APPENDIX C2

Analysis of Historic and Future Coastal Erosion with Sea Level Rise

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Memorandum

date	July 21, 2016
to	Insert to Appendix C2, Draft Environmental Impact Report/Environmental Impact Statement
from	Project Team
subject	Use of Coastal Erosion Technical Memorandum Titled: Analysis of Historic and Future Coastal Erosion with Sea Level Rise dated March 19, 2014

In support of the April 2015 Draft Environmental Impact Report (EIR) for the Monterey Peninsula Water Supply Project (MPWSP), ESA analyzed sea level rise and coastal erosion for the Monterey Bay coastline. The purpose was to describe coastal processes that could be relevant to assessing the environmental impacts of the MPWSP and its alternatives, and to identify potential damages to infrastructure from coastal erosion. The ESA report *Analysis of Historic and Future Coastal Erosion with Sea Level Rise*, dated March 19, 2014, was included in Appendix C2 of the 2015 Draft EIR. As discussed in the April 2015 Draft EIR, some of the project components would be affected by coastal erosion within the project lifetime and a mitigation measure was proposed to reduce the impact to less than significant.

Subsequently, the proposed action for the MPWSP was revised and is analyzed in this Draft Environmental Impact Report/Environmental Impact Statement (EIR/EIS). The proposed locations of some project components have been relocated. The results of the coastal erosion study are still applicable because the change in project component locations does not change the coastal erosion anticipated to occur in response to sea level rise. The updated locations of the proposed action components were compared to the anticipated extent of coastal erosion as shown on Figures 4.2-7 and 4.2-8, presented in Section 4.2, Geology, Soils, and Seismicity.

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memorandum

date March 19, 2014

to Michael Burns and Eric Zigas

from Elena Vandebroek, David Revell and Doug George

project Monterey Peninsula Water Supply Project (205335.01)

subject Analysis of Historic and Future Coastal Erosion with Sea Level Rise

1 Purpose and Scope

The Monterey Peninsula Water Supply Project (Project) proposes infrastructure that is located near or along the Monterey Bay coastline (Figure 1). Sea level is predicted to rise over the next century and could affect some of these project components. Coastal erosion, an ongoing issue in Southern Monterey Bay, is also expected to increase with accelerating sea level rise. The primary focus of this memo is to describe coastal processes that could be relevant to assessing the environmental impacts of the Project and the viability of Project alternatives, and to identify potential damages to Project infrastructure from coastal erosion. This memo is organized as follows:

Section 2 – Historic and existing erosion processes in Southern Monterey Bay
Section 3 – Future erosion in the face of accelerating sea level rise

2 Historic and Existing Erosion Processes

The following section summarizes the existing and historic processes affecting coastal erosion. These processes include Wave Climate and Storm Characteristics, Historic Shoreline Change Trends, Sand Mining, and Rip Embayments.

2.1 Wave Climate and Storm Characteristics

The coast of Monterey Bay is exposed to high energy waves throughout the year, with seasonal differences resulting in waves approaching from many directions. Wave data measured by offshore wave buoys show these seasonal and annual differences (Storlazzi and Wingfield 2005). The largest waves typically occur in the late fall and winter and are associated with wave generation in the Gulf of Alaska. These winter waves have long wave periods (12 to 14 seconds), large significant waves heights (~9 ft on average), and come from the northwest (310°) (Storlazzi and Wingfield 2005). In the spring, smaller wave heights and shorter wave periods result from strong northwest winds. In the summer, the coast is exposed to long period south swells. Point Piños partially shelters the coast from these waves, especially farther south in the bay, toward the City of Monterey. Estimates of recurrence intervals for large wave events can be statistically derived from a time series of wave data. For example, a 100-year wave event at the Monterey wave buoy (NDBC #46042) is projected to have an offshore significant wave height of 40 ft OR a dominant wave period of 32 seconds (Storlazzi and Wingfield 2005)[1]. This

[1] A swell period of 32 seconds is not expected to govern at the 100-year recurrence level because the associated wave height would be much smaller than the 100-year wave height of 40'. For this and a range of reasons beyond the scope of this memo, a shorter wave period would be associated with the governing 100-year swell.

means that every year, there is a 1% chance that waves will achieve the above combination of significant wave height and dominant period. Similar calculations can be made for more frequent storm events, such as 10-yr or 25-yr occurrences, which reflect the 10% and 4% annual probabilities respectively.

Large waves are not the only contributing factor to coastal erosion. A common indicator of coastal erosion is the *total water level*, which is the sum of tides, wave runup on the beach, and other atmospheric conditions which affect ocean water levels. When all of these constituents are added together, the resulting total water elevation provides a useful measure for projecting coastal erosion (Ruggiero et al 1996, Revell et al 2011). Historically, some of the most damaging wave erosion events have occurred during El Niño events, when wave directions shift more to the south and west and come less impeded into Monterey Bay. This more direct wave energy coupled with elevated ocean water levels (on the order of one foot[2]) can cause dramatic and often devastating erosion along the Monterey Bay coast.

The ideal situation to minimize damage to the desalination infrastructure is to avoid the dynamic beach environment, which will migrate inland over time from sea level rise. The storm waves discussed above drive the episodic erosion events that are typical in Monterey Bay, and periodically threaten existing development. Following these storm events, beaches can sometimes recover over a season or a few years. Other parts of the Bay are experiencing continuous erosion without full recovery, especially in southern Monterey Bay (see section 2.2).

2.2 Historic Shoreline Change Trends

It is essential to understand historic shoreline change trends in order to accurately project future erosion. Shoreline change data was compiled from a variety of sources and is summarized in Figure 2. This figure shows the locations of the MPWSP representative profiles shown on Figure 1 (discussed in detail later in this technical memorandum) and other landmarks relative to the historic accretion or erosion rates. Table 1 summarizes each of the datasets plotted in Figure 2. For the erosion analysis, we combined the updated shoreline change rates (#2) with the Thornton et al 2006 dune erosion rates (#1), where available. Thornton et al 2006 estimated recent erosion rates based on dune crest recession, which is a more robust estimate of erosion than shoreline change.

TABLE 1
EROSION RATE DATA SOURCES FOR SOUTHERN MONTEREY BAY

#	Dataset	Timespan	Notes
1	Thornton 2006, dune crest recession rate	1984 – 2002	This was the most detailed study available for erosion rates in the study area. Erosion was measured at 6 locations in Southern Monterey Bay. Erosion rates were interpolated between these measurements for this analysis.
2	Analysis by ESA for this study: short-term linear regression erosion rate calculated based on the 1933, 1998, and 2010 shorelines.	1932 – 2010	The 1932 and 1998 shorelines were obtained from Hapke et al 2006 and updated with a 2010 shoreline, extracted from a high resolution LiDAR DEM (NOAA 2012, collected in May/June 2010).
3	Hapke et al 2006, shoreline change rate	1945 – 1998	Not used in this analysis, included for context only.
4	Hapke et al 2007, soft bluff recession rate	1933 – 1998	Not used in this analysis, included for context only. This study was for the entire California coast, while Thornton 2006 focused on this study area.
5	Analysis by ESA for this study: long-term linear regression erosion rate calculated based on the 1852, 1933, 1998, and 2010 shorelines.	1852 – 2010	The 1852, 1932 and 1998 shorelines were obtained from Hapke et al 2006 and updated with a 2010 shoreline. Because sand mining, which started in 1906, plays such a large role in coastal erosion, these rates were not used in this analysis.

[2] Tide stations have recorded an increase in average winter water levels of about one foot during the strong 1982-3 and 1997-8 El Niños, and individual deviations above predicted tides of over 2’ during El Niño storms.

2.3 Sand Mining

The mining of sand can increase erosion rates, modify shoreline orientation, and change sand transport rates. Thornton et al (2006) suggests that the alongshore variation in dune recession rates is a function of wave energy and sand mining. Southern Monterey Bay has been mined intensively for sand for more than a century. Sand mining near the mouth of the Salinas River started in 1906, and expanded to six commercial sites: three at Marina and three at Sand City. Five of these operations closed by 1990, leaving the Pacific Lapis Plant in Marina (owned by CEMEX) as the only active sand mining operation.

2.4 Rip Embayments

Rip embayments have been correlated with dune erosion in Monterey Bay (Thornton et al, 2007). Also known as beach mega-cusps, rip embayments are localized narrowing and deepening of the beach. They are caused by the erosive action of cross-shore rip currents. The beach is the narrowest at the embayment, allowing swash and wave run-up to reach the toe of the dune and cause erosion during coincident high tides and storm wave events. In Monterey Bay, these embayments are on the order of 200 feet wide (alongshore and cross-shore), and occur at approximately 600-foot along-shore spacing intervals (MacMahan et al, 2006, Thornton et al, 2007). Rip currents are highly dynamic, migrating up to 12 feet per day (Thornton et al, 2007). Field observations of rip channels in Monterey Bay between Wharf II in Monterey and Sand City found that typical rip channels are 5 feet deeper than the adjacent beach face.

3 Projecting Future Erosion

Future erosion was analyzed at six locations along the study area (Figure 1) and assessed using two methods. The first was to look at the aerial extent of potential erosion. Coastal erosion hazard zones, which delineate areas potentially at risk from coastal erosion, are described and discussed in Section 3.1. The second method considers erosion on a vertical profile. Profiles were selected at locations of key infrastructure (Figure 1) and projected into the future. The methods and results of this analysis are described in Section 3.2.

