APPENDIX C1

Coastal Water Elevations and Sea Level Rise Scenarios

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memorandum

date April 2, 2013

to Michael Burns, ESA

from Doug George, ESA PWA

subject Monterey Peninsula Water Supply Project: Coastal Water Elevations and Sea Level Rise Scenarios

Introduction

The purpose of this memo is to provide a set of coastal water elevations under three sea level rise scenarios that the Monterey Peninsula Water Supply Project study will use for modeling groundwater. The scenarios are summarized in Table 1 and the application of these scenarios is presented below.

Table 1: Sea Level Rise Scenarios

Scenario #	Scenario Name	Sea Level Rise	Additional Assumptions in Scenario
1	Average of Models, High	65.5 in by 2100	Existing wave conditions & continued CEMEX sand mining
2	Projection	36.2 in by 2100	Existing wave conditions & continued CEMEX sand mining
3	Average of Models, Low	16.7 in by 2100	Existing wave conditions & continued CEMEX sand mining

The work described in this memorandum was completed by Doug George, Elena Vandebroek, Louis White and David Revell, PhD, with oversight by Bob Battalio, PE.

Sea Level Rise

Climate change is likely to result in increases in temperature with associated changes in precipitation, more extreme storm events, including rainfall intensity and droughts, as well as increases in sea level and other consequences. Rising sea levels associated with global warming result from both thermal expansion of water (e.g. warmer water occupies more volume) and increasing ice melt. This sea level rise is expected to contribute to an increase in the severity and duration of flooding and an acceleration of shoreline erosion.

Existing Sea Level Trends

Local rates of sea level rise can be estimated as a result of two components – a regional rate of sea level rise associated with the nominal global rate of sea level rise and a local component controlled by local or regional processes, such as tectonics, subsidence and changes to local wind fields. The combination of these two components lead to a rate of relative sea level rise as it combines changes in the both the sea and land elevations. If sea level rises and the shoreline rises or subsides, the relative rise in sea level could be lesser or greater than the global sea level rise. Vertical land movement can occur due to tectonics (earthquakes, regional subsidence or uplift), sediment compaction, isostatic readjustment and groundwater depletion (USACE, 2011).

The Monterey tide gage has a 30-year long period of record and a mean historic local sea level trend of 5.3 inches per century ± 5.3 inches per century (Table 2) (NOAA 2009).

Table 2: Existing Sea Level Trends

Source	Location	Period of Record	Local Mean Sea Level Trend	Est. Vertical Land Movement
IPCC, 2007	Global	1961 - 2003	7.1 inches per century	N/A
NOAA, 2009 & Gill, 2011	Monterey tide gage	1973 - 2006	5.3 ± 5.3 inches per century	1.3 inches per century
NRC, 2012 Table 4.6	San Francisco	1930 - 1980	7.1 – 7.6 inches per century	
NRC, 2012 Table 5.3	San Andreas Region			-6 ± 5 inches per century

Note: Positive values indicate upward movement.

Table 2 reports the vertical land movement as estimated using a recently developed NOAA methodology (Gill, 2011) and as published in a recent National Research Council (NRC) report (NRC, 2012). Rates of estimated vertical land movement vary depending on the study, showing a difference in both magnitude and direction. The NRC rate is a rough estimate that doesn't take into account localized variations in vertical land motion due to shallow subsidence and local tectonic movement. Accurate, long-term trends in vertical land motion are difficult to obtain for specific sites. However, as rates of global sea level continue to increase with climate change, at some point, the rate of vertical land movement will become less significant in determining the impact of sea level rise.

Future Projections and Guidance on Sea Level Rise

In March 2011, the OPC published a resolution recommending that state agencies incorporate the risks posed by sea level rise into project and program plans (OPC, 2011). The resolution was targeted towards state agencies and non-state entities implementing projects or programs funded by the state or on state property (OPC, 2011). The OPC (2011) provides the following guidance on which SLR projections to use:

- Assess vulnerabilities over a range of SLR projections, including analysis of the highest SLR values presented in the state guidance document;
- Avoid making decisions based on SLR projections that would result in high risk; and
- Coordinate and use the same SLR projections when working on the same project or program.

