Memo

To: Richard Weber, P.E., Whitson Engineers

From: Eric Riedner, P.E. and Edward Ballman, P.E.

Date: May 28, 2013

Subject: Carmel River Lagoon EPB- Riverine Flooding Impacts Assessment

This memorandum summarizes the riverine flooding impacts assessment completed for a range of potential alignments and elevations that have been proposed for the Ecosystem Protective Barrier (EPB) project. The focus of this assessment is a hydraulic analysis comparing modeled water surface elevations for pre- and post-project conditions along the lower Carmel River during the 100-year flood event.[1]

This memo was prepared for use by Monterey County, the Monterey County Water Resources Agency (MCWRA), and the project team to aid in the selection of a preferred EBP alignment for further refinement and presentation in the final project reporting.

Hydraulic Model Description

The hydraulic model used to complete the analysis was provided by the MCWRA and was developed as the technical basis for the update to the FEMA Flood Insurance Study (FIS) made effective in 2009. The FEMA model was built on the Army Corps of Engineers HEC-RAS software platform and developed to use steady state flow calculations.

The portion of the model covering the lower Carmel River quantifies flooding hazards influenced by both riverine and lagoon flooding processes. According to the technical documentation provided with the model, calculated flood depths resulting from riverine flooding conditions were compared to a statistical analysis of measured annual peak stages in the lagoon with the final water surface profiles and flood hazard mapping based on the higher of the two results. During the 100-year flood event, riverine flooding was estimated to produce higher water surface elevations at all but the downstream-most cross section in the model (Section 3+80).[2]

The potential failure of uncertified levees separating the main channel from the north and south overbank areas was addressed in the FIS through developing multiple model runs for “with levee”, “without north overbank levee”, and “without south overbank levee” conditions. The respective flood elevations (“base flood elevation” or BFE) in the floodplain were defined using

[1] The 100-year flood is the flood event predicted to have a 1-percent chance of occurring in any given year. In fact, “1-percent chance flood event” is gaining acceptance as a more accurate name. However, this memo will use the more traditional terminology of the “100-year flood”.

[2] The currently-effective Flood Insurance Rate Map shows an extended area of floodplain with a base flood elevation of 16 feet covering essentially all of the Lagoon area. This does not imply a flat flood surface elevation, but rather results from the mapping convention of rounding elevations to the nearest whole number.

the highest calculated water surface elevations from each model run. An overview of the FEMA modeling results for existing conditions along the lower Carmel River is provided in the FEMA FIRM (Flood Insurance Rate Map) panel attached as Figure 1.

Summary of Modeled EPB Alignments and Elevations

Potential impacts of the EPB to riverine hydraulics were assessed by modifying the currently-effective FEMA modeling for the changes in channel geometry associated with selected EPB alignment scenarios. Consistent with FEMA modeling guidelines, the original HEC-RAS model was run to demonstrate fidelity with the BFE information in the FIS and as shown on the FIRM panel for existing conditions. Once model performance for existing conditions was confirmed, the geometry of the channel cross-sections was modified to reflect the alignment of the EPB for the selected scenarios. The proposed alignments were imported into the modeling work map so that a vertical wall feature could be added to the respective cross-sections at the appropriate locations. Area behind the EPB was changed to "ineffective flow area", however, the underlying assumption in all cases was that final EPB heights would be such that overtopping from riverine flood events (as contrasted with lagoonal flood events) would not occur.

Two separate EPB scenarios were modeled in detail. These included EPB Alignment #2(as described in previous technical memorandums) and EPB Alignment #2 in conjunction with EPB Extension 3A. The two alignments are more fully described as:

> *EPB Alignment #2*
>
> The EPB Alternative 2A alignment extends along the southern limits of the Fourth Addition neighborhood from approximately the intersection of Carmelo Street and 17th Avenue to the eastern end of the Carmel Unified School District property. This alignment would be offset a minimum of 40 feet into the State Parks parcel. A more detailed description of the EPB Alternative 2A can be found in other technical memorandums prepared for this project.
>
> This alignment was represented in the hydraulic model primarily using the "levee" feature that was added to represent the wall location across 11 modeled cross sections from Main Channel Sections 5+93 through 2+206[3]. A workmap including the barrier location in relation to the modeled cross sections is included as Figure 2[4].
>
> *EPB Alignment #2 in conjunction with EPB Extension #3A*
>
> An additional alignment providing flood protection for Mission Ranch was considered and would entail extension of the EPB to the east. The alignment was selected in a manner that it could afford protection to the improvements on the property, but still provide an outlet for flood flow release from the Mission Fields neighborhood in cases where the north overbank area is inundated.

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[3] Stations are used to label the modeled cross sections and are measured along the average flow paths for each of the modeled reaches. Stationing along the main channel is measured relative to the mouth of the river with the disconnected overbank stationing measured from their convergence with the main channel.

[4] The topographic data used for the workmap is consistent with the cross-section data from the currently-effective FEMA hydraulic model.

This alignment was represented in the hydraulic model primarily using the "levee" feature that was added to represent the barrier location across 13 modeled cross sections including Main Channel Sections 5+93 through 2+595 and North Overbank Sections 3+41 and 5+74. This alignment is also shown in Figure 2.

These alignments were selected for detailed hydraulic modeling as they would represent the maximum encroachment into the floodplain of all the EPB configurations. Therefore, they would be expected to frame the maximum potential impact to base flood elevations.

Each alignment was modeled with top of wall elevations of 16[5] and 19 feet (all elevations are presented in NAVD-88) for a total of 6 analyzed project alternatives, although the modeling confirmed that there are no differences from a riverine flood hazard perspective between the two top of wall elevations. Following the conventions of the FIS, each alignment was run for the three different potential flood conditions (levees intact, north bank levee failure, and south bank levee failure). The downstream tailwater condition was kept the same across all model runs.

Modeling Results and Conclusions

The modeled 100-year water surface elevations for the two EPB alignments are summarized in the attached Table 1.

Modeling results for EPB Alignment #2 predict that water surface elevations would be higher in the lagoon by an average of less than 0.01 feet in the immediate vicinity of the EPB relative to existing conditions during the 100-year flood event. The maximum increase is 0.02 feet at Section 22+06, located near the eastern end of the barrier in this alignment. Very minor increases in base flood elevations would extend upstream roughly to the western limit of the Carmel Area Wastewater District Treatment Plant. Base flood elevations are not predicted to increase in the north overbank area. Modeling results are identical for both the 16- and 19-foot elevation top of wall alternatives.

Modeling results for EPB Alignment #2 in conjunction with Extension #3A predict that water surface elevations would be higher than for EPB Alignment #2 as is expected with the larger floodplain encroachment. The maximum increase in the vicinity of the Fourth Addition would continue to be 0.02 feet at Station 22+06. The maximum increase in main channel BFE is predicted at Station 27+85, just downstream from the CAWD Treatment Plant, with the maximum increase adjacent to the plant shown as 0.04 feet at Station 29+72. BFE values in the north overbank would only be slightly higher immediately adjacent to the Mission Ranch property, with a maximum increase of 0.02 feet at the downstream-most Section 3+41. Again, modeling results are identical for both the 16- and 19-foot elevation top of wall alternatives as long as riverine flood flows are excluded by the EPB.

While the model does not explicitly assess potential impacts to flow patterns and erosion, the model does indicate that the lagoon along the proposed EPB alignment is in a relatively low

[5] The top of wall elevation of 16 feet would have to be increased slightly at the eastern end of Alignment Extensions #3A and #3B to avoid overtopping from flood flows moving through the north overbank. However, this alternative will be referred to herein as having a 16-foot top of wall.

energy environment due to the downstream flow restriction at the beach. The model estimates velocities across the impacted cross sections are low, averaging 1.4 feet/second, and are anticipated to be lower along the EPB away from the predominant flow path along the main channel.

Closing

Again, the results presented in this memo should be considered preliminary and are intended to inform the selection of key design considerations used to define a preferred interior drainage design alternative. After the preferred project alternative is identified, the associated design concepts and analyses will be refined and summarized in the Planning and Feasibility Analysis Report.

Do not hesitate to contact us if you have any questions or comments on the information presented in this memo.

Table 1. Modeled 100-year maximum water surface elevations for the analyzed Alternative #2A and extended EPB alignments

Cross-Section	Modeled 100-year Water Surface Elevations				
		16-foot Top of Wall Elevation		19-foot Top of Wall Elevation	
	Existing Conditions	Alignment #2A	Extended Alignment	Alignment #2A	Extended Alignment
	feet	*feet*	*feet*	*feet*	*feet*
Main Channel					
3+80	14.70	14.70	14.70	14.70	14.70
5+93	15.45	15.45	15.45	15.45	15.45
7+91	15.48	15.48	15.48	15.48	15.48
9+97	15.54	15.55	15.55	15.55	15.55
11+96	15.54	15.55	15.55	15.55	15.55
14+03	15.57	15.57	15.57	15.57	15.57
15+98	15.62	15.62	15.62	15.62	15.62
18+00	15.64	15.64	15.64	15.64	15.64
19+95	15.67	15.68	15.68	15.68	15.68
22+06	15.74	15.76	15.76	15.76	15.76
23+75	15.75	15.76	15.76	15.76	15.76
25+95	15.78	15.79	15.81	15.79	15.81
27+85	15.93	15.94	15.99	15.94	15.99
29+72	16.41	16.42	16.45	16.42	16.45
31+83	17.18	17.18	17.20	17.18	17.20
33+89	17.86	17.86	17.87	17.86	17.87
35+31	18.50	18.50	18.50	18.50	18.50
36+78	19.08	19.08	19.08	19.08	19.08
37+05	19.12	19.12	19.13	19.12	19.13
37+66	19.35	19.35	19.35	19.35	19.35
North Overbank					
3+41	15.99	15.99	16.01	15.99	16.01
5+74	16.67	16.67	16.53	16.67	16.53
8+22	17.50	17.50	17.47	17.50	17.47
10+84	19.12	19.12	19.12	19.12	19.12
12+65	20.34	20.34	20.34	20.34	20.34
14+09	20.37	20.37	20.37	20.37	20.37
15+06	20.38	20.38	20.38	20.38	20.38
16+40	20.63	20.63	20.64	20.63	20.63
South Overbank					
3+63	15.43	15.43	15.43	15.43	15.43
4+71	15.65	15.65	15.65	15.65	15.65
6+85	16.01	16.02	16.02	16.02	16.02
8+03	16.08	16.08	16.08	16.08	16.08
9+16	16.10	16.10	16.10	16.10	16.10
10+46	16.11	16.11	16.11	16.11	16.11
12+72	16.14	16.15	16.15	16.15	16.15
14+30	16.20	16.20	16.20	16.20	16.20
17+09	16.30	16.31	16.31	16.31	16.31
20+99	16.46	16.46	16.46	16.46	16.46
24+82	16.63	16.64	16.64	16.64	16.64
26+34	16.73	16.74	16.74	16.74	16.74
28+40	16.89	16.90	16.90	16.90	16.90

Notes:

1. Cross-section numbering as per the currently-effective FEMA hydraulic model. See Figure 2 for location of the cross-sections.

2. Note that the top of the EPB for the 16-foot alternative would be raised above the predicted 100-year water surface at Stations3+41 and 5+74 in the North Overbank to preclude flood flows from overtopping the EPB at the upstream end.

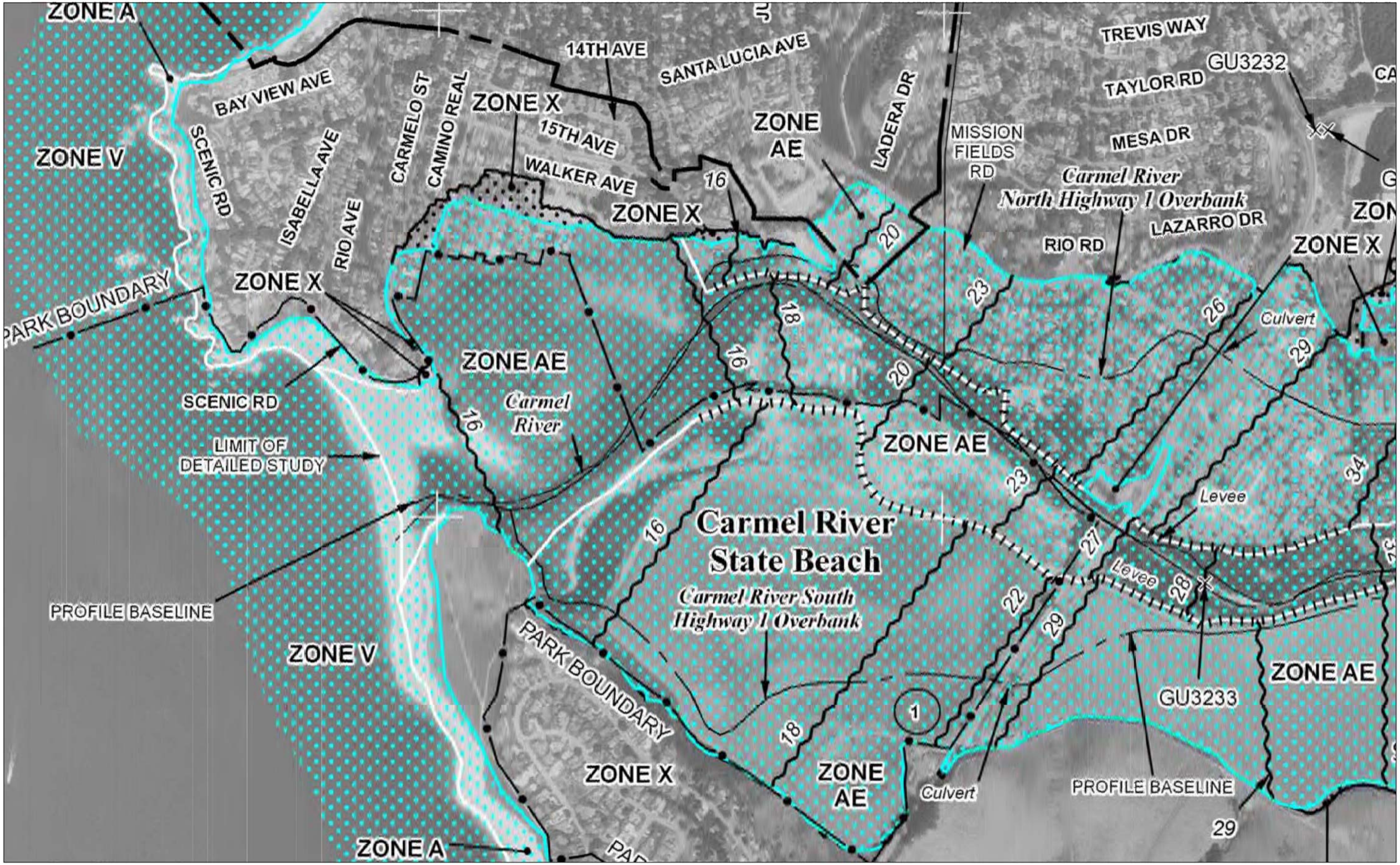

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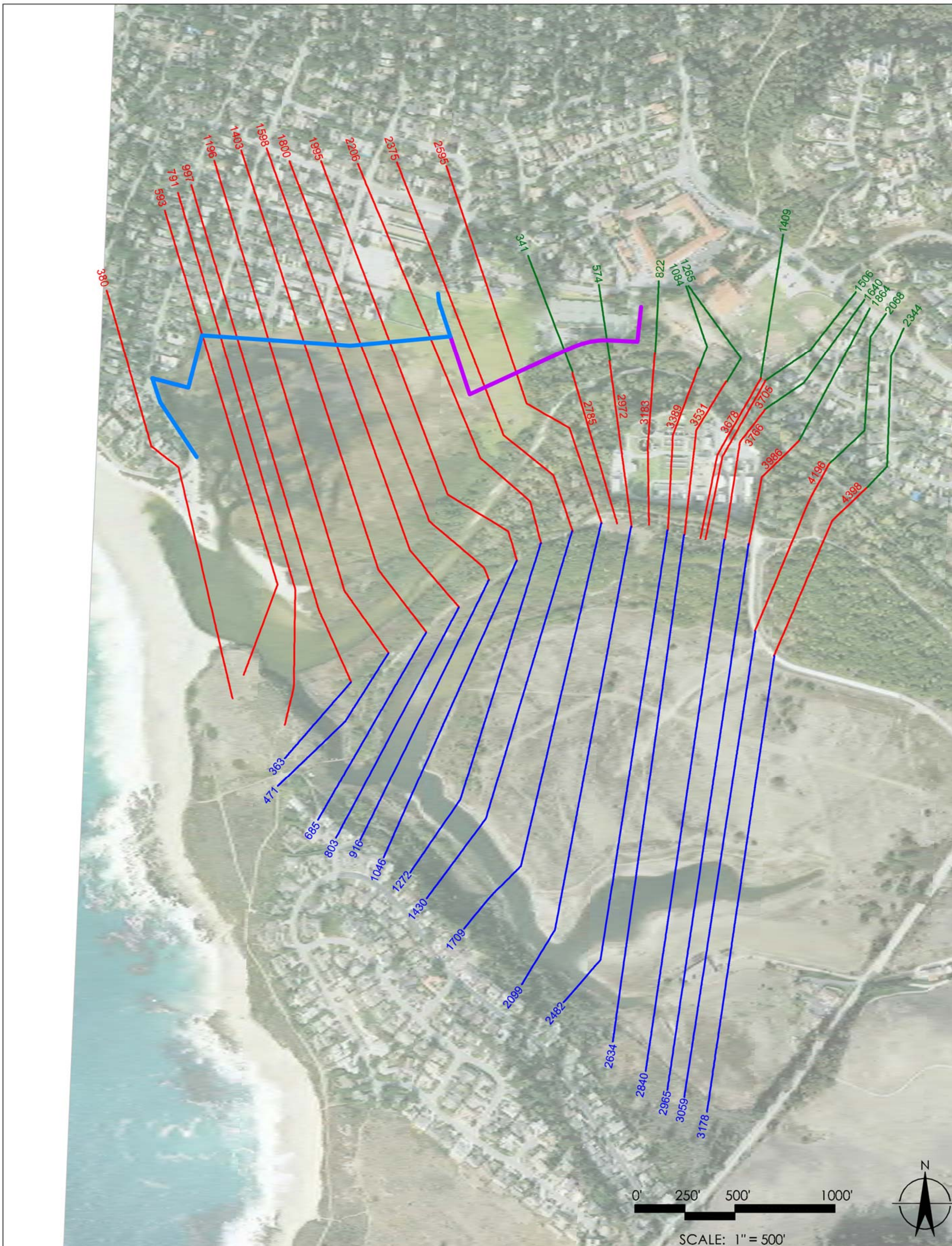
Figure 1. Detail from FEMA Flood Insurance Rate Map, Lower Carmel River Valley, County of Monterey.

Detail taken from FEMA FIRM Map Number 06053c0320G

211067 Hydraulics Workmap Figure 1.dwg



LEGEND

1265	NORTH OVERBANK FEMA CROSS-SECTION AND LABEL		ECOSYSTEM PROTECTIVE BARRIER ALIGNMENT #2
3389	MAIN CHANNEL FEMA CROSS-SECTION AND LABEL		ECOSYSTEM PROTECTIVE BARRIER EXTENSION #3A
2840	SOUTH OVERBANK FEMA CROSS-SECTION AND LABEL		

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Figure 2. HEC-RAS Model Workmap, Ecosystem Protection Barrier Project, County of Monterey

The Geomorphic Role of Riverine Processes in Carmel Lagoon Water Surface Elevation and Sand Bar Breaching Dynamics for the Carmel River-Lagoon Biological Assessment Report

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1.1 Project Description

Carmel Lagoon Ecosystem Protective Barrier (EPB), Scenic Road Protection Structure (SRPS), and Interim Sand bar Management Plan (ISMP) Project

The Carmel River Lagoon, located at the mouth of the Carmel River, is a very productive estuary which serves as rearing habitat for juvenile, federally listed South-Central California Coast steelhead. The Carmel River was designated as critical habitat for South-Central California Coast steelhead in September 2005. The ecosystem in and around the Carmel River Lagoon also supports other federally listed species such as the California red-legged frog, western snowy plover, and Smith's blue butterfly, and numerous other special-status species.

The Carmel River drains approximately 255 square miles of the Santa Lucia and Sierra de Salinas Mountains into the Carmel Bay. About 270 acres of the Carmel River Beach and Lagoon are owned by the State of California/California Department of Parks and Recreation (State Parks). Other property owners within the Lagoon include Carmel Area Wastewater District (16 acres), Carmel Unified School District (9 acres), City of Carmel-by-the-Sea (6 acres), and Homestead Inn/Mission Ranch (16 acres). Public and private stakeholders have worked together over the past decade to identify best management practices that would maintain the Carmel Lagoon in a more natural state (MPWMD, 2007).

The Carmel Lagoon Ecosystem Protective Barrier (EPB), Scenic Road Protection Structure (SRPS), and Interim Sand bar Management Plan (ISMP) Project (hereafter referred to as Project) is a comprehensive plan meant to promote improvement in ecological function of the Carmel Lagoon, including natural floodplain function and improvement of habitat for threatened and endangered species within the existing lagoon. The goal is to allow the lagoon to breach naturally, without increasing flood risk to private structures and public facilities. The EPB would provide protection from flooding to low-lying homes and other local Carmel-by-the-Sea infrastructure along the north edge of the Lagoon. The SRPS would provide protection along the northern sand cliffs from erosion associated with lagoon-ocean processes that might occur if sand bar management were to cease. The ISMP is an interim sand bar management plan meant to provide a short-term solution to potential flooding issues with select sand bar breaching actions that allow additional natural function in the lagoon while still protecting properties and infrastructure, with the understanding that the development of the EPB and SRPS lead to potential long-term solutions that return the Lagoon, its sand bar, and associated riverine and ocean dynamics to more natural cycles.

1.2 Purpose and Objectives of this Report

The main objective of this report is to summarize both natural and impaired processes associated with the Carmel River Lagoon ecosystem from a riverine perspective. To do so, we present a descriptive hydrologic characterization of (1) how lagoon systems function naturally in Coastal California, (2) how current and past management practices impair Coastal California lagoon systems, (3) a quantitative and qualitative assessment of recent Carmel Lagoon function, and (4) an assessment of how implementation of the Project will work to restore more-natural functions in Carmel Lagoon. The term lagoon will be used in this report to represent both lagoonal and estuarine functions (i.e., systems closed and open to the ocean, respectively). Quantitative measures will be identified where possible to supplement qualitative findings from this and other lagoon systems.

1.3 Literature Review

Existing literature was reviewed to understand how naturally functioning lagoon systems along Coastal California promote healthy ecosystems for aquatic species, including steelhead. Further literature review revealed information on how management practices can negatively affected lagoon habitat.

2 NATURALLY FUNCTIONING LAGOONS ALONG THE CALIFORNIA COAST

Lagoons found along Coastal California have unique qualities with respect to semi-arid Mediterranean climate conditions, geologically active tectonics, relatively small watershed areas, and riverine processes associated with frequency and duration of lagoon openings and closures (Jacobs, et al., 2011). Streamflow plays a critical role via seasonal and episodic variability in the temporal pattern of lagoon openings and closures, and thus has a large effect on specific geomorphic and environmental conditions such as sand bar breaching behavior, lagoon morphology during open and closed conditions, groundwater-surface water interactions, and habitat quality. Such conditions are key drivers in the ability of aquatic and terrestrial species to successfully survive and thrive within this environment.

2.1 Natural Sand Barrier Breaching Behavior

The dynamics associated with a natural sand bar breach depend on the morphology of the sand bar itself, river discharge, and wave dynamics (Smith, 1990). In a naturally functioning lagoon ecosystem on the California coast, sand bar breaching occurs during the winter rainy season. Streamflows increase as rains begin. Depending on the watershed and precipitation patterns, flows may fill the lagoon to the point where riverine forces overcome sand bar stability and an outflow channel breach is created that releases impounded waters into the ocean.

Sand bar breaching can occur via an accumulation of low flows or from an abruptly larger flood flow. The outflow channel, once open, additionally provides a route for tidal flows to enter the lagoon. The morphology and elevation of the outflow channel to the ocean are important factors in the availability of lagoon habitat (NMFS, 2008; Alley, 2013), while water surface elevation (WSE), volume and depth of the lagoon are functions of streamflow as well as tidal fluctuations and ocean swells.

When low flows fill a lagoon to its full volume and then breach the sand bar, a sinuous outflow channel can develop, creating a pathway based on beach slope, sediment size, and longshore wave patterns (Smith, 1990; Thornton, 2005). Large flow events on the other hand, may create a breach at a point perpendicular to the bar resulting in a shorter and more direct outlet to the sea. But once a flood flow diminishes, it is likely that the outlet will migrate toward a pathway based on beach slope, sediment size, and longshore wave patterns.

2.2 Natural Perched Lagoon Morphology

Perched lagoon morphology is defined by NMFS (2008) as a lagoon with a WSE above mean high tide, and can refer to fresh water lagoons with closed sand bars as well as to lagoons where fresh water flows out to the ocean over the sand bar at the lagoon's mouth. Summer wave action that tends to deposit sand onto beaches helps build up beach berms (Jacobs et al., 2011). This elevational increase can create perched lagoon morphology by formation of a high berm combined with an outflow channel that provides the greatest ratio of fresh water to saline water during open-bar dynamics, as well as providing the highest lagoon WSE upon closure.

2.3 Natural Closed Lagoon Conditions

In Coastal California environments, with their associated dry-Mediterranean summers, streamflow generally decreases through the spring and into the summer months. As flow recedes, riverine processes are progressively less able to overcome the opposing ocean forces driving sand up and onto the bar. Eventually, this leads to the seasonal closure of the barrier bar at a point when river and any (generally small) groundwater (GW) inflows to the lagoon system are not sufficient enough to maintain an open outflow channel. The WSE associated with the final lagoon closure of the year is related to the morphology of the lagoon and whether the outlet channel is in a perched or non-perched state. When the outflow channel is perched (i.e. at a higher elevation and in an advantageous position that maximizes fresh water lagoon habitat), the initial WSE will be higher, thus accumulating an increasingly higher ratio of fresh water to brackish water while river discharge continues.