3.1 Coastal Erosion Hazard Zones[3]

Coastal erosion hazard zones were developed using methods described in PWA 2009 and Revell et al 2011. A coastal erosion hazard zone represents an area where erosion (caused by coastal processes) has the potential to occur over a certain time period. This does not mean that the entire hazard zone is eroded away; rather, any area within this zone is at risk of damage due to erosion during a major storm event. Actual location of erosion during a particular storm depends on the unique characteristics of that storm (e.g. wave direction, surge, rainfall, and coincident tide). As sea level rises, higher mean sea level will make it possible for wave run-up to reach the dune more frequently, undercutting at the dune toe and causing increased erosion. This analysis used a sea level rise projection of 15 inches by 2040 and 28 inches by 2060, relative to 2010. These projections are based on a 2012 study by the National Research Council (NRC) which provided regional sea level rise estimates for San Francisco (the closest projection to the Project). The 2040 and 2060 values were derived by fitting a curve to the "Average of Models, High" projections for 2030, 2050, and 2100 published in the NRC study (NRC 2012).

[3] The coastal erosion hazard zones are being developed by ESA PWA as part of the ongoing Monterey Bay Sea Level Rise Vulnerability Study (anticipated completion in early 2014). The zones presented here are preliminary and are subject to change in the final maps delivered to the Monterey Bay Sanctuary Foundation (the client). However, particular attention was given to the Project focus locations. Therefore any final modifications are expected to be minimal at these locations.

Coastal Hazard Zone Model Development

The coastal hazard zones are developed from three components: historic erosion, additional erosion due to sea level rise, and the potential erosion impact caused by a large storm wave event (e.g. 100-year). The most important variables in the hazard zone model address these components (Table 2).

TABLE 2
COASTAL HAZARD ZONE MODEL COMPONENTS AND PRIMARY VARIABLES

Coastal Hazard Zone Component	Primary Variables
historic erosion	historic erosion trend
erosion due to sea level rise	backshore toe elevation, shoreface slope, sea level rise curve
erosion impact caused by a large storm wave event	storm total water level, beach slope, backshore toe elevation

This section gives a brief description of the erosion hazard zone methods. For more details about the methods please see the Pacific Institute study (PWA, 2009 and Revell et al, 2011).

The historic erosion rate is applied to the planning horizon (2010 through 2060 at 10 year increments) to get the baseline erosion, which is an indirect means to account for the sediment budget. Section 2.2 explains how historic erosion rates were selected for each location. The erosion model does not account for other shore management actions, such as sand placement, that could mitigate future shore recession. In this region, where beaches are controlled in part by sand mining, we assumed that there are no changes to existing sand mining practices.

The potential inland shoreline retreat caused by sea level rise and the impact from a large storm event was estimated using the geometric model of dune erosion originally proposed by Komar et al (1999) and applied with different slopes to make the model more applicable to sea level rise (Revell et al, 2011). This method is consistent with the FEMA Pacific Coast Flood Guidelines (FEMA, 2005). Potential erosion accounts for uncertainty in the duration of a future storm. Instead of predicting storm specific characteristics and response, this potential erosion projection assumes that the coast would erode or retreat to a maximum storm wave event regardless of duration. This is considered to be a “conservative” approach to estimating impact of a 100-year storm event because larger erosion estimates are produced.

Results

Figure 3 presents the coastal hazard zones, with detailed maps for each analysis location. These plan view maps do not represent the vertical extent of erosion, which is relevant to most of the proposed Project infrastructure which will be buried. As a result, the plan view maps indicated a more robust cross-shore profile analysis was needed to elucidate how Project infrastructure may be affected by coastal erosion.

3.2 Representative Coastal Profiles

The coastal profile analysis developed a set of representative profiles that show how the shoreline is likely to evolve from the present (2010) to 2040 and 2060, and the locations of selected Project components relative to those profiles. As previously discussed, the Monterey Bay shoreline is affected seasonally by localized erosion (rip currents), long term erosion, and sea level rise. Each of these factors is important in defining the horizontal and vertical elements of a profile shape and location through time. For this reason, we identify a projected future profile and an extremely eroded profile (lower envelope) for each future time horizon. The profiles contain both horizontal and vertical erosion. As described below, the future profile is the current profile eroded horizontally at the historic rate, with added erosion caused by sea level rise. The lower profile envelope represents a highly eroded condition, which could occur from a combination of localized erosion (rip currents), a large winter storm, and seasonal changes. The upper envelope (a highly accreted profile) was not analyzed because a key Project concern is the exposure of buried project components in the future.

Methods and Assumptions

Topographic and bathymetric data, summarized in Table 3, was compiled in the vicinity of the representative profiles specified by the ESA Project team (Figure 1). Three recent LiDAR profiles and one bathymetric survey were available. The locations of the Thornton representative profile envelopes (dataset #6 in Table 3), which were developed for a previous study (ESA PWA 2012), are located in the vicinity of the Project profiles at Sand City and to the east of Wharf II perpendicular to Del Monte Ave in Monterey.

TABLE 3
BATHYMETRY AND TOPOGRAPHY DATA USED TO DEVELOP REPRESENTATIVE PROFILES

#	Dataset	Date Collected	Elevation Limits (Approximate)	Source
1	Hydro-flattened bare earth digital elevation model (1 meter resolution)	May/June 2010	Minimum of ~0 ft NAVD	NOAA Digital Coast – CA Coastal Conservancy Coastal LiDAR Project
2	Bathymetry in offshore Monterey Bay (2 meter resolution)	Sept/Oct/Nov 2009	Maximum of -8 to -12 ft NAVD	California State University, Monterey Bay – Seafloor Mapping Lab
3	Bathymetry within Moss Landing Harbor (1 meter resolution)	June 2011	Maximum of -25 to -45 ft NAVD	California State University, Monterey Bay – Seafloor Mapping Lab
4	LiDAR topography (3 meter resolution)	April 1998 (post El Nino winter)	Minimum of ~0 ft NAVD	NOAA Digital Coast – Airborne LiDAR Assessment of Coastal Erosion Project (NOAA/NASA/USGS)
5	LiDAR topography (3 meter resolution)	Fall 1997 (pre El Nino winter)	Minimum of ~0 ft NAVD	NOAA Digital Coast – Airborne LiDAR Assessment of Coastal Erosion Project (NOAA/NASA/USGS)
6	Representative profiles and profile envelopes at Marina, Sand City, and Del Monte	Unknown – based on several surveys.	N/A	Published in ESA PWA 2012, originally Ed Thornton, unpublished data. Shown in Figure 4.

The raw profile data were processed as follows to develop a representative profile and a corresponding "highly eroded" profile for existing conditions:

1. A representative profile was created by combining the June 2010 LiDAR onshore with the 2009 fall California State University Monterey Bay (CSUMB) bathymetry offshore. The 2009 – 2010 winter was a minor El Nino year, resulting in a relatively eroded starting beach profile. A linear profile was interpolated between the offshore bathymetry and the terrestrial LiDAR. It is unlikely that the profile is linear, and more likely has a concave shape with one or more sand bars, depending on season and other factors. The surf and swash zone is highly dynamic and hence judgment is required to select a design profile. In this study, we account for this uncertainty in the eroded profile by using an envelope of possible shapes, based on perturbations from the estimated profile, as described in the following steps.
2. The Thornton envelopes (Figure 4) were horizontally aligned with the representative profiles using the backshore toe location as a reference feature, which is easily identified in all datasets. Since the profiles were not collected at exactly the same location and time as the representative profiles, some of profiles do not align as well in the upland areas. Since upland areas are much more static than the beach (the profile variability is much smaller), we do not focus on these areas in the profile evolution model, unless erosion through upland is expected.
3. As discussed above, rip currents can contribute to significant (~5 feet) lowering of the beach profile through the rip channel. The Thornton profiles were typically measured away from localized rip embayments. The profile envelope was adjusted to include uncertainty associated with rip channels by narrowing and

lowering the nearshore elevations. The beach berm was shifted shoreward by 50 feet or the distance between the berm crest and the dune toe (whichever was smaller), and the profile was lowered by 5 feet at MLLW. This adjustment assumes that the rip current would mainly impact the swash zone.

4. The profile envelope was lowered in any areas where the LiDAR or bathymetry data fell below the lower Thornton envelope. However, measured profile envelopes were unavailable for Profiles 1, 2, and 3. An envelope of shore profile elevation was created using Thornton's "Del Monte" profile (the most variable profile envelope located near Wharf II in Monterey). The vertical variability of the Del Monte profile was tabulated as a function of distance from shore, and then the elevations in Profiles 1, 2 and 3 were lowered accordingly.

Once a representative profile and lower profile envelope were identified for existing conditions, an equilibrium profile approach was used to shift the existing conditions profile and envelope based on projected erosion, which includes the historic erosion trend and future sea level rise (see Section 3.1). For profiles 1, 2, and 3, which show a historic trend in accretion, we include only the erosion due to sea level rise (setting the historic trend to 0). Detailed erosion rates were not available for these profiles, so erosion was calculated based on four shorelines (June 2010, April 1998, July 1952, and May 1933). The overall linear regression shows accretion, but the shorelines have fluctuated historically, and the most recent shoreline (spring 2010) is more eroded than the spring 1998 post-El Nino LiDAR. For this reason, we conservatively do not include the accretion signal.

The profiles were shifted horizontally inwards by the projected erosion and raised by the projected sea level rise. The existing dune elevations were held as maximums even though the profile shift would imply dune "growth" in some locations. The shifted profiles were truncated at the back beach location where the toe of dune starts. From this location, the profile was drawn sloping upward at the approximate angle of repose of loose sand, and truncated when the existing dune profile was intersected. The slope so drawn is an approximation of the eroded dune face extending from the beach to the top of the existing dune profile. An angle of 32 degrees was assumed for these locations (PWA, 2009). We did this because most of southern Monterey Bay shore is receding landward, erosion is cutting into relict dunes, and the steep dune faces and narrow beaches impede dune growth (Thornton et al 2006). Dune migration and other changes have not been modeled and dune elevations may change whether the shore is accreting or eroding due to changes in vegetation, other disturbance, etc. North of the Salinas River, the shore is accreting and dune growth appears to be occurring but accretion was neglected in these locations as well.