The State of California provided interim guidance via the OPC on SLR projections and requested that the NRC establish a committee to assess sea-level rise to inform the state efforts. The states of Washington and Oregon, the U.S. Army Corps of Engineers, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey subsequently joined California in sponsoring the NRC study to evaluate sea-level rise in the global oceans and along the coasts of California, Oregon, and Washington for 2030, 2050, and 2100. The NRC released their final report in June 2012 and in March 2013, the OPC revised the interim guidance to incorporate the report findings (OPC, 2013).

In the NRC recently released results, regional sea level rise (which includes an allowance for vertical land motion) for San Francisco (the regional estimate nearest to Monterey Bay) is predicted to be 4.8 to 24.0 inches by 2050 and 16.7 to 65.5 inches by 2100 relative to 2000 (Table 3). The San Francisco projection incorporates a 5.9 inches/century rate of subsidence.

Table 3: San Francisco Sea-Level Rise Projections (in inches) Relative to Year 2000 (from Table 5.3, NRC 2012)

2030		2050		2100	
Projection	Range	Projection	Range	Projection	Range
5.7 ± 2.0	1.7 to 11.7	11.0 ± 3.6	4.8 to 24.0	36.2 ± 10.0	16.7 to 65.5

Note: NRC 2012 projections include a vertical subsidence of 5.9 ± 5.1 inches/century.

Coastal Water Elevations

Groundwater modeling for the MPWSP requires considering the influence of additional seawater volume above the aquifer. A curve was fit to the four data points provided in the NRC 2012 report (2030, 2050, 2070, 2100) for each scenario to generate an annual time series of sea level rise between 2012 to 2073. The values were normalized to 2012 by subtracting the projected sea level rise at 2012 from all annual sea level rise values (Figure 1). Table 4 contains annual sea level rise projections for each scenario.

Figure 1. Monterey Bay Sea Level Rise Curves for 2012 to 2073.

Note: The values are normalized to 2012 after subtracting the change in sea level from 2000-2012.

