2018

CAWD WWTP Sea Level Rise Study

Carmel Area Wastewater District

12/5/2018

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Section 1: Introduction

This report presents the results of the technical analysis to evaluate climate change-driven flooding impacts on the Carmel Area Wastewater District (CAWD) Wastewater Treatment Plant (WWTP) assets and its ability to treat wastewater. The bulk of the evaluation summarized herein was completed by Environmental Science Associates (ESA) and is represented in their report in Appendix A. This report presents a summary of the ESA evaluation and focuses more on the WWTP asset vulnerability and impacts that the sea level rise projections could have on critical infrastructure at the CAWD WWTP.

1.1 Sea-level Rise Scenarios

The sea-level rise scenarios proposed for this study were selected to be consistent with the latest guidance. Environmental Science Associates (ESA) provided a summary of the recommendations for Sea Level Rise scenarios for CAWD in Appendix A. The Ocean Protection Council (OPC) 2018 guidance for sea level rise was used as the basis for the current analysis.

The "Medium-High Risk Aversion" scenario included in the 2018 OPC guidance was selected for the ESA modelling of water levels at the WWTP. The "Medium-High Risk Aversion" can be compared to the "Extreme Risk Aversion". For instance, the timing of "Extreme Risk Aversion" in 2070 is roughly equivalent to the "Med-High Risk Aversion" of 2085. Table 1 contains a summary of the sea level rise estimates in the 2018 OPC guidance.

Table 1 - Sea-Level Rise Scenarios For Planning

Scenario	**2050**	**2070**	**2100**
Med-High Risk Aversion	2 feet	3 feet	6 feet
Extreme Risk Aversion	2.7 feet	5.1 feet	10.1 feet

The "Extreme Risk Aversion" scenario and the "Medium-High Risk Aversion" scenario are illustrate in Figure 1 and are consistent with the OPC 2018 guidance.

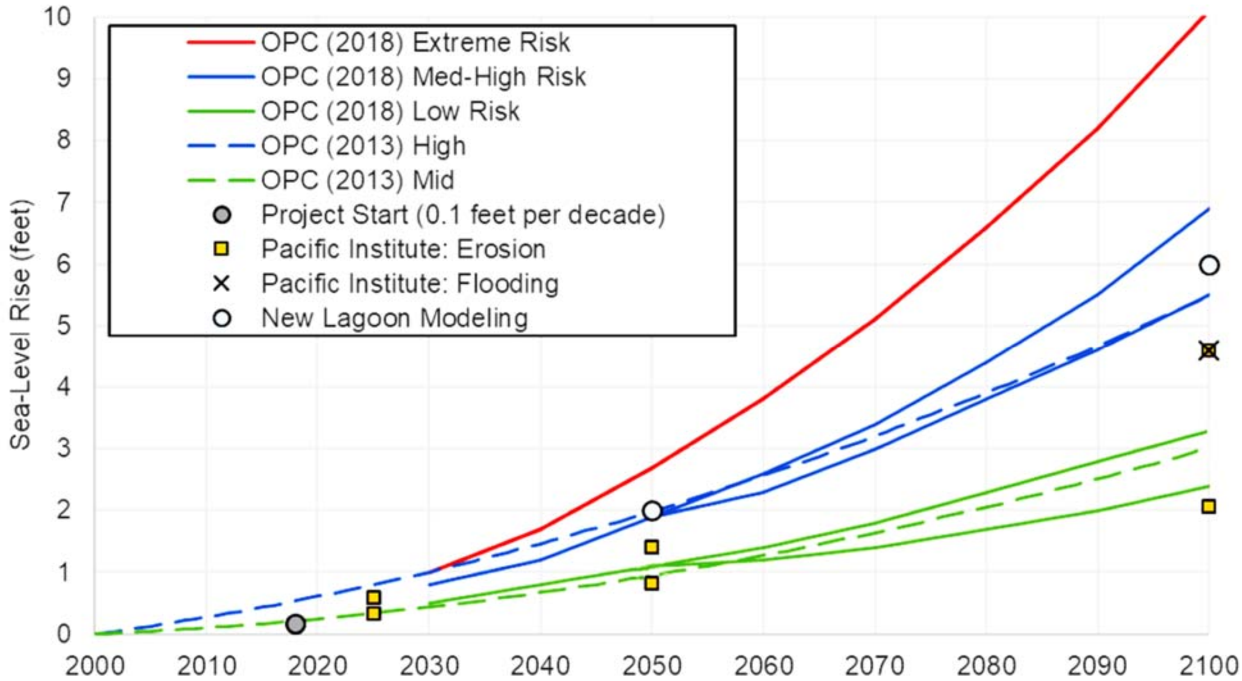


Figure 1 - Comparison of Proposed Analysis and Available Hazard Maps to Updated OPC (2018) Sea-Level Rise Guidance Curves

Section 2: Exposure Analysis

2.1 Exposure Scenarios

The CAWD WWTP was evaluated for three different scenarios of flooding as follows:

Closed Lagoon Conditions

- **Backwatered Lagoon Inundation Level**: A sustained high-water level representative of typical conditions when the lagoon mouth is closed. Groundwater elevations are likely to equilibrate with this surface water level.

- **Moderate Storm with Closed Lagoon Inundation Level**: A temporary high water event in the lagoon associated with backup of water in the lagoon when the rivermouth is closed and water collects behind the sand bar. The source of water could be either moderate river streamflow, or wave overtopping into the lagoon. This does not represent extreme fluvial floods.

Open Lagoon Conditions

- **100-yr Fluvial Flooding Level**: Flooding during extreme river flow events can cause elevated water levels adjacent to the treatment plant and overtopping of the river channel. Flooding has occurred at the WWTP in the past and has been a known hazard since before the current treatment facilities were built and the 100-year flood was used as a basis for design. Flooding is short duration for hours or days. Past flooding has not reached the theoretical 100-year storm levels in historical records. The probability of a 100-yr storm occurring is 1%.

Figure 2 is an illustration of these three scenarios.

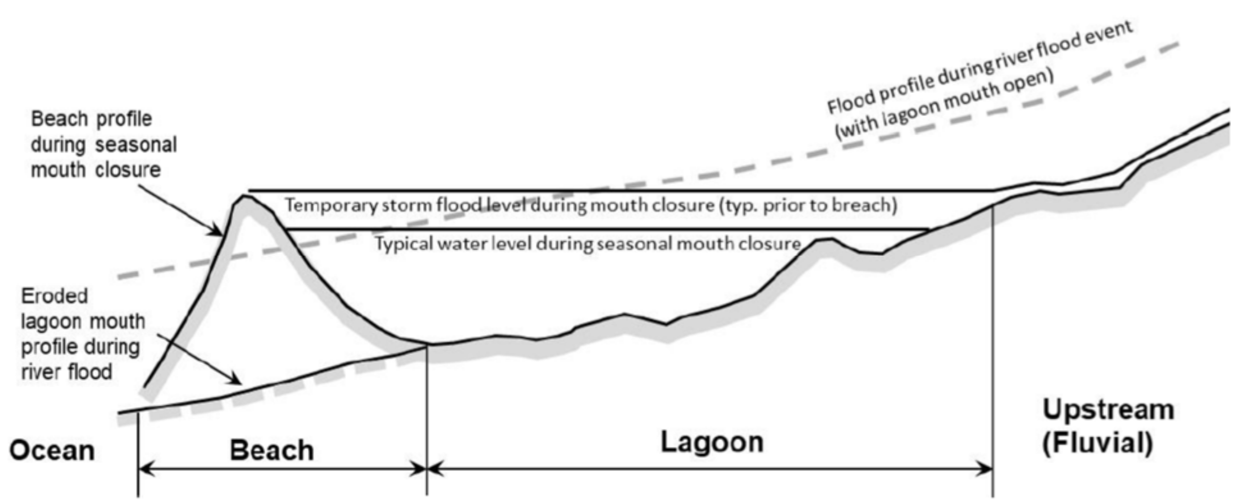


Figure 2 - Schematic of Closed Lagoon Conditions and River Flood Events

2.2 Lagoon Levels During Closed-Lagoon Conditions

Projection of the lagoon water levels over time was modeled by ESA using a hydrologic and geomorphic approach (Appendix A). The lagoon modeling was conducted to determine how lagoon processes would respond to sea-level rise. Two primary reference lagoon water levels were determined for each time horizon that represent the following conditions used for the impacts analysis:

- **Backwatered Lagoon Inundation Level**: A sustained high water level representative of typical conditions when the lagoon mouth is closed. Groundwater elevations are likely to equilibrate with this surface water level.

- **Moderate Storm with Closed Lagoon Inundation Level**: A temporary high water event in the lagoon associated with backup of water in the lagoon when the rivermouth is closed and water collects behind the sand bar. The source of water could be either moderate river streamflow, or wave overtopping into the lagoon. This does not represent extreme fluvial floods.

These two conditions occur when the mouth of the lagoon is closed due to wave action, and the ponded water in the lagoon is essentially a flat surface, that can be easily mapped to understand which assets are exposed to flooding. A third condition, flooding during extreme river flow events, typically leads to a scoured lagoon mouth and a sloping water surface along the lagoon. Under these conditions (described in the next section), peak water surface elevations at any location depend on the flow rate in the Carmel River.

Table 2 presents the water levels computed by ESA for the range of sea levels and their corresponding forecast dates. The Backwatered Lagoon Inundation water levels range from 11 to 16 feet NAVD, and the Moderate Storm Closed Lagoon flood water levels range from 15 to 20 feet NAVD. The water level does not increase linearly with sea-level rise because the storage of the lagoon significantly expands at elevations greater than 13 feet NAVD.

This modeling and results implicitly presume that waves and rainfall-runoff are steady (not increased or decreased by climate change) and there is adequate deposition of sand for the beach to rise linearly with sea-levels. It should be noted that ESA believes that the sand on the beach will most likely not rise linearly with sea level rise and therefore the analysis is conservative.

Table 2 - Lagoon Water Levels Over Time For Closed Lagoon Conditions

	Existing	2030	2050	2070	2100
Sea Level Rise (feet)	0	1	2	3	6
Backwatered Lagoon Inundation Level (Feet NAVD88)	11	12	13	14	16
Moderate Storm Closed Lagoon Inundation Elevation (feet NAVD88)	15	15.5	16	17	20

Figure 3 presents lagoon water levels for Backwatered Lagoon Inundation and Moderate Storm Closed Lagoon flooding over time with sea-level rise. The lines in the figures are best-fit polynomials that can be used to approximate the year associated with impacts of specific threshold elevations. Note that the existing condition is assumed to occur at year 2000, consistent with state guidance (CCC 2015).

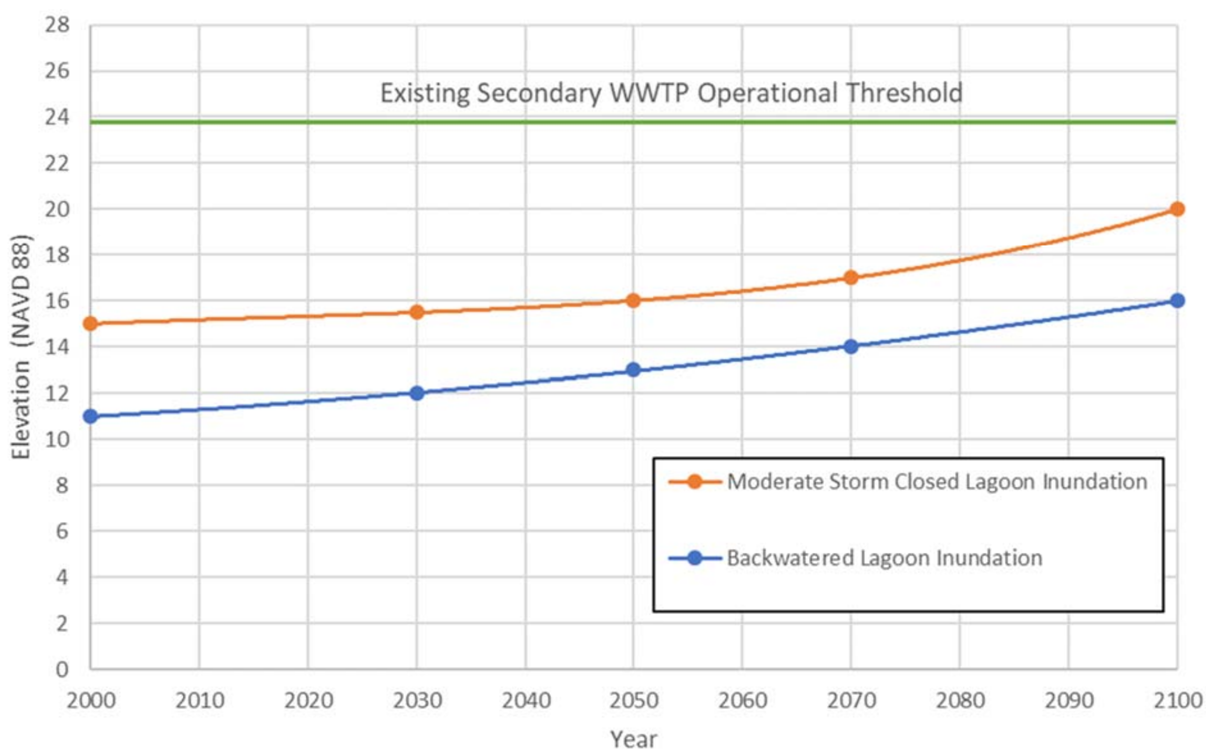


Figure 3 - Projections Of Lagoon Flooding During Closed Lagoon Conditions Over Time With Sea-Level Rise

2.3 Flooding During Extreme River Flow Events

Flooding during extreme river flow events can cause elevated water levels adjacent to the treatment plant and overtopping of the river channel. This has occurred at the WWTP in the past and has been a known hazard since before the current treatment facilities were built. Ongoing climate change is expected to alter the amount of rainfall arriving during storm events, which will affect the risk of flooding of assets during these high river flow events. This coupled with sea level rise will change the current flood dynamics.

To predict future changes in flooding frequency in the Carmel River, ESA analyzed publicly available historical and forecasted future precipitation data for the Carmel River watershed. Changes in frequency of extreme precipitation events over time were used as an indicator for anticipated future changes in extreme flows. The precipitation data were derived from climate model output from general circulation models (GCMs) developed by international modeling teams as part of the International Panel on Climate Change's (IPCC) fifth assessment report (AR5). These data have been downscaled to a 6 kilometer by 6 kilometer grid scale and aggregated under a Scripps Institution of Oceanography online database (Pierce et al. 2014). The data are based on the latest set of global emissions scenarios referred to as Representative Concentration Pathways (RCPs). The analysis conducted for this study included processing this downscaled climate data in Matlab and conducting extreme value analysis to estimate the change in frequency for a 24-hour precipitation event. Two time horizons, a mid-century (2050) and late-century (2100), and two climate scenarios, RCP 4.5 and RCP 8.5, were considered for this analysis. Increased flow rates are listed in Table 3 for a range of flood events. Although the GCMs predict a broad range of future precipitation, ESA recommends applying the average of the GCM outputs for planning purposes. Applying the average of GCM outputs gives rise to a 22 to 36 percent increase in peak flows by 2050, an increase of 28 to 72 percent by 2100. For context, using GCM outputs at the 95th percentile of predictions would result in higher flows in the future. The 95th percentile of outputs would result in an increase in peak flows by 98 to 159 percent by 2050 and 114 to 283 percent by 2100.

Table 3 - Predicted Future Flow Rates On The Carmel River With Climate Change

	Existing Conditions	2050		2100	
Annual Recurrence Flood Event	Flow Rate Upstream of Lower Carmel River	GCM Average Flow Rate (cfs)	GCM Average Flow Rate (% Increase)	GCM Average Flow Rate (cfs)	GCM Average Flow Rate (% Increase)
RCP 4.5					
2	2,951	3,152	22%	3,304	28%
5	6,220	7,872	27%	8,228	32%
10	9,204	11,811	28%	12,335	34%
50	16,545	21,548	30%	22,509	36%
100	19,770	25,834	31%	26,996	37%
500	27,159	35,707	31%	37,344	38%
RCP 8.5					
2	2,591	3,337	29%	3,631	40%
5	6,220	8,211	32%	9,640	55%
10	9,204	12,268	33%	14,839	61%
50	16,545	22,330	35%	27,941	69%
100	19,770	26,779	35%	33,714	71%
500	27,159	37,068	36%	46,792	72%

To relate the increased flow rates to water levels at the treatment plant, ESA used prior hydraulic modeling conducted by Schaaf and Wheeler (2014), who examined the 10-, 50-, 100-, and 500-year annual recurrence flood events on the river. Modeled water levels were reported at the treatment plant for each flood event, allowing a regression to be made between river flow rates and water levels. This regression was used along with the increased flow rates reported in Table 3 to give future flood levels at the treatment plant for 2050 and 2100. These levels are shown in Table 4, and also incorporate the suggested sea-level rise amounts of 2 feet and 6 feet by 2050 and 2100, respectively. Figure 4 illustrates the results listed in Table 4.

Table 4 - Predicted Future Flow Rates On The Carmel River And Resulting Water Levels At The Treatment Plant

	Existing Conditions		2050		2100	
Annual Recurrence Flood Event	Flow Rate Upstream of Lower Carmel River	Water Level at Treatment Plant[1]	Flow Rate Upstream of Lower Carmel River	Water Level at Treatment Plant[2]	Flow Rate Upstream of Lower Carmel River	Water Level at Treatment Plant[3]
RCP 4.5						
10	9,204	N/A	11,811	20.4	12,335	24.5
50	16,545	18.9	21,548	21.2	22,509	25.3
100	19,770	19.1	25,834	21.5	26,996	25.5
500	27,159	19.5	35,707	21.9	37,344	26.0
RCP 8.5						
10	9,204	N/A	12,268	20.5	14,839	24.7
50	16,545	18.9	22,330	21.3	27,941	25.6
100	19,770	19.1	26,779	21.5	33,714	25.8
500	27,159	19.5	37,068	22.0	46,792	26.3

NOTES:
1 Reported by Schaaf and Wheeler (2014)
2 Water Levels in 2050 include an assumed 2 feet of sea-level rise, per Table 1
3 Water Levels in 2100 include an assumed 6 feet of sea-level rise, per Table 1

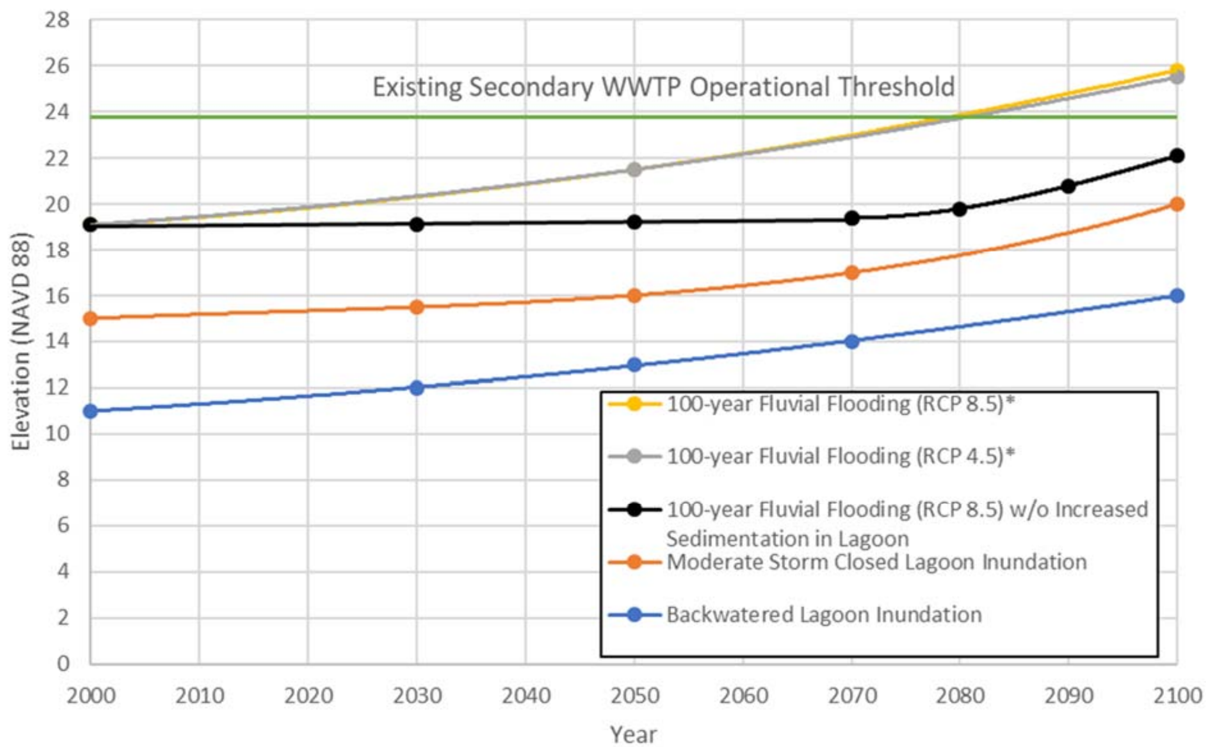
2.3.1 Sensitivity to Sedimentation in the Lagoon

The flood analysis calculations assume that sedimentation would keep pace with sea-level rise in the future, meaning that the flood levels reported by Schaaf and Wheeler would shift upward in the future. We do not expect sedimentation to be uniform throughout the lagoon, and the rate of bed elevation rise could be outpaced by sea-level rise as it accelerates between 2050 and 2100. Thus, the predictions in Table 4 should be considered conservative (high). In reality, the availability of beach sand to build up the sandbar is likely a limiting factor in increased sedimentation build up and increase in the downstream flood weir elevation.

To better illustrate the sensitivity to sedimentation, ESA also examined results from the prior hydraulic modeling work that looked at sensitivity of flood levels to the downstream tailwater elevation in the lagoon. In particular, for the 100-year river flood case, Schaaf and Wheeler (2014) (Appendix B) compared flood levels for a tailwater at normal depth, and for a tailwater at normal depth 'plus ineffective flow from sandbar' (see Table 3 in Schaaf and Wheeler 2014). The latter case has a tailwater height that is 2.8 feet higher, leading to an increase in flood levels at the WWTP from 19.1 to 19.45 feet NAVD88. Since the shape of the lagoon is otherwise unchanged, we take this case to be analogous to a 100-year river flow event with approximately 3 feet of sea-level rise and no sedimentation in the lagoon. This is represented in Figure 2 by a black curve. Taken together with the results described above, this gives an approximate envelope of expected flood levels at the WWTP during the 100-year river flood event.

2.3.2 Sensitivity to Floodplain Area

The flood analysis calculations assume that the area of the floodplain will not change. This is a conservative assumption since the flood plain will spread out as flood elevations rise and this will result in a reduction of the flood elevation at the WWTP from what is shown in this report.



Notes:

1. 100-Year Fluvial Flooding assumes that sedimentation in lagoon occurs at same pace as sea level rise. It is believed that sedimentation will be out paced by sea level rise so these numbers are conservative. The availability of sand will be a limiting factor in the ability for the sandbar elevation to increase.
2. Projections do not include modeling of larger floodplain area created by higher flood elevations. Larger flood plain area would reduce flood elevation at WWTP.
3. 100-year Fluvial Flood elevations are for the Main River Channel on the North East Corner of Treatment Plant. Flood elevations decrease about 2 feet as water moves across the treatment plant.

Figure 4 - Projections of WWTP Flood Elevation for 100-year Fluvial Flooding and Other Conditions

2.3.3 Floods of Record

Table 5 shows flood events in the recent past to provide real world case studies as a comparison to the flood modeling work that has been done. In general the flood history correlates well with the modeling done. Figure 5 shows the downstream lagoon elevation during the storms. For reference the current 100-yr storm is predicted to create river flows of 22,000 cfs.

Table 5 – Recent Floods of Record

Year	River Flow (cfs)	Impact to WWTP
March 10th, 1995	~16,000 cfs	Water entered treatment plant site. No permit violations.
February 3rd, 1998	~14,500 cfs	Water entered treatment plant site. No permit violations
March 11th, 2011	~6,000 cfs	No water onsite. No permit violations.
January 9th, 2017	~5,500 cfs	No water onsite. No permit violations.
January 11th, 2017	~6,700 cfs	No water onsite. No permit violations.
February 21st, 2017	~9,200 cfs	No water onsite. No permit violations

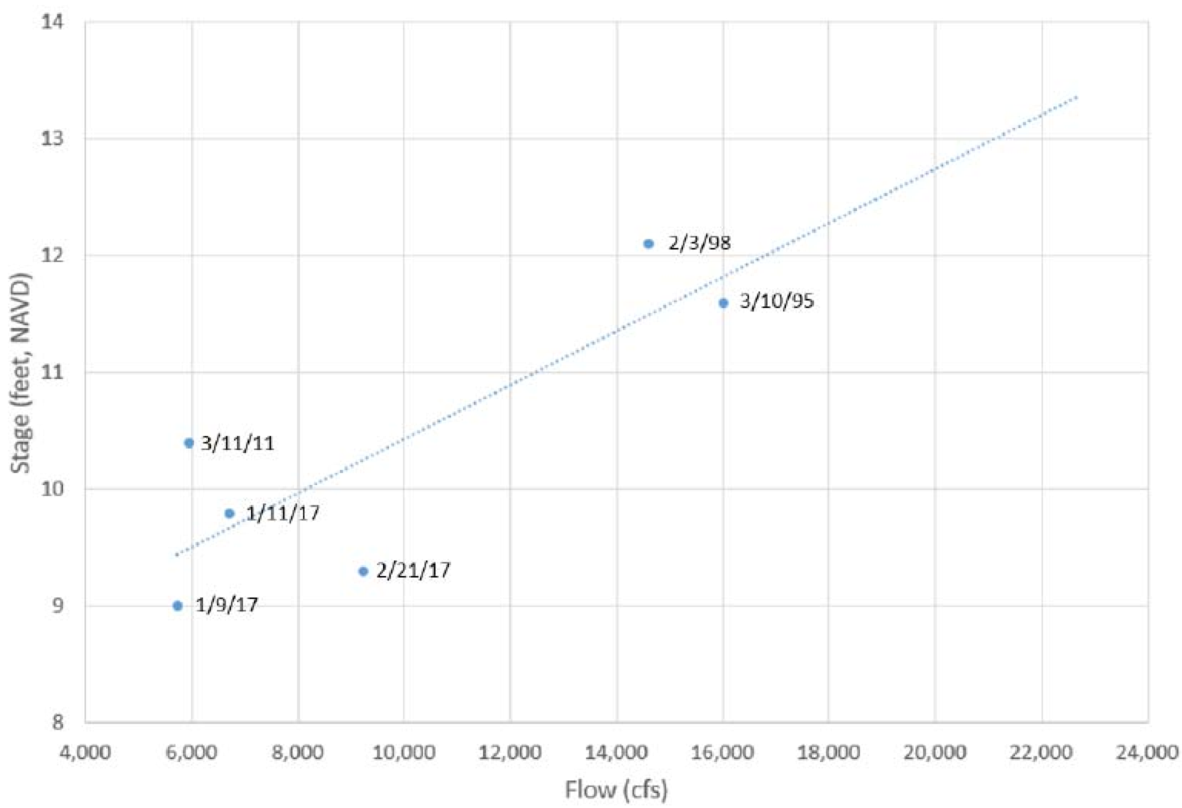


Figure 5 - Downstream Lagoon Levels during recorded storm events

2.3.4 Carmel River FREE Project Effect on Extreme River Flow Events

The Carmel River Floodplain Restoration and Ecosystem Enhancement (FREE) Project is a flood control project being developed by the Big Sur Land Trust and the County of Monterey to protect Hwy 1 and homes on the North Side of the Carmel River from impacts due to floods. The project as is currently defined will divert approximately 8,000 cfs (30% of total flow) from the main river channel adjacent to the CAWD WWTP to the South Arm of the Carmel Lagoon. The modeling conducted by the project proponents suggests that this will reduce the flood elevation at the CAWD WWTP by about 1 ft. A 2015 modelling report by Balance Hydrologics for the Carmel River Free Project is provided in Appendix C. Figure 6 shows modelling of the CAWD WWTP by Balance Hydrologics in 2015 done for the Carmel River FREE Project. The model shows the base flood elevation at the upstream (East side) of the CAWD WWTP as 19.1 feet and about 16.1 feet at the downstream (West side) of the treatment plant. It also shows the reduction in flood elevation estimated as a result of the project.

The 19.1 feet base flood elevation at the eastern boundary of the WWTP is consistent with the flood modelling by ESA and Schaff & Wheeler.

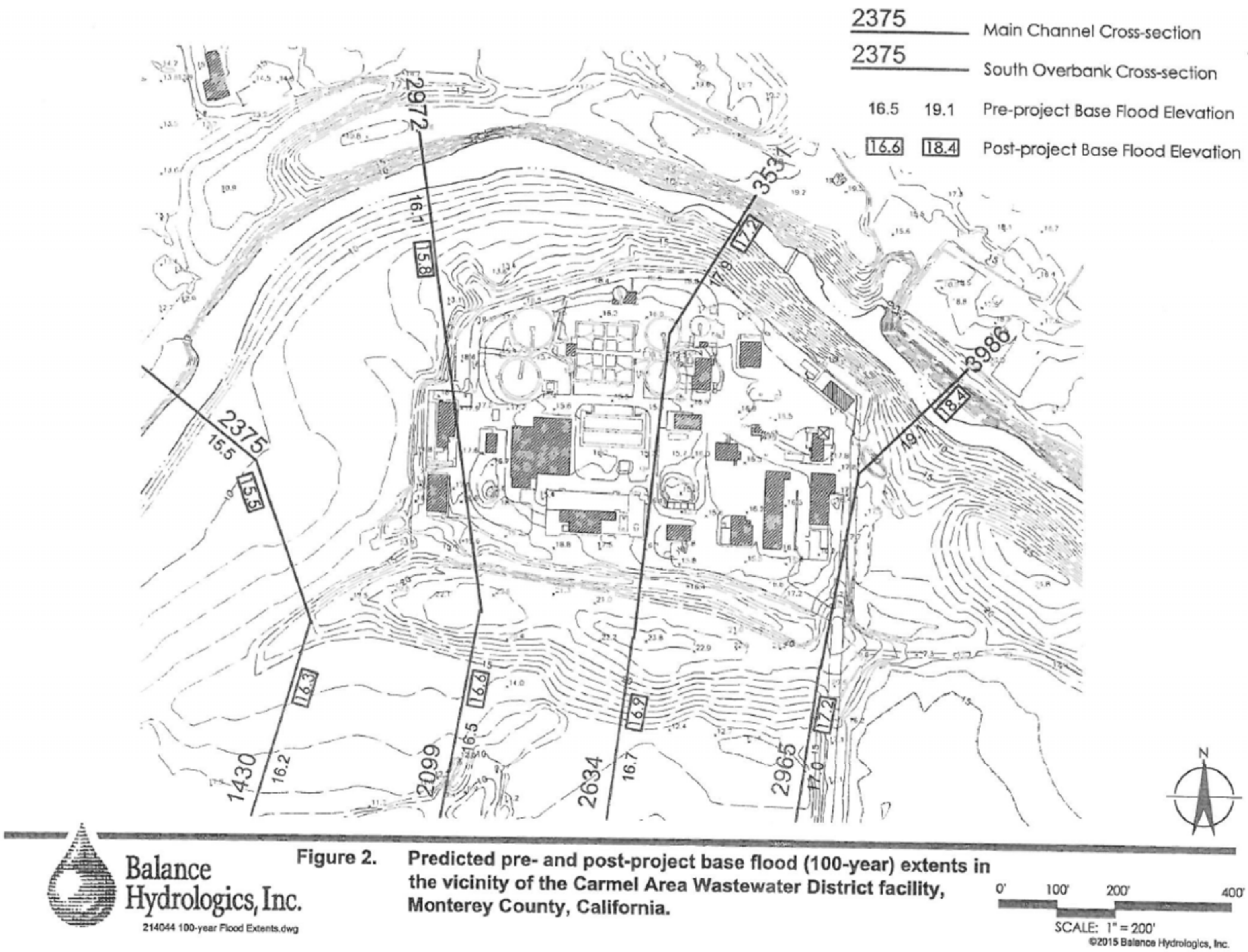


Figure 6 - Third Party Modelling of CAWD WWTP 100-Year Flood Elevations for CRFREE project

Section 3: Impacts Analysis

Evaluation of impacts to the wastewater treatment plant by flooding was conducted by a threshold analysis that compares vulnerable elevations to projections of the flood water levels over time.

3.1 Threshold Analysis

Vulnerable CAWD assets were compared with the exposure analysis described in Section 2 to determine threshold timeframes of impact. Vulnerability thresholds were developed with the following procedure:

- Tabulation of asset elevations where temporary or extended loss of service would occur.
- ESA's lagoon modeling was used to compute flood levels in Carmel Lagoon under future conditions with a set of sea-level rise values (Table 2 and Table 4).
- Fitted curves were developed using the water level predictions in Table 1 and 4. These allow prediction of flood levels in the lagoon for any year between 2000 and 2100.
- Asset elevations were compared to the fitted curves to give an expected timeline for impacts.

Figure 7 is a map showing the WWTP assets with Building Numbers and Figure 8 is an aerial photo of the WWTP.

CARMEL AREA WASTEWATER DISTRICT
WASTEWATER TREATMENT FACILITY
BUILDING NUMBER PLAN

BUILDING NUMBERS LEGEND

1	INFLUENT BUILDING
2	INFLUENT HEADBOX
3	HEADWORKS
4	PRIMARY SEDIMENTATION BASINS
5	ANOXIC SELECTOR
6	EQ BASIN
7	AERATION BASINS
8	BLOWER BUILDING
9	MIXED LIQUOR DISTRIBUTION STRUCTURE
10	MIXED LIQUOR FLOWMETER VAULT
11	SECONDARY SEDIMENTATION BASINS
12	RAS/WAS BUILDING
13	SECONDARY EFFLUENT DIVERSION VAULT
14	CHLORINE CONTACT CHANNELS AND BUILDING
15	TERTIARY BUILDING
16	GYPSUM SILO
17	MF/RO PAD
18	EFFLUENT BUILDING
19	OUTFALL
20	DISSOLVED AIR FLOTATION THICKENER
21	DIGESTER NO. 1
22	DIGESTER NO. 2
23	DIGESTER NO. 2 CONTROL BUILDING
24	SLUDGE HOLDING TANK
25	DIGESTER NO. 1 CONTROL BUILDING
26	WASTE GAS BURNER
27	DEWATERING BUILDING
28	SLUDGE TRAILER
29	FATS-OILS-GREASE RECEIVING FACILITY
30	OPERATIONS BUILDING
31	LOCKER ROOM
32	LAB BUILDING
33	VEHICLE STORAGE BUILDING
34	MAINTENANCE SHOP
35	STORAGE BUILDING
36	HYPO/SBS FACILITY
37	OFFICE TRAILER
38	LUNCH ROOM
39	OFFICE TRAILER
40	OFFICE TRAILER
41	VEHICLE FUEL STORAGE TANKS
42	FERRIC CHLORIDE STORAGE
43	STORMWATER PUMP STATION
44	CONEX STORAGE
X	STRUCTURES OUT OF SERVICE

Figure 7 - WWTP Building Number Plan

Figure 8 - CAWD WWTP Aerial

3.1.1 Threshold Analysis - Vulnerable Assets

Flooding impacts in Table 6 are assessed for any assets that were found to be vulnerable within the modelling timeframe for the potential flooding scenarios described in Table 2 and Table 4. These are:

- 100-yr River Flooding (RCP 8.5) – Limited duration flooding due to heavy rainfall and fluvial flooding.

- Moderate Storm with Closed Lagoon Inundation – Temporary increase in lagoon levels due to collection of moderate storm river flows behind closed sand bar.

- Backwatered Lagoon Inundation – Long term water levels at the WWTP created from sea level rise impact on normal lagoon levels. Groundwater elevations are likely to equilibrate with this surface water level.

Table 6 also contains information on the assets as to whether it is critical to the Secondary Treatment Plant process and the potential adaptation strategy to deal with sea level rise projections.

Table 6 - Vulnerable Assets And Approximate Time Thresholds Of Impact

Building #	Description	Operation Critical for Secondary Treatment	Asset Designed to Operate thru Flood Water Elevation (feet NAVD)	Timing of 100-yr River Flooding Impact (RCP 8.5)	Timing of Closed Lagoon Moderate Storm Impact	Timing of Backwatered Lagoon Inundation Impact	Notes	Adaptation Strategy
Treatment Plant Assets								
29	Grease Receiving Station	No	16.7	Existing	2060	beyond 2100	Receive fats-oils-grease and ground up food waste from grocery stores. Not required to accept the waste, can stop at anytime.	Demolish assets. Rebuilding to a higher elevation could be an option but would depend on payback analysis.
35	Storage Building	No	16.8	Existing	2066	beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding or demolish building.
34	Maintenance Shop	No	16.84	Existing	2067	beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding or build new elevated maintenance shop.
33	Vehicle Storage Building	No	16.87	Existing	2067	beyond 2100	Not used in treatment plant process.	None required. Relocate vehicles offsite during flood.
44	Conex Storage	No	17	Existing	2070	beyond 2100	Storage of materials and equipment. Can be removed from site.	Remove from site or place on an elevated concrete pad or anchor to protect structure from flooding.
28	Sludge Trailer	Yes	17.62	Existing	2078	beyond 2100	Not a structure. Dewatering can be offline for extended periods by using the standby digester for additional sludge storage. Therefore transport truck could be relocated offsite during a flood event without impacts to treatment.	Adapt treatment strategy during winter months by having second digester empty and available for storing digested sludge onsite for long periods (~30 days of storage).
13	Secondary Effluent Diversion Structure	Yes	17.95	2040	2080	beyond 2100	Pile supported below ground flow diversion structure (Approx 10 ft x 20 ft x 15 ft deep).	Accommodate by installing water tight access lids.
14A	Chlorine Contact Channels	Yes	17.98	2040	2080	beyond 2100	Pile supported structure for disinfection contact of treated effluent before discharge to the ocean.	Accommodate by installing water tight access lids.
30	Ops Building Restroom Sump	No	18	Existing	2081	beyond 2100	Small concrete sump that receives on site restroom drainage.	Accommodate by raising top of sumps to above flood level.
17	Microfiltration/Reverse Osmosis Facility	No	18.05	2025	2081	beyond 2100	Not designed to operate during flood event. MF/RO System is not required for NPDES permit.	Protect by building a three foot high flood wall on top of existing foundation slab.
44	Conex Storage	No	18.5	2045	2086	beyond 2100	Storage of materials. Can be removed from site.	Remove from site or place on an elevated concrete pad or anchor to protect structure from flooding.

Building #	Description	Operation Critical for Secondary Treatment	Asset Designed to Operate thru Flood Water Elevation (feet NAVD)	Timing of 100-yr River Flooding Impact (RCP 8.5)	Timing of Closed Lagoon Moderate Storm Impact	Timing of Backwatered Lagoon Inundation Impact	Notes	Adaptation Strategy
38	Lunch Room Restroom Sump	No	18.6	Existing	2086	beyond 2100	Small concrete sump that receives on site restroom drainage.	Accommodate by raising top of sumps to above flood level.
16	Gypsum Silo	No	19	2040	2091	beyond 2100	For Recycled Water pH control. Not currently in use.	Abandon or replace with a calcium carbonate filter in Tertiary Building above flood level.
30	Operations Building First Floor and Basement	No	19.37	Existing	2094	beyond 2100	Basement was designed to flood. No equipment is in the basement. Office equipment is located on the first floor at elevation 19.04 ft. Main power Switchgear is located on second floor at elevation 24.75 ft.	None required. Accommodate flooding in future.
42	Ferric-Chloride Storage	No	19.38	Existing	2094	beyond 2100	Structure would not be damaged by flooding. Small pump is vulnerable, but can be offline for extended periods.	None required. Accommodate flooding in future. Could elevate pump to higher elevation in future. Or extend containment wall to higher elevation.
26	Waste Gas Burner	No	19.45	2030	2095	beyond 2100	Skid mounted unit. Floodable without damage for 72 hrs. Can be bypassed if required.	Accommodate flooding by raising the waste gas burner skid up on existing slab.
1	Manhole just upstream of influent pump station	Yes	19.6	Existing	2096	beyond 2100	Main WWTP Influent Manhole South of Carmel River on WWTP Property	Accommodate by installing water tight access lid or raising grade.
37	Office Trailer A	No	19.83	Existing	2098	beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding in future or build a new elevated office building/break room.
39	Office Trailer B	No	19.83	Existing	2098	beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding in future or build a new elevated office building/break room.
40	Office Trailer C	No	19.83	Existing	2098	beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding in future or build a new elevated office building/break room.
38	Employee Break Building	No	20.01	Existing	2100	beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding in future or build a new elevated office building/break room.
43	Storm water Pump Station	No	20.3	2030	beyond 2100	beyond 2100	Pumps station is designed to be flooded. Electrical controls are vulnerable to sustained flooding.	Protect by moving electrical panel to higher elevation in future.
31	Locker Room	No	20.47	2032	beyond 2100	beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding in future.

Building #	Description	Operation Critical for Secondary Treatment	Asset Designed to Operate thru Flood Water Elevation (feet NAVD)	Timing of 100-yr River Flooding Impact (RCP 8.5)	Timing of Closed Lagoon Moderate Storm Impact	Timing of Backwatered Lagoon Inundation Impact	Notes	Adaptation Strategy
15	Tertiary Building	No	20.59	2035	beyond 2100	beyond 2100	Pile supported tank structure holds disinfected secondary treated water. Tertiary system is not required for NPDES permit.	Protect by raising tank walls.
41	Vehicle Fuel Storage	No	22	2060	beyond 2100	beyond 2100	Diesel and Gasoline storage tanks for vehicles and equipment. Tanks are anchored and watertight and the air vent is elevated to elevation 22 ft.	Accommodate by raising air vent higher. Could also elevate the tanks on an elevated concrete structure.
Collection System Assets Near Carmel River								
	PBCSD Sewer Manholes on North Side of Carmel River Main Sewer Crossing (Two Manholes)	Yes	15.4	Existing	2030	2090	Manhole near River Bank	Accommodate by installing water tight lids.
	CAWD Sewer Manholes on North Side of Carmel River Main Sewer Crossing	Yes	17.9	Existing	2040	beyond 2100	Manhole near River Bank	Accommodate by installing water tight lids.

3.1.2 Threshold Analysis – Critical Assets

A limited number of assets shown in Table 6 are critical to the operation of the CAWD WWTP. These assets should be the first to be addressed in adaptation. The critical assets to the operation of the CAWD WWTP are summarized in Table 7.

