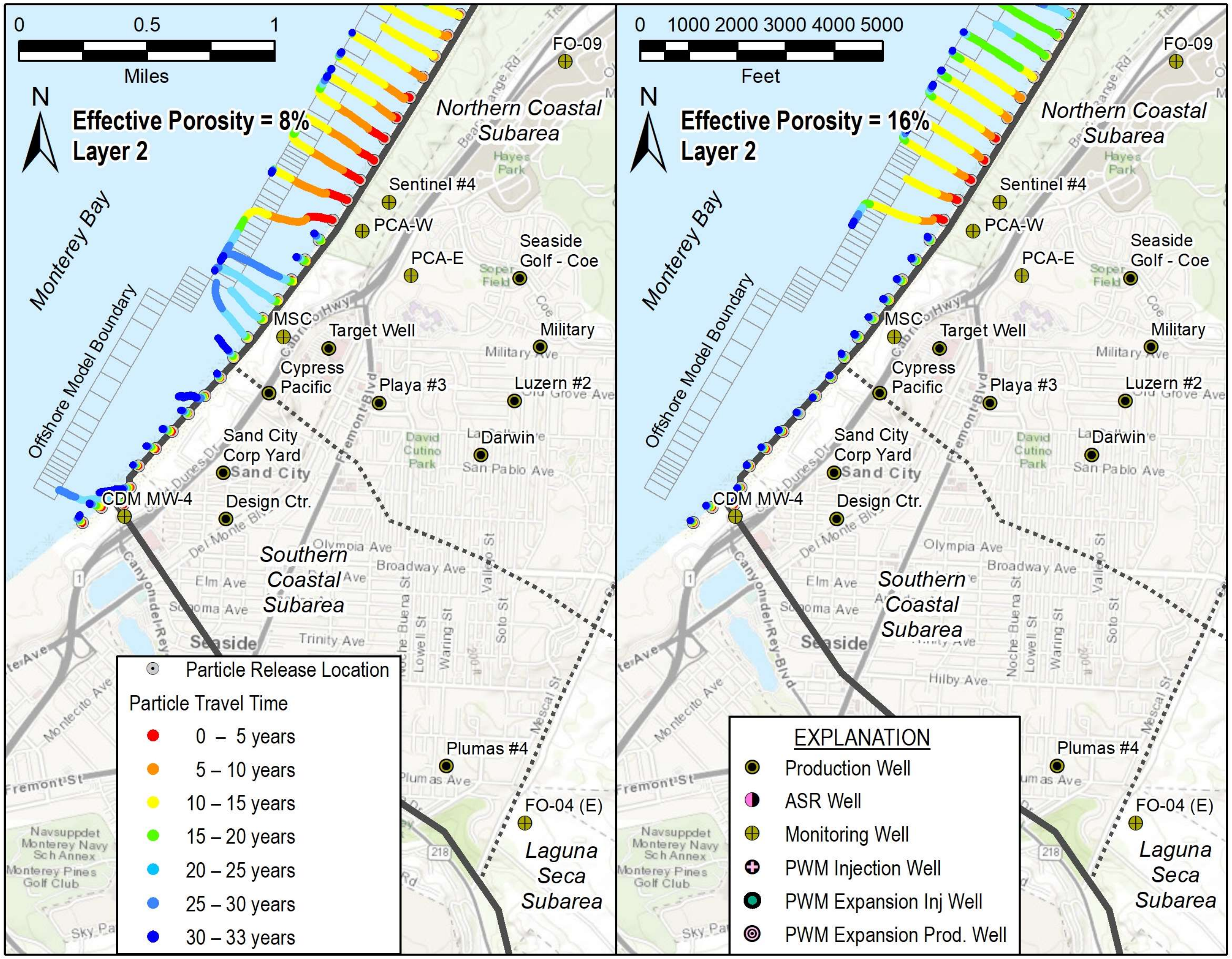

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Figure 11. Particle Tracks in Southern Coastal Subarea Layer 1 (Lower Paso Robles) for Assumed 8% Effective Porosity

