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Application for Certification
(15-AFC-01)

Puente Power Project (P3)
Oxnard, CA

Responses to City of Oxnard Data Requests Set 2 30-Day Extension (59, 60 and 62)

November 2015

Submitted to:
The California Energy Commission

Prepared by: AECOM

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RESPONSES TO CITY OF OXNARD DATA REQUESTS SET 2

30 DAY EXTENSION

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LIST OF ACRONYMS AND ABBREVIATIONS USED IN RESPONSES

AFC	Application for Certification
Cal-EMA	California Emergency Management Agency
CGS	California Geological Survey
NAVD88	North American Vertical Datum of 1988
PTHA	probabilistic tsunami hazard analyses
SAFRR	Science Application for Risk Reduction

LIST OF TERMS USED IN THE DISCUSSION

Geomorphic Region: Naturally defined geologic region that has a distinct landscape or landform shaped by a particular process.

Submarine Landslide: Marine landslides that displace soil and rock masses and transport sediment from the continental shelf into the deep ocean.

Thrust Fault: A tectonically induced inclined fracture where the rupture displacement and plate movement is mostly vertical.

Fold: When one or more originally flat, level surfaces, such as sedimentary strata, are bent or curved. The basic cause is likely to be some aspect of plate tectonics under high stress.

Fold-and-Thrust system: Deformed sedimentary rock in which the layers are folded by thrust faults.

Blind Thrust Fault: A thrust fault that does not rupture all the way up to the surface, so there is no evidence of it on the ground. It is "buried" under the uppermost layers of rock in the crust.

Subduction Zone: Subduction is the tectonic process of the oceanic crust colliding with and descending beneath the continental crust.

Co-seismic: When earthquake waves arrive simultaneously at a location, or the adjoining fault slip occurs simultaneously.

Uplift: Vertical ground block or plate displacement.

Holocene: The last 11,700 years of the earth's history.

Technical Area: Environmental Hazards

BACKGROUND: TSUNAMI INUNDATION

The AFC's analysis for a tsunami is based on the 2009 Oxnard tsunami map, confirmed with LIDAR data. This analysis indicates a water level elevation of 10 to 15 feet. AFC Appendix N-2, p. 5. With 2 feet of sea level rise, this leaves 3 feet of freeboard on the lowest part of the 25- to 30-foot-high berms/levees. This is a very small safety margin, given the omissions from the analysis. The AFC's cumulative sea level rise analysis was based on an historic 2009 tsunami map that does not include recently reported information on the Ventura Fault and other Southern California offshore fault systems and worst case sea level rise estimates. Thus, it underestimates potential tsunami impacts. Further, the AFC's tsunami analysis fails to consider cumulative effects from other sources of flooding.

Awareness of the hazards of tsunami inundation has grown since the 2011 Japan earthquake and tsunami. This event led scientists to investigate similar fault systems in Southern California that could unleash tsunamis along the California coast. Recent geological work has indicated that the Ventura fault could cause a major earthquake that could create a tsunami that would begin "in the Santa Barbara Channel area, and would affect the coastline…down through the Santa Monica area and further south." Other work has reported active fault zones off the Southern California coast.[1] These fault systems were not considered in developing the "Tsunami Inundation Map for Emergency Planning, Oxnard Quadrangle," that the AFC relied on. AFC, Appendix N-2, Attachment 2, Inset Table 1. As a result of these studies, the California Geological Survey is studying whether it needs to revise tsunami hazard maps.[2] The resulting inundation would be "severe right along the coast."[3]

The Preliminary Geotechnical Evaluation (AFC, Appendix A, pdf 259/260) states the project site is adjacent to a mapped tsunami run-up hazard area and notes that while dunes elevated up to about 25 feet above MSL offer some protection, "due to the site location in an area mapped as susceptible to tsunami run-up hazards, the potential for tsunami run-up hazards at the site and possible mitigation techniques should be evaluated during the detailed design phase of the project." The Sea Level Rise Analysis in Appendix N-2, on the other hand, dismisses tsunami inundation as an issue because the elevation of a tsunami with sea level rise is less than the height of the berm. AFC, Appendix N-2, p. 6. This conclusion fails to consider the impact of storm surges, coastal erosion and sea level risk on the structural integrity of the dunes and berms.