The lower profile envelopes do not necessarily encompass the full range of possible profile configurations. The profiles are not statistically defined or associated with a specific return interval. The profile construction did consider historic erosion, which includes a pre-El Nino shoreline and two post- El Nino shorelines, accelerated erosion from sea level rise, and an additional buffer factor associated with rip currents. The lower envelope for these profiles does not reflect potential dune erosion that could happen during a major (e.g. 100-year) storm event. This type of event could contribute as much as 100 feet of dune erosion. The representative profile may accrete or experience less erosion than projected, which would result in more sand covering the project components. This analysis is configured to provide estimates of the downward and inland extent of erosion, with the assumption that higher elevations are not a concern or are addressed by others.

Results

Figure 5 through Figure 11 show the existing (2010) and future (2040 and 2060) profiles and lower envelopes at each location. There are two profile/envelope combinations for each time step: one to represent long-term profile evolution (consisting of historic erosion and accelerated erosion from sea level rise) and a second that adds potential erosion from a 100-year erosion event, which could be as high as much as 125 feet, to the long-term profile.

Approximate locations and other descriptors of proposed Project infrastructure are shown on profiles where pipes or outfalls cross the profile. These data were provided by the applicant (California American Water Company) and are shown as a spatial reference to aid in the interpretation of the profiles. The geometry was not proposed by this study and may be revised based on this study and for other reasons beyond the scope of this document.

- At Moss Landing Harbor (Profile 1, Figure 5b), ongoing erosion is relatively low. The dune erosion envelopes extend inland 105 feet by 2060, with another 68 feet possible with a 100-year erosion event.
- Sandholdt Road (Profile 2, Figure 6). The dune erosion envelopes extend inland 105 feet by 2060, with another 65 feet possible with a 100-year erosion event.
- At Potrero Road (Profile 3, Figure 7). The dune erosion envelopes extend inland 120 feet by 2060, with another 30 feet possible with a 100-year erosion event.
- At the CEMEX Pacific Lapis sand mining plant (Profiles 4a and b, Figure 8 and Figure 9). The greatest uncertainty for these lies in the effects of sand mining, which are not explicitly addressed but may be implicitly addressed by the use of historic erosion rates. The dune erosion envelopes extend inland 300 feet by 2060, with another 130 feet possible with a 100-year erosion event.
- At Sand City (Profile 5, Figure 10). The dune erosion envelopes extend inland 180 feet by 2060, with another 40 feet possible with a 100-year erosion event.
- In the City of Monterey (Profile 6, Figure 11). The dune erosion envelopes extend inland 65 feet by 2060, with another 110 feet possible with a 100-year erosion event.

Assessment of methodology and accuracy of erosion envelopes

The methodology uses historic data and applied geomorphology methods generally consistent with coastal engineering and geology practice. There are sufficient data available to have confidence in the results. In general, we believe that the projections of potential erosion envelopes to be on the more conservative side and actual erosion may be less. The methodology addresses wave driven processes only, and assumes that historic changes are representative of future changes, and historic changes can be adjusted based on the rate of sea level rise. This analysis is consistent with our interpretation of the draft guidance recently published by the Coastal Commission[4]. It is important to note that actual sea level rise and the effects are not known, and that relatively high values were used in this study. Also, interventions may change shore recession.

Alternative estimates could be developed by computer-aided modeling of sand transport. For example, XBEACH and other available software can provide estimates of storm-induced profile erosion (USGS, 2009)[5]. Also, GENESIS and other available software can provide estimates of future shoreline positions[6]. Such further analysis may enhance the ability to assess the likelihood of shore recession estimates presented herein.

[4] California Coastal Commission's Public Review Draft, Sea-Level Rise Policy Guidance, dated October 14, 2013

[5] http://oss.deltares.nl/web/xbeach/

[6] http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Software;34

List of Figures

References

ESA PWA (2012). "Evaluation of Erosion Mitigation Alternatives for Southern Monterey Bay." Prepared for Monterey Bay Sanctuary Foundation and The Southern Monterey Bay Coastal Erosion Working Group on May 30, 2012.

California State University Monterey Bay (CSUMB) (2009-2010). Marine habitat mapping data for the Southern Monterey Bay region. California Coastal Conservancy, Ocean Protection Council, Department of Fish and Game, and the NOAA National Marine Sanctuary Program. Available online: http://seafloor.csumb.edu/SFMLwebDATA_mb.htm

Hanson, Hans (1989). GENESIS-A generalized shoreline change numerical model. Journal of Coastal Research, 5(1), 1-27, Charlottesville (Virginia). ISSN 0749-0208.

MacMahan, J.H., E.B. Thornton, and J.H.M. Reniers (2006). "Rip current review." Coastal Engineering: 53:191-208.

NOAA (2012). "2009 – 2011 CA Coastal Conservancy Coastal LiDAR Project: Hydro-flattened Bare Earth DEM." NOAA Coastal Services Center. Charleston, South Carolina. Available online: http://www.csc.noaa.gov/dataviewer/#.

NRC (2012). "Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future." Prepublication. National Academy Press: Washington, D. C.

PWA (2004). "Southern Monterey Bay Coastal Erosion Services." Memo prepared for the Monterey Regional Water Pollution Control Agency (MRWPCA). November 24, 2004. PWA Project #1729.00.

PWA (2009). "California Coastal Erosion Response to Sea Level Rise - Analysis and Mapping." Prepared for the Pacific Institute.

Revell, D.L., R. Battalio, B. Spear, P. Ruggiero, and J. Vandever, (2011). A Methodology for Predicting Future Coastal Hazards due to Sea-Level Rise on the California Coast. Climatic Change 109:S251-S276. DOI 10.1007/s10584-011-0315-2.

Stockdon, H., R. Holman, P. Howd, and A. Sallenger (2006). “Empirical parameterization of setup, swash, and runup.” Coastal Engineering: 53:573-588.

Storlazzi, C.D. and D.K. Wingfield (2005). "Spatial and Temporal Variations in Oceanographic and Meteorologic Forcing Along the Central California Coast, 1980 - 2002." USGS Scientific Investigations Report 2005-5085.

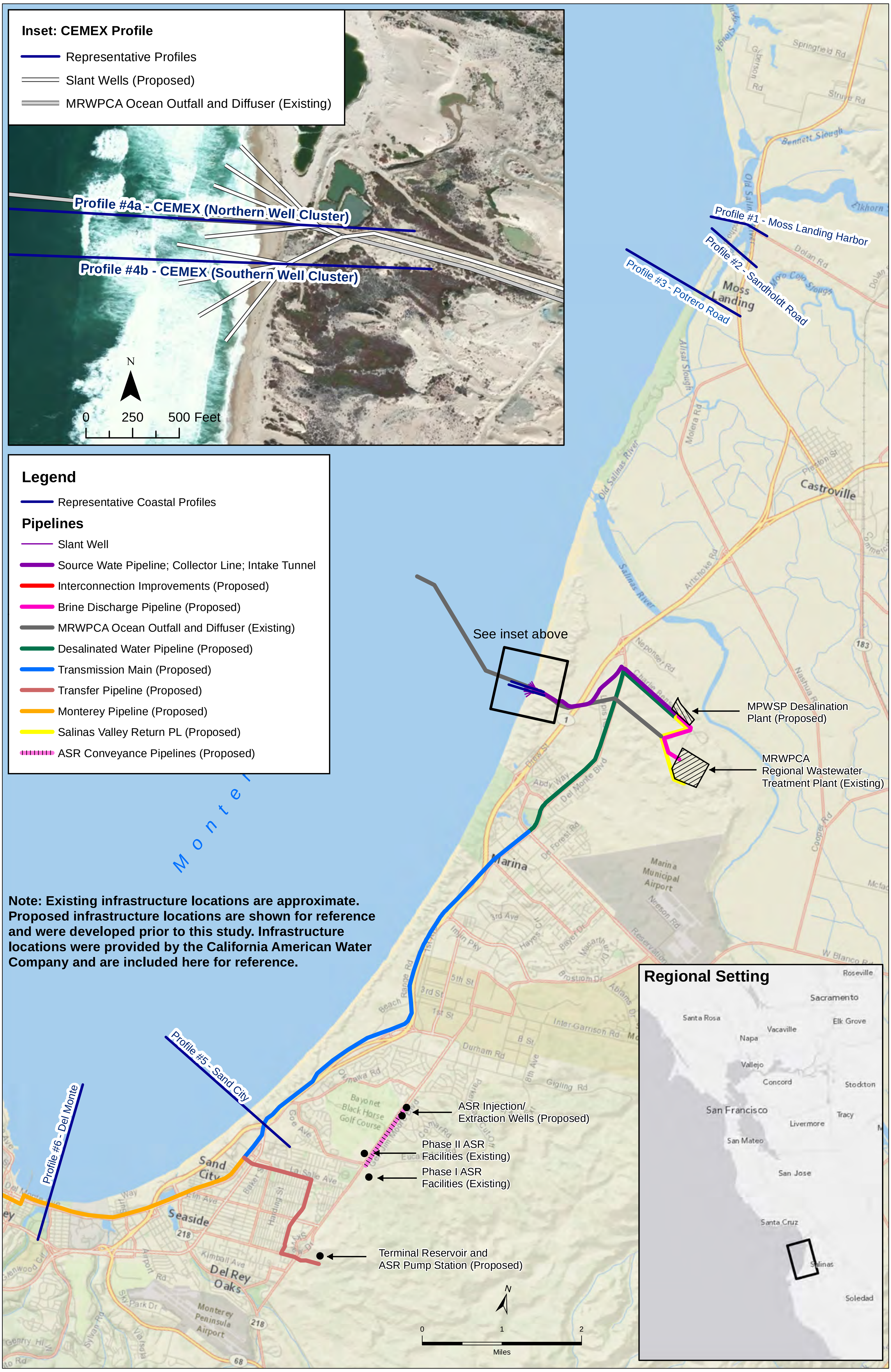
Thornton, E.B., A.H. Sallenger, J. Conforto Sesto, L. A. Egley, T. McGee, and A.R. Parsons, (2006). Sand mining impacts on long-term dune erosion in southern Monterey Bay, Marine Geology, v. 229, p. 45-58.