Table 7 - Critical Treatment Assets And Approximate Time Thresholds Of Impact of 100-yr Storm (RCP 8.5)

Building #	Treatment Process	Required Level of Service	Assets Designed for Flood at Elevation	Timing of Potential RCP 8.5 Flood Impact (Med-High Risk Aversion)	Timing of Potential RCP 8.5 Flood Impact (Extreme Risk Aversion)	Description of Impact	Adaptation Strategy
-	Conveyance Manholes Upstream of Influent Pump Station	Convey Wastewater into Influent Pump Station	15.4 to 19.6 ft	Existing	Existing	River inflow into WWTP Influent Pump Station could cause sewer overflows.	Install water tight lids.
1	Influent Pump Station	Pump Wastewater Into Influent Headbox	23.53 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
2	Influent Headbox	Convey Wastewater to Headworks by Gravity	29.50 ft	Beyond 2100	Beyond 2100	Impact Outside 2050 Planning Horizon	Subject to future planning
3	Headworks	Removes Grit and Rags from Wastewater	29.46 ft	Existing	Existing	Potential for flooding in basement due to old flood door.	Need to replace old basement flood door.
4A and 4B	Primary Clarifiers	Removes Settleable Solids from Wastewater	23.59 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
7A and 7B	Aeration Basins	Removes Nutrients from Wastewater	23.48 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
8	Aeration Blowers	Provides Air for Aeration Basins	24.49 ft	2085	2065	Impact Outside 2050 Planning Horizon	Subject to future planning
12	RAS/WAS Pump Station	Supports Aeration Process	23.67 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
11A and 11B	Secondary Clarifiers	Removes Suspended Solids	23.62 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
13	Secondary Effluent Diversion Structure	Conveys Secondary Effluent to Chlorine Contact Channels	17.95 ft	2040	2035	Inflow into Chlorine Contact Channels could cause overflow of treated secondary effluent.	Install water tight lids.
14A	Chlorine Contact Channels	Provides Contact Time for Disinfection	17.98 ft	2040	2035	Inflow into Chlorine Contact Channels could cause overflow of treated secondary effluent.	Install water tight lids.
14B	Chlorination Building	Monitoring of Disinfection Process	23.62 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
36	Hypo/SBS Facility	Feeds Disinfection and Dechlorination Chemicals before Final Effluent	23.75 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
18	Effluent Pump Station	Pumps Final Effluent to	23.5 ft	2080	2062	Impact Outside 2050 Planning	Subject to future planning

Building #	Treatment Process	Required Level of Service	Assets Designed for Flood at Elevation	Timing of Potential RCP 8.5 Flood Impact (Med-High Risk Aversion)	Timing of Potential RCP 8.5 Flood Impact (Extreme Risk Aversion)	Description of Impact	Adaptation Strategy
		Ocean				Horizon	
20	Dissolved Air Flotation Thickener	Thickens Plant Waste and sends it to Digesters	23.75 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
21 and 22	Digesters	Removes pathogens from Sludge	37 ft	Beyond 2100	Beyond 2100	Impact Outside 2050 Planning Horizon	Subject to future planning
23 and 25	Digester Control Buildings	Supports Digesters	23.57 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
26	Waste Gas Burner	Burns Digester Gas not Used in Cogen or Boiler	19.45	2030	2030	Flaring could be impacted for about 1 day.	Raise or modify waste gas burner so that the burners are at a higher elevation. The controls can be submerged. Or burn all gas in digester heater.
27	Dewatering Building	Removes liquid from Sludge so Solids can be disposed of	23.60 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
28	Sludge Trailer	Transports Solids off-site.	17.62 ft	Existing	Existing	May be difficult to drive sludge transport truck. If flooding duration is less than 1 week there may be no impact.	Use redundant Digester for emergency sludge storage.
30	Main Power Switchgear	Distribution Center for PG&E and Standby Power	25 ft	2100	2082	Impact Outside 2050 Planning Horizon	Subject to future planning
1	Standby Power Generator	Provides Power in Case of a PG&E Outage	23.53 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning
1	Standby Generator Fuel Tank	Provides Fuel for Standby Generators	24.2 ft	2080	2062	Impact Outside 2050 Planning Horizon	Subject to future planning

Section 4: Conclusion

The CAWD WWTP was originally designed to continue to operate during and after flood events which were known to occur at the time of the design of the existing facilities. The CAWD WWTP has operated through multiple flood events in the past, and the CAWD WWTP has been at the current site treating sewage for over 100-years.

The sea level rise projections do not identify new hazards to the WWTP of greater concern than the 100-year flood risks that CAWD has previously planned for. However, increased storm intensities as well as higher sea levels may increase the base flood elevations. According to this study increased storm intensity as well as sea level rise will not detrimentally effect the CAWD WWTP before the year 2062 under the "Extreme Risk Aversion" scenario. This allows for over 40-years of continued operation in the existing location. Furthermore, the next 40 years will provide time for CAWD to evaluate future improvements of increasing flood resiliency at higher levels vs. potentially relocating the WWTP.

The worst case projections contained in this report assume that sedimentation at the lagoon sandbar will increase with sea level rise. However, it is foreseeable that sedimentation will not increase with sea level rise. If this were the case the increases in 100-year fluvial flood levels will not change significantly over the next 50-years. Furthermore, the higher 100-year fluvial flood projections did not take into account the increased area of the flood plain as flood levels increase. In reality the increased flooded area will reduce the flood elevations at the WWTP from what is projected in this report.

Appendix A

Carmel Area Wastewater District Sea-Level Rise Vulnerability Assessment, Climate Change Impact Analysis and Adaptation Strategies, ESA December 2018

CARMEL AREA WASTEWATER DISTRICT SEA-LEVEL RISE VULNERABILITY ASSESSMENT

Climate Change Impact Analysis and Adaptation Strategies

Prepared for

Carmel Area Wastewater District

December 2018

CARMEL AREA WASTEWATER DISTRICT SEA-LEVEL RISE VULNERABILITY ASSESSMENT

Climate Change Impact Analysis and Adaptation Strategies

Prepared for **December 2018**

Carmel Area Wastewater District

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Services provided pursuant to this Agreement are intended solely for the use and benefit of the Carmel Area Wastewater District.

No other person or entity shall be entitled to rely on the services, opinions, recommendations, plans or specifications provided pursuant to this agreement without the express written consent of ESA, 550 Kearny Street, Suite 800, San Francisco, CA 94108.

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1 INTRODUCTION

The Carmel Area Wastewater District (CAWD; District) owns and operates a wastewater plant and collection system located in a low-lying area adjacent to the Carmel River Lagoon in Carmel-by-the-Sea, California. In preparation for future regulatory requirements of the Regional Water Quality Control Board and the California Coastal Commission, the District tasked ESA with developing a sea-level rise vulnerability and climate change impacts and alternatives study. This study intends to provide a clear understanding of the potential impacts to the District's wastewater infrastructure and operations due to sea-level rise and climate change. This study aims to identify what the potential impacts are, when they may occur, and identify alternatives to mitigate the anticipated impacts. This study will help the District plan for future funding requirements, to plan for potential capital projects, and to guide an asset management strategy for infrastructure subject to climate change impacts

The Carmel River Lagoon is a bar-built estuary located south of the town of Carmel-by-the-Sea, in central California. The hydrology of the lagoon is dictated by the seasonal interaction of the Carmel River with wave-driven beach-building processes at the mouth. Low-lying neighborhoods and infrastructure, including the CAWD Treatment Plant, are located within or adjacent to the lagoon basin. Naturally-occurring high water levels in the lagoon periodically create flood risk for this infrastructure. High water levels often result from water ponding behind the beach berm, which is blocked ('closed') seasonally by wave action during the dry season. To mitigate flooding hazards, the mouth of the lagoon is mechanically breached when floodwaters reach a trigger elevation to drain the lagoon and prevent flood damages to existing developments.

There has been little study of the expected impacts of future climate change on conditions in the lagoon. This is an important data gap, since future sea-level rise will exacerbate flooding issues and limit the utility of mouth breach events to manage water levels below flood elevations. Prior studies have focused primarily on fluvial flooding or were completed to inform lagoon and river restoration. These are discussed in more detail below.

This report is organized into the following sections:

- **Section 2 – Project Setting**
  This section provides a summary of the project geography, geomorphology, and hydrology, including descriptions of prior studies, ongoing development, and related projects in the area.

- **Section 3 – Sea-Level Rise Policy and Projections**
  This section summarizes the relevant sea-level rise policy guidance and presents recommendations for sea-level rise projections and associated time horizons to be used for this study.

- **Section 4 – Wastewater Assets and Flood Scenarios**
  This section provides brief summary of the source of various CAWD assets within the lagoon and defines the flood scenarios considered in the sea-level rise analysis to determine potential impacts.

- **Section 5 – Climate Change Impacts Assessment**
  This section presents the findings of the technical analyses completed to assess potential impacts to climate change, including sea-level rise and future changes to extreme precipitation and river flows. Adaptation strategies are identified for the vulnerable wastewater assets that can be considered by the District to improve resilience of the CAWD assets and treatment plant, and which can be used as a basis for further assessment, planning and design.

The analyses presented in this report were conducted by Hannah Snow, Dane Behrens, PhD, PE, Alex Trahan, PE, James Jackson, PE, and Louis White, PE, with review by Bob Battalio, PE. The information presented in this report includes publicly available data from various government agencies, engineering calculations by ESA, and observations made at the site by ESA, as well as information provided to ESA by others. The results presented in this report are intended to inform the planning efforts by CAWD for their facilities. ESA is not responsible for the use of the information included in this report for applications other than planning for improvements to the CAWD wastewater system.

2 PROJECT SETTING

The CAWD Treatment Plant is located approximately 2,500 feet inland from the shoreline on the lower stretch of the Carmel River. The Carmel River watershed drains an area of approximately 250 square miles, most of which is located within the Santa Lucia Mountains. Where the river meets the Pacific Ocean, it forms the Carmel Lagoon. The lagoon is located south of the City of Carmel-by-the-Sea in Monterey County, California (Figure 1). Regionally important infrastructure exists within the lagoon basin, including the CAWD Treatment Plant and a portion of Highway 1. Low-lying residential areas border the lagoon to the north and northeast.

Carmel Area Wastewater District Sea-Level Rise Vulnerability Assessment / D170475.00

SOURCE: USGS

Figure 1
Project Location

This section presents information on the project setting. Additional details on the site hydrology, ESA's analyses, and modeling of the lagoon hydrology is included in Appendix A.

2.1 Existing Lagoon Basin Features

The lagoon basin includes several notable geomorphic features, which are highlighted in Figure 2. Generally, the basin can be described in terms of the main stems of the lagoon, the lagoon mouth and beach, adjacent lagoon wetlands, and upland areas.

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Figure 2
Project Setting

Carmel River Lagoon consists of two main branches; the main stem of Carmel River and the South Arm. The main stem of the Carmel River flows from east to west through the lagoon basin and drains into Carmel Bay through the lagoon mouth at Carmel State Beach. South of the lagoon mouth, the lagoon branches into the South Arm. The South Arm was restored in 2004 as part of the Carmel River Lagoon Enhancement Project and currently extends to the southeast almost to Highway 1.

The lagoon terminates at Carmel State Beach, a sandy, steep beach that is approximately 1,000 feet long and is flanked by rocky headlands to the north and south. The elevation of the beach fluctuates seasonally; it is high in the summer and lower in the winter when high-energy waves and elevated water levels push sand offshore. The beach berm (the highest crest of the beach) intermittently blocks the lagoon mouth when under certain wave and flow conditions.

A low-lying wetland area called the Carmel River Lagoon & Wetland Natural Preserve exists to the north of the lagoon mouth and the main stem of the Carmel River. The marsh channels in this area are typically connected as part of the lagoon and ponding can occur throughout much the marsh area under closed-mouth lagoon conditions.

Higher elevation areas of the lagoon basin consist of historic agricultural fields (Odello Property), the CAWD Treatment Plant, and neighboring residential areas. The Odello Property is divided into west and east segments, which are bisected by Highway 1. The west Odello Property was restored as part of the Carmel River Lagoon Enhancement Project in 2004 (PWA 1999) and the east Odello Property is still an active agricultural property. However, plans exist to convert part of the East Odello Property land to floodplain under the of the Carmel FREE Project (Balance 2015).

2.2 Prior Studies

Previous studies on the Carmel River Lagoons have looked at lagoon hydrology, flooding, and beach morphology and management. Prior efforts include those by PWA (1992 and 1999), Thornton (2005), Kraus et al. (2008), Laudier et al. (2011), Rich and Keller (2013), Moffatt & Nichol (2013), Shaaf & Wheeler (2014 and 2016), and Balance Hydrologics (2015). Edward Thornton, a professor emeritus at the Naval Postgraduate School, has studied the Carmel Lagoon and has observed conditions at the site for several decades. This section gives a brief overview of some these studies.

2.2.1 Pre-Restoration Lagoon Studies

In 1992, PWA created the Carmel River Lagoon Enhancement Plan (PWA 1992). This plan set the framework for steelhead habitat restoration efforts carried out in the lagoon in 1997 and 2004 by Caltrans and California State Parks, respectively. The plan included HEC-2 modeling as well as extensive historic and geomorphic analysis to inform restoration options. The modeling proved to be sensitive to lagoon tailwater conditions and lagoon mouth scour, which were not well understood at the time (PWA 1992). The modeling results were not reported.

PWA also produced a conceptual design report as part of the Carmel River Lagoon Enhancement Plan in 1999 (PWA 1999). The selected conceptual design was based on detailed fluvial modeling results using the MIKE 11 software and additional geomorphic and hydrologic analysis. The MIKE 11 model was calibrated using historical water surface records and was run for eight different restoration alternatives and several flow conditions. Modeling scenarios that directed flows onto the floodplain resulted in lower water levels in the main stem of the river, thus providing flood control and habitat enhancement benefits. PWA also characterized lagoon dynamics and mouth behavior in the conceptual design report, although no modeling or sea-level rise analyses were performed.

2.2.2 Post-Restoration and Ongoing Studies

In 2009, the Federal Emergency Management Agency (FEMA) released the most-current Flood Insurance Study for unincorporated Monterey County (FEMA 2009). Flooding along the lower reaches of the Carmel River was modeled using a steady, 1-dimensional HEC-RAS model. This publically available model has been utilized and modified by other consultants since its release.

In 2009, Shaaf & Wheeler analyzed specific flood risks to the CAWD Treatment Plant using the 2009 FEMA model. Shaaf & Wheeler adjusted the FEMA model to account for site-specific conditions near the plant. Their modifications generally resulted in increased modeled water levels in the channel near the treatment plant. As a part of the same analysis, Shaaf & Wheeler also assessed the tailwater sensitivity of the FEMA model. Their results showed water levels at the CAWD plant to be sensitive to the downstream tailwater elevation, which is the water surface elevation of the lagoon. The tailwater influenced water levels up to approximately 4,200 feet upstream of the mouth under the highest tailwater state modeled (16.92 feet NAVD). ESA converted Shaaf & Wheeler elevation of 14.17 feet NGVD to 16.92 feet NAVD using a conversion of 2.75 feet (National Geodetic Survey 2018)

Balance Hydrologics also performed modeling to inform the 2015 Carmel River Floodplain Restoration and Environmental Enhancement (FREE) Project (Balance 2015). Balance analyzed flooding conditions and potential restoration scenarios by making modifications to the FEMA model. Balance additionally developed a channel evolution model to predict long-term sediment transport and inform restoration design.

The proposed restoration design selected as part of the Carmel River FREE Project is relevant to CAWD due to the potential impacts to the existing CAWD outfall pipe (see Figure 2). Shaaf & Wheeler used a HEC-RAS model to analyze the proposed restoration design and found that the project has the potential to increase flow rates in the South Arm of the lagoon. Shaaf & Wheeler noted that increased flow rates could induce geometry changes that may impact the pipeline and increase the amount and size of transported debris in the South Arm (Shaaf & Wheeler 2016).

2.2.3 Beach and Mouth Studies

Thornton (2005) provides an overview coastal conditions at the site, and the resulting beach and lagoon mouth morphology. This report outlines some of the unique features that influence the site morphology, and is useful as a framework for subsequent detailed work on wave overtopping into lagoon (Laudier et al. 2011), and seasonal lagoon hydrology (Rich and Keller 2013). Kraus et al. (2008) developed a conceptual model for mouth breach events, and included the Carmel River Lagoon as a case example for breach behavior. Laudier et al. (2011) used concurrent beach surveys and changes in stored water volume in the lagoon to develop an accurate model of wave overtopping. Rich and Keller (2013) developed a lagoon hydrology model based on a prior study by Battalio et al. (2006) to better understand how mouth breach events and the 2004 restoration influence water levels lagoon.

2.3 Development in Lagoon Basin

The Carmel Lagoon is located in a suburban environment, and as such, there are existing developments located within and adjacent to the lagoon basin. These developments include CAWD facilities, Highway 1 and adjacent utility lines, and residential neighborhoods.

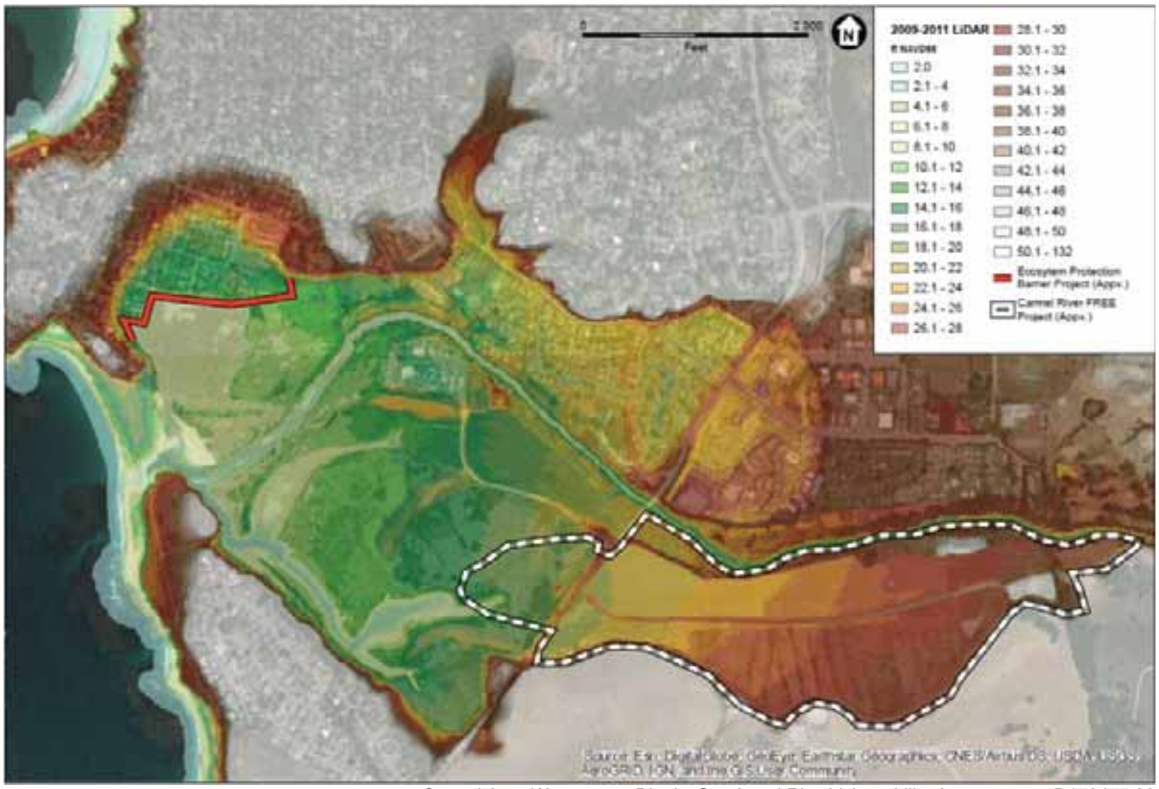
The CAWD operates a treatment plant and associated facilities within the lagoon basin. The plant itself is located south of the main stem of the Carmel River and north of the South Arm of the lagoon. A CAWD access road runs from Highway 1 northwest to the plant. A buried treated wastewater effluent pipeline extends from the plant to Carmel Bay. The pipeline includes an elevated crossing over the South Arm of the lagoon approximately 1,000 feet south of the lagoon mouth.

Highway 1 crosses the lagoon basin from southwest to northeast. Several major utility lines serving the Carmel area including electrical, gas, and water run adjacent to the highway. A bridge exists over the main stem of the Carmel River near the Mission Fields neighborhood and several culverts under the highway provide drainage connections between the East Odello site and the restored lagoon (west).

Residential neighborhoods border the lagoon to the north and south. While the neighborhood to the south of the lagoon is elevated, households in the low-lying areas to the north of the Carmel River Lagoon & Wetland Natural Preserve have experienced issues with flooding under high lagoon water levels.

2.4 Proposed Projects Within Lagoon Basin

Two major projects within the Carmel Lagoon basin are currently in planning stages: the Carmel River FREE Project (Balance 2015) and the Carmel Lagoon Ecosystem Protective Barrier. The EIR for the protective barrier project also includes the associated Scenic Road Protection Structure, which is an erosion control project to protect the coastal bluff from erosion caused by the migrating lagoon mouth. The proposed area and alignment of the projects are shown in Figure 3, which also presents LiDAR topography for the project area used in the analyses. The related projects are described in the following sections.



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SOURCE: Coastal Conservancy and ESRI

Figure 3
Locations of Carmel River FREE Project and Ecosystem Protective Barrier on Site Topography

2.4.1 Carmel River FREE

The Carmel River Floodplain Restoration and Environmental Enhancement Project is a floodplain restoration project conducted by Big Sur Land Trust with design consultation provided by Balance Hydrologics. The project focuses on distributing flood flows out of the lower Carmel River and onto the historical floodplain east of Highway 1 (Odello East area). Five levee segments are proposed to be lowered to convey flood flows into a new distributary channel network within the floodplain. The channels would connect to the South Arm of the lagoon via a 350-foot elevated causeway along Highway 1.

Balance Hydrologics released a 35% Design Basis report in May 2015 (Balance 2015). This project is relevant to the current study because alterations in floodplain elevations could affect peak water levels in the lagoon, and adjacent to the CAWD facility. Lowering the floodplain elevation would effectively increase the storage volume of the lagoon. This could impact the mouth morphology by slowing the rate that inflows fill the lagoon to the level where an artificial breach would be required.

2.4.2 Ecosystem Protective Barrier

The Carmel Lagoon Ecosystem Protective Barrier Project consists of installing a sheet pile wall along the edge of the existing lagoon marsh to protect low-lying residential properties from flooding (see Figure 3). Installing the wall would allow for less-frequent mechanical beaching of the beach berm under high water conditions, thus maintaining the current level of flood protection for properties while allowing for a reduction in the number of mechanical breaches. Reducing the frequency of breaches are of interest to environmental agencies, as mechanical breaching reduces freshwater habitat available to juvenile salmonids in the lagoon. A Draft Environmental Impact Report (EIR) was published for the proposed barrier project in December 2016 and public comments on the EIR were released in February 2017.

This project could impact the current study by slightly reducing the storage of the lagoon up to the height of the barrier, and by potentially leading to a change in artificial breach protocols for the lagoon mouth. Without artificial breaching, water levels in the lagoon could become higher in the weeks of seasonal closure events, when the first major rain storms of the year begin filling the lagoon behind the closed beach.

2.5 Landowners and Stakeholders

Many organizations have interest in the management and future of Carmel Lagoon. A brief list of parties relevant to this lagoon modeling effort include:

- California State Parks
- City of Carmel-by-the-Sea
- Carmel Area Wastewater District
- Monterey county Water Resources Agency
- Monterey Peninsula Water Management District
- County Department of Public Works
- Big Sur Land Trust

2.6 Site Hydrology and Causes of Flooding

As discussed by Thornton (2005) and Laudier et al. (2011), the Carmel River Lagoon is a bar-built estuary with an intermittently closed mouth. Figure 4 illustrates the time series of ocean and lagoon water levels from 2006 to 2016, along with watershed runoff measured upstream of the Highway 1 crossing, and estimates of nearshore waves at the site. The lagoon undergoes a typical seasonal pattern that varies from year to year depending on wave and river conditions. Figure 5 illustrates a typical year, based on daily average conditions from 2006 to 2016.

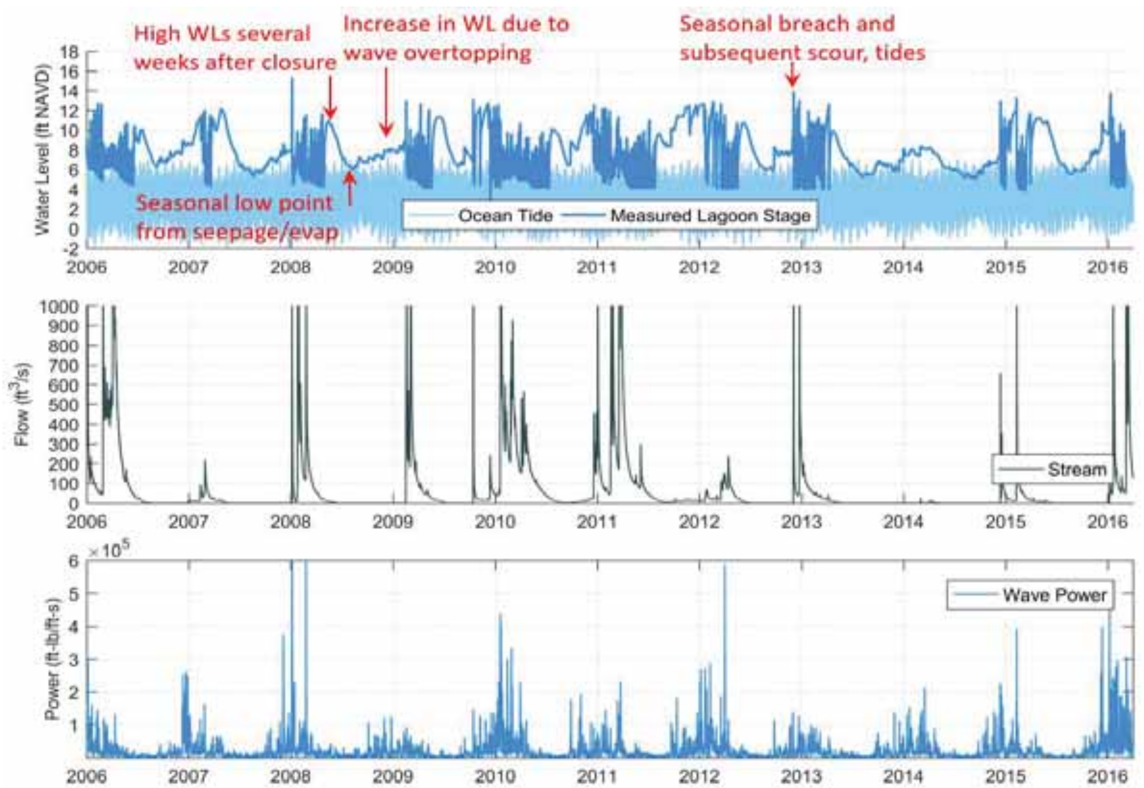

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Figure 4
Daily Average Hydrologic Conditions in the Carmel River Lagoon from 2006 to 2016

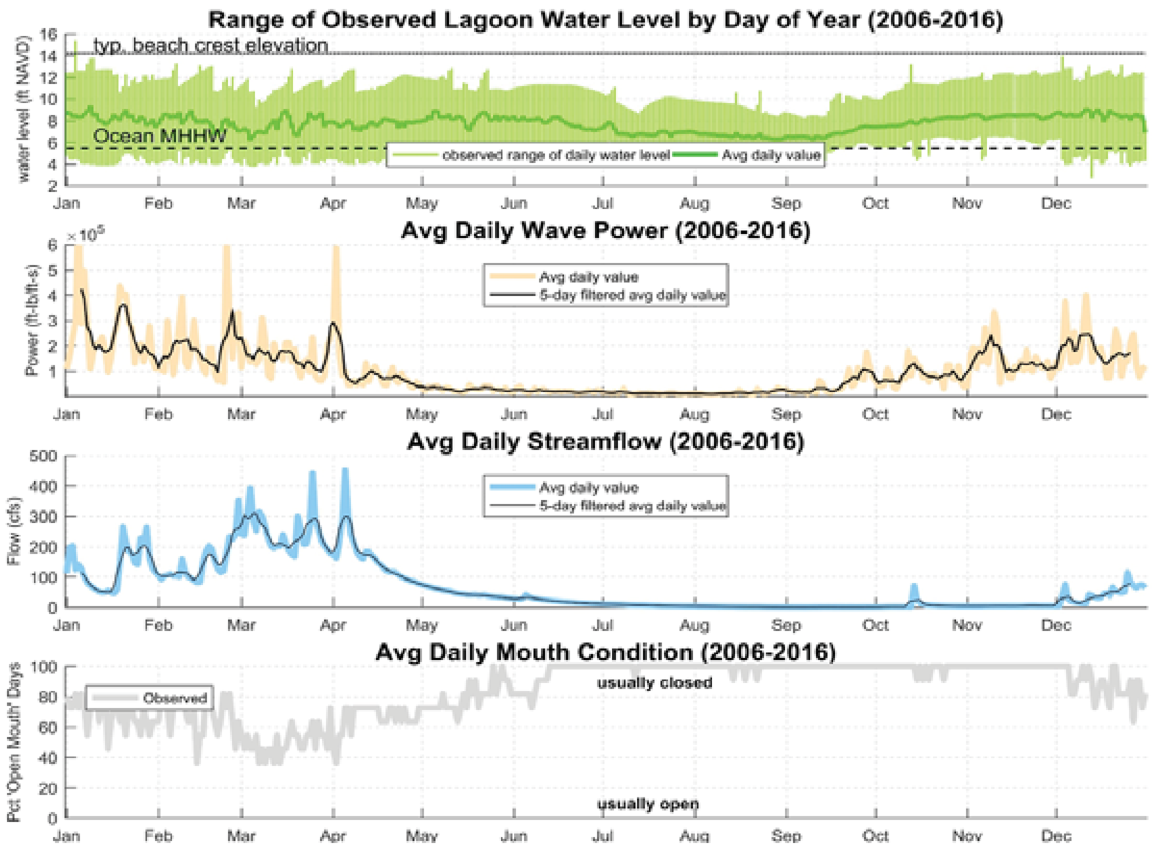

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Figure 5
Seasonal Range of Lagoon Conditions: Water Level, Wave Power, Streamflow, and Mouth Condition

2.6.1 Influence of Lagoon Mouth Conditions

After seasonal closure occurs, remaining watershed runoff ponds behind the closed beach. The lagoon typically does not breach (experience a new mouth opening either naturally or from mechanical excavation of a channel) until the first major rainfall event of the winter. Water levels just prior to breaching are typically the highest water levels of the year, higher than flood peaks during fluvial flood events. Initially, runoff and contributions from waves overtopping the beach cause the water level to rise in the lagoon immediately after seasonal mouth closure. This is an indication that losses due to seepage through the beach berm and to evapotranspiration are initially overmatched by these inflows (Rich and Keller 2013). Over time, inflows decrease, due to seasonal declines in wave energy and watershed runoff. At the point that evaporation and seepage through the beach berm begin to compensate these inflows, the lagoon water level begins to decline. This decline typically lasts from June or July until September.

Although stream flow to the lagoon does not generally increase until winter, the lagoon water level usually rises periodically from September to December. This is most likely attributed to wave overtopping, as waves begin to increase in power again in fall (Laudier et al. 2011). This is because the water level rises are episodic and tend to happen during high tides or powerful, long-period swell wave events.

When the first major rainfall event of the season is imminent, the lagoon is typically breached mechanically when water levels reach 12-15 feet NAVD to prevent water levels from reaching elevations that would flood private property adjacent to the lagoon. Without these preventative measures, the lagoon would likely breach naturally at a higher elevation, set by the height that September-December waves are able to build the beach crest. In years with exceptionally high waves, waves can build a berm that is much higher than 15 feet NAVD, such as during the 2015-2016 El Nino event when the beach crest was observed at approximately 18 feet NAVD (pers. comm. D. Lander).

2.6.2 Influence of River and Coastal Conditions

When watershed runoff is high, the lagoon mouth typically scours to a low elevation, with the depth of erosion constrained by a rock sill buried within the beach (Thornton 2005). Despite this, flows leaving the mouth toward the ocean cause a persistent setup of water levels in the lagoon, with minimum water levels usually at approximately mean higher high water (MHHW) when runoff exceeds 200 cubic feet per second (cfs), although the highest tides may enter the lagoon. During the peaks of flood events, the setup in the lagoon is more extreme, with flood stages typically surpassing 8 feet NAVD when flows exceed 1000 cfs. The lagoon water level during fluvial floods is also affected by waves, which lose momentum in the reef offshore of the mouth and generate a coastal setup that raises tides above the static still water level that would be measured further offshore (Thornton 2005).

2.6.3 Lagoon Management Practices

Artificial breaching of the mouth with heavy equipment is used to periodically drain the lagoon and prevent flooding of low-lying properties. Breaching is usually performed by digging a pilot channel in the beach, and allowing water to then spill to ocean and erode a new mouth. Recommendations for breaching timing were provided by Moffatt and Nichol (2013) who considered how breaching practices can influence the potential for erosion on the northern Scenic Road.

2.7 Tidal Datums

Table 1 presents the published tidal datums for the Monterey tide gage (NOAA NOS Station 9413450), located approximately 13 miles north along the coast from the mouth of the Carmel Lagoon. The mean higher high water (MHHW) elevation is calculated by averaging the higher high water height of each tidal day observed over the tidal epoch (a 19-year period of water level averaging – the National Tidal Datum Epoch (NTDE)).

TABLE 1
TIDAL DATUMS AT MONTEREY, CA STATION 9413450

Datum	Description	Value (feet NAVD)
Max	Highest Observed Water Level (1/27/83)	8.02
HAT	Highest Astronomical Tide	7.18
MHHW	Mean Higher High Water	5.48
MHW	Mean High Water	4.78
MTL	Mean Tide Level	3.01
MSL	Mean Sea Level	2.97
NGVD	National Geodetic Vertical Datum of 1929[1]	2.75
MLW	Mean Low Water	1.23
MLLW	Mean Lower Low Water	0.14
NAVD	North American Vertical Datum of 1988	0.00
LAT	Lowest Astronomical Tide	-1.77

[1]Tidal Datum Analysis Period: 01/01/1983-12/31/2001
[2]Based on NGS Data Sheet PID GUI3233

3 SEA-LEVEL RISE POLICY AND PROJECTIONS

As sea-level rise progresses in the future, typical water levels in the lagoon and upstream will shift upward. This rate of change could vary based on many factors, including the change to the lagoon shape either from future sedimentation or progressive drowning from higher tides, the response of the beach to sea-level rise, construction of projects discussed above, and other unforeseen changes to future management of the beach and lagoon mouth.

Despite these uncertainties, an upward shift of flood levels is expected, which will alter the vulnerability of WWTP assets in the future. Addressing these challenges requires selection of a set of sea-level rise planning horizons and scenarios, which is described here. ESA provided recommendations to CAWD in a technical memorandum on May 18, 2018 (see Appendix B), and which were subsequently selected by CAWD to conduct the analysis.

3.1 Sea-Level Rise Policy Guidance

Appendix B provides a detailed summary of recent state and federal policy guidance on sea-level rise, as well as tables that document the most recent projections for the California coast. For context, this section provides a brief summary, but more information is provided in Appendix B.

The California Ocean Protection Council (OPC) first released a statewide sea-level rise guidance document in 2010 following Governor Schwarzenegger's executive order S-13-08. After being adopted by the California Ocean Protection Council (OPC), this interim guidance document informed and assisted state agencies to develop approaches for incorporating sea-level rise into planning decisions (OPC 2011). The OPC (2011) document was updated in 2013 (OPC 2013) after the NRC released its final report *Sea-Level Rise for the Coasts of California, Oregon, and Washington* (NRC 2012), which provided three projections of future sea-level rise associated with low, mid, and high greenhouse gas emissions scenarios, respectively.

Recently, the California Natural Resource Agency and OPC released a 2018 guidance update (OPC 2018) to the 2013 State of California guidance document (OPC 2013). The updated guidance provides a synthesis of the best available science on sea-level rise in California, a step-by-step approach for state agencies and local governments to evaluate sea-level rise projections, and preferred coastal adaptation strategies. The key scientific basis for this update was developed by the working group of the California OPC Science Advisory Team titled *Rising Seas in California: An Update on Sea-Level Rise Science* (Griggs et al. 2017).

The 2018 guidance update includes the following key changes and additions to the OPC (2013) guidance:

- **For years before 2050, sea-level rise projections are provided only for the high emissions scenario using representative concentration pathway[1] RCP 8.5.** The world is currently on the RCP 8.5 trajectory, and differences in sea-level rise projections under different scenarios are minor before 2050.
- **Includes new "extreme" sea-level rise projections associated with rapid melting of the West Antarctic ice sheet.**
- **Shifts from scenario-based (deterministic) projections to probabilistic projections of sea-level rise.** The guidance update recommends a range of probabilistic projections for decision makers to select given their acceptable level of risk aversion for a given project.
- **Provides estimated probabilities of when a particular sea-level rise amount will occur.** In addition to sea-level rise projections that are tied to risk acceptability, updated guidance provides information on the likelihood that sea-level rise will meet or exceed a specific height (1 foot increments from 1 to 10 feet) over various timescales.

3.2 Planning Horizons

After reviewing ESA's recommendations in its memorandum dated May 18, 2018, CAWD selected the planning horizons of 2050 and 2100 for the purposes of the project. ESA's recommendation is based on the need to plan for near- and long-term impacts related to sea-level rise, as well as the existence of available coastal hazard maps that were developed for these planning horizons (PWA 2009). Most climate models show strong agreement on the amount of sea-level rise that is likely to occur by 2050, and start to diverge after 2050 based on the range of potential emissions scenarios (OPC 2013). Therefore, it is important to consider a range of sea-level rise scenarios for future planning and projects with timeframes that look beyond 2050.

3.3 Sea-Level Rise Scenarios

The sea-level rise scenarios that were adopted for this project were selected to be consistent with the latest guidance and to utilize available coastal hazard maps for the Carmel area. This project considers the most recent OPC (2018) probabilistic projections of sea-level rise for low risk and medium-high risk aversion scenarios, as well as the H++ scenario. Applying this range of scenarios (see Table 2 and Figure 6) is intended to account for uncertainties in sea-level rise over time. In total, five sea-level rise scenarios were used for this study, including existing conditions (no sea-level rise) as well as future sea-level rise at 2050 and 2100: 0, 1, 2, 3, and 6 feet of sea-level rise.

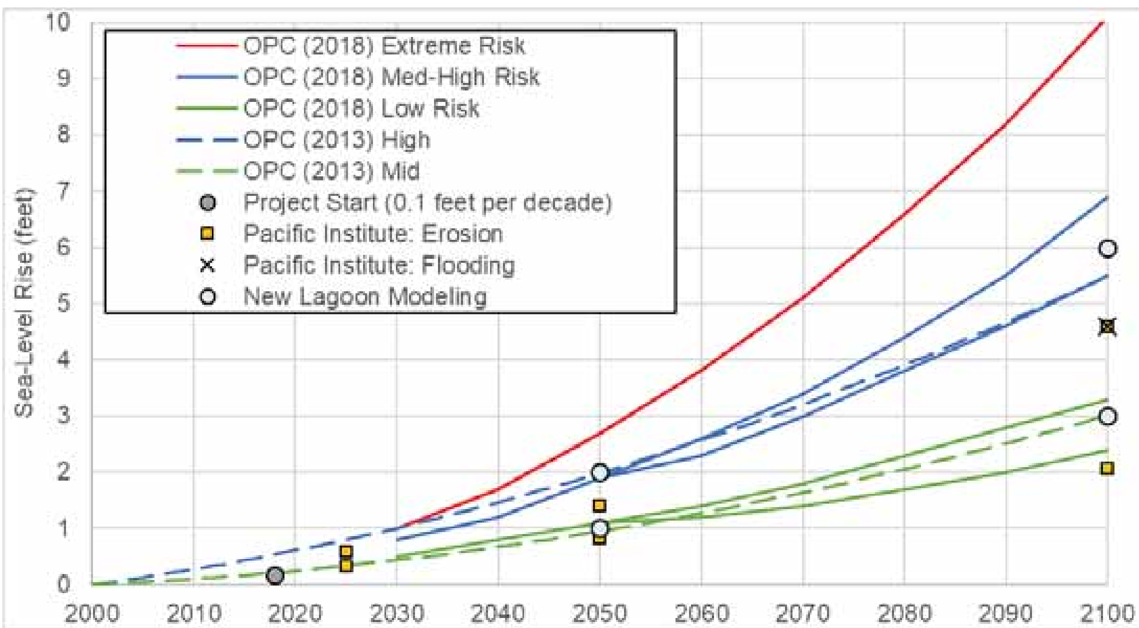
[1] Representative concentration pathways (RCPs) are named for the associated radiative forcing (heat trapping capacity of the atmosphere) level in 2100 relative to pre-industrial levels. RCP8.5 indicates that the RCP represents an increase of 8.5 watts per square meter by 2100 relative to pre-industrial levels.

PWA (2009) previously developed hazard maps for the project area for the Pacific Institute. Although these relied on earlier sea-level rise projections (Cayan et al. 2008; OPC 2011) that are slightly lower than existing projections, the mapping products have been considered as conservatively high estimates of flooding and erosion, and are within an acceptable range of uncertainty so that they can be used to inform potential impacts that could occur using the new OPC (2018) guidance.

TABLE 2
PROPOSED SEA-LEVEL RISE SCENARIOS FOR PROJECT

Scenario	2050	2075	2100
Low Risk Aversion[1]	1.1 feet	--	2.3 to 3.3 feet
Med-High Risk Aversion[2]	1.9 feet	--	5.5 to 6.9 feet
Extreme Risk Aversion	--	5.5 to 6.9 feet	--

1 Low Risk Aversion approximately equal to NRC (2012) Medium Curve
2 Med-High Risk Aversion approximately equal to NRC (2012) High Curve



Carmel Area Wastewater District Sea-Level Rise Vulnerability Assessment / D170475.00

Figure 6
Comparison of Proposed Analysis and Available Hazard Maps to Updated OPC 2018 Sea-Level Rise Curves

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4 WASTEWATER ASSETS AND FLOOD SCENARIOS

This section presents a brief summary of the sources of wastewater asset data and definitions of flood scenarios used in the exposure analysis to determine the potential impacts to the wastewater system.

4.1 Mapping Assets

CAWD and their contractor Turf Image provided ESA with different databases of asset information for the wastewater system:

- GIS Geodatabase that included the collection system assets, including force mains, gravity mains, and structures

- Flood Risk Assessment table of treatment plant assets with associated base flood elevation, designed flood proof elevations, descriptions of compliance with Federal guidance, and the asset criticality for secondary treatment, dated January 30, 2018 (Appendix C)

- Table of wastewater assets, vulnerable elevations, threat, and potential adaptation options (Appendix D)

These data were used as a basis for understanding what infrastructure would be at risk, what is critical, and what the threshold for damage by flooding or erosion would be.

4.2 Definition for Flood Elevations

Flooding in the lagoon can occur as a result of different physical mechanisms:

1. Ponding of trapped water in the lagoon during closed-mouth conditions, or

2. Due to the setup of lagoon water levels during the passage of river flood flows to the ocean.

The main difference between these two types of events is that closed-mouth conditions lead to a relatively flat water surface and long inundation times (on the scale of days to months), while flood levels during high river flow events tend to be more transient (lasting hours to days) and have a sloping surface through the lagoon (i.e. the flood elevation depends on location). These types of flooding are illustrated in Figure 7. Properly assessing the vulnerability of CAWD assets in the lagoon requires an understanding of both the height of flood levels and the duration of flooding.

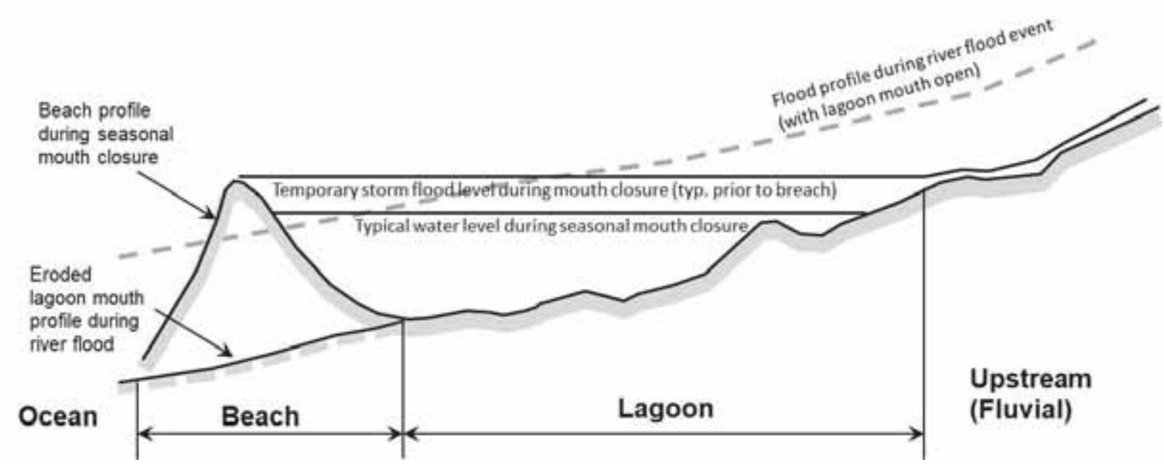

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Figure 7
Schematic of Flood Levels During Closed Lagoon Conditions and River Flood Events

For the purpose of evaluating vulnerabilities of CAWD assets to flooding (see Section 5), we define types of flood levels here. We consider two closed-lagoon flood levels and one river flood event, illustrated in Figure 7 above:

- ‘Permanent Inundation Level’: A sustained high water level representative of typical conditions when the lagoon mouth is closed. Groundwater elevations are likely to equilibrate with this surface water level.