Because tidal exchange occurs until a sand bar closes, saline waters are generally present within the lagoon at closing. Salt water is denser than fresh water and thus tends to stratify into the lower layers of a lagoon. Conversion from highly saline conditions to more fresh water conditions occurs when fresh water river discharge forces salt waters against the inland side of the closed sand bar (Coates and Guo, 2003; NMFS, 2008). Because of stratification, a forcing mechanism exists at the boundary between the two layers. The upper wedge of fresh water pushes the salt water wedge against the porous sand bar. If there are enough fresh water flows, three processes can occur: entrainment, which carries a mixture of fresh water and salt water into the ocean if a shallow or intermittent channel remains open to the ocean; mixing, which de-stratifies the lagoon and blends the stratified layers together, moderating salinity values; and seepage of salt water through the permeable sand bar and out of the lagoon (Smith, 1990; Debler and Imberger, 1996; NMFS, 2008; Zhang et al, 2008). All of these processes can play a role in the conversion of a lagoon to fresh water. The conversion can take more than a month after sand bar closure (Smith, 1990), and generally depends on continuation of fresh water flows into the lagoon.

An additional element in these complex systems is that of ocean waters entering the lagoon while the sand bar is closed. This occurs primarily through wave overtopping, but also through seepage into the lagoon through the sand bar—seepage can occur in either direction and is mainly a function of tides (Watson and Casagrande, 2004). Seepage out of the lagoon may happen when tides are out, while seepage into the lagoon may happen when tides bring waves onto the beach and against the sand bar.

Overtopping is a function of wave energy. Higher energy waves crash onto a sand bar and overtop it, adding small to large volumetric quantities of salt water to the lagoon (Thornton, 2005; Moffatt and Nichols, 2013). Along the California coast, wave energy decreases in the late spring and summer and increases in the fall and winter. The addition of salt water into the lagoon in late summer/early fall while the lagoon remains closed increases WSEs and salinity values in the lagoon, generally lowering water quality shortly before rains begin to contribute streamflows, which then provide relief with better water quality (Hayes et al., 2011).

2.4 Natural Surface Water-GW Interactions

Once a coastal lagoon is in a closed configuration, WSEs and water quality are governed by a balance of outflows (seepage through the bar and evaporation), the aforementioned salt water inflows, and fresh water inflows (stream baseflow and GW inflows).

With the degree of variability in Mediterranean climate conditions in California, most lagoon systems experience some degree of closure under natural conditions (Jacobs et al., 2011). From a fresh water fisheries perspective, ideal summer conditions would occur when waters of a closed lagoon system convert to fresh water before streamflows stop, be it in late spring or over the summer, depending on flow persistence. When streamflows cease, GW inflows from the local aquifer become the single source of additional fresh water influxes into the lagoon system, and must partially counteract evaporation rates and barrier bar seepage rates, at least to some degree, if fresh water conditions are to be maintained over the course of lagoon closure.

GW aquifer storage levels are predicated on antecedent hydrologic conditions of the previous and current year, and potentially over a longer time frame following drought conditions or excessive GW pumping. In a best-case scenario, there would be no GW pumping or instream diversions, and aquifer storage capacities would be at potential maximums depending on precipitation and runoff. In many Coastal California settings, GW storage has been greatly reduced by mechanical pumping of water for agriculture and municipal uses. At the bottom of a coastal watershed, salt water and fresh water 'compete', such that salt water can encroach landward into fresh water aquifers. When fresh water aquifers are full enough, gradients that push seaward generally keep salt water intrusions from encroaching into fresh GW supplies (Jacobs et al., 2011). When excessive GW pumping creates over-drafting of the aquifer, a fresh water gradient reversal can occur, and seawater intrusions can infiltrate into local coastal water supplies. Such dynamics are of great concern to coastal communities (e.g. Johnson, 2007). GW inflows into lagoons become important particularly once surface flows cease for the summer, and are the only counteractive to evapotranspiration in terms of fresh water inflows.

Persistent GW seepage likely occurred in lagoons along the coast prior to GW extractions and continues today in some systems, potentially providing fresh water supplies for good quality habitat during yearly lagoon closures. Pumping likely has reduced GW contributions to lagoon ecosystems, depending on local conditions (PWA, 2007). A comparison of two instances showed that a GW gradient indicating a small but valuable GW input rate relative to the potentially progressive decline in water quality through the dry summer months has been found in Carmel Lagoon (Larson et al., 2006), while numerous springs and seeps in the vicinity of Elkhorn Slough have disappeared since the 1940's, likely due to GW pumping (Van Dyke and Wasson, 2005).

2.5 Ecosystem Benefits of a Naturally Functional Lagoon

Naturally functioning lagoon ecosystems provide myriad, year-round benefits to aquatic and terrestrial species, including high habitat diversity, abundant invertebrate food sources, and refugia from predators and other environmental stressors (Cannatta, 1998). Steelhead thrive in conditions where abundant invertebrates are found (Larson et al., 2005). Tolerance capability of invertebrates to salinity provides a good indicator of the ability of the system to support good rearing habitat for steelhead (NMFS, 2008; pers. comm. J. Pearson-Meyer, 2013).

In California when lagoons are opened in the winter season by river discharge, full mixing of fresh water and salt water can provide opportunities for fish to thrive (Smith, 1990). When lagoons close at the beginning of the dry season, river discharge generally is still flowing at low rates, in which case with enough end-of-season inflow the lagoon can naturally convert from stratified saline conditions to fresh water conditions. In fresh water conditions, studies have shown that steelhead smolts have a higher survival rate and greater growth rates (Smith, 1990) as well as greater densities in lagoon systems (NMFS, 2008, Table 12). Steelhead smolt growth rates in Scott Creek Lagoon, California were higher than those rearing in the upper watershed, leading to conclusions that lagoon habitat conditions that promoted steelhead growth and survival were strong predictors of ocean survival (Hayes et al., 2008; Bond et al., 2008).

3 IMPLICATIONS OF IMPAIRED LAGOON BEHAVIOR

Lagoon ecosystems found along Coastal California have experienced high degrees of modification due to human interactions. Development of towns and cities and associated infrastructure has had multiple negative effects on these ecosystems (Van Dyke and Wasson, 2005). Impaired lagoon/estuarine ecosystems are not able to provide the full range of benefits to aquatic and terrestrial species that are required for healthy ecosystem function. Modifications leading to impaired lagoon ecosystem function include: alteration of the natural cyclical opening and closure of the lagoon by breaching and closing the sand bar artificially; encroachment onto the lagoon floodplain via infill, built structures, and agricultural uses; channelization of the river; diversions of streamflow; GW pumping; and loss of sediment supply via hardening of channel banks and damming.

Although each modification could be discussed in depth, this chapter will focus on alteration of the natural cyclical opening and closure of the lagoon by breaching and closing the sand bar artificially. The negative impacts associated with manipulation of natural barrier bar processes can propagate through each water year and potentially beyond, producing negative effects to bar morphology, sediment transport, water quality, and water volume in the coastal lagoons.

3.1 Impaired Sand Bar Breaching Behavior

Artificial barrier bar breaching can negatively affect lagoon health by promoting formation of a wide and deep outflow channel that removes large quantities of sand from the beach. This can cause fresh water to flush from a lagoon into the ocean prematurely and at a rapid rate, likely opening the lagoon earlier than if a natural breaching regime were in place. Once fresh water has been flushed, the often deep and direct outlet channel allows large quantities of seawater into the lagoon, which results in an abrupt increase in salinity levels that may not be tolerated by aquatic organisms, particularly juvenile fish.

Salinity gradients drive other water quality parameters such as temperature and dissolved oxygen. When salinity concentrations are high, lagoons stratify and the saline layer sinks to the bottom. Dissolved oxygen concentrations decrease, and high salinity promotes heat absorption, raising temperatures (NMFS, 2008). In Pescadero Creek, artificial sand bar breaching has led to steelhead die-offs, likely caused by very low dissolved oxygen concentrations (Smith, 1990; Sloan, 2006). Increased salinity can drive fish into shallower waters, exposing them to increased predation and potential stranding, forcing out-migration of fish before they are ready for the ocean environment, and decreasing productive lagoon habitat (Smith, 1990; NMFS, 2008).

3.2 Impaired Lagoon Morphology during Open Conditions

Since wave action continually moves sand onto and off of beaches, and streamflows may not be large enough to keep a breach open, there are instances where artificial breaching is performed multiple times a year in order to promote an open lagoon condition (Smith, 1990; e.g. MPWMD, 2013). This intermittent disruption of lagoon waters suggests that what should be equilibrium conditions within the lagoon prior to natural opening are instead punctuated with large spikes of abruptly changing water quality. Eventually, streamflows may be large enough to keep an outlet channel open, yet if the channel has been artificially placed, it is unknown where a natural channel would have formed, where it potentially would have moved to, or what geometry such channels would have had in the case where natural breaching occurred.

When artificial breaches are cut across a beach directly perpendicular to the river mouth, this practice could affect any further evolving morphology of the outflow channel and the remaining beach berm. This action could propagate through the year, leading to a situation where the outflow channel is at a low elevation and ocean water tidal flows are able to move freely into and out of the lagoon. Fresh waters that form a lens on top of saline waters could then be carried out to sea when tides recede. This process could continue throughout the yearly open cycle until the sand bar closes for the summer (J. Pearson-Meyers, pers. comm., 2013).

3.3 Impaired Conditions during Lagoon Closure

Salinity measures provide strong evidence of whether a lagoon has converted to fresh water after bar closure. If the outflow channel geometry brought about by artificial sand bar breaching is wide and deep, fresh water accumulating in the lagoon is largely flushed with each tidal cycle, precluding the ability of the lagoon to retain high quality aquatic habitat. This flushing occurs because fresh water is less dense than salt water, so if the outlet elevation is low, more of the stratified fresh water lens is preferentially removed. Atkinson (2010) found that artificial breaching in the San Gregorio Lagoon consistently raised salinity values at sampling stations.

If streamflows are low at lagoon closure, high salinity concentrations can create very poor quality habitat conditions very quickly, which can lead to fish die-offs (Sloan, 2006). Persistent flows are needed over a long enough period of time to convert the lagoon to relatively fresh water after seasonal closure. However, when beginning at a deficit compared to what natural conditions might provide conversion of the lagoon to a relatively fresh water condition may not be possible depending on a particular water year's streamflow condition and how long low flows persist upon closure.

Additional salinity impacts can emerge due to preferential evaporation of the fresh water lens and wave overtopping events, which occur regularly in fall and winter months along the California coast. GW becomes the only potential fresh water source once streamflows cease, a source that may be muted depending on local consumptive use and GW extraction practices. If so, an impaired GW condition can potentially magnify water quality impacts associated with outflow channel geometry brought about by artificial sand bar breaching.

3.4 Impaired GW-Surface Water Interactions

Lagoon WSEs are controlled by a number of factors when the barrier bar is closed including timing of riverine flow cessation, initial WSE at closure, GW supply in aquifer storage at the beginning of each dry-summer season, anticipated regional GW pumping, the hydraulic gradient of the GW aquifer and its relationship to sea level, through-bar seepage rates, and evaporation.

Lagoon WSE at the time of seasonal closure can have a direct effect on potential GW inflows, due to hydraulic gradient conditions at the coast between infiltrating seawater and fresh water aquifer storage (Johnson, 2007). If seawater intrusions are occurring, there is little chance that fresh water GW will be able to percolate out of the substrate. Lagoon stage and GW levels have been shown to have a strong correlation, as reported via Feeney (2002) in Watson and Casagrande (2004).

GW pumping can have negative effects on the overall watershed flow regime. These effects may manifest as early cessation of streamflows in early summer. A consequence may be diminished GW gradients, resulting in a reduction in GW flow into coastal lagoons if GW elevations were impaired by pumping. These considerations show that high WSE at lagoon closure is important because GW flows may not be consistent enough or of sufficient volume to help maintain lagoon water quality through a dry season.

3.5 Ecosystem Effects of an Impaired Lagoon

Artificial breaching at the beginning of the rainy season results in significant habitat losses that can reduce lagoon volume and area by as much as 80 percent of pre-breach values (Whitson, 2013). Depending on streamflow volume and breach timing, artificial breaching can occur hours to weeks prior to natural breaching. In all cases where artificial breaching occurs, aquatic habitat conditions are negatively affected. If an artificial breach creates high rates of lagoon emptying, juvenile steelhead can be pushed into the ocean prematurely (Allen, 2013). Smith (1990) found that after artificial breaching, some steelhead were flushed from lagoons but some also remained; differences in lagoon morphology and topography may play a role in the ability of fish to find refugia under these circumstances.

In San Gregorio Lagoon, California, a sampling program showed that water quality declined when the barrier bar was breached repeatedly in the summer, preventing maintenance of the lagoon as a body of relatively fresh water. Survival rates declined; seining found reduced numbers of steelhead from early summer to late fall, and dead threespine stickleback fishes were found stranded in dewatered sections of the lagoon (Atkinson, 2010).

In a study covering water quality and habitat conditions in lagoon ecosystems along California’s Central Coast, Smith (1990) concluded that the two most important management recommendations to promote high degrees of water and habitat quality were: (1) to pay close attention to the amount of streamflow diverted from the system, as a decrease in flows impacts the ability of lagoons to convert to fresh water conditions during the summer dry months, and (2) noted that in the case of the lagoon systems under study, Pescadero Creek, San Gregorio Creek, and Waddell Creek, artificial opening of the lagoons severely altered habitat conditions, adversely affecting steelhead abundance and growth rates.

This brief review of a small number of concepts and case studies is but an indication of the damage that has occurred in lagoon ecosystems due to modification and alteration of dynamic natural ecosystem regimes.

4 IMPAIRED PROCESSES IN CARMEL LAGOON

Having gained an appreciation of natural and impaired processes associated with Coastal California lagoons, a focused examination is now needed to understand how the Carmel River Lagoon ecosystem has been impacted by various management actions. Many studies have been conducted over the past 10 to 20 years to better grasp ecological conditions in the Carmel River watershed and the Carmel Lagoon (e.g. Watson et al., 2001; Watson and Casagrande, 2004; James, 2005; Thornton, 2005; Urquhart, 2013). Studies have been initiated in part by the Water Allocation Program Final Environmental Impact Report, prepared in 1990 for the Monterey Peninsula Water Management District (MPWMD), by subsequent California Environmental Quality Act monitoring requirements, which sought to insure compliance with mitigation measures (MPWMD, 2013), by the Caltrans mitigation bank project in 1997 that excavated the South Arm of the lagoon, and in order to document the Carmel River Lagoon Enhancement Project that excavate the South Arm an additional 3,000 feet toward Highway 1 in what is called the Odello West area (James, 2005).

The Carmel River Watershed has large variations in seasonal and yearly discharge rates, brought about in large part by the unique nature of the coastal California geographic location within a Mediterranean climate zone, as well as by the size, vertical extent, geology, and geomorphic structure of the watershed. Carmel Lagoon, located at the bottom of the watershed, serves as an ecological interface zone between the watershed and the ocean. The Lagoon is generally not connected to the ocean during times of very low or zero streamflow, when ocean waves build a barrier beach (sand bar) across the mouth of the lagoon and close the outflow channel. When river inflow is relatively low and the Lagoon is not open to the ocean, a dynamic equilibrium is reached between streamflow and groundwater inflows, outflow through the barrier beach, evapotranspiration, and ocean wave overtopping. In summer this leads to lower WSEs and in the fall prior to opening, abrupt increases in WSE can occur due to overtopping. As streamflows increase in the fall and early winter, Lagoon WSEs can rise to flood stage depending on precipitation patterns. When flooding does occur, infrastructure along the northern edge of the lagoon and within the Lagoon floodplain, are threatened before the sand bar would typically open naturally.

In response to the flooding scenario, since at least the early 20th century the sand bar has been mechanically managed (breached) in order to lower WSEs to below flood stage. Since 1973, emergency sand bar management has been carried out by the County of Monterey (County), Monterey County Water Resources Agency (MCWRA), and State Parks. On average in recent years, at least one artificial breach has occurred yearly, with as many as three or four management breaching actions occurring in some years. When the annual rainy season ends and the sand bar may have not yet closed off naturally, the decision may be made to mechanically close the sand bar before streamflows subside entirely, in order to maximize the volume of water in the lagoon for the dry season. This practice seeks to mitigate early-season artificial breaches that opened the Lagoon and promoted deeper, wider outflow channels than might otherwise have formed.

Following the designation of the Carmel Lagoon as critical habitat for South-Central California Coast steelhead in 2005, concern has grown about adverse impacts in Carmel Lagoon associated with artificial breaching activities that, while serving to protect local infrastructure, also dramatically alter natural ecosystem functions in the lagoon. The National Marine Fisheries Service (NMFS) suggested a northerly sand barrier breach in winter 2005, as this pathway is known to maintain a higher WSE in the lagoon, thus providing better habitat (MPWMD, 2007). The northerly outflow channel was considered a success in that WSEs in the Lagoon were maintained at a higher elevation at high river flows that reached upwards of 5,000 cfs. An unintended consequence of the northerly outlet path was that erosion occurred along the toe of the local bluff, potentially threatening homes and the Scenic Road in Carmel-by-the-Sea. The erosion of the bluff likely occurred because of the confluence of high flood flows and ocean wave activity creating waves 22 to 26 feet in elevation. The bluffs experienced sloughing once the waves receded. A similar event occurred in 2008 when the outlet channel was directed to the south. In that case, the northern bluffs were eroded in a similar fashion independent of flood flows and outlet channel position.

A technical advisory committee was formed to address maintaining the current level of protection for built infrastructure within the context of complying with the Endangered Species Act's requirements of reducing impacts to endangered species and returning the lagoon to a natural function state. The committee subsequently produced a long-term adaptive management plan for Carmel River State Beach and Lagoon (MPWMD, 2007). This document set in motion the development of potential solutions that would return the Lagoon to a more natural state that provides necessary ecological functionality for steelhead and other species that inhabit and depend on the system, while also ameliorating the potential increase in flood risk to surrounding infrastructure that could result from compliance with federal law. The current set of potential solutions is termed the Project in this document, as explained in the introduction. Technical studies including this one are addressing the complex natural, physical processes and interactions of the lagoon, beach, and ocean in order to provide the necessary studies needed for stakeholder to make informed decisions (e.g. Alley, 2013; Moffatt and Nichols, 2013; Whitson Engineers, 2013a,b).

From a riverine perspective, data associated with a 20-year record of Carmel River streamflows and Carmel Lagoon WSEs encompassing water years[1] (WY) 1993-2012, are presented in Appendices A and B. **Appendix A** contains WSE and streamflow data in graphical form. These figures and associated data in **Appendix B** can be used to compare general WY conditions, but should not be considered as an unimpaired dataset, as the Carmel River-Lagoon watershed has been heavily managed for decades, including within the timeframe of these data.

Summary statistics were collected into a series of tables and are reported herein as Tables 1-4. The tables consist of (1) flow and WSE values and relationships with lagoon breaching behavior, (2) WSE and lagoon surface area relationships pre- and post-breaching, (3) breaching events and days open to the ocean, (4) and lagoon closure dynamics.

Figure 1 of Appendix A, the WY2012 WSE and flow graphic, was annotated to help orient the reader with the information available in the 20 years of data found in Appendix A[2].

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[1] Water years (WYs) are defined as October 1 of the preceding calendar year through September 30 of the named year. For example, WY 2012 encompassed October 1, 2011 through September 30, 2012.

[2] Figure 1 annotation data on artificial breaching dates and closure dates were taken from the 2011-2012 Annual Report for the MPWMD Mitigation Program (MPWMD, 2013).

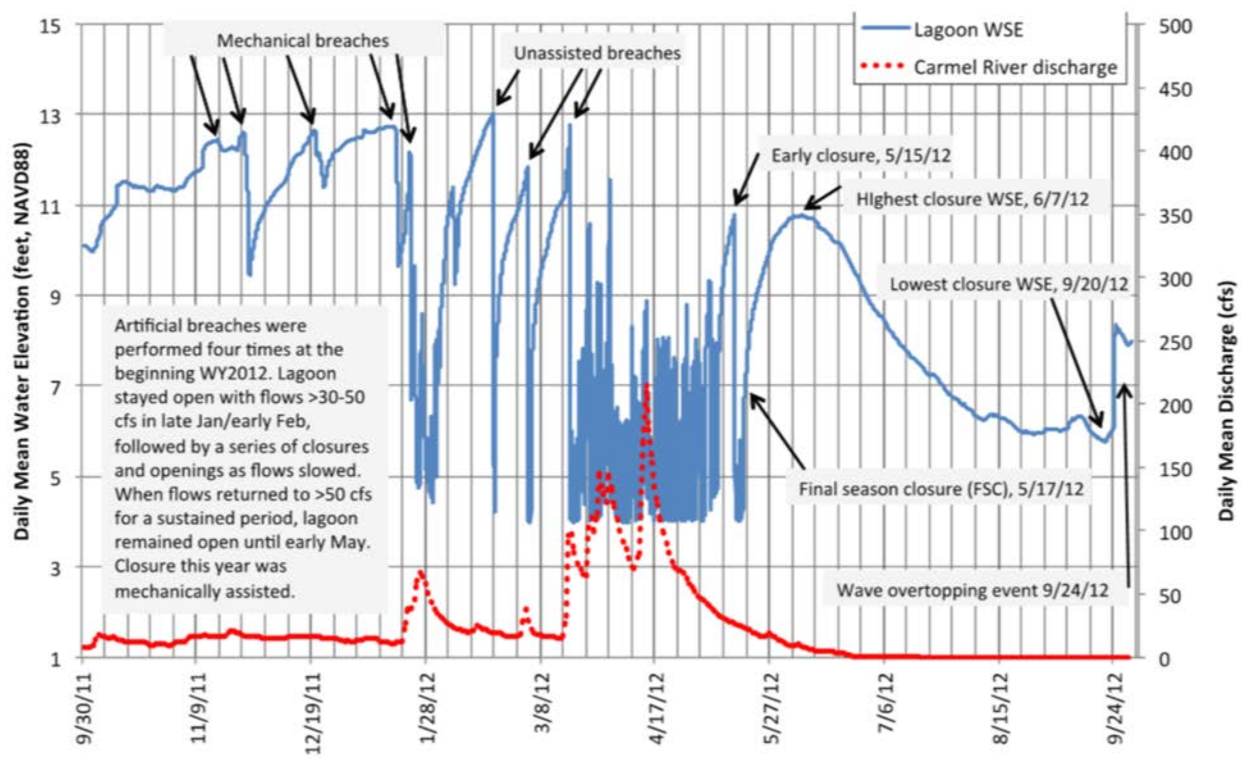

Figure 1. Water level in Carmel River Lagoon at south arm gage and flow in Carmel Rive at Highway 1 gage, water year 2012, Monterey County, California. Sources: Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

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Appendix B contains specific date, time, and WSEs related to all breaches and closures as defined below. When compiling Appendix B, thresholds were defined in order to produce a consistent dataset. All referenced WSEs are reported in the NAVD88 datum[3]. Definitions are provided in the notes section of each WY summary table in Appendix B, and are explained here as follows:

- "Sustained closure" is from October 1st of each WY until the first breach.
- In a "temporary breach", the lagoon remains open to tidal influences for < 7 consecutive days.

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[3] Water surface elevations (WSEs) in this study are based on the North American Vertical Datum of 1988 (NAVD88). Lagoon WSE is recorded in NGVD29, so all WSE records were adjusted upward by +2.74 feet based on information from the National Geodetic Survey. For instance, an NGVD29 elevation of 10.00 feet was adjusted to an NAVD88 elevation of 12.74 feet. Mean tide level in nearby Monterey Bay is 3.01 feet NAVD88.

- In a “sustained breach”, the lagoon remains open to tidal influences for > 7 consecutive days.
- “In-season closures” occur when lagoon WSE > 11 feet persists for > 24 consecutive hours during the winter-spring time period in each WY when the lagoon is generally persistently open to the ocean rather than in a dry-summer closed state.
- “Early closures” occur when the lagoon is mostly closed and WSEs increase to a point that would be considered a final closure, but then the lagoon opens up again briefly for about a week to a month prior to final closure.
- “Final seasonal closure” (FSC) is when the lagoon closes for the last time with receding river flow and does not open again until the following WY. The date chosen is when obvious tidal influences cease.
- A “significant increase” in WSE occurs only in the dry season, and is almost always associated with a wave-overtopping event, but can also occur due to river flow. In either case, a rapid increase in lagoon WSE of 1-foot was selected as ‘significant’.
- “Total days of closure” was calculated as the sum of the number of days between the start of a WY on October 1st and the initial breach, plus the number of days between final season closure and the end of the WY on September 30th, plus the number of days of temporary closures.

4.1 Deleterious Impacts Related to Artificial Sand Bar Breaching Behavior

The primary impacts related to the lagoon environment due to sand bar management and the artificial timing of lagoon breaching, are as follows: Impacted lagoon WSEs throughout the year during both open and closed conditions; rapidity and magnitude of lagoon drainage; extent of salt water intrusion; stratification dynamics in the lagoon; water quality in the lagoon; and habitat loss and deterioration for steelhead and California red-legged frogs, as well as other aquatic and terrestrial species. Further, physical impacts to the sand bar have a profound effect on: where the outlet channel forms and subsequently moves over the course of the open-lagoon condition; where river sediments transport offshore and deposit; where beach sands transport offshore and deposit. This leads to loss of sand necessary for the formation of the beach, bluffs and sand bars, and causes the breakdown or non-formation of natural protective barriers at the beach, bluffs and along the shoreline. All of these impacts will be discussed in greater detail in the following sections.

4.2 Impaired Conditions Related to Artificial Sand Bar Breaching Behavior

In the Carmel River-Lagoon ecosystem, among other similar Coastal California systems, riverine dynamics play an important role in lagoon dynamics and, at least to some degree, drive “whether, when, and for how long” the lagoon is open, while the formation of the sand bar beach and configuration of the outlet channel are somewhat more wave-dominated processes (Jacobs et al., 2011). The dual role of river processes and ocean dynamics can be seen in the Carmel Lagoon during California’s summer dry season, as streamflows dry up (in part due to GW extractions and streamflow diversions), and ocean forces deposit sands onto the beach that are structurally capable of keeping the lagoon closed. Likewise in the winter season, streamflows can gradually fill the lagoon and breach the sand barrier, or suddenly generate fresh water forces strong enough to overcome ocean forces for extended periods, depending on the timing, duration, and quantity of rainfall and runoff.

In the Carmel River Lagoon, artificial breaching has disrupted seasonal flow and sediment dynamics for decades, directly impacting aquatic and terrestrial habitat (PWA, 2007). Historical, artificial breaching actions have had consistently deleterious effects on Carmel Lagoon habitat conditions, which differ significantly from what would have occurred with a natural opening and closing regime (e.g., MPWMD, 2011).

Table 1 shows that in WYs 1993-2012, the first breach of each WY was mechanically assisted with the exception of WY2008. In WY2008the combination of flow conditions and wave action compromised safety. In WYs 1993-2000, management action generally occurred when WSE exceeded 11.5 feet (L. Hampson, pers. comm.), which assured that adjacent properties would not flood. From 2000-2010, management activities were not generally undertaken until lagoon WSE and streamflow forecasts showed that WSEs were likely to exceed 12.8 feet, the elevation at which houses would begin to flood. This threshold has gone up in recent years due to the adoption of adaptive management techniques including sandbag placement. Currently (WYs 2011 and 2012), a WSE of about 13.2 feet triggers breaching, with some room for maneuvering based on anticipated flow and/or wave action (CL-MOU-2012).

