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memorandum

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to Mary McDonald (Orion Environmental)

cc Paul Mitchell (ESA)

from Louis White, PE

subject Summary of Existing Tsunami Hazard Mapping in Vicinity of the Proposed Golden State Warriors Mission Bay Project and Refined Limits of Maximum Anticipated Hazard (ESA Ref. #D120424.03)

Introduction

This memorandum presents a summary of the implications of tsunami hazard mapping and an application of results from tsunami studies by others to the proposed project site for the Golden State Warriors Mission Bay project. The purpose of this memorandum is to provide a description and interpretation of existing, publicly available tsunami hazard map products, and to leverage available technical studies by others that present maximum anticipated tsunami events in San Francisco Bay to facilitate assessment of the tsunami hazard zone in the vicinity of the project site. Mapping products and technical studies considered in this memorandum include:

- Numerical modeling study of tsunami hazards for marine oil terminals in San Francisco Bay (Borrero et al. 2006)
- Tsunami inundation maps for emergency planning (State of California 2009)
- Technical report summarizing and updating prior tsunami modeling studies and hazard mapping in San Francisco Bay (URS 2013)

Based on the analysis described below, we assigned an elevation of 11.2 feet NAVD (or 99.9 feet relative to the project datum) to the maximum anticipated tsunami hazard inundation zone presented in the State of California (2009) maps, and calculated an inundation depth of less than 1 foot in areas of the project site that are located within the hazard zone depicted in the State's maps. The question of how the State of California (2009) tsunami inundation maps relate to regulatory and jurisdictional requirements remains unknown.

2006 Tsunami Report for SF Bay

Tsunami impacts in SF Bay from seismic events were previously examined in a study titled *Numerical Modeling of Tsunami Effects at Marine Oil Terminals in San Francisco Bay* (Borrero et al. 2006). The study was funded by the Marine Facilities Division of the California State Lands Commission, and considered historical tsunami runup from both local seismic sources and from subduction zones around the Pacific Rim. Using the Method of Splitting

Tsunami (MOST) model, the study predicted the propagation and inundation of tsunamis resulting from historic and hypothetical events to identify the sources that have the greatest impact in the San Francisco Bay. The MOST model is used by the National Ocean and Atmospheric Administration (NOAA) and has been calibrated and verified using known events (Titov and Gonzales 1997). Although all of the earthquake scenarios that were examined caused significant tsunamis in the Pacific, the tsunami height at the Golden Gate (entrance to San Francisco Bay) was very dependent on the direction of tsunami propagation across the Pacific. The study found that the tsunami height decreases as the wave propagates into San Francisco Bay.

After considering 51 scenarios of credible tsunamis that have been recorded or observed within the San Francisco Bay, Borrero et al. (2006) determined that the largest response in the SF Bay resulted from displacements along the Alaska Peninsula segment of the Alaska-Aleutian subduction zone. They authors developed a worst-case scenario that combined two 8.8 magnitude subduction ruptures (resulting in a 9.15 magnitude) in the Aleutian Islands west of the historic 1964 Alaskan earthquake (magnitude 9.26). Table 1 summarizes the authors' recommendations for the locations listed.

TABLE 1
MAXIMUM TSUNAMI HEIGHTS AND VELOCITIES FROM MODELED TSUNAMI FOR PLANNING PURPOSES AT SEVERAL MARINE OIL TERMINALS IN SAN FRANCISCO BAY. NOTE THAT THE "POTRERO" SITE IS LOCATED JUST SOUTH OF THE PROJECT SITE.