DATA REQUEST

59. Please prepare a tsunami runup hazard analysis that includes the most recent information on the Ventura Fault and Southern California fault system and propose mitigation for any impacts. Your analysis should include an updated tsunami hazard map that includes all recently discovered faults.

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1 Mark R. Legg et al., High-Resolution Mapping of Two Large-Scale Transpressional Fault Zones in the California Continental Borderland: Santa Cruz-Catalina Ridge and Ferrelo Faults, Journal of Geophysical Research: Earth Surface, May 30, 2015; Sci-News.com, Researchers Map Active Fault Zones off Southern California, June 1, 2015, See: http://www.sci-news.com/other sciences/geophysics/science-fault-zones-southerncalifornia-02862.html.

2 Rong-Gong Lin II, Earthquake Fault Heightens California Tsunami Threat, Experts Say, Los Angeles Times, June 6, 2015, See: http://www.latimes.com/local/california/la-meventura-fault-20150420-story.html#page= 1.

3 Rong-Gong Lin II, Earthquake Fault Heightens California Tsunami Threat, Experts Say, Los Angeles Times, June 6, 2015, See: http://www.latimes.com/local/california/la-meventura-fault-20150420-story.html#page= 1.

RESPONSE

Introduction

The proposed project site is near the shoreline at the eastern end of the Santa Barbara Channel. It is within the northern extent of the Continental Borderland, an offshore geomorphic region extending from Point Conception in the north, to Vizcaini Peninsula in Baja California to the south. The inner Continental Borderland region is tectonically active and contains several faults that are potential seismic hazards to nearby cities (Astiz and Shearer, 2000). The Santa Barbara Channel offshore of the project site is characterized by pronounced bathymetric features bounded to the south by the Channel Islands (San Miguel to Anacapa), and is therefore relatively isolated from the rest of the Continental Borderlands. Therefore, local tsunami sources are limited to the fault systems in the near vicinity of Oxnard and Ventura.

The tsunami hazard stems from both local and distant sources. Local sources include:

- Goleta landslide complex: an area along the continental rise off Santa Barbara that shows evidence of repeated submarine landslides;

- Ventura-Pitas Point fold and thrust: a fold-and-thrust system that runs through Ventura and offshore under the Santa Barbara Channel; and

- Oak Ridge blind thrust: an offshore blind thrust structure.

Distant sources include:

- Alaska-Aleutian subduction zone: the source area for the 1964 Alaska earthquake (among others), which historically has had the strongest tsunami impact in central and southern California; and

- Other sources, such as the Chile subduction zone and the Kuril-Kamchatka system, which have had moderate impact in southern California.

Tsunami Inundation and Recurrence Intervals

Goleta Landslide Complex: Return periods for the local sources in particular are highly uncertain. For the Goleta complex, Lee et al. (2004) dated several slide events with 30,000- to 50,000-year intervals, the last one dated 5,500 years ago. Greene et al. (2006) modeled the tsunami effects of such a landslide, and found runups as high as 33 feet (10 meters) in the Goleta area—the area that would be most affected. Submarine landslides tend to have a very strong directional effect; this means that the largest tsunami occurs in the direction of the slide, with smaller tsunamis in other directions. Because Ventura and Oxnard are situated away from the direction of maximum wave heights, the expected effect of a Goleta submarine landslide at the project site would be much less. In fact, the California State tsunami inundation maps (Cal-EMA, 2009), which show the areas likely to be inundated due to tsunamis, are partly based on the Goleta landslide, and the inundation line does not reach the project site (see Application for Certification [AFC] Appendix N-2 for a copy of the inundation map). Therefore, the Goleta complex does not pose a significant tsunami hazard to the project.