Table 1. Carmel Lagoon first seasonal breach of each year

Water Year[1]	Wate Year Type[2]	Date of first breach[3]	Days into WY	Mechanical or Natural[4]	Daily Mean Flow on day of breach	Date of assumed natural breach[5]	Days into WY	Days between mechancial breach and assumed natural opening of the lagoon outlet channel[6]	Number of days from first breach until lagoon summer closure[7]
		(date)	*(days)*		*(cfs)*	*(date)*	*(cfs)*		
2012	Dry	11/25/2011	56	Mechanical	18	12/16/2011	77	21	174
2011	Above Normal	11/24/2010	55	Mechanical	19	12/19/2010	80	25	238
2010	Above Normal	10/14/2009	14	Mechanical	759	10/14/2009	14	0	271
2009	Normal	2/16/2009	139	Mechanical	749	2/16/2009	139	0	91
2008	Normal	1/5/2008	97	Natural	509	1/5/2008	97	0	114
2007	Critically Dry	2/11/2007	134	Mechanical	29	2/16/2007	139	5	37
2006	Wet	12/28/2005	89	Mechanical	81	12/31/2006	92	3	170
2005	Wet	12/30/2004	91	Mechanical	532	12/30/2004	91	0	194
2004	Below Normal	12/30/2003	91	Mechanical	416	12/30/2003	91	0	120
2003	Normal	12/16/2002	77	Mechanical	1250	12/16/2002	77	0	197
2002	Below Normal	12/3/2001	64	Mechanical	402	12/3/2001	64	0	178
2001	Normal	1/11/2001	103	Mechanical	148	1/11/2001	103	0	141
2000	Above Normal	1/24/2000	116	Mechanical	1000	1/24/2000	116	0	100
1999	Normal	11/3/1998	34	Mechanical	21	11/23/1998	54	20	233
1998	Extremely Wet	12/6/1997	67	Mechanical	112	12/6/1997	67	0	270
1997	Above Normal	12/9/1996	70	Mechanical	27	12/10/1996	71	1	154
1996	Above Normal	12/13/1995	74	Mechanical	36	12/21/1995	82	8	184
1995	Extremely Wet	1/9/1995	101	Mechanical	445	1/9/1995	101	0	201
1994	Critically Dry	2/17/1994	140	Mechanical	106	2/18/1994	141	1	404
1993	Wet	1/3/1993	95	Mechanical	85	1/7/1993	99	4	173
Summary Statistics									
Average			85		337		90	4	182
Median			90		130		91	0	176
Maximum			140		1250		141	25	404
Minimum			14		18		14	0	37
Standard Deviation			33		367		30	8	79

Notes

1. Water Year (WY) is defined as October 1 of one year to September 30 of each subsequent year, for instance WY 2012 encompassed Oct 1, 2011 through September 30, 2012.
2. WY type as designated by MPWMD.
3. Date of first breach is defined as that in which the lagoon area > 2 feet in depth declines by > 20%.
4. The lagoon has been breached since the 1930's (CCoWS, Fall 2007), and in recent decades to prevent infrastructure flooding.
5. Date of assumed natural breach used an assumed seepage rate and known inflows that traced predicted changes in lagoon WSE and volume (Whitson Engineers, 2013b), and then calculating date of assumed breach, using a WSE of 15 feet as the arbitrary elevation at which breaching would occur.
6. Number of days where artificial breaching opened lagoon earlier than natural processes. Calculations were not performed in increments of less than a day.
7. First breach was mechanically initiated in each year of this analysis (with one exception in 2008 due to safety issues), even when days between mechanical and assumed natural opening of the outlet channel were zero.

An analysis of the day of mechanical breaching versus calculations estimating the day of natural breaching over WYs 1993-2012 showed that in nine of the 20 years analyzed (45% of the time), the lagoon was artificially breached at least one day earlier than the predictions calculated for the day of natural breaching. In three of those years artificial breaching occurred earlier than predicted by 20 days or more (Table 1). WYs 2011 and 2012 may have been anomalous, as alternative breaching techniques were being used to create shallow, pre-graded outlet channels rather than a wide and deep outlet channel, resulting in lagoon WSEs staying above 9 feet upon the initial breach, as shown in Figure 1 (MPWMD, 2013). Alternatively, in WY1993, 1994, 1996, and 1999 WSEs initially fell to about 5 feet, resulting in essentially full evacuation of the lagoon. Artificial breaching significantly reduces lagoon volume, which has a negative effect on volumetric and surface area habitat that remains following emptying (Casagrande et al., 2002). Whitson Engineers (2013b) calculated a volume of 13.7 acre-feet at 4.74 feet of WSE versus a 382 acre-foot estimate for total volume when WSEs are at 12.74 feet (i.e. near the current artificial breaching threshold; CL-MOU-2012). At elevations of 15.74 feet, which would allow higher WSEs than typical breaching patterns now but well below a 17.5-foot Project EPB top of wall, lagoon volume is estimated as 804 acre-feet. This suggests that the implementation of the project could more than double the volume of the lagoon at a maximum WSE of 15.74 feet, providing an example of the significant increase in WSE during closed conditions, and likely additional days of closed lagoon habitat.

Review of mean daily flow on the day of breaching (Table 1) shows that in the nine years in which artificial breaches were performed at least one day prior to calculated predictions of natural breaches, flows were less than 110 cfs in each case. For the Carmel River-Lagoon system, a conservative estimate was calculated by James (2005) suggesting that natural breach events would occur when flows were 200 cfs or greater. According to NMFS, analyses showed that in the years 1989-2010, approximately 80% of the time artificial breaching occurred at flows lower than 200 cfs, providing an indication that the lagoon has been prevented from functioning naturally during those times.

One might conclude from reviewing Table 1 that as long as flows are above approximately 200 cfs, there are no negative impacts associated with artificial breaching. This conclusion would be incorrect. Artificial breaching creates effects to the beach that may last for months to years, and which affect natural processes year-round. When the barrier bar is artificially breached in high-flow years, the breach is often made at the shortest distance between the lagoon and the ocean, generally due west (James, 2005). This initial opening may ‘set’ the beach with a structurally altered bar morphology, causing evacuation of sand via sediment transport mechanisms that may have otherwise remained on the beach. These altered physical processes and the associated inherent instability likely cannot be reinstated quickly by new sand filling in the breach. Consequently, this may alter the beach for the entire year, and potentially beyond.

As specified in Section 4.1, there are numerous deleterious effects from artificial sand bar breaching that extend far beyond the simple act of mechanically opening the sand bar. For instance, once the sand bar is mechanically breached, all subsequent lagoon WSE fluctuations and sand bar opening-closure scenarios could be considered impaired. In most years, this impairment causes the lagoon to empty rapidly due to the initial position of the mechanically created outlet channel. For example, when the outlet channel position and orientation is mid-bar and straight out to the ocean (a condition that would not have occurred naturally), salt water intrusion into the lagoon is extensive during the upper spikes in tidal fluctuations. This behavior is easily seen in the magnitude in WSE differences on a daily basis in the figures in Appendix A. Lowest recorded WSEs have shifted slightly over the years, likely due to new equipment placement. In recent years, the water surface drops below the pressure transducer at the gage station in the southern arm of the lagoon at about 4 feet NAVD (James, 2013, pers. comm.). Water volume evacuation from the lagoon is very extensive at these levels (Whitson Engineers, 2013b). These intense cycles create significant disturbances to stratification dynamics as the lagoon begins to close, with higher ratios of salt water intrusion preventing important oligohaline conditions (where a gradient of fresh water to saline conditions establishes appropriate salinity and habitat conditions for aquatic species at more than one shallow depth) to form at the appropriate time, as should happen when perched-lagoon conditions prevail and tidal influences are muted. Stratification rather than oligohaline conditions leads to poor water quality for steelhead, California red-legged frogs, and other aquatic and terrestrial species that depend upon fresh water conditions within the lagoon over the summer months.

Impairment caused by a reduction in the fresh water lens can eliminate the fresh water habitat provided by the lagoon and can create an inhospitable environment because of low water levels, high salinities and low dissolved oxygen concentrations. The influx of seawater creates a salinity-stratified lagoon and alters potential lagoon productivity as well as water quality because the availability of fresh water may become compromised. When the denser seawater that has breached into the lagoon naturally sinks within the water column, it pushes fresh water to the surface, creating a narrow, shallow fresh water lens. Then, during subsequent breaches or tidal fluctuations of inflow and outflow in those times when the lagoon is not in a perched configuration, there is a greater likelihood that the heavier salt water will remain in place while the upper fresh water lens gets mixed or drains away. This type of situation leads to poor habitat and water quality conditions, and the only area in the lagoon that remains viable steelhead habitat is the small, shallow fresh water lens at the lagoon surface coupled with what amount may be replenished via fresh water groundwater influx (Casagrande and others, 2002; Watson and Casagrande, 2004). These conditions do not lead to the oligohaline lagoon environment necessary to provide suitable habitat for steelhead and other aquatic species that over-summer in Carmel Lagoon.

From a physical perspective, mechanical breaching impacts the development and direction of an outlet channel that responds to ocean wave, longshore transport and riverine dynamics in its formation. Mechanical breaching does not allow natural development of the outlet channel in a physically-driven direction. With respect to a northerly position of the outlet channel, westerly mechanical breaching prevents delivery of riverine sediments just off-shore where such sediments might build up to attenuate wave dynamics against the northern bluffs. In addition, sand bar 'blow-out' results in loss of sand and gravels into the offshore canyon, rather than shoaling just off shore in the northerly direction. Removing or preventing offshore natural barriers to form increases the risk of ocean swells to the bluff and surrounding infrastructure. Lagoon seepage rates to the ocean may also be affected during the dry season due to removal of hardened sands on the lagoon side of the barrier bar that could potentially form. Mechanical breaching likely eliminates some of the potential for hardening of barrier beach sand on the lagoon side of the beach. Considering decades of artificial breaching—as illustrated very clearly over the last 20 years (Table 1)—it may take a number of years after artificial breaching ceases before the sand bar begins to behave naturally.

4.3 Impaired Lagoon Morphology during Open Conditions

Carmel Lagoon is primarily open to the ocean during each winter season (**Table 2**). The period of opening is directly related to flow conditions as well as to ocean dynamics (James, 2005; Jacobs et al., 2007). Occasional closures may occur as flows decrease near the end of the falling limb of a specific hydrograph (Appendix A), but this process is also dependent on the prevailing wet-season baseflow condition (which differs significantly from the dry season baseflow condition of 'no flow') and ocean dynamics. If average wet season baseflows are relatively elevated, closures are temporary, generally on the order of 2-7 days (Appendix B), but can occur multiple times a year depending on water year type and streamflow regime (Tables 1 and 2).

Table 2. Carmel Lagoon breaching events and days open to ocean

Water Year[1]	Number of artificial breaching events[2]	Number of other breaching events[3]	Wet season days open[4]	Wet season days closed[5]	Percent of time lagoon open to the ocean[6]
	(days)	*(days)*	*(days)*	*(days)*	*(%)*
2012	5	4	153	21	42
2011	5	0	227	12	62
2010	6	0	224	48	61
2009	1	2	87	5	24
2008	0	2	111	3	30
2007	1	3	21	17	6
2006	1	2	151	20	41
2005	1	0	193	2	53
2004	1	3	111	9	30
2003	1	1	197	1	54
2002	2	0	177	2	48
2001	1	0	142	0	39
2000	1	0	92	8	25
1999	8	0	196	38	54
1998	2	0	267	4	73
1997	1	0	155	0	42
1996	3	0	180	4	49
1995	1	0	202	0	55
1994	1	2	35	5	10
1993	1	1	172	2	47
Summary Statistics					
Average	2	1	155	10	42
Median	1	0	164	5	45
Maximum	8	4	267	48	73
Minimum	0	0	21	0	6
Standard Deviation	2	1	63	13	17

Notes

1. Water Year (WY) is defined as October 1 of one year to September 30 of each subsequent year, for instance WY 2012 encompassed Oct 1, 2011 through September 30, 2012.
2. Artificial breaching events were counted as (a) first breach of the year unless reported otherwise, and (b) when reports indicated additional mechanical breaches.
3. Other breaching events were counted when wet season lagoon closures were (a) > 1-2 days and (b) when flows were > 50 cfs prior to next opening (generally unassisted openings when later in the year)
4. Wet season days open is defined as number of days from first breach to final closure, not counting wet season days closed.
5. Wet season days closed is defined as those days when WSE remained > 11 feet (NAVD88) for longer than 24 hours.
6. Percent of time WY lagoon open to the ocean is defined as wet season days open minus wet season days closed divided by 365 days per year times 100.

In an unimpaired state, one might expect the days of open lagoon conditions to have the two following characteristics: (1) a long, sinuous outlet channel that prevents tides from rushing in and out of the lagoon and creating large WSE fluctuations that have adverse effects on water quality, and (2) a perched WSE condition in the lagoon such that the lower limit of WSE remains above the mean high tide elevation. Combined, these two states allow important fluxes (i.e. flow, sediment, salt water) to move into and out of the lagoon at a rate and intensity that is within the natural variability of the system, unlike those to which the lagoon has been subjected with sand bar management techniques of the past decades. When the conditions are such that the outlet channel is mechanically created in a pathway that would not have happened naturally and thus the lagoon is not in a perched state, the deleterious effects as enumerated in Section 4.1 and discussed in the last two paragraphs of Section 4.2

greatly affect natural lagoon functions. The fact that the lagoon is open to the ocean on average about 40-45% of each WY (Table 2) provides an indication of the proportion of the year when open-lagoon conditions that may be negatively affected by mechanical breaching. Further, impaired open conditions need directly to impaired closed conditions, a topic of discussion in Section 4.4.

Streamflows can be large enough to fill the lagoon rapidly (see Appendix A for a visual depiction of streamflows and lagoon WSEs for each WY 1993-2000), and then depending on continuing streamflows (whether large or small, both can be drivers of openings), the outflow channel stays open or ocean forces begin to overcome riverine processes. The sand bar can remain in place for some period of time or can open up and then reform when flows are low, as it takes a longer period of time to increase lagoon volumes and WSE to the point of the next breaching. This process is illustrated most clearly in the critically dry WYs of 1994 and 2007 (Appendix A, Figures 19 and 6, respectively). In WY2007, peak flow was low and overall yearly discharge was low, so lagoon openings were limited in duration and largely dominated by ocean processes working to deposit sand and close the lagoon. A slightly different pattern can be seen in WY1994, where the peak flow was large but quite short in duration and with total yearly discharge low also, resulting in a very similar short seasonal opening pattern for the lagoon.

The ideal lagoon morphology during open conditions would be to retain a perched condition, where lagoon WSEs of greater than about 6 feet persist when mean high tides are in, providing a minimum of about 41 acre-feet of volume (Whitson Engineers, 2013b). WY2005 (Appendix A, Figure 8) is an example of the ability of the lagoon to retain a WSE of greater than 6 feet. WY2005 represents the only WY in which WSEs remained above 6 feet for the entire lagoon opening, so in 19 of 20 years, perched conditions in the lagoon were not achieved.

In WY2005, Monterey County graded an outlet channel along a “non-traditional” north-northwesterly alignment based on consultation with National Oceanic and Atmospheric Administration National Marine Fisheries Service (NMFS). The intent was that channel alignment would result in a decrease in both the rate of lagoon draw-down and a reduction in the total drop in lagoon level, thereby reducing impacts to the newly federally listed steelhead and the lagoon habitat that provides critical ecosystem functions for them. The longer more sinuous breach channel moderated flow rates and limited the total volume of lagoon draw-down. The project was a success, as lagoon WSEs maintained an extra foot or so in elevation throughout the entire lagoon open period, improving habitat quality and volume. In at least five years over the period 1993-2005, the outflow channel has been intentionally directly away from the north end of the beach to avoid exposing the bluff area along Scenic Drive to erosive forces (MPWMD, 2007). This type of intervention would not be necessary with the Project SRPS in place, which would be intended to provide protection from erosion to Scenic Drive and local properties that sit atop the bluff.

When a perched morphology is not maintained and WSEs dip to 5 feet, approximately 14 acre-feet of lagoon water volume remains, a 65 percent reduction in volume compared to an elevation of 6 feet associated with a perched morphology. This reduction occurs when habitat quality is likely tenuous due to large quantities of fresh water evacuating the lagoon and flowing out to the ocean. Conversely, as tides come in, the outlet channel provides a pathway for salt water ingress. When fresh water streamflows are adequate, thorough mixing of the two—fresh water and salt water—prevents stratification and provides good quality habitat (Smith, 1990). When fresh water flows are not adequate, salt water influx raises salinity concentrations to levels that juvenile steelhead may not be able to tolerate (NMFS, 2008).

Another impact of the inability of the lagoon to maintain a perched morphology due to artificial breaching is that as much as 80 percent of lagoon surface area > 3 feet in depth is flushed from the system when the sand bar breach runs directly westward (**Table 3**). This depth within the lagoon habitat zone is particularly important for juvenile steelhead, as they become more susceptible to predation and thermal stress in shallow waters.

The rate of lagoon draining presents additional issues for salmonids and other aquatic organisms (**Table 3**). Rapid evacuation of lagoon waters can force fish into shallower waters, exposing them to increased predation and potential stranding in addition to forcing out-migration of fish before they are ready for the ocean environment (Smith, 1990; NMFS, 2008; Atkinson, 2010).

Table 3. Carmel Lagoon water surface elevations and estuary surface areas pre- and post-breaching

Water Year[1]	WSE before breaching, NAVD88[2]	Estuary surface area before breaching	WSE after breaching, NAVD88	Estuary surface area after breaching[3]	Rate of lagoon draining
	(ft)	*(acres)*	*(ft)*	*(acres)*	*(ft/hr)*
2012	12.2	69.9	6.7	8.6	0.7
2011	11.8	63.8	6.7	8.6	0.2
2010	13.3	89.3	6.1	5.7	1.5
2009	13.1	86.7	6.1	5.6	2.2
2008	15.4	135.1	5.9	5.6	1.2
2007	11.5	58.3	8.8	25.3	0.3
2006	11.4	56.8	6.4	7.1	0.0
2005	13.0	85.2	7.3	12.1	0.0
2004	13.2	88.7	6.1	5.6	0.7
2003	13.6	95.1	7.1	11.3	2.1
2002	13.4	92.0	5.6	3.9	0.9
2001	14.8	120.9	5.5	3.3	2.2
2000	14.1	105.2	6.9	9.5	0.4
1999	12.8	80.0	5.0	2.1	0.4
1998	12.4	73.1	6.6	7.9	0.4
1997	12.3	72.8	8.3	20.5	0.3
1996	11.7	61.9	5.7	3.9	1.1
1995	10.5	44.8	6.4	7.0	0.1
1994	11.7	62.1	6.5	7.3	0.1
1993	12.7	79.8	6.2	6.2	0.8
Summary Statistics					
Average	12.7	81.1	6.5	8.4	0.8
Median	12.7	79.9	6.4	7.1	0.6
Maximum	15.4	135.1	8.8	25.3	2.2
Minimum	10.5	44.8	5.0	2.1	0.0
Standard Deviation	1.2	22.1	0.9	5.6	0.7

Notes

1. Water Year (WY) is defined as October 1 of one year to September 30 of each subsequent year, for instance WY 2012 encompassed Oct 1, 2011 through September 30, 2012.
2. First breach of the year.
3. Surface area with depth > 3 feet, suitable for steeelhead habitat.

4.4 Impaired Conditions at Lagoon Closure

Carmel Lagoon has exhibited an impaired condition at lagoon closure in at least 17 of 20 years between WYs 1993-2012 (**Table 4 and 5**; Appendix A) because perched lagoon morphology was not present at that time, thus impeding the development and maintenance of high quality habitat for steelhead and other species during closed conditions in the lagoon.

NMFS and CDFW have indicated that a lagoon WSE of 6.74 NAVD88 (4 feet NGVD29) to 12.74 feet (10 feet NGVD29) is an optimal range for good quality habitat for steelhead (MPWMD, 2011), whereas in most of the recent years between WYs 1993-2012, closure WSEs have measured within the 4-foot to 5-foot range. Table 5 presents the lowest WSE prior to final season closure for these years. If the threshold of 6.74 feet is considered as the minimum WSE to qualify closure conditions as perched, then only one year, WY1998, would qualify as having closed with a perched condition. Conversations with NMFS have indicated that WY2005 exhibited a perched condition for the entire open cycle, so if that lowest WSE prior to closure would be selected as defining a perched condition, the WSE threshold would be 5.89 feet. To provide for uncertainties in WSE measures, it may be reasonable to set a WSE threshold of 5.75 feet as potentially qualifying as a perched condition at closing, although it is important to note that this value is 1 foot below the optimal range indicated by NMFS and CDFW. Using this criterion—defining 5.75 feet as lowest WSE prior to closing to constitute perched lagoon morphology—only three WYs qualify as perched: WYs 1998, 2000, and 2005.

Table 4. Carmel Lagoon final season closure dynamics

Water Year[1]	Date of final seasonal closure[2]	Days into WY	Daily Mean Flow at Closure	Highest WSE During Seasonal Closure	Lowest WSE During Seasonal Closure	Time Lagoon Closed in Dry Season	Annual Time Closed[3]
	(date)	*(days)*	*(cfs)*	*(ft)*	*(ft)*	*(days)*	*(%)*
2012	5/17/2012	229	25	10.8	5.8	191	58
2011	7/20/2011	292	28	9.7	8.2	126	38
2010	7/12/2010	284	28	10.2	6.3	93	39
2009	5/18/2009	229	25	11.4	6.3	273	76
2008	4/28/2008	210	17	11.0	5.9	251	70
2007	3/20/2007	170	27	12.3	5.3	327	94
2006	6/16/2006	258	46	10.1	6.3	194	59
2005	7/12/2005	284	15	8.7	5.8	170	47
2004	4/28/2004	210	15	10.0	5.1	245	70
2003	7/1/2003	273	10	8.0	5.4	167	46
2002	5/30/2002	241	12	10.0	5.3	186	52
2001	6/1/2001	243	14	9.9	5.6	223	61
2000	5/3/2000	215	73	10.7	5.7	265	75
1999	6/24/1999	266	17	10.5	5.4	131	46
1998	9/2/1998	336	18	8.9	7.2	94	27
1997	5/12/1997	223	24	9.9	5.5	210	58
1996	6/14/1996	257	13	10.4	5.5	181	51
1995	7/29/1995	301	15	9.4	5.6	163	45
1994	3/28/1995	178	19	10.7	5.4	325	90
1993	6/25/1993	267	18	8.8	5.5	191	53
Summary Statistics							
Average		248	23	10.1	5.8	200	58
Median		250	18	10.1	5.6	191	55
Maximum		336	73	12.3	8.2	327	94
Minimum		170	10	8.0	5.1	93	27
Standard Deviation		42	14	1.0	0.7	66	17

Notes

1. Water Year (WY) is defined as October 1 of one year to September 30 of each subsequent year, for instance WY 2012 encompassed Oct 1, 2011 through September 30, 2012.
2. Date of final seasonal closure is the latest date in the WY on which the lagoon is no longer subject to tidal influences.
3. Annual time closed is defined as the sum of time lagooon closed in dry season plus the number of days closed in the wet season (see Table 2 also).

Table 5. Carmel Lagoon perched morphology dynamics

Date of lowest WSE before closing	Lowest WSE (ft) before closing	Mean daily flow (cfs) at lowest WSE before closing
(date)	*(ft)*	*(cfs)*
5/17/2012	4.01	25
7/25/2011	4.04	26
7/12/2010	4.07	28
5/17/2009	4.10	26
4/27/2008	4.11	19
3/20/2007	4.13	27
6/14/2006	4.41	51
7/11/2005	5.89	16
4/28/2004	5.52	15
6/28/2003	5.06	13
5/29/2002	5.27	15
5/31/2001	5.00	16
4/16/2000	5.76	78
6/18/1999	5.27	26
6/9/1998	6.91	190
5/10/1997	5.59	25
6/11/1996	5.37	16
6/20/1995	5.38	85
3/28/1994	5.71	19
6/25/1993	5.56	18
Summary Statistics		
Average	5.1	37
Median	5.3	25
Maximum	6.9	190
Minimum	4.0	13
Standard Deviation	0.8	41

Considering the three qualifying WYs more closely (see Appendix A for graphical representation), WY1998 was dominated by riverine processes very late into the spring with a mean daily flow rate of 190 cfs on the day of lowest WSE prior to closure. Flows did not cease the entire summer, so it is very likely that fresh water conditions and a mixed lagoon environment prevailed through the dry closure season. In WY2000, a late flow peak likely helped fill the lagoon with fresh water as the sand bar closed, providing a perched condition and relatively large ratio of fresh water to salt water at time of closure. Flows in this year continued into late July, so it is likely that a mixed lagoon environment prevailed through at least the beginning of the dry closure season.

What makes WY2005 notable in terms of perched conditions is that WSEs were maintained at elevated levels for the entire open condition of the WY, as well as closing at a high WSE, thus providing a much enhanced fresh water condition for steelhead through the year. This season-long condition was very likely a direct result of the lagoon outflow pathway being directed to the north, thus maintaining an elevated WSE with sand bar morphology playing a primary role in this condition.

In an effort to address other primary water balance parameters related to hydrologic processes in the lagoon, a few points related to seepage and evaporation follow. Seepage rates from the lagoon into the barrier bar have been estimated as 8 and 12 cfs, which convert to 8 and 12 acre-feet of outflow per day if considering tides are out 50 percent of the time. These values were calculated for WY2005 and WY2009, respectively, when lagoon WSEs were on the order of 10.5 to 11.5 feet (MPWMD, 2011). The increase in seepage flow rates was conjectured to be due to artificial closure of the lagoon barrier bar at a higher elevation in WY2009, and possibly aided by additional lagoon storage capacity after the two South Arm phases of lagoon restoration were completed. Seepage rates of ocean water into the lagoon are unknown; overtopping events are the largest water influx into the lagoon in late fall (Appendix A and B).

Evaporation from the exposed areal water surface contributes to lower WSEs and potentially higher salinity concentrations. Carmel River Lagoon and the Lower Carmel Valley are classified in the evapotranspiration zone of upland central coast and Los Angeles basin in the California Irrigation Management Information System (CIMIS, 2010). Evapotranspiration rates for this zone average from a high of 6.51 inches/month in July to a low of 1.86 inches/month in January, for a total rate of 49.7 inches/year. Losses via seepage were estimated to be about 10 times greater than evaporation rates (Watson and Casagrande, 2004), so while this is a water balance output, it is relatively small.