ID*	Location	1964		Aleutians III	
		Height (m)	Velocity (m/sec)	Height (m)	Velocity (m/sec)
3	Outer Richmond	1.4	0.9	2.3	1.5
5	Inner Richmond	1.7	2.2	2.4	2.7
14	Martinez	0.3	0.4	0.7	0.2
10	Selby	0.5	0.4	0.8	0.5
13	Rodeo	0.5	0.3	0.8	0.6
17	Benicia	0.3	0.2	0.6	0.3
18	Portrero District, San Francisco	0.8	0.8	1.8	1.5
19	Entrance to San Francisco Bay	3.1	1.9	8.0	4.3
20	Presidio (Fort Point)	2.0	2.4	4.4	7.5

Source: Borrero et al. (2006)

Borrero et al. (2006) does note that while large ruptures along the central and western portions of the Alaska-Aleutian subduction zone have occurred, the arc in these areas is oriented such that even great earthquakes in this area will not impact the San Francisco Bay as significantly as the worst-case model scenario (Aleutians III). Furthermore, Borrero et al. (2006) used a factor of safety of 1.5 to estimate peak water heights resulting from a 1964 event and the worst-case scenario for planning purposes. The values presented in Table 1 are considered a conservative estimate, and simulations suggest that the model slightly overestimates water level heights and drawdowns.

Borrero et al. (2006) did not assign probabilities to the scenarios modeled in their study, but cite recurrence estimates for the Alaska 1964 events ranging from 350 years to 800 years. There is no precedent for the "worst-case" scenario, a magnitude 9.2 event rupturing 800 kilometers from Kodiak Island to the Alaska Peninsula.

2009 CA State Tsunami Inundation Maps

Tsunami hazards in San Francisco Bay and along the entire California coast were published by the California Geological Survey (CGS) to provide tsunami inundation hazard zones that can be used for emergency and evacuation planning by California Emergency Management Agency (CalEMA) (State of California 2009). The maps are available online as PDFs and in KMZ format for display in Google Earth¹. The maps were developed using several worst-case scenarios. The Tsunami Research Center at the University of Southern California used the MOST model to propagate tsunamis across nested grids (~90 m resolution for the open coast and ~30 m for SF Bay). The resulting coarse maximum wave elevation grid was then extended onshore to a finer DEM and manually checked and adjusted based on field surveys where appropriate.

2013 URS Study

The URS Corporation prepared a study for Chevron in April 2013 called *Tsunami Hazard at the Chevron Richmond Oil Refinery and Terminal* (URS, 2013). The report reexamined the Borrero et al. (2006) study with respect to inundation at the Richmond refinery and raised two key questions of the 2006 study: as to whether the 2006 study identified:

- Were all likely subduction zone sources in the Pacific considered?
- Did the 2006 study underestimate the magnitude of earthquakes?

URS (2013) confirmed that the theoretical 9.2 magnitude earthquake in the Aleutian trench appears to be a representative estimate of the greatest water heights sustained in San Francisco bay from a tsunami. According to a personal communication cited in the URS (2013) study, the 2009 tsunami inundation maps prepared for the SF Bay Area were based on the Aleutians III scenario presented in Borrero et al. (2006).

URS (2013) modeled a hypothetical event located along the Aleutian arc, the same as the Aleutian III scenario modeled by Borrero et al. (2006), but assumed a shorter rupture length and a larger slip. This modification caused a slight increase in maximum tsunami wave height in the Richmond Refinery area as compared to the Aleutian III scenario, but the differences were attributed to different model extraction locations. URS (2013) notes that the State of California (2009) Tsunami Inundation Hazard Maps may be conservatively high, as the State's maps showed areas of Richmond that were inundated while URS (2013) modeling did not show any inundation.

The URS (2013) report also examined probabilistic tsunami hazard analysis (PTHA) which applies goals and statistical approach used to quantify probabilistic seismic risk for buildings and infrastructure. In contrast to the Borrero et al. (2006) study that focused on the results of specific events (deterministic analysis), the probabilistic approach focused on the probability that a certain maximum tsunami height will be exceeded by all possible events in a given return period. The results of this analysis showed maximum wave heights at Richmond comparable to those of Borrero et al (2006). The URS (2013) report concludes:

“From the results of this study, we conclude that new insights from the recent Tohoku earthquake and some recent tsunami hazard studies do not appear to warrant a significant increase in the hazard model for the Richmond refinery.”