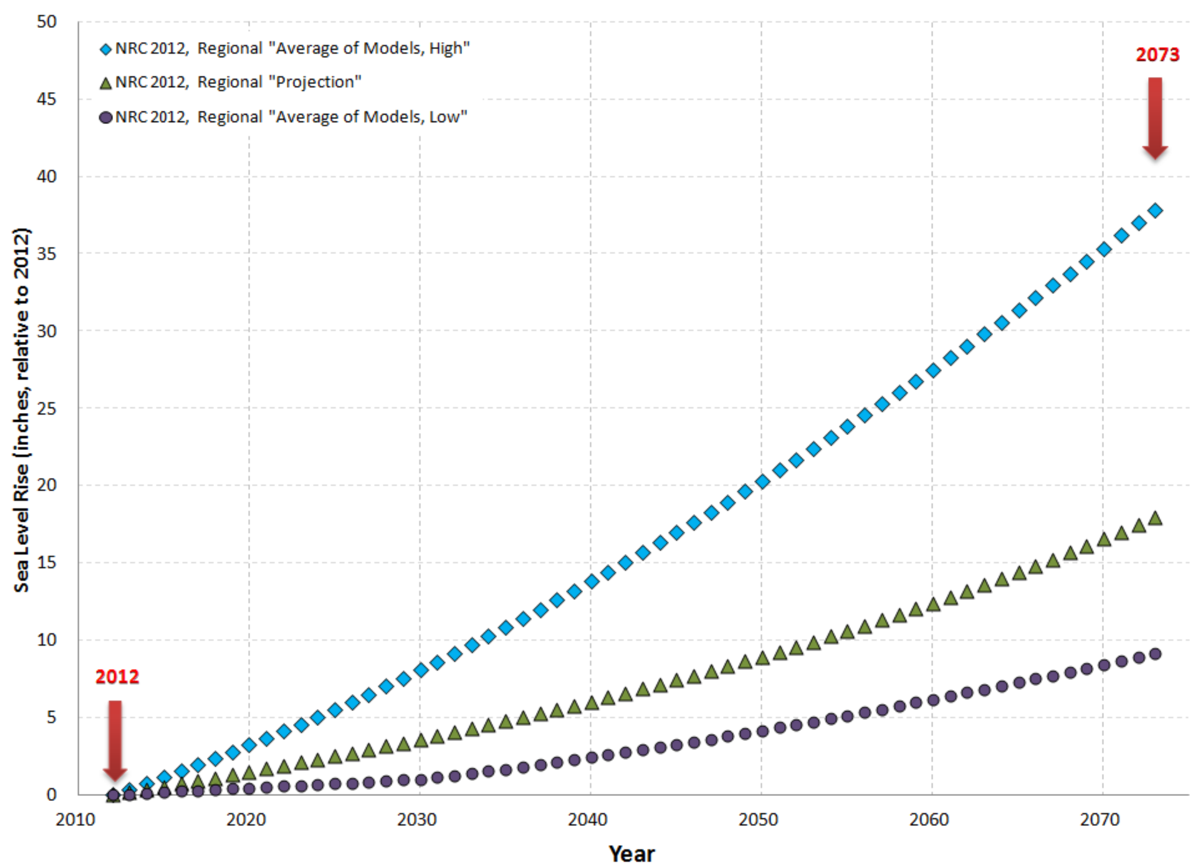

Table 4: Projected Annual Sea Level Rise for Monterey Bay

Year	Sea Level Rise Relative to 2012 (inches)			Incremental Sea Level Rise (inches)		
	High Range of Models	Projection	Low Range of Models	High Range of Models	Projection	Low Range of Models
2012	0.0	0.0	0.0	--	--	--
2013	0.4	0.2	0.1	0.368	0.181	0.056
2014	0.7	0.4	0.1	0.378	0.182	0.056
2015	1.1	0.5	0.2	0.388	0.184	0.056
2016	1.5	0.7	0.2	0.398	0.186	0.056
2017	1.9	0.9	0.3	0.407	0.188	0.056
2018	2.4	1.1	0.3	0.417	0.190	0.056
2019	2.8	1.3	0.4	0.427	0.192	0.056
2020	3.2	1.5	0.5	0.436	0.195	0.056
2021	3.7	1.7	0.5	0.446	0.197	0.056
2022	4.1	1.9	0.6	0.455	0.200	0.056
2023	4.6	2.1	0.6	0.464	0.202	0.056
2024	5.1	2.3	0.7	0.473	0.205	0.056
2025	5.5	2.5	0.7	0.482	0.208	0.056
2026	6.0	2.7	0.8	0.491	0.211	0.056
2027	6.5	2.9	0.8	0.500	0.214	0.056
2028	7.0	3.2	0.9	0.509	0.217	0.056
2029	7.6	3.4	1.0	0.518	0.220	0.056
2030	8.1	3.6	1.0	0.527	0.224	0.056
2031	8.6	3.8	1.1	0.535	0.227	0.124
2032	9.2	4.1	1.3	0.544	0.231	0.128
2033	9.7	4.3	1.4	0.552	0.235	0.132
2034	10.3	4.5	1.5	0.561	0.238	0.136
2035	10.8	4.8	1.7	0.569	0.242	0.139
2036	11.4	5.0	1.8	0.577	0.246	0.143
2037	12.0	5.3	2.0	0.586	0.251	0.146
2038	12.6	5.5	2.1	0.594	0.255	0.150
2039	13.2	5.8	2.3	0.602	0.259	0.153
2040	13.8	6.0	2.4	0.610	0.264	0.157
2041	14.4	6.3	2.6	0.617	0.268	0.160
2042	15.1	6.6	2.7	0.625	0.273	0.163
2043	15.7	6.9	2.9	0.633	0.278	0.167
2044	16.3	7.1	3.1	0.640	0.283	0.170
2045	17.0	7.4	3.3	0.648	0.288	0.173
2046	17.6	7.7	3.4	0.655	0.293	0.176
2047	18.3	8.0	3.6	0.663	0.298	0.179
2048	19.0	8.3	3.8	0.670	0.303	0.182
2049	19.6	8.6	4.0	0.677	0.309	0.185
2050	20.3	8.9	4.2	0.684	0.314	0.188
2051	21.0	9.3	4.4	0.692	0.320	0.190
2052	21.7	9.6	4.5	0.699	0.326	0.193