4.5 Impaired GW-Surface Water Interactions

GW is pumped from the Lower Carmel River aquifer for consumptive uses. In past years, the shallow water aquifer has been pumped at a rate of about 11,000 acre-feet per year (PWA, 2007), while current GW withdrawals in the Lower Carmel Valley are on the order of 8,000-10,000 acre-feet per year from source areas AS3 and AS4 (MPWMD, 2011; MPWMD, 2013). AS3 and AS4 are the areas which correspond to the aquifer near the lagoon. Monitoring wells are located at three elevations within the near-shore aquifer and near the salt water-fresh water interface (Watson and Casagrande, 2004).

GW-surface water interactions are necessary to provide fresh water additions to the lagoon during closed conditions, as there are no other fresh water sources available once flows cease in the river. The ability of the aquifer to fill to a higher GW elevation is impaired if the lagoon has been mechanically breached throughout the wet season, as more fresh water is directed seaward rather than backwatering within and upstream of the lagoon, and percolating into the aquifer. Thus, the effects of breaching may lead to 2 or more feet of loss to GW elevation in the local aquifer, depending on position, and can cause the lower Carmel River surface flow to dry back and go subsurface at an earlier date. Lowered GW elevations can significantly reduce the amount of GW flow into the lagoon after surface flows have ceased, thus effecting summer habitat conditions. NOAA staff worked up an approximate estimate of the GW lost due to mechanical breaching from storage in the aquifer by using a storativity value (percent of water stored per unit of volume) for the local aquifer along with lower aquifer acreage and a conservative change in aquifer elevation. For Carmel Lagoon, the GW aquifer surrounding and upstream of the lagoon potentially affected by lagoon levels was approximated as 1,400 acres. The storativity value for the local aquifer was roughly estimated as 0.2, or 20% of the volume (NOAA staff pers. comm. with Martin Feeney, 2003). A 2 feet of loss in aquifer elevation in the wet season was used by NOAA as potential GW losses. Thus, NOAA developed a calculation of 1400 acres * 0.2 storativity * 2 feet in aquifer elevation loss = 560 acre-feet of potential GW loss due to mechanical breaching activities, with potentially different magnitudes of loss if any of the variables are different than this assumed set. Further, as the fresh water lens diminishes due to evaporation and seepage, a higher initial GW elevation provides a more robust fresh water supply throughout the dry summer months and into late fall and early winter until rains begin again. A more robust GW-surface water connection provides higher water quality during closed conditions.

A restoration project to create additional lagoon volume by digging out the Odello West extension of the South Arm of Carmel Lagoon uncovered a fresh water spring in the far-eastern finger of the project site (Larson et al., 2006, see Fig. 4-5, Fig. 4-6). Subsequent salinity sampling showed that a strong linear relationship exists between increases in salinity and distance from the spring. A similar linear relationship was found from the South Arm to the river channel.

Varying degrees of fresh water lens development have been documented in studies conducted in recent years (i.e. Larson et al., 2006). In Anderson et al. (see Figure 3, 2007), a longitudinal profile of salinity and other water quality parameters from data collected in late October to early November, 2007, showed that the freshest water, at an acceptable salinity concentration of 2 ppt, was found only in the far-eastern corner of the Odello West South Arm. In Castorini et al. (see Figure 8, 2008), a longitudinal profile of salinity and other water quality parameters from data collected on October 9, 2008, indicated that a fresh water lens with a salinity concentration of 2 ppt was found spread over a larger area than in 2007, extending almost to the pipe in the South Arm. In both years a small fresh water lens was detected in the far North Arm also, suggesting that GW springs may exist at both ends of the lagoon, potentially providing some measure of refugia during the dry season.

Although fresh water has been documented as present in the lagoon late in the dry season, the areas in which it is found are small, likely leading to increased competition between and among species for available food sources. It is quite possible that higher initial closure elevations (as was the case in WY2007 and WY2008), persistent streamflows further into the summer, and more GW inflows would result in greater volumes of fresh water throughout the dry season, creating high quality over-summer habitat by promoting growth of invertebrates that are primary steelhead food sources.

4.6 Impaired Conditions Related to Carmel Lagoon Ecosystem Health

Carmel Lagoon has been altered and modified for decades. Built infrastructure encroaches onto the lagoon floodplain as well as along much of the Carmel River corridor within the Lower Carmel Valley. The sand bar barrier between the lagoon and ocean is artificially manipulated on a consistent, yearly basis, causing evacuation of lagoon waters early in the WY. This results in tidally-open conditions that significantly increase flushing of fresh water from the system on a daily tidal basis, and closure conditions where a high ratio of highly saline ocean waters are present. Further, mechanical breaching disrupts formation of the outlet channel and sediment transport. Reestablishment of the natural beach-river transport regime is particularly important in order for sands to replenish the longshore bar to the north, which will then provide natural protection via wave energy dissipation especially during long period, large swell events. Such build-up of the longshore bar will eventually help to attenuate bluff erosion.

Upon closure, stratification of the lagoon persists until and if conversion to fresh water is achieved (NMFS, 2008). GW pumping is prevalent, extracting more water than is replenishing via infiltration and percolation into the aquifer on a yearly basis, and thus the aquifer is unable to supply as much GW inflow to the lagoon as in an unimpaired situation.

During the onset of stratified conditions, some habitat is present for juvenile steelhead in the shallow fresh water lens situated on top of the more saline lower lens. The ability of juveniles to utilize the entire water column in the lagoon is restricted by the highly saline, low dissolved oxygen, and higher temperature conditions in the lower lens. Aquatic invertebrate densities, the prey base for juvenile steelhead, are negatively correlated with increasing salinity. When conversion of a lagoon to fresh water is complete, steelhead have more abundant space and a broader prey-base leading to greater survival and growth rates (NMFS, 2008).

Steelhead run numbers are low in the Carmel River. The impact of current sand bar management activities lowers the quality of critically needed S-CCC steelhead habitat, negatively affecting the likelihood of S-CCC steelhead survival and recovery.

Restructuring the management of the lagoon sand bar to more closely resemble the natural physical processes and hydrologic cycle of the lagoon is necessary to minimize and avoid adverse effects to critical habitat in the lagoon year-round, as well as to minimize the direct loss of S-CCC steelhead juveniles when the lagoon drains quickly to the ocean.

5 ANTICIPATED RESPONSE OF CARMEL LAGOON TO PROJECT IMPLEMENTATION

In 2010, the MCWRA submitted an application to the USACE for a permit to manage the sand bar. In September 2011, Monterey County (RMA/Public Works) assumed a lead role for the Carmel Lagoon management. The USACE consulted with NMFS through the required section 7 consultation process under the federal ESA. During the consultation process, the NMFS affirmed that annual artificial breaching as proposed in the permit application would likely adversely affect S-CCC steelhead and destroy and adversely modify its critical habitat, and, therefore, a Jeopardy Opinion (JO) would be issued. A meeting with the NMFS and USACE to better define a solution to artificial breaching identified that the EPB and SRPS projects are viewed as their preferred projects with a means to achieving the following objectives:

- To improve the functions and values of the ecosystem in and around the Lagoon by allowing lagoon levels to rise and the lagoon to breach naturally (versus mechanically breaching the Lagoon)

- To reduce potential flood risks for existing public facilities and private structures in the low-lying developed areas located immediately to the north of, and within, the Lagoon as a result of predicted sea level rise during the next 50 years and reduction in mechanical breaching.

- To protect public infrastructure (e.g., Scenic Road embankment, State Parks restroom and parking facilities) from storm surge and scour resulting from a northerly-aligned channel.

The USACE and NMFS informed the MCWRA and County that issuance of a JO could be avoided if the application was withdrawn and a new application was filed for the EPB and SRPS projects. Therefore, the County withdrew its application for long-term sand bar management, and submitted new applications to all permitting agencies for approval of the EPB and SRPS projects, as well as a 5-year Interim Sand bar Management Plan, while the County and MCWRA completes the plans and construction of the projects. These applications were deemed incomplete pending technical studies, which are being completed as part of a feasibility study (completed June 2013) and this environmental review process.

In an effort to demonstrate the commitment to assess these projects and implement a long-term solution to mechanical breaching, the RMA worked with the USACE to develop a draft Memorandum of Understanding (MOU) that would include the USACE, County, and NMFS as signatory agencies. This document was reviewed by the USFWS as a consulting agency to the USACE. In September 2011, a draft MOU was completed for management of the Carmel River Lagoon. The MOU:

- Establishes a long-term plan to balance protection of private property with protection of federally listed species

- Recognizes that mechanical managing the Carmel River Lagoon over the long run was not in the best interest of the County, USACE, and NMFS' protected resources

- Identifies two long-term solutions as alternatives to performing sand bar management: the EPB and the SRPS

- Agrees to allow an Interim Sand bar Management Plan (ISMP) for temporary (5 years) management of the sand bar while the County develops the EPB and SRPS projects (design, environmental review, and construction)

- Establishes a target schedule to complete the projects by 2018.

Because the County has managed the sand bar only under approved emergency permits, and due to the time necessary to assess the various options, the timeframe identified in the MOU for obtaining a non-emergency permit was extended to October 2013. The County is working to complete the required environmental documents consistent with the expectations of the permitting agencies. The MOU was approved by the Board of Supervisors (BOS) on June 11, 2013.

5.1 Anticipated Sand Bar Dynamics without Artificial Breaching

When river flows surpass about 30-50 cfs and remain within or above that flow range, it becomes much more likely that riverine processes are the driving mechanism of bar breaching (Rich and Keller, 2013). The tendency of breach location is likely related to the architecture of the barrier beach sand bar, sand supply, wind dynamics, and wave form and shape. The cessation of artificial breaching will allow for a more natural sediment transport regime. This would be manifest when the annual cycles of barrier bar building and opening experience more of the natural dynamics associated with river outflow, tides, wave action, cross-shore, and littoral and longshore transport (Moffatt and Nichol, 2013; J. Pearson-Meyers, pers. comm., 2013).

5.2 Anticipated Lagoon Morphology

Breach outflow channel width and depth are primarily a function of wave and littoral transport processes as well as inflow rate and lagoon volume prior to opening, so affects naturally-occurring channel widths and depths would vary according to ocean and flow conditions. Data from WY2005 indicates that perched lagoon morphology will occur in Carmel Lagoon when the outflow channel runs to the north (Appendix A, Figure 8). There is a tendency for outflows to migrate north, as determined in WYs 1993, 1996, 1997, and 2000 by Thornton's (2005) littoral processes study of existing data and aerial photos, and in 2005 as reported by MPWMD (2007). It is expected that a northerly route will likely develop more often than currently occurs once artificial breaching ceases. A natural channel might form to the south in some years, as outlet formation is dependent on the longshore current. Ocean wave patterns can change in some years, although an outlet channel to the south should occur with a lower frequency than to the north.

NMFS and CDFW have indicated that a lagoon WSE in the range of 6.74 to 12.74 feet NAVD88 (4 to 10 feet NGVD29) is an optimal range for steelhead (MPWMD, 2011) while a threshold value of 5.75 feet was used in Table 5 to assess the probability of perched conditions in recent years. Conditions in WY2005 provide evidence of a perched morphology that would promote a WSE that might be achieved regularly with a northerly configuration to the outflow channel. The northern beach has smaller sand grain-sizes and a lower slope than the southern portion of the beach (Moffat and Nichol, 2013), while longshore currents tend to carry sand to the north due to diffraction of waves around Steward's Cove (Thornton, 2005). Slopes on the northern portion of the beach are much lower than those on the south end of the beach: 12 percent versus 28 percent, respectively (Thornton, 2005). These observations provide an indication of why the lagoon outlet might tend to migrate to the north, as there may be less resistance in the architecture of smaller grain sizes, and the lower slopes may provide a path of least resistance to the ocean.

When higher WSEs prevail in the lagoon over the course of an open-lagoon winter season, the lagoon WSE should remain high upon closure and with a higher ratio of fresh water because tidal inflow cannot negotiate the sinuous outflow pathway easily, thus less salt water will enter and remain in the lagoon (J. Pearson-Meyers, pers. comm., 2013).

5.3 Anticipated Conditions at Lagoon Closure

Carmel Lagoon geology includes a bedrock sill at the northern and southern ends of the river mouth. This sill may play a role in maintaining lagoon WSE, particularly when the outflow path is oriented to the north and a long and sinuous channel can form. Meandering outflow channels that flow across this bedrock sill, such as in Carmel Lagoon in water year 2005, are able to retain higher WSEs in the lagoon.

The higher WSE and continuing inflows until those dry up should provide a perched, fresh water lagoon at the beginning of the summer dry season that will remain as a fresh water system throughout the closure season and year-round.

5.4 Anticipated GW-Surface Water Interactions

There are a number of projects in progress associated with the Lower Carmel River and Lagoon, including Odello East floodplain restoration, retrofit of San Clemente Dam in the upper watershed, and GW infiltration into the floodplain aquifer on the Odello West floodplain area of the lower watershed at the lagoon (PWA, 2007). These projects will likely have effects on the Lagoon and its interaction with streamflow and local GW, and should provide net positive benefits to lagoon ecosystem health.

5.5 Anticipated Ecosystem Effects

The purpose of Project implementation is to restore the natural function of the lagoon by reducing the necessity to artificially breach the sand bar. Anticipated ecosystem effects should subsequently help restore the natural function of the lagoon and protect surrounding infrastructure. These effects include (1) more natural breaching cycles, (2) increased WSE in the lagoon while open in a northerly direction, (3) a higher ratio of fresh water to salt water, (4) conversion of the lagoon into a fresh water system during closure via the higher ratio of fresh water and streamflow prior to drying up in the summer, and (5) greater connectivity between the lagoon and the local GW. A return to naturally functioning lagoon ecosystem conditions should allow for steelhead and other aquatic and terrestrial species to thrive within a highly productive lagoon ecosystem.

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A report prepared for:

January 24, 2014

Monterey County Resource Management Agency
168 West Alisal Street, 2nd Floor
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by

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APPENDICES

APPENDIX A

Water surface elevations in Carmel Lagoon and streamflow in Carmel River at Highway 1 gage, WYs 1993-2012

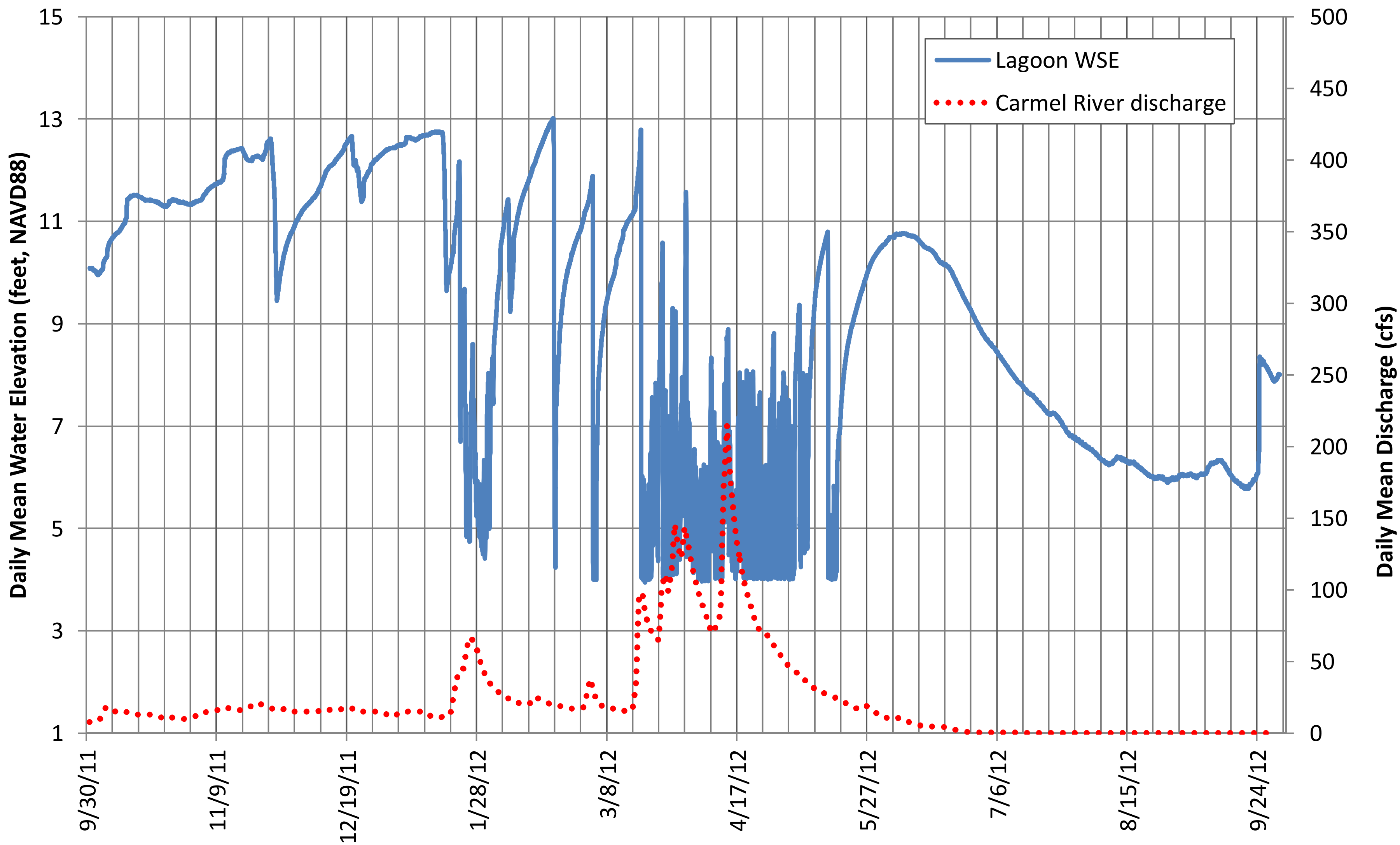

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Figure 1. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2012, Monterey County, California. Sources: Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

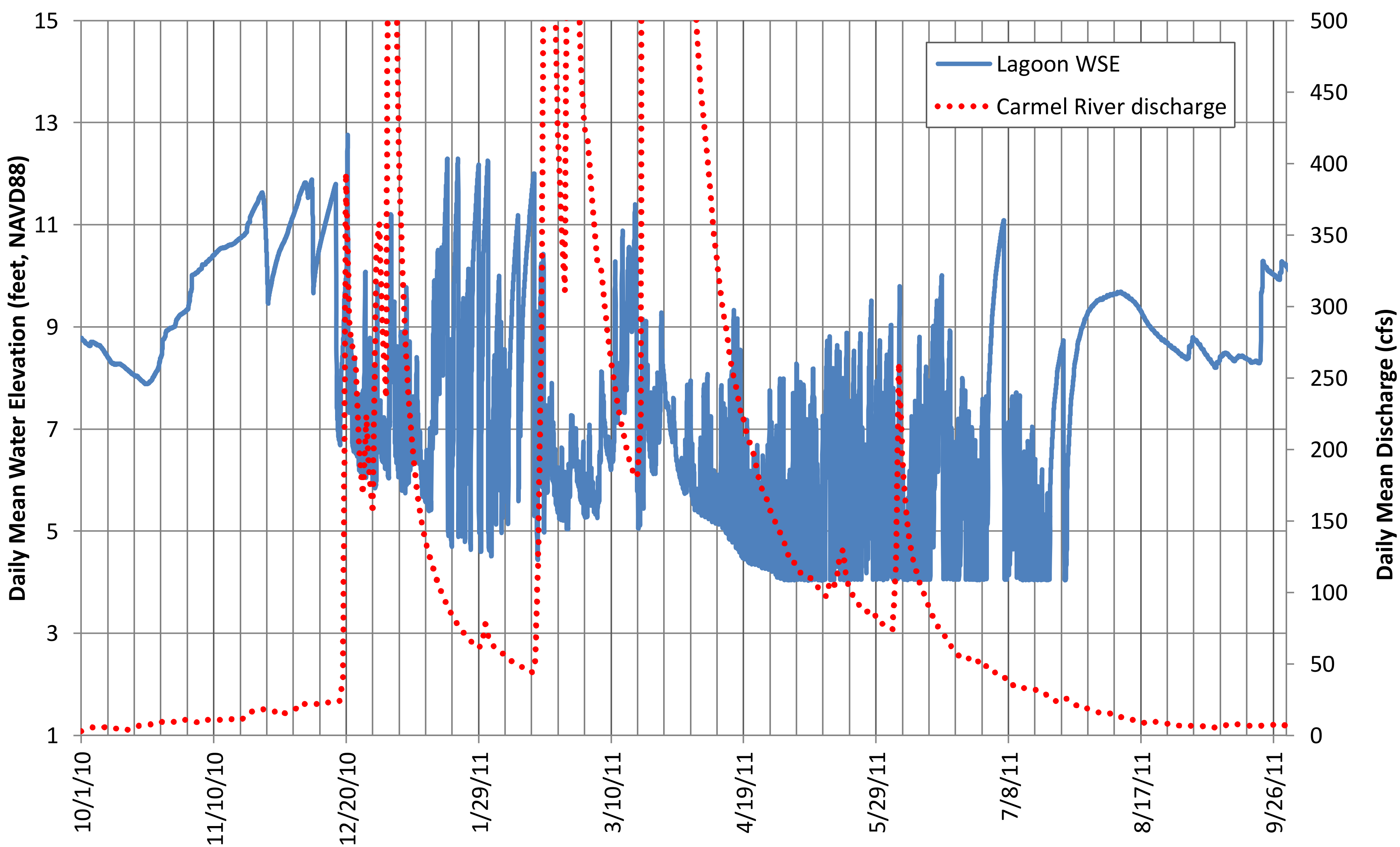

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Figure 2. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2011, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

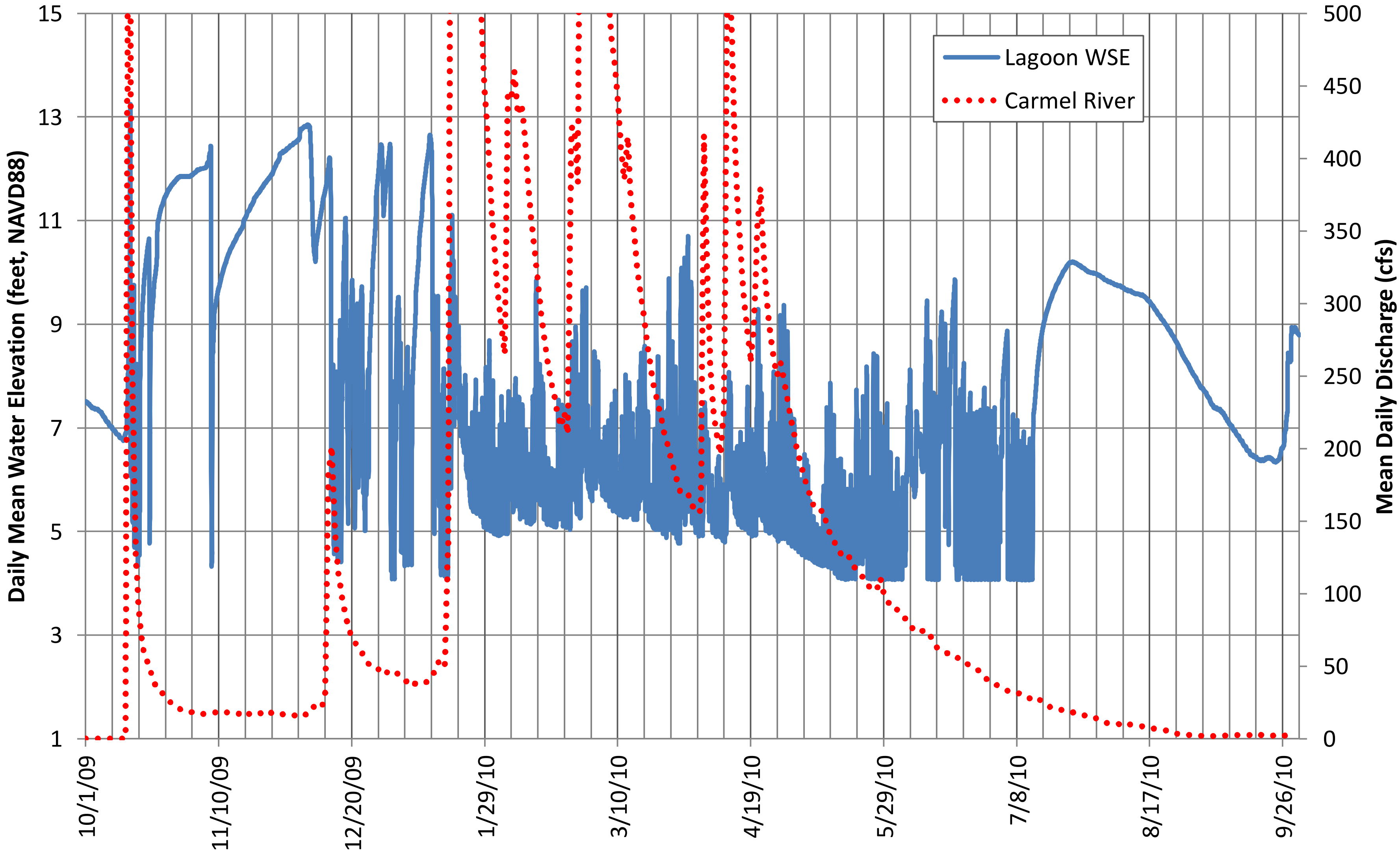

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Figure 3. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2010, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