Ventura-Pitas Point Complex: The Ventura-Pitas Point complex has recently received significant attention (Shaw et al., 2015) due to the studies by Hubbard et al. (2014) and Ryan et al. (2015). Shaw et al. (2015) postulated the occurrence of very large earthquakes along the Ventura-Pitas Point complex, based on 15 to 30 feet (5 to 10 meters) of co-seismic uplift of marine terraces in the Ventura area. In a simple faulting environment, such uplift would need large amounts of slip on the fault, which would require a much larger earthquake magnitude (and thus fault length) than can be sustained on the Ventura–Pitas Point complex itself, and would therefore require co-seismic slip on an eastward or westward extension such as the San Cayetano and Red Mountain faults (simultaneous earthquakes on multiple faults). Ryan et al. (2015) presented a dynamic rupture model of an earthquake that is consistent with the uplift given in Hubbard et al. (2014), one that is much simplified compared to the published geologic models. Their results show significant inundation in the Ventura and Oxnard regions, with an amplitude of 8.2 feet (2.5 meters) at the project site (see Figure 59-1), based on an elevation model with 100 feet (30 meters) of horizontal resolution. The inundation map included in the Ryan study shows the project site in the inundation zone; however, because the predicted amplitude is below the top of the dunes and below the site elevation, it is unclear how the site would be inundated. The mapping shown in the Ryan study is therefore questionable with respect to the project site.

Nicholson et al. (2015) have argued that the large uplift of the marine terraces is only a local manifestation due to complexities in the fault geometry, and does not reflect the overall deformation on the Ventura-Pitas Point system, which they estimate to be significantly smaller. Furthermore, Sorlien and Nicholson (2015) argue that the source model used for the tsunami simulations of Ryan et al. (2015) is inconsistent with the observed crustal structure under the seafloor. Most notably, they find that there is no evidence that the fault rupture extends to the surface; this means that the Ryan et al. (2015) study overestimated the seafloor uplift, and therefore the size of the tsunami and extent of the inundation zone.

Thio et al. (2015) also modeled the earthquakes on the Ventura-Pitas Point complex using geologically consistent geometries, but with maximum uplift of about 16 feet (5 meters), which is at the low end of the Hubbard et al. (2014) numbers. Their results show no inundation at the project site for any of their scenarios, with wave amplitudes generally lower than the Ryan et al. (2015) results, which is to be expected given the higher uplift in the latter model.

Therefore, with the exception of Ryan et al, (2015), modeling of the Ventura-Pitas Point complex shows no inundation of the site. Furthermore, the mapping in the Ryan study does not appear to take into consideration the presence of the dune that fronts the project site. The maximum wave height predicted by the Ryan study is well below the height of the dune. Taking all of this into consideration, it does not appear that the Ventura-Pitas Point complex poses a significant tsunami hazard to the project site.

Oak Ridge Blind Thrust: This structure is under the Santa Barbara channel, several kilometers south of the Ventura-Pitas Point complex, and consists of a south-dipping blind-thrust fault. It is not clear whether this structure has been active in the Holocene, but its location poses a potential tsunami hazard for the Ventura-Oxnard region. Thio et al. (2015) modeled a single-scenario earthquake on this fault (Figure 59-1). The results showed that a tsunami generated by the Oak Ridge fault (for the modeled scenario) did not inundate the site, and therefore does not contribute significantly to the tsunami hazard at the site.

Science Application for Risk Reduction Scenario: In 2013, the U.S. Geological Survey carried out a multi-disciplinary study of the impact that a hypothetical large (Japanese Tohoku-like) tsunami scenario originating in Alaska would have on the coast of California (Ross et al., 2013). Generally, this scenario caused little inundation around the Santa Barbara Channel, and the biggest hazard came from the increased currents in ports and harbors. This scenario, which was thought to represent a 400- to 500-year event, would not result in inundation at the project site.

Probabilistic Results: Several probabilistic tsunami hazard analyses have included the project site area. Thio et al. (2010) carried out a probabilistic analysis of the tsunami hazard in California. This analysis was based on distant large earthquake sources around the Pacific Rim. The analysis produced inundation maps at about 100 feet (30 meters) horizontal resolution for return periods of 72, 475, 975, and 2,500 years. Even for the 2,500-year return period (2 percent probability of exceedance in 50 years or 1.2 percent probability in 30 years), the inundation does not reach the project site in these models. Figure 59-2 presents the hazard curve for this model for an offshore location close to the site (note graph has log-log axes). Figure 59-2 shows that the hazard is small for return periods less than 1,000 years (tsunami wave height of about 6 feet [or 2 meters]), and the hazard increases significantly above an annual return period of about 1,500 years.