Inland flow velocities

A zoomed in view of the area of fastest inland penetration in Layer 4 is shown on the inset map of Figure 12. The graph on the left of the figure shows the annually average inland velocity (in feet per year) of the fastest particle track trace outlined by the blue rectangle in the inset map, over the simulation period for the 8% effective porosity scenario. Values greater than zero represent the inland velocity when the particle is traveling inland from the coastline, and negative values represent velocity of travel toward the coastline. The numbered bullet points on the map and the graph represent simulated periods with different operational and hydrologic conditions in the basin as follows:

1. This first period represents current conditions in the basin under current operations before the simulated planned projects begin in WY 2024 and reflective of prolonged multi-year drought conditions that limit natural recharge and ASR recharge. Inland groundwater levels are at their lowest, creating conditions of maximum seawater intrusion potential with the highest inland flow velocity (as high as 250 feet inland per year). On the inset map this period is shown as the red color-coded portion of the particle paths.

2. This period represents when the projects come online in WY 2024 and after the multi-year drought period ends. The particles are still moving inland from the coast, but at increasingly slower velocity as groundwater levels in the basin rise reducing the inland hydraulic gradients. This is shown as the orange and yellow segments on the particle path map.

3. This period represents the transition period when the gradient reverses from a condition of inflow from the offshore area to one of outflow toward the ocean, with the groundwater levels reaching their highest simulated point, buoyed by 5 back-to-back extremely wet and above-normal wet years that allow for large amounts of net-ASR recharge. The particles no longer move any further inland and begin moving back toward the ocean.

4. This period represents conditions when flow gradients are still in the offshore direction, and the particles move back toward the ocean at a generally steady rate that fluctuates with changes in WY type and begins to decrease after a critically dry year in WY 2041 (shown in the green, cyan, and light blue particle colors on the map).

5. This final period represents the effects of a new multi-year drought that significantly reduces ASR and PWM recharge and allows groundwater levels to drop to the point that the flow gradient reverses again. The particles begin to move inland again, though at a much slower rate than during the earlier inland flow period, ending at rate of 50 feet of inland travel per year in the simulated WY 2050.

Potential Inland Travel Times of Seawater Interface Along a Preferential Flow Path

The analysis in the previous section allows us to develop a range of inland flow rates along the coastline that can be associated with different hydrologic and operational conditions in the basin. From the perspective of the threat posed by potential seawater intrusion, the temporal and spatial distribution of seawater intrusion in the Salinas Valley suggests that seawater intrusion occurs not as a uniform front moving inland across the entire coastline at one rate, but rather occurs and advances largely as localized fingers or lobes where the combination of both inland gradients and aquifer properties create preferential pathways for inland intrusion. In this context it makes sense to focus the next step of our analysis on evaluating how quickly and how far could the seawater interface move inland from the coastline along one such fast pathway, such as the one that formed around the area of PCA-W, under conservative worst-case conditions.

The seawater interface moves not as a sharp interface, but rather as a diffuse transition zone between freshwater and full-strength seawater, as depicted conceptually on Figure 13. The seawater interface transition zone can be characterized by the distance between the leading edge at some threshold salinity level that is much lower than full strength seawater, but above the native groundwater salinity, and a midpoint between the leading edge and full-strength seawater. The midpoint would usually already represent a very high salinity concentration that is much greater than groundwater quality objectives for the basin.