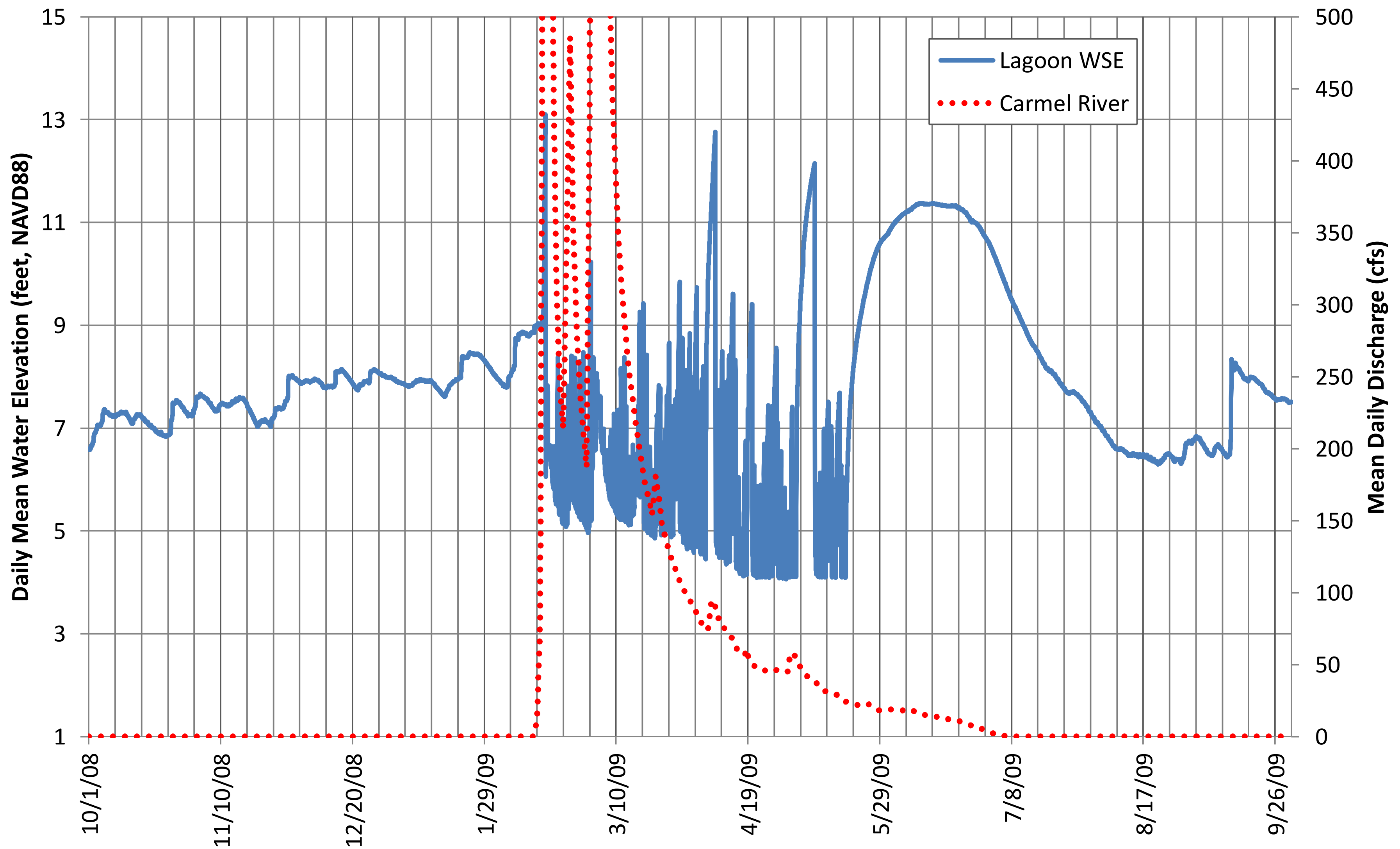

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Figure 4. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2009, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

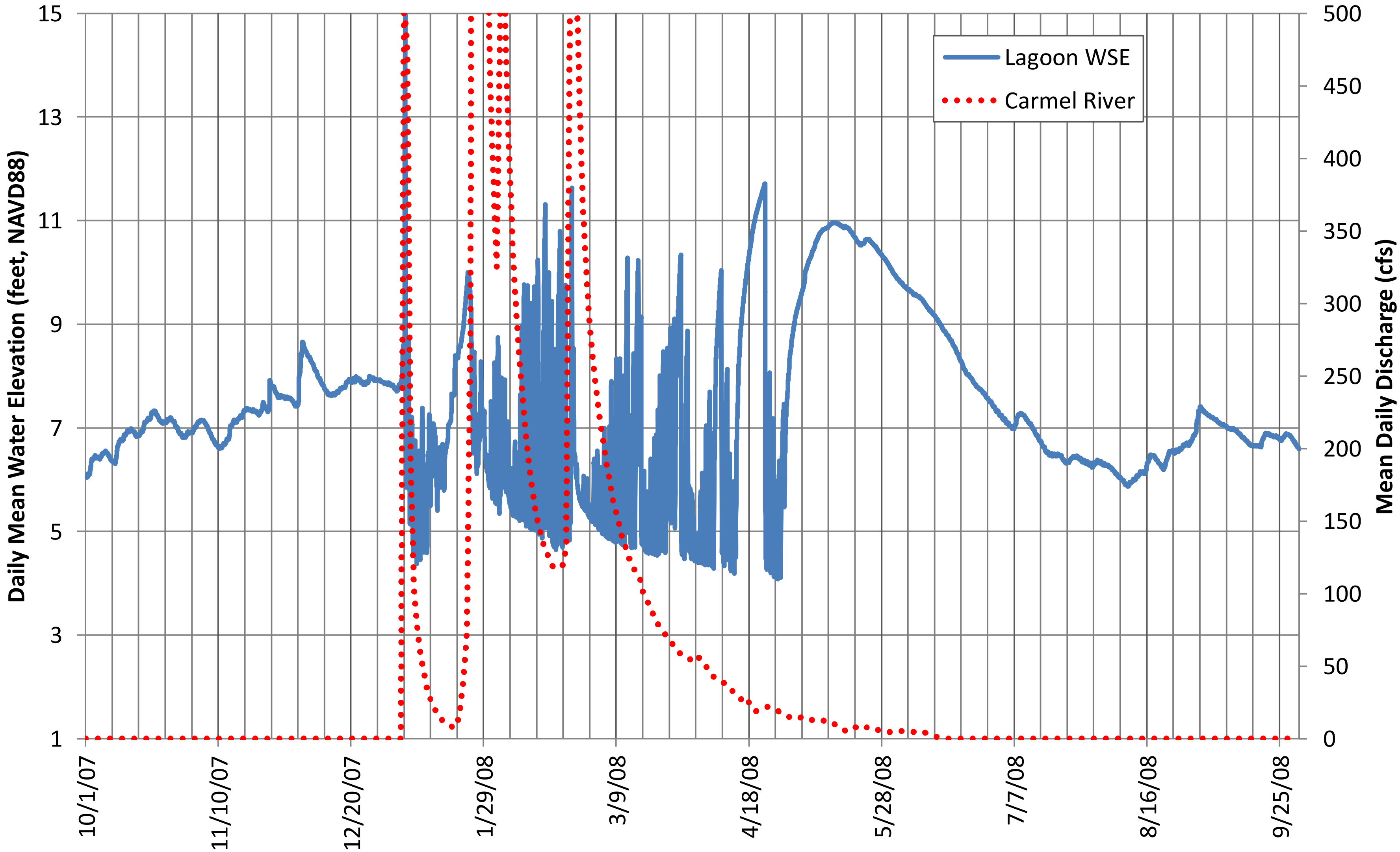

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Figure 5. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2008, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

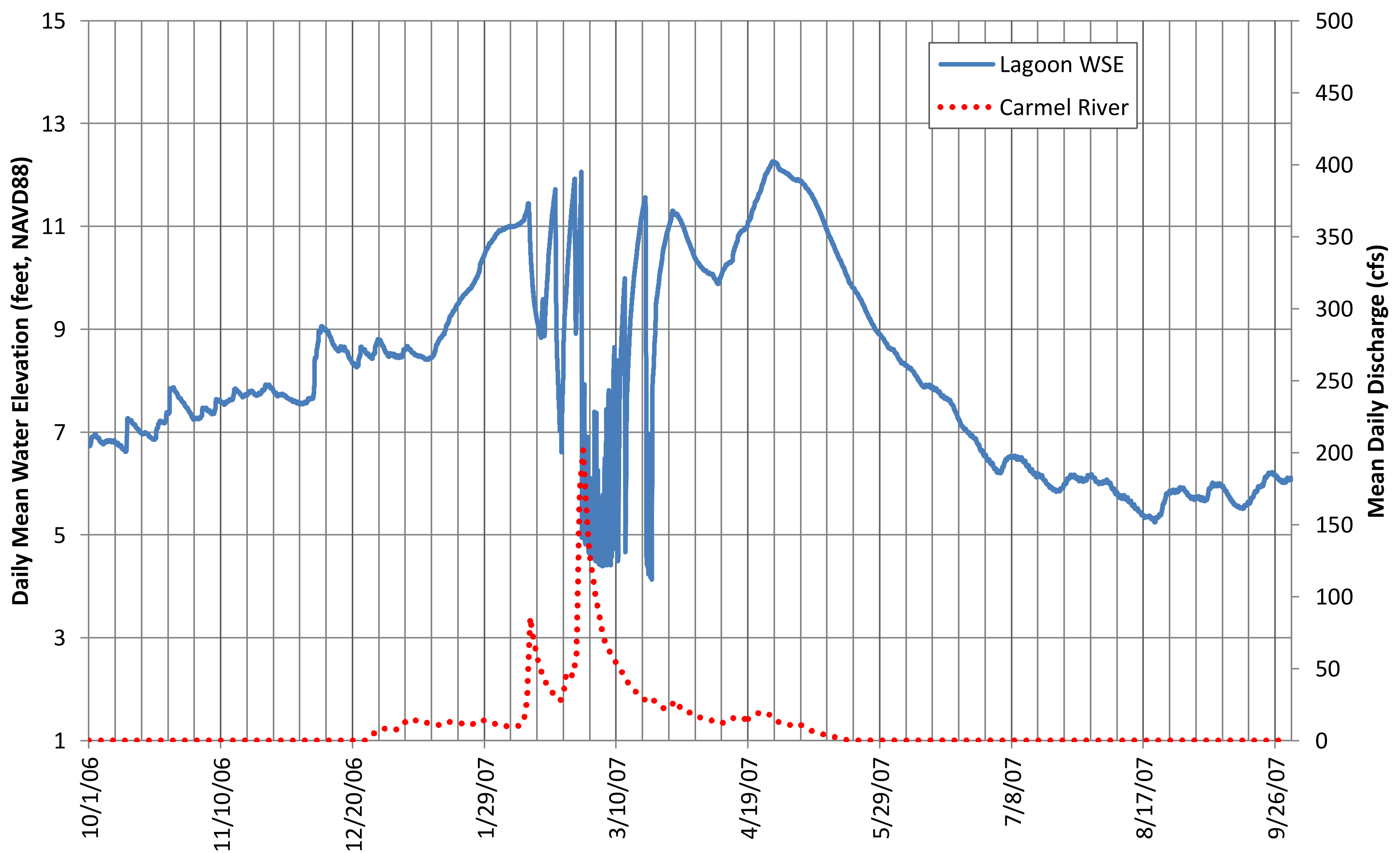

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Figure 6. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2007, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

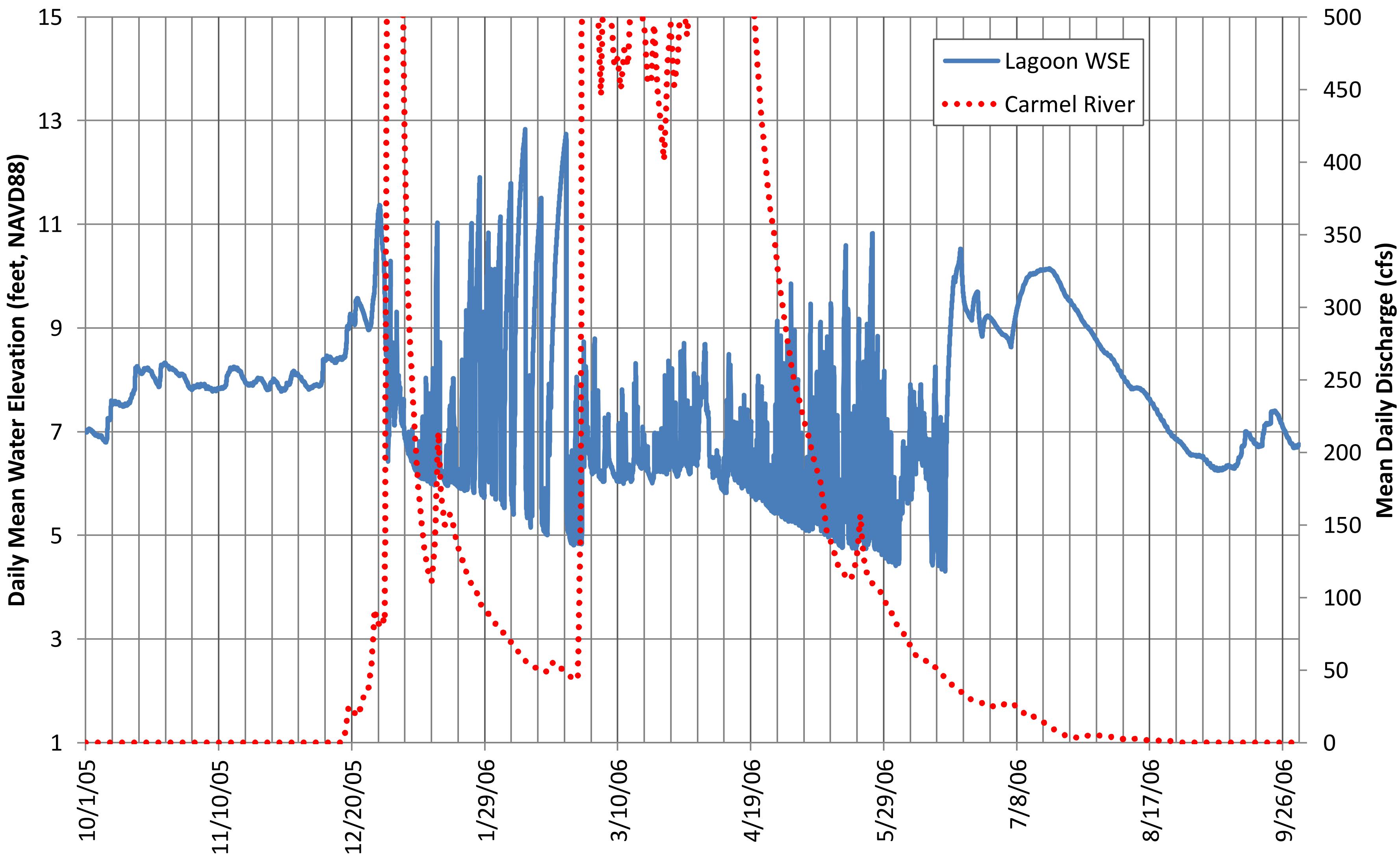

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Figure 7. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2006, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

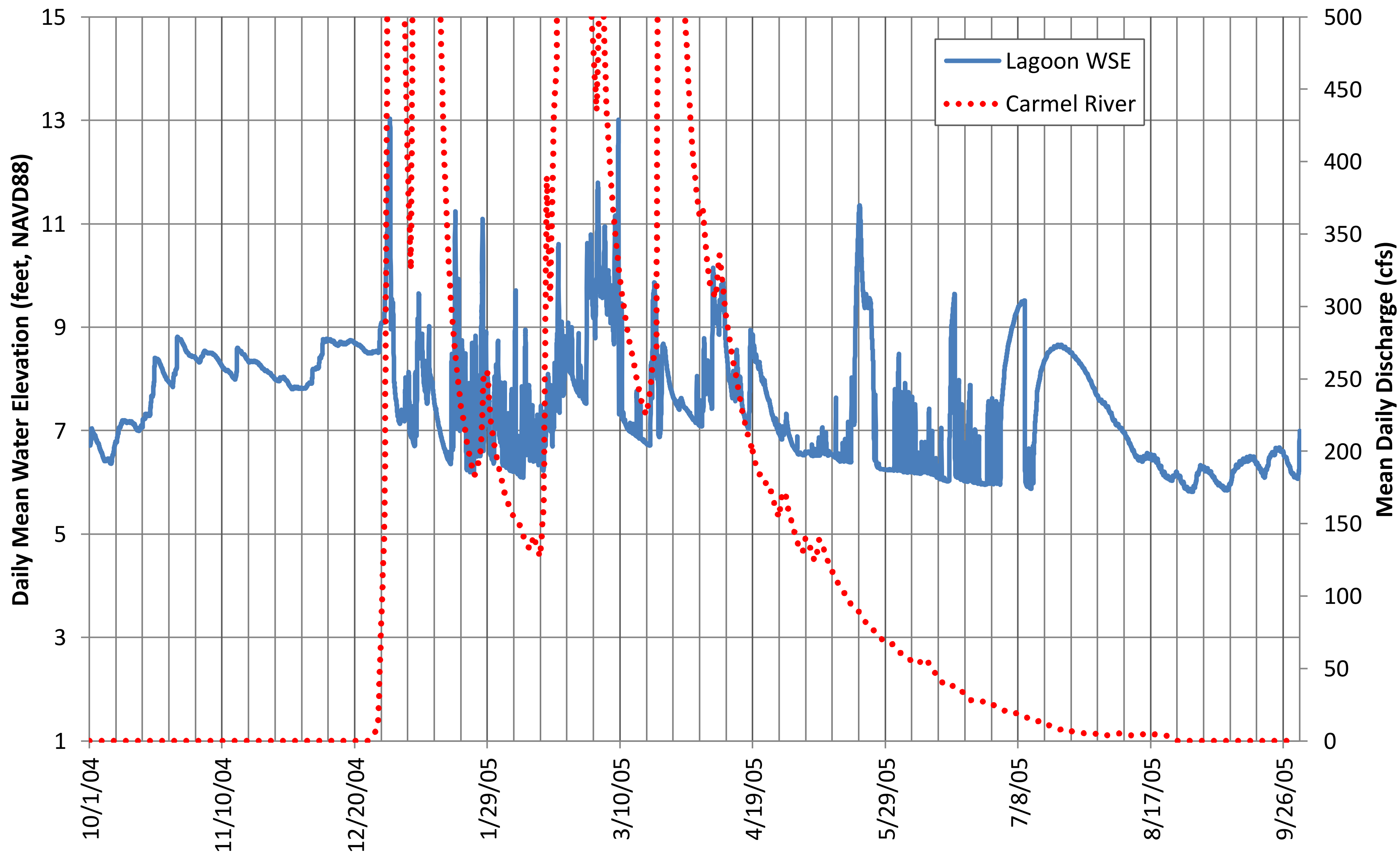

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Figure 8. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2005, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

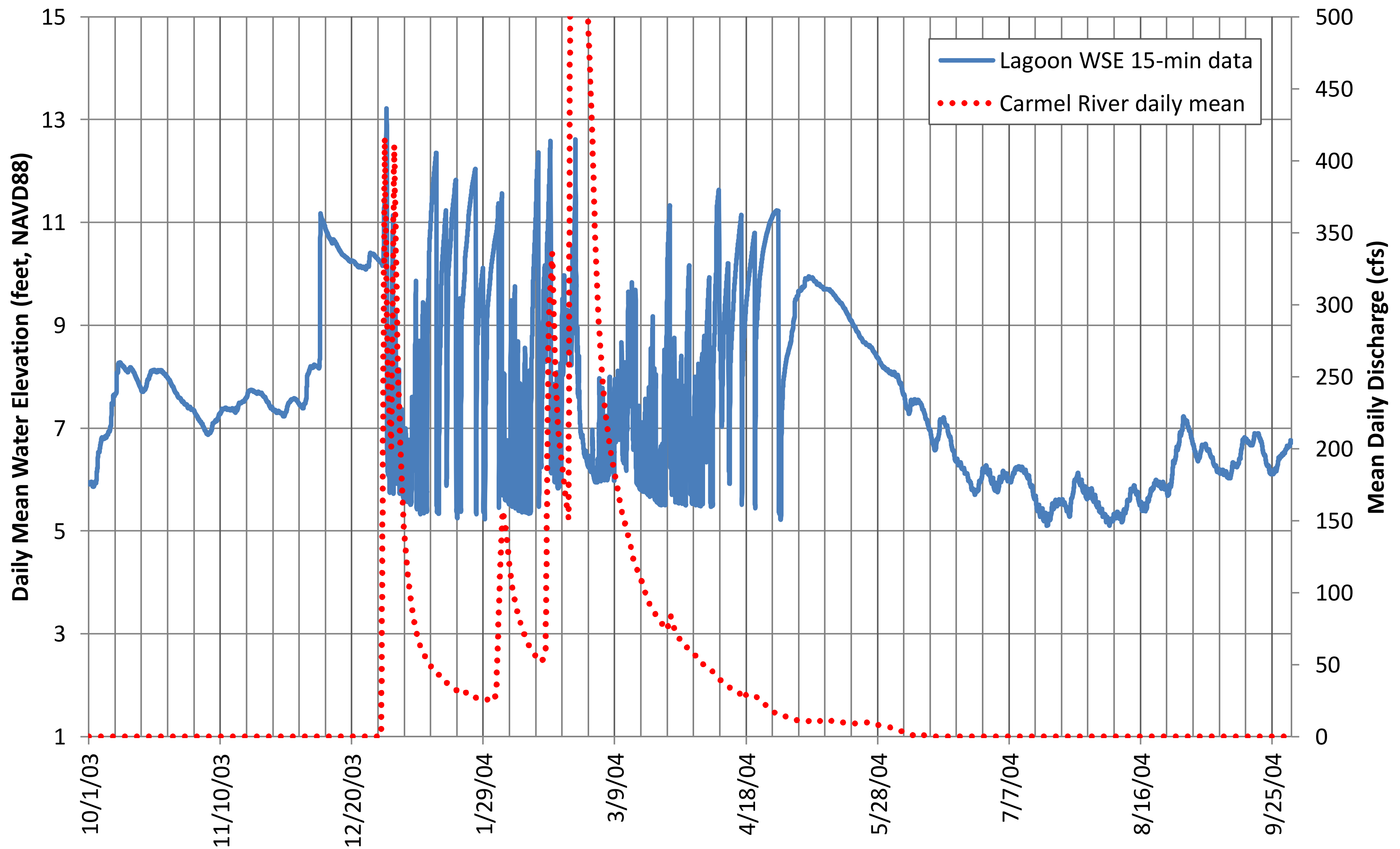

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Figure 9. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2004, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

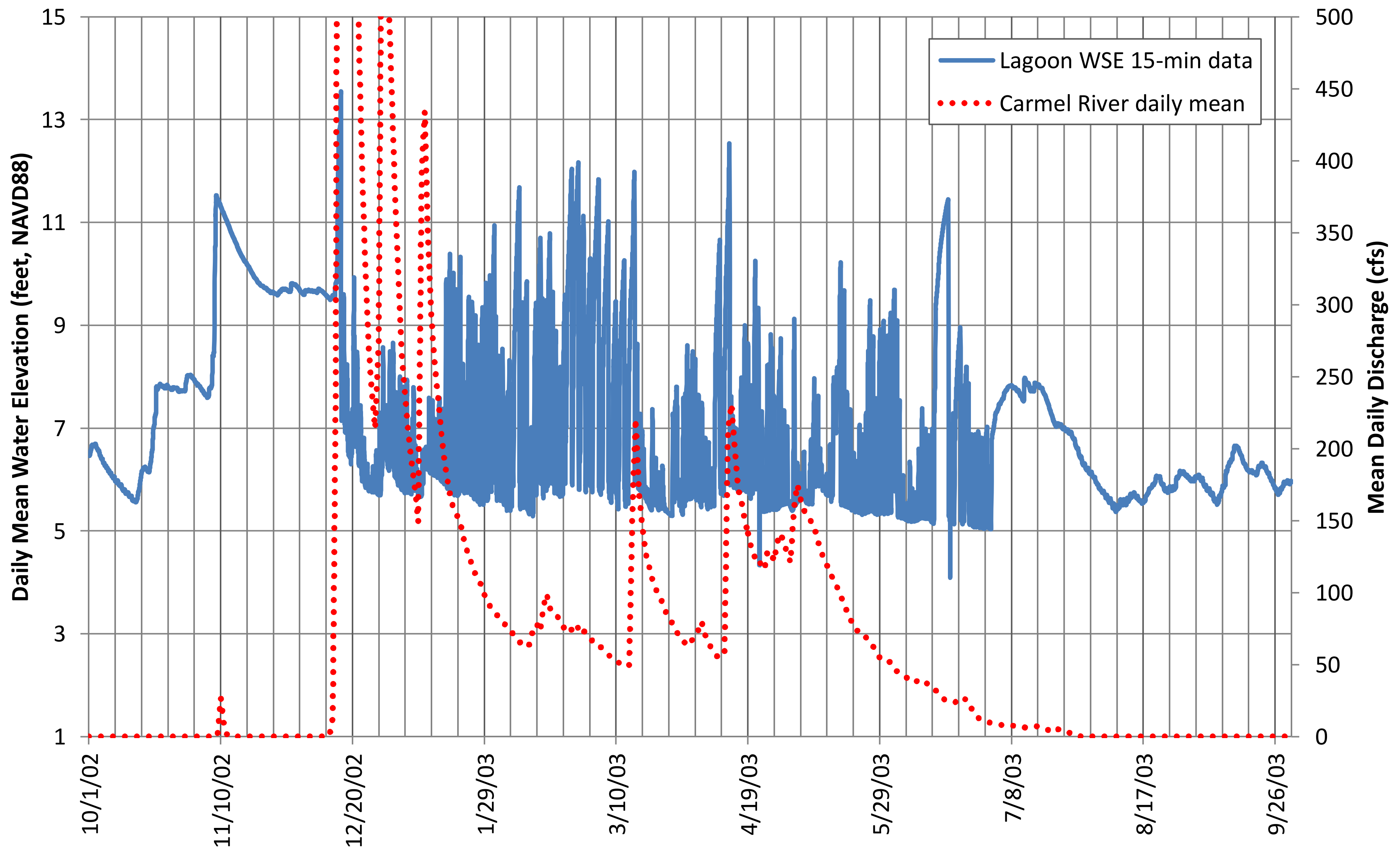

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Figure 10. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2003, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