- ‘Temporary Storm Flood Level’: A temporary high water event in the lagoon associated with storm conditions, such as moderate river streamflow, large wave event and wave overtopping into the lagoon, when the lagoon mouth is closed or about to breach. This does not represent extreme fluvial floods.

- ‘River Flood Event’: A temporary high water event in the lagoon associated with a large river flood (100-year recurrence interval) that naturally breaches the beach berm. This event is currently the dominant flood source at the treatment plant, and which was used to set existing flood proof elevations for most assets.

In Section 5, these elevations are estimated for a range of future sea-level rise scenarios. Vulnerable assets in the lagoon are then tabulated and a level of risk is assessed based on their exposure to these types of flooding.

5 CLIMATE CHANGE IMPACTS & ADAPTATION STRATEGIES

The overarching objective of the ESA lagoon modeling is to provide insight on how climate change will affect future water levels in the Carmel Lagoon, and to thereby determine the vulnerability of the CAWD infrastructure in the future. Since key infrastructure elements are located throughout the lagoon, and since climate change is expected to evolve in the future, this assessment needed to explicitly account for both location and timing of future hazards. To address this issue, ESA applied the following approach:

- Develop a lagoon hydrologic model to understand future flooding under seasonal closed-lagoon conditions.
- Apply downscaled climate models to estimate future runoff amounts and thereby future river flood peak heights.
- Map wastewater asset data provided by the District (Section 4) with flood and erosion hazard areas from the above steps.
- Conduct a threshold analysis to estimate when assets would be expected to face flood hazards in the future.
- Identify potential adaptation strategies for the vulnerable assets.

The following sections describe the approaches and results in more detail.

5.1 Flooding During Closed-Lagoon Conditions

5.1.1 Approach

As discussed in Section 2, flood levels in the lagoon are a response to both fluvial and coastal conditions. Often, the highest water levels observed in a given year occur don't occur during river flood conditions, but either:

- In late spring, within the first few weeks after the lagoon mouth has been closed seasonally from wave action, as seasonally-high base flows fill the lagoon behind the closed beach, or

- At the end of the seasonal closure event in late fall or early winter, when the first major rainfall event of the season causes the lagoon to fill to the height of the beach, which has often had 3 to 6 months to build to a high elevation from wave action.

Although many of these processes that lead to these conditions have been studied extensively (Thornton 2005, Laudier et al. 2011, Rich and Keller 2013, Orescanin and Scooler 2018), the usefulness of data alone or models that are limited to a few individual processes becomes limiting when trying to understand how flooding might change under future sea-level rise. Addressing this question requires a tool that can incorporate the lessons learned from studies at the site, integrating the approaches into a combined water balance for the lagoon and sediment balance for the lagoon mouth that can resolve both conditions at the same time.

To address this, ESA developed a quantified conceptual model (QCM) for the lagoon and beach. This is a simplified time-series model which implements a lagoon water balance alongside parametric model of the lagoon mouth and beach, and builds on a number of prior studies (Battalio et al. 2006, Rich and Keller 2013, Behrens 2013). The model uses time series of nearshore waves and tides, watershed runoff, and evapotranspiration data as boundary conditions. Using these as forcing conditions with the lagoon's topography, the model dynamically simulates time series of lagoon water levels, along with inlet, beach, and lagoon state. With each time step, the net inflows or outflows to the system are estimated, along with the net sedimentation or erosion in the mouth.

Appendix A provides a more detailed description of the model. The model was trained by hindcasting lagoon water level and mouth conditions from 2006 to 2016. We use the model here to forecast water levels under the sea-level rise scenarios discussed in Section 3.

5.1.2 Predicted Flood Levels

Table 3 presents the permanent and storm water levels computed with the lagoon model for the range of sea levels and their corresponding forecast dates. As defined earlier, 'permanent' refers to typical closed-lagoon water levels during the dry season, which typically remain steady for several months at a time. 'Storm' refers to water levels that occur briefly at the end of a seasonal closure event, when rainfall causes the lagoon to fill to the beach crest, which has had several months to build.

The permanent inundation water levels range from 11 to 16 feet NAVD, and the temporary storm flood water levels range from 15 to 20 feet NAVD. The water level does not increase linearly with sea-level rise because the storage of the lagoon significantly expands at elevations greater than 13 feet NAVD. This modeling and results implicitly presume that waves and rainfall-runoff are steady (not increased or decreased by climate change) and there is adequate sand for the beach to rise with sea-levels.

TABLE 3
LAGOON WATER LEVELS OVER TIME FOR PERMANENT INUNDATION AND TEMPORARY STORM FLOOD CONDITIONS

	Existing Condition	2030	2050	2070	2100
Sea-Level Rise (feet)	0	1	2	3	6
Permanent Inundation Level (feet NAVD)	11	12	13	14	16
Storm Flood Elevation (feet NAVD)	15	15.5	16	17	20

Figure 8 presents lagoon water levels for Permanent inundation and Temporary flooding over time with sea-level rise. The dashed lines in the figures are best-fit polynomials that can be used to approximate the year associated with impacts of specific threshold elevations. Note that the existing condition is assumed to occur at year 2000, consistent with state guidance (CCC 2015). This information is referenced in the impacts analysis.

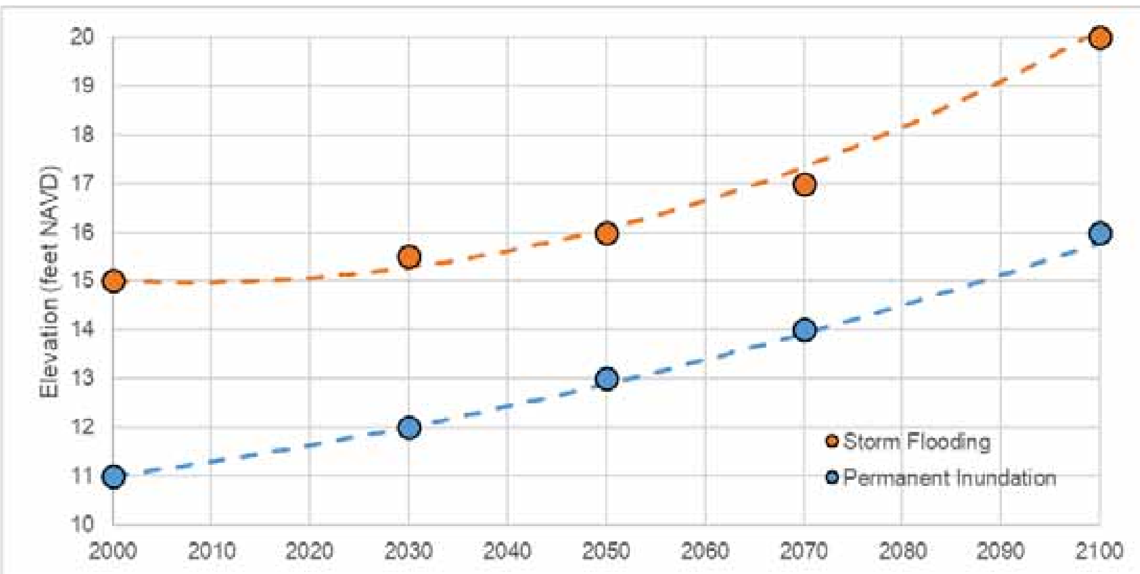

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Figure 8
Projections of Lagoon Flooding Over Time with Sea-Level Rise: Permanent Inundation and Temporary Flooding Water Levels

5.1.3 Predicted Event Durations

In addition to peak flood elevations, the duration that a given flood threshold is overtopped for several consecutive days is another important factor. This is a better indicator of how often access to the treatment plant would be limited by flooding. Often, the peak flood elevation in a given year only occurs for a few hours prior to the mouth breaching and draining the lagoon. Appendix

A includes a discussion of the frequency that flood levels in the lagoon exceeded several thresholds for three consecutive days. For most sea-level rise scenarios (0-3 feet), water levels were predicted to surpass 15 feet NAVD for three consecutive days less than once per year. For the scenario with six feet of sea-level rise, this increased to an average of about two times per year.

Appendix A also includes histograms that show the average number events that exceed a given threshold for a range of inundation event durations. Appendix A provides an example of an event where the water surface elevation of the lagoon is greater than a threshold of 15 feet NAVD88. The results show that for existing conditions, this type of flood event is very rare, but with sea-level rise the number of events increases in frequency and duration. Clearly, events lasting at least 24 hours are more common than events lasting 48 hours, 72 hours, and so on. As expected, with sea-level rise the likelihood of extended duration flooding events increases.

5.2 Flooding During Extreme River Flow Events

5.2.1 Approach

In addition to flooding caused by ponding of water behind the closed beach, flooding during extreme river flow events can cause elevated water levels adjacent to the treatment plant and vulnerable assets. Ongoing climate change is expected to alter the amount of rainfall arriving during storm events, which will affect the risk of flooding of assets during these high river flow events.

To predict future changes in flooding frequency in the Carmel River, ESA analyzed publicly available historical and forecasted future precipitation data for the Carmel River watershed. Changes in frequency of extreme precipitation events over time were used as an indicator for anticipated future changes in extreme flows. The precipitation data were derived from climate model output from general circulation models (GCMs) developed by international modeling teams as part of the International Panel on Climate Change's (IPCC) fifth assessment report (AR5). These data have been downscaled to a 6 kilometer by 6 kilometer grid scale and aggregated under a Scripps Institution of Oceanography online database (Pierce et al. 2014). The data are based on the latest set of global emissions scenarios referred to as Representative Concentration Pathways (RCPs). The analysis conducted for this study included processing this downscaled climate data in Matlab and conducting extreme value analysis to estimate the change in frequency for a 24-hour precipitation event. Two time horizons, a mid-century (2050) and late-century (2100), and two climate scenarios, RCP 4.5 and RCP 8.5, were considered for this analysis.

5.2.2 Predicted Future Flow Rates

Increased flow rates are listed in Table 4 for a range of flood events. Although the GCMs predict a broad range of future precipitation, ESA recommends applying the average of the GCM outputs for planning purposes. Applying the average of GCM outputs gives rise to a 22 to 36 percent increase in peak flows by 2050, and increase of 28 to 72 percent by 2100. For context, using

GCM outputs at the 95th percentile of predictions would result in higher flows in the future. The 95th percentile of outputs would result in an increase in peak flows by 98 to 159 percent by 2050 and 114 to 283 percent by 2100.

TABLE 4
PREDICTED FUTURE FLOW RATES ON THE CARMEL RIVER WITH CLIMATE CHANGE

	Existing Conditions	2050		2100	
Annual Recurrence Flood Event	**Flow Rate**	**GCM Average Flow Rate (cfs)**	**GCM Average Flow Rate (% increase)**	**GCM Average Flow Rate (cfs)**	**GCM Average Flow Rate (% increase)**
RCP 4.5					
2	2,591	3,152	22%	3,304	28%
5	6,220	7,872	27%	8,228	32%
10	9,204	11,811	28%	12,335	34%
50	16,545	21,548	30%	22,509	36%
100	19,770	25,834	31%	26,996	37%
500	27,159	35,707	31%	37,344	38%
RCP 8.5					
2	2,591	3,337	29%	3,631	40%
5	6,220	8,211	32%	9,640	55%
10	9,204	12,268	33%	14,839	61%
50	16,545	22,330	35%	27,941	69%
100	19,770	26,779	35%	33,714	71%
500	27,159	37,068	36%	46,792	72%

To relate the increased flow rates to water levels at the treatment plant, ESA used prior hydraulic modeling conducted by Schaaf and Wheeler (2014), who examined the 10-, 50-, 100-, and 500-year annual recurrence flood events on the river. Modeled water levels were reported at the treatment plant for each flood event, allowing a regression to be made between river flow rates and water levels. This regression was used along with the increased flow rates reported in Table 4 to give future flood levels at the treatment plant for 2050 and 2100. These levels are shown in Table 5, and also incorporate the suggested sea-level rise amounts of 2 feet and 6 feet by 2050 and 2100, respectively. Figure 9 illustrates the results listed in Table 5. The elevations of the extreme fluvial flood events are considered to be conservatively high values. This exercise was conducted to provide the maximum potential flood elevation, and refinements are recommended by running a hydraulic model with the pertinent flow rates and boundary conditions that reflect the effects of sea-level rise and climate change.

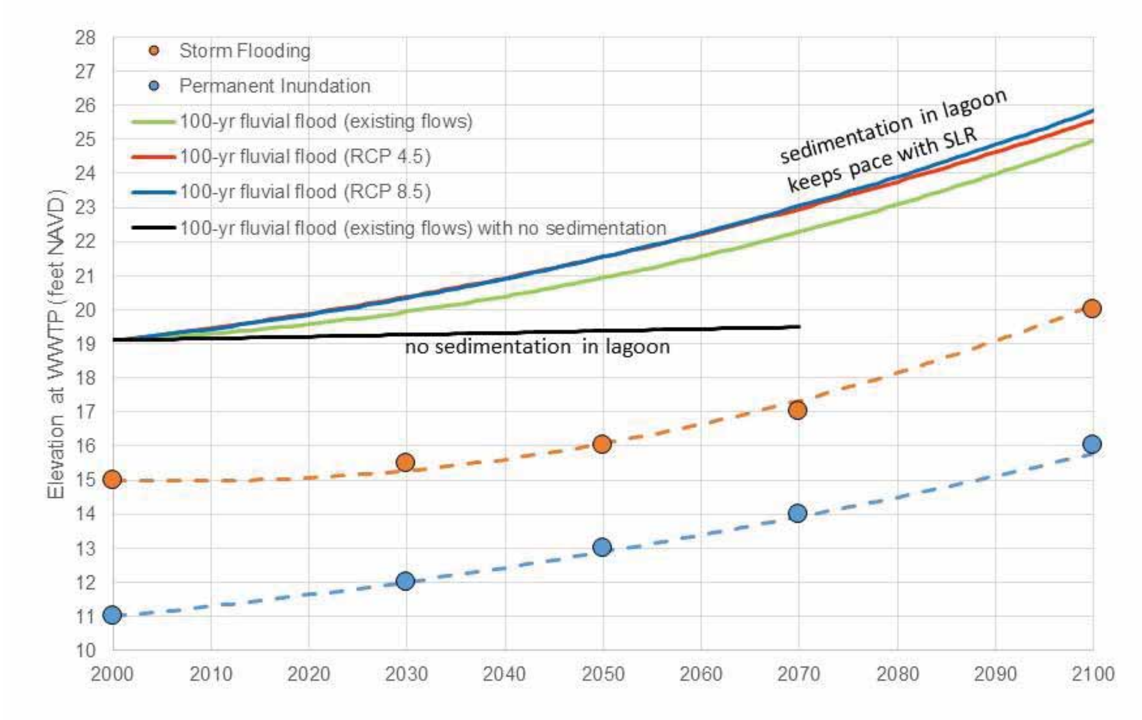

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Figure 9
Projections of Flood Elevation for a Range of Flood Sources and Conditions: Closed Lagoon Flooding and Extreme River Flows

5.2.3 Sensitivity to Sedimentation in the Lagoon

The flood analysis calculations assume that sedimentation would keep pace with sea-level rise in the future, meaning that the flood levels reported by Schaaf and Wheeler would shift upward in the future. We do not expect sedimentation to be uniform throughout the lagoon, and the rate of bed elevation rise could be outpaced by sea-level rise as it accelerates between 2050 and 2100. Thus, the predictions in Table 3 should be considered conservative (high).

To better illustrate this sensitivity to sedimentation, we also examined results from the prior hydraulic modeling work that look at sensitivity of flood levels to the downstream tailwater elevation in the lagoon. In particular, for the 100-year river flood case, Schaaf and Wheeler (2014) compare flood levels for a tailwater at normal depth, and for an tailwater at normal depth 'plus ineffective flow from sandbar' (see Table 4 in Schaaf and Wheeler 2014). The latter case has a tailwater height that is 2.8 feet higher, leading to an increase in flood levels at the WWTP from 19.1 to 19.45 feet NAVD88. Since the shape of the lagoon is otherwise unchanged, we take this case to be analogous to a 100-year river flow event with approximately 3 feet of sea-level rise and no sedimentation in the lagoon. This is represented in Figure 9 by a black curve. Taken together with the results described above, this gives an approximate envelope of expected flood levels at the WWTP during the 100-year river flood event.

TABLE 5
PREDICTED FUTURE FLOW RATES ON THE CARMEL RIVER AND RESULTING WATER LEVELS AT THE TREATMENT PLANT

	Existing Conditions		2050		2100	
Annual Recurrence Flood Event	Flow Rate	Water Level at Treatment Plant[1]	Flow Rate	Water Level at Treatment Plant[2]	Flow Rate	Water Level at Treatment Plant[3]
RCP 4.5						
10	9,204	18.2	11,811	20.5	12,335	24.5
50	16,545	18.9	21,548	21.3	22,509	25.3
100	19,770	19.1	25,834	21.5	26,996	25.6
500	27,159	19.7	35,707	22.0	37,344	26.0
RCP 8.5						
10	9,204	18.2	12,268	20.5	14,839	24.8
50	16,545	18.9	22,330	21.3	27,941	25.6
100	19,770	19.1	26,779	21.6	33,714	25.9
500	27,159	19.7	37,068	22.0	46,792	26.3

NOTES:
1 Reported by Schaaf and Wheeler (2014) in feet NGVD29. Converted to feet NAVD88 datum using a conversion of 2.75 feet
2 Water Levels in 2050 include an assumed 2 feet of sea-level rise, per Table 3
3 Water Levels in 2100 include an assumed 6 feet of sea-level rise, per Table 3

5.3 Hazard Overlay Analysis

The flood and erosion hazards over time were developed in spatial GIS layers. The analysis was conducted for existing conditions, 2050, and 2100. The intersection analysis is a general overlay of the asset data and the hazard area. This type of analysis does not consider failure mechanisms of the assets, and therefore is a simple approach to indicate what assets may be impacted by flooding and erosion. However, the use of Permanent inundation and Temporary storm flooding hazard layers are used to indicate whether assets are permanently lost or damaged, respectively. Additional analysis is needed to ascertain whether assets are designed to withstand these impacts (such as the outfall pipe crossing the South Arm) and to determine detailed elevation relationships that could be missed due to the use of coarse Lidar data. However, this approach yields useful information as a general overview to vulnerability.

Flood hazards were mapped in the vicinity of the lagoon by defining the Permanent inundation and Temporary storm flood hazard zones using the elevations presented in Table 3. These elevations were mapped in GIS on publicly available Lidar collected by the California Coastal Conservancy in 2011. We overlaid the asset data for the collection system on the flood and erosion hazard areas. Figures 10, 11, and 12 present the lagoon flooding maps for existing conditions, 2050 and 2100, respectively. Figures 13 through 17 present the erosion hazard maps for 2050 and 2100 for several sections of the Carmel shore, from Pebble Beach Golf Course in the north to Point Lobos in the South. Table 6 presents a legend and summarizes the symbology of the asset data that is included in each map in Figures 10 through 17.

TABLE 6
LEGEND AND DEFINITIONS OF ASSETS PRESENTED IN ASSET EXPOSURE MAPS

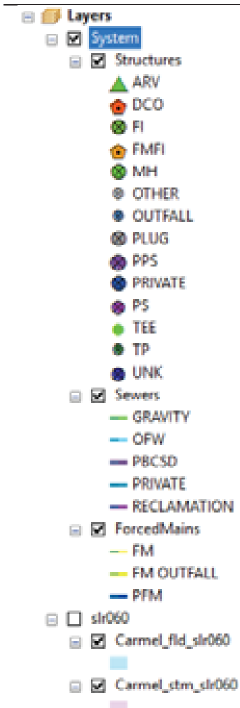
Legend	Abbreviation	Description
	ARV	--
	DCO	Double Cleanout
	FI	Flushing Inlet (i.e. single cleanout)
	FMFI	Force Main Flushing Inlet
	MH	Manhole
	OTHER	Other
	OUTFALL	Outfall
	PLUG	--
	PPS	Private Pump Station
	PRIVATE	Private Line
	PS	Pump Station
	TEE	--
	TP	Treatment Plant
	UNK	Unknown
	GRAVITY	Gravity Sewer
	OFW	--
	PBCSD	Pebble Beach Community Services District Sewer Line
	PRIVATE	Private Line
	RECLAMATION	Treated Recycled Water Pipeline
	FM	Force Main
	FM OUTFALL	Force Main Outfall
	PFM	Private Force Main Outfall

Table 7 presents a summary of the total quantities of assets that intersect each hazard type shown in Figures 10 through 17. The quantities are cumulative over time and hazard type, such that the assets impacted by Permanent inundation are also included in the quantity for temporary storm flooding impacts. The erosion and flood impacts were computed separately. This analysis did not consider the temporary impacts of coastal flooding along the Pacific shore, but that can be included in future iterations of this analysis if desired.

For existing conditions (no sea-level rise), most of the collection system assets surrounding the lagoon are impacted only during Temporary storm conditions. Although Table 7 indicates that some assets are in the Permanent inundation zone, these were determined to include the outfall crossing the South Arm, and the sewer lines entering the treatment plant across the South Arm and across the Carmel River. Temporary storm impacts for existing conditions generally agree with information provided by CAWD staff during a site visit in November 2017, during which the project discussed prior flood events and observed the low-lying pump station on the north edge of the lagoon.

For future conditions at 2050 and 2100, the footprints of the Permanent inundation and Temporary storm flooding hazards increase as the water levels increase, impacting a greater number of collection system assets and the treatment plant itself.

TABLE 7
CUMULATIVE LENGTHS OF IMPACTED WASTEWATER COLLECTION SYSTEM ASSETS

			Existing Conditions		Year 2050 (+2' SLR)			Year 2100 (+6' SLR)		
Asset Type	Asset	Units	Permanent Inundation	Storm Flooding	Erosion	Permanent Inundation	Storm Flooding	Erosion	Permanent Inundation	Storm Flooding
Force Mains	Force Main	ft	453	1,794	2,325	1,587	2,424	3,018	2,424	3,701
	Force Main Outfall	ft	598	1,828	0	1,655	1,848	0	1,848	2,244
Gravity Mains	Gravity Sewer	ft	72	1,758	10,662	83	2,671	14,475	2,671	8,059
	PBCSD Sewer Line	ft	0	0	1,952	0	0	2,310	0	439
	Private Line	ft	0	491	0	180	510	0	510	594
	Treated Recycle Water Pipeline	ft	67	91	0	80	97	784	97	669
Structures	Double Cleanout	ct	0	0	1	0	0	1	0	0
	Flushing Inlet	ct	0	3	7	0	3	10	3	5
	Manhole	ct	0	5	31	0	8	39	8	29
	Private Pump Station	ct	0	0	0	0	0	1	0	0
	Pump Station	ct	0	0	2	0	1	3	1	4
	Treatment Plant	ct	0	0	0	0	1	0	1	1
	Unknown	ct	0	0	1	0	1	1	1	1

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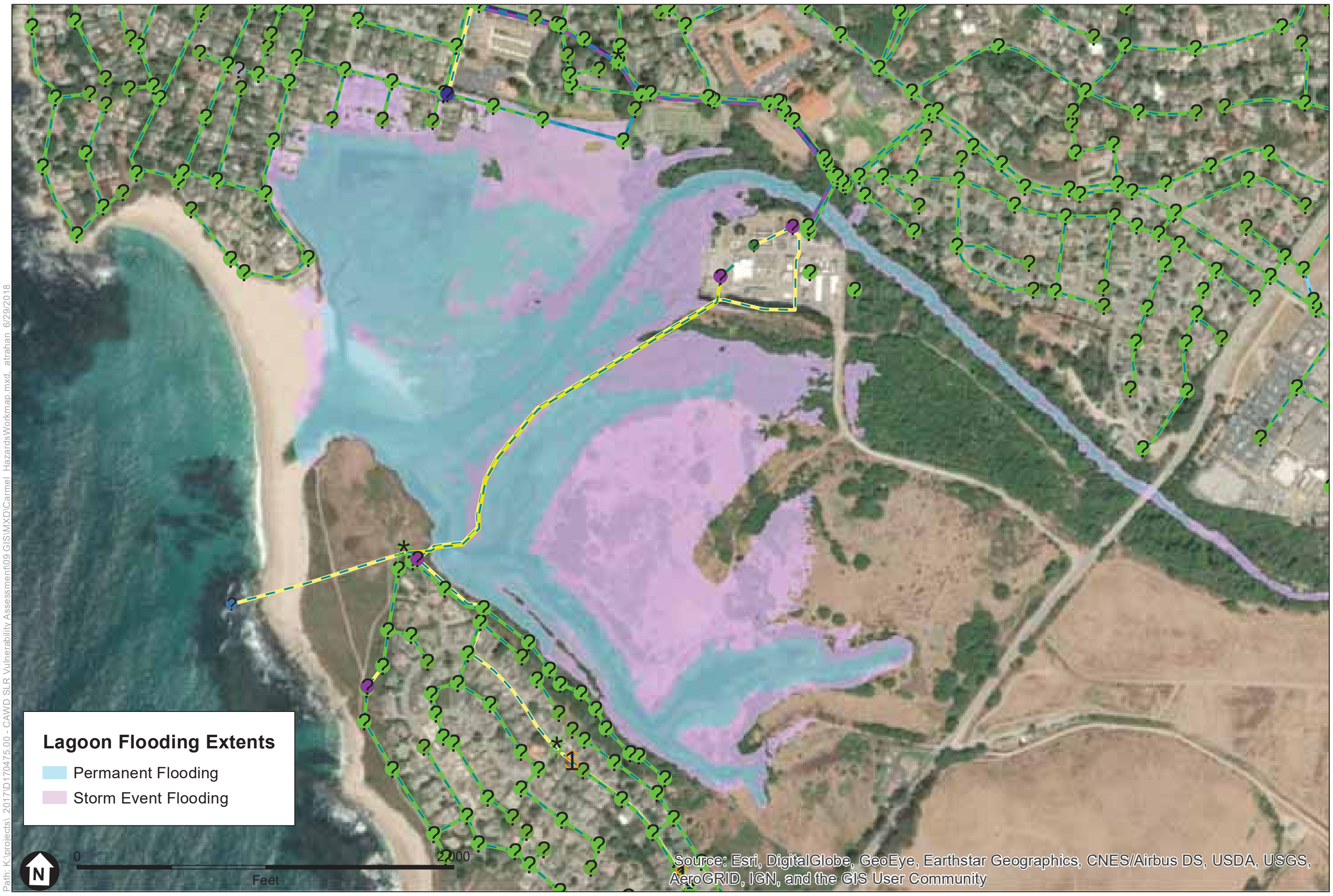

SOURCE:
Assets, CAWD 2018
LiDAR, CCC 2011
Hazards, ESA 2018

ESA

CAWD SLR Vulnerability Assessment . D170475.00

Figure 10
CAWD Asset Exposure
Lagoon Flooding under Existing Conditions

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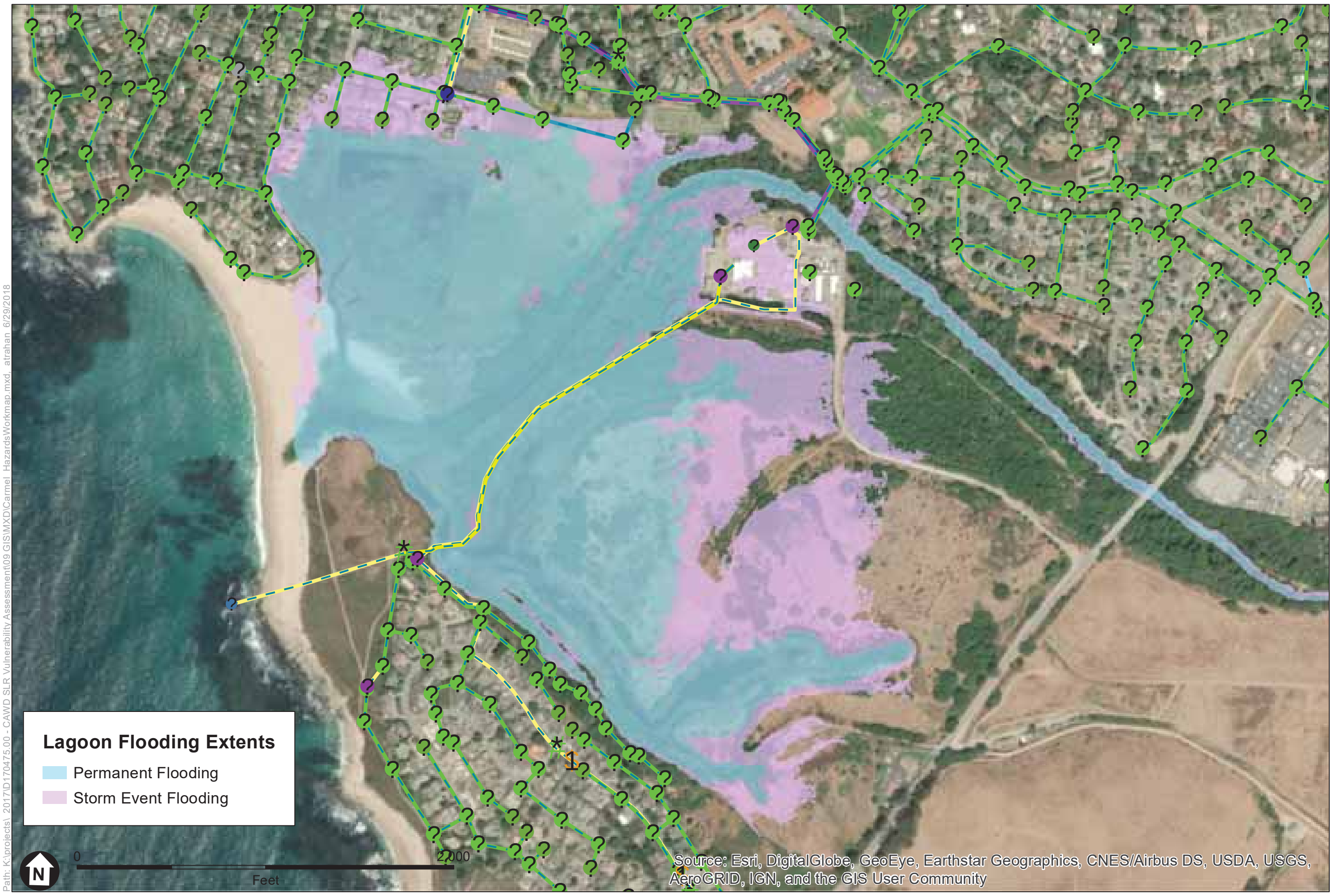

SOURCE:
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LiDAR, CCC 2011
Hazards, ESA 2018

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CAWD SLR Vulnerability Assessment . D170475.00

Figure 11
CAWD Asset Exposure
Lagoon Flooding at 2050

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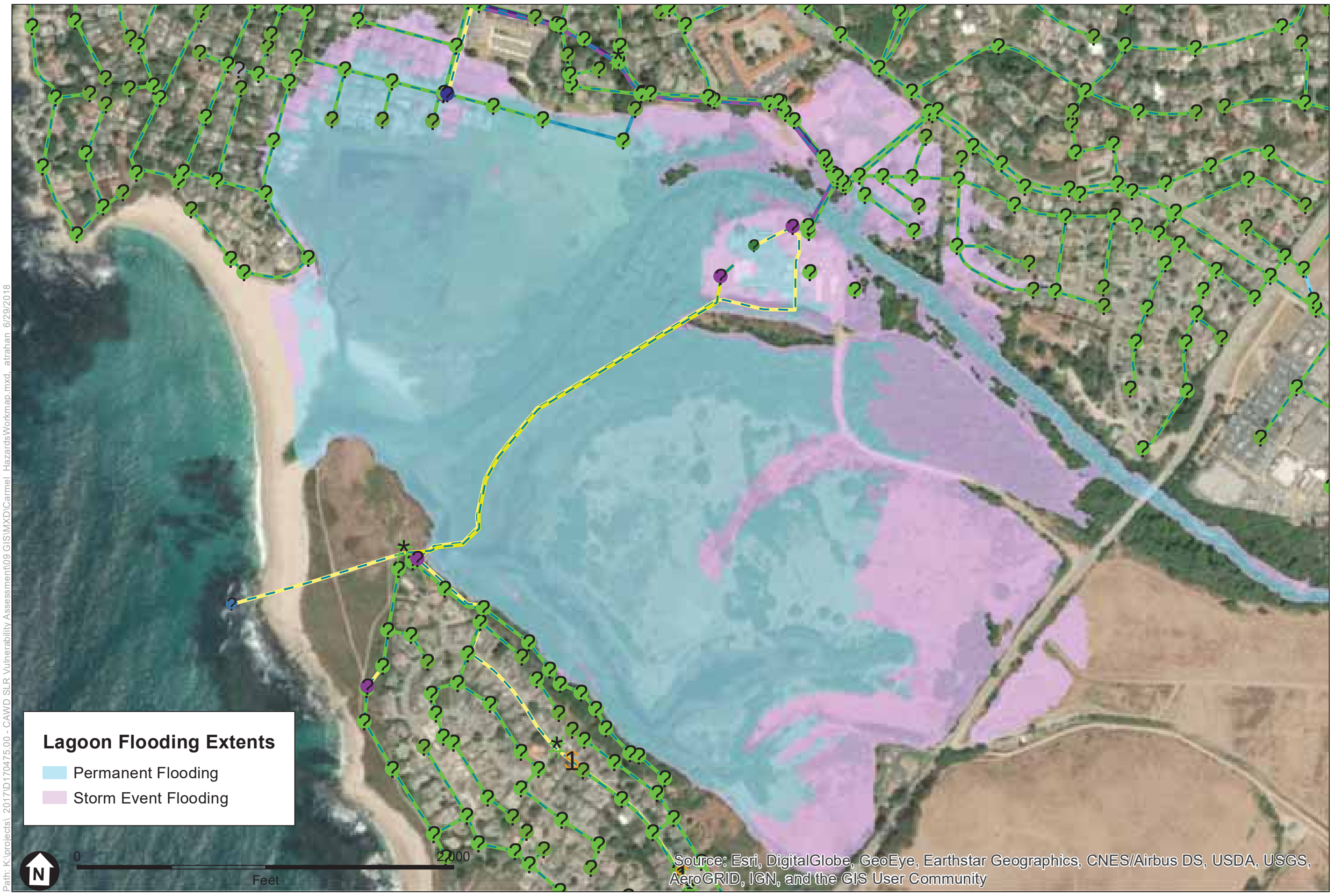

SOURCE:
Assets, CAWD 2018
LiDAR, CCC 2011
Hazards, ESA 2018

ESA

CAWD SLR Vulnerability Assessment . D170475.00

Figure 12
CAWD Asset Exposure
Lagoon Flooding at 2100

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SOURCE:
Assets, CAWD 2018
Erosion, PWA 2009

CAWD SLR Vulnerability Assessment . D170475.00

Figure 13
CAWD Asset Exposure
Shore Erosion

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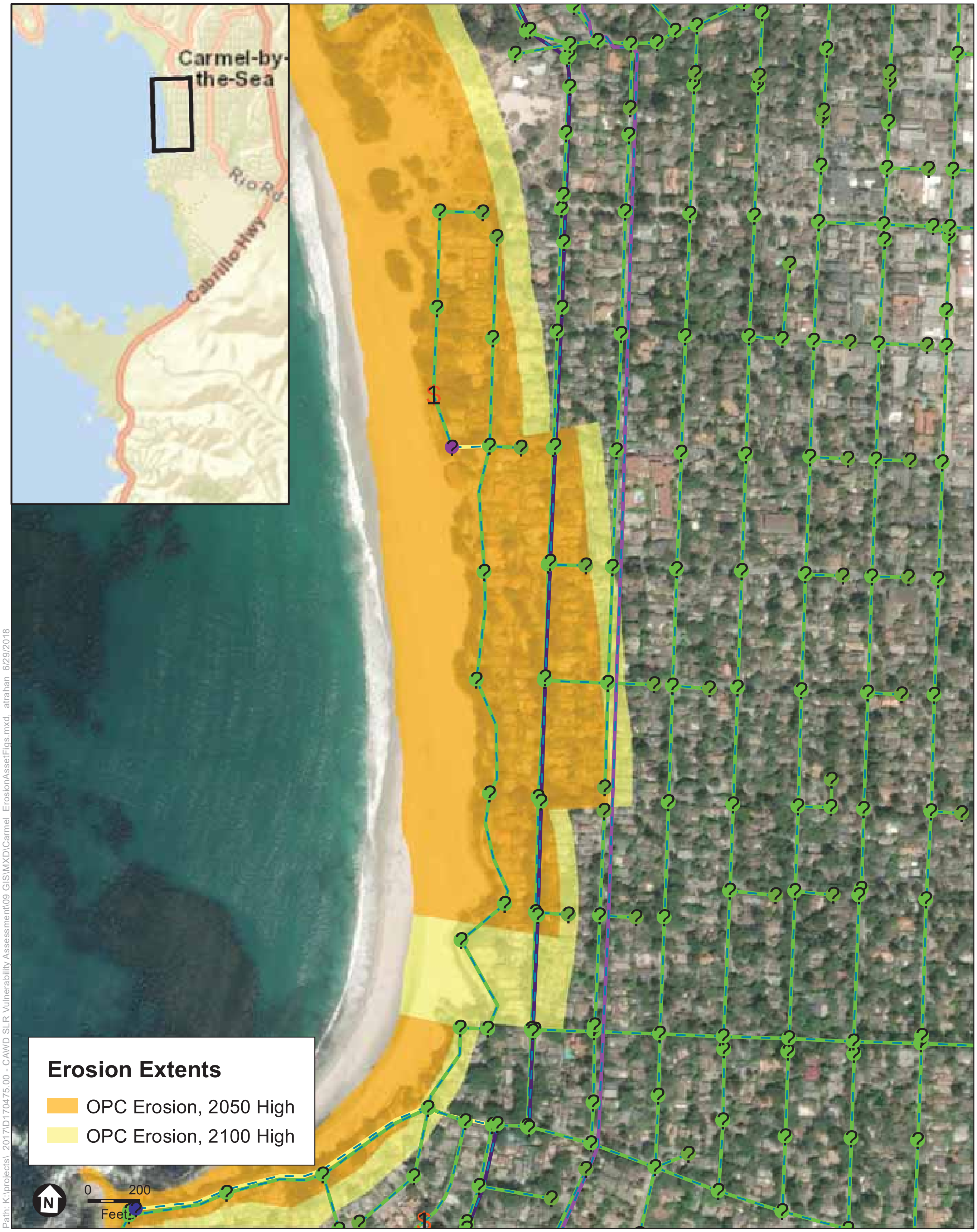

SOURCE:
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Erosion, PWA 2009

CAWD SLR Vulnerability Assessment . D170475.00

Figure 14
CAWD Asset Exposure
Shore Erosion

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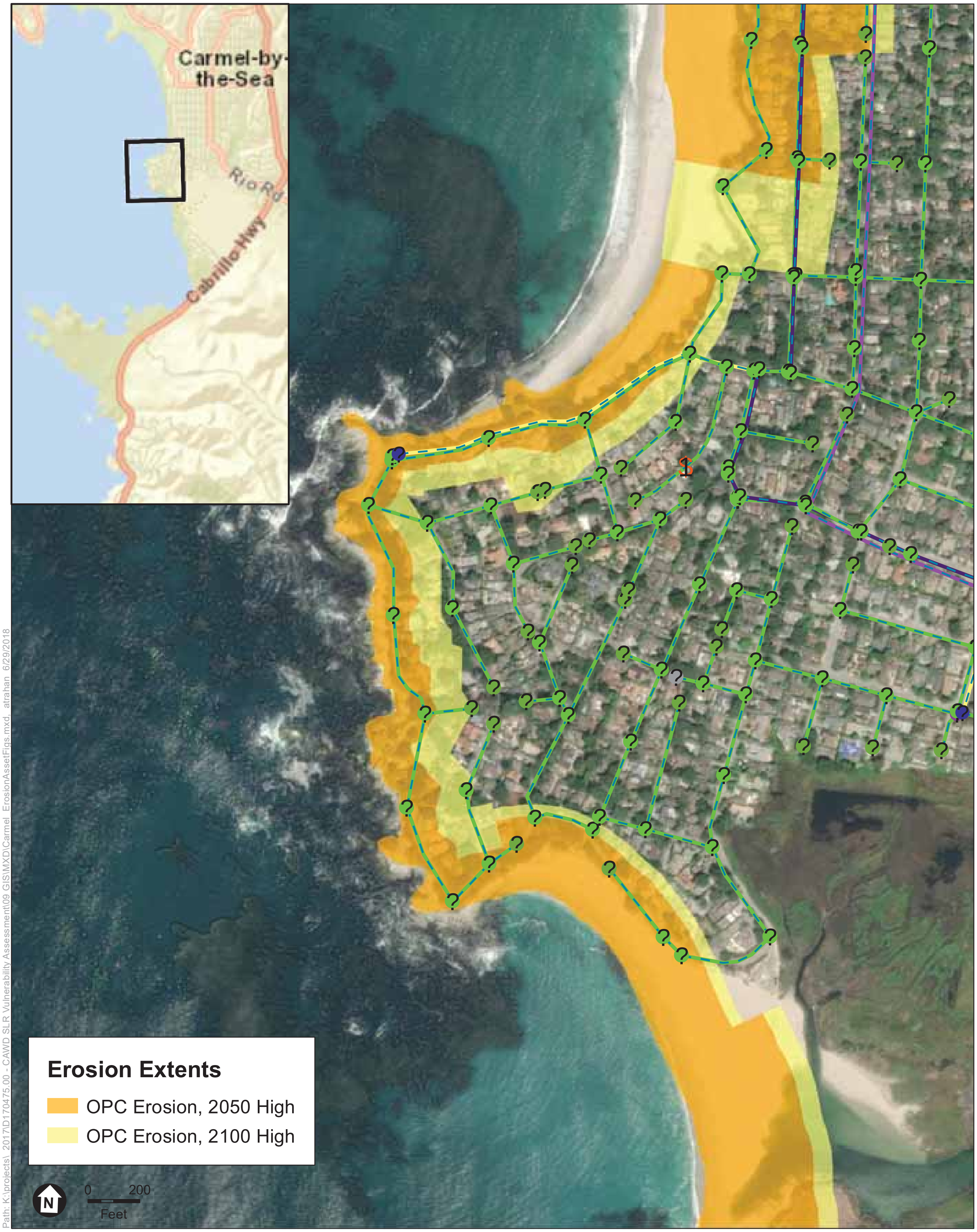

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SOURCE:
Assets, CAWD 2018
Erosion, PWA 2009