For our analysis we assumed that the basin conditions that resulted in the fastest simulated pre-WY 2024 travel rates are held constant and that the seawater interface moves inland from the coast at that same maximum rate of 250 feet per year for the 8% effective porosity scenario. Additionally, we do not account for the fact that the travel velocity will accelerate closer to an active production well because of the exponential steepening of the gradients around the cone of depression that forms around a pumping well. For these assumed conditions, Figure 14 shows a graph of distance traveled inland from the coastline versus travel time. For a given distance inland on the vertical axis, one can read off the estimated travel time from the coastline on the horizontal axis. For reference, the names of several production and monitoring wells in the area are shown, placed vertically at their respective distances inland from the coastline. For this scenario for example, it could take as little as 1 year between when the leading edge of seawater interface is observed at a coastal monitoring well such as PCA-W and when the seawater interface would reach smaller wells located close to the coast, such as the small SNG or Calabrese/Cypress wells located only 1,000 feet from the coastline. For a well a bit further inland, such as Playa 3 at a distance of 3,800 feet from the coastline, it could take on the order of 9 years of travel time to arrive after detection of the leading edge at a coastal monitoring well. If we were to hypothetically assume a seawater interface transition zone width of 2,000 feet and assume that the midpoint of the seawater interface moves at the same rate as the leading edge, it would take as little as 4 years between when the leading edge of the seawater interface is observed at a monitoring location and when the very high concentration of the midpoint arrives at that well.

It should be emphasized that there are a lot of assumptions and unknowns at play here, so these estimates should be taken only as order of magnitude values to provide a sense of the possible scale of travel times and distances. There are no data currently available on the position of the seawater interface offshore, or the width of the transition zone. Similarly, there are no data sets that allow us to identify where potential preferential paths may be located and to improve the estimates of the effective porosity. Analysis of the ongoing PWM added tracer study indicates that effective porosity parameter values as low as 5% may be needed to represent travel times between PWM injection wells and downgradient production wells in the Santa Margarita formation. So, while the assumed 8% effective porosity scenario may be representative of fast travel times, it may not necessarily represent the fastest possible travel rates that could occur.