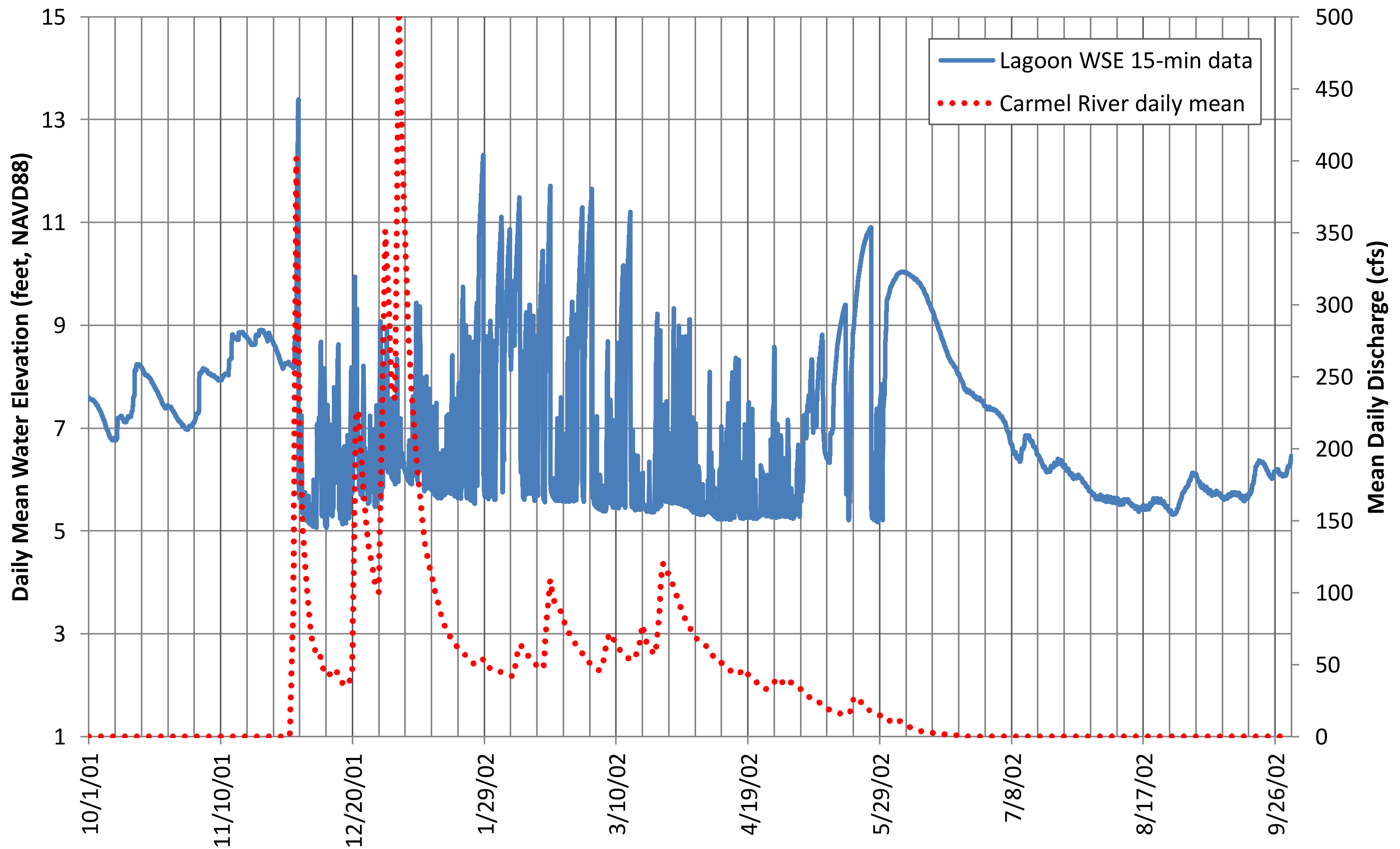

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Figure 11. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2002, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

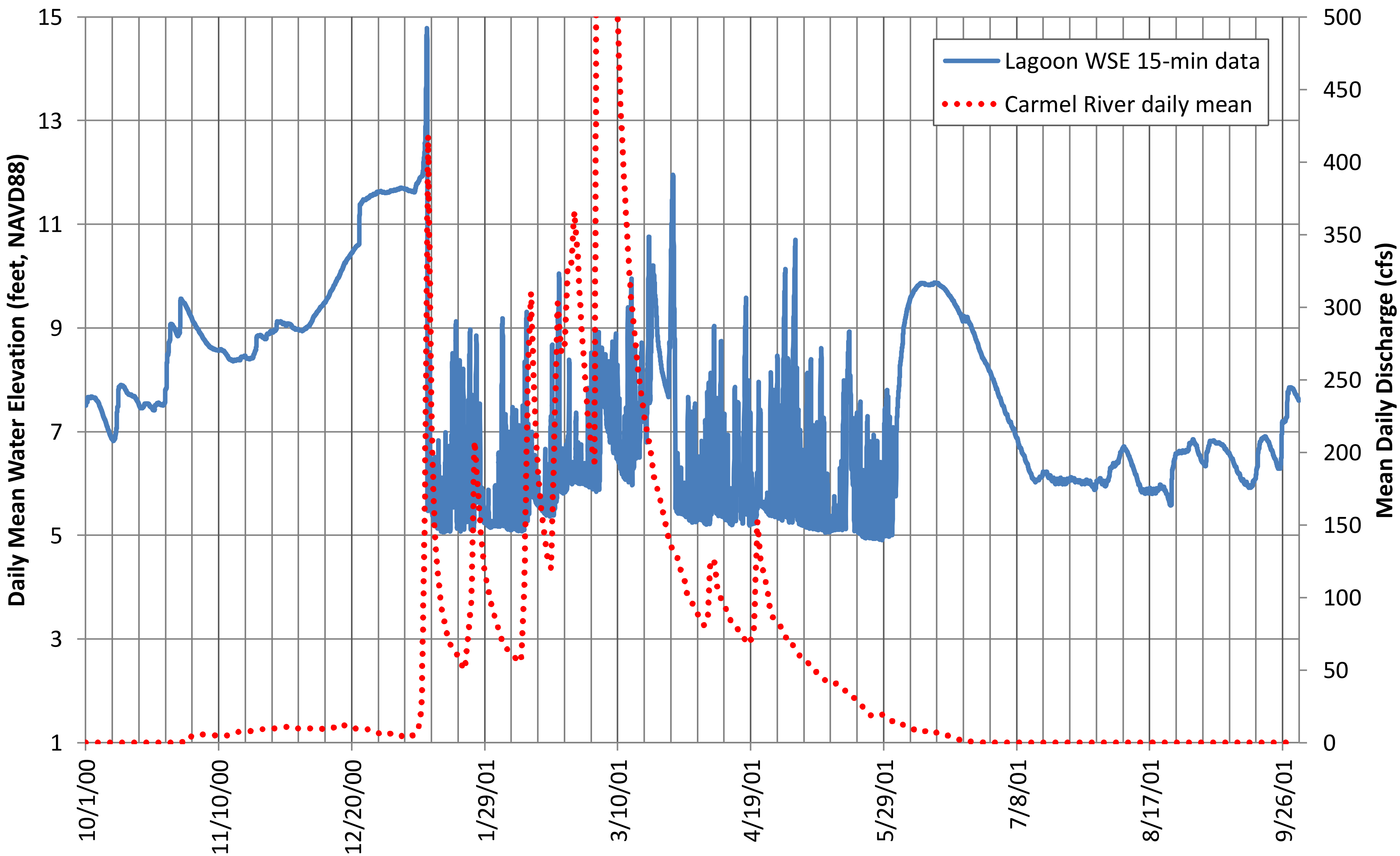

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Figure 12. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2001, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

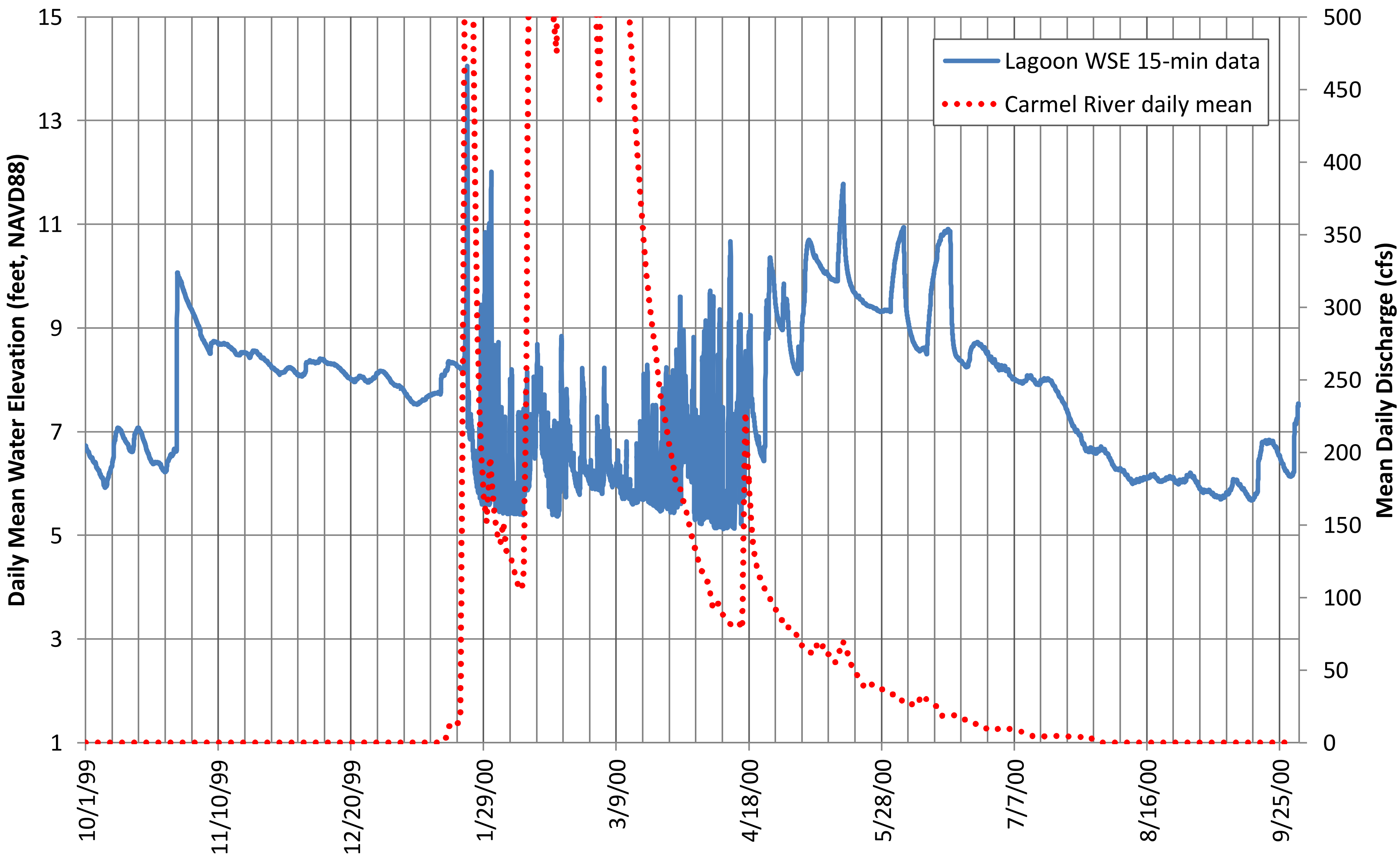

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Figure 13. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 2000, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

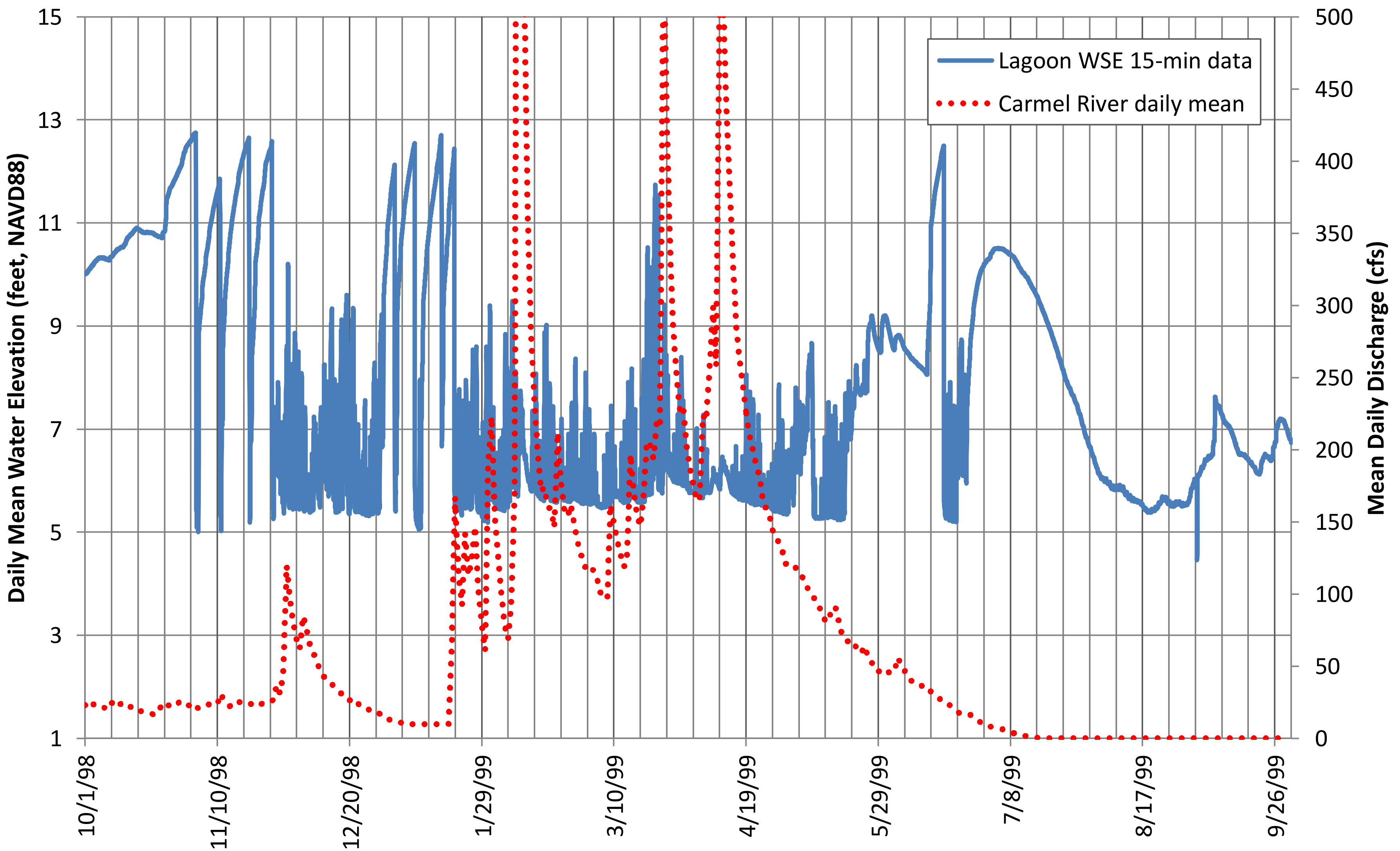

Figure 14. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 1999, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

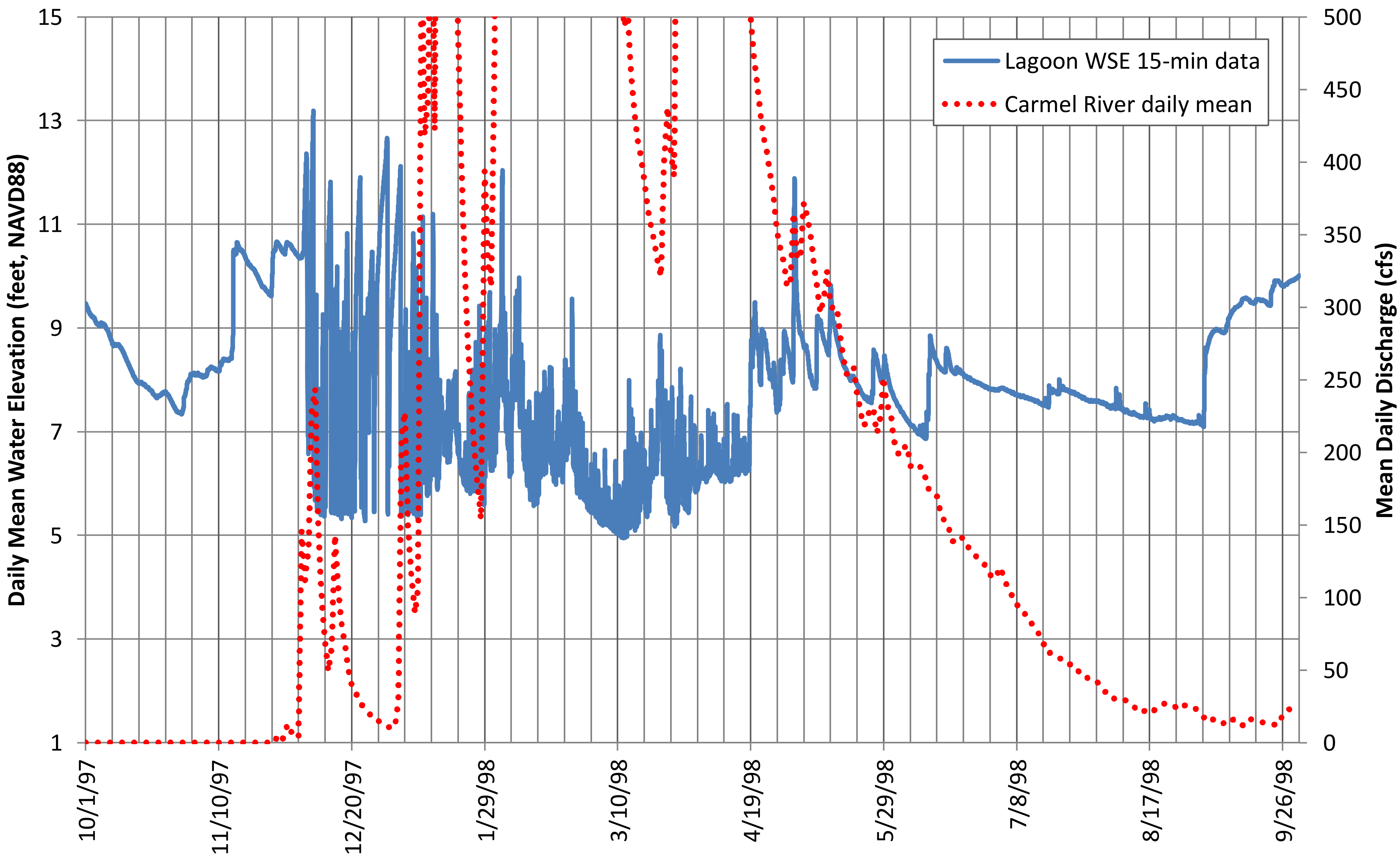

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Figure 15. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 1998, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

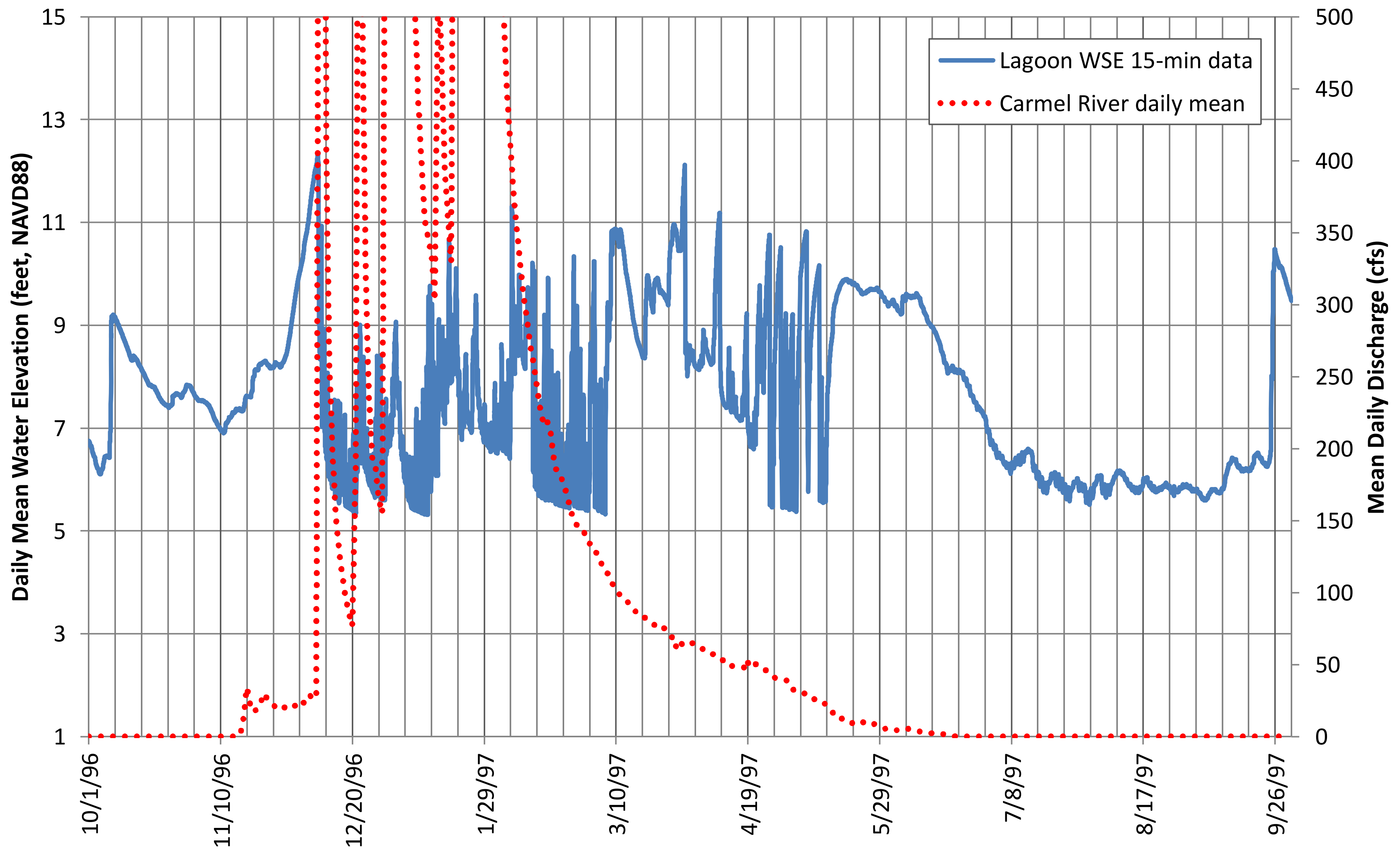

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Figure 16. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 1997, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

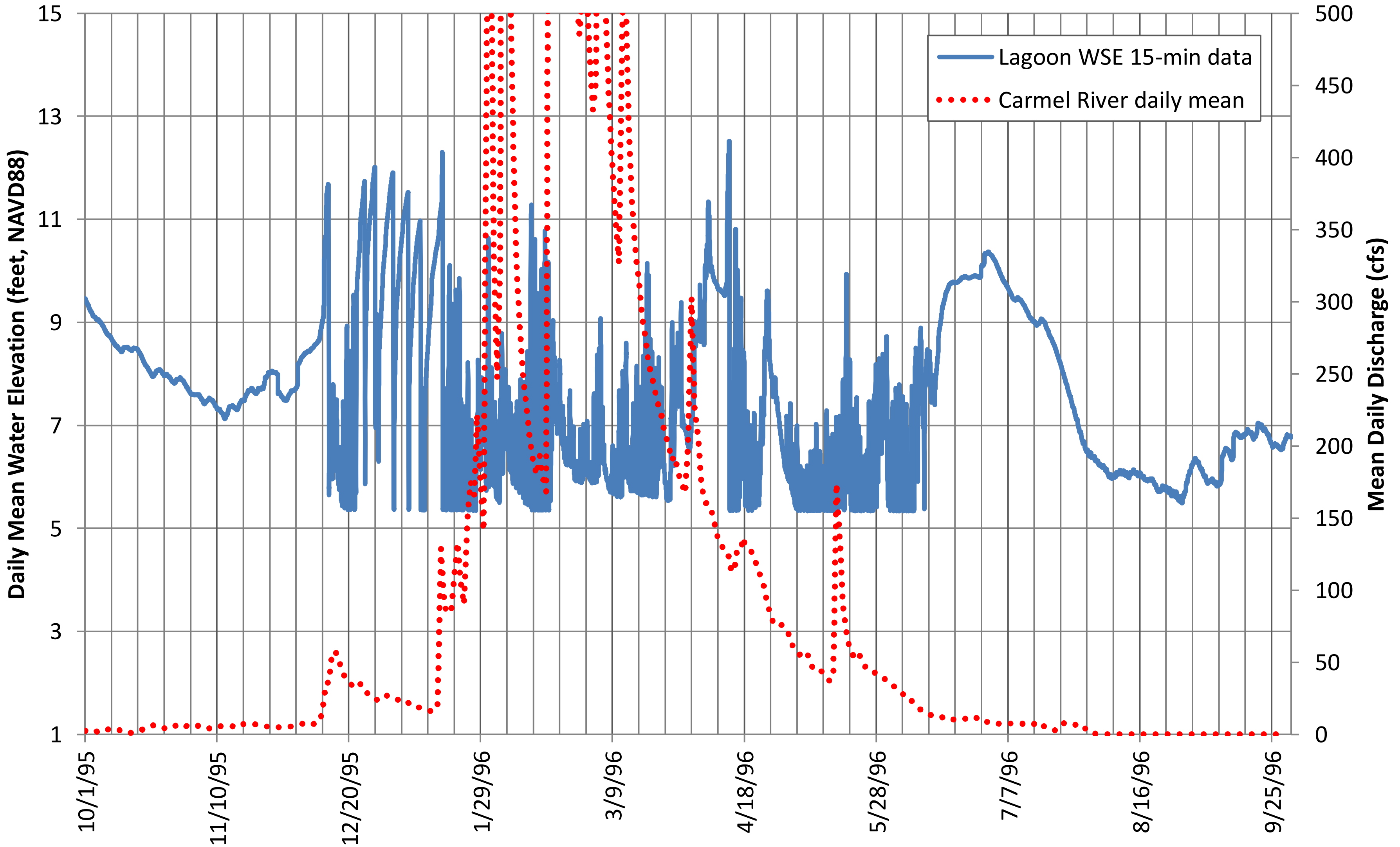

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Figure 17. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 1996, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