Thornton, E.B. J. MacMahan, and A.H. Sallenger Jr. (2007). Rip currents, mega-cusps, and eroding dunes. Marine Geology, v. 240: 2-4, p. 151-167. 5 June 2007.

Thornton, E.B., L.A. Egley, A. Sallenger, and R. Parsons (2003). Erosion in Southern Monterey Bay during the 1997-98 El Nino. Coastal Sediments 2003.

USGS (2009). Barnard, P.L., O'Reilly, Bill, van Ormondt, Maarten, Elias, Edwin, Ruggiero, Peter, Erikson, L.H., Hapke, Cheryl, Collins, B.D., Guza, R.T., Adams, P.N., and Thomas, J.T., 2009, The framework of a coastal hazards model; a tool for predicting the impact of severe storms: U.S. Geological Survey Open-File Report 2009-1073, 21 p. [http://pubs.usgs.gov/of/2009/1073/].

Figures



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Monterey Peninsula Water Supply Project . 205335.01

Figure 1

Regional Map of Analysis Profiles

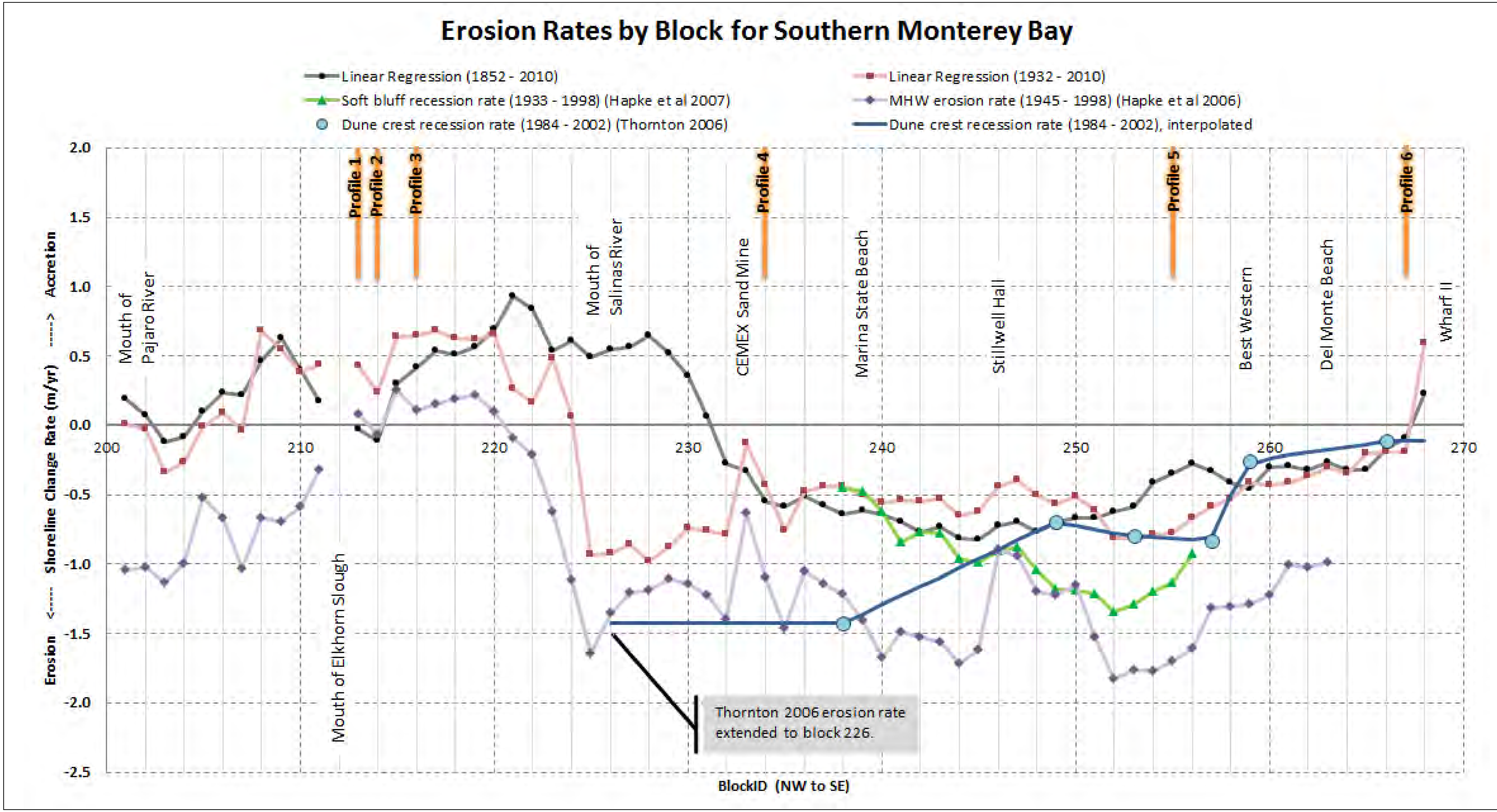
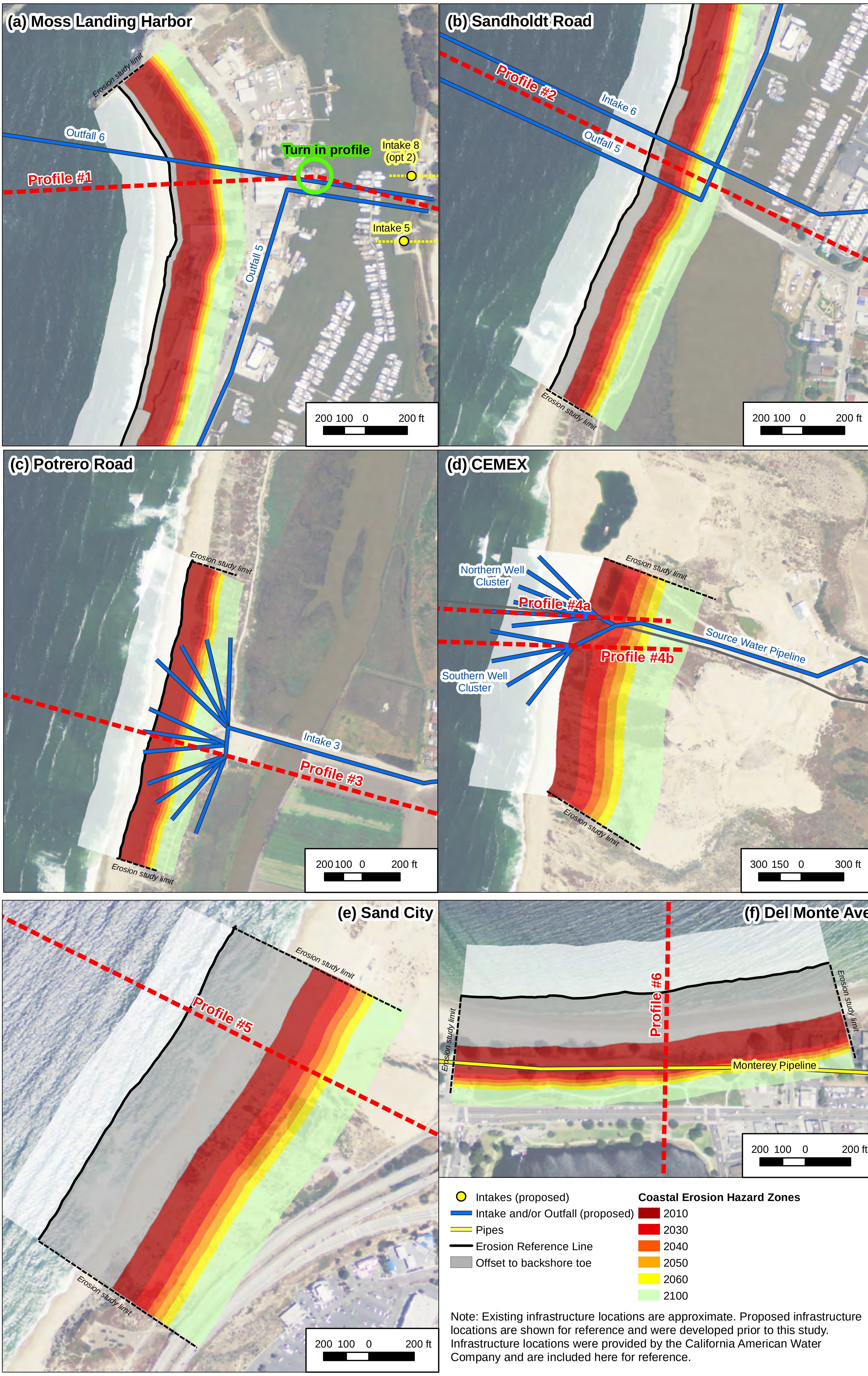


Figure 2. Historic Erosion Rates in Monterey Bay



Note: Existing infrastructure locations are approximate. Proposed infrastructure locations are shown for reference and were developed prior to this study. Infrastructure locations were provided by the California American Water Company and are included here for reference.

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Figure 3

Coastal Erosion Hazard Zones

Data Source: ESA PWA 2013 hazard zone analysis, NAIP 2012 imagery

Please see Figure 1 for regional map of profile locations.

N

These hazard zones show coastal **erosion** hazard areas, with the inland limit representing the potential future dune crest. Flood hazards may be more extensive, especially if the area is low-lying compared to the potential wave run-up and flood water levels. Future erosion through dunes has the potential to flood low-lying areas that are currently protected by high dunes.