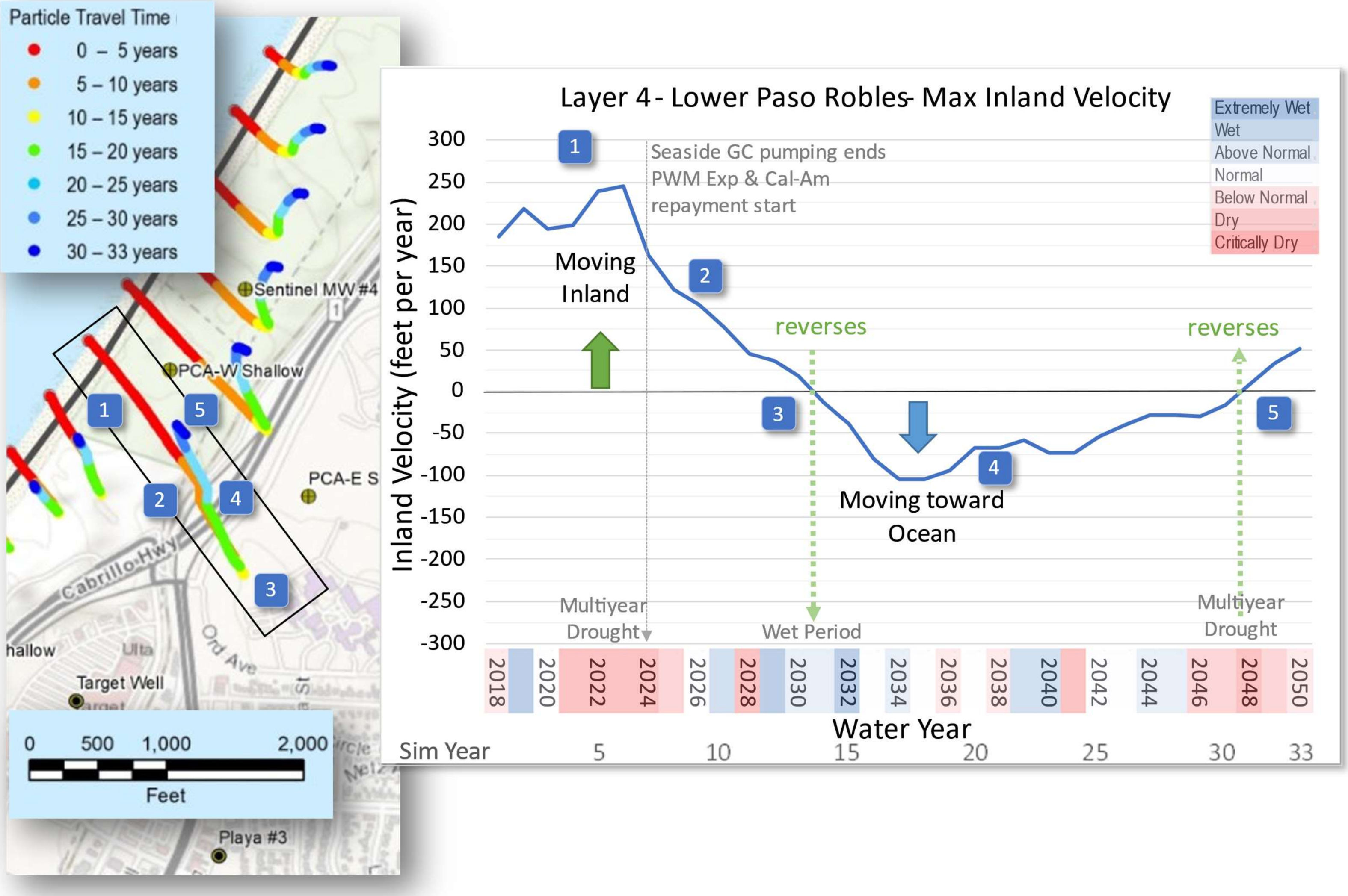

Figure 12. Particle Flow Paths and Inland Velocity Along Fastest Pathway for 8% Effective Porosity Scenario