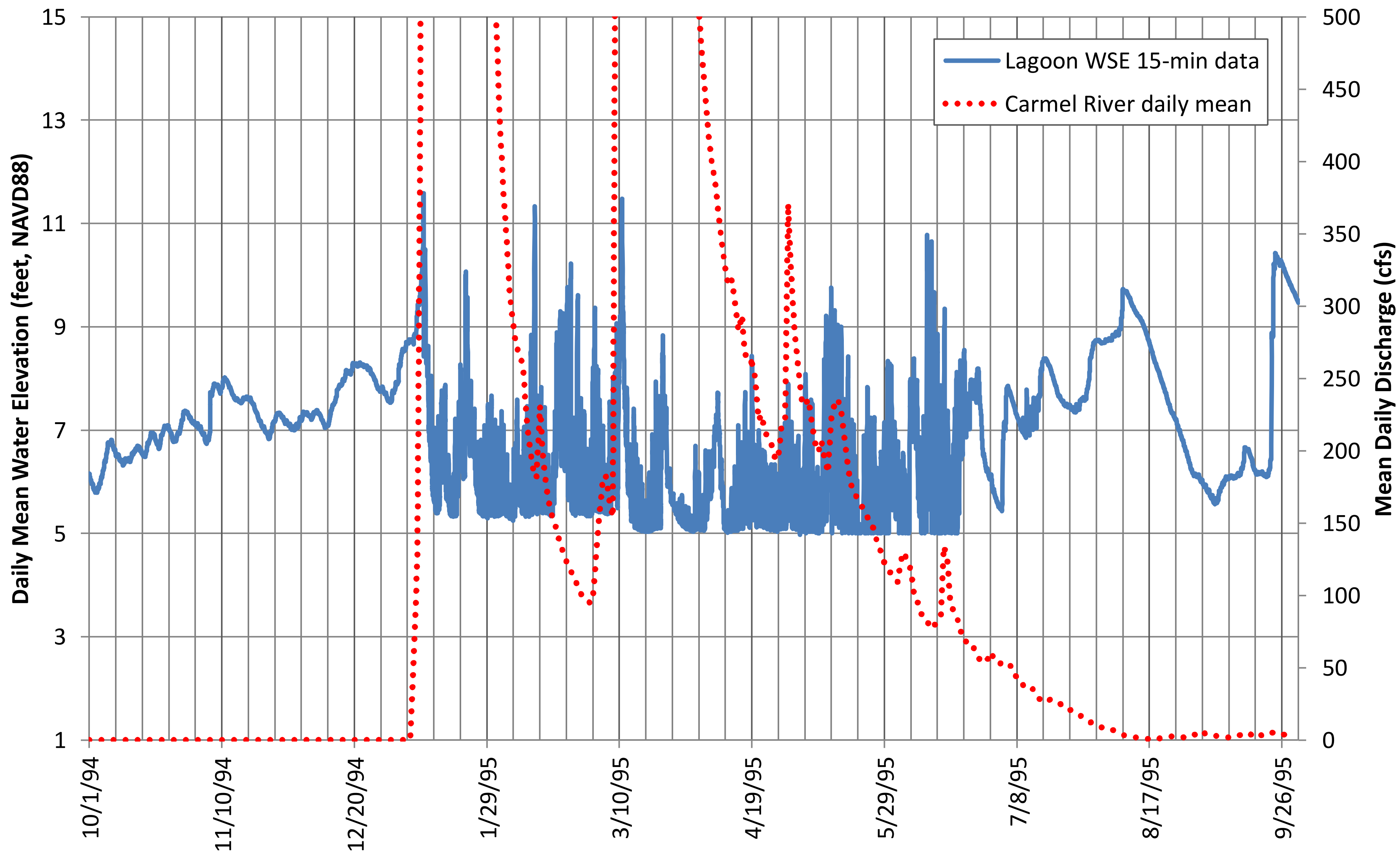

Figure 18. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 1995, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

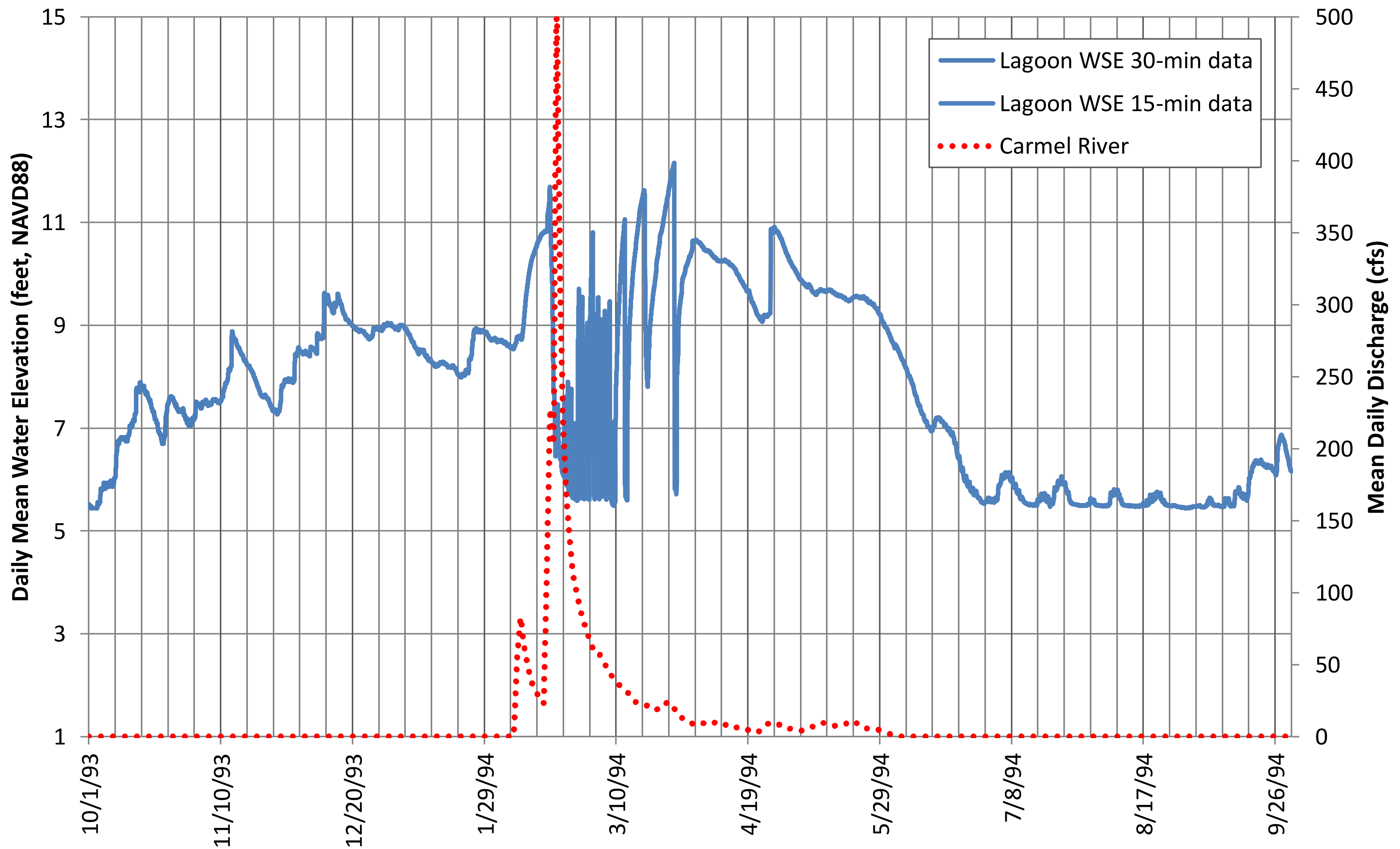

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Figure 19. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 1994, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

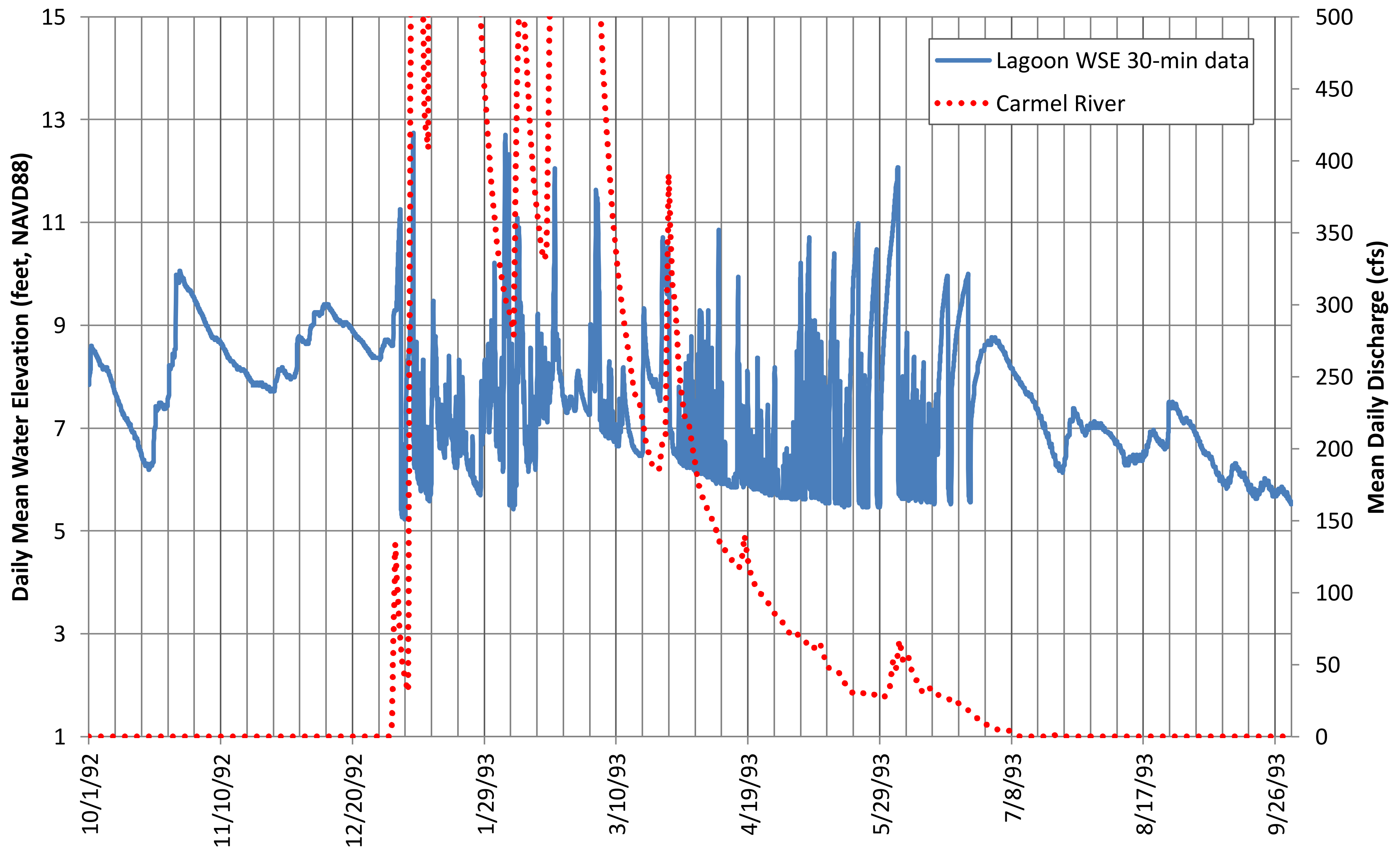

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Figure 20. Water level in Carmel River Lagoon at south arm gage and flow in Carmel River at Highway 1 gage, water year 1993, Monterey County, California. Monterey Peninsula Water Management District raw lagoon water surface elevation datalogger files are provisional and subject to revision. USGS 11143250 daily mean discharge data are approved for publication.

APPENDIX B

Compilation tables of riverine dynamics of breaches and closures, WYs 1993-2012

Table 1. WY 2012, Riverine Dynamics of Breaches and Closures

Breach Type	Sustained closure	Temporary breach	Temporary breach	In-season closure	Temporary breach	Temporary breach	In-season closure	Sustained breach*	In-season closure	Temporary breach	In-season closure	Sustained breach	In-season closure	Sustained breach	In-season closure	Sustained breach	Early closure	Final Closure	WSE increase while closed
Mechnical, Natural, or Unknown		Mechanical	Mechanical		Mechanical	Mechanical		Mechanical		Natural		Natural		Natural		Natural	Mechanical	Mechanical	
Dry Season Events	10/1/2011 0:00																		
Date-Time of lowest lagoon WSE prior to breach	10/3/2011 15:30																		
Lowest lagoon WSE during closure, this WY	9.95																		
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach																			
Date-Time of lowest WSE prior to significant increase in WSE																			9/21/12 9:15
WSE (ft)																			5.78
Date-Time of highest WSE post-increase																			9/24/12 21:15
WSE (ft)																			8.36
Increase in WSE (ft)																			2.58
Likely mechanism with greatest influence on WSE increase process																			Wave overtopping
Mean daily flow rate (cfs) on day of highest WSE																			0
Date-Time of most recent WSE > 11 ft prior to breach, this WY	11/16/2011 20:15																		
Time (days) between start of WY and first seasonal breach	46.8																		
Breachs and Closures during rainy season																			
Date-Time of highest WSE at time of breach		11/16/2011 20:15	11/25/2011 17:45		12/20/2011 16:00	1/17/2012 11:30		1/22/2012 17:30		2/6/2012 18:30		2/20/2012 14:30		3/3/2012 17:30		3/18/2012 13:30			
WSE (ft)		12.43	12.62		12.66	12.74		12.17		11.43		13.01		11.89		12.79			
Date-Time of lowest WSE directly following breach		11/19/2011 13:30	11/27/2011 15:30		12/23/2011 15:00	1/18/2012 18:15		1/23/2012 1:30		2/7/2012 9:15		2/21/2012 5:30		3/4/2012 0:15		3/18/2012 17:15			
WSE (ft)		12.19	9.45		11.38	9.64		6.69		9.24		4.24		4.00		4.03			
WSE pre-breach minus post-breach (ft)		0.23	3.17		1.28	3.10		5.47		2.19		8.77		7.88		8.76			
Time difference (days)		2.72	1.91		2.96	1.28		0.33		0.61		0.63		0.28		0.16			
Time difference (hours)		65.25	45.75		71.00	30.75		8.00		14.75		15.00		6.75		3.75			
Rate of WSE decline (ft/hr)		0.00	0.07		0.02	0.10		0.68		0.15		0.58		1.17		2.34			
Mean daily flow rate (cfs) on day of breach		16	18		17	11		39		25		20		38		96			
Mean daily flow rate (cfs) on day of lowest WSE following breach		17	17		15	12		39		24		20		30		96			
Likely mechanism with greatest influence on breaching process		Mechanical	Mechanical		Mechanical	Mechanical		Mechanical/Riverine		Mechanical		Unknown		Riverine		Riverine			
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours				11/27/2011 15:30			1/18/2012 18:30		2/2/2012 3:15		2/7/2012 9:45		2/21/2012 5:30		3/4/2012 18:45				
WSE (ft)				9.45			9.64		7.43		9.23		4.24		3.99				
Date-Time of lagoon WSE fills to > 11 feet				12/3/2011 13:00			1/21/2012 17:45		2/5/2012 11:15		2/9/2012 10:00		2/29/2012 16:30		3/14/2012 11:00				
WSE (ft)				11.00			11.00		11.00		11.00		11.00		11.00				
Date-Time of lagoon falls below WSE > 11 feet				1/18/2012 9:00			1/22/2012 21:30		2/6/2012 22:30		2/20/2012 20:45		3/3/2012 18:30		3/18/2012 14:30				
WSE (ft)				10.97			10.83		10.99		10.93		10.85		9.76				
Time (days) of WSE > 11 feet				45.83			1.16		1.47		11.45		3.08		4.15				
Time (hours) of WSE > 11 feet				1100.0			27.8		35.3		274.8		74.0		99.5				
Mean daily flow rate (cfs) on day lowest WSE				17			12		33		24		20		30				
Mean daily flow rate (cfs) on day WSE > 11 feet				15			27		27		22		17		15				
Mean daily flow rate (cfs) on day WSE < 11 feet				12			39		25		20		38		96				
Likely mechanism with greatest influence on closure process				Ocean			Ocean		Ocean		Ocean		Ocean		Ocean				
Dry Season Closure																			
Date-Time of highest WSE at WY closure																	5/15/2012 1:15	6/7/2012 2:15	
WSE (ft)																	10.80	10.77	
Date-Time of lowest WSE during WY closure																	5/15/2012 16:15	9/20/2012 13:00	
WSE (ft)																	4.02	5.77	
Time (days) difference highest minus lowest WSE																	0.63	105.45	
Time (hours) difference highest minus lowest WSE																	15.00	2530.75	
Highest WSE at closure minus lowest WSE during closure in this WY																	6.77	5.00	
Rate of decrease in WSE (ft/day)																	0.452	0.002	
Mean daily flow rate (cfs) on day of highest WSE at closure																	27	27	
Mean daily flow rate (cfs) on day of lowest WSE of dry season																	n/a	0	
Likely mechanism with greatest influence on process																	Mechanical	Ocean	
End of WY																		9/30/2012 23:45	
Time (days) between final season closure and end of WY																		115.9	
Total days of lagoon closure in this WY (pre- and post-rainy season)																		162.7	
Totel days of closure including all partial closures																		184.0	

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as temporary lagoon closing due to mechanical or ocean processes approximately 1 month to 1 week before than final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included the sum of days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in the MPWMD WY 2012 fisheries report (Urquhart, 2013)

Table 2. WY 2011, Riverine Dynamics of Breaches and Closures

	Sustained closure	Temporary breach	In-season closure	Temporary breach	In-season closure	Sustained breach*	In-season closure	Sustained breach	In-season closure	Sustained breach	Final Closure
Breach Type											
Natural, Mechanical or Unknown		Mechanical		Mechanical		Mechanical		Mechanical		Mechanical	Mechanical
Dry Season Events	10/1/2010 0:00										
Date-Time of lowest lagoon WSE prior to breach	10/21/2010 8:15										
Lowest lagoon WSE during closure, this WY	7.89										
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach											
Date-Time of lowest WSE prior to significant increase in WSE											
WSE (ft)											
Date-Time of highest WSE post-increase											
WSE (ft)											
Increase in WSE (ft)											
Likely mechanism with greatest influence on WSE increase process											
Mean daily flow rate (cfs) on day of highest WSE											
Date-Time of most recent WSE > 11 ft prior to breach, this WY	11/24/2010 16:00										
Time (days) between start of WY and first seasonal breach	54.7										
Breachs and Closures during rainy season											
Date-Time of highest WSE at time of breach		11/24/2010 16:00		12/9/2010 15:15		12/16/2010 20:45		1/29/2011 0:15		2/14/2011 17:45	
WSE (ft)		11.63		11.89		11.80		12.18		12.01	
Date-Time of lowest WSE directly following breach		11/26/2010 9:30		12/10/2010 1:30		12/18/2010 3:30		1/29/2011 3:30		2/14/2011 21:15	
WSE (ft)		9.46		9.66		6.69		4.97		5.30	
WSE pre-breach minus post-breach (ft)		2.16		2.22		5.11		7.21		6.71	
Time difference (days)		1.73		0.43		1.28		0.14		0.15	
Time difference (hours)		41.50		10.25		30.75		3.25		3.50	
Rate of WSE decline (ft/hr)		0.05		0.22		0.17		2.22		1.92	
Mean daily flow rate (cfs) on day of breach		19		15		17		51		21	
Mean daily flow rate (cfs) on day of lowest WSE following breach		17		15		16		51		21	
Likely mechanism with greatest influence on breaching process		Mechanical		Mechanical		Mechanical		Riverine		Mechanical	
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours			11/26/2010 9:30		12/10/2010 1:30		1/26/2011 14:15		2/3/2011 5:30		
WSE (ft)			9.46		9.66		4.63		5.13		
Date-Time of lagoon WSE fills to > 11 feet			12/3/2010 0:45		12/13/2010 14:15		1/27/2011 21:00		2/13/2011 6:00		
WSE (ft)			11.00		11.00		11.00		11.00		
Date-Time of lagoon falls below WSE > 11 feet			12/9/2010 21:45		12/16/2010 22:15		1/29/2011 1:15		2/14/2011 19:30		
WSE (ft)			10.99		10.94		10.48		10.70		
Time (days) of WSE > 11 feet			6.88		3.33		1.18		1.56		
Time (hours) of WSE > 11 feet			165.0		80.0		28.3		37.5		
Mean daily flow rate (cfs) on day lowest WSE			18		22		67		61		
Mean daily flow rate (cfs) on day WSE > 11 feet			15		17		64		21		
Mean daily flow rate (cfs) on day WSE < 11 feet			15		17		51		21		
Likely mechanism with greatest influence on closure process			Ocean		Ocean		Ocean		Unknown		
Dry Season Closure											
Date-Time of highest WSE at WY closure											8/11/2011 1:45
WSE (ft)											9.69
Date-Time of lowest WSE during WY closure											9/8/2011 12:00
WSE (ft)											8.20
Time (days) difference highest minus lowest WSE											28.43
Time (hours) difference highest minus lowest WSE											682.25
Highest WSE at closure minus lowest WSE during closure in this WY											1.48
Rate of decrease in WSE (ft/day)											0.002
Mean daily flow rate (cfs) on day of highest WSE at closure											13
Mean daily flow rate (cfs) on day of lowest WSE of dry season											0
Likely mechanism with greatest influence on process											Ocean
End of WY											9/30/2011 23:45
Time (days) between final season closure and end of WY											50.9
Total days of lagoon closure in this WY (pre- and post-rainy season)											105.6
Totel days of closure including all partial closures											118.5

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in MPWMD, 2010-2011 annual mitigation report

Table 3. WY 2010, Riverine Dynamics of Breaches and Closures

	Sustained closure	Sustained breach*	In-season closure	Sustained breach	In-season closure	Temporary breach	In-season closure	Sustained breach	In-season closure	Sustained breach	In-season closure	Sustained breach	Final Closure
Breach Type													
Natural, Mechanical or Unknown		Mechanical		Mechanical		Mechanical		Mechanical		Mechanical		Mechanical	Natural
Dry Season Events	10/1/2009 0:00												
Date-Time of lowest lagoon WSE prior to breach	10/12/2009 5:00												
Lowest lagoon WSE during closure, this WY													
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach													
Date-Time of lowest WSE prior to significant increase in WSE	--												
WSE (ft)													
Date-Time of highest WSE post-increase													
WSE (ft)													
Increase in WSE (ft)													
Likely mechanism with greatest influence on WSE increase process													
Mean daily flow rate (cfs) on day of highest WSE													
Date-Time of most recent WSE > 11 ft prior to breach, this WY	10/14/2009 9:45												
Time (days) between start of WY and first seasonal breach	13.4												
Breachs and Closures during rainy season													
Date-Time of highest WSE at time of breach		10/14/2009 9:45		11/7/2009 15:30		12/7/2009 0:15		12/13/2009 10:15		12/31/2009 14:30		1/12/2010 14:45	
WSE (ft)		13.25		12.44		12.85		12.21		12.48		12.65	
Date-Time of lowest WSE directly following breach		10/14/2009 14:30		11/7/2009 22:15		12/9/2009 2:30		12/14/2009 3:15		12/31/2009 22:15		1/13/2010 20:00	
WSE (ft)		6.10		4.32		10.21		5.88		4.24		4.95	
WSE pre-breach minus post-breach (ft)		7.15		8.12		2.64		6.33		8.24		7.69	
Time difference (days)		0.20		0.28		2.09		0.71		0.32		1.22	
Time difference (hours)		4.75		6.75		50.25		17.00		7.75		29.25	
Rate of WSE decline (ft/hr)		1.51		1.20		0.05		0.37		1.06		0.26	
Mean daily flow rate (cfs) on day of breach		759		18		20		182		47		40	
Mean daily flow rate (cfs) on day of lowest WSE following breach		759		18		22		202		47		42	
Likely mechanism with greatest influence on breaching process		Mechanical/Riverine		Mechanical		Mechanical		Mechanical/Riverine		Riverine		Unknown	
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours			10/20/2009 6:00		11/7/2009 22:15		12/9/2009 4:00		12/24/2009 1:30		1/7/2010 0:30		
WSE (ft)			4.78		4.32		10.21		5.01		4.35		
Date-Time of lagoon WSE fills to > 11 feet			10/22/2009 20:15		11/17/2009 14:15		12/10/2009 9:45		12/27/2009 5:00		1/9/2010 22:15		
WSE (ft)			11.00		11.00		11.00		11.00		11.00		
Date-Time of lagoon falls below WSE > 11 feet			11/7/2009 18:15		12/8/2009 7:00		12/13/2009 18:15		12/31/2009 17:30		1/13/2010 6:00		
WSE (ft)			10.39		10.98		10.44		10.42		10.79		
Time (days) of WSE > 11 feet			15.92		20.70		3.35		4.52		3.32		
Time (hours) of WSE > 11 feet			382.0		496.7		80.5		108.5		79.7		
Mean daily flow rate (cfs) on day lowest WSE			51		18		22		55		41		
Mean daily flow rate (cfs) on day WSE > 11 feet			37		18		21		48		38		
Mean daily flow rate (cfs) on day WSE < 11 feet			18		22		182		47		42		
Likely mechanism with greatest influence on closure process			Ocean		Ocean		Ocean		Unknown		Unknown		
Dry Season Closure													
Date-Time of highest WSE at WY closure													7/25/2010 2:45
WSE (ft)													10.21
Date-Time of lowest WSE during WY closure													9/23/2010 19:00
WSE (ft)													6.34
Time (days) difference highest minus lowest WSE													60.68
Time (hours) difference highest minus lowest WSE													1456.25
Highest WSE at closure minus lowest WSE during closure in this WY													3.86
Rate of decrease in WSE (ft/day)													0.003
Mean daily flow rate (cfs) on day of highest WSE at closure													18
Mean daily flow rate (cfs) on day of lowest WSE of dry season													2.3
Likely mechanism with greatest influence on process													Ocean
End of WY													9/30/2010 23:45
Time (days) between final season closure and end of WY													67.9
Total days of lagoon closure in this WY (pre- and post-rainy season)													81.3
Totel days of closure including all partial closures													129.1

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in MPWMD, 2009-2010 annual mitigation report