CAWD SLR Vulnerability Assessment . D170475.00

Figure 15
CAWD Asset Exposure
Shore Erosion

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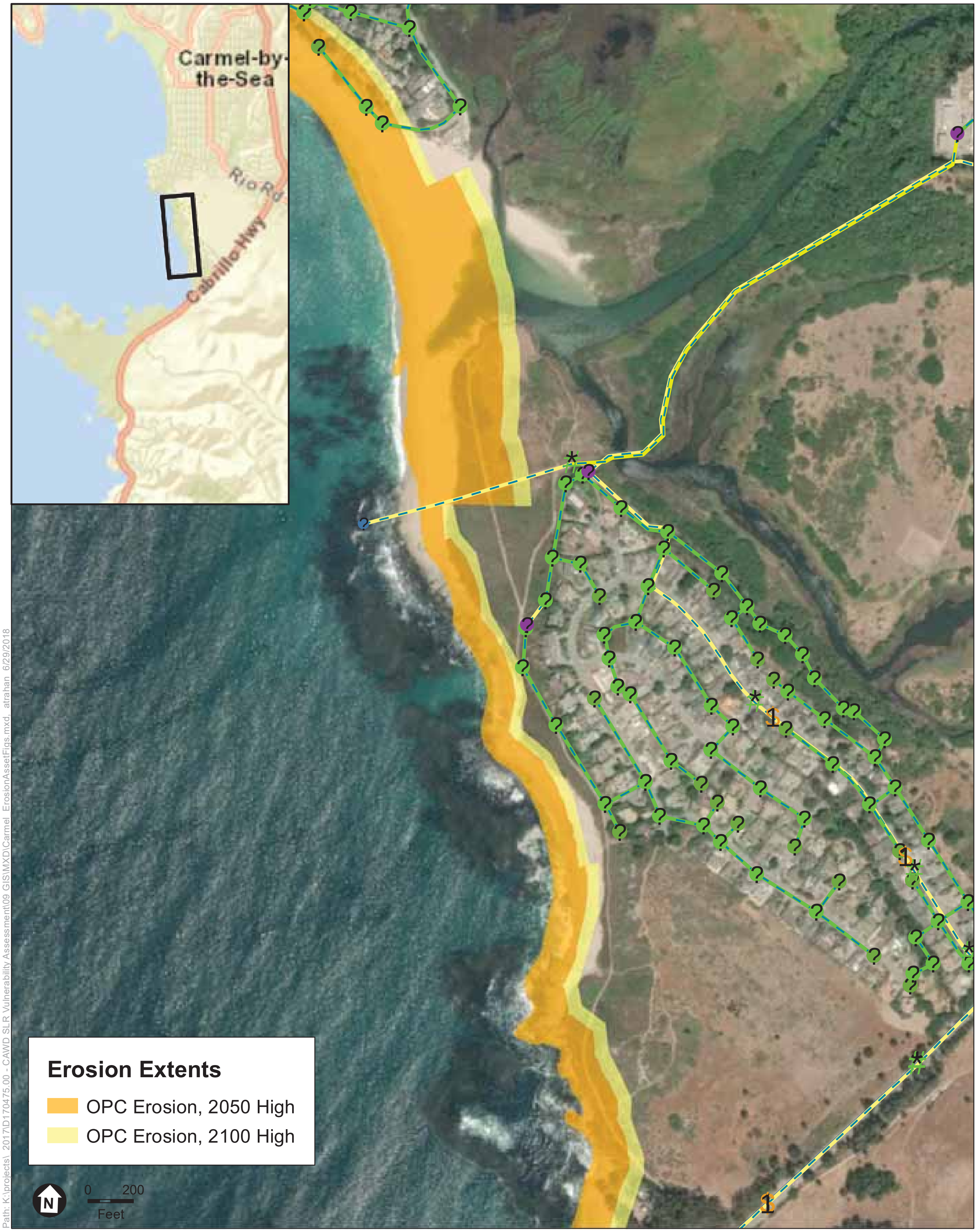

SOURCE:
Assets, CAWD 2018
Erosion, PWA 2009

CAWD SLR Vulnerability Assessment . D170475.00

Figure 16
CAWD Asset Exposure
Shore Erosion

ESA

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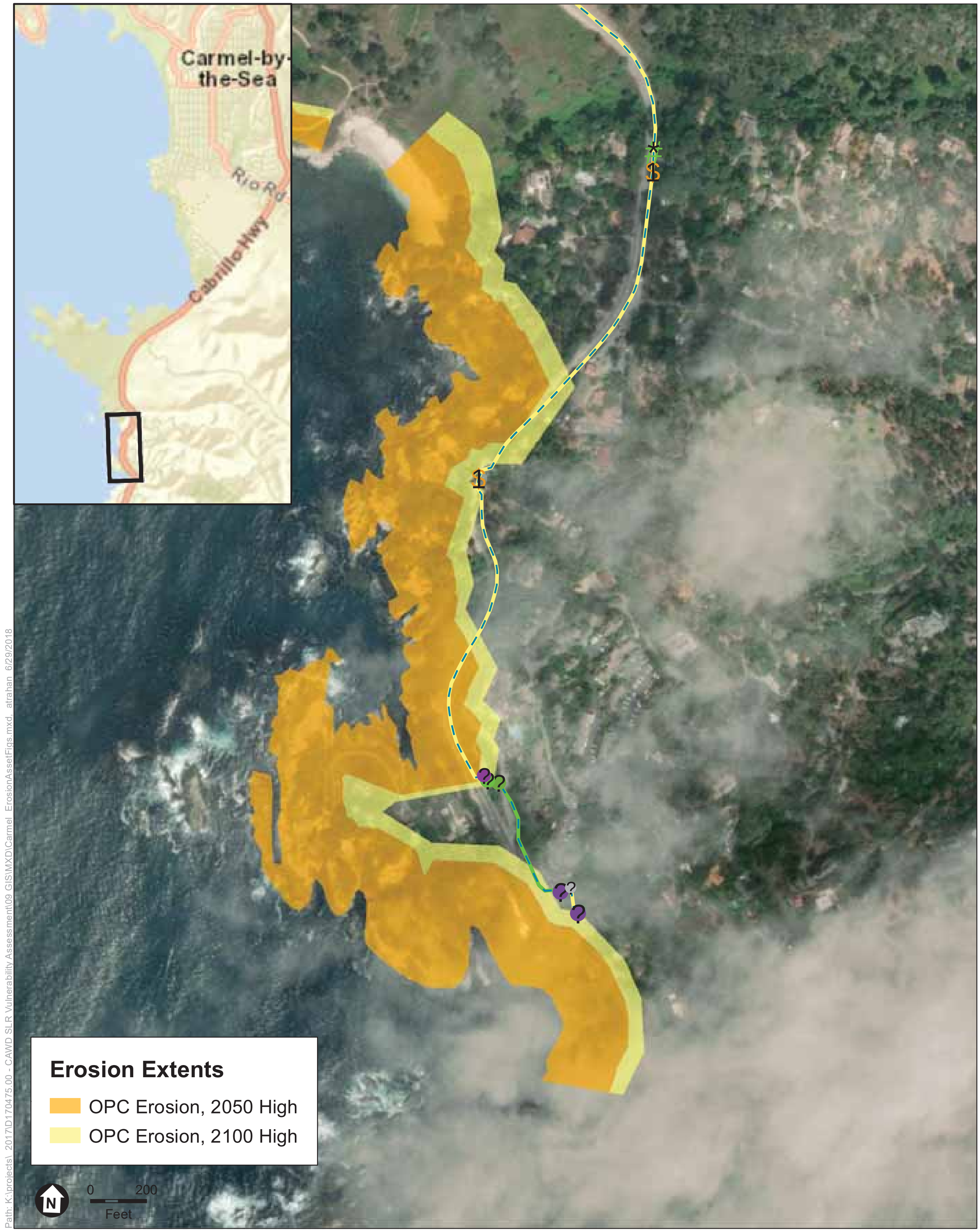

SOURCE:
Assets, CAWD 2018
Erosion, PWA 2009

CAWD SLR Vulnerability Assessment . D170475.00

Figure 17
CAWD Asset Exposure
Shore Erosion

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5.4 Threshold Analysis

This section presents a description of the threshold analysis that was conducted to determine potential future timeframes that impacts are projected due to sea-level rise. Identification of adaptation strategies for the vulnerable assets are described in the following section.

Vulnerable asset data provided by CAWD were used with exposure assessments described in Section 2 to determine threshold timeframes of impact. This information is presented in Table 8, and was developed with the following procedure:

- Elevations of vulnerable assets were tabulated.
- ESA's lagoon model described in Section 5.1 and Appendix A was used to compute flood levels in Carmel Lagoon under future conditions with a set of sea-level rise values (Table 2 and Table 3).
- Fitted curves (Figure 9) were developed using the water level predictions in Table 3. These allow prediction of flood levels in the lagoon for any year between 2000 and 2100.
- Asset elevations were compared to the fitted curves to give an expected timeline for impacts.
- Adaptation strategies for the vulnerable assets were tabulated

Flooding impacts in Table 8 are separated into two categories: (1) long-term (3-6 month) flooding that would be expected during typical closed-lagoon conditions ('Permanent inundation' as described above) and (2) flooding that would occur when rainfall collects in the lagoon and temporarily raises water levels to the beach crest elevation before breaching the mouth ('Temporary storm impact' as described above).

Although flood levels from the 100-year fluvial flood event are not included in the table, we expect that this event will lead to progressively higher water levels in the future (see Figure 9). The rate that water levels increase with this event will depend on the rate of sedimentation in the lagoon relative to sea-level rise.

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TABLE 8
VULNERABLE WASTEWATER ASSETS: APPROXIMATE TIME THRESHOLDS OF IMPACT & POTENTIAL ADAPTATION STRATEGIES

Structure # (See Map)	Description	Operation Critical for Secondary Treatment	Asset Designed to Operate through Flood Water Elevation (feet NAVD)	Timing of River Flooding Impact (1% Annual Recurrence)	Timing of Closed Lagoon Flooding Impact	Timing of Permanent Inundation	Note	Adaptation Strategy
Treatment Plant Assets								
10	Mixed Liquor Flowmeter Vault	No	16.02	Existing	2049	Beyond 2100	Vault - Electronics are sealed and water proof. Flowmeters are not critical for process control.	None required. Could protect further by installing water tight access lids.
28	Dewatered Sludge Transport	Yes	16.62	Existing	2060	Beyond 2100	Not a structure. Dewatering can be offline for extended periods by using the standby digester for additional sludge storage. Therefore transport truck could be relocated offsite during a flood event without impacts to treatment.	Adapt treatment strategy during winter months by having second digester empty and available for storing digested sludge onsite for long periods (~30 days of storage).
29	Grease Receiving Station	No	16.7	Existing	2061	Beyond 2100	Receive fats-oils-grease and ground up food waste from grocery stores. Not required to accept the waste, can stop at any time.	Demolish assets. Rebuilding to a higher elevation could be an option but would depend on payback analysis.
35	Equipment Storage Building	No	16.8	Existing	2063	Beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding or demolish building.
34	Maintenance Shop	No	16.84	Existing	2063	Beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding or build new elevated maintenance shop.
33	Vehicle Storage Building	No	16.87	Existing	2063	Beyond 2100	Not used in treatment plant process.	None required. Relocate vehicles offsite during flood.
-	Conex Storage	No	17	Existing	2065	Beyond 2100	Storage of materials and equipment. Can be removed from site.	Remove from site or place on an elevated concrete pad or anchor to protect structure from flooding.
13	Secondary Effluent Diversion Structure	Yes	17.95	Existing	2078	Beyond 2100	Pile supported below ground flow diversion structure (Approx. 10 ft x 20 ft x 15 ft deep).	Accommodate by installing water tight access lids.
14b	Chlorine Contact Channels	Yes	17.98	Existing	2078	Beyond 2100	Pile supported structure for disinfection contact of treated effluent before discharge to the ocean.	Accommodate by installing water tight access lids.
30	Ops Building Restroom Sump	No	18	Existing	2078	Beyond 2100	Small concrete sump that receives on site restroom drainage.	Accommodate by raising top of sumps to above flood level.
17	Microfiltration/Reverse Osmosis Facility	No	18.05	Existing	2079	Beyond 2100	Not designed to operate during flood event. MF/RO System is not required for NPDES permit.	Protect by building a three foot high flood wall on top of existing foundation slab.
-	Conex Storage	No	18.5	Existing	2084	Beyond 2100	Storage of materials and equipment. Can be removed from site.	Remove from site or place on an elevated concrete pad or anchor to protect structure from flooding.
38	Lunch Room Restroom Sump	No	18.6	Existing	2085	Beyond 2100	Small concrete sump that receives on site restroom drainage.	Accommodate by raising top of sumps to above flood level.
16	Gypsum Silo	No	19	Existing	2089	Beyond 2100	For Recycled Water pH control. Not currently in use.	Abandon or replace with a calcium carbonate filter in Tertiary Building above flood level.
30	Operations Building First Floor and Basement	No	19.04	Existing	2090	Beyond 2100	Basement was designed to flood. No equipment is in the basement. Office equipment is located on the first floor at elevation 19.04 ft. Main power Switchgear is located on second floor at elevation 24.75 ft.	None required. Accommodate flooding in future.
42	Ferric-Chloride Storage	No	19.38	Existing	2093	Beyond 2100	Structure would not be damaged by flooding. Small pump is vulnerable, but can be offline for extended periods.	None required. Accommodate flooding in future. Could elevate pump to higher elevation in future.
26	Waste Gas Burner	No	19.45	Existing	2094	Beyond 2100	Skid mounted unit. Floodable without damage for 72 hrs. Can be bypassed if required.	Accommodate flooding by raising the waste gas burner skid up on existing slab.
1	Manhole just upstream of influent pump station	Yes	19.6	Existing	2095	Beyond 2100	Main WWTP Influent Manhole South of Carmel River on WWTP Property	Accommodate by installing water tight access lid or raising grade.
37	Office Trailer A	No	19.83	2020	2097	Beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding in future or build a new elevated office building/break room.
39	Office Trailer B	No	19.83	2020	2097	Beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding in future or build a new elevated office building/break room.

Table 8 (Continued)
Vulnerable Wastewater Assets: Approximate Time Thresholds of Impact & Potential Adaptation Strategies

Structure # (See Map)	Description	Operation Critical for Secondary Treatment	Asset Designed to Operate through Flood Water Elevation (feet NAVD)	Timing of River Flooding Impact (1% Annual Recurrence)	Timing of Closed Lagoon Flooding Impact	Timing of Permanent Inundation	Note	Adaptation Strategy
40	Office Trailer C	No	19.83	2020	2097	Beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding in future or build a new elevated office building/break room.
38	Employee Break Building	No	20.01	2024	2099	Beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding in future or build a new elevated office building/break room.
43	Storm water Pump Station	Yes	20.3	2029	Beyond 2100	Beyond 2100	Pumps station is designed to be flooded. Electrical controls are vulnerable to sustained flooding.	Protect by moving electrical panel to higher elevation in future.
31	Locker Room	No	20.47	2033	Beyond 2100	Beyond 2100	Not used in treatment plant process.	None required. Accommodate flooding in future.
15	Tertiary Building	No	20.59	2035	Beyond 2100	Beyond 2100	Pile supported tank structure holds disinfected secondary treated water. Tertiary system is not required for NPDES permit.	Protect by raising tank walls.
41	Vehicle Fuel Storage	No	22	2057	Beyond 2100	Beyond 2100	Diesel and Gasoline storage tanks for vehicles and equipment. Tanks are anchored and watertight and the air vent is elevated to elevation 22 ft.	Accommodate by raising air vent higher. Could also elevate the tanks on an elevated concrete structure.
Collection System Assets Near Lagoon								
	CAWD WWTP Outfall Lagoon Aerial Crossing		9	Existing	Existing	Existing	24-inch Diameter Treated Effluent Pipe from WWTP to Ocean Outfall	No adaptation required for buried pipeline and pipeline in ocean. Lagoon aerial crossing replacement is in design/environmental phase to be buried under lagoon in 2020.
	Manhole A on South End of Camino Real		9.4	Existing	Existing	Existing	Manholes in street at low elevation and near the Carmel River Lagoon	Accommodate by installing water tight manhole lid, or retreat subject to County planning.
	Manhole at 17th and Carmelo St		9.6	Existing	Existing	Existing	Manhole in street at low elevation and near the Carmel River Lagoon	Accommodate by installing water tight manhole cover and coating interior of manhole. Or raise road elevation/retreat subject to County planning.
	Laterals for homes on East Side of Carmelo St		10	Existing	Existing	Existing	Laterals for homes at low elevations.	Retreat subject to County planning.
	Laterals for homes on Monte Verde, Park Place, and Camino Real		10	Existing	Existing	Existing	Laterals for homes at low elevations.	Retreat subject to County planning.
	Manhole on Carmelo St North of 17th		10.5	Existing	Existing	Existing	Manhole in street at low elevation and near the Carmel River Lagoon	Accommodate by installing water tight manhole cover and coating interior of manhole. Or raise road elevation/retreat subject to County planning.
	Cleanout on River Park Place		11.6	Existing	Existing	2019	Cleanout in street at low elevation and near the Carmel River Lagoon	Accommodate by installing pressure rated cleanout, or retreat subject to County planning.
	Manhole at East End of 16th		12.2	Existing	Existing	2037	Manhole in street at low elevation and near the Carmel River Lagoon	Accommodate by installing water tight manhole cover and coating interior of manhole. Or raise road elevation/retreat subject to County planning.
	Manhole B at Mission Ranch		12.3	Existing	Existing	2037	On Mission Ranch property near the Carmel River Lagoon	Accommodate by installing water tight manhole cover and coating interior of manhole. Or raise road elevation/retreat subject to County planning.
	Manhole on River Park Place		12.6	Existing	Existing	2044		Cleanout in street at low elevation and near the Carmel River Lagoon
	Cleanout on South End of Monte Verde		13.1	Existing	Existing	2055	Cleanout in street at low elevation and near the Carmel River Lagoon	Accommodate by installing pressure rated cleanout, or retreat subject to County planning.
	Manhole B on South End of Camino Real		13.5	Existing	Existing	2062	Manholes in street at low elevation and near the Carmel River Lagoon	Accommodate by installing water tight manhole lid, or retreat subject to County planning.
	Monte Verde and 16th Pump Station		15	Existing	Existing	2088	Pump Station at low elevation and near the Carmel River Lagoon	Accommodate by retrofitting station with electrical enclosures that can be submerged or move electrical controls above flood elevation.

Table 8 (Continued)
Vulnerable Wastewater Assets: Approximate Time Thresholds of Impact & Potential Adaptation Strategies

Structure # (See Map)	Description	Operation Critical for Secondary Treatment	Asset Designed to Operate through Flood Water Elevation (feet NAVD)	Timing of River Flooding Impact (1% Annual Recurrence)	Timing of Closed Lagoon Flooding Impact	Timing of Permanent Inundation	Note	Adaptation Strategy
	Manhole A at Mission Ranch		15.5	Existing	2037	2096	On Mission Ranch property near the Carmel River Lagoon	Accommodate by installing water tight manhole cover and coating interior of manhole. Or raise road elevation/retreat subject to County planning.
	Calle La Cruz Pump Station		19.7	2057	2096	Beyond 2100	Pump Station on South Side of Carmel Lagoon; note existing BFE approx. 16 feet NAVD	Accommodate by remodeling existing concrete structure to raise access into the building to a higher elevation and seal all lower doorways and louvers. New access can be via elevated roof top hatch.
Collection System Assets Near Carmel River								
	PBCSD Sewer Manholes on North Side of Carmel River Main Sewer Crossing (Two Manholes)		15.4	Existing	2034	2094	Manhole near River Bank	Accommodate by raising the top of the manhole and coating the interior of the manhole.
	Manholes in Mission Fields Neighborhood		16	Existing	2049	Beyond 2100	Manholes serving Mission Fields Neighborhood on North Side of Carmel River	Accommodate by installing water tight manhole lid, or retreat subject to County planning.
	Laterals for homes in Mission Fields Neighborhood		16	Existing	2049	Beyond 2100	Laterals for homes at low elevations.	Retreat subject to County planning.
	Hacienda Pump Station		51	other	other	other	Pump Station Up River on South Bank of Carmel River	None required.
Collection System Assets Near Pacific Ocean								
	Bay and Scenic Pump Station				Erosion risk by 2050			Pump Station serves beachfront homes that may also be impacted by erosion. Pump station is small (5,000 gallons per day) and could be relocated if necessary.
	8th and Scenic Pump Station				Erosion risk by 2050			Pump Station serves coastal cliff homes that may also be impacted by erosion. Pump station is small (24,000 gallons per day) and could be relocated if necessary.

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5.5 Potential Adaptation Strategies

This section of the report describes potential sea-level rise adaptation strategies for the CAWD facilities. Recognizing that adaptation to sea-level rise is a topic of interest in the region, and that other efforts will be needed to develop large-scale strategies for the communities and critical assets, this section is focused on adaptation strategies and measures specific to the CAWD assets.

Sea-level rise will impact many assets to the community beyond the wastewater assets being considered in this report. As one of the most important pieces of infrastructure for the community, it is natural to consider the wastewater facilities as part of regional sea-level rise adaptation efforts. However, the adaptation strategies identified in this report are presented as asset-specific for planning purposes.

The approach to describing adaptation as it relates to the CAWD facility is to present adaptation measures using the general categories defined by the CCC (2015) relative to the scale and timing of the measure.

5.5.1 General Adaptation Categories

The adaptation strategies presented in this report follow the CCC (2015) guidance, which defines the following general adaptation categories that could be used to consider different options:

- **Protect:**
  Strategies that employ some sort of engineered structure or other measure to defend development in its current location without changes to the development itself. Protection strategies include “hard” and “soft” defensive measures or armoring.

- **Accommodate:**
  Accommodation strategies employ methods that modify existing developments or design new developments to decrease hazard risks and thus increase the resilience of development to risks of sea-level rise. Accommodation strategies can be asset-specific community-based.

- **Retreat:**
  Retreat strategies involve relocation or removal of existing development out of hazard areas and limit the construction of new development in vulnerable areas.

- **Hybrid:**
  Hybrid strategies combine measures from the three strategies described above, such as accommodating over the short-term and relocating long-term.

5.5.2 Adaptation Strategies for Wastewater Assets

Table 8 above presents potential adaptation strategies that were identified for each of the wastewater assets that were considered. The strategies tabulated above are based on the general adaptation strategies, and identify specific modifications or actions that could be implemented to enhance the performance of the system in the future with sea-level rise. Next steps to be taken by CAWD will be to consider these adaptation actions in more detail, and to incorporate them into the project planning and design for upgrades to the treatment plant and facilities. Part of the next steps will include cost estimating so that the District can appropriately plan for implementation of measures that address the vulnerabilities to sea-level rise.

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Appendix A
Hydrologic and Geomorphic Modeling of Carmel River Lagoon

1 INTRODUCTION

This appendix provides information on the hydrologic and geomorphic analyses of Carmel Lagoon conducted to inform the Carmel Area Wastewater District Sea-Level Rise Vulnerability Study. It provides background on the site setting and details the development of a lagoon quantified conceptual model (QCM), which is being developed for this project to understand how peak water levels in the lagoon will change as a result of sea-level rise.

1.1 Background

The Carmel River Lagoon is a bar-built estuary located south of the town of Carmel-by-the-Sea, in central California. The hydrology of the lagoon is dictated by the seasonal interaction of the Carmel River with wave-driven beach-building processes at the mouth. The Carmel Area Wastewater District (CAWD) operates a treatment facility located in the Carmel Lagoon Basin, immediately south of Carmel-by-the-Sea.

Although the lagoon is located within a developed, suburban region, the lagoon is regionally important from a habitat perspective. The lagoon basin and lower reaches of the Carmel River are classified as critical habitat for juvenile steelhead. Several habitat-focused mitigation and restoration projects have been carried out or are in planning phases. Completed projects include the Caltrans bank mitigation project, constructed in 1997, and the Carmel River Lagoon Enhancement Project, constructed in 2004 (PWA 1999). Future projects still in planning stages include the Carmel River Floodplain Restoration and Environmental Enhancement (FREE) Project (Balance Hydrologics 2015) and the Ecosystem Protection Barrier. The goal of most of these projects has been to increase steelhead habitat area and quality while reducing flooding risks to nearby municipal and private properties.

Low-lying neighborhoods and infrastructure, including the CAWD Treatment Plant, are located within or adjacent to the lagoon basin. Naturally-occurring high water levels in the lagoon periodically create flood risk for this infrastructure. High water levels often result from water ponding behind the beach berm, which is blocked (‘closed’) seasonally by wave action during the dry season. To mitigate flooding hazards, the mouth of the lagoon is currently breached when floodwaters reach a trigger elevation to drain the lagoon and prevent flood damages to existing developments.

There has been little study of the expected impacts of future climate change on conditions in the lagoon. This is an important data gap, since future sea-level rise will exacerbate flooding issues, and limit the utility of mouth breach events at keeping water levels below flood levels. Prior studies have focused primarily on fluvial flooding or were done to inform lagoon and river restoration. These are discussed in more detail below.

1.1.1 Prior Studies

Previous studies on the Carmel River Lagoons have looked at lagoon hydrology, flooding, and beach morphology and management. Prior efforts include those by PWA (1992 and 1999), Thornton (2005), Kraus et al. (2008), Laudier et al. (2011), Rich and Keller (2013), Moffatt & Nichol (2013), Shaaf & Wheeler (2014 and 2016), and Balance Hydrologics (2015). Edward Thornton, a professor emeritus at the Naval Postgraduate School, has studied the Carmel Lagoon and has observed conditions at the site for several decades. This section gives a brief overview of some these studies.

Pre-Restoration Lagoon Studies

In 1992, PWA created the Carmel River Lagoon Enhancement Plan (PWA 1992). This plan set the framework for steelhead habitat restoration efforts carried out in the lagoon in 1997 and 2004 by Caltrans and California State Parks, respectively. The plan included HEC-2 modeling as well as extensive historic and geomorphic analysis to inform restoration options. The modeling proved to be sensitive to lagoon tailwater conditions and lagoon mouth scour, which were not well understood at the time (PWA 1992). The modeling results were not reported.

PWA also produced a conceptual design report as part of the Carmel River Lagoon Enhancement Plan in 1999 (PWA 1999). The selected conceptual design was based on detailed fluvial modeling results using the MIKE 11 software and additional geomorphic and hydrologic analysis. The MIKE 11 model was calibrated using historical water surface records and was run for eight different restoration alternatives and several flow conditions. Modeling scenarios that directed flows onto the floodplain resulted in lower water levels in the main stem of the river, thus providing flood control and habitat enhancement benefits. PWA also characterized lagoon dynamics and mouth behavior in the conceptual design report, although no modeling or sea-level rise analyses were performed.

Post-Restoration and Ongoing Studies

In 2009, the Federal Emergency Management Agency (FEMA) released the most-current Flood Insurance Study for unincorporated Monterey County (FEMA 2009). Flooding along the lower reaches of the Carmel River was modeled using a steady, 1-dimensional HEC-RAS model. This publically available model has been utilized and modified by other consultants since its release.

In 2009, Shaaf & Wheeler analyzed specific flood risks to the CAWD Treatment Plant using the 2009 FEMA model. Shaaf & Wheeler adjusted the FEMA model to account for site-specific conditions near the plant. Their modifications generally resulted in increased modeled water levels in the channel near the treatment plant. As a part of the same analysis, Shaaf & Wheeler also assessed the tailwater sensitivity of the FEMA model. Their results showed water levels at the CAWD plant to be sensitive to the downstream tailwater elevation, which is the water surface elevation of the lagoon. The tailwater influenced water levels up to approximately 4,200 feet upstream of the mouth under the highest tailwater state modeled (16.92 feet NAVD). ESA converted Shaaf & Wheeler elevation of 14.17 feet NGVD to 16.92 feet NAVD using a conversion of 2.75 feet (National Geodetic Survey 2018)

Balance Hydrologics also performed modeling to inform the 2015 Carmel River Floodplain Restoration and Environmental Enhancement (FREE) Project (Balance 2015). Balance analyzed flooding conditions and potential restoration scenarios by making modifications to the FEMA model. Balance additionally developed a channel evolution model to predict long-term sediment transport and inform restoration design.

The proposed restoration design selected as part of the Carmel River FREE Project is relevant to CAWD due to the potential impacts to the existing CAWD outfall pipe (see Figure 1). Shaaf & Wheeler used a HEC-RAS model to analyze the proposed restoration design and found that the project has the potential to increase flow rates in the South Arm of the lagoon. Shaaf & Wheeler noted that increased flow rates could induce geometry changes that may impact the pipeline and increase the amount and size of transported debris in the South Arm (Shaaf & Wheeler 2016).

Beach and Mouth Studies

Thornton (2005) provides an overview coastal conditions at the site, and the resulting beach and lagoon mouth morphology. This report outlines some of the unique features that influence the site morphology, and is useful as a framework for subsequent detailed work on wave overtopping into lagoon (Laudier et al. 2011), and seasonal lagoon hydrology (Rich and Keller 2013). Kraus et al. (2008) developed a conceptual model for mouth breach events, and included the Carmel River Lagoon as a case example for breach behavior. Laudier et al. (2011) used concurrent beach surveys and changes in stored water volume in the lagoon to develop an accurate model of wave overtopping. Rich and Keller (2013) developed a lagoon hydrology model based on a prior study by Battalio et al (2007) to better understand how mouth breach events and the 2004 restoration influence water levels lagoon.

1.1.2 Lagoon Management Practices

As discussed above, artificial breaching of the mouth with heavy equipment is used to periodically drain the lagoon and prevent flooding of low-lying properties. Breaching is usually performed by digging a pilot channel in the beach, and allowing water to then spill to ocean and erode a new mouth. Recommendations for breaching timing were provided by Moffatt and Nichol (2013) who considered how breaching practices can influence the potential for erosion on the northern Scenic Road.

1.2 Modeling Objectives

The overarching objective of the ESA lagoon modeling is to provide insight on how climate change will affect future water levels in the Carmel Lagoon, and to thereby determine the vulnerability of the CAWD infrastructure in the future.

Modeling seeks to address the following questions:

- What CAWD infrastructure assets are most vulnerable presently and in the future?
- What is the level of vulnerability of each asset?

- What is the anticipated timing of sea-level rise impacts for each asset?
- How frequently is access to the treatment plant site impeded presently and in the future?
- Can modifications to existing breaching practices be implemented to reduce flooding risk in the future?
- How will proposed projects within the lagoon impact flood levels and timing?

2 PROJECT SETTING

2.1 Site Description

The CAWD Treatment Plant is located approximately 2,500 feet inland from the shoreline on the lower stretch of the Carmel River. The Carmel River watershed drains an area of approximately 250 square miles, most of which is located within the Santa Lucia Mountains. Where the river meets the Pacific Ocean, it forms the Carmel Lagoon. The lagoon is located south of the City of Carmel-by-the-Sea in Monterey County, CA.

Regionally important infrastructure exists within the lagoon basin, including the CAWD Treatment Plant and a portion of Highway 1. Low-lying residential areas border the lagoon to the north and northeast.

2.1.1 Existing Lagoon Basin Features

The lagoon basin includes several notable geomorphic features, which are highlighted Figure 1. Generally, the basin can be described in terms of the main stems of the lagoon, the lagoon mouth and beach, adjacent lagoon wetlands, and upland areas.

Carmel River Lagoon consists of two main branches; the main stem of Carmel River and the South Arm. The main stem of the Carmel River flows from east to west through the lagoon basin and drains into Carmel Bay through the lagoon mouth at Carmel State Beach. South of the lagoon mouth, the lagoon branches into the South Arm. The South Arm was restored in 2004 as part of the Carmel River Lagoon Enhancement Project and currently extends to the southeast almost to Highway 1.

The lagoon terminates at Carmel State Beach, a sandy, steep beach that is approximately 1,000 feet long and is flanked by rocky headlands to the north and south. The elevation of the beach fluctuates seasonally; it is high in the summer and lower in the winter when high-energy waves and elevated water levels push sand offshore. The beach berm (the highest crest of the beach) intermittently blocks the lagoon mouth when under certain wave and flow conditions.

A low-lying wetland area called the Carmel River Lagoon & Wetland Natural Preserve exists to the north of the lagoon mouth and the main stem of the Carmel River. The marsh channels in this area are typically connected as part of the lagoon and ponding can occur throughout much the marsh area under closed-mouth lagoon conditions.

Higher elevation areas of the lagoon basin consist of historic agricultural fields (Odello Property), the CAWD Treatment Plant, and neighboring residential areas. The Odello Property is divided into west and east segments, which are bisected by Highway 1. The west Odello Property was restored as part of the Carmel River Lagoon Enhancement Project in 2004 (PWA 1999) and the east Odello Property is still an active agricultural property. However, plans exist to convert part of the East Odello Property land to floodplain under the of the Carmel FREE Project (Balance 2015).

2.1.2 Existing Development in Lagoon Basin

The Carmel Lagoon is located in a suburban environment, and as such, there are existing developments located within and adjacent to the lagoon basin. These developments include CAWD facilities, Highway 1 and adjacent utility lines, and residential neighborhoods.

The CAWD operates a treatment plant and associated facilities within the lagoon basin. The plant itself is located south of the main stem of the Carmel River and north of the South Arm of the lagoon. A CAWD access road runs from Highway 1 northwest to the plant. A buried treated wastewater effluent pipeline extends from the plant to Carmel Bay. The pipeline includes an elevated crossing over the South Arm of the lagoon approximately 1,000 feet south of the lagoon mouth.

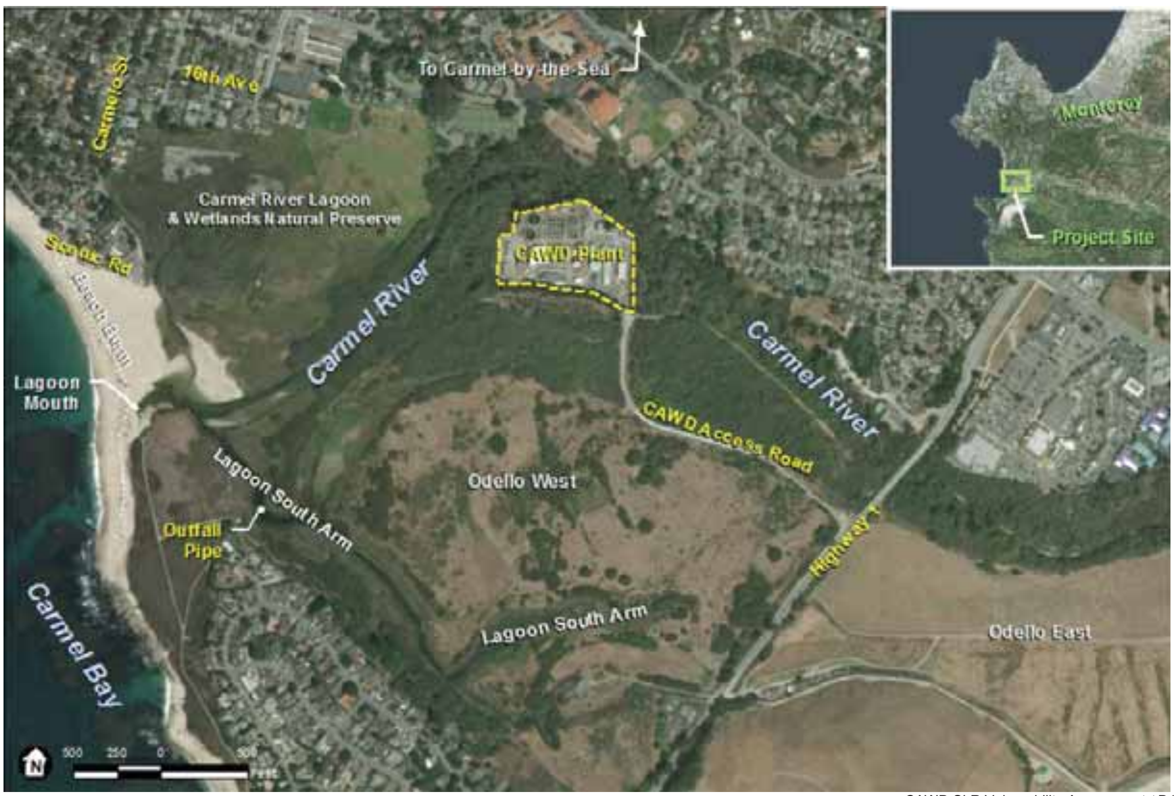
Highway 1 crosses the lagoon basin from southwest to northeast. Several major utility lines serving the Carmel area including electrical, gas, and water run adjacent to the highway. A bridge exists over the main stem of the Carmel River near the Mission Fields neighborhood and several culverts under the highway provide drainage connections between the East Odello site and the restored lagoon (west).

Residential neighborhoods border the lagoon to the north and south. While the neighborhood to the south of the lagoon is elevated, households in the low-lying areas to the north of the Carmel River Lagoon & Wetland Natural Preserve have experienced issues with flooding under high lagoon water levels.

2.1.3 Landowners and Stakeholders

Many organizations have interest in the management and future of Carmel Lagoon. A brief list of parties relevant to this lagoon modeling effort include:

- California State Parks
- City of Carmel-by-the-Sea
- Carmel Area Wastewater District
- Monterey county Water Resources Agency
- Monterey Peninsula Water Management District
- County Department of Public Works
- Big Sur Land Trust



SOURCE:

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Figure 1
Project Setting

2.2 Hydrology and Geomorphology

2.2.1 Tidal Water Levels and Datums

The tides near the project site exhibit mixed semi-diurnal characteristics, with two high tides and two low tides of unequal height occurring approximately every 24 hours. Table 1 presents the published tidal datums for the Monterey tide gage (NOAA NOS Station 9413450), located approximately 13 miles north along the coast from the mouth of the Carmel Lagoon. The mean higher high water (MHHW) elevation is calculated by averaging the higher high water height of each tidal day observed over the tidal epoch (a 19-year period of water level averaging – the National Tidal Datum Epoch (NTDE)).

The highest water levels are typically observed in the winter months of November through February and the summer months of June and July, reaching elevations of greater than 8 feet NAVD88. Coastal ocean water levels at the project site are not available, but would also include the effects of wave setup, which can cause a super-elevation of the water surface above the astronomical tides.

TABLE 1
TIDAL DATUMS AT MONTEREY, CA STATION 9413450

Datum	Description	Value (feet NAVD)
Max	Highest Observed Water Level (1/27/83)	8.02
HAT	Highest Astronomical Tide	7.18
MHHW	Mean Higher High Water	5.48
MHW	Mean High Water	4.78
MTL	Mean Tide Level	3.01
MSL	Mean Sea Level	2.97
NGVD	National Geodetic Vertical Datum of 1929[1]	2.75
MLW	Mean Low Water	1.23
MLLW	Mean Lower Low Water	0.14
NAVD	North American Vertical Datum of 1988	0.00
LAT	Lowest Astronomical Tide	-1.77

[1]Tidal Datum Analysis Period: 01/01/1983-12/31/2001
[2]Based on NGS Data Sheet PID GUI3233

2.2.2 Watershed Runoff

Like most coastal lagoons in central California, watershed inputs are sharply seasonal, with most of the runoff occurring between the months of November and May. Freshwater runoff is measured by the U.S. Geological Survey immediately upstream of the lagoon. During peak flood events in the winter, flows can surpass 10,000 cubic feet per second (cfs), with the 100-year recurrence flood event estimated at 29,000 cfs.

Flows typically decline significantly in spring or summer after the final rainfall event of the year. Under normal conditions, freshwater runoff to the lagoon is below 10 cfs for much of the summer and fall, with inflows approaching zero in some of the driest years on record.

2.2.3 Nearshore Waves

Nearshore wave conditions at the site control the morphology of the beach. Constructive waves in the summer and fall move sand onshore and contribute to growth of the berm. Destructive wave events during storms can contribute to beach erosion in the winter. Waves also contribute a significant amount of water to the lagoon when the water level from combined tides, wave setup, and dynamic runup on the beach face allow waves to spill over the beach crest and into the lagoon (Laudier et al. 2011).

The wave climate is temporally variable. During the winter (November- March), waves are typically generated by cyclones in the north Pacific with deep water significant wave heights up to 11 m (Wyland and Thornton 1991) with wave directions from north-west to west-south-west. Local wind driven seas typically develop rapidly when low pressure systems track offshore in the winter months. The winter months are typically times of long-period swell waves.

The summer months (July-August) are a time of the most persistent winds and waves that come from the northwest owing to a persistent high-pressure system offshore. Low, long period swell waves arrive from the south generated by storms in the Southern Ocean during summer months but are mostly blocked by Point Lobos. In addition, sea breezes are typically generated during the summer months as the result of heating of the interior land of the Carmel Valley with the hot air rising in the afternoon and being replaced by the cooler air flowing off the ocean. In summary, the larger winter storm waves with longer period waves tend to arrive from the west or southwest with the waves predominantly from the northwest the rest of the year.

Carmel River Beach is aligned approximately northeast-southwest to and is protected from the waves from the northwest by both Cypress Point and the rocky headland directly north of the beach and from waves from the the south by Point Lobos. The narrower aperture tends to filter out higher frequencies so that mostly low-frequency swell impacts the beach.

There are three CDIP nearshore wave stations along the Carmel River beach spaced 200m apart specified by their Lat/Long locations on the back beach: MO633 at the south end, MO634 at the center and MO635 at the north end of the beach. The offshore CDIP buoy spectra are refracted to the 15m depth location that intersects a line perpendicular to the back-beach location. Interestingly, the perpendicular lines projected offshore intersect the 15m contour at almost the same location suggesting the shoreline is in near equilibrium with the incoming waves.

Overtopping of the berm occurs primarily during the winter but can occur any time of year when long period swell waves coincide with high tide. Oscillations in the lagoon were found by Scooler (2017) at the infragravity wave band of 1-4 minute periods. The oscillations appear to be the result of groupiness of the swell dominated, narrow-band waves, where only the highest waves in the group result in overtopping

2.3 Lagoon Processes

As discussed by Thornton (2005) and Laudier et al. (2011), the Carmel River Lagoon is a bar-built estuary with an intermittently closed mouth. Figure 2 illustrates the time series of ocean and lagoon water levels from 2006 to 2016, along with watershed runoff measured upstream of the Highway 1 crossing, and estimates of nearshore waves at the site. The lagoon undergoes a typical seasonal pattern that varies from year to year depending on wave and river conditions. Figure 3 illustrates a typical year, based on daily average conditions from 2006 to 2016.

2.3.1 Wet Season Conditions

When watershed runoff is high, the lagoon mouth typically scours to a low elevation, with the depth of erosion constrained by a rock sill buried within the beach (Thornton 2005). Despite this, flows leaving the mouth toward the ocean cause a persistent setup of water levels in the lagoon, with minimum water levels usually at approximately mean higher high water (MHHW) when runoff exceeds 200 cubic feet per second (cfs), although the highest tides may enter the lagoon. During the peaks of flood events, the setup in the lagoon is more extreme, with flood stages typically surpassing 8 feet NAVD when flows exceed 1000 cfs. The lagoon water level during fluvial floods is also affected by waves, which lose momentum in the reef offshore of the mouth and generate a coastal setup that raises tides above the static still water level that would be measured further offshore (Thornton 2005).

2.3.2 Transition to Dry Season Conditions

After flood flows begin to draw down in the spring, the mouth often remains relatively scoured for several weeks or months, allowing a portion of the oceanic tide to propagate into the lagoon each day. Although wave energy reaches a seasonal minimum in summer, the seasonal decline of wave energy tends to happen later in spring than the decline of river flows, which has been observed elsewhere throughout the State (e.g. Behrens et al. 2013). The remaining high-energy swell waves reaching the mouth in spring tend to push more sediment into the mouth than can be removed by tides or river flow. This typically leads to either (1) a gradual increase of the mouth elevation and a corresponding decrease of tidal fluctuations in the lagoon, or (2) a sudden closure of the mouth when wave-driven sediment fully blocks connection with the ocean. Seasonal closure has occurred in every year since 1993.