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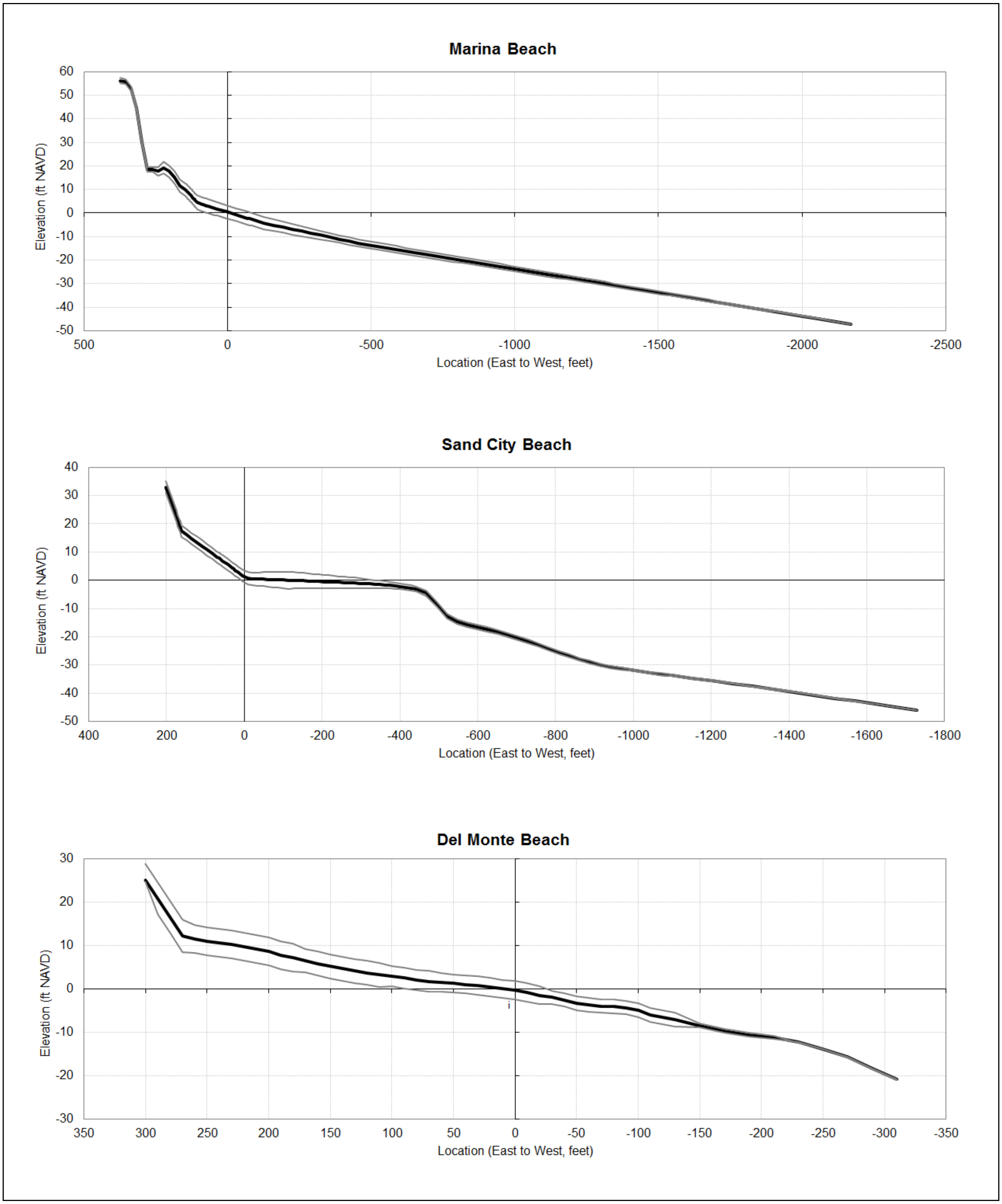

SOURCE: Data from Thornton, unpublished.
Figures published in ESA PWA 2012.

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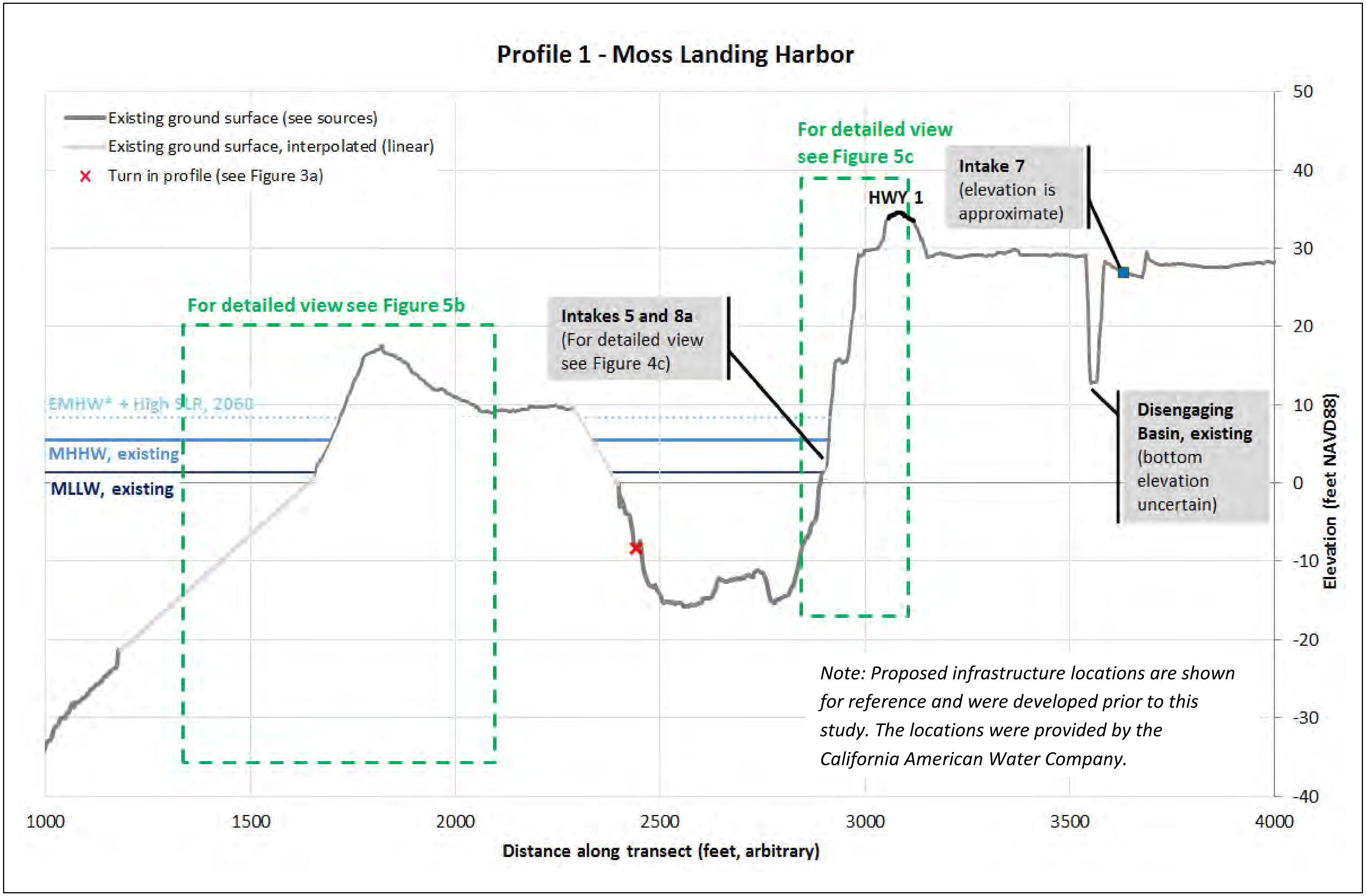
Figure 4
Representative Profiles and Envelopes by Ed Thornton, unpublished



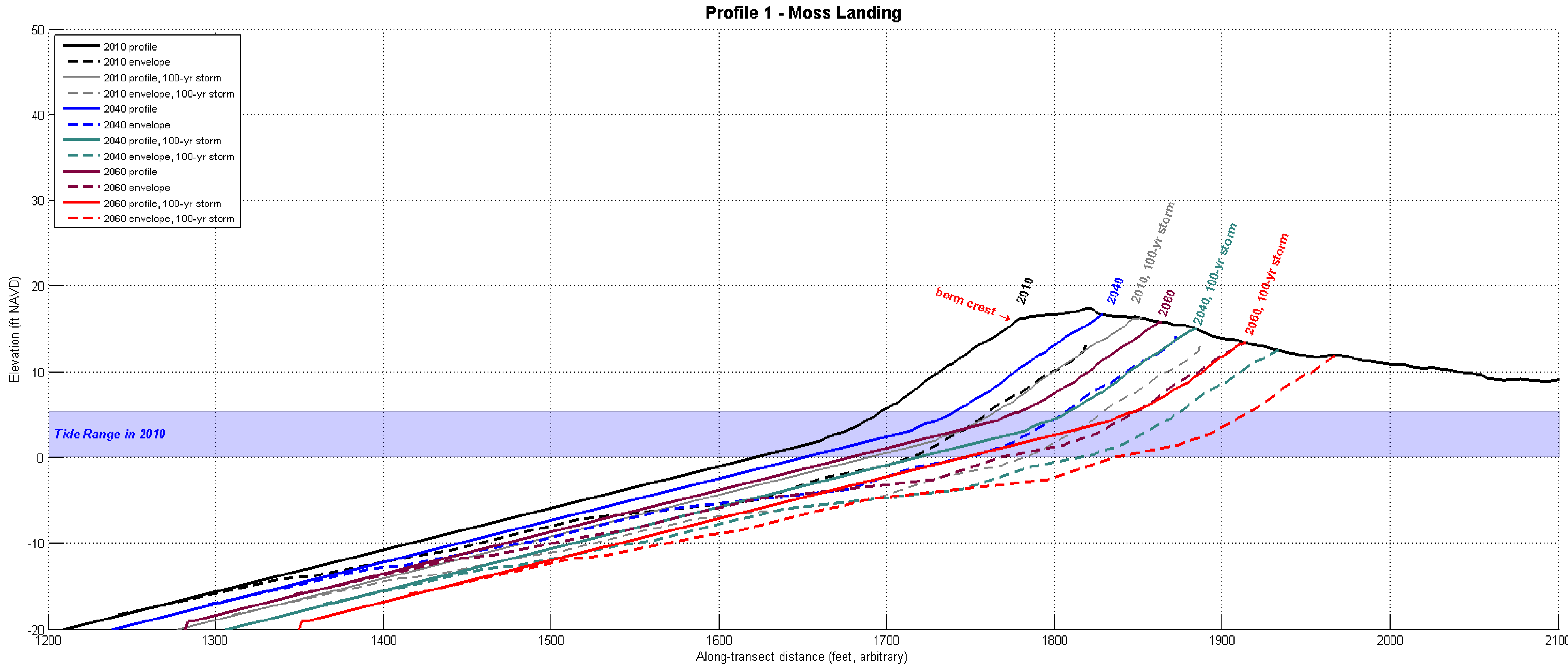
Sources: Topography from CA Coastal Conservancy LiDAR Project (collected in June 2010).
Bathymetry from the CSUMB Seafloor Mapping Lab (collected in September 2011).