Conclusion

Studies of distant earthquakes (teletsunamis) indicate that the site is unlikely to be in the inundation zone. Studies of tsunamis generated by local earthquakes indicate that the site is unlikely to be in an inundation zone for "frequent" events (events with return periods of 1,000 to 1,500 years or less). Studies that used conservative assumptions indicate that the site might be in an inundation zone for less frequent events, e.g., 2,500-year return period; however, the predicted water level is lower than the top of the dunes. The recent study by Ryan et al. (2015) showed the site possibly in the inundation zone, but appears to be very conservative by virtue of their simplified modeling environment (Ryan et al., 2015) in terms of fault geometry or model resolution. Ryan et al. also stress that their model is not sufficient for quantitative hazard estimates ("*Our simple model is not complete enough to provide a true quantitative measure of tsunami hazard or the precise spatial extent of the inundation zone in the Ventura and Oxnard region."*) Table 59-1 summarizes the results from the various studies presented above. The values shown in Table 59-1 assume that the tsunami occurs at mean high water. The tsunami is just as likely to occur at mean low water, in which case the tsunami would be about 3 to 4 feet lower. Because the return periods shown in the table are based on the likelihood of the source earthquake occurring (and not on the tide level), a tsunami occurring simultaneously at high tide would have a greater return period than shown in Table 59-1. In all cases, the maximum projected wave height is well below the top of the existing dunes that protect the project site.

Table 59-1
Maximum Tsunami Wave Amplitudes

Source	Shoreline		Tsunami Model Horizontal Grid Resolution (feet)	Annual Return Period (years)	Reference
	Maximum Wave Height (feet)[1]	Maximum Velocity (feet per second)			
Ventura-Pitas Point	19.4	NA	100	800 to 2,500	Ryan et al.
Ventura-Pitas Point	13.6	NA	33	800 to 2,500	Thio et al., 2015
Ventura-Pitas Point	14.8	NA	33	800 to 2,500	Thio et al., 2015
Oak Ridge	15.4	7.9	33	> 10,000	Thio et al., 2015
PTHA	NA	NA	100	2,500	Thio et al., 2010
SAFRR	12.1	3.8	100	500	Ross et al., 2013
Cal-EMA	14.6[2]	NA	NA	> 5,000	Cal-EMA, 2009

Notes:

[1] Heights are relative to NAVD88 at the shoreline for various seismic sources found in the literature. Tsunami results are expressed relative to mean high water; 4.6 feet were added to convert to NAVD88. Top of dune height ranges from 20 feet to 35 feet.

[2] CGS (2014) indicated a maximum runup of 10 feet in Oxnard; 14.6 feet is the elevation if the tsunami occurs at mean high water.

“NA” indicates that the data are not available.

Cal-EMA = California Emergency Management Agency
PTHA = probabilistic tsunami hazard analyses
NAVD88 = North American Vertical Datum of 1988
SAFRR = Science Application for Risk Reduction