¹ California Tsunami Inundation Hazard Maps: http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Inundation_Maps/Pages/Statewide_Maps.aspx

Application of Prior Studies to Golden State Warriors Mission Bay Project

Drawing on the approach and conclusions of the above mentioned studies, we have determined the possible range of depths associated with the current State of California (2009) Tsunami Inundation Hazard maps using the existing topography at the project site. Since URS (2013) confirms the inundation shown for San Francisco Bay is the result of the Aleutian III scenario, the maximum wave height of 1.8 m (5.9 feet) at the Potrero District from Table 10 of Borrero et al (2006) was selected (see Table 1 of this memo). We added the maximum wave height of 5.9 feet to the MHW² tidal datum (MHW = 5.29 feet NAVD³) to obtain the elevation of the maximum anticipated tsunami in the vicinity of the project site (approximately 11.2 feet NAVD). To the best of our understanding based on review of available documents, this procedure is consistent with the mapping methods of the State of California (2009). This maximum tsunami inundation elevation of 11.2 ft NAVD converted to the project datum by adjusting it to the City datum (defined as 11.326 feet above NAVD) plus 100 feet (Table 2).

TABLE 2
CALCULATION OF MAXIMUM INUNDATION ELEVATION FOR TSUNAMI HAZARD AREA

Maximum Tsunami Inundation Elevation (max height + MHW feet NAVD)	Elevation in Project Datum (NAVD - 11.326 ft + 100 ft)
11.2 feet NAVD	99.9 feet NAVD

The project is shown to be inundated by the CGS tsunami hazard zone along the western boundary. The extent of tsunami inundation presented by the State of California (2009) for the project site is shown in Figure 1. Given the site topography provided by Martin M. Ron Associates, the inundation depth resulting from the maximum water height is ranges from approximately 0.5 to 1 feet along the site boundary in the areas indicated as within the hazard zone. Figure 2 presents the same areas of tsunami inundation plus zones of the site that are lower in elevation than the maximum tsunami inundation elevation of 11.2 feet NAVD (99.9 feet project datum), which are indicated by the red shading. This shows that the site may be less vulnerable to inundation by a tsunami for present conditions than indicated in the State of California (2009) tsunami hazard inundation maps and that the mapped elevation should be projected to the shore rather than into hydraulically disconnected areas. A more detailed analysis would be needed to calculate the actual extents of tsunami runup on the shore and the potential extents of inundation. However, with sea level rise the elevation of the tsunami hazard is expected to increase, and which will likely alter the runup and overtopping extents.

The information presented in this memorandum is based on worst-case scenarios that were derived for emergency planning purposes, and the question remains of how the mapping relates to the regulatory and jurisdictional requirements. This study does not consider the hydraulic pathways of water movement across the site, and is based on a bathtub modeling of the anticipated tsunami runup elevation.

References

Borrero, J., Dengler, L., Uslu, B., and Synolakis, C., 2006, Numerical Modeling of Tsunami Effects at Marine Oil Terminals in San Francisco Bay, prepared for the Marine Facilities Division of the California State Lands Commission, June 8, 2006.

² MHW refers to mean high water: a tidal datum; the average of all the high water heights observed over the National Tidal Datum Epoch.

³ NAVD, or NAVD88, refers to the North American Vertical Datum of 1988, a fixed reference for elevations determined by geodetic leveling. The datum was derived from a general adjustment of the first-order terrestrial leveling nets of the United States, Canada, and Mexico.

State of California, 2009, Tsunami Inundation Map for Emergency Planning, San Francisco North/South Quadrangle (San Francisco Bay), San Francisco County, produced by California Emergency Management Agency, California Geological Survey, and University of Southern California – Tsunami Research Center; dated June 15, 2009, mapped at 1:24,000 scale.

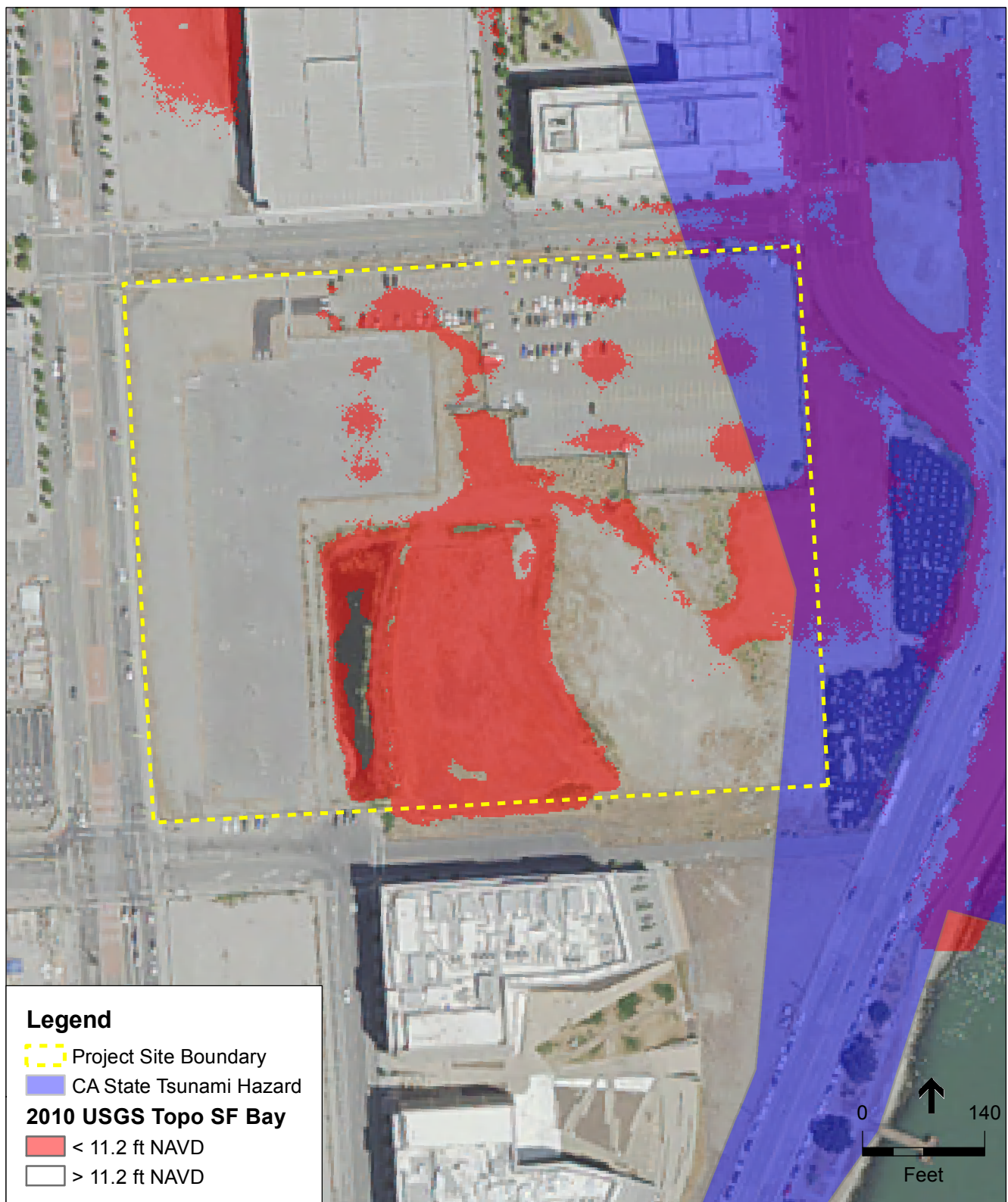
URS, 2013, Tsunami Hazard at the Chevron Richmond Oil Refinery and Terminal, prepared for Chevron, April 19, 2013.



SOURCE: CalEMA 2009; NAIP 2014

GSW Mission Bay SEIR . 120424.03

Figure 1
CA State Tsunami Inundation Extents



SOURCE: CalEMA 2009; USGS 2010; NAIP 2014

GSW Mission Bay SEIR . 120424.03

Figure 2
CA State Tsunami Inundation Extents