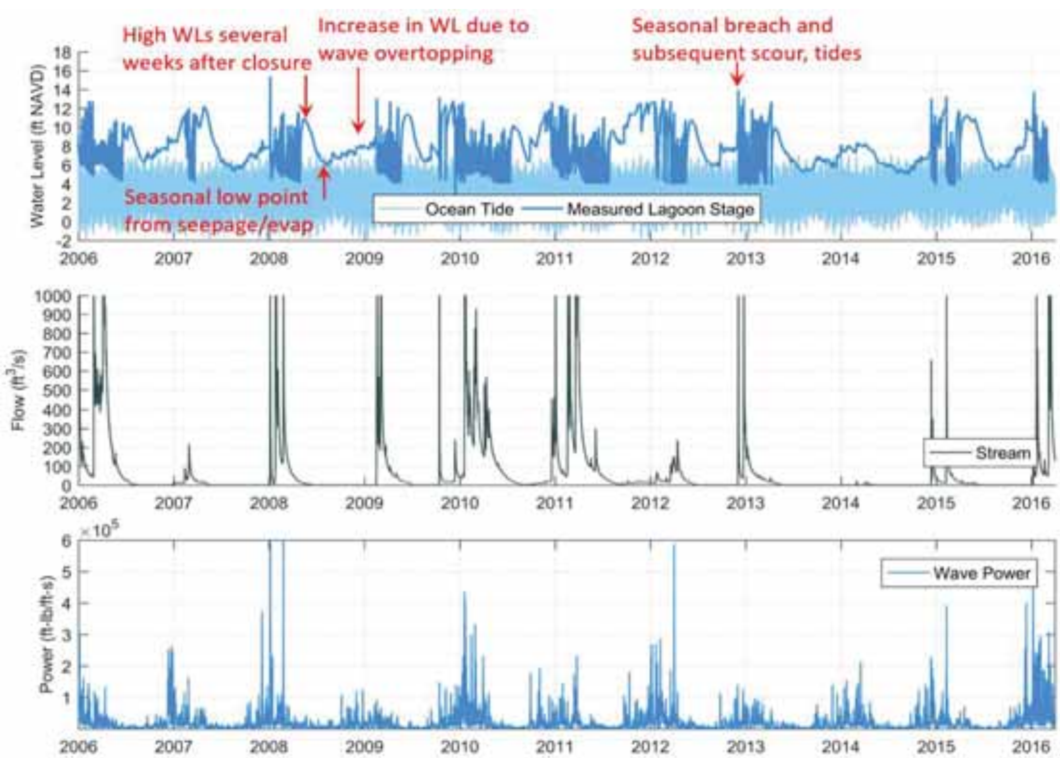

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Figure 2
Daily average conditions in the Carmel River Lagoon from 2006 to 2016

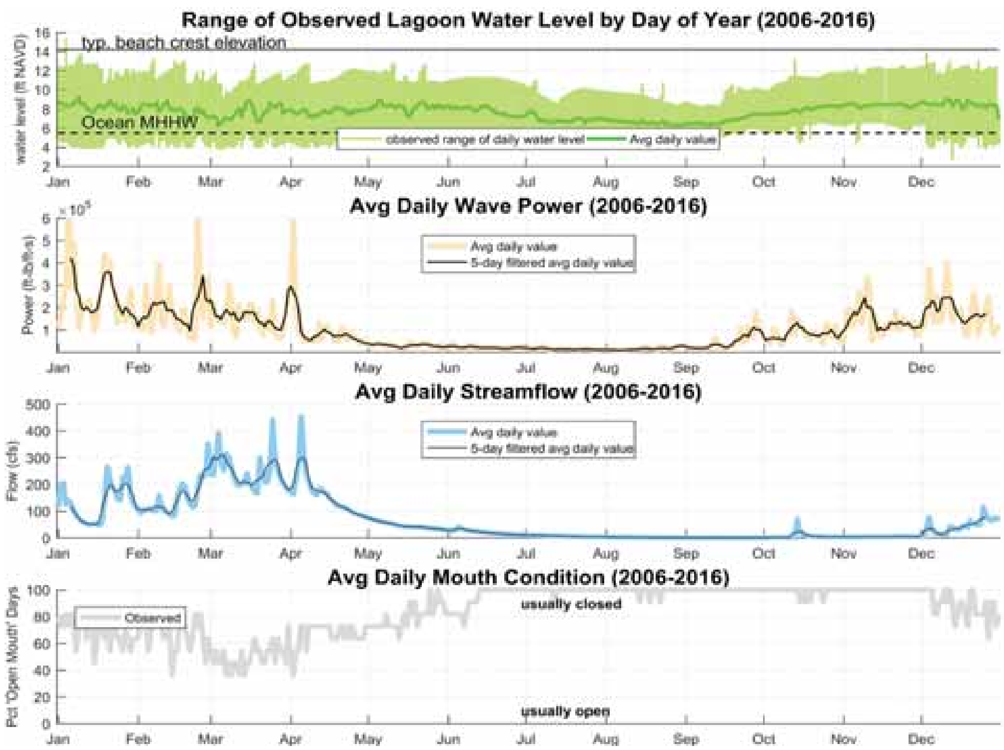

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Figure 3
Seasonal Range of Lagoon Conditions:
Water Level, Wave Power, Streamflow, and Mouth Condition

2.3.3 Seasonal Mouth Closure

After seasonal closure occurs, remaining watershed runoff ponds behind the closed beach. The lagoon typically does not breach (experience a new mouth opening either naturally or from mechanical excavation of a channel) until the first major rainfall event of the winter. Water levels just prior to breaching are typically the highest water levels of the year, higher than flood peaks during fluvial flood events. Initially, runoff and contributions from waves overtopping the beach cause the water level to rise in the lagoon immediately after seasonal mouth closure. This is an indication that losses due to seepage through the beach berm and to evapotranspiration are initially overmatched by these inflows (Rich and Keller 2013). Over time, inflows decrease, due to seasonal declines in wave energy and watershed runoff. At the point that evaporation and seepage through the beach berm begin to compensate these inflows, the lagoon water level begins to decline. This decline typically lasts from June or July until September.

Although stream flow to the lagoon does not generally increase until winter, the lagoon water level usually rises periodically from September to December. This is most likely attributed to wave overtopping, as waves begin to increase in power again in fall (Laudier et al. 2011). This is because the water level rises are episodic and tend to happen during high tides or powerful, long-period swell wave events.

When the first major rainfall event of the season is imminent, the lagoon is typically breached mechanically when water levels reach 12-15 feet NAVD to prevent water levels from reaching elevations that would flood private property adjacent to the lagoon. Without these preventative measures, the lagoon would likely breach naturally at a higher elevation, set by the height that September-December waves are able to build the beach crest. In years with exceptionally high waves, waves can build a berm that is much higher than 15 feet NAVD, such as during the 2015-2016 El Nino event when the beach crest was observed at approximately 18 feet NAVD (pers. comm. D. Lander).

2.3.4 Inter-Annual Variability

The seasonal pattern described varies from year to year, although a seasonal closure in spring or early summer and a seasonal breach in winter are common. In the driest of years, such as 2013 to 2014, watershed runoff may not be sufficient to raise water levels to the beach crest and cause a new mouth to form. In wetter years, such as 2010-2011, the mouth may remain open for longer and close seasonally later in spring than other years. This interplay of seasonal and inter-annual conditions is summarized for 2006-2016 in Figures 2 and 3.

2.4 Proposed Projects Within Lagoon Basin

Two major projects within the Carmel Lagoon basin are currently in planning stages: the Carmel River FREE Project (Balance 2015) and the Carmel Lagoon Ecosystem Protective Barrier. The EIR for the protective barrier project also includes the associated Scenic Road Protection Structure, which is an erosion control project to protect the coastal bluff from erosion caused by the migrating lagoon mouth. The proposed area and alignment of the projects are shown in Figure 4 below.

2.4.1 Carmel River FREE

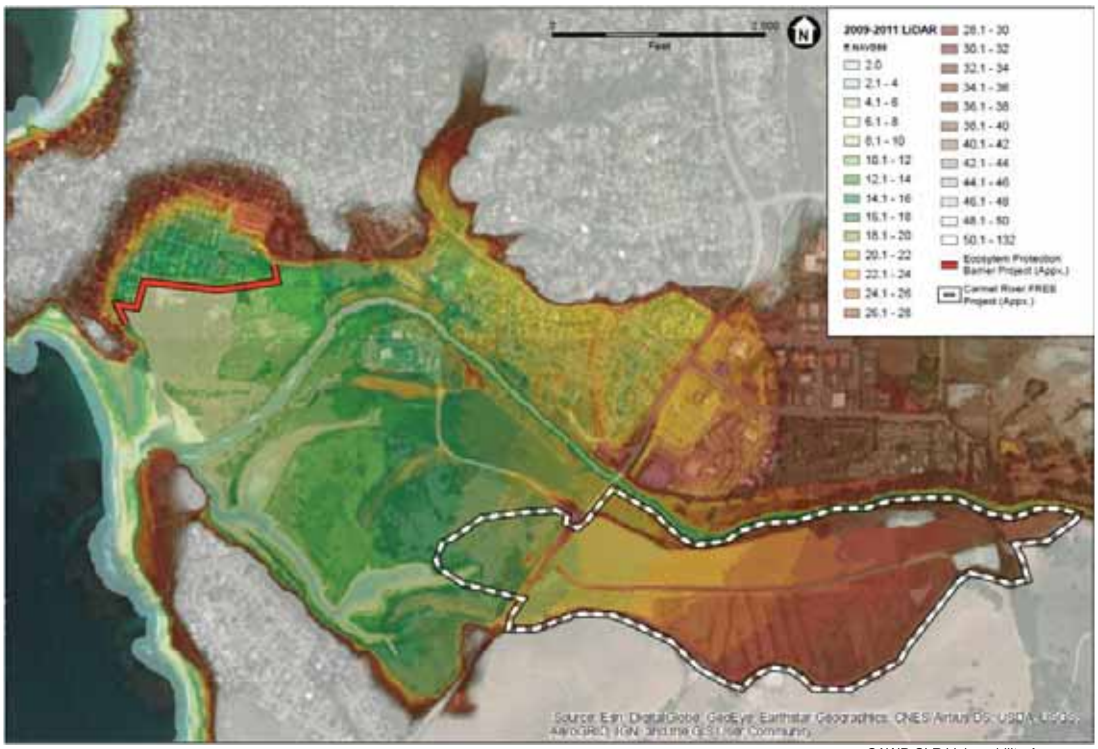
The Carmel River Floodplain Restoration and Environmental Enhancement Project is a floodplain restoration project conducted by Big Sur Land Trust with design consultation provided by Balance Hydrologics. The project focuses on distributing flood flows out of the lower Carmel River and onto the historical floodplain east of Highway 1 (Odello East area). Five levee segments are proposed to be lowered to convey flood flows into a new distributary channel network within the floodplain. The channels would connect to the South Arm of the lagoon via a 350-foot elevated causeway along Highway 1.

Balance Hydrologics released a 35% Design Basis report in May 2015 (Balance 2015). This project is relevant to the current study because alterations in floodplain elevations could affect peak water levels in the lagoon, and adjacent to the CAWD facility. Lowering the floodplain elevation would effectively increase the storage volume of the lagoon. This could impact the mouth morphology by slowing the rate that inflows fill the lagoon to the level where an artificial breach would be required.

2.4.2 Ecosystem Protective Barrier

The Carmel Lagoon Ecosystem Protective Barrier Project consists of installing a sheet pile wall along the edge of the existing lagoon marsh to protect low-lying residential properties from flooding (Figure 4). Installing the wall would allow for less-frequent mechanical beaching of the beach berm under high water conditions, thus maintaining the current level of flood protection for properties while allowing for a reduction in the number of mechanical breaches. Reducing the frequency of breaches are of interest to environmental agencies, as mechanical breaching reduces freshwater habitat available to juvenile salmonids in the lagoon. A Draft Environmental Impact Report (EIR) was published for the proposed barrier project in December 2016 and public comments on the EIR were released in February 2017.

This project could impact the current study by slightly reducing the storage of the lagoon up to the height of the barrier, and by potentially leading to a change in artificial breach protocols for the lagoon mouth. Without artificial breaching, water levels in the lagoon could become higher in the weeks of seasonal closure events, when the first major rain storms of the year begin filling the lagoon behind the closed beach.



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SOURCE: 2009-2011 California Coastal Conservancy LiDAR, 2018 ESRI

Figure 4
Locations of Carmel River FREE Project and Ecosystem Protective Barrier Project on Site Topography

3 LAGOON MODELING APPROACH

To provide an understanding of how Carmel Lagoon would respond to future changes, ESA developed a quantified conceptual model (QCM) for the site, which predicts lagoon mouth morphology and the resulting water levels of the lagoon. A QCM is a simplified time-series model which implements a lagoon water balance alongside parametric model of the lagoon mouth and beach.

The current QCM approach is an adapted and refined version of earlier approaches for tidal conditions from Crissy Field Lagoon (Battalio et al. 2006) and for fluvial conditions for the Carmel River (Rich and Keller 2013), and builds on lessons learned from both approaches. In recent years, ESA has further developed the QCM as a more complete tool to assess systems with both tidal and fluvial characteristics (Behrens et al. 2015). It has been used most recently by ESA at Pescadero Creek (ESA 2017) in northern California, and at Los Peñasquitos Lagoon (ESA 2016) and Devereux Slough (ESA 2015), in southern California.

The QCM approach is centered on a water budget for the lagoon, which is coupled with a sediment budget for the lagoon mouth. The model is based on two core concepts:

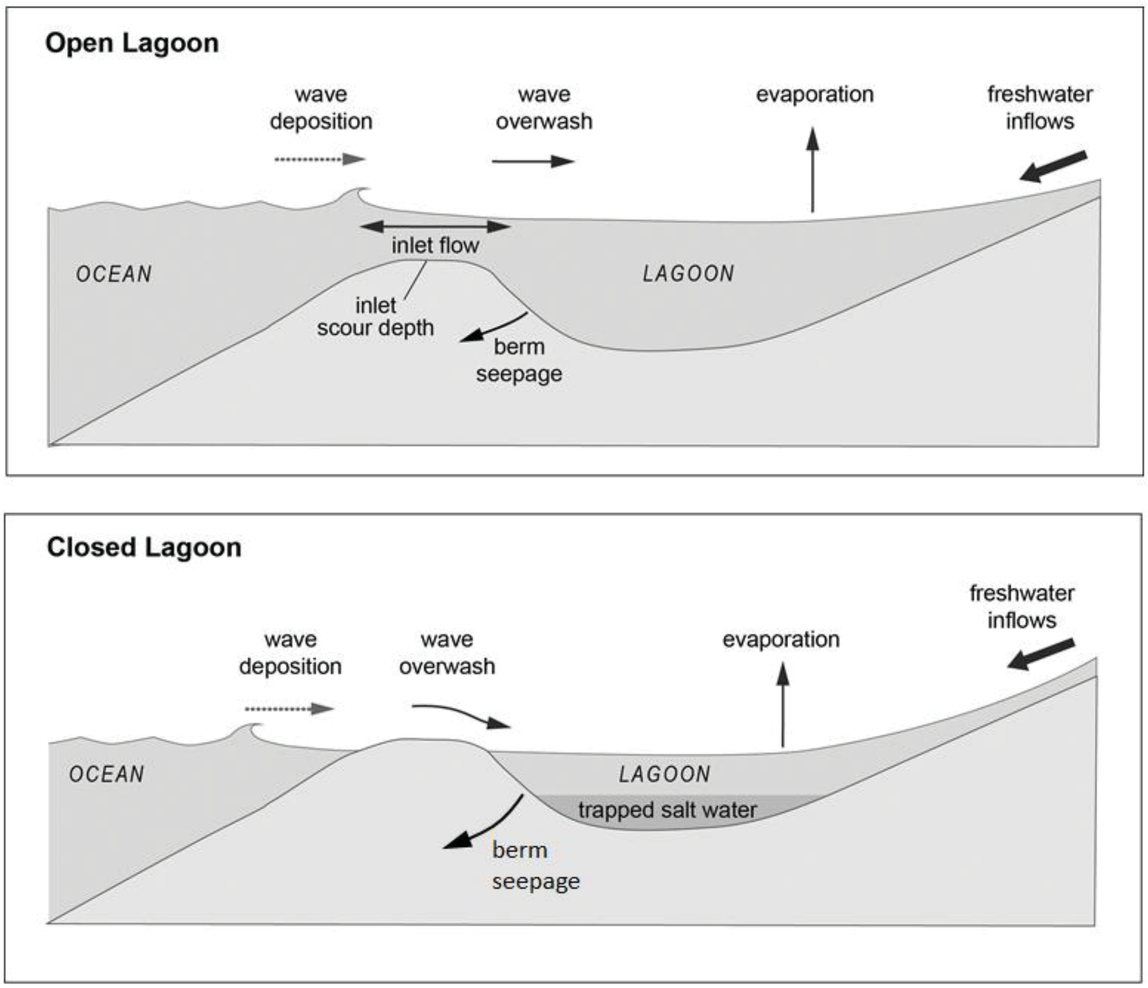
- All water flows entering and leaving the lagoon should balance.
- The net erosion/sedimentation of the inlet channel results from a balance of erosive (fluvial and tidal) and constructive/deconstructive (wave) processes.

The model uses time series of nearshore waves and tides, watershed runoff, and evapotranspiration data as boundary conditions. Using these as forcing conditions with the lagoon's topography, the model dynamically simulates time series of lagoon water levels, along with inlet, beach, and lagoon state. With each time step, the net inflows or outflows to the system are estimated, along with the net sedimentation or erosion in the mouth. The flow terms vary depending on whether the mouth of the lagoon is open or closed. During closed conditions, inflows are based on watershed runoff, wave overwash into the lagoon, and while outflows are based from beach berm seepage and evapotranspiration. These processes are represented in Figure 5. For more information on how the model resolves different processes, refer to Behrens et al. (2015).

During open-mouth conditions, flows between the lagoon and ocean are resolved differently depending on the ocean water level and inlet thalweg. When the thalweg is deep enough that ocean and lagoon water levels can communicate directly, a solution to a simplified one-dimensional momentum equation is applied to resolve velocities (see Behrens et al. 2015). When ocean levels drop below the thalweg elevation (i.e. causing one-way drainage outflow from the lagoon to the ocean), outflows are resolved using the approach of Williams and Stacey (2016). Seepage flows through the beach are characterized using a Darcian approach (Rich and Keller

2013). Wave overwash is estimated by by calculating wave runup on the beach face, and pairing this with the predicted beach crest height to get an overtopping rate based on the methodology of Laudier et al. (2011).

The model is trained by adjusting empirical coefficients that control the amount of sediment trapped in the mouth, beach berm growth, and frictional losses in the channel during outflow. Flow terms such as wave overwash and berm seepage are also adjusted to allow variations in lagoon water levels to match observations.



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SOURCE: Behrens et al. (2015)

Figure 5
Conceptual Model of a Typical California Lagoon

As the model steps forward in time, it continuously transitions the mouth through tidal, perched, and closed conditions. When deposition in the inlet bed exceeds erosion, the bed rises vertically, eventually perching above most tidal elevations and closing. Mouth closure occurs in the model when sediment fills the bed higher than lagoon water levels. Breaching occurs in the model when the Lagoon fills from accumulation of either watershed runoff or wave overwash, and water levels overtop the beach berm crest, eroding a new lagoon mouth.

Model accuracy is tested by comparing modeled lagoon water level time series against observed water levels, and by comparing the timing and length of inlet closure events to those of historical records. Closure time series and lagoon water level time series usually provide a good indication of which processes are dominating the system at a given time, such as runoff during floods, or powerful waves prior to closure. Thus, reproducing these time series is taken to mean that the dominant processes are meaningfully represented.

2.5 Data Sources

Input data for the QCM were obtained for a variety of publically available sources and field data. Table 2 summarizes the data sources for the model.

TABLE 2. SUMMARY OF HYDROLOGIC AND TOPOGRAPHIC DATA FOR CARMEL RIVER LAGOON.

Parameter	Source/Location	Availability
Hydrology: Coastal		
Offshore Waves	NDBC Monterey Buoy (#46042) CDIP Monterey Buoy (#185): CDIP Point Sur (#157)	Directional data:1987- present Full spectral data:2008- present
Nearshore Wave Estimates	CDIP MOP	2000-present
Tide Stage	NOAA Monterey Gage (#9413450)	1973-present
Hydrology: Lagoon		
Runoff	USGS Carmel River Gauge (#11143250)	1988-present
Evapotranspiration	CIMIS #210 (Carmel)	2008-present
Lagoon Stage	MPWMD	1991-present
Morphology		
Mouth Condition (Open/Closed)	James (2005), MPWMD	1991-present
Beach Topography	Laudier et al. (2011): (2006, 2008, 2009) SCC Coastal LiDAR: (1998, 2011)	1998, 2006, 2008, 2009, 2011
Lagoon Bathymetry	RMC (2007)	2007

2.5.1 Coastal Hydrology

Nearshore wave estimates (significant wave height, peak wave period, and peak direction) were obtained from the Coastal Data Information Program (CDIP) California Coastal Wave Monitoring and Prediction System (O'Reilly et al. 2016) at the CDIP model output point number MO633. MO633 is located approximately 2,000 feet offshore of the Lagoon in approximately 33 feet of water. Model data were downloaded from January 2000 to November 2017.

The importance of using nearshore estimates, rather than offshore buoy measurements, is apparent from observations at the site by Thornton (2005) and others. The positioning of the headlands and the narrow aperture they create causes waves to undergo an extensive amount of refraction and diffraction before reaching the beach and lagoon mouth. This effectively filters out many wind waves and reduces the power of most long-period swell waves before they arrive at the beach, with the exception of some waves from a westerly direction (Thornton 2005). Littoral drift is thought to be small at the site (Thornton 2005), although some net northerly transport occurs in the northern portion of the beach and net southerly transport occurs in the southern portion. The common location of the mouth is at a divergence point for this separation (Thornton 2005).

Ocean tides were obtained from the National Oceanic and Atmospheric Administration (NOAA) at Monterey. In the lagoon, water levels have been documented extensively by the Monterey Peninsula Watershed Management District (MPWMD), as documented by James (2005). Water levels were provided by MPWMD from 1994 to 2016. Ocean and lagoon water levels used the North American Vertical Datum of 1988 (NAVD88).

2.5.2 Lagoon Hydrology

Freshwater flow into the lagoon was obtained from the U.S. Geological Survey (USGS) gauge located roughly 2.5 miles upstream of the mouth (gauge #11143250). Evapotranspiration data for the lagoon was obtained from the California Irrigation Management Information System (CIMIS).

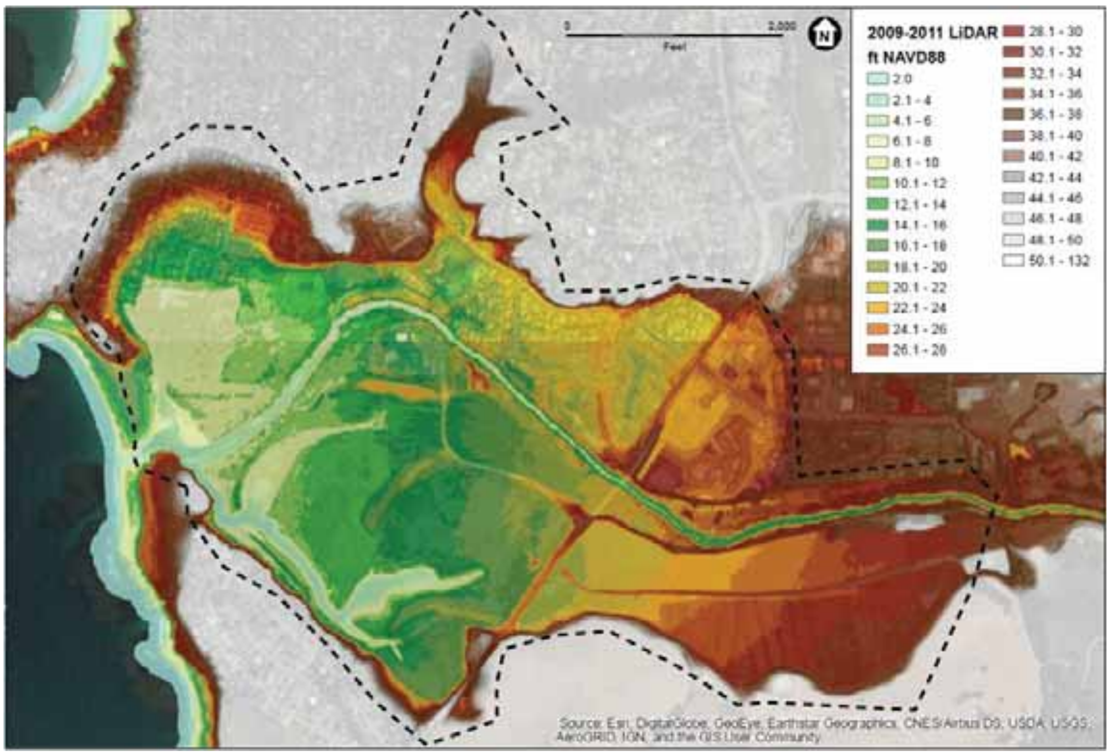
Water levels in the lagoon were provided by the MPWMD.

2.5.3 Beach and Lagoon Morphology

Lagoon bathymetry was resolved by RMC (2007) using bathymetric surveys of the lagoon in May 2006 and September 2007, supplemented by aerial photogrammetry in May 2006. The bathymetric surveys had horizontal and vertical accuracies of ± 0.1 feet, while the aerial survey had an accuracy of ± 0.5 feet. The combined surveys were processed in ArcMap to develop a stage-storage relationship curve for the lagoon. The RMC stage-storage curve extends from approximately 1 feet NAVD88 to 18 feet NAVD88. ESA extended the stage-storage curve using a 2009-2011 California Coastal Conservancy Lidar above elevations 18 feet NAVD88. Figure 6 presents the Lidar data used to project the lagoon bathymetry to higher elevations.

Surveys extending back to 1876 to the present show that the shoreline has remained stable. Shoreline variations tend to be at the north and southern ends of the beach, which may be seasonal and depend on the direction of littoral transport.

The condition of the lagoon mouth (open or closed) has been documented by MPWMD since 1993 and have been summarized by Balance (2014). The summary from Balance also provides information on manual mouth breaching actions that have been taken by MPWMD to mitigate flooding of homes adjacent to the lagoon.



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SOURCE: 2009-2011 California Coastal Conservancy LiDAR, 2018 ESRI

Figure 6
Lidar data for the Carmel River Lagoon and vicinity

2.6 Key Assumptions and Considerations

For this assessment, we have assumed the following:

- Artificial breaches by beachgoers are not explicitly modeled, as they would be difficult to predict and implement correctly.
- Surveys used to generate the DEM are generally representative of 2006-2016 lagoon and marsh shape, although changes may occur over time.
- Slope of water surface in the lagoon is small under most flow conditions (i.e. that the surface can be assumed flat for the purpose of volume calculations)
- For the purposes of this study, we assume that if SLR causes the beach to shift inland, the estuary would also shift upstream so that the net change in estuary volume would be small.
- Although mouth migration has been documented by Thornton (2005), and would likely influence the mouth morphology (especially depth of scour), we have not included it here at this time, although it could be added if data on migration exist after 2005.
- While future runoff rates and sea-level rise are considered, wave conditions could also change (Bromirski et al. 2012), but these were not considered as part of the current study.

3 RESULTS

ESA ran the QCM from January 1, 2006 to December 31, 2016, a period which contains a range of wet and dry years, and a high overlap of available data sets for testing the model. Although water level data extend back to 1993, we focused on the more recent period because it occurs after the expansion of the South Arm of the lagoon, which significantly increased the tidal prism and influenced mouth conditions (Rich and Keller 2013). To explore how future changes could influence the behavior of Carmel Lagoon, ESA will run the same 2006-2016 time series for a series of sea-level rise scenarios, once interaction with the Naval Postgraduate School has allowed for refinement of the model and a better understanding of the future response of the beach to sea-level rise.

3.1 2006-2016 Hindcast

The QCM was used to hindcast conditions from 2006 to 2016, the period described in Section 3. Overall, the model compares well against the available water level data (Figure 7: upper panel), although further refinement is needed in terms of seasonal beach growth and mouth hydraulics. During relatively wet conditions, the model reproduces the observed deep scouring of the mouth and periods of strong tidal communication between the lagoon and the ocean. The model approximates the progressive shallowing of the mouth (cutting off low tides in the lagoon) prior to seasonal closure events, capturing the transitional weeks of muted tides that lead up to closure events in some years. The model also captures subtle differences in the progression of water levels after closure commences, including the seasonal high water level in the weeks after seasonal closure occurs, the seasonal low in late summer, and the rise in fall due to wave overtopping. Figure 8 shows how the model calibration run compares against the lagoon water level data between January 2006 and January 2017.

Artificial breaching was enforced in the model when data on breaching was available (2006 to 2012) and for years when data were not available, by assuming a maximum beach crest elevation of 14 feet NAVD, and allowing the lagoon to breach by overtopping when it reached this elevation. This will be refined in the future by tabulating more recent artificial breaching data. The choice of 14 feet NAVD currently leads the model under-predicting water levels for events when the lagoon was breached at higher levels.

Given the complexity of Carmel Lagoon and other similar estuaries, the QCM is best used to reproduce the seasonality of the closures and the expected distribution of water levels in the lagoon, and not the exact timing of closure or breach events. Overall, the model performs well in reproducing the water level exceedance (Figure 9). Figure 10 indicates that the model reproduces measured lagoons levels which frequently sit well above the tides. The percentage of days closed in the measured record from Balance (2014) was compared against the model predictions of closure in Figure 11. The model closely predicts the seasonality of closure, although the model slightly under-predicts closure in the spring and slightly over-predicts closure in the summer and autumn.

At this stage, model results are less accurate during peak fluvial flow events, as it is difficult to accurately portray the passage of a fluvial flood event through the lagoon with a water balance approach. Under low-flow conditions, the model assumption of a horizontal water surface is likely adequate, making it possible to quickly relate changes in storage of the lagoon to a water surface elevation (based on the hypsometry). However, under high fluvial flow rates, the surface slope will be nonzero, and the storage in the lagoon is reliant on complex conditions at the mouth, where the turbulent freshwater jet leaving the lagoon interact with the coincident wave conditions. Peak water levels during fluvial floods are likely influenced by changing tailwater (ocean tide plus wave setup on the reef) conditions.

Although the model reproduced most flood events during mouth-closure conditions to within less than one foot, it under-predicted the seasonal breach event in the winter of 2008 (observed 15.4 feet NAVD88 vs modeled 14.4 feet NAVD88). During this event, the mouth breached during a period of high river discharge and extreme wave conditions. The powerful waves likely influenced the tailwater elevation that was experienced by flood flows leaving the lagoon. The physics involved with this interaction are difficult to replicate with a simple approach, although the model could be refined in the future to better capture this or similar events.

Wave overwash is another area in need of refinement, particularly because this has a large impact on water levels in the fall, and could contribute to peak flood levels prior to seasonal breaching. Although the model allows the beach slope and crest height to vary throughout the year (in response to long-term shifts in wave conditions), these terms are uncertain and could be refined greatly of seasonal beach profiles are available.

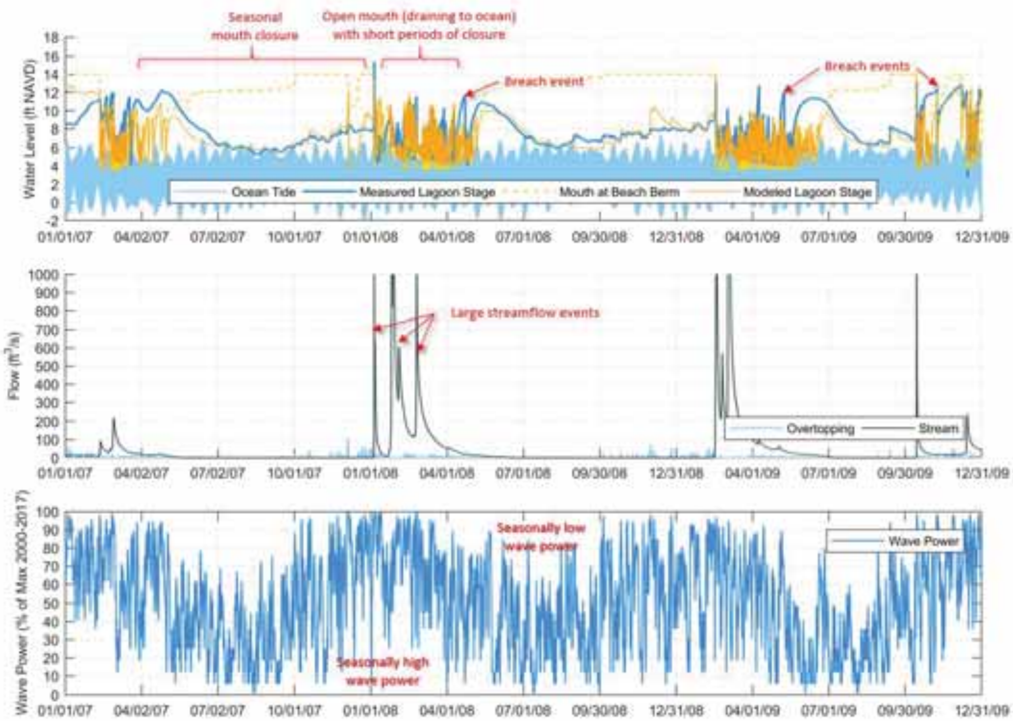

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Figure 7
Example QCM Results for 2007-2009

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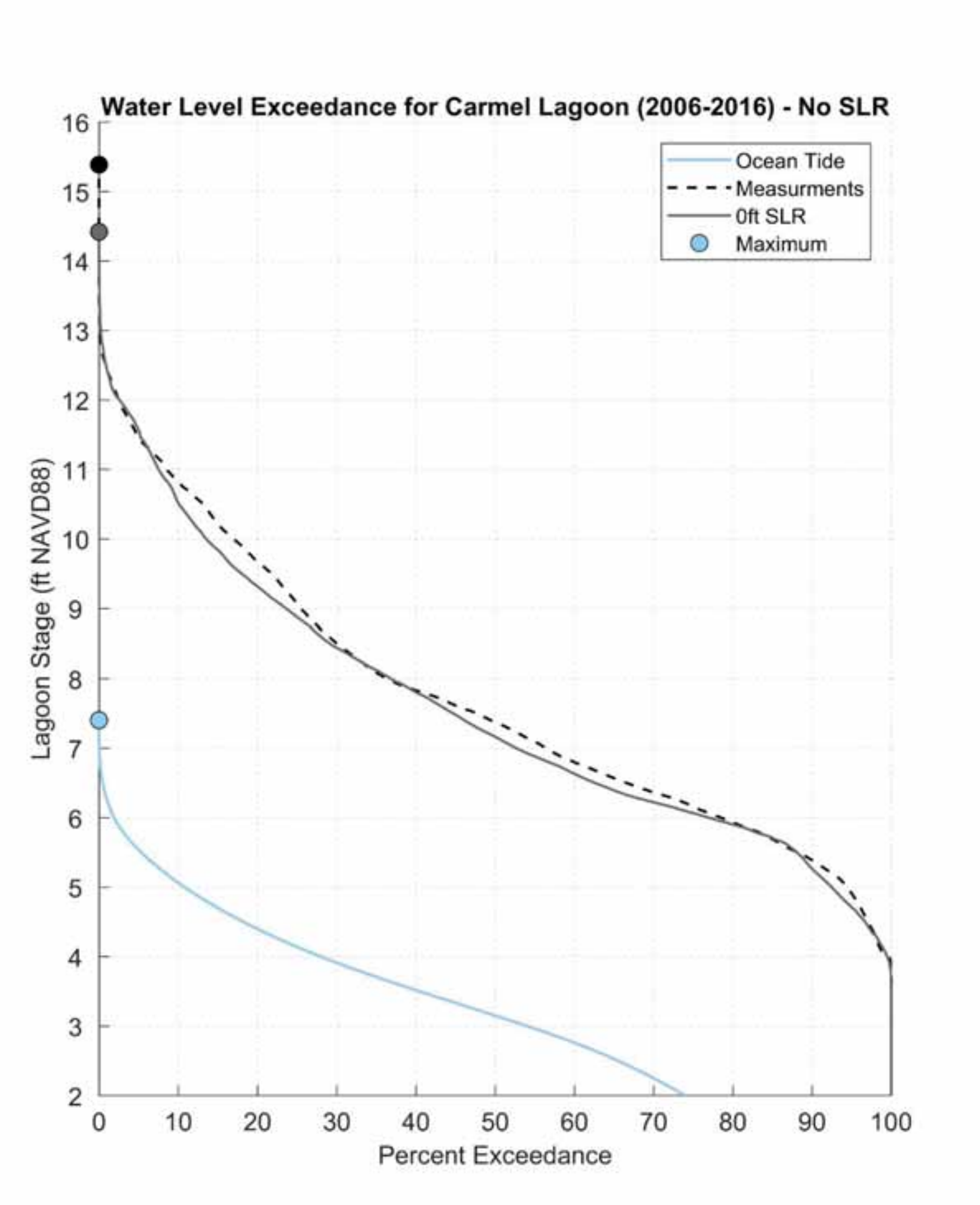
Figure 8
QCM Results for 2006-2016



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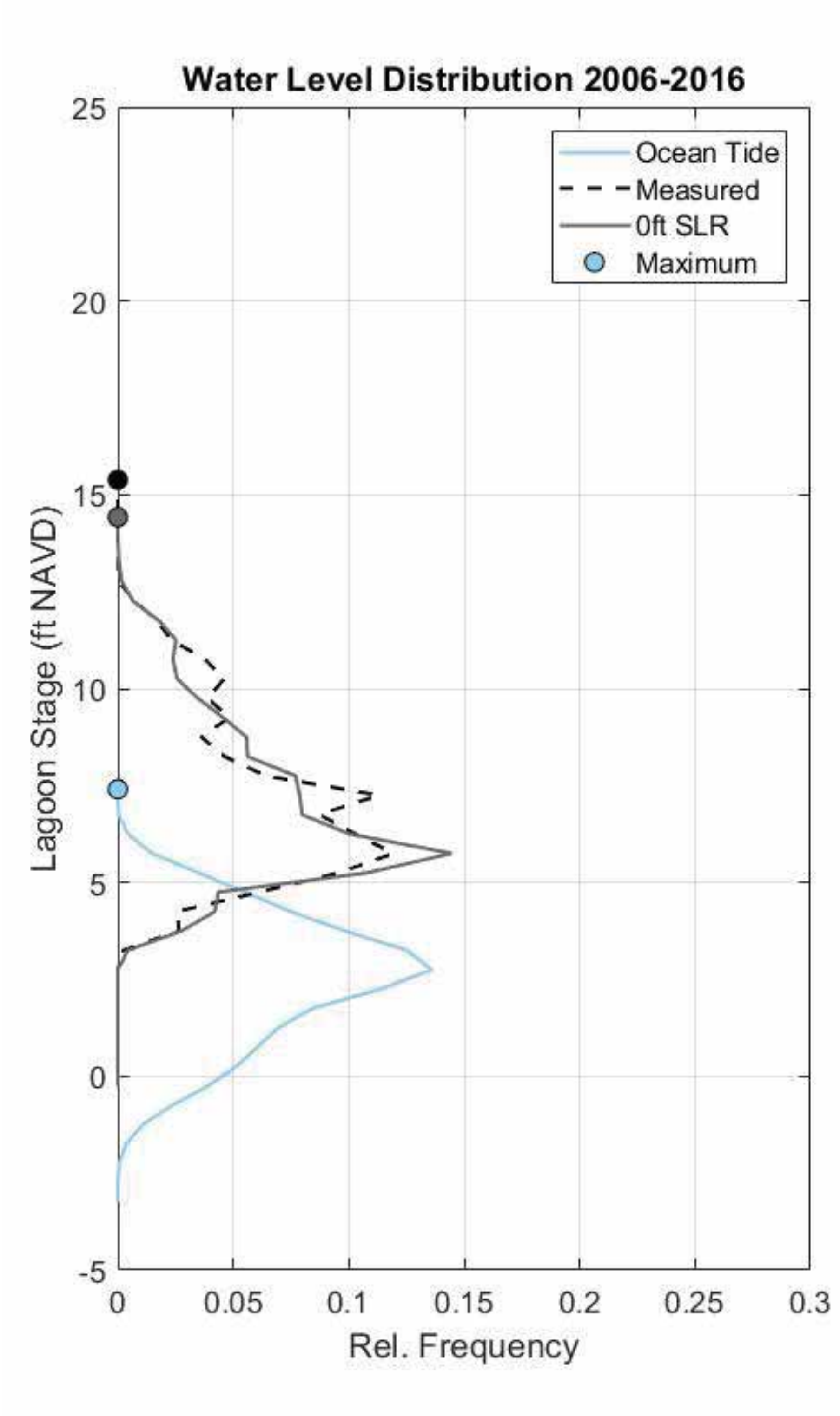
NOTE: '0 feet SLR' is the model output for zero feet of sea-level rise

Figure 9
Comparison of modeled and observed lagoon water level exceedances



NOTE: '0 feet SLR' is the model output for zero feet of sea-level rise

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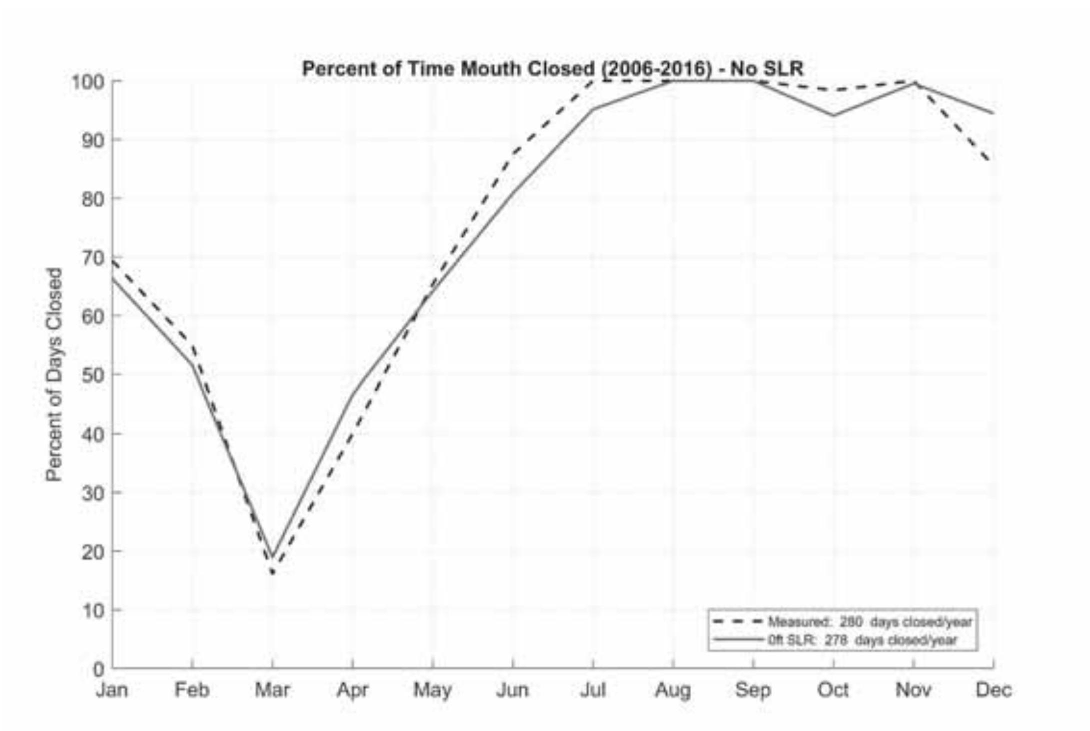
Figure 10
Lagoon Water Level Distribution



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NOTE: '0 feet SLR' is the model output for zero feet of sea-level rise

Figure 11
Comparison of modeled and observed number of days with mouth closure per month, from 2006 to 2016

3.2 Sea-Level Rise Scenarios

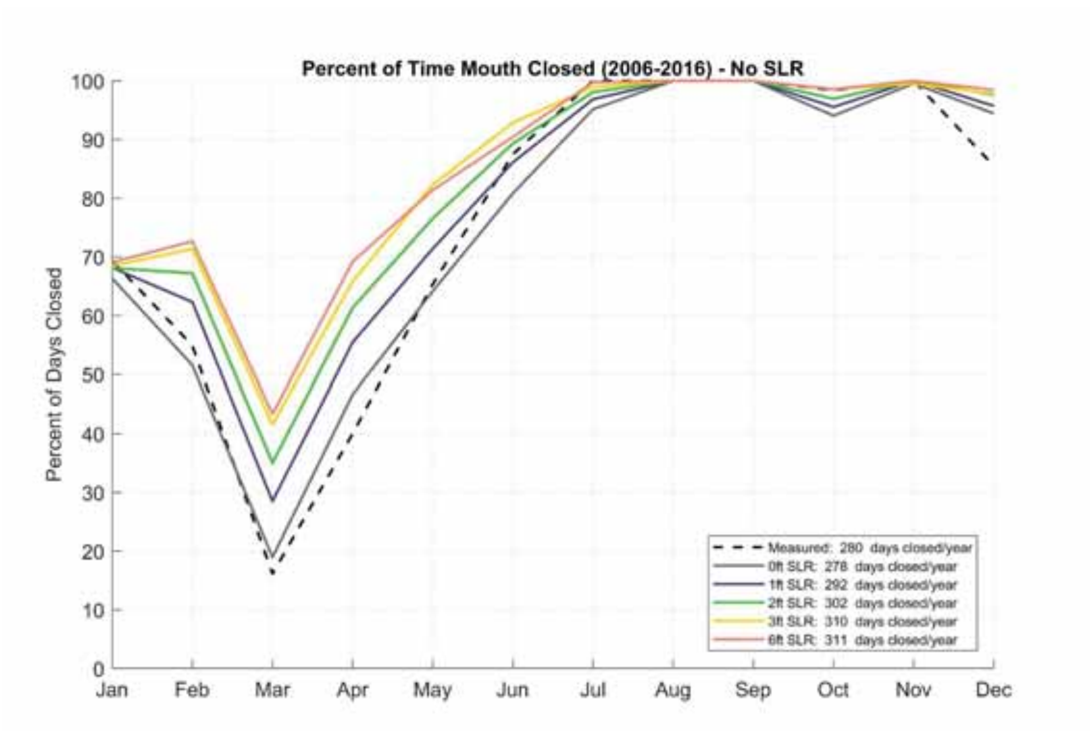
Sea-level rise was accounted for in the model by raising oceanic tidal elevations and assuming the beach would move upward at the same rate. Since the horizontal location of the beach has not changed significantly from its historical location (Section 2.5.3), and given the role that the adjacent headlands have in fixing the edges of the beach berm (Thornton 2005), we assumed that inland transgression with sea-level rise would be small, or would have a negligible impact on the lagoon hypsometry in the model. To simulate future conditions, we ran the 2006-2016 hindcast period again, but with 1 to 6 feet of sea-level rise, assuming that river discharge and oceanic wave conditions would be similar.