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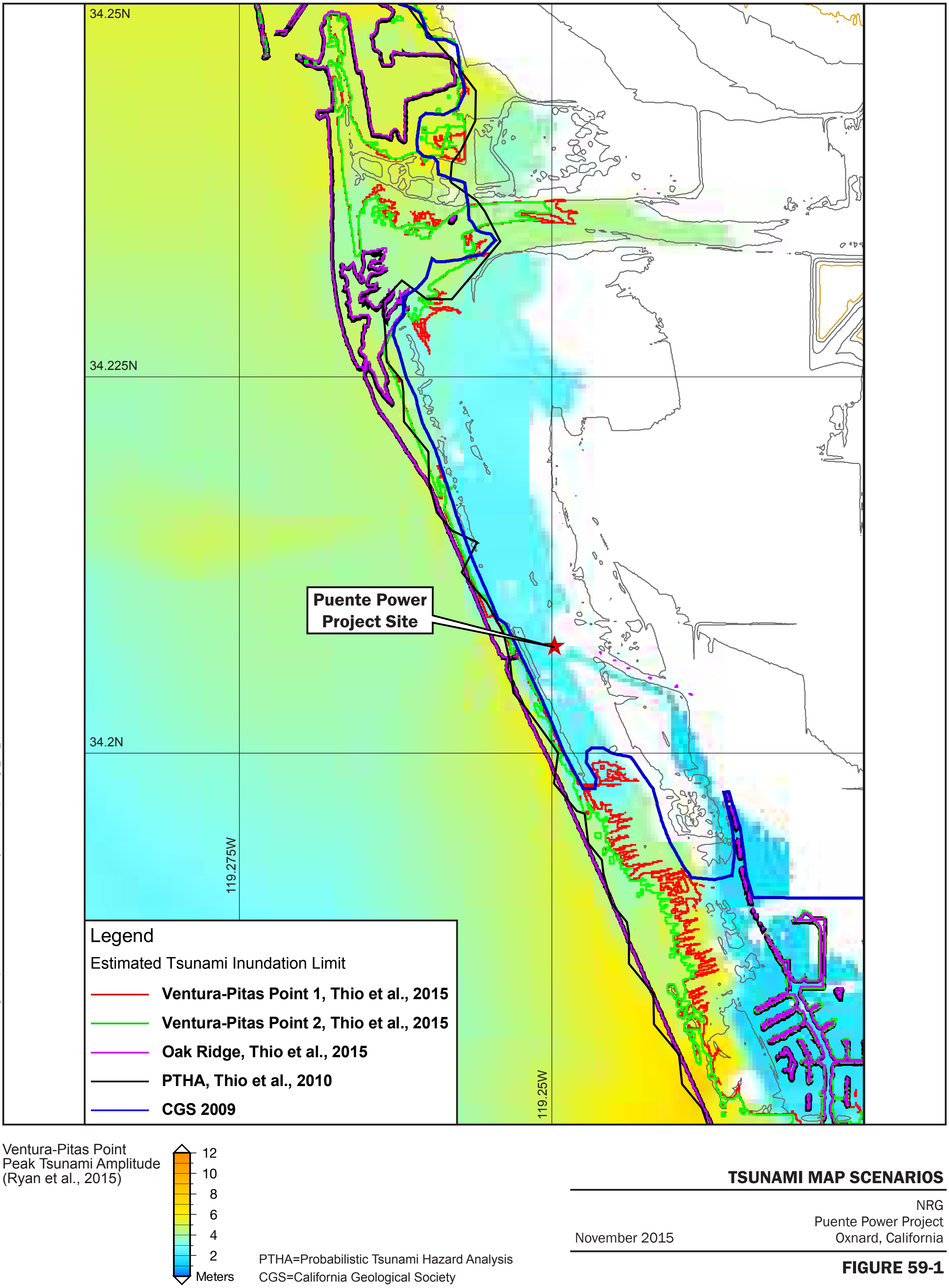