Table 4. WY 2009, Riverine Dynamics of Breaches and Closures

	Sustained closure	Sustained breach*	In-season closure	Sustained breach	In-season closure	Sustained breach	Final closure	WSE increase while closed
Breach Type								
Mechnical, Natural, or Unknown		Mechanical		Natural		Natural	Natural	
Dry Season Events	10/1/2008 0:00							
Date-Time of lowest lagoon WSE prior to breach	10/1/2008 0:15							
Lowest lagoon WSE prior to breach, in current WY	6.59							
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach								
Date-Time of lowest WSE directly prior to overtopping	--							9/11/2009 11:15
WSE (ft)								6.44
Date-Time of highest WSE post-wave overtopping								9/12/2009 18:45
WSE (ft)								8.34
Increase in WSE (ft)								1.90
Likely mechanism with greatest influence on WSE increase process								Wave overtopping
Mean daily flow rate (cfs) on day of highest WSE								
Date-Time of most recent WSE > 11 ft prior to breach, in current WY	none							
Time (days) between start of WY and first seasonal breach	138.6							
Breachs and Closures during rainy season								
Date-Time of highest WSE at time of breach		2/16/2009 13:30		4/9/2009 3:15		5/9/2009 7:30		
WSE (ft)		13.11		12.76		12.15		
Date-Time of lowest WSE directly following breach		2/16/2009 16:45		4/9/2009 9:45		5/9/2009 18:45		
WSE (ft)		6.08		4.71		4.15		
WSE pre-breach minus post-breach (ft)		7.03		8.05		7.99		
Time difference (days)		0.14		0.27		0.47		
Time difference (hours)		3.25		6.50		11.25		
Rate of WSE decline (ft/hr)		2.16		1.24		0.71		
Mean daily flow rate (cfs) on day of breach		749		91		38		
Mean daily flow rate (cfs) on day of lowest WSE following breach		749		91		38		
Likely mechanism with greatest influence on process		Mechanical/Riverine		Riverine		Riverine		
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet			4/5/2009 18:00		5/3/2009 16:00			
WSE (ft)			4.53		4.11			
Date-Time of lagoon WSE fills to > 11 feet			4/7/2009 16:15		5/6/2009 14:45			
WSE (ft)			11.00		11.01			
Date-Time of lagoon falls below WSE > 11 feet			4/9/2009 4:00		5/9/2009 8:00			
WSE (ft)			11.44		11.95			
Time (days) of WSE > 11 feet			1.5		2.7			
Time (hours) of WSE > 11 feet			35.75		65.25			
Mean daily flow rate (cfs) on day lowest WSE			79		57			
Mean daily flow rate (cfs) on day WSE > 11 feet			74		45			
Mean daily flow rate (cfs) on day WSE < 11 feet			91		38			
Likely mechanism with greatest influence on process			Ocean		Ocean			
Dry Season Closure								
Date-Time of highest WSE at final WY closure							6/10/2009 4:15	
WSE (ft)							11.37	
Date-Time of lowest WSE during WY closure							8/21/2009 12:15	
WSE (ft)							6.30	
Time (days) difference highest minus lowest WSE							72.3	
Time (hours) difference highest minus lowest WSE							1736	
Highest WSE at closure minus lowest WSE during closure in this WY							5.07	
Rate of decrease in WSE (ft/day)							0.003	
Mean daily flow rate (cfs) on day of highest WSE at closure							16	
Mean daily flow rate (cfs) on day of lowest WSE of dry season							0	
Likely mechanism with greatest influence on process							Ocean	
End of WY							9/30/2009 23:45	
Time (days) between final season closure and end of WY							112.8	
Total days of lagoon closure, from previous WY closure to this WY 1st breach							251.4	
Totel days of closure including all partial closures							255.6	

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in MPWMD, 2008-2009 annual mitigation report

Table 5. WY 2008, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	Sustained breach*	In-season closure	Sustained breach	Final closure
Breach Type						
Mechnical, Natural, or Unknown			Natural		Natural	Natural
Dry Season Events	10/1/2007 0:00					
Date-Time of lowest lagoon WSE prior to breach	10/1/2007 10:00					
Lowest lagoon WSE during closure, this WY	6.04					
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0					
Date-Time of lowest WSE directly prior to significant overtopping		12/3/2007 16:00				
WSE (ft)		7.41				
Date-Time of highest WSE post-wave overtopping		12/5/2007 10:15				
WSE (ft)		8.66				
Increase in WSE (ft)		1.25				
Likely mechanism with greatest influence on WSE increase process		Wave overtopping				
Mean daily flow rate (cfs) on day of highest WSE		0				
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none					
Time (days) between start of WY and first seasonal breach	96.0					
Breachs and Closures during rainy season						
Date-Time of highest WSE at time of breach			1/5/2008 9:15		4/22/2008 20:30	
WSE (ft)			15.40		11.71	
Date-Time of lowest WSE directly following breach			1/5/2008 17:30		4/23/2008 9:30	
WSE (ft)			5.85		4.26	
WSE pre-breach minus post-breach (ft)			9.55		7.44	
Time difference (days)			0.34		0.54	
Time difference (hours)			8.25		13.00	
Rate of WSE decline (ft/hr)			1.16		0.57	
Mean daily flow rate (cfs) on day of breach			509		21	
Mean daily flow rate (cfs) on day of lowest WSE following breach			509		22	
Likely mechanism with greatest influence on process			Riverine		Unknown	
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours				4/13/2008 16:00		
WSE (ft)				4.19		
Date-Time of lagoon WSE fills to > 11 feet				4/19/2008 18:45		
WSE (ft)				11.00		
Date-Time of lagoon falls below WSE > 11 feet				4/22/2008 21:45		
WSE (ft)				10.99		
Time (days) of WSE > 11 feet				3.1		
Time (hours) of WSE > 11 feet				75.00		
Mean daily flow rate (cfs) on day lowest WSE				33		
Mean daily flow rate (cfs) on day WSE > 11 feet				21		
Mean daily flow rate (cfs) on day WSE < 11 feet				21		
Likely mechanism with greatest influence on process				Ocean		
Dry Season Closure						
Date-Time of highest WSE at final WY closure						5/13/2008 22:30
WSE (ft)						10.96
Date-Time of lowest WSE during WY closure						8/10/2008 6:45
WSE (ft)						5.87
Time (days) difference highest minus lowest WSE						88.34
Time (hours) difference highest minus lowest WSE						2120.25
Highest WSE at closure minus lowest WSE during closure in this WY						5.09
Rate of decrease in WSE (ft/day)						0.002
Mean daily flow rate (cfs) on day of highest WSE at closure						11
Mean daily flow rate (cfs) on day of lowest WSE of dry season						0
Likely mechanism with greatest influence on process						Ocean
End of WY						9/30/2008 23:45
Time (days) between final season closure and end of WY						140.1
Total days of lagoon closure in this WY (pre- and post-rainy season)						236.0
Totel days of closure including all partial closures						239.1

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in MPWMD 2007-2008 annual mitigation report

Table 6. WY 2007, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	WSE increase while closed	Temporary breach	In-season closure	Temporary breach	In-season closure	Sustained breach*	In-season closure	Temporary breach	Early closure	Final Closure
Breach Type												
Mechnical, Natural, or Unknown				Mechanical		Natural		Natural		Natural	Natural	Natural
Dry Season Events	10/1/2006 0:00											
Date-Time of lowest lagoon WSE prior to breach	10/12/2006 3:45											
Lowest lagoon WSE during closure, this WY	6.61											
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0											
Date-Time of lowest WSE prior to significant increase in WSE		12/5/2006 23:45	1/10/2007 20:45									
WSE (ft)		7.56	8.43									
Date-Time of highest WSE post-increase		12/10/2006 16:00	2/11/2007 10:30									
WSE (ft)		9.06	11.45									
Increase in WSE (ft)		1.51	3.02									
Likely mechanism with greatest influence on WSE increase process		Wave overtopping	Riverine									
Mean daily flow rate (cfs) on day of highest WSE		0										
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none											
Time (days) between start of WY and first seasonal breach	133.4											
Breachs and Closures during rainy season												
Date-Time of highest WSE at time of breach				2/11/2007 10:30		2/19/2007 14:30		2/25/2007 10:45		3/18/07 22:45		
WSE (ft)				11.45		11.72		11.92		11.57		
Date-Time of lowest WSE directly following breach				2/15/2007 6:30		2/21/2007 12:00		2/25/2007 19:30		3/19/07 9:15		
WSE (ft)				8.84		6.61		8.92		4.42		
WSE pre-breach minus post-breach (ft)				2.62		5.11		3.01		7.15		
Time difference (days)				3.83		1.90		0.36		0.44		
Time difference (hours)				92.00		45.50		8.75		10.50		
Rate of WSE decline (ft/hr)				0.03		0.11		0.34		0.68		
Mean daily flow rate (cfs) on day of breach				29		32		45		30		
Mean daily flow rate (cfs) on day of lowest WSE following breach				50		28		45		28		
Likely mechanism with greatest influence on breaching process				Mechanical		Unknown		Riverine		Ocean		
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours					2/16/2007 7:30		2/20/2007 22:30		3/12/2007 20:15			
WSE (ft)					8.86		7.05		4.67			
Date-Time of lagoon WSE fills to > 11 feet					2/18/2007 8:30		2/24/2007 3:00		3/17/2007 8:30			
WSE (ft)					11.01		11.00		11.01			
Date-Time of lagoon falls below WSE > 11 feet					2/19/2007 16:15		2/25/2007 13:30		3/19/2007 0:00			
WSE (ft)					10.89		10.91		10.93			
Time (days) of WSE > 11 feet					1.3		1.4		1.6			
Time (hours) of WSE > 11 feet					31.75		34.50		39.50			
Mean daily flow rate (cfs) on day lowest WSE					44		29		47			
Mean daily flow rate (cfs) on day WSE > 11 feet					36		46		32			
Mean daily flow rate (cfs) on day WSE < 11 feet					32		45		28			
Likely mechanism with greatest influence on closure process					Ocean		Ocean		Ocean			
Dry Season Closure												
Date-Time of highest WSE at WY closure											3/27/2007 3:45	4/26/2007 22:45
WSE (ft)											11.30	12.25
Date-Time of lowest WSE during WY closure											4/8/2007 0:15	8/20/2007 11:45
WSE (ft)											10.07	5.25
Time (days) difference highest minus lowest WSE											11.85	115.54
Time (hours) difference highest minus lowest WSE											284.50	2773.00
Highest WSE at closure minus lowest WSE during closure in this WY											1.24	7.01
Rate of decrease in WSE (ft/day)											0.004	0.003
Mean daily flow rate (cfs) on day of highest WSE at closure											25	17
Mean daily flow rate (cfs) on day of lowest WSE of dry season											14	0
Likely mechanism with greatest influence on process											Ocean	Mechanical
End of WY												9/30/2007 23:45
Time (days) between final season closure and end of WY												157.0
Total days of lagoon closure in this WY (pre- and post-rainy season)												290.5
Totel days of closure including all partial closures												306.7

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in MPWMD 2006-2007 annual mitigation report and Perry et al. 2006-07 CCoWS report

Table 7. WY 2006, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	Sustained breach*	In-season closure	Temporary breach	In-season closure	Sustained breach	Early Closure	Final Closure
Breach Type									
Mechnical, Natural, or Unknown			Mechanical		Natural		Natural	Natural	Natural
Dry Season Events	10/1/2005 0:00								
Date-Time of lowest lagoon WSE prior to breach	10/4/2005 9:00								
Lowest lagoon WSE during closure, this WY	6.91								
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0								
Date-Time of lowest WSE prior to significant increase in WSE		12/9/2005 4:15							
WSE (ft)		7.89							
Date-Time of highest WSE post-increase		12/21/05 15:30							
WSE (ft)		9.58							
Increase in WSE (ft)		1.69							
Likely mechanism with greatest influence on WSE increase process		Wave overtopping							
Mean daily flow rate (cfs) on day of highest WSE		20							
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none								
Time (days) between start of WY and first seasonal breach	88.5								
Breachs and Closures during rainy season									
Date-Time of highest WSE at time of breach			12/28/2005 11:45		2/10/2006 5:45		2/22/2006 12:15		
WSE (ft)			11.35		12.83		12.74		
Date-Time of lowest WSE directly following breach			12/30/2005 22:45		2/10/2006 20:15		2/23/2006 1:30		
WSE (ft)			6.42		5.33		5.06		
WSE pre-breach minus post-breach (ft)			4.93		7.49		7.68		
Time difference (days)			2.46		0.60		0.55		
Time difference (hours)			59.00		14.50		13.25		
Rate of WSE decline (ft/hr)			0.08		0.52		0.58		
Mean daily flow rate (cfs) on day of breach			81		57		49		
Mean daily flow rate (cfs) on day of lowest WSE following breach			82		57		47		
Likely mechanism with greatest influence on breaching process			Mechanical/Riverine		Riverine		Riverine		
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours				2/6/2006 17:15		2/15/2006 21:00			
WSE (ft)				5.40		5.08			
Date-Time of lagoon WSE fills to > 11 feet				2/8/2006 6:00		2/19/2006 23:00			
WSE (ft)				11.01		11.00			
Date-Time of lagoon falls below WSE > 11 feet				2/10/2006 6:45		2/22/2006 14:00			
WSE (ft)				10.75		11.35			
Time (days) of WSE > 11 feet				2.0		2.6			
Time (hours) of WSE > 11 feet				48.75		63.00			
Mean daily flow rate (cfs) on day lowest WSE				69		49			
Mean daily flow rate (cfs) on day WSE > 11 feet				63		55			
Mean daily flow rate (cfs) on day WSE < 11 feet				57		49			
Likely mechanism with greatest influence on closure process				Ocean		Ocean			
Dry Season Closure									
Date-Time of highest WSE at WY closure								6/21/2006 5:15	7/17/2006 9:00
WSE (ft)								10.53	10.14
Date-Time of lowest WSE during WY closure								7/6/2006 7:30	9/4/2006 18:45
WSE (ft)								8.63	6.31
Time (days) difference highest minus lowest WSE								15.09	49.41
Time (hours) difference highest minus lowest WSE								362.25	1185.75
Highest WSE at closure minus lowest WSE during closure in this WY								1.89	3.83
Rate of decrease in WSE (ft/day)								0.005	0.003
Mean daily flow rate (cfs) on day of highest WSE at closure								36	13
Mean daily flow rate (cfs) on day of lowest WSE of dry season								27	0
Likely mechanism with greatest influence on process								Mechanical	Ocean
End of WY									9/30/2006 23:45
Time (days) between final season closure and end of WY									75.6
Total days of lagoon closure in this WY (pre- and post-rainy season)									164.1
Totel days of closure including all partial closures									183.9

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in MPWMD 2005-2006 annual mitigation report and the Larson et al. 2005-06 CCoWS report

Table 8. WY 2005, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	Sustained breach*	Early closure	Final closure
Breach Type					
Mechnical, Natural, or Unknown			Mechanical	Natural	Natural
Dry Season Events	10/1/2004 0:00				
Date-Time of lowest lagoon WSE prior to breach	10/7/2004 11:30				
Lowest lagoon WSE during closure, this WY	6.37				
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0				
Date-Time of lowest WSE prior to significant increase in WSE		10/16/2004 0:15			
WSE (ft)		6.99			
Date-Time of highest WSE post-increase		38281.36			
WSE (ft)		8.39			
Increase in WSE (ft)		1.39			
Likely mechanism with greatest influence on WSE increase process		Wave overtopping			
Mean daily flow rate (cfs) on day of highest WSE					
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none				
Time (days) between start of WY and first seasonal breach	90.7				
Breachs and Closures during rainy season					
Date-Time of highest WSE at time of breach			12/30/2004 16:00		
WSE (ft)			13.03		
Date-Time of lowest WSE directly following breach			1/2/2005 0:45		
WSE (ft)			7.27		
WSE pre-breach minus post-breach (ft)			5.76		
Time difference (days)			2.36		
Time difference (hours)			56.75		
Rate of WSE decline (ft/hr)			0.10		
Mean daily flow rate (cfs) on day of breach			532		
Mean daily flow rate (cfs) on day of lowest WSE following breach			642		
Likely mechanism with greatest influence on breaching process			Mechanical/Riverine		
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours					
WSE (ft)					
Date-Time of lagoon WSE fills to > 11 feet					
WSE (ft)					
Date-Time of lagoon falls below WSE > 11 feet					
WSE (ft)					
Time (days) of WSE > 11 feet					
Time (hours) of WSE > 11 feet					
Mean daily flow rate (cfs) on day lowest WSE					
Mean daily flow rate (cfs) on day WSE > 11 feet					
Mean daily flow rate (cfs) on day WSE < 11 feet					
Likely mechanism with greatest influence on closure process					
Dry Season Closure					
Date-Time of highest WSE at WY closure				7/10/2005 0:45	7/20/2005 1:45
WSE (ft)				9.52	8.66
Date-Time of lowest WSE during WY closure				7/11/2005 23:30	8/29/2005 13:00
WSE (ft)				5.87	5.81
Time (days) difference highest minus lowest WSE				1.95	40.47
Time (hours) difference highest minus lowest WSE				46.75	971.25
Highest WSE at closure minus lowest WSE during closure in this WY				3.64	2.85
Rate of decrease in WSE (ft/day)				0.08	0.003
Mean daily flow rate (cfs) on day of highest WSE at closure					8.6
Mean daily flow rate (cfs) on day of lowest WSE of dry season					0
Likely mechanism with greatest influence on process					Ocean
End of WY					9/30/2005 23:45
Time (days) between final season closure and end of WY					72.9
Total days of lagoon closure in this WY (pre- and post-rainy season)					163.6
Totel days of closure including all partial closures					165.5

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in the Larson et al. 2004-05 CCoSW report

Table 9. WY 2004, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	Sustained breach*	In-season Closure	Temporary breach	In-season Closure	Temporary breach	In-season Closure	Sustained breach	Early Closure	Final Closure	WSE increase while closed
Breach Type												
Mechnical, Natural, or Unknown			Mechanical		Natural		Natural		Natural	Natural	Natural	
Dry Season Events	10/1/2003 0:00											
Date-Time of lowest lagoon WSE prior to breach	10/2/2003 12:00											
Lowest lagoon WSE during closure, this WY	5.86											
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0											
Date-Time of lowest WSE prior to significant increase in WSE		12/8/2003 6:00										8/24/04 14:15
WSE (ft)		8.17										5.71
Date-Time of highest WSE post-increase		12/10/2003 12:45										8/29/04 2:15
WSE (ft)		11.18										7.23
Increase in WSE (ft)		3.01										1.53
Likely mechanism with greatest influence on WSE increase process		Wave overtopping										Wave overtopping
Mean daily flow rate (cfs) on day of highest WSE		0										0
Date-Time of most recent WSE > 11 ft prior to breach, this WY	12/11/2003 9:15											
Time (days) between start of WY and first seasonal breach	90.6											
Breachs and Closures during rainy season												
Date-Time of highest WSE at time of breach			12/30/2003 15:00		1/14/2004 17:30		1/20/2004 17:30		1/26/2004 15:30			
WSE (ft)			13.22		12.35		11.82		12.0			
Date-Time of lowest WSE directly following breach			12/31/2003 1:00		1/15/2004 0:30		1/21/2004 4:00		1/26/2004 22:30			
WSE (ft)			6.09		5.36		5.25		5.3			
WSE pre-breach minus post-breach (ft)			7.13		6.99		6.57		6.72			
Time difference (days)			0.42		0.29		0.44		0.29			
Time difference (hours)			10		7		10.5		7			
Rate of WSE decline (ft/hr)			0.71		1.00		0.63		0.96			
Mean daily flow rate (cfs) on day of breach			416		45		34		28			
Mean daily flow rate (cfs) on day of lowest WSE following breach			249		44		32		28			
Likely mechanism with greatest influence on breaching process			Mechanical/Riverine		Riverine		Unknown		Unknown			
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours				1/11/2004 21:00		1/17/2004 21:00		1/22/2004 4:45		4/20/2004 19:00		
WSE (ft)				5.37		5.88		5.4		5.44		
Date-Time of lagoon WSE fills to > 11 feet				1/13/2004 1:00		1/19/2004 8:30		1/24/2004 11:00		4/25/2004 6:30		
WSE (ft)				11.0		11.01		11.0		11.00		
Date-Time of lagoon falls below WSE > 11 feet				1/14/2004 19:00		1/20/2004 18:30		1/26/2004 18:15		4/27/2004 20:30		
WSE (ft)				9.9		10.57		8.77		10.88		
Time (days) of WSE > 11 feet				1.75		1.42		2.30		2.58		
Time (hours) of WSE > 11 feet				42.0		34.0		55.25		62.0		
Mean daily flow rate (cfs) on day lowest WSE				57		41		30		29		
Mean daily flow rate (cfs) on day WSE > 11 feet				49		36		29		20		
Mean daily flow rate (cfs) on day WSE < 11 feet				45		34		28		16		
Likely mechanism with greatest influence on closure process				Ocean		Ocean		Ocean		Ocean		
Dry Season Closure												
Date-Time of highest WSE at WY closure											5/7/2004 3:30	
WSE (ft)											9.95	
Date-Time of lowest WSE during WY closure or following break											7/18/2004 13:45	
WSE (ft)											5.10	
Time (days) difference highest minus lowest WSE											72.43	
Time (hours) difference highest minus lowest WSE											1738.25	
Highest WSE at closure minus lowest WSE during closure in this WY											4.85	
Rate of decrease in WSE (ft/day)											0.003	
Mean daily flow rate (cfs) on day of highest WSE at closure											11	
Mean daily flow rate (cfs) on day of lowest WSE of dry season											0	
Likely mechanism with greatest influence on process											Ocean	
End of WY											9/30/2004 23:45	
Time (days) between final season closure and end of WY											146.8	
Total days of lagoon closure in this WY (pre- and post-rainy season)											237.5	
Totel days of closure including all partial closures											245.5	

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events as reported in the Smith et al. 2003-04 CCoSW report

Table 10. WY 2003, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	WSE increase while closed	Sustained breach*	In-season Closure	Sustained breach	Final Closure
Breach Type							
Mechnical, Natural, or Unknown				Mechanical		Natural	Natural
Dry Season Events	10/1/2002 0:00						
Date-Time of lowest lagoon WSE prior to breach		10/15/2002 9:30					
Lowest lagoon WSE during closure, this WY		5.56					
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach		0					
Date-Time of lowest WSE prior to significant increase in WSE		10/15/2002 9:30	11/6/2002 0:30				
WSE (ft)		5.56	7.59				
Date-Time of highest WSE post-increase		10/22/2002 16:00	11/8/2002 17:15				
WSE (ft)		7.86	11.53				
Increase in WSE (ft)		2.30	3.94				
Likely mechanism with greatest influence on WSE increase process		Wave overtopping	Wave overtopping				
Mean daily flow rate (cfs) on day of highest WSE		0	0				
Date-Time of most recent WSE > 11 ft prior to breach, this WY	11/12/2002 1:45						
Time (days) between start of WY and first seasonal breach	76.5						
Breachs and Closures during rainy season							
Date-Time of highest WSE at time of breach				12/16/2002 12:15		6/18/2003 19:45	
WSE (ft)				13.55		11.45	
Date-Time of lowest WSE directly following breach				12/16/2002 15:15		6/19/2003 0:15	
WSE (ft)				7.14		5.29	
WSE pre-breach minus post-breach (ft)				6.41		6.16	
Time difference (days)				0.13		0.19	
Time difference (hours)				3.00		4.50	
Rate of WSE decline (ft/hr)				2.14		1.37	
Mean daily flow rate (cfs) on day of breach				1250		25	
Mean daily flow rate (cfs) on day of lowest WSE following breach				1250		25	
Likely mechanism with greatest influence on breaching process				Mechanical/Riverine		Riverine	
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours					6/14/2003 8:45		
WSE (ft)					5.1		
Date-Time of lagoon WSE fills to > 11 feet					6/17/2003 11:45		
WSE (ft)					11.0		
Date-Time of lagoon falls below WSE > 11 feet					6/18/2003 20:45		
WSE (ft)					10.7		
Time (days) of WSE > 11 feet					1.4		
Time (hours) of WSE > 11 feet					33.0		
Mean daily flow rate (cfs) on day lowest WSE					33		
Mean daily flow rate (cfs) on day WSE > 11 feet					27		
Mean daily flow rate (cfs) on day WSE < 11 feet					25		
Likely mechanism with greatest influence on closure process					Ocean		
Dry Season Closure							
Date-Time of highest WSE at WY closure							7/11/2003 22:30
WSE (ft)							7.98
Date-Time of lowest WSE during WY closure or following break							8/8/2003 15:45
WSE (ft)							5.37
Time (days) difference highest minus lowest WSE							27.72
Time (hours) difference highest minus lowest WSE							665.25
Highest WSE at closure minus lowest WSE during closure in this WY							2.61
Rate of decrease in WSE (ft/day)							0.004
Mean daily flow rate (cfs) on day of highest WSE at closure							6.8
Mean daily flow rate (cfs) on day of lowest WSE of dry season							0
Likely mechanism with greatest influence on process							Ocean
End of WY							9/30/2003 23:45
Time (days) between final season closure and end of WY							81.1
Total days of lagoon closure in this WY (pre- and post-rainy season)							157.6
Totel days of closure including all partial closures							158.9

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in the Casagrande and Watson 2002-03 CCoSW report

Table 11. WY 2002, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	WSE increase while closed	Sustained breach*	In-season Closure	Sustained breach	Early Closure	Final Closure
Breach Type								
Mechnical, Natural, or Unknown				Mechanical		Mechanical	Natural	Natural
Dry Season Events	10/1/2001 0:00							
Date-Time of lowest lagoon WSE prior to breach	10/8/2001 2:30							
Lowest lagoon WSE during closure, this WY	6.76							
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0							
Date-Time of lowest WSE prior to significant increase in WSE		10/8/2001 2:30	10/31/2001 0:15					
WSE (ft)		6.76	6.97					
Date-Time of highest WSE post-increase		10/16/2001 0:45	11/4/2001 17:00					
WSE (ft)		8.24	8.16					
Increase in WSE (ft)		1.48	1.19					
Likely mechanism with greatest influence on WSE increase process		Wave overtopping	Wave overtopping					
Mean daily flow rate (cfs) on day of highest WSE		0	0					
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none							
Time (days) between start of WY and first seasonal breach	63.6							
Breachs and Closures during rainy season								
Date-Time of highest WSE at time of breach				12/3/2001 14:15		1/28/2002 16:45		
WSE (ft)				13.39		12.32		
Date-Time of lowest WSE directly following breach				12/3/2001 22:30		1/29/2002 6:45		
WSE (ft)				5.64		5.65		
WSE pre-breach minus post-breach (ft)				7.75		6.67		
Time difference (days)				0.34		0.58		
Time difference (hours)				8.25		14.0		
Rate of WSE decline (ft/hr)				0.94		0.48		
Mean daily flow rate (cfs) on day of breach				402		53		
Mean daily flow rate (cfs) on day of lowest WSE following breach				402		54		
Likely mechanism with greatest influence on breaching process				Mechnical/Riverine		Mechnical/Riverine		
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours					1/26/2002 21:00			
WSE (ft)					5.88			
Date-Time of lagoon WSE fills to > 11 feet					1/27/2002 15:45			
WSE (ft)					11.00			
Date-Time of lagoon falls below WSE > 11 feet					1/28/2002 18:30			
WSE (ft)					10.56			
Time (days) of WSE > 11 feet					1.11			
Time (hours) of WSE > 11 feet					26.75			
Mean daily flow rate (cfs) on day lowest WSE					50			
Mean daily flow rate (cfs) on day WSE > 11 feet					53			
Mean daily flow rate (cfs) on day WSE < 11 feet					53			
Likely mechanism with greatest influence on closure process					Ocean			
Dry Season Closure								
Date-Time of highest WSE at WY closure							5/26/2002 9:15	6/4/2002 11:15
WSE (ft)							10.90	10.04
Date-Time of lowest WSE during WY closure or following break							5/26/2002 20:15	8/25/2002 21:45
WSE (ft)							5.25	5.31
Time (days) difference highest minus lowest WSE							0.46	82.44
Time (hours) difference highest minus lowest WSE							11.00	1978.50
Highest WSE at closure minus lowest WSE during closure in this WY							5.65	4.73
Rate of decrease in WSE (ft/day)							0.514	0.002
Mean daily flow rate (cfs) on day of highest WSE at closure							18	11
Mean daily flow