3.2.1 Shift in Mouth Closure Seasonality

Currently, the Carmel River Lagoon is dominated by wave conditions and runoff, with tides playing a smaller role. With progressive sea-level rise, the model predicts that the lagoon will be closed for longer periods of time. Although sea-level rise would be expected to increase the volume of the lagoon in the tidal range (which could make it easier for flows through the mouth to prevent mouth-closure), wave conditions were still predicted to be capable of closing the mouth frequently. Once the mouth closes from wave action, the added volume of the lagoon with sea-level rise mainly had the effect of slowing the rate that river inflows could fill the lagoon behind the closed beach, meaning that it took longer for it to fill to an elevation where breaching would be expected to occur. Figure 12 illustrates the shift in the number of days of closure per month for each of the sea-level rise cases.

3.2.2 Change in Lagoon Water Levels

The increase in lagoon water levels with sea-level rise is not predicted to be 1:1 compared with ocean levels. This is a result of the change in timing and duration of mouth-closure events, described above. While drowning of the lagoon with sea-level rise would increase its volume, we expect that this would make it more difficult for river discharge to fill the lagoon to the beach crest elevation. This effect is illustrated in Figure 13, and is especially clear for 3- and 6- feet of sea-level rise, as the curve for lagoon water levels begins to overlap more with the curve for ocean levels. This overlap is an indication that water levels in the lagoon were relatively low during seasonal closure events, not that the lagoon was open to the ocean.



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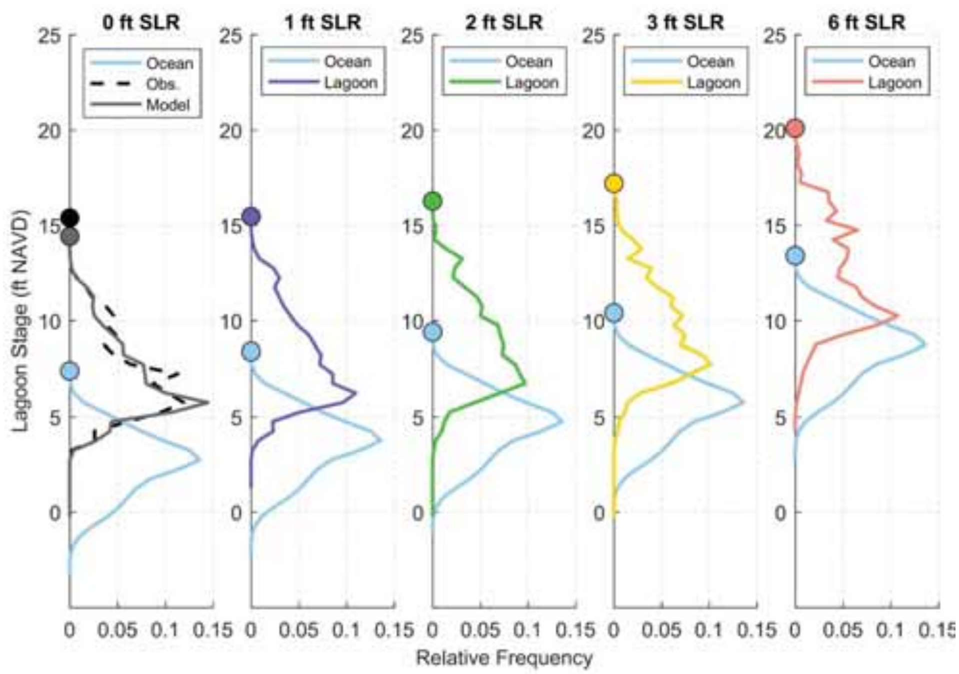
NOTE: '0 feet SLR' is the model output for zero feet of sea-level rise

Figure 12
Comparison of modeled and observed number of days with mouth closure per month, from 2006 to 2016 with Sea-Level Rise



NOTE: '0 feet SLR' is the model output for zero feet of sea-level rise

CAWD SLR Vulnerability Assessment / D170475.00

Figure 13
Lagoon Water Level Distribution with Sea-level Rise

3.2.3 Summary Statistics of Future Water Levels

Since flooding occurs in the Carmel River Lagoon is a result of both fluvial runoff during open-mouth conditions and also slow ponding of the lagoon behind the beach berm during closed-mouth conditions, we looked at these events separately. Fluvial flooding produces a sloping water level, with higher water levels at the treatment plant, and lower water levels in the lower lagoon near the mouth (Shaaf and Wheeler, 2014). Flooding during mouth closure events results from slow filling of the lagoon behind the beach and leads to a relatively flat surface in the lagoon (little difference between the mouth and treatment plant).

Overall peak water levels (for all events in 2006-2016) are listed in Table 3. In all cases, these occurred during closed-mouth conditions, just prior to mouth breaching. These increased from 14.4 feet NAVD88 for existing conditions, and increased to as high as 20.1 feet NAVD88 for 6 feet of sea-level rise.

TABLE 3
PEAK WATER LEVEL IN CARMEL RIVER LAGOON WITH SEA-LEVEL RISE

Sea-Level Rise Scenario	Observed (2006-2016)	Model (2006-2016)
0 feet	15.4	14.4
1 foot	--	15.5
2 feet	--	16.3
3 feet	--	17.2
6 feet	--	20.1

We also separated the water level time series from 2006 to 2016 into periods with open- and closed-mouth conditions, to look in more detail at how flood conditions varied between these two types of events. Then, we filtered the water level time series with a 3-day moving average to remove short-duration flood events to identify a lagoon water level that is representative of a sustained condition that could influence groundwater levels. We then estimated the maximum monthly water level for open- and closed-mouth conditions, and averaged for the same month across all years, to give a sense of the seasonality of peak flood levels for both types of flooding events (Tables 4a and 4b).

Three-day moving-averaged flood levels for open-mouth conditions tend to be higher in the months of December through February when river discharge is highest. For closed-mouth conditions, they were also highest during these months, but this was because the highest water levels were found at the end of seasonal closure events, usually when the first large rainfall event of the year breached the mouth. The results listed in Tables 4a and 4b indicate that in the lower lagoon, flood levels tend to be higher during mouth closure events than during fluvial events when the mouth was already open. Often, the highest observed and modeled flood events happened in the last few hours of seasonal closure, when rainfall events quickly filled the lagoon to the height of the beach crest and started spilling to the ocean.

With sea-level rise, flood levels are predicted to increase. For open-mouth conditions, the filtered flood levels increased from roughly 9.0-10.0 feet NAVD88 to 13.0-14.0 feet NAVD88 with 6 feet of sea-level rise. For closed-mouth conditions, the increase was higher, from 10.0-11.0 feet NAVD88 in the highest months under existing conditions, to roughly 16.0 feet NAVD88 with 6 feet of sea-level rise.

TABLE 4A
AVERAGE MAXIMUM MONTHLY WATER LEVEL IN CARMEL RIVER LAGOON FROM 2006 TO 2016 DURING OPEN-MOUTH LAGOON CONDITIONS (3 DAY RUNNING AVERAGE OF TIME SERIES)

Month	Observed (2006-2016)	Model (2006-2016)	Model + 1 foot SLR	Model + 2 foot SLR	Model + 3 foot SLR	Model + 3 foot SLR
January	9.8	8.6	9.6	10.1	11.2	13.6
February	9.0	9.2	10.2	10.4	10.7	12.6
March	8.2	8.6	9.4	10.2	9.9	12.3
April	7.3	7.7	8.6	9.8	9.2	11.6
May	7.4	7.1	8.1	8.1	--	12.1
June	7.4	5.6	--	--	--	12.9
July	--	--	--	--	--	--
August	--	--	--	--	--	--
September	--	--	--	--	--	--
October	--	--	--	--	--	--
November	--	--	--	--	--	--
December	9.8	9.6	9.4	10.5	10.3	13.2

[1]'—' denotes that fewer than 10 days of observations were available for the specified month. Maximum WL not computed

TABLE 4B
AVERAGE MAXIMUM MONTHLY WATER LEVEL IN CARMEL RIVER LAGOON FROM 2006 TO 2016 DURING CLOSED-MOUTH LAGOON CONDITIONS (3 DAY RUNNING AVERAGE OF TIME SERIES)

Month	Observed (2006-2016)	Model (2006-2016)	Model + 1 foot SLR	Model + 2 foot SLR	Model + 3 foot SLR	Model + 6 foot SLR
January	10.3	10.9	12.0	12.5	13.0	16.1
February	10.5	10.6	11.7	12.3	13.0	15.8
March	9.8	9.5	10.6	11.5	12.4	15.0
April	10.5	9.3	10.1	11.1	11.8	14.9
May	9.7	8.8	10.2	11.1	11.7	14.6
June	9.2	8.6	9.5	10.5	11.3	14.2
July	8.5	7.8	8.7	9.7	10.7	13.6
August	7.3	7.0	7.8	8.5	9.5	12.5
September	7.5	7.5	7.9	8.4	9.1	11.8
October	8.4	9.1	9.5	9.9	10.4	12.4
November	8.9	9.9	10.3	10.7	11.2	13.3
December	10.3	11.0	12.4	13.1	13.8	16.1

[1]'—' denotes that fewer than 10 days of observations were available for the specified month. Maximum WL not computed

3.2.4 Flooding Event Durations

In addition to peak flood elevations, the duration that a given flood threshold is overtopped for several consecutive days is another important factor. This is a better indicator of how often access to the treatment plant would be limited by flooding. Often, the peak flood elevation in a given year only occurs for a few hours prior to the mouth breaching and draining the lagoon. Figure 14 shows how often flood levels in the lagoon surpassed several thresholds for three consecutive days. For most sea-level rise scenarios (0-3 feet), water levels were predicted to surpass 15 feet NAVD for three consecutive days less than once per year. For the scenario with six feet of sea-level rise, this increased to an average of about two times per year.

Figure 15 expands on Figure 14 by showing histograms for a range of inundation event durations, where the water surface elevation of the lagoon is greater than a threshold of 15 feet NAVD88. Clearly, events lasting at least 24 hours are more common than events lasting 48 hours, 72 hours, and so on. As expected, with sea-level rise the likelihood of extended duration flooding events increases.

3.2.5 Uncertainty in Flood Levels with Sea-Level Rise

Modeling sea-level rise in a coastal lagoon is expected to involve a degree of uncertainty, as projections for future conditions may change, and as the future management of the beach and lagoon mouth may change. The following uncertainties are expected from this modeling exercise:

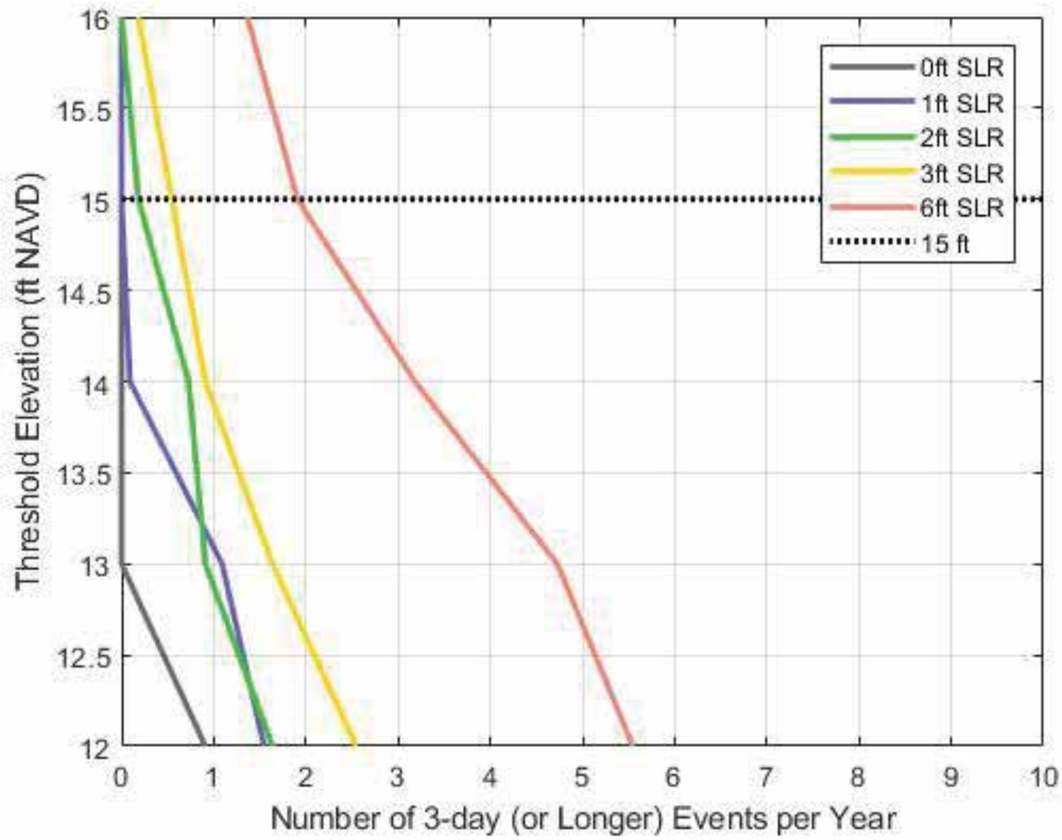
- As sea-level rise progresses, existing flood protection barriers around communities to the north of the Carmel River may be adapted to provide more protection from flooding. This would result in a smaller lagoon volume, as areas behind the protection line would presumably not allow flow across the barrier. This could result in higher water levels in the lagoon.

- Long-term deposition in the lagoon bed over time could partially offset the expected drowning from sea-level rise. Deposition would have the effect of making the lagoon volume smaller, which could result in higher water levels.

- For simplicity, we have assumed artificial breaching does not take place during future sea-level rise scenarios. Depending on regulatory conditions and the protective barriers available to communities adjacent to the river, this practice may occur in the future, which would have the effect of capping water levels in the lagoon.

- Future runoff conditions into the lagoon could change as future precipitation and atmospheric temperature alter the watershed-scale hydrologic balance. This could lead to higher flows in winter and potentially lower flows in the dry season (Flint and Flint 2012).

Given these uncertainties, peak flood water levels reported here for the lagoon are expected to have a range of plus or minus 1 foot. In particular, the role of deposition and future mouth management could have an important influence on these levels, and can be studied further to refine these estimates in the future.



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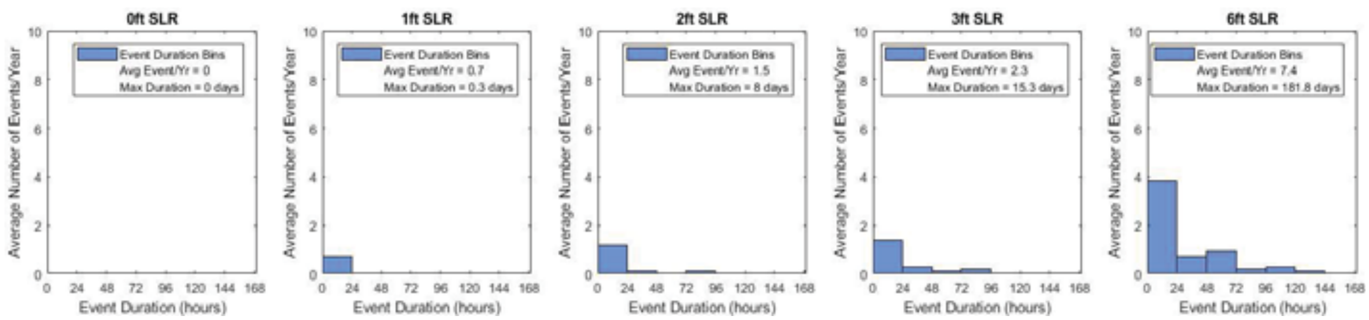
NOTE: '0 feet SLR' is the model output for zero feet of sea-level rise

Figure 14
Number of events three days or longer exceeding a threshold elevation



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NOTE: '0 feet SLR' is the model output for zero feet of sea-level rise

Figure 15
Event duration histograms with sea-level rise. Threshold for flood event set at 15 feet NAVD88

4 CONTRIBUTORS

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Appendix B

Sea-Level Rise Scenario Recommendations and Summary of Policy Guidance

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memorandum

date	May 18, 2018
to	Drew Lander, Carmel Area Wastewater District
from	Louis White, PE
subject	Sea-Level Rise Scenario Recommendations and Summary of Policy Guidance: Carmel Area Wastewater District Sea Level Rise Vulnerability Study

The purpose of this memorandum is to facilitate selection of sea-level rise scenarios for the Carmel Area Wastewater District Sea Level Rise Vulnerability Study. It is Environmental Science Associate's (ESA) understanding that the Carmel Area Wastewater District (District) will review this memo and select the scenarios for the project, and may share this memo with the California Coastal Commission (CCC) staff. Therefore, ESA has recommended sea-level rise scenarios (Section 4, Table 5 and Figure 3) and documented the reasons for the recommended scenarios in this memo. ESA has also included a summary of State and Federal policy guidance and other relevant information. ESA is available to discuss and revise this document based on direction from the District, including comments from the CCC staff. This document is not authorized for public release except at the discretion of the District.

1. Introduction

This memo includes recommendations for selecting sea-level rise amounts and time horizons based on different projections of sea-level rise over time as a function of greenhouse gas emission scenario and risk aversion. This memo also relates the sea-level rise scenarios used in prior work by ESA to the California sea-level rise guidance recently updated in March 2018. Based on this information, ESA will assist the District to select the sea-level rise scenarios to be used in the project. ESA recommends two planning horizon timeframes (i.e., 2050, 2100) and two sea-level rise scenarios that account for variable greenhouse gas emissions and risk aversion, and a third extreme emission scenario for one timeframe (called the H++ scenario). See Section 4 for details on the recommended scenarios.

2. Summary of Prior Sea-Level Rise Hazard Mapping Studies in Vicinity of Carmel River Lagoon

As part of the Pacific Institute's 2009 study, which assessed the impacts of sea-level rise along the coast of California, ESA[1] prepared flooding and erosion hazard maps representative of future conditions with sea-level rise (Heberger et al. 2009; PWA 2009). The Pacific Institute maps were produced with funding from the State of

[1] Formerly Philip Williams & Associates

California to inform a state-side assessment of vulnerability to climate change. Theses maps include projected hazards in the vicinity of the project site at Carmel River Lagoon.

The Pacific Institute maps show future coastal flood and erosion hazards with sea level rise for several time periods. The sea-level rise projections were informed by Cayan et al. (2008), which projected up to 4.6 feet of sea-level rise by 2100. The Cayan et al. (2008) study was later used to inform development of the State's Interim Guidance for sea level rise (see Section 3.1). The maps are available online from the Pacific Institute. The work was peer-reviewed by the Ocean Science Trust (OST, affiliated with the California Ocean Protection Council), and there are several peer-reviewed publications (Heberger et al. 2011, Revell et al. 2011, Bromirski et al. 2012). These were the first maps to project future coastal erosion due to accelerated sea level rise. The hydrodynamic and geomorphic work was accomplished by PWA (now ESA) for the Pacific Coast and the USGS model results were used for the SF Bay (Knowles et al. 2008). There were several other key study partners including Scripps (future water level and wave time series for 100 years) and the Coastal Data Information Program (CDIP; provided regional wave transformations).

The hazard analysis was conducted to inform California's assessment of vulnerability to climate change and the adaptation strategy, and greatly expanded the perception of coastal hazards associated with sea level rise to locations above and landward of future sea levels. Subsequent work has reinforced that accelerated erosion due to accelerated sea level rise is both important for planning but inherently uncertain given available methods and data. One aspect of the study that has been largely overlooked is that it developed estimates of the 100-year wave runup elevation for the entire California coast, most of which was not mapped by FEMA at the time. The coastal flood maps are known to overstate the potential for wave-induced flooding in back barrier areas due to the projection of wave runup elevations that were computed for the coastal barriers (i.e. dunes). This study is a "first generation" study (circa 2008) with updated methods and results for several regions (i.e. Ventura County, Monterey Bay – Santa Cruz County, Santa Barbara County and Los Angeles County).

The project site in the Carmel River Lagoon is a back barrier lagoon and wetland system, for which the Pacific Institute maps typically overestimated the flood risk, and therefore ESA has proposed an approach using a quantified conceptual model to evaluate flood levels in the lagoon (Behrens et al. 2015). However, the maps of projected erosion hazards associated with sea-level rise will be used to assess the potential vulnerability of portions of the District's wastewater collection system to erosion over time. Table 1 presents a summary of the sea-level rise projections used in the development of the Pacific Institute coastal hazard maps.

TABLE 1
SEA-LEVEL RISE SCENARIOS MODELED IN PACIFIC INSTITUTE STUDY OF 2009

Scenario	2025	2050	2100
High	0.6 feet	1.4 feet	4.6 feet[1]
Low	0.3 feet	0.8 feet	2.1 feet

1 Future flood impacts modeled only for existing conditions and for 2100, high scenario. Erosion modeled for all horizons and scenarios shown in table.

3. Sea-Level Rise Policy Guidance

The sections below present State and Federal guidance on sea-level rise.

3.1 State Guidance on Sea-Level Rise

The California Ocean Protection Council (OPC) first released a statewide sea-level rise guidance document in 2010 following Governor Schwarzenegger's executive order S-13-08. After being adopted by the California Ocean Protection Council (OPC), this interim guidance document informed and assisted state agencies to develop approaches for incorporating sea-level rise into planning decisions (OPC 2011). The OPC (2011) document was updated in 2013 (OPC 2013) after the NRC released its final report *Sea-Level Rise for the Coasts of California, Oregon, and Washington* (NRC 2012), which provided three projections of future sea-level rise associated with low, mid, and high greenhouse gas emissions scenarios, respectively.

The CCC adopted sea-level rise policy guidance in 2015 (CCC 2015). The document recommends using a range of climate change scenarios (i.e., emissions scenarios) at multiple planning horizons for vulnerability and adaptation planning. The guidance presents a step-by-step process for addressing sea-level rise and adaptation planning in Coastal Development Permits (CDPs; CCC 2015, pg. 20). This memo focuses on the first step of the CCC recommended process: Establish the projected sea-level rise range for the proposed project's planning horizon using the best available science. At the time of the CCC (2015) report, NRC (2012) was included in State policy by OPC (2013). Since then, California commissioned an update (Griggs et al. 2017) and released an update to the sea-level rise policy in March 2018. Consequently, a key question is how to select the "best available science" and incorporate the changes in the State Policy update. Additional information is provided in the following sections of this document.

California guidance for sea-level rise was updated in March 2018. Since this guidance is new, a summary of the prior guidance established in 2013 is described first, followed by the new guidance.

The California Natural Resource Agency and OPC released a 2018 guidance update (OPC 2018) to the 2013 State of California guidance document (OPC 2013). The updated guidance provides a synthesis of the best available science on sea-level rise in California, a step-by-step approach for state agencies and local governments to evaluate sea-level rise projections, and preferred coastal adaptation strategies. The key scientific basis for this update was developed by the working group of the California OPC Science Advisory Team titled *Rising Seas in California: An Update on Sea-Level Rise Science* (Griggs et al. 2017). The above mentioned studies and guidance documents are shown in Figure 1 to illustrate the relationship between these documents.

Figure 1
California Sea-level Rise Guidance Documents and Scientific Basis for Each

3.1.1 2013 Guidance on Climate Change and Sea-Level Rise Scenarios

The accumulation of greenhouse gases in the Earth's atmosphere is causing and will continue to cause global warming and resultant climate change. For the coastal setting, the primary exposure will be an increase in mean sea-level rise due to thermal expansion of the ocean's waters and melting of ice sheets.

State planning guidance for coastal flood vulnerability assessments call for considering a range of emission scenarios (OPC 2013; CCC 2015). These scenarios bracket the likely ranges of future greenhouse gas emissions and ice sheet loss, two key determinants of climate whose future values cannot be precisely predicted. Scenario-based analysis promotes the understanding of impacts from a range of emission scenarios and identifies the amounts of climate change that would cause impacts.

The state guidance recommends using emission scenarios that represent low, medium, and high rates of climate change. Recent studies of current greenhouse gas emissions and projections of future loss of ice sheet indicate that the low scenario probably underrepresents future sea-level rise (Rahmstorf et al. 2012; Horton et al. 2014). Also, note that even if sea-level rise does not increase as fast as projected for the high scenario, sea-level rise is projected to continue beyond 2100 under all emission scenarios. The assumptions that form the basis for the NRC (2012) scenarios are as follows:

Low Emissions Scenario – The low scenario assumes population growth that peaks mid-century, high economic growth, and assumes a global economic shift to less energy-intensive industries, significant reduction in fossil fuel use, and development of clean technologies.

Medium Emissions Scenario – The medium scenario assumes population growth that peaks mid-century, high economic growth, and development of more efficient technologies, but also assumes that energy would be derived from a balance of sources (e.g., fossil-fuel, renewable sources), thereby reducing greenhouse gas emissions.

High Emissions Scenario – The high scenario assumes population growth that peaks mid-century, high economic growth, and development of more efficient technologies. The associated energy demands would be met primarily with fossil-fuel intensive sources.

Table 2 presents sea-level rise projections for prior State guidance of OPC (2013) based on NRC (2012). The values for relative sea-level rise[2] at 2030, 2050 and 2100 for San Francisco[3] are relative to 2000 and includes regional projections of both mean sea-level rise and vertical land motion of -1.5 millimeters per year for the San Andreas region south of Cape Mendocino.

TABLE 2
OPC (2013) STATE GUIDANCE: SEA-LEVEL RISE PROJECTIONS FOR CALIFORNIA[1]

Scenario	2030	2050	2100
Low Range	0.2 feet	0.4 feet	1.5 feet
Mid Curve	0.5 feet	0.9 feet	3.1 feet
High Range	1.0 feet	2.0 feet	5.5 feet

1 Values are for the San Andreas region south of Cape Mendocino, where the vertical land motion is approximately -1.5 mm per year – indicating subsidence
Source: Table 5.3, NRC (2012)

3.1.2 Sea-Level Rise Guidance Update of 2018

The 2018 guidance update includes the following key changes and additions to the OPC (2013) guidance:

- **For years before 2050, sea-level rise projections are provided only for the high emissions scenario using representative concentration pathway[4] RCP 8.5.** The world is currently on the RCP 8.5 trajectory, and differences in sea-level rise projections under different scenarios are minor before 2050.

- **Includes new "extreme" sea-level rise projections associated with rapid melting of the West Antarctic ice sheet.**

- **Shifts from scenario-based (deterministic) projections to probabilistic projections of sea-level rise.** The guidance update recommends a range of probabilistic projections for decision makers to select given their acceptable level of risk aversion for a given project.

- **Provides estimated probabilities of when a particular sea-level rise amount will occur.** In addition to sea-level rise projections that are tied to risk acceptability, updated guidance provides information on the

[2] The term *relative sea-level rise* indicates that the local effects of vertical land motion are included in the sea-level rise projection

[3] San Francisco relative sea-level rise amounts are regional values and assumed to be representative of projections for Carmel

[4] Representative concentration pathways (RCPs) are named for the associated radiative forcing (heat trapping capacity of the atmosphere) level in 2100 relative to pre-industrial levels. RCP8.5 indicates that the RCP represents an increase of 8.5 watts per square meter by 2100 relative to pre-industrial levels.

likelihood that sea-level rise will meet or exceed a specific height (1 foot increments from 1 to 10 feet) over various timescales.

The guidance update includes significant advances in the scientific understanding of sea-level rise. Compared to the ***scenario-based*** sea-level rise projections in the 2013 version of state guidance, the updated guidance incorporates ***probabilistic*** sea-level rise projections, which associate a likelihood of occurrence (or probability) with various sea-level rise heights and rates into the future and are directly tied to a range of emissions scenarios (described below). Using probabilistic sea-level rise projections is currently the most appropriate scientific approach for policy setting in California, providing decision makers with increased understanding of potential sea-level rise impacts and consequences. The guidance update also includes an extreme sea-level rise scenario that is based on rapid melting of the West Antarctic ice sheet.

The guidance update now provides a range of probabilistic projections of sea-level rise that are based on two Intergovernmental Panel on Climate Change (IPCC) emissions scenarios called representative concentration pathways (RCPs), as well as a non-probabilistic projection associated with rapid West Antarctic ice sheet mass loss. These three climate scenarios are explained below:

RCP 2.6 *Scenario* – This scenario corresponds closely to the aspirational goals of the 2015 Paris Agreement, which calls for limiting mean global warming to 2 degrees Celsius and achieving net-zero greenhouse gas emissions in the second half of the century. This scenario is considered very challenging to achieve, and is analogous to the low emissions scenario in NRC (2012).

RCP 8.5 *Scenario* – This scenario is consistent with a future where there are no significant global efforts to limit or reduce emissions. This emission scenario is consistent with that used to develop the high emissions scenario in NRC (2012).

H++ Scenario – This extreme scenario was proposed by the OPC Science Advisory Team in response to recent scientific studies that have projected higher rates of sea-level rise due to the possibility of more rapid melting of ice sheets.

Table 3 presents State-recommended projections for Monterey in terms of low, medium-high and extreme risk aversion (outlined by dark blue boxes in Table 3). The State suggests that decision makers take a precautionary, risk-averse approach of using the medium-high sea-level rise projections across the range of emissions scenarios for longer lasting projects with low adaptive capacity[5] and high consequences[6]. The State further recommends incorporating the H++ scenario in planning and adaptation strategies for projects that could result in threats to public health and safety, natural resources and critical infrastructure such as large power plants, wastewater treatment, and toxic storage sites. Table 3 includes the probabilities for the RCPs and the non-probabilistic H++ scenario (depicted in blue on the right-hand side). High emissions scenario represents RCP 8.5; low emissions scenario represents RCP 2.6. Table 3 presents high-emission (RCP 8.5) projections of sea-level rise up to 2050 because the sea-level rise projections for the different emissions scenarios are similar before 2050. The probabilities included in Table 3 do not represent the actual probabilities of occurrence of sea-level rise, but

[5] Adaptive capacity is the ability of a system or community to evolve in response to, or cope with the impacts of sea-level rise.
[6] Consequences are a measure of the impact resulting from sea level rise, typically quantitative.

provide probabilities that the ensemble of climate models used to estimate the contributions of sea-level rise will predict a certain amount of sea-level rise (OPC 2018).

TABLE 3
OPC (2018) STATE GUIDANCE: PROJECTED SEA-LEVEL RISE FOR MONTEREY IN FEET

		Probabilistic Projections (in feet) (based on Kopp et al. 2014)				H++ scenario (Sweet et al. 2017) *Single scenario
		MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE	
		50% probability sea-level rise meets or exceeds...	66% probability sea-level rise is between...	5% probability sea-level rise meets or exceeds...	0.5% probability sea-level rise meets or exceeds...	
			(upper value: Low Risk Aversion)		Medium - High Risk Aversion	Extreme Risk Aversion
High emissions	2030	0.4	0.3 - 0.5	0.6	0.8	1.0
	2040	0.6	0.4 - 0.8	0.9	1.2	1.7
	2050	0.8	0.5 - 1.1	1.3	1.9	2.7
Low emissions	2060	0.9	0.5 - 1.2	1.5	2.3	
High emissions	2060	1.0	0.7 - 1.4	1.8	2.6	3.8
Low emissions	2070	1.0	0.6 - 1.4	1.9	3.0	
High emissions	2070	1.3	0.9 - 1.8	2.3	3.4	5.1
Low emissions	2080	1.2	0.7 - 1.7	2.3	3.8	
High emissions	2080	1.6	1.1 - 2.3	2.9	4.4	6.6
Low emissions	2090	1.3	0.8 - 2.0	2.7	4.6	
High emissions	2090	2.0	1.3 - 2.8	3.5	5.5	8.2
Low emissions	2100	1.5	0.9 - 2.3	3.1	5.5	
High emissions	2100	2.3	1.5 - 3.3	4.3	6.9	10.1
Low emissions	2110*	1.6	1.0 - 2.4	3.3	6.1	
High emissions	2110*	2.5	1.7 - 3.4	4.4	7.2	11.8
Low emissions	2120	1.7	1.0 - 2.7	3.8	7.3	
High emissions	2120	2.8	2.0 - 4.0	5.2	8.5	14.0
Low emissions	2130	1.9	1.1 - 3.0	4.2	8.3	
High emissions	2130	3.1	2.2 - 4.5	5.9	9.9	16.4
Low emissions	2140	2.0	1.1 - 3.2	4.7	9.5	
High emissions	2140	3.5	2.4 - 5.1	6.7	11.3	18.9
Low emissions	2150	2.1	1.1 - 3.6	5.3	10.8	
High emissions	2150	3.8	2.6 - 5.7	7.6	12.9	21.8

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

Source: OPC (2018)

The H++ projection is a single scenario and does not have an associated likelihood of occurrence as do the probabilistic projections. Probabilistic projections are with respect to a baseline of the year 2000, or more specifically the average relative sea level over 1991 - 2009.

3.2 Federal Guidance

The US Army Corps of Engineers (USACE) issued circular EC 1100-2-8162 in December 2013, which provides guidance for the incorporation of direct and indirect physical effects of projected future sea-level rise (USACE 2013). This circular superseded all previous USACE-issued guidance on the subject, including the prior guidance issued (USACE 2011). According to the circular, planning studies and engineering designs should evaluate alternatives against a range of local sea-level rise projections defined by "low," "intermediate" and "high" rates of local sea-level rise. The USACE circular suggests using three sea level curves (historic and NRC-I and NRC-III from NRC 1987) modified to reflect the increase in the present rate of global sea-level rise to 1.7 mm per year. USACE (2013) provided guidance on how to incorporate local vertical land motion into the "intermediate" and "high" projections of sea-level rise. Additional guidance can be found in USACE (2014).

In comparison to the State guidance described above, the USACE recommended curves are slightly lower for the respective emissions scenarios. Table 4 presents a summary of the sea-level rise projections at 2030, 2060, and 2100 using the USACE (2013) guidance for values associated with Monterey.[7] For purposes of this study, we recommend using sea-level rise projections that comply with the State guidance. However, consideration should also be given to the USACE guidance if there is federal participation in the project.

TABLE 4
SEA-LEVEL RISE PROJECTIONS FOR MONTEREY USING USACE (2013) GUIDANCE

Scenario	2030	2050	2100
Low	0.2 feet	0.2 feet	0.5 feet
Intermediate	0.4 feet	0.8 feet	2.1 feet
High	0.8 feet	1.8 feet	5.4 feet

Note: Values computed using methods described in USACE (2013) with parameters specific to Monterey area. See footnote #7 below.

3.3 Comparison and Combination of Federal and State Guidance

Sea-level rise scenarios for projects can be based on a combination of State and Federal guidance. Figure 2 presents a comparison of the updated OPC (2018) sea-level rise guidance to the federal USACE (2013) guidance. The solid, colored lines represent the projections of the new OPC (2018) guidance, and the dashed, colored lines represent the USACE (2013) sea-level rise scenarios for Monterey. Figure 2 illustrates that the USACE (2013) high sea-level rise curve generally falls within the range of values for the medium-high risk aversion from the OPC (2018) guidance, while the USACE (2013) intermediate sea-level rise curve falls within the range of values for the low risk aversion from the OPC (2018). The low curve for USACE (2013) is not shown. The low scenario for the USACE (2013) is lower than the recommended projections described by the current State guidance, and not recommended for evaluation in this study (see Section 4).

[7] Sea-level rise projections using the USACE (2013) guidance assume a project start at 2000 to facilitate comparison to State guidance; a subsidence rate of -1.5 mm/yr based on NRC (2012); and a historic sea-level rise rate of 1.48 mm/yr based on NOAA values for Monterey NOS station 9413450.

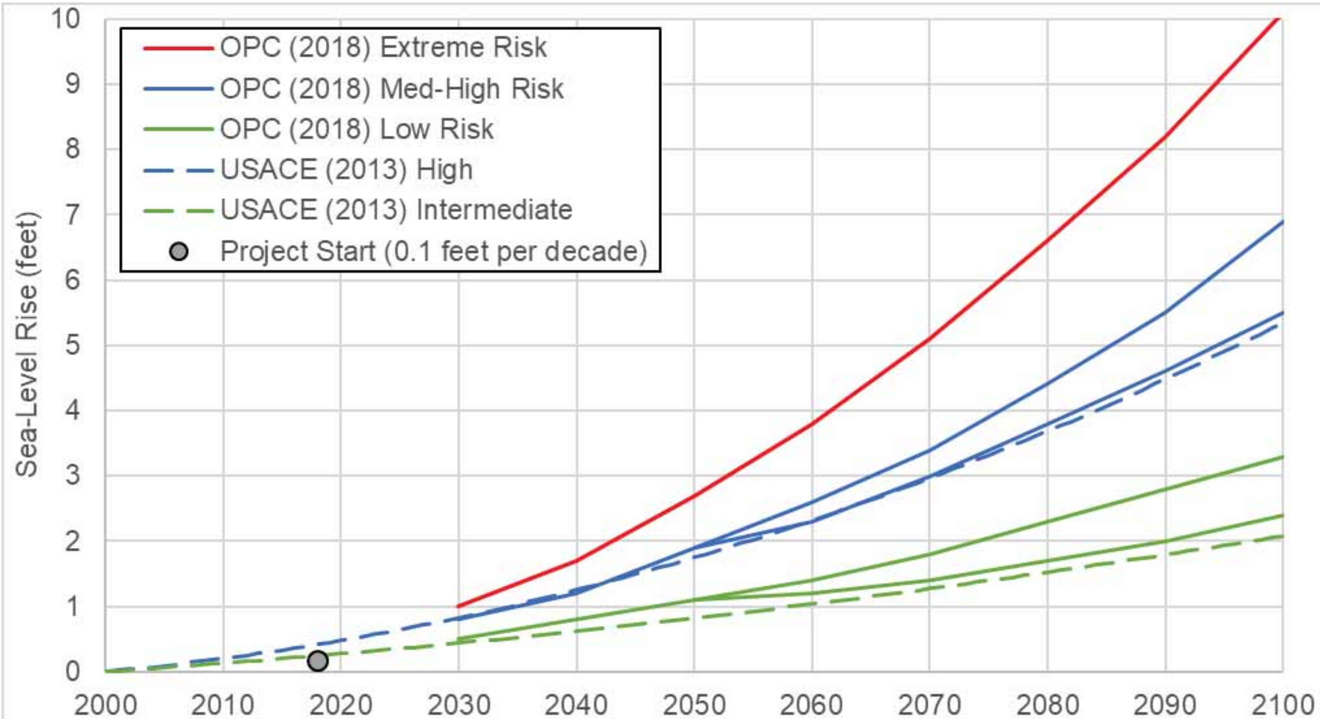

Figure 2
Comparison of Federal (USACE 2013) and State (OPC 2018) Sea-Level Rise Projections

4. Sea-Level Rise Scenarios for Carmel Area Wastewater District Vulnerability Study

Considering the updated guidance discussed above, public webinars on the guidance update process[8], the latest science on sea-level rise and the need to use existing sea-level rise hazard data for portions of this study, the following planning horizons and sea-level rise scenarios are proposed for the Carmel Area Wastewater District Sea-Level Rise Vulnerability Study.

4.1 Planning Horizons

ESA proposes the planning horizons of 2050 and 2100 for the purposes of the project. ESA's recommendation is based on the need to plan for near- and long-term impacts related to sea-level rise, as well as the existence of available coastal hazard maps that were developed for these planning horizons (PWA 2009). Most climate models show strong agreement on the amount of sea-level rise that is likely to occur by 2050, and start to diverge after 2050 based on the range of potential emissions scenarios (OPC 2013). Therefore, it is important to consider a range of sea-level rise scenarios for future planning and projects with timeframes that look beyond 2050.

The proposed planning horizons are consistent with sea-level rise policy guidance documents and consistent with existing hazard mapping performed for the State (PWA 2009). Years 2050 and 2100 will be used to evaluate the vulnerability of the wastewater system to flooding and erosion impacts associated with sea-level rise. An extreme sea-level rise scenario will be assessed by considering that the impacts associated with the medium-high risk level

[8] More information can be found here: http://www.opc.ca.gov/climate-change/updating-californias-sea-level-rise-guidance/

will occur earlier, approximately between 2075 and 2080. The updated guidance introduces planning horizons beyond 2100 but these projections are presented with caution by the authors. As described in OPC (2018), most climate model experiments do not extend beyond 2100, which results in a large increase in uncertainty. Therefore, ESA has not presented sea-level rise amounts projected beyond 2100.

The 2050 and 2100 planning horizons are recommended so that decisions about operations and site improvements can be matched to the timeframe for project lifespans and to facilitate the identification of triggers for potential adaptation measures. By using the planning horizons of 2050 and 2100, we can assess a range of sea-level rise that could occur in the Carmel area in the mid and long-term whether or not the amounts of sea-level rise are realized at, before or after these years. These planning horizons (years) will determine the amounts of sea-level rise that are used to assess vulnerability to coastal flooding hazards and the timeframes over which coastal erosion hazards and consequent impacts are evaluated.

The study will not be limited to impacts at these times, however, and the potential timing of impacts to assets with specific elevations can be assessed by using the sea-level rise projection curves. Therefore, the study can present information of vulnerability to assets that do not occur in the specific planning horizons at 2050 and 2100, which will assist the District in better understanding the potential timing of impacts to various portions of the wastewater system.