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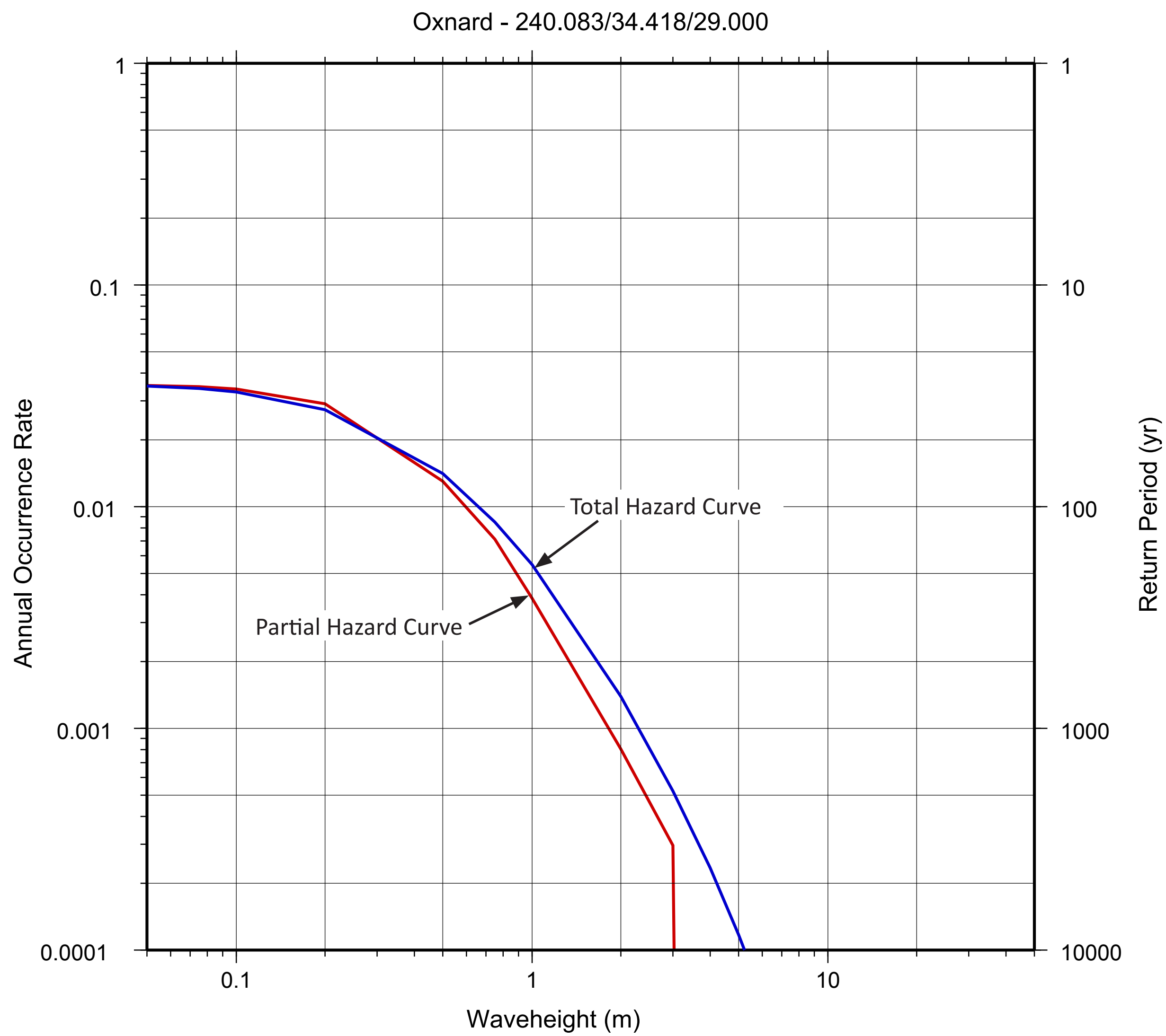
PTHA=Probabilistic Tsunami Hazard Analysis
CGS=California Geological Society

TSUNAMI MAP SCENARIOS

NRG
Puente Power Project
Oxnard, California

November 2015

FIGURE 59-1



Source: Thio et al., (2010).

TSUNAMI HAZARD CURVES

NRG
Puente Power Project
Oxnard, California

November 2015

FIGURE 59-2

DATA REQUEST

60. Please revise the cumulative sea level rise analysis in Appendix N-2 to include recent information on the Ventura Fault and Southern California fault systems.[4]

RESPONSE

Table 47-2 provided information on the combined effects of various potential sources of flooding. In the response to Data Request 47, the water levels associated with tsunamis were not included and were to be determined. Based on information presented in the response to Data Request 59, Table 47-2 was updated to include the tsunami data. The results are provided in Table 60-1. For reference , note that the elevation of the project site is 14 feet North American Vertical Datum of 1988 (NAVD88). The height of the frontal dunes is between about 25 and 30 feet NAVD88.

Sea-level rise is unaffected by tsunamis. The effect of sea level on tsunami levels is assumed additive. The tsunami amplitudes shown in Table 60-1 do not include sea-level rise. For the year 2050, 2.1 feet should be added to the values in Table 60-1 to account for sea-level rise.