** EMHW = Extreme Monthly High Water. This is, on average, the highest tide level that occurs each month.*

Monterey Peninsula Water Supply Project. 205335.01

Figure 5a

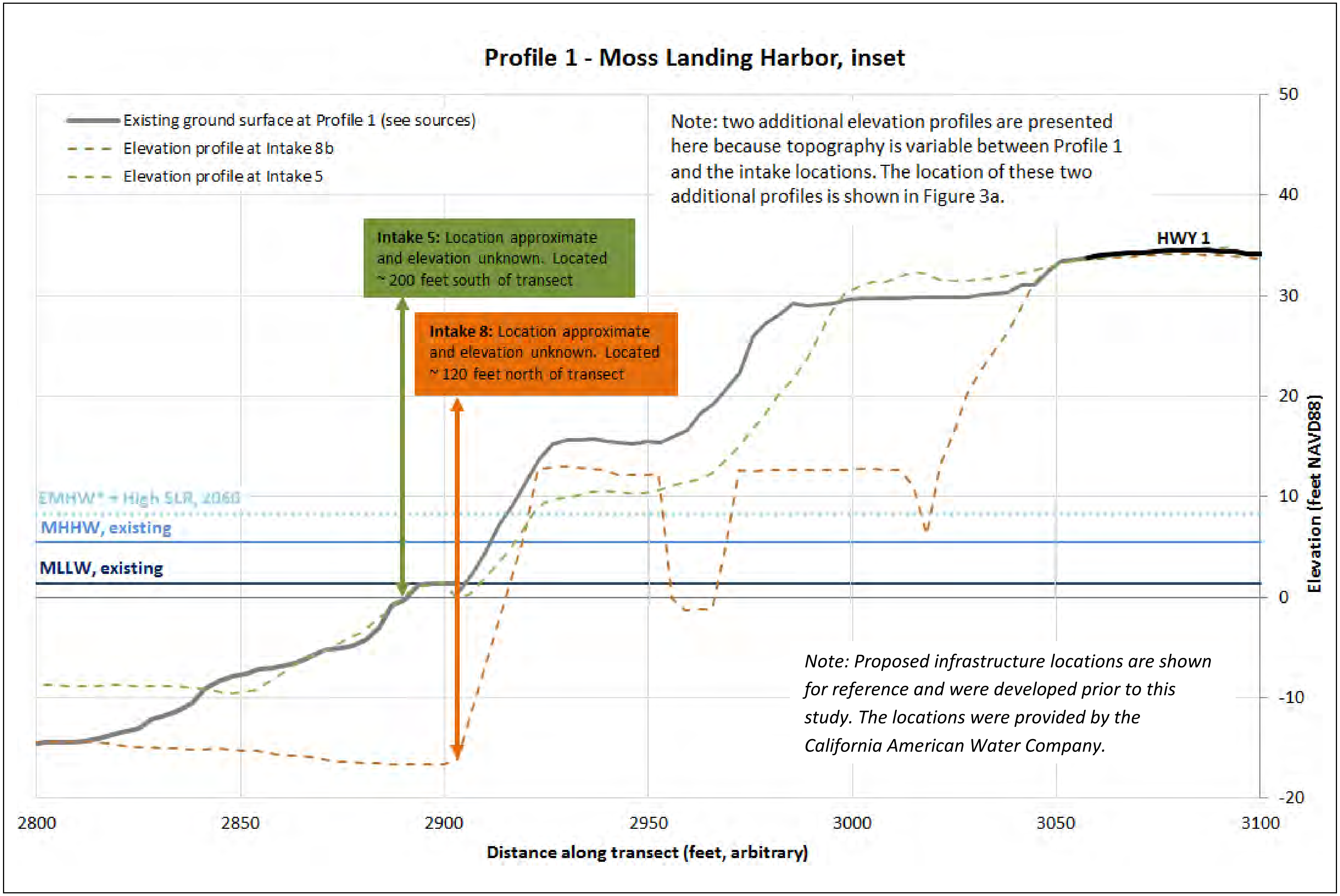
Profile 1 Overview



Notes:

1. These envelopes of erosion consider seasonal changes in beach width, localized erosion (rip currents), long-term erosion, and accelerated erosion caused by sea level rise.
2. The profile shape is linearly interpolated between the bathymetry data and the topography data (between x = 1181 ft and x = 1657 ft).

Figure 5b. Representative Profile #1 at Moss Landing Harbor



Sources: Topography from CA Coastal Conservancy LiDAR Project (collected in June 2010).
Bathymetry from the CSUMB Seafloor Mapping Lab (collected in September 2011).

** EMHW = Extreme Monthly High Water. This is, on average, the highest tide level that occurs each month.*

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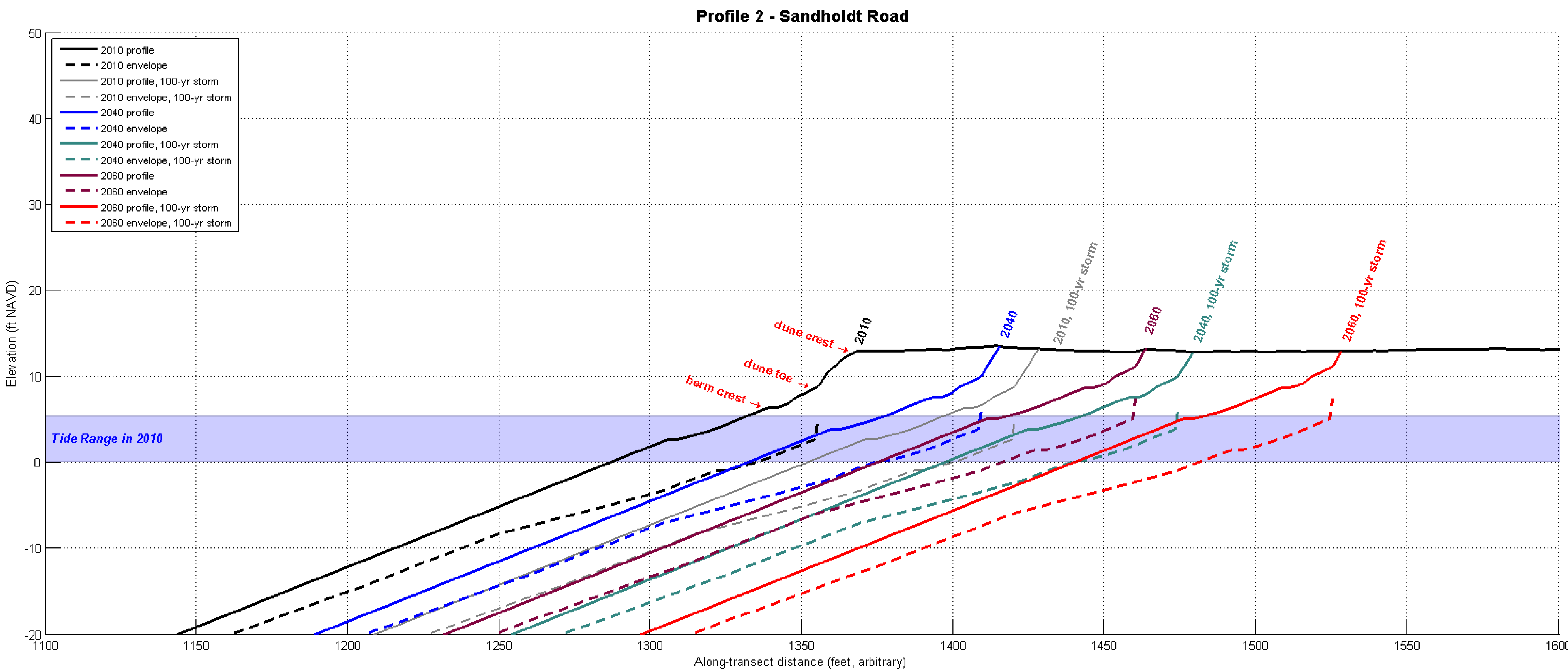
Figure 5c