4.2 Sea-level Rise Scenarios

The sea-level rise scenarios proposed for this study were selected to be consistent with the latest guidance and to utilize available coastal hazard maps for the Carmel area. The available existing information for future hazards is limited to the erosion and flood hazards prepared for the Pacific Institute study by PWA in 2009 (see Table 1, Section 2). The Pacific Institute study utilized sea-level rise projections by Cayan et al. (2008) that were used to inform the State's Interim Guidance Document (OPC 2011). Although the scenarios from OPC (2011) present sea-level rise projections that are slightly lower than the new OPC (2018) guidance, the mapping products have been considered as conservatively high estimates of flooding and erosion, and are within an acceptable range of uncertainty so that they can be used to inform potential impacts that could occur using the new OPC (2018) guidance.

Now that the State guidance update is in-effect, ESA proposes that this study consider the probabilistic projections of sea-level rise for low risk and medium-high risk aversion scenarios, as well as consideration of the H++ scenario. To account for uncertainties in sea-level rise over time, and a range of assets at risk (e.g., high risk assets include critical community facilities; low risk assets could include recreational assets and non-critical assets), ESA proposes to utilize the probabilistic projections for each Risk Aversion level from Table 3. A total of six sea-level rise scenarios are proposed to perform the vulnerability assessment and adaptation plan, including existing conditions (no sea-level rise) as well as future sea-level rise at 2050 and 2100. Table 5 below presents the proposed future sea-level rise scenarios based on the State-recommended projections for each Risk Aversion level.

TABLE 5
PROPOSED SEA-LEVEL RISE SCENARIOS FOR PROJECT

Scenario	2050	2075	2100
Low Risk Aversion[1]	1.1 feet	--	2.3 to 3.3 feet
Med-High Risk Aversion[2]	1.9 feet	--	5.5 to 6.9 feet
Extreme Risk Aversion	--	5.5 to 6.9 feet	--

1 Low Risk Aversion approximately equal to NRC (2012) Medium Curve
2 Med-High Risk Aversion approximately equal to NRC (2012) High Curve

In order to conduct the vulnerability assessment, ESA will conduct new modeling of the Carmel River Lagoon, and will rely on the available coastal hazard maps from the Pacific Institute effort. New modeling and existing hazard maps will be selected that best match the sea-level rise scenarios presented in Table 5 above. While the existing Pacific Institute coastal hazards maps do not exactly match the proposed sea-level rise scenarios in Table 5, the differences are acceptable given the uncertainties associated with sea-level rise and the method uncertainty for erosion.

Figure 3 presents a chart of the sea-level rise projections based on the current OPC (2018) guidance, the proposed new lagoon modeling scenarios, and the available hazard maps that can be used for assessing vulnerability to erosion. Although maps were not evaluated at the exact sea-level rise amounts of OPC (2018) tabulated in Table 3, they are representative of the new guidance within a reasonable amount of uncertainty.

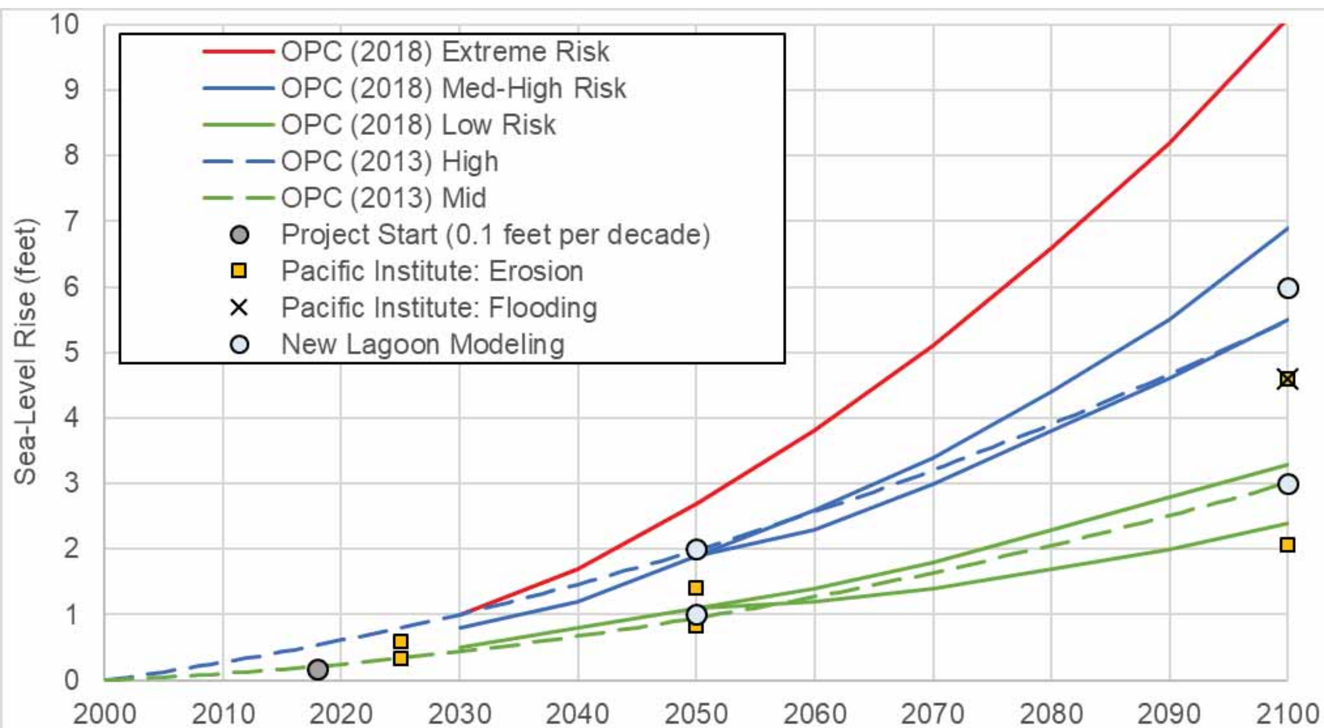

Figure 3
Comparison of Proposed Analysis and Available Hazard Maps to Updated OPC (2018) Sea-Level Rise Guidance Curves

The Extreme Risk sea-level rise scenario of 10.1 feet at 2100 is not well represented in available coastal hazard maps. This scenario will be evaluated by considering that the highest sea-level rise scenario modeled will occur at the time indicated in the Extreme Risk Aversion sea-level rise projection shown in Figure 3. Table 5 summarizes the potential sea level rise scenarios to be modeled, including the extreme H++ scenario that occurs at approximately 2075. These values can be modified based on review by the District and the CCC.

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Appendix C
Flood Risk Assessment Table

Carmel Area Wastewater District - Flood Risk Assessment

Tuesday, January 30, 2018

Carmel Area Wastewater District
26900 Highway 1
Carmel Ca 93923

Notes:
Survey exhibit dated 12/22/2017 - Data received from ground survey conducted by Bestor Engineers.
All Elevations are presented in North American Vertical Datum 1988 (NAVD88).

REGISTERED PROFESSIONAL ENGINEER
DREW ALLEN LANDER
No. 79561
CIVIL
STATE OF CALIFORNIA

I certify that the information included to be true, and the building Water Proof Elevations represent the elevations at which riverine flooding could occur without damage to the structure or the equipment interior to the building.

Drew A. Lander CPE 789561

Structure#	Description	Operation Critical For Secondary Treatment	Base Flood Elevation (NAVD88) FEMA Effective Detailed Study	Lowest Adjacent Grade (LAG)	Structure designed to be Water Proof Elevation (Ft) (NAVD88)	Freeboard Above Base Flood Elevation (Ft)	Compliant with Federal Guidance 3+ ft above BFE for Community Critical Structures (FEMA 543)	Compliant with Federal Guidance 1+ ft above BFE or resistant to flood damage for limited duration.	Portion of Structure Sullgrade	
1	Influent Pump Station/Standby By Generator Building	Yes	19	17.13	23.53	4.53	✓		Yes	Pump Dry well - Engineered for integrity of building in saturated soil.
2	Influent Head Box	Yes	19	17.60	29.50	10.50	✓		No	
3	Headworks	Yes	19	17.30	29.46	10.46	✓		Yes	Flood proof locking door, engineered for integrity of building during flood stage.
4A	Primary Sedimentation Tank #1	Yes	19	17.30	23.62	4.62	✓		Yes	Tank - Engineered for integrity of tank during flood stage.
4B	Primary Sedimentation Tank #2	Yes	19	16.90	23.59	4.59	✓		Yes	Tank - Engineered for integrity of tank during flood stage.
5	Anoxic Selector Structure	Yes	19	15.52	23.65	4.65	✓		Yes	Tank - Engineered for integrity of tank during flood stage.
6	Equalization tank	Yes	19	15.25	23.65	4.65	✓		Yes	Tank - Engineered for integrity of tank during flood stage.
7A	Aeration Basins 3/4	Yes	19	15.52	23.65	4.65	✓		Yes	Tank - Engineered for integrity of tank during flood stage.
7B	Aeration Basins 5/6	Yes	19	15.25	23.48	4.48	✓		Yes	Tank - Engineered for integrity of tank during flood stage.
8	Blower Building	Yes	19	15.52	24.49	5.49	✓		No	Elevated and backfilled foundation.
9	Mixed Liquor Distribution Structure	Yes	18	15.82	23.56	5.56	✓		Yes	Tank - Engineered for integrity of tank during flood stage.
10	Mixed Liquor Flowmeter Vault	No	17	15.60	16.02	-0.98		✓	No	Vault - Electronics are sealed and water proof. Equipment can run in Manual and be bypassed if required.
11A	Secondary Sedimentation Tanks #1	Yes	18	15.14	23.62	5.62	✓		Yes	Tank - Engineered for integrity of tank during flood stage.
11B	Secondary Sedimentation Tanks #2	Yes	18	15.10	23.75	5.75	✓		Yes	Tank - Engineered for integrity of tank during flood stage.

Structure#	Description	Operation Critical For Secondary Treatment	Base Flood Elevation (NAVD88) FEMA Effective Detailed Study	Lowest Adjacent Grade (LAG)	Structure designed to be Water Proof Elevation (Ft) (NAVD88)	Freeboard Above Base Flood Elevation (Ft)	Compliant with Federal Guidance 3+ ft above BFE for Community Critical Structures (FEMA 543)	Compliant with Federal Guidance 1+ ft above BFE or resistant to flood damage for limited duration.	Portion of Structure Subgrade	
12	RAS/WAS Pump Station	Yes	19	15.51	23.67	4.67	✔		Yes	Submersible pumps and power. All service equipment elevated as indicated.
13	Secondary Effluent Diversion Structure	Yes	17	17.95	17.95	**0.95**		✔	Yes	This Tank holds treated disinfected effluent ready for discharge to the ocean. This is a low risk hazard.
14	Chlorination Building	Yes	16.5	17.98	23.62	7.12	✔		No	Chlorination Building has been decommissioned from service, however electrical feed to limited plant processes are still inside this structure and elevated.
	Chlorine Contact Channels	Yes	16.5	17.98	17.98	**1.48**		✔	Yes	Tank - Engineered for integrity of tank during flood stage. This Tank holds treated disinfected effluent ready for discharge to the ocean. This is a low risk hazard.
15	Tertiary Building	No	18	15.74	20.59	**2.59**		✔	No	Tank - Engineered for integrity of tank during flood stage.
16	Gypsum Feed Silo	No	18	N/A	N/A	**N/A**		✔	No	Not critical to process control.
17	Microfiltration/Reverse Osmosis Facility	No	17	15.61	18.05	**1.05**		✔	No	Minor damage if flooded, not designed to operate during flood event. Can be brought back on line with little cleanup.
18	Effluent Pump Station	Yes	17	17.87	23.50	6.50	✔		Yes	Pump Dry well - Engineered for integrity of building in saturated soil.
19	Outfall Pipe	Yes	N/A	N/A	N/A	**N/A**	✔		Yes	Sealed and submersible equipment.
20	Dissolved Air Flotation Thickener	No	18	16.22	25.23	7.23	✔		Yes	Mechnical Flood Panel required to be installed. Tank - Engineered for integrity of tank during flood stage.
21	Digester No. 1-1974	Yes	19	16.41	N/A	**N/A**	✔		Yes	Sealed Tank - Engineered for integrity of tank during flood stage empty or full.
22	Digester No. 2-2018	Yes	19	16.31	N/A	**N/A**	✔		Yes	Sealed Tank - Engineered for integrity of tank during flood stage empty or full.
23	Digester Control Building #2	Yes	19	16.17	23.73	4.73	✔		Yes	Equipment Room - Engineered for integrity of building in flood stage.
24	Sludge Holding Tank	No	19	N/A	N/A	**N/A**	✔		No	Not critical to process control.
25	Digester Control Building #1	Yes	19	16.89	23.57	4.57	✔		Yes	Basement will not sustain damage. If flooding reaches the LAG basement will begin to flood. No critical equipment present in basement.
26	Waste Gas Burner	No	19	15.66	16.45	-2.55		✔	No	Equipment is Submersible. Floodable without damage for 72 hrs. Can also be bypassed for a limited duration.
27	Dewatering Building	Yes	19	16.15	23.60	4.60	✔		Yes	Equipment Room - Engineered for integrity of building in flood stage.
28	Dewatered Sludge Transport	Yes	19	15.62	15.62	-3.38		✔	No	Not a structure. Floodable

Structure#	Description	Operation Critical For Secondary Treatment	Base Flood Elevation (NAVD88) FEMA Effective Detailed Study	Lowest Adjacent Grade (LAG)	Structure designed to be Water Proof Elevation (Ft) (NAVD88)	Freeboard Above Base Flood Elevation (Ft)	Compliant with Federal Guidance 3+ ft above BFE for Community Critical Structures (FEMA 543)	Compliant with Federal Guidance 1+ ft above BFE or resistant to flood damage for limited duration.	Portion of Structure Subgrade	
29	Grease Receiving Station	No	19	N/A	N/A	**N/A**		✓	No	Not critical to process control.
30	Operations Building	No	18.5	16.53	19.04	**0.54**			Yes	Basement will not sustain damage. If flooding reaches the LAG basement will begin to flood but no equipment is stored below.
31	Locker Room	No	19	17.80	20.47	**1.47**		✓	No	Elevated and backfilled foundation.
32	Laboratory	Yes	16.5	17.72	23.37	6.87	✓		No	Elevated and backfilled foundation.
33	Vehicle Storage Building	No	19	16.87	16.87	-2.13			No	Not critical to process control.
34	Maintenance Shop	No	19	16.84	16.84	-2.16			No	Not critical to process control.
35	Equipment Storage Building	No	18	16.80	16.80	-1.20			No	Not critical to process control.
36	Hypo/SBS Distribution Structure	Yes	17	19.00	25.24	8.24	✓		No	Tank - Engineered for integrity of tank when empty and submerged.
37	Office Trailer A	No	19	17.50	19.83	**0.83**			No	Not critical to process control.
38	Employee Break Building	No	19	18.25	20.01	**1.01**		✓	No	Elevated and backfilled foundation.
39	Office Trailer B	No	19	17.50	19.83	**0.83**			No	Not critical to process control.
40	Office Trailer C	No	19	17.00	19.83	**0.83**			No	Not critical to process control.
41	Fuel Station	No	19	16.50	N/A	**N/A**			No	Equipment is Submersible, Tanks are anchored against flotation.
42	Ferric Chloride Storage	Yes	17	16.17	19.38	**2.38**		✓	No	Elevated and backfilled foundation.
43	Storm water Pump Station	Yes	16.5	16.85	17.97	**1.47**		✓	Yes	All electrical connections elevated to elevation of building 14A.
44	VacCon Water Decant	No	19	N/A	N/A	**N/A**			No	Not a structure. Not critical to process control.
90	Plumbing Storage CONEX	No	17	N/A	N/A	**N/A**			No	Anchored to resist flotation. Not critical to process control.
91	Paint Storage CONEX	No	17	N/A	N/A	**N/A**			No	Anchored to resist flotation. Not critical to process control.
92	Surplus Storage CONEX	No	17	N/A	N/A	**N/A**			No	Anchored to resist flotation. Not critical to process control.
93	Surplus Storage CONEX	No	17	N/A	N/A	**N/A**			No	Anchored to resist flotation. Not critical to process control.


Carmel Area Wastewater District
Building Locations by Number
See Flood Risk Assessment for Structure #
Google Earth
400 ft
N
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Appendix D
Wastewater Asset Vulnerability and Adaptation Table and Maps

Potentially Vulnerable Infrastructure to Sea Level Rise or Carmel River Flooding

Name	Description	Vulnerable Elevation	Threat	Adaptation Options	Map Key
Collection System Assets Near Lagoon					
Manhole at 17th and Carmelo St	Manhole in street at low elevation and near the Carmel River Lagoon	9.6 ft	Carmel Lagoon Elevation Rise	• Install Watertight Lid • Coat/Seal Interior of Manhole to limit groundwater intrusion • Raise Street Elevation • Reroute Sewer	A
Manhole on Carmelo St North of 17th	Manhole in street at low elevation and near the Carmel River Lagoon	10.5 ft	Carmel Lagoon Elevation Rise	• Install Watertight Lid • Coat/Seal Interior of Manhole to limit groundwater intrusion • Raise Street Elevation • Reroute Sewer	A
Laterals for homes on East Side of Carmelo St	Laterals for homes at low elevations.	10 ft	Carmel Lagoon Elevation Rise	• Install Sewer Popper SRVs to stop inflow	A
Cleanout on South End of Monte Verde	Cleanout in street at low elevation and near the Carmel River Lagoon	13.1 ft	Carmel Lagoon Elevation Rise	• Install Watertight Lid • Raise Street Elevation	B
Cleanout and Manhole on River Park Place	Cleanout in street at low elevation and near the Carmel River Lagoon	11.6 ft and 12.6 ft	Carmel Lagoon Elevation Rise	• Install Watertight Lid • Coat/Seal Interior of Manhole to limit groundwater intrusion • Raise Street Elevation	B
Two Manholes on South End of Camino Real	Manholes in street at low elevation and near the Carmel River Lagoon	9.4 ft and 13.5 ft	Carmel Lagoon Elevation Rise	• Install Watertight Lid • Coat/Seal Interior of Manhole to limit groundwater intrusion • Raise Street Elevation	B
Monte Verde and 16th Pump Station	Pump Station at low elevation and near the Carmel River Lagoon	15 ft	Carmel Lagoon Elevation Rise	• Install Watertight Lid • Coat/Seal Interior of Wet Well to limit groundwater intrusion	B

Name	Description	Vulnerable Elevation	Threat	Adaptation Options	Map Key
				• Raise Street Elevation • Relocate Pump Station	
Laterals for homes on Monte Verde, Park Place, and Camino Real	Laterals for homes at low elevations.	10 ft	Carmel Lagoon Elevation Rise	• Install Sewer Popper SRVs to stop inflow	B
Manhole at East End of 16th	Manhole in street at low elevation and near the Carmel River Lagoon	12.2 ft	Carmel Lagoon Elevation Rise	• Install Watertight Lid • Coat/Seal Interior of Manhole to limit groundwater intrusion • Raise Street Elevation	C
Two Manholes at Mission Ranch	On Mission Ranch property near the Carmel River Lagoon	15.5 ft (12.3 ft owned by Mission Ranch)	Carmel Lagoon Elevation Rise	• Install Watertight Lid • Coat/Seal Interior of Manhole to limit groundwater intrusion • Raise Manhole Elevation	
Calle La Cruz Pump Station	Pump Station on South Side of Carmel Lagoon	19.7 ft	Carmel Lagoon Elevation Rise	• Make Structure Watertight/Completely Bury Station • Relocate Pump Station	D
CAWD WWTP Outfall Lagoon Crossing	24-inch Diameter Treated Effluent Pipe from WWTP to Ocean Outfall	9 ft	Carmel Lagoon Elevation Rise	• Bury Lagoon Crossing	
Collection System Assets Near Carmel River					
Sewer Manholes on North Side of Carmel River Main Sewer Crossing	Manhole near River Bank	15 ft to 17 ft	Carmel River Flooding	• Install Watertight Lid • Coat/Seal Interior of Manhole to limit groundwater intrusion • Raise Manhole Elevation	I
Manholes in Mission Fields Neighborhood	Manholes serving Mission Fields Neighborhood on North Side of Carmel River	Varies: 16 ft to 25 ft	Carmel River Flooding	• Install Watertight Lid • Coat/Seal Interior of Manhole to limit groundwater intrusion • Raise Street Elevation	II

Name	Description	Vulnerable Elevation	Threat	Adaptation Options	Map Key
Laterals for homes in Mission Fields Neighborhood	Laterals for homes at low elevations.	16 ft	Carmel River Flooding	• Install Sewer Popper SRVs to stop inflow	II
Hacienda Pump Station	Pump Station Up River on South Bank of Carmel River	51 ft	Carmel River Flooding	• Install Watertight Lid • Relocate Pump Station	III
Collection System Assets Near Pacific Ocean					
Bay and Scenic Pump Station	Pump Station located on bluffs potential subject to coastal erosion.	Height of Seawall 16 ft	Ocean Inundation/Erosion	• Raise/Rebuild Seawall • Relocate Pump Station • Use (e) wet well with submersible pumps and relocate electrical to East Side of Scenic Drive	1
8th and Scenic Pump Station	Pump Station located on landside of Carmel Beach	28.8 ft	Ocean Inundation/Erosion	• Install Watertight Lid • Relocate Pump Station • Build Wall Around Pump Station/Raise Station	2
Wastewater Treatment Plant					
Manhole just upstream of Influent Pump Station	Main WWTP Influent Manhole South of Carmel River on WWTP Property	19.6 ft	Carmel River Flooding	• Install Watertight Lid • Coat/Seal Interior of Manhole to limit groundwater intrusion • Build Flood Wall Around Manhole	i
Chlorine Contact Channels	Treated/chlorinated effluent in an underground structure that has inlets below flood level	18 ft	Carmel River Flooding	• Install Watertight Lids • Build Flood Wall Around Structure	
Ferric Feed to Digester	Pump and Tank for feeding Ferric Chloride into Digester for H2S control	19 ft	Carmel River Flooding	• Take offline during a flood.	

Name	Description	Vulnerable Elevation	Threat	Adaptation Options	Map Key
Restroom Sumps (Typ 2)	Wet wells that receive on site restroom drainage	20 ft	Carmel River Flooding	• Raise top of Sumps • Coat/Seal Interior of Manhole to limit groundwater intrusion	i
Buried Structures	Concrete tanks or buildings that extend below grade	10 ft	Groundwater Intrusion	• Seal any cracks in Buried Concrete Structure Walls/Floors	

A
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Appendix B

Schaff and Wheeler 2014, Review of Hydraulic Models for Lower Carmel River

Schaaf & Wheeler
Consulting Civil Engineers

1171 Homestead Rd., Suite 255
Santa Clara, CA 95050
(408) 246-4848
FAX (408) 246-5624

TECHNICAL MEMO

TO:	Drew Lander	DATE:	February 18, 2014
FROM:	Jim Schaaf Daniel J. Schaaf Lawrence Johnson	JOB #:	CARM.01.13
SUBJECT:	**Review of Hydraulic Models for Lower Carmel River**		

Schaaf & Wheeler has reviewed the recent hydraulic modeling of the Lower Carmel River and plans to provide flood protection to neighborhoods along the north bank. This review focuses on how the model techniques represent the potential hydraulics of the existing treatment plant site along with the potential impacts on the site from proposed improvements. The duplicate Flood Insurance Study (FIS) hydraulic model for the Lower Carmel River was provided by Balance Hydrologics, Inc. for assessing potential impacts to the Treatment Plant based on various modeling assumptions.

HEC-RAS Model Background:

The channel reaches of interest are Channel 3 (CHNL03) and the right and left overbanks (FLDPLN1 and FLDPLN2 respectively). Channel 3 extends from approximately 4100 feet upstream of Highway 1 to just downstream of the Carmel Area Water District Treatment Plant. The left and right overbanks are modeled as separate reaches. (see Figure 1)

The following outlines the various modeling assumptions and flow scenarios.

Base Plan

The base plan used for analysis and comparison was the With-Levee condition where both levees are assumed to hold. The flow profiles and based on the 100-year FEMA flow rate and the normal depth tidal boundary condition. Channel 'n' values range from 0.04 to 0.075, south overbank 'n' values were set at 0.04. Flow spilling from the main channel to the south overbank is simulated using lateral weirs with a coefficient of 2.0. The model cross sections do not include obstructions for the physical buildings on the site. In general, this modeling approach appears standard for FEMA studies.

Treatment Plant Obstructions

To better simulate the treatment plant flooding, the portions of the model cross sections that pass through structures on the plant site were blocked using obstructions in the HEC-RAS geometry. Ineffective flow blockages were also added to cross sections using 1:1 encroachment for structures in the upstream direction and 4:1 encroachment for structures in the downstream direction (see figure 2). A comparison was made with and without these blockages to determine the impact on the channel and overbank 100-Year water surface elevations. (see Table 2)

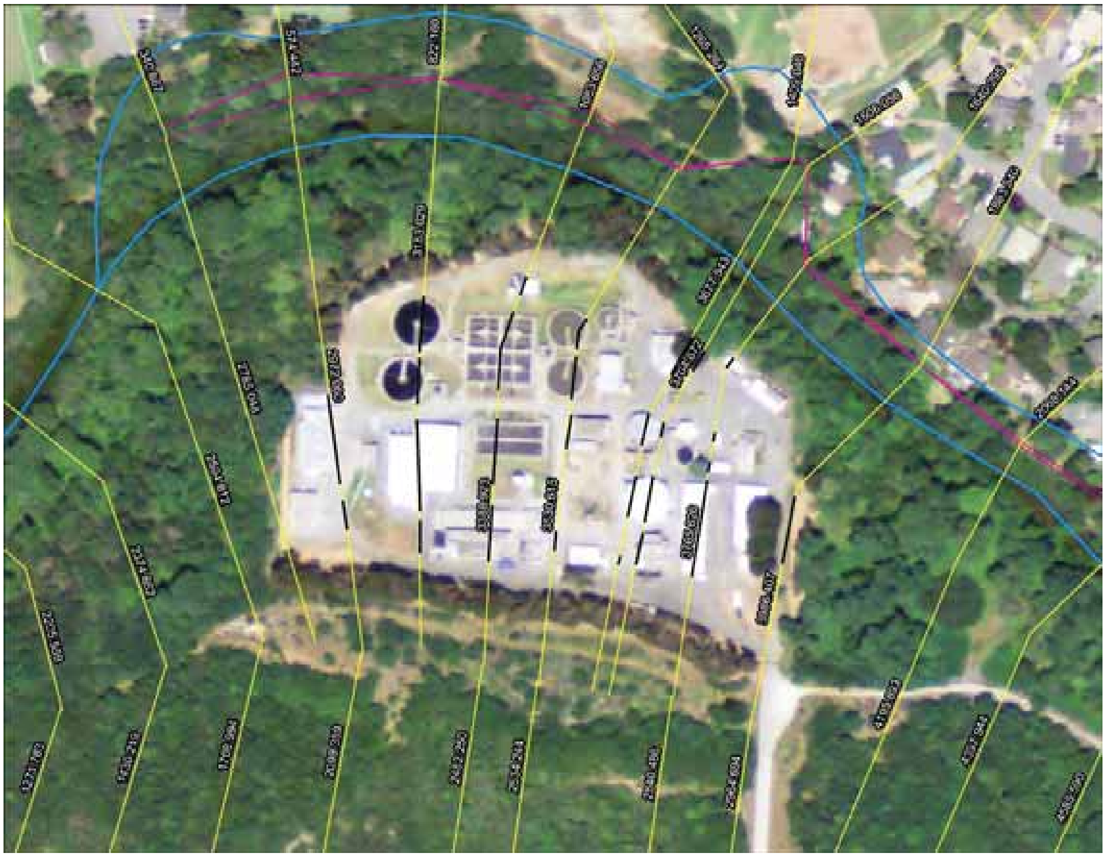


Figure 2: Treatment Plant Obstructions (shown in Black)

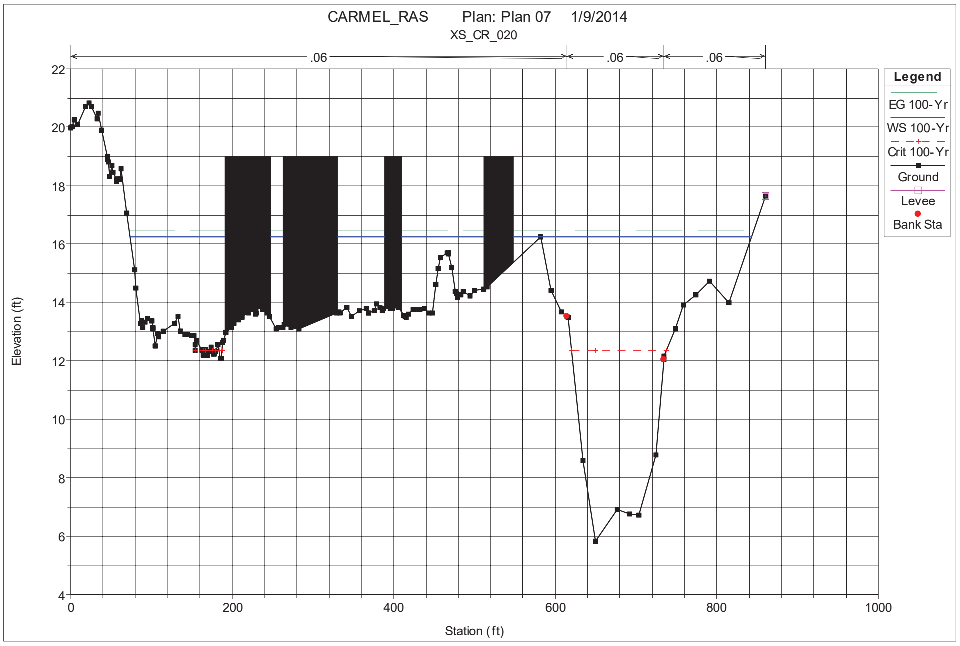


Figure 3: Typical Cross Section with Treatment Plant Obstructions

Adjust Lateral Weir on Channel 3

The lateral weirs on Channel 3 were modified to better depict the controlling high points for channel overflows to the south overbank. Lateral weirs (5199 through 4194) were moved from the left overbank station to the left bank station of the corresponding cross sections. The remaining lateral structures (numbered 5784 through 5399) remained positioned on the left overbank station of Channel 3. Figure 3 and Figure 4 show the adjustment of the lateral structures within the HEC-RAS geometry file. The lateral structure elevations were assumed to be the high points of each connected cross section with linear interpolation between cross sections. A comparison was made with and without the lateral weir adjustment in order to determine the impact on the channel and overbank 100-Year water surface elevations. (see Table 2)This comparison includes the Treatment Plant obstructions to the cross sections.

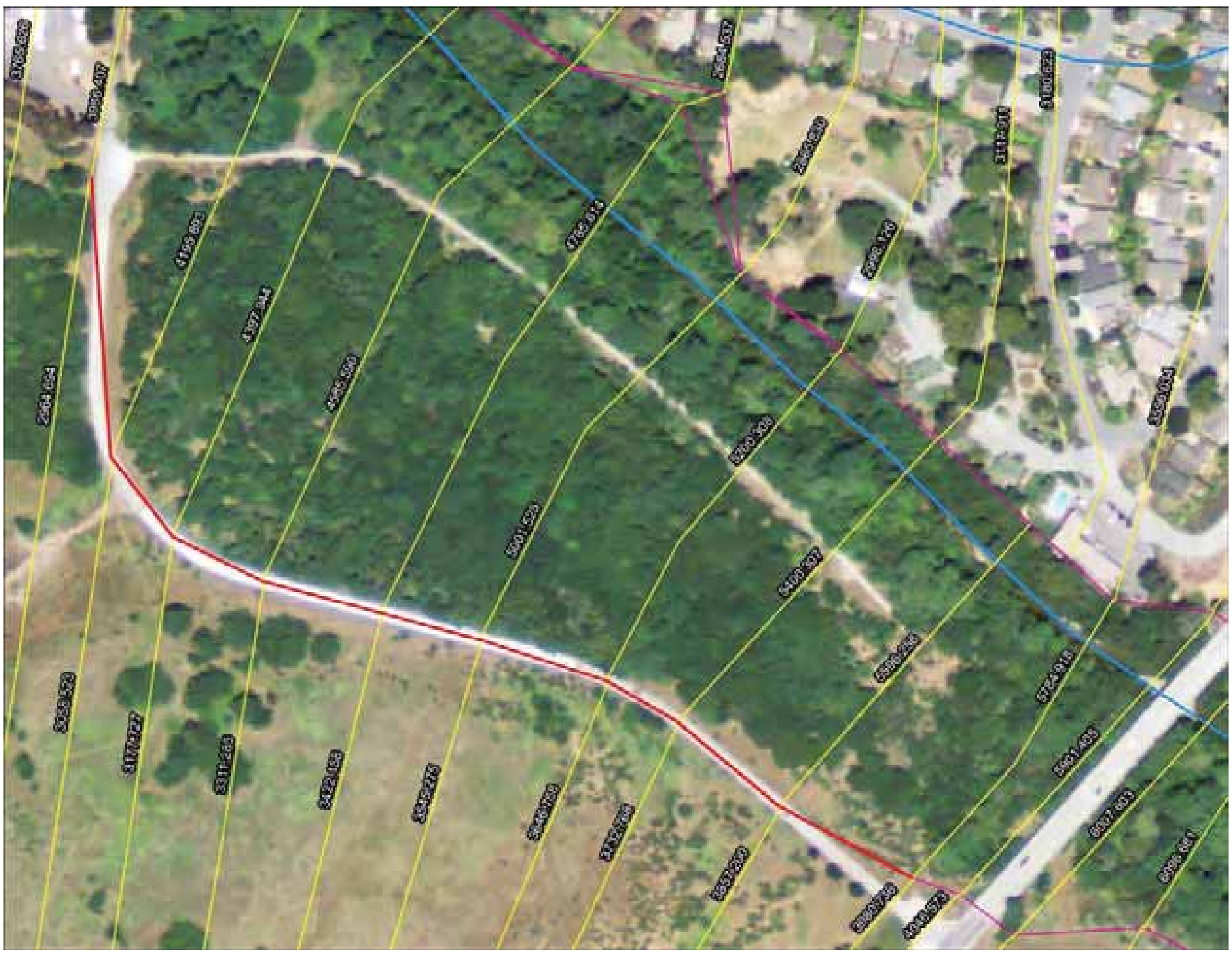


Figure 3: Original Lateral Structure (shown in Red)

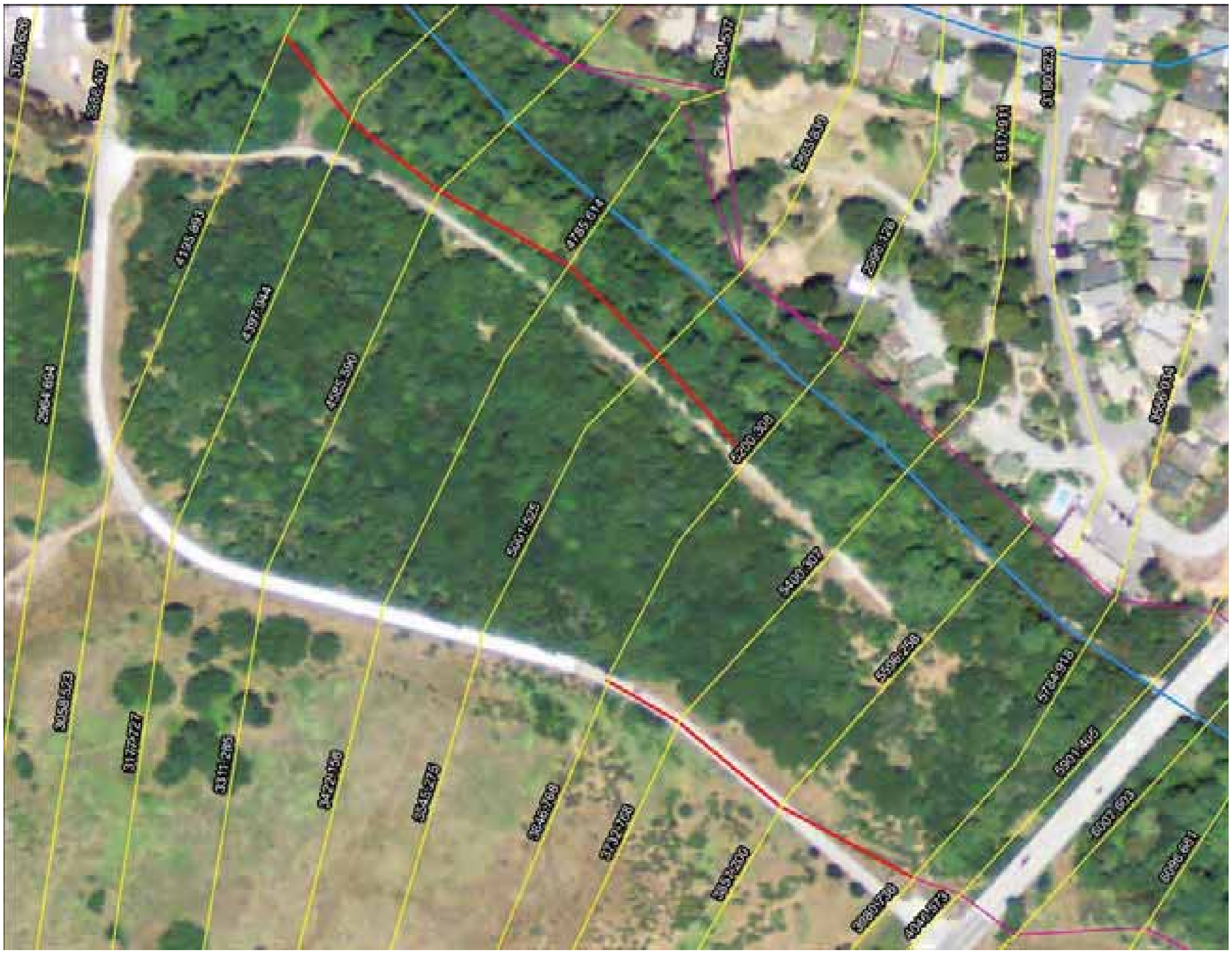


Figure 4: Adjusted Lateral Structure (shown in Red)

Modify the south overbank Manning's n

There has been significant vegetative growth in the floodplain south of the main channel. The Manning's "n" for the south overbank (FLDPLN 2) was increased from 0.04 to 0.10 to better depict existing roughness conditions. A comparison was made with and without the Manning's "n" modification to see the impact on the channel and overbank 100-Year water surface elevations (see Table 2). This comparison included the lateral weir adjustment and the Treatment Plant cross section obstructions.

Wall to the perimeter of the Treatment Plant

For this analysis the Treatment Plant site was assumed to be removed from effective flow by a wall constructed to protect the plant from 100-Year flood event. The model cross sections were altered with blocked obstructions for the entirety of the plant site (see figure 5). A comparison was made with and without this obstruction in order to assess the impact that constructing a wall would have on the surrounding floodplain for the 100-Year event (see Table 2). This comparison included the lateral weir adjustment.

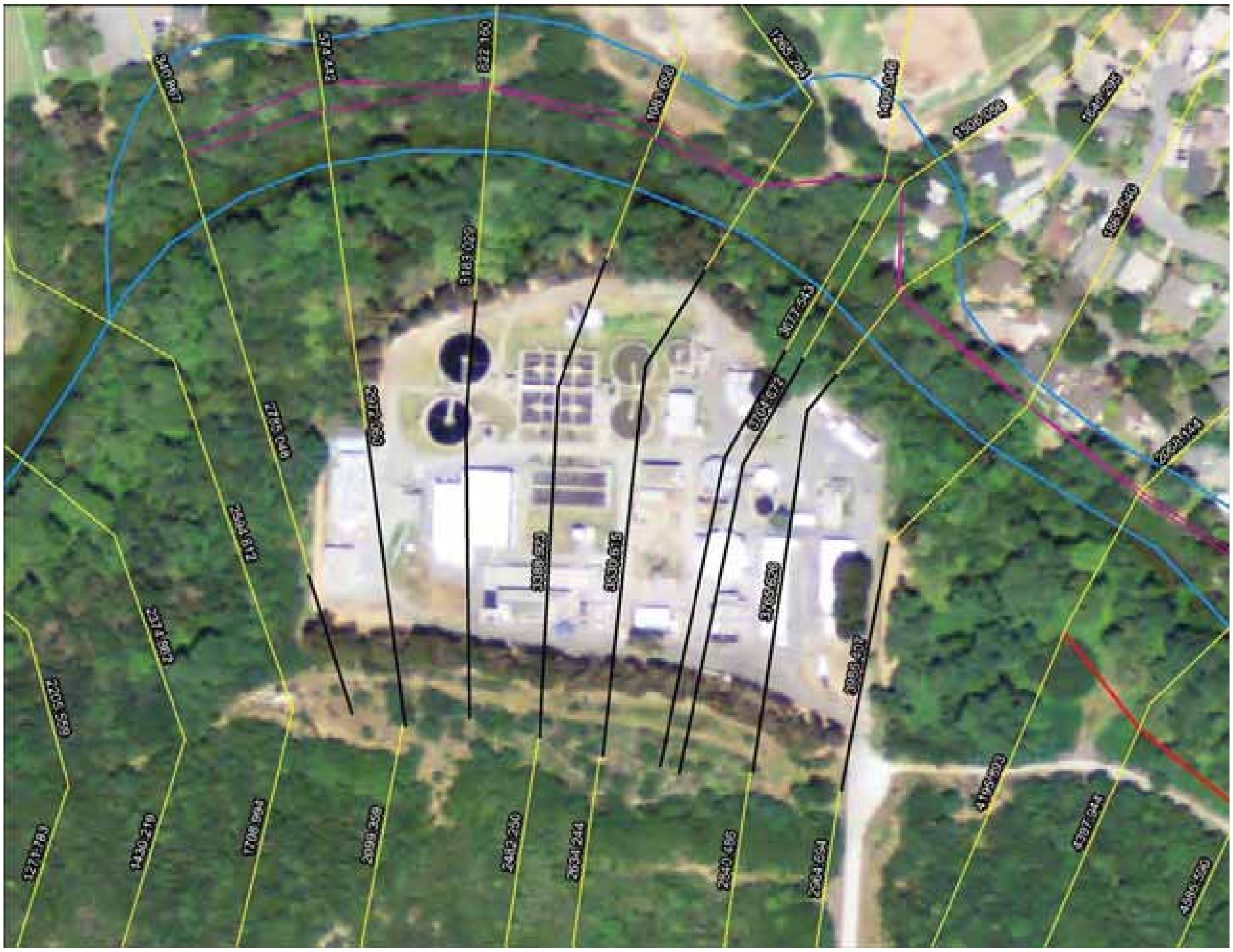


Figure 5: Completely obstructed Treatment Plant in HEC-RAS

Proposed Wall on the north side of Channel 2

The proposed floodwall on the north bank was added to the updated model based on the geometry provided by Balance Hydrologics. A comparison was made with and without the addition of the proposed wall in order to assess its impact on the channel and overbank for the 100-Year water surface elevations. This comparison also included the lateral weir adjustment, Manning's "n" adjustment in the south overbank, and the treatment plant cross section obstructions.

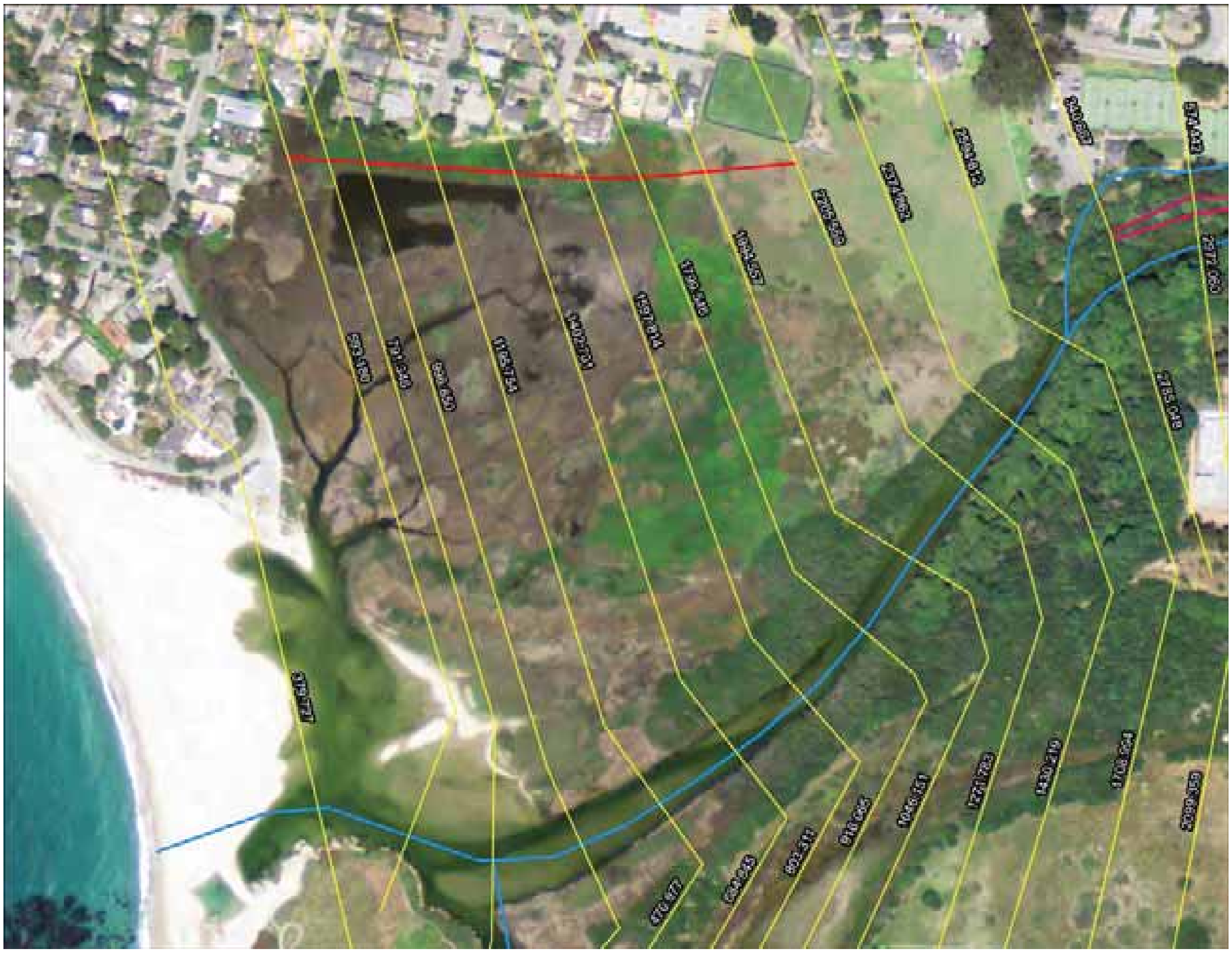


Figure 6: Proposed wall upstream of sandbar

Tailwater Sensitivity Analysis:

The tailwater boundary conditions were modified in order to gauge the models sensitivity to changes in the downstream water surface. The following tailwater scenarios were performed on the 100 year "base" model:

- Critical Depth
- Normal Depth with ineffective flow assumed for the sandbar with 1:1 upstream encroachment.
- Critical Depth with ineffective flow assumed for the sandbar with 1:1 upstream encroachment.
- Known Water surface of 12.60 FT based on the Lagoon Stage flood frequency analysis
- Known water surface of 12.60 FT based on the Lagoon Stage flood frequency analysis, plus ineffective flow assumed for the sandbar with 1:1 upstream encroachment.

The WSELs for each of the tailwater scenarios (shown in Table 1) were compared to the 100 year "base" model to determine any potential impact of WSELs at the Treatment Plant. Table 1 illustrates that the model is sensitive to the downstream boundary condition in regards to WSELs at the Treatment Plant. Additional tailwater analysis was then performed on Scenarios 4, 6, 8, and 9 assuming the worst case boundary condition (i.e. Normal Depth with ineffective flow). The results are shown in Table 3

Table 1

TAILWATER SENSITIVITY: 100YR, BASE MODEL FOR ALL CASES			
Downstream Boundary Condition	**Max Change in WSEL @ Treatment Plant**	**Channel Distance of Tailwater Impact**	**Starting Tailwater WSEL**
Normal Depth	NA	NA	11.88 FT
Critical Depth	-1.01 FT	3388 FT	7.23 FT
[1]Normal Depth plus ineffective flow from Sandbar @ 1:1 U/S	2.74 FT	4195 FT	14.17 FT
Critical Depth plus ineffective flow from Sandbar @ 1:1 U/S	0.38 FT	3183 FT	8.30 FT
12.60FT Lagoon Stage FFA	0.46 FT	3530 FT	12.6 FT
[1]12.60FT Lagoon Stage FFA; plus ineffective flow from Sandbar @ 1:1 U/S	1.68 FT	3986 FT	12.6 FT

[1]Sandbar is assumed to be 200FT wide with 1:1 ineffective flow encroachment upstream. NOTE: the Treatment plant encompasses cross sections 3986.407 through 2785.078 of the main channel.

Summary:

The following tables summarize the comparisons made per the modeling assumptions and scenarios identified above along with additional scenarios indentified in the table matrix. The values below reflect the maximum impact that each scenario had on each overbank and channel cross sections. The maximum water surface elevations at the Treatment Plant are also provided for each case.

- Adding the treatment plant obstructions to the channel cross sections shows a slight increase in 100-year WSELs at the plant by reducing the conveyance area.
- Adjusting the lateral weir allows more flow to remain in the channel with less spilling to the south overbank. This creates higher water surface elevations in the channel and an increase in the maximum WSEL at the Treatment Plant.
- The modification of the Manning's "n" in the south overbank only impacts WSELs within the south overbank and does not affect the WSEL at the Treatment Plant.
- Constructing a wall around the Treatment Plant increases channel WSELs along with the potential risk of overtopping the right levee allowing spills to the north overbank.
- The model is sensitive to changes in the downstream boundary conditions in regards to changes in WSELs at the treatment plant.
- Lastly, adding the proposed wall upstream of the sandbar has no significant effect on 100-year WSELs in channel or the overbanks.

TABLE 2

RETURN PERIOD	SCENARIO ANALYSIS										
	MODEL CHANGES	BASE MODEL	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6	SCENARIO 7	SCENARIO 8	SCENARIO 9
	TP OBSTRUCTIONS			X	X	X			X		
	ADJUSTED WEIR		X		X	X		X	X	X	
	MODIFIED MANNINGS "N"					X		X	X	X	
	WALL AROUND TREATMENT PLANT						X	X		X	X
	PROPOSED WALL								X	X	X
RETURN PERIOD	WSEL (NGVD29)										
100 YR	MAX CHANGE IN CHANNEL	-	1.74	0.1	1.75	1.75	0.32	2.17	1.75	2.17	0.32
	MAX CHANGE IN ROB	-	0.08	0	0.07	0.07	0	0.02	0.08	0.02	0
	MAX CHANGE IN LOB	-	0.69	0.04	0.7	2.42	0.12	2.42	2.42	2.42	0.12
	MAX WSEL @ TP	16.35	16.65	16.45	16.92	16.92	16.67	18.11	16.92	18.12	16.67
	MAX WSEL @ 470.977	12.9	12.88	12.91	12.88	13.62	12.93	13.68	13.63	13.69	12.94
	MAX VELOCITY (FT/S) @ 470.977	4.52	4.32	4.61	4.35	3.89	4.78	3.99	3.89	3.98	4.77
10 YR	MAX CHANGE IN CHANNEL	-	1.28	0.11	1.29	1.29	0.13	1.32	1.29	1.32	0.13
	MAX CHANGE IN ROB	-	0.04	0.03	0.04	0.04	0.03	0	0.04	0	0.03
	MAX CHANGE IN LOB	-	0.74	0.04	0.75	3.08	0.14	3.1	3.08	3.1	0.14
	MAX WSEL @ TP	15.42	15.48	15.41	15.53	15.53	15.5	15.83	15.53	15.83	15.5
	MAX WSEL @ 470.977	8.68	8.67	8.68	8.67	9.57	8.69	9.59	9.57	9.59	8.69
	MAX VELOCITY (FT/S) @ 470.977	3.96	3.9	4.01	3.91	3.04	4.16	3.06	3.04	3.06	4.15
50 YR	MAX CHANGE IN CHANNEL	-	1.64	0.1	1.65	1.65	0.26	1.84	1.65	1.84	0.26
	MAX CHANGE IN ROB	-	0.12	0	0.11	0.11	0	0.06	0.11	0.06	0
	MAX CHANGE IN LOB	-	0.82	0.03	0.83	2.24	0.1	2.28	2.24	2.28	0.1
	MAX WSEL @ TP	16.15	16.37	16.19	16.59	16.59	16.38	17.33	16.59	17.33	16.38
	MAX WSEL @ 470.977	11.87	11.86	11.88	11.86	12.57	11.9	12.61	12.58	12.61	11.91
	MAX VELOCITY (FT/S) @ 470.977	4.22	4.03	4.29	4.04	3.57	4.45	3.62	3.56	3.62	4.44
500 YR	MAX CHANGE IN CHANNEL	-	2.05	0.19	2.07	2.08	0.42	2.48	2.08	2.48	0.42
	MAX CHANGE IN ROB	-	0.04	0	0.04	0.04	0	0.01	0.04	0.01	0
	MAX CHANGE IN LOB	-	0.42	0.08	0.43	3.08	0.17	3.08	3.08	3.08	0.17
	MAX WSEL @ TP	16.91	17.31	17	17.64	17.68	17.33	18.78	17.68	18.78	17.33
	MAX WSEL @ 470.977	14.9	14.86	14.92	14.86	15.69	14.96	15.77	15.69	15.77	14.96
	MAX VELOCITY (FT/S) @ 470.977	5.26	5.03	5.34	5.06	4.58	5.54	4.69	4.58	4.69	5.54

Table 3

RETURN PERIOD	MODEL CHANGES	BASE MODEL	BASE MODEL	SCENARIO 4	SCENARIO 4b	SCENARIO 6	SCENARIO 6b	SCENARIO 8	SCENARIO 8b	SCENARIO 9	SCENARIO 9b
	DOWNSTREAM BOUNDARY CONDITION ANALYSIS:										
	TP OBSTRUCTIONS			X	X						
	ADJUSTED WEIR			X	X	X	X	X	X		
	MODIFIED MANNINGS "N"			X	X	X	X	X	X		
	WALL AROUND TREATMENT PLANT					X	X	X	X	X	X
	PROPOSED WALL							X	X	X	X
	TAILWATER AT NORMAL DEPTH	X		X		X		X		X	
	[1]TAILWATER AT NORMAL DEPTH PLUS INEFFECTIVE FLOW FROM SANDBAR		X		X		X		X		X
RETURN PERIOD	**WSEL (NGVD29)**										
100 YR	MAX CHANGE IN CHANNEL	-	2.94	1.75	2.95	2.17	2.95	2.17	2.99	0.32	2.94
	MAX CHANGE IN ROB	-	2.67	0.07	2.72	0.02	2.71	0.02	2.76	0	2.67
	MAX CHANGE IN LOB	-	3.15	2.42	3.21	2.42	3.2	2.42	3.2	0.12	3.11
	MAX WSEL @ TP	16.35	16.7	16.92	17.32	18.11	18.13	18.12	18.14	16.67	17
	MAX WSEL @ 470.977	12.9	15.74	13.62	16.02	13.68	16.04	13.69	16.04	12.94	15.75
	MAX VELOCITY (FT/S) @ 470.977	4.52	3.23	3.89	2.93	3.99	3	3.98	3	4.77	3.43

[1]Sandbar is assumed to be 200FT wide with 1:1 ineffective flow encroachment upstream.


Figure 1
Cross Section
Levee
Carmel Channel
0 250 500 1,000 1,500 2,000
Feet

Appendix C

Balance Hydrologics 2015, Anticipated Changes in Downstream Base Flood Elevations Due to the Carmel River Floodplain Restoration and Environmental Enhancement Project

MEMO

To: Josh Harwayne (Denise Duffy & Associates)

From: Edward Ballman, P.E.

Date: August 26, 2015

Subject: Anticipated Changes in Downstream Base Flood Elevations Due to the Carmel River Floodplain Restoration and Environmental Enhancement Project

At your request Balance Hydrologics has reviewed the hydraulic modeling analyses prepared earlier for the Carmel River Floodplain Restoration and Environmental Enhancement Project (CRFREE) in order to characterize anticipated changes in downstream flood elevations. The focus of this review has been on Base Flood Elevations (BFEs), also known as 100-year flood elevations, since they are the primary regulatory standard for County ordinances and regulations under the National Flood Insurance Program. Specific areas of interest include various California Department of Parks and Recreation (State Parks) facilities located on the former Odello West property just west of State Route 1 and the treatment plant operated by the Carmel Area Wastewater District (CAWD). This memo summarizes the currently-effective BFE information and anticipated changes in BFE at each location to better characterize project impacts with respect to flood control.

Floodplain Mapping Considerations

As you may be aware, the currently-effective FEMA hydraulic modeling for the Carmel River uses three distinct flow paths to represent the complexities of the river valley west of approximately Rancho Cañada. These include the main channel, north overbank, and south overbank. The various flow paths are used to model scenarios that include all levees remaining intact through the flood event, failure of the south bank levees, and, finally, failure of the north bank levees. For the purposes of the CRFREE project, the main channel and south overbank flow paths are most pertinent, in no small part because the risk of flooding in the north overbank would be markedly reduced through implementation of the project.

Our staff reviewed the FEMA modeling files to confirm that they correspond appropriately to the base flood information shown on the Flood Insurance Rate Map and in the Flood Insurance Study for this reach of the river. That information is an appropriate base case against which to measure any impacts from the CRFREE project. Revised hydraulic modeling using the project geometry was then used to tabulate the predicted post-project BFE values. Predicted flood elevations do change slightly due to increases in the portion of the flood discharge that would be conveyed through the south overbank after the floodplain is restored and the new State Route 1 causeway. These changes are summarized briefly below.

State Parks Properties

State Parks owns and administers Carmel River State Beach, which occupies much of the valley bottom and lagoon area west of State Route 1. This area includes several structures remaining from past agricultural activities on the former Odello West property, including sheds and a barn. These facilities are shown on the attached Figure 1, which also depicts several of the cross-sections from the hydraulic model runs. The entire area with structures shown in Figure 1 is within the south overbank portion of the models. Table 1 below summarizes the predicted base flood elevations at the respective cross-sections for both the pre- and post-project conditions.

Table 1. Predicted base elevations in the vicinity of the State Park barn

	Base Flood Elevation (*ft, NAVD*)		
Cross-section	Pre-project	Post-project	Difference
35+45	18.6	18.4	-0.2
33+11	18.0	17.9	-0.1
30+59	17.2	17.3	0.1
28+40	16.9	17.1	0.2

The model output summarized in Table 1 shows that base flood elevations are predicted to both decrease and increase along the reach with the State Park structures. At the eastern end, nearer the highway, BFEs are shown to decrease slightly due to the fact that under existing conditions floodwaters have to flow over the roadway and do not then have a defined channel down to the lagoon. In the post-project condition the causeway and restored floodplain channel prevent roadway overflow and let water move more efficiently down to the lagoon even though the flow rates are higher. However, far enough to the west, the effect of the increased south overbank flow predominates and there is a slight increase in the post-project case, reaching a maximum of 0.2 feet (2.5 inches) at the western end of the barn structure.

The area immediately adjacent to the barn structure and other outbuildings is subject to shallow flooding under existing conditions, with flood depths generally on the order of one to two feet. Should mitigation be desired for the small increase in base flood elevation, it could readily be achieved through a modest increase in the elevation of the driveway and construction of a low berm or wall structure along the west and south perimeter of the pad area.

CAWD Treatment Plant

From a flood modeling perspective, the CAWD treatment plant is uniquely situated along the border between the main channel and south overbank flow paths. The main channel reach sets the BFEs for the north, east, and west perimeters of the plant. The south overbank reach defines the BFEs for the south side. Predicted base flood information is summarized in Table 2.

Table 2. Predicted base elevations in the vicinity of the CAWD treatment plant

Cross-section	Base Flood Elevation (*ft, NAVD*)		
	Pre-project	Post-project	Difference
Main Channel			
39+86	19.1	18.4	-0.7
35+31	17.9	17.2	-0.7
29+72	16.1	15.8	-0.3
23+75	15.5	15.5	0.0
South Overbank			
29+65	17.0	17.2	0.2
26+34	16.7	16.9	0.2
20+99	16.5	16.6	0.1
14+30	16.2	16.3	0.1

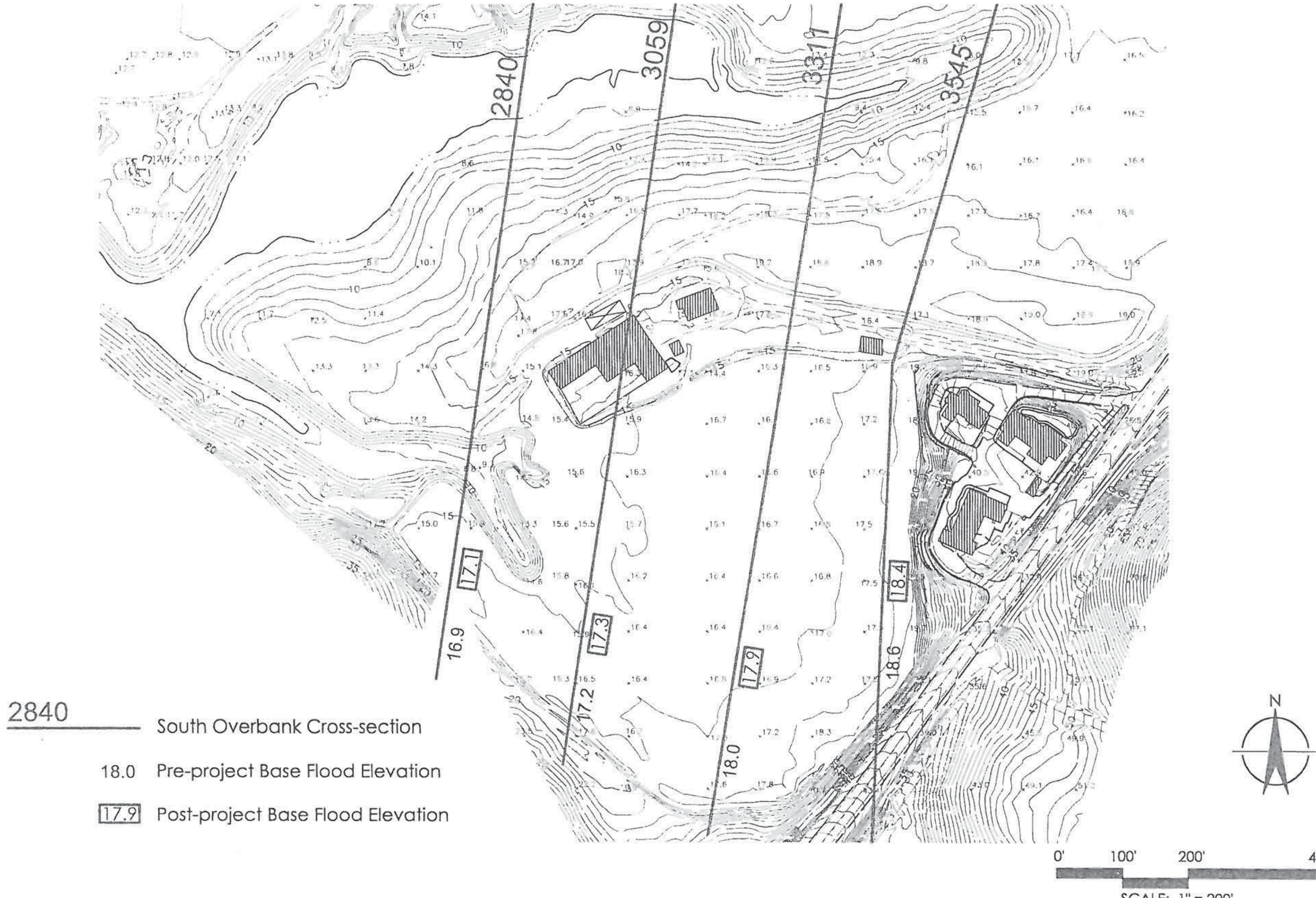
The values in Table 2 show that the reduction in the portion of the flood flow conveyed in the main channel generally leads to decreases in BFEs, especially along the north and east perimeter of the plant where the channel is much more confined. The increased discharge in the south overbank is predicted to lead to modestly higher BFEs along the south perimeter (maximum increase of 0.2 feet).

However, the residual flood risk to the plant is from the main channel, as the south perimeter is protected by high ground well in excess of the post-project BFE values. Therefore, the modeling predicts an overall reduction in the flood hazard at the CAWD facility as a result of the CRFREE project, and mitigation is not necessary.

Closing

Thank you for this opportunity to clarify the impacts of the proposed CRFREE project with respect to downstream flood elevations.

Do not hesitate to contact us if you have any questions or comments on the design assumptions and estimates summarized in this memo.



Balance Hydrologics, Inc.

214044 100-year Flood Extents.dwg

Figure 1. **Predicted pre- and post-project base flood (100-year) extents in the vicinity of the State Park barn area, Monterey County, California.**

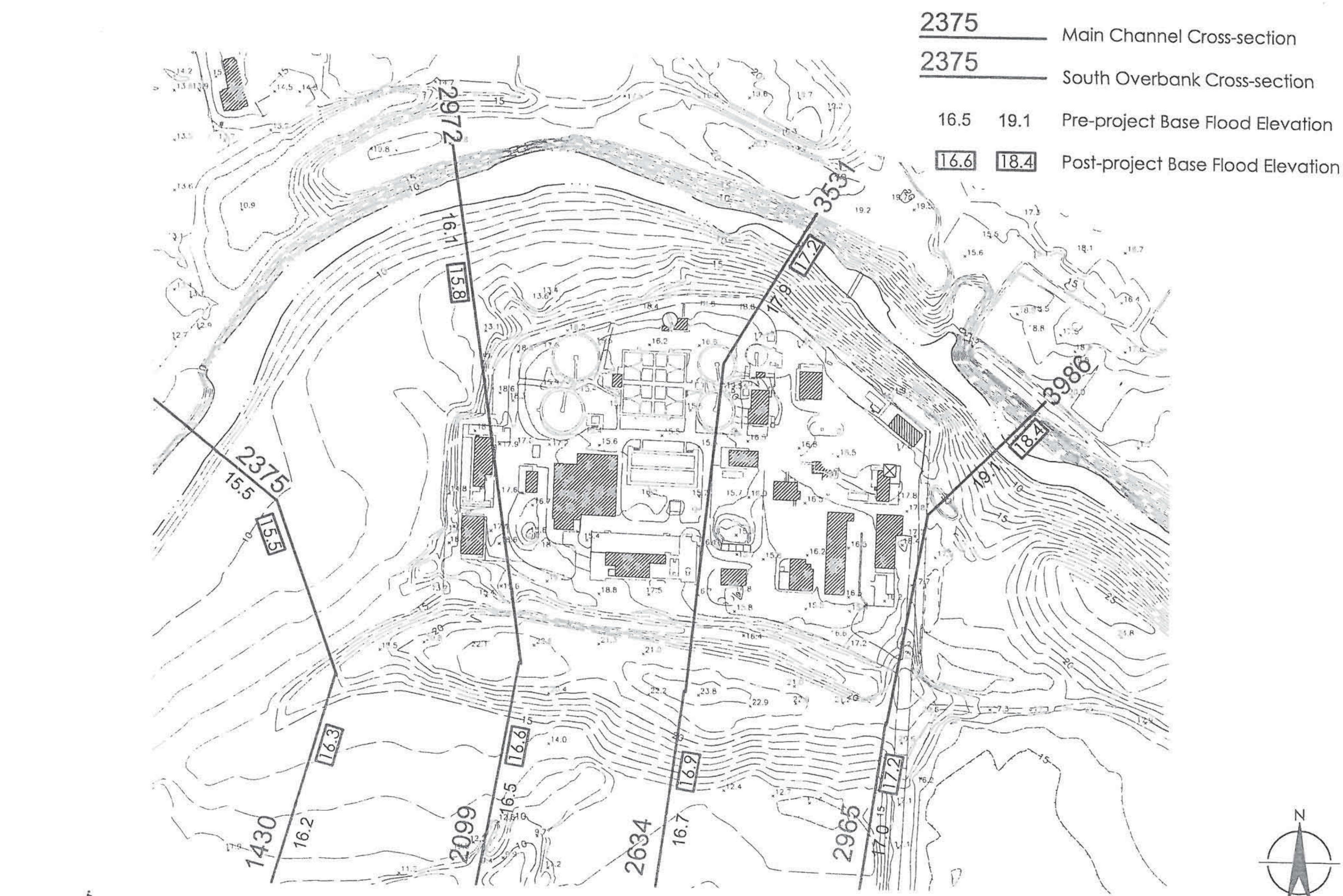
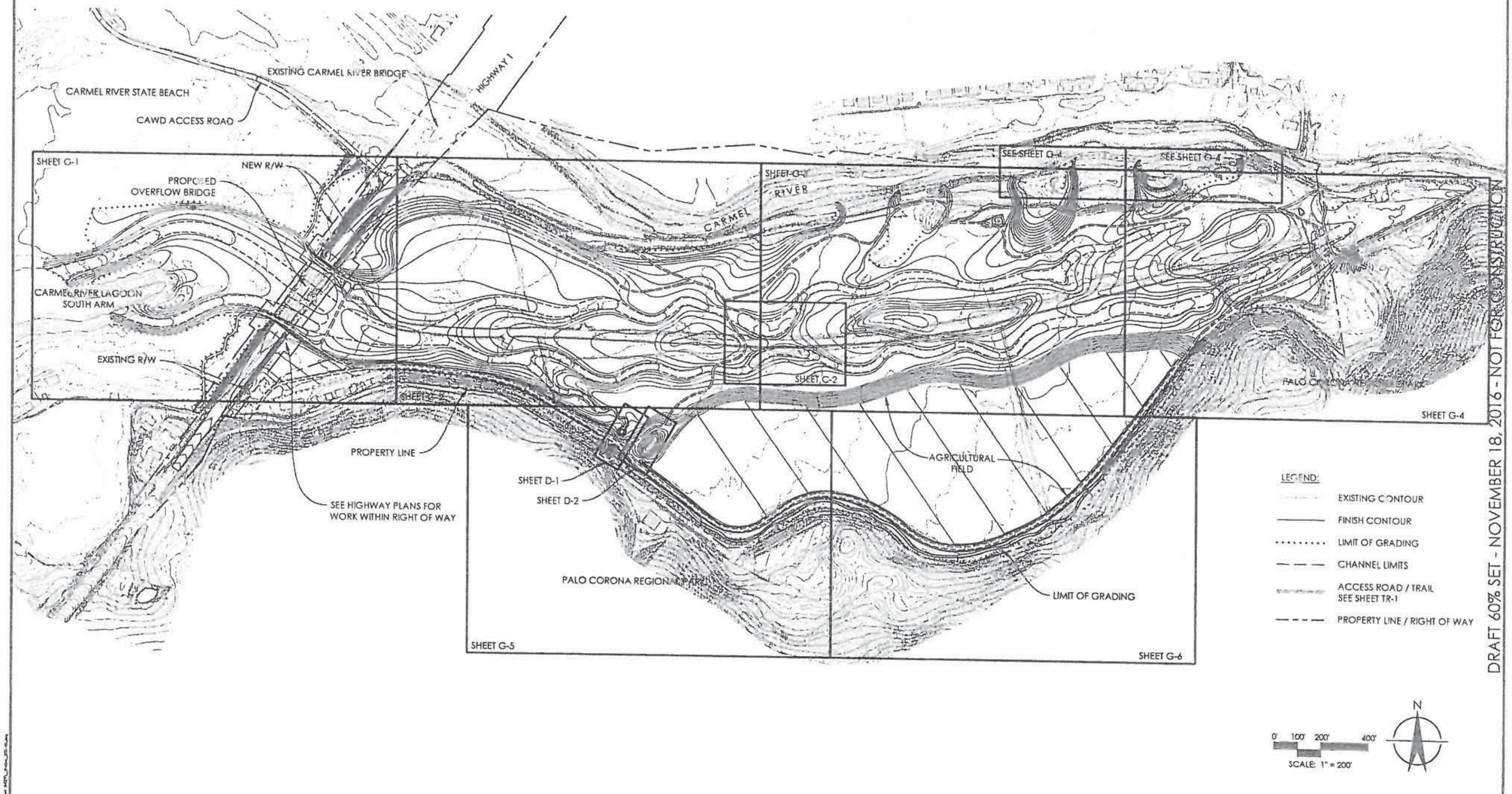


Figure 2. **Predicted pre- and post-project base flood (100-year) extents in the vicinity of the Carmel Area Wastewater District facility, Monterey County, California.**

Balance Hydrologics, Inc.

214044 100-year Flood Extents.dwg



DRAFT 60% SET - NOVEMBER 18, 2016 - NOT FOR CONSTRUCTION

OVERALL SITE PLAN

BIG SUR LAND TRUST

CARMEL RIVER FLOODPLAIN RESTORATION AND ENVIRONMENTAL ENHANCEMENT PROJECT

PROJECT No. 7200

COUNTY PLAN SET

REVISIONS:		
BY:	DATE:	DESCRIPTION:

DATE: 11/18/2016
SCALE: 1" = 200'
DRAWN BY: DJ
JOB #: BH # 214044

NOT FOR CONSTRUCTION

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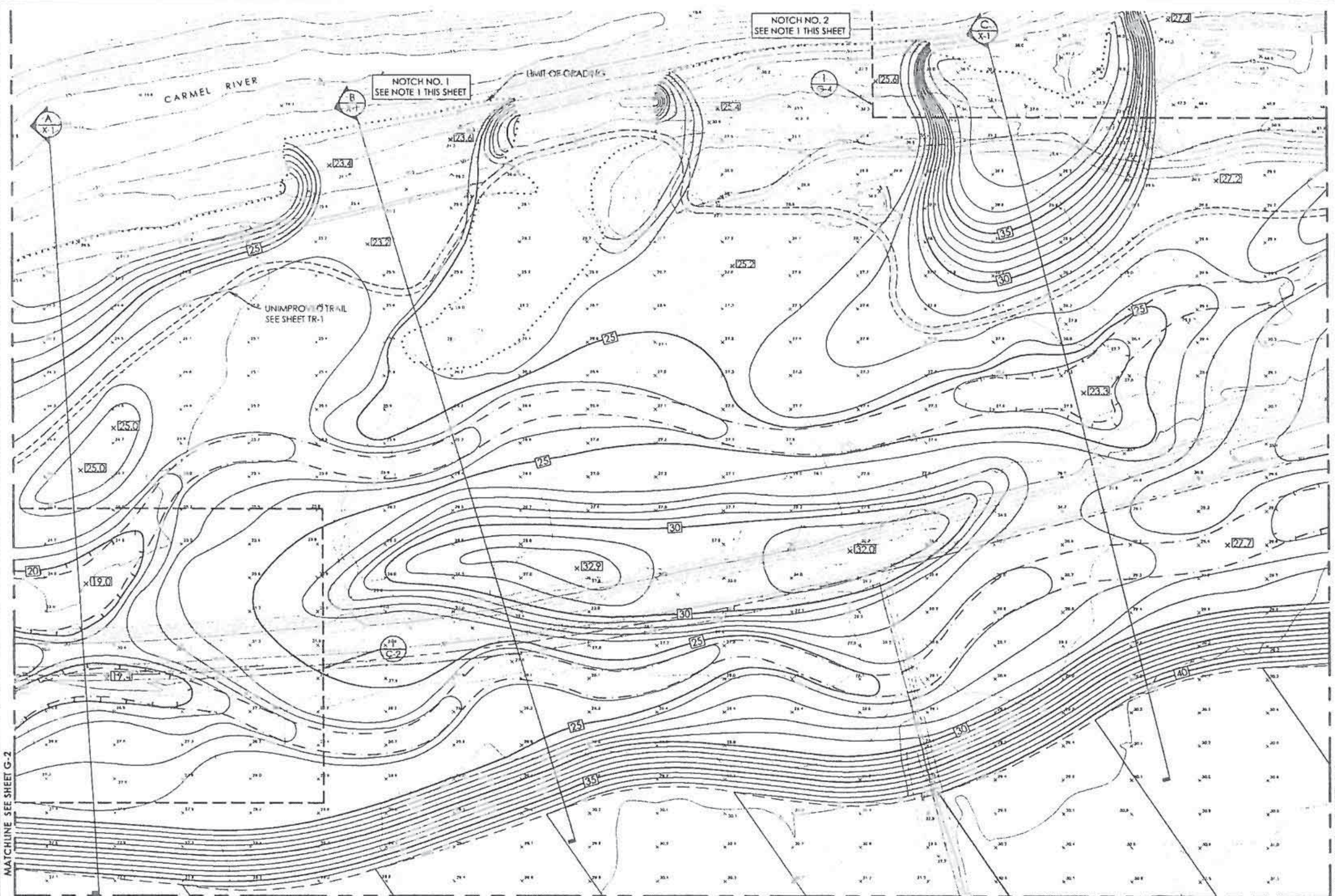
tel (510) 704-1000 · fax (510) 704-1001 · www.balancehydro.com

SHEET S-1 OF

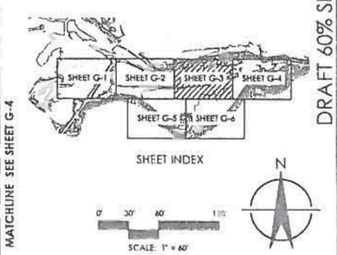


NOTES:

1. THE GRADING PLAN CALLS FOR THE EXCAVATION OF FOUR NOTCHES IN THE BERM ALONG THE SOUTH SIDE OF THE CARMEL RIVER. NOTCHES 1 AND 2 ARE SHOWN ON THIS SHEET. NOTCHES 3 AND 4 ARE SHOWN ON SHEET G-4. AFTER GRADES SHOWN ON THIS SHEET HAVE BEEN ACHIEVED, FURTHER EARTH WORK IN THE NOTCH AREAS IS REQUIRED. SEE SHEET G-7.
2. SEE SHEET C-1 FOR DETAILS ON LOG PLACEMENT.

LEGEND:

- EXISTING INDEX CONTOUR
- EXISTING INTERMEDIATE CONTOUR
- x21.5 EXISTING POINT ELEVATION
- 15 FINISH INDEX CONTOUR
- FINISH INTERMEDIATE CONTOUR
- x23.3 FINISH POINT ELEVATION
- BREAKLINE
- LIMIT OF GRADING
- CHANNEL LIMITS
- TRAIL SEE SHEET TR-1



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GRADING PLAN

BIG SUR LAND TRUST

CARMEL RIVER FLOODPLAIN RESTORATION AND ENVIRONMENTAL ENHANCEMENT PROJECT

PROJECT No. 7200

COUNTY PLAN SET

REVISIONS:		
BY:	DATE:	DESCRIPTION:

DATE: 11/18/2016

SCALE: 1" = 60'

DRAWN BY: DJ

JOB #: BH # 214044

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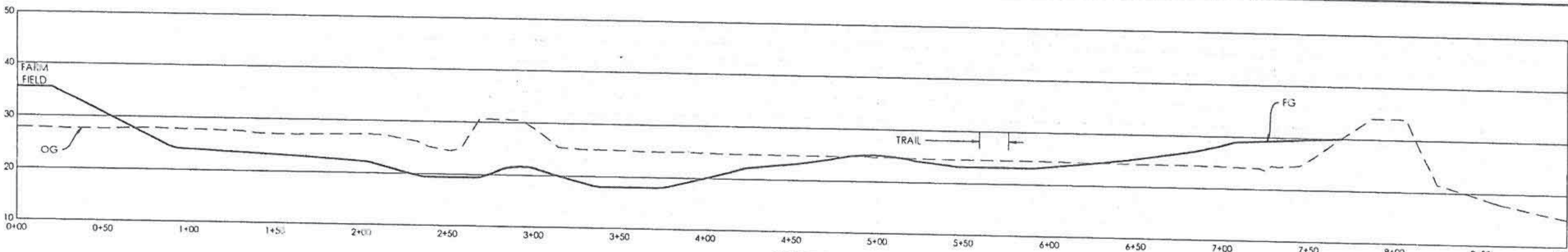
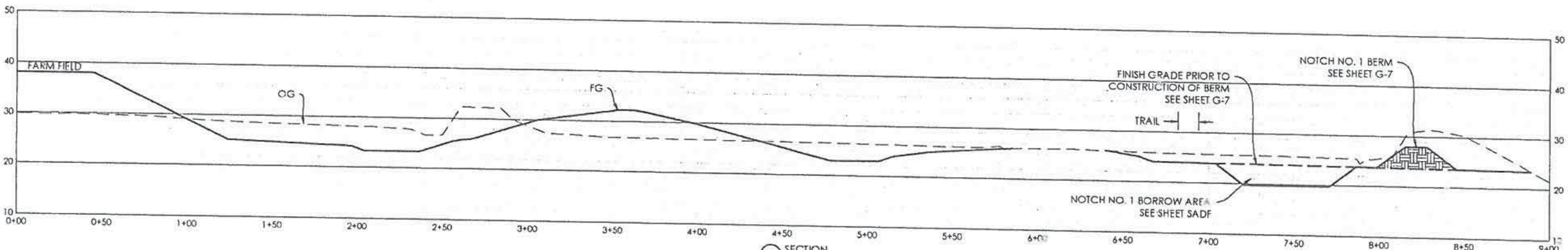
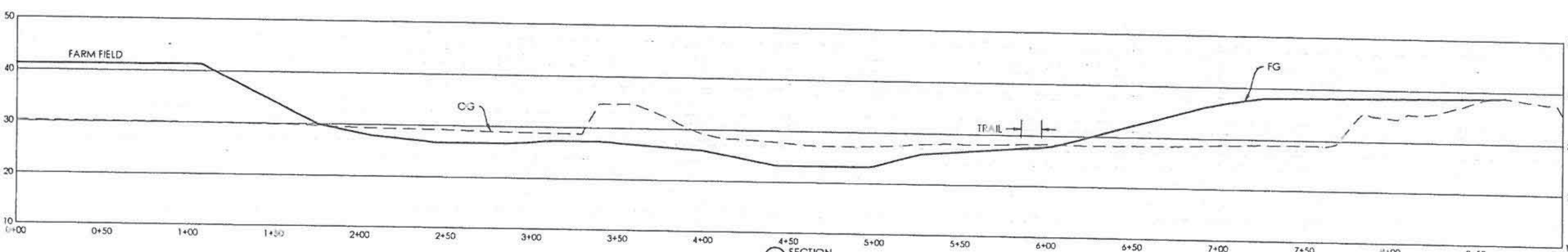
SHEET G-3 OF



G-3 (A) SECTION
SCALE: 1" = 30' HORIZONTAL
1" = 10' VERTICAL



G-3 (B) SECTION
SCALE: 1" = 30' HORIZONTAL
1" = 10' VERTICAL



G-3 (C) SECTION
SCALE: 1" = 30' HORIZONTAL
1" = 10' VERTICAL

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BIG SUR LAND TRUST

CARMEL RIVER FLOODPLAIN RESTORATION AND ENVIRONMENTAL ENHANCEMENT PROJECT
PROJECT No. 7200
COUNTY PLAN SET

REVISIONS:		
BY:	DATE:	DESCRIPTION:

DATE: 11/18/2016
SCALE: AS NOTED
DRAWN BY: DJ
JOB #: BH # 214044

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SECTIONS
SHEET
X-1
OF

Appendix D

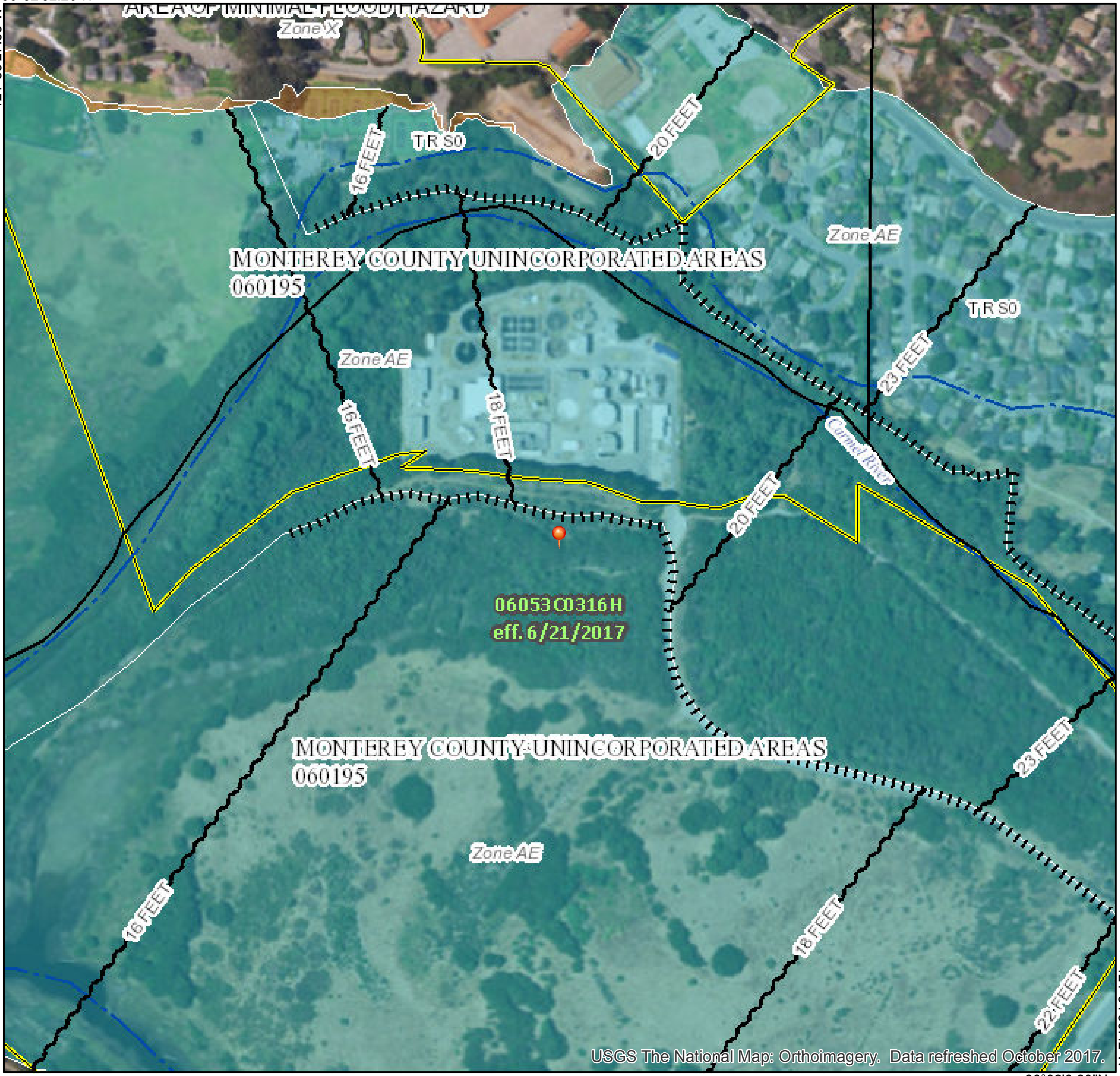
2009 FEMA Flood Map

National Flood Hazard Layer FIRMette

FEMA

36°32'32.20"N

121°55'27.88"W



121°54'50.42"W

36°32'3.30"N

Feet 0 250 500 1,000 1,500 2,000

1:6,000

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- B 20.2 17.5 Cross Sections with 1% Annual Chance Water Surface Elevation
- 8 Coastal Transect
- 513 Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 11/30/2018 at 1:02:14 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.