For 500-year or more frequent events, tsunamis likely do not contribute to the probability of flooding. For less frequent events, tsunamis can contribute to the combined level of flooding; because of the small likelihood of tsunamis occurring at the site, however, the probabilities are very low.

Table 60-1
Updated Cumulative Inundation Sources
at the P3 Site and Corresponding Annual Probabilities

Return Period (years)	Annual Probability of Exceedance	Input Values				Calculated Values	
		Tsunami Water Surface Elevation[1] (feet, NAVD88)	Extreme Tidal Elevation (feet)	Wind Wave Height (feet)	Wind Wave Period (second)	Wind Wave Run Up[2] (feet)	Maximum Potential Erosion from Storm Surge[3] (feet)
2	0.5	NA	7.28	6	18.25	7.6	24.3
5	0.20	NA	7.39	7.1	20.2	8.7	70.5
10	0.10	NA	7.44	7.8	21.3	9.4	95.2
25	0.04	NA	7.53	8.7	22.3	10.0	125
50	0.02	NA	7.60	9.4	23.0	10.5	145
75	0.013	NA	7.8	9.7	23.3	10.8	155
100	0.01	NA	7.81	10.1	23.5	11.0	163
200	0.005	NA	7.85	10.7	23.9	11.5	179
500	0.002	12.0[4]	8.0	11.6	24.4	12.1	204
1,000	0.001	13.5[5] – 19.3[6]	8.05	12.3	24.6	12.5	229
2,500	0.004	13.5 – 24.1[7]	8.1	13.2	24.9	12.8	248
10,000	0.0001	14.5[1] – 15.3[8]	8.5	14.5	25.2	13.1	304

Notes:
1 Assumes the tsunami occurs at mean high tide. From Cal-EMA (2014), assuming 4.5 feet between mean high water and NAVD88.
2 Excludes tsunami.
3 Maximum potential erosion for annual probabilities shown in table is based on the Komar (1999) method to calculate dune erosion. See response to Data Request 54.
4 SAFRR Tsunami Source, see Table 59-1. Value is for wave amplitude.
5 Ventura-Pitas Point Fault, Thio et al. (2015). See Table 59-1.
6 Ventura-Pitas Point Fault, Ryan al. (2015). See Table 59-1.
7 Low-end value from Ventura-Pitas Point Fault, Thio et al. (2015). See Table 59-1.
8 Oak Ridge Fault, Thio et al. 2015. See Table 59-1.

4 J. Hubbard, J.H. Shaw and others, Structure and Seismic Hazard of the Ventura Avenue Anticline and Ventura Fault, California: Prospect for Large, Multisegment Ruptures in coastline.. .south." 1 "Quadrangle," 2 the Western Transverse Ranges, Bulletin of the Seismological Society of America, May 2014.

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DATA REQUEST

62 Please evaluate the ability of the existing berm to contain the force of a tsunami that raises water elevation to the top of the berm along the entire length of the berm.

RESPONSE

As discussed in previous responses to Data Requests, the beach dunes along the west and the dike along the north are not expected to be overtopped by a tsunami. Nevertheless, Applicant has done a preliminary calculation to evaluate the potential stability of the dunes and dike assuming that the water level is at the top of the dunes and/or dike.

To evaluate the ability of the existing berm (interpreted to be both the west frontal beach dunes and the north dike) to contain the force of a tsunami that raises the water elevation to the top of the berm, the estimated maximum tsunami inundation loads and scour conditions were evaluated.

Significant dune erosion can result from multiple tsunami wave cycles (typically three significant waves),from repetitive severe winter storms, or from a combination of both. Considering the ongoing monitored dune growth and the protective effect of significant vegetation or pavement cover for the unconsolidated Aeolian and angular sand deposits, a tsunami scour failure of the berms from runup to the crest is considered unlikely due to two effects:

- The broad sloping beach approaching the berms, which reduces initial energy and flow depth at the toe of the berms; and
- Relatively wide berm crests.

This protective buffer width also provides passive resistance to the tsunami hydrostatic and hydrodynamic loads. With these factors taken into account, the dunes are considered stable.