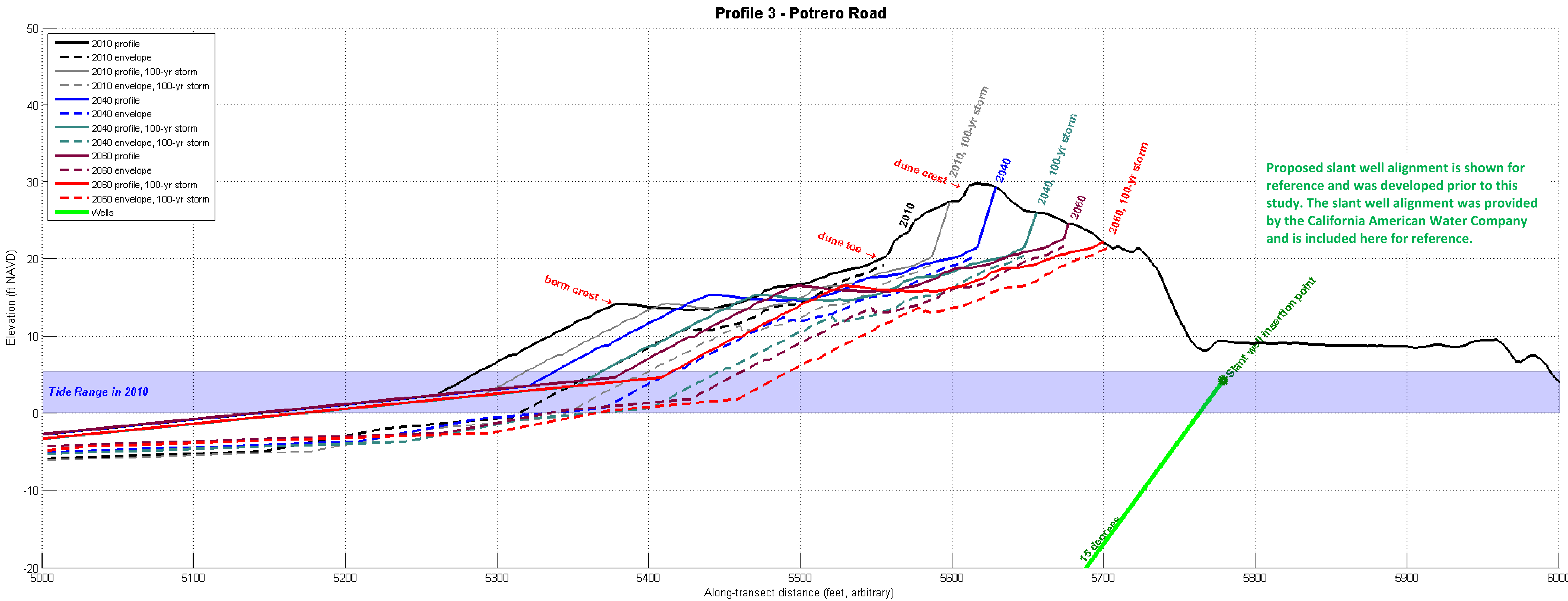
Profile 1 - Inland Inset



Notes:

1. These envelopes of erosion consider seasonal changes in beach width, localized erosion (rip currents), long-term erosion, and accelerated erosion caused by sea level rise.
2. The profile shape is linearly interpolated between the bathymetry data and the topography data (between x = 958 ft and x = 1299 ft).
3. This profile crosses the shore-parallel portion of Outfall 5 at x = 1648 ft (see Figure 3). This portion of the outfall does not fall within the erosion hazard zones through 2060. Location of Outfall 5 provided by California American Water Company. Vertical location of the shore-perpendicular portion of Outfall 5 and Intake 6 were not available and therefore are not shown in this profile view.

Figure 6. Representative Profile #2 at Sandholdt Road

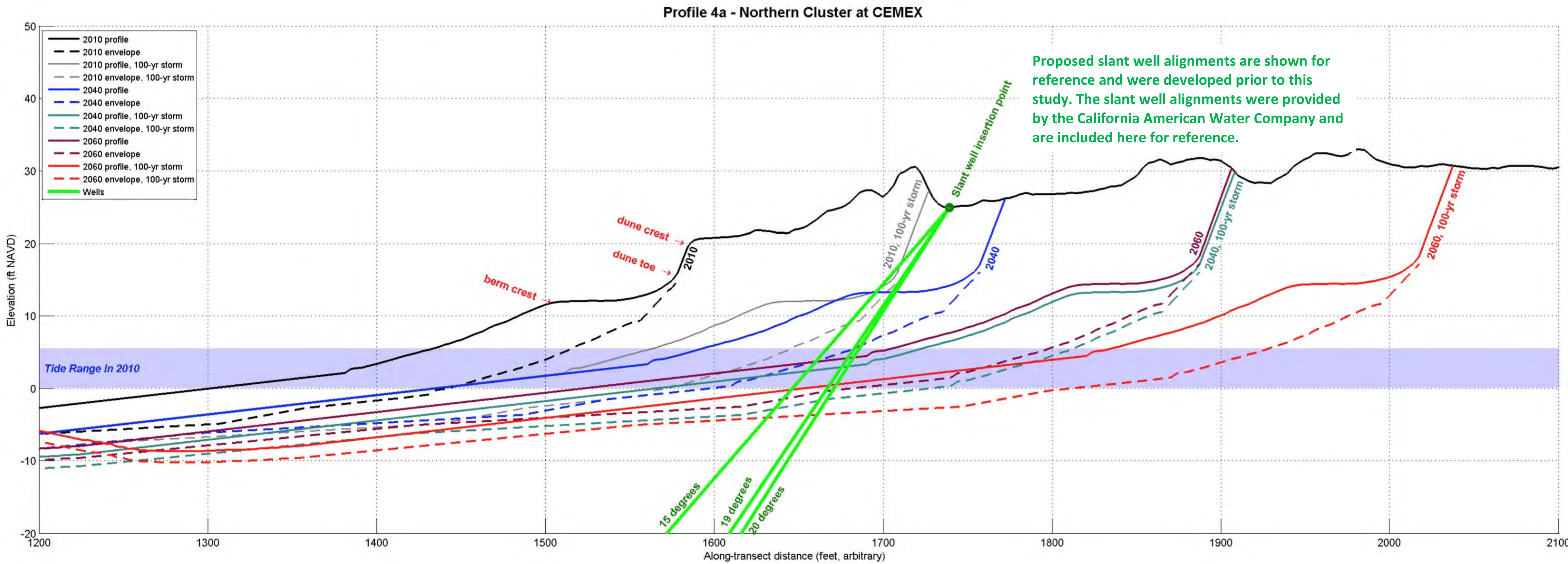


Notes:

1. These envelopes of erosion consider seasonal changes in beach width, localized erosion (rip currents), long-term erosion, and accelerated erosion caused by sea level rise.
2. The profile shape is linearly interpolated between the bathymetry data and the topography data (between x = 4777 ft and x = 5259 ft).
3. Pumped well location is based on the "Potrero Rd Pumped Wells Test Well" Google Earth map provided by CalAm on September 27, 2013.
4. This profile assumes the pumped well is perpendicular to shore.
5. The well input parameters in the table to the right were developed prior to this study and provided by the California American Water Company.

Potrero Road Parameters		Notes
type of well	Pumped Well	
inputs		
angle (degrees from horizontal)	15	
depth of insertion pt (ft)	5	
depth change (ft)	149	
insertion pt elevation (feet NAVD)	4.3	
insertion point loc (feet, arbitrary)	5778	
calculations		
length (feet)	576	
intake elevation (feet NAVD)	-145	
intake loc (feet, arbitrary)	5221	
Bed elevation at intake (ft NAVD)	1.60	*linearly interpolated btwn bathy and topo data*
Depth of sediment above intake (ft)	146	*difference between bed and intake elevation*

Figure 7. Representative Profile #3 at Potrero Road

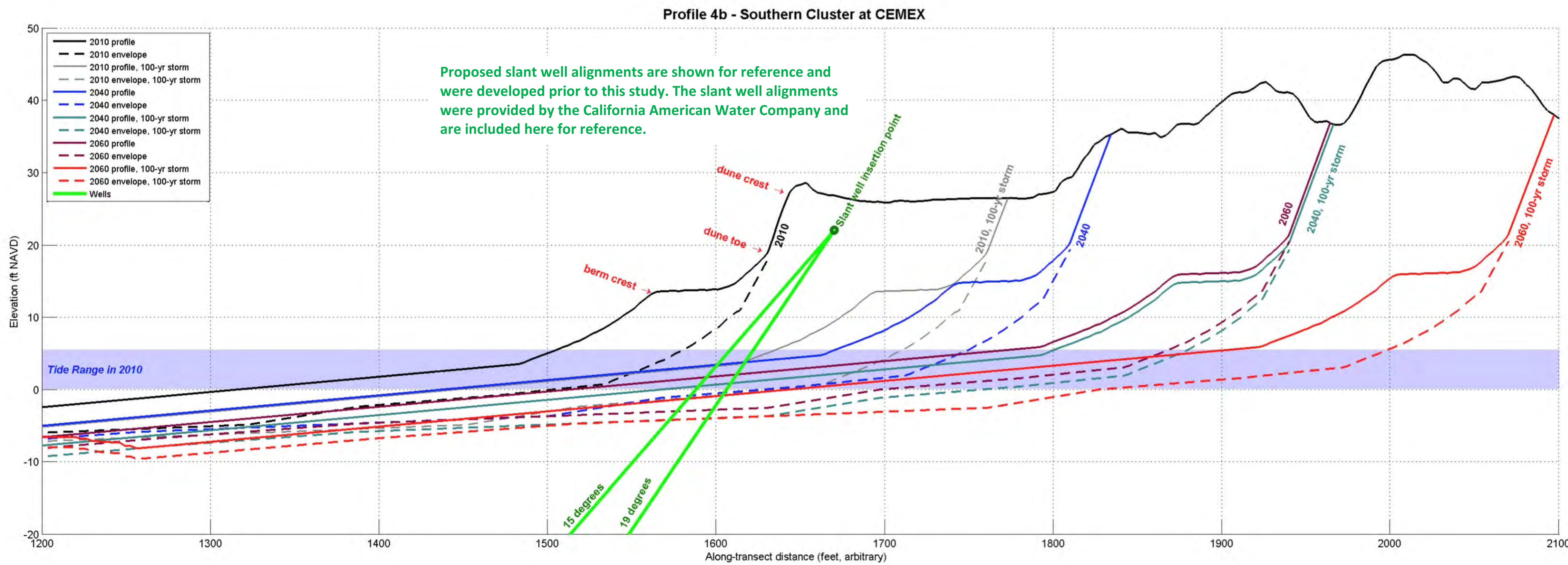


Notes:

1. These envelopes of erosion consider seasonal changes in beach width, localized erosion (rip currents), long-term erosion, and accelerated erosion caused by sea level rise.
2. The profile shape is linearly interpolated between the bathymetry data and the topography data (between x = 919 ft and x = 1385).
3. This profile is located immediately south of the CEMEX Pacifica Lapis sand mining plant. No data is available to quantify the uncertainty in adjacent beach and dune erosion related to sand mining activities. The potential for fluctuations in beach width associated with sand mining were not considered in this analysis.
4. Slant well location and angle are based on the “Test Slant Well Alignment” and “Test Slant Well Cross-Section” drawings provided by Geoscience on July 30, 2013.
5. The well input parameters in the table to the right were developed prior to this study and were provided by the California American Water Company.