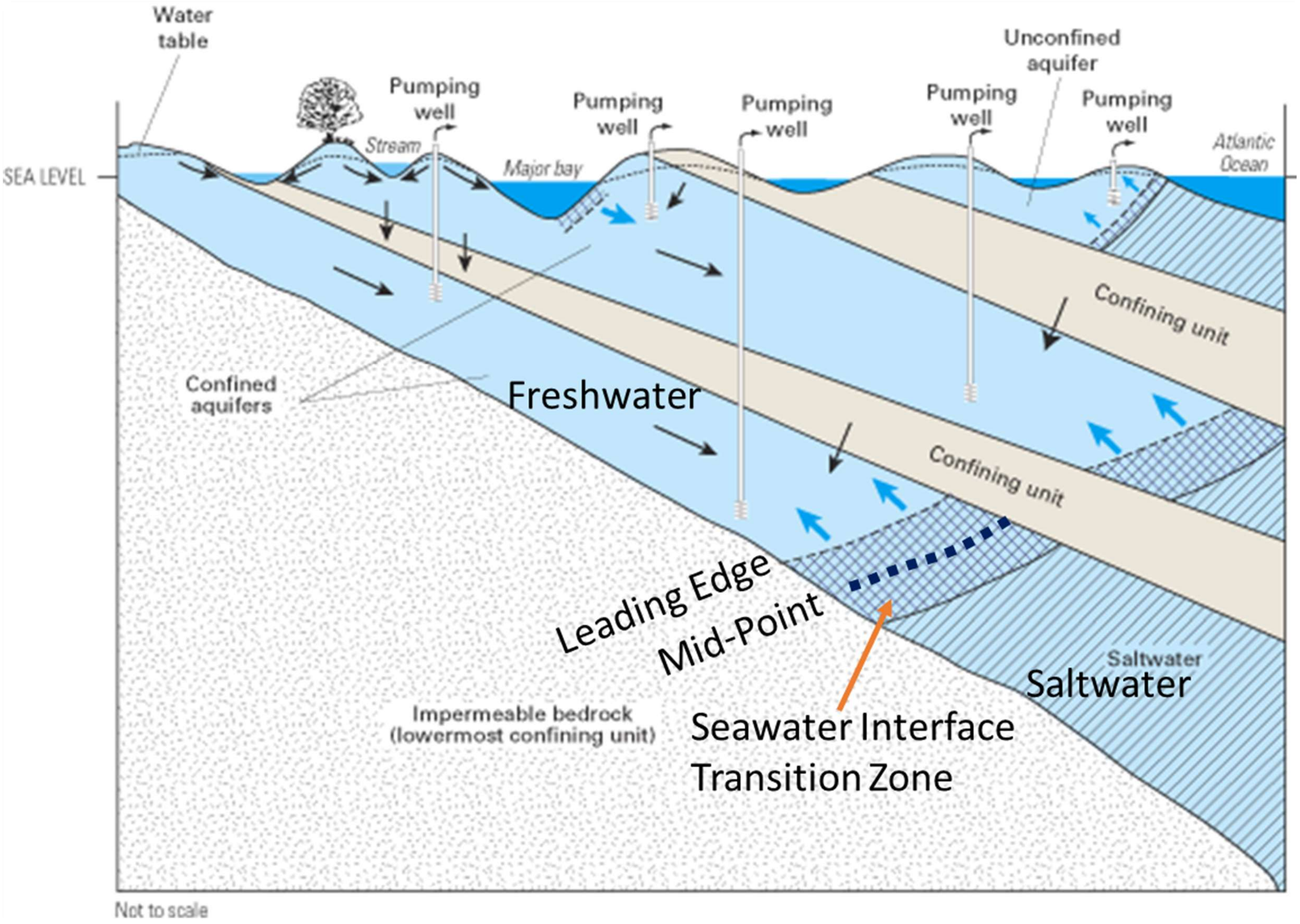

Figure 13. Schematic Representation of Inland Movement of Seawater Interface (Modified from Barlow, 2003)

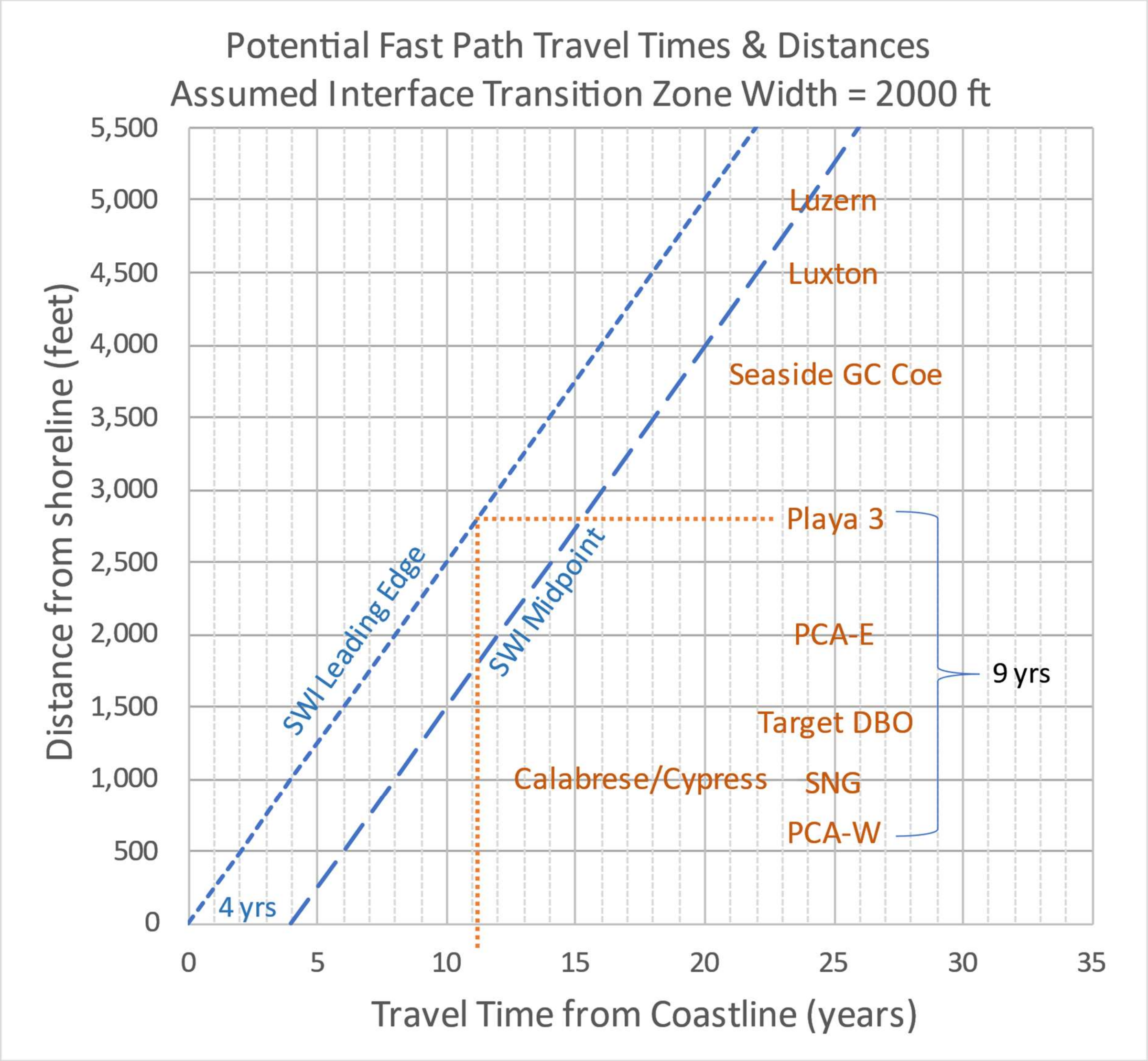

Figure 14. Potential Maximum Inland Travel Times and Distances Along a Preferential Flow Path

Conclusions & Considerations

1. In Layers 1 (Aromas Sands & Older Dune Deposits) and Layers 2-3 (Upper and Middle Paso Robles) flow in the basin is predominantly in the offshore direction during the simulation period.

2. Offshore flow rates increase and accelerate as recharge operations in the basin increase post WY 2024 because of planned project operations and periods of wetter simulated hydrologic conditions that allow for increased net recharge.

3. The most significant inland flows (in terms of both rates and distance) occur in Layer 4 (Lower Paso Robles) in the Northern Coastal Subarea. The fastest travel times are concentrated in line with the main pumping depression where production wells are screened in the Lower Paso Robles and where model calibration also has resulted in higher hydraulic conductivity values.

4. Maximum inland flow velocities of up to 250 feet per year are simulated under current and near-term basin conditions (e.g., pre-WY 2024), and are shown to decrease as basin groundwater levels rise and can reverse direction as gradients change from an inland to an offshore direction due to rising water levels in the basin. Faster travel rates are possible depending on the nature of preferential flow paths.

5. The inland velocities and travel distances are sensitive to changes in hydrologic conditions that impact the amount of water available for net ASR recharge in the basin. Periods of prolonged drought will increase potential inland travel rates and increase the seawater intrusion risk. The sequence of projected hydrologic conditions in the baseline simulation represents only a single realization of many possible future hydrology scenarios. If desired, other future climatic conditions could be considered for future modeling.

6. Inland flow in the Monterey Subbasin and cross-boundary flows between the Seaside and Monterey Subbasins may be dependent on assumptions on the groundwater levels assigned to the model in the Marina/Ord area and the assumptions that these remain unchanged should be reviewed and the impact evaluated.

7. More work and data would be needed to develop an understanding of where the seawater interface is currently located offshore of the basin, and to better characterize potential preferential flow paths along which seawater intrusion could move quickly inland.

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