2053	22.4	9.9	4.7	0.705	0.332	0.196
2054	23.1	10.3	4.9	0.712	0.338	0.199
2055	23.9	10.6	5.1	0.719	0.344	0.201
2056	24.6	11.0	5.3	0.726	0.350	0.204
2057	25.3	11.3	5.6	0.732	0.356	0.206
2058	26.1	11.7	5.8	0.739	0.363	0.209
2059	26.8	12.0	6.0	0.745	0.369	0.211
2060	27.5	12.4	6.2	0.751	0.376	0.213
2061	28.3	12.8	6.4	0.758	0.382	0.216
2062	29.1	13.2	6.6	0.764	0.389	0.218
2063	29.8	13.6	6.8	0.770	0.396	0.220
2064	30.6	14.0	7.1	0.776	0.403	0.222
2065	31.4	14.4	7.3	0.782	0.410	0.224
2066	32.2	14.8	7.5	0.788	0.418	0.226
2067	33.0	15.2	7.7	0.794	0.425	0.228
2068	33.8	15.7	8.0	0.799	0.432	0.230
2069	34.6	16.1	8.2	0.805	0.440	0.232
2070	35.4	16.6	8.4	0.811	0.448	0.234
2071	36.2	17.0	8.7	0.816	0.456	0.235
2072	37.0	17.5	8.9	0.821	0.463	0.237
2073	37.9	18.0	9.1	0.827	0.471	0.239

Additional Information

The uncertainty in these projections is large (NRC, 2012) and the probability of a particular sea level rise occurring at a particular date is not known (USACE, 2011). Hence, each project design should consider the risk of sea level changes to the project and environment, with risk typically considered the product of the likelihood of an impact and the consequences of that impact (NRC, 2012). Other work by Flick and others (2003) have suggested that tidal ranges are increasing with sea level rise. In particular, the increase of the high tides was observed to be larger than that of the mean and low tides, which has implications for setting the mean higher high water (MHHW) line in the future. In addition, the values provided above do not address any local vertical land motion that could affect the relative sea level rise at the site. Subsidence or settlement of the land will increase relative sea level rise. Such local vertical land lowering can be induced by consolidation of subsurface soils due to groundwater extraction and additional vertical loads such as fill. Vertical land motions can be estimated based on elevation surveys of benchmarks over time. The data in Table 4 implicitly assume that vertical land motions at the project site(s) are small relative to the values of future sea level rise and uncertainty but evaluation of vertical land motions is beyond the scope of the work performed. Also, these computations do not include wave-driven dynamics and coastal geomorphic responses which may affect ground water levels.

Attachment

SLRScenarios_data_final.xls - Table 4: Projected Annual Sea Level Rise for Monterey Bay

References

Flick, R.E., J. F. Murray, and L.C. Ewing (2003). Trends in United States Tidal Datum Statistics and Tide Range. Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 129, No. 4, July 1, 2003, 155-164.

Gill (2011). "NOAA regional estimates - Estimating Local Vertical Land Motion from Long-term Tide Gage Records" Version 2 draft (NOAA 6/8/2011).

NOAA (2009). "Sea Level Variations of the United States 1854 - 2006." Technical Report NOS CO-OPS 053. National Oceanic and Atmospheric Administration. Silver Spring, Maryland. December 2009.

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

OPC (2013). California Ocean Protection Council. *State Of California Sea-Level Rise Guidance Document.* Presented on March 27, 2013. Available online: http://www.opc.ca.gov/webmaster/ftp/pdf/docs/2013_SLR_Guidance_Update_FINAL1.pdf (last visited April 2, 2013).

OPC (2011). California Ocean Protection Council. *Resolution of the California Ocean Protection Council on Sea-Level Rise.* Adopted on March 11, 2011. Available online: http://www.opc.ca.gov/webmaster/ftp/pdf/docs/OPC_SeaLevelRise_Resolution_Adopted031111.pdf (last visited August 14, 2012).

USACE (2011). "Sea-Level Change Considerations for Civil Works Programs." US Army Corps of Engineers, EC 1165-2-212.