Northern Cluster Parameters				Notes
type of well	Production	Production	Test	
inputs				
angle (degrees from horizontal)	15	19	20	
length (feet)	800	800	800	
insertion pt elevation (feet NAVD)	24.0	24.0	24.0	AMSL to NAVD 88 conversion: 2.97 ft
insertion point loc (feet, arbitrary)	1739	1739	1739	
calculations				
intake elevation (feet NAVD)	-183	-236	-250	
intake loc (feet, arbitrary)	966	982	987	
Bed elevation at intake (ft NAVD)	-9	-9	-8	*linearly interpolated btwn bathyand topo data*
Depth of sediment above intake (ft)	174	228	241	*difference between bed and intake elevation*

Figure 8. Representative Profile #4a at CEMEX

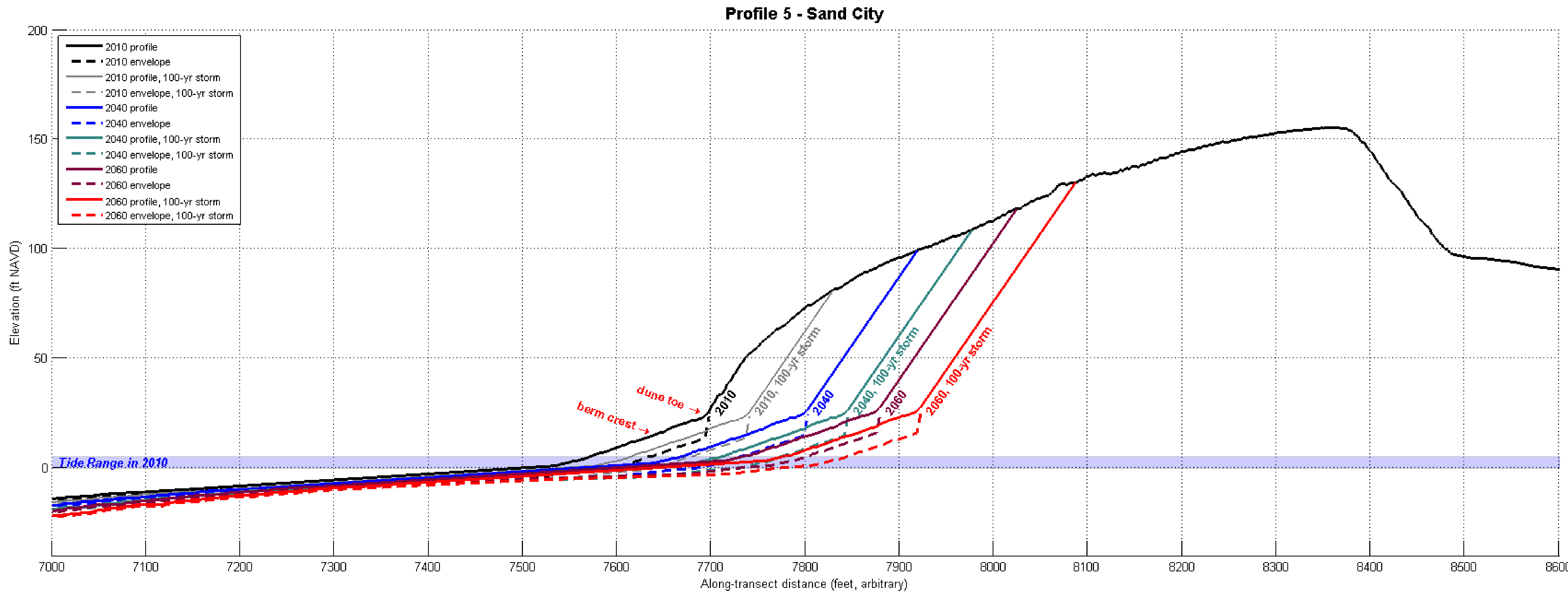


Notes:

1. These envelopes of erosion consider seasonal changes in beach width, localized erosion (rip currents), long-term erosion, and accelerated erosion caused by sea level rise.
2. The profile shape is linearly interpolated between the bathymetry data and the topography data (between x = 820 ft and x = 1480).
3. This profile is located immediately south of the CEMEX Pacifica Lapis sand mining plant. No data is available to quantify the uncertainty in adjacent beach and dune erosion related to sand mining activities. The potential for fluctuations in beach width associated with sand mining were not considered in this analysis.
4. Slant well location and angle are based on the “Well 3 Alignment” and “Well 3 Cross-Section” drawings provided by Geoscience on July 30, 2013.
5. The well input parameters in the table to the right were developed prior to this study and were provided by the California American Water.

Southern Cluster Parameters			Notes
type of well	Production Well	Production Well	
inputs			
angle (degrees from horizontal)	15	19	
length (feet)	800	800	
insertion pt elevation (feet NAVD)	22.0	22.0	AMSL to NAVD 88 conversion: 2.97 ft
insertion point loc (feet, arbitrary)	1670	1670	
calculations			
intake elevation (feet NAVD)	-185	-238	
intake loc (feet, arbitrary)	897	914	
Bed elevation at intake (ft NAVD)	-9	-9	*linearly interpolated btwn bathy and topo data*
Depth of sediment above intake (ft)	176	230	*difference between bed and intake elevation*

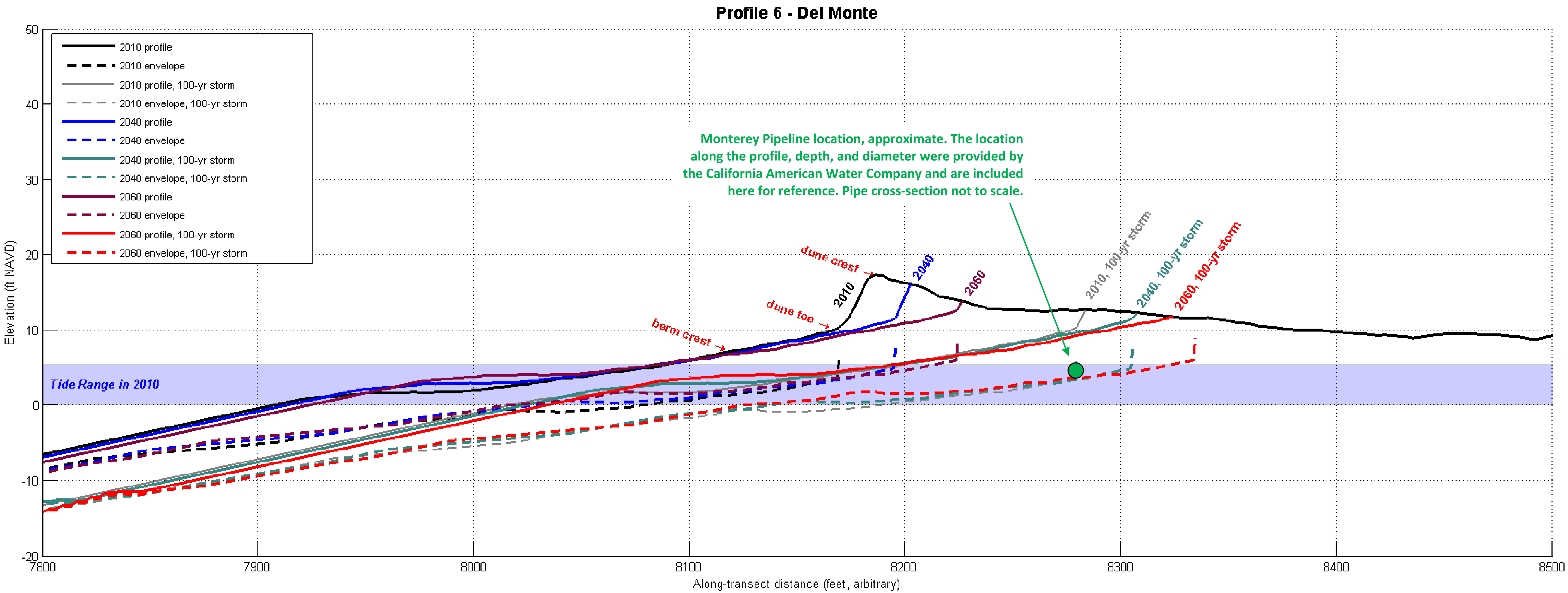
Figure 9. Representative Profile #4b at CEMEX



Notes:

1. These envelopes of erosion consider seasonal changes in beach width, localized erosion (rip currents), long-term erosion, and accelerated erosion caused by sea level rise.
2. The profile shape is linearly interpolated between the bathymetry data and the topography data (between x = 7127 ft and x = 7533 ft).
3. This profile does not intersect any proposed desalination infrastructure.

Figure 10. Representative Profile #5 at Sand City



Notes:

1. These envelopes of erosion consider seasonal changes in beach width, localized erosion (rip currents), long-term erosion, and accelerated erosion caused by sea level rise.
2. The profile shape is linearly interpolated between the bathymetry data and the topography data (between x = 7960 ft and x = 7920 ft).
3. Approximate horizontal and vertical location of the Monterey Pipeline provided by California American Water Company.

Figure 11. Representative Profile #6 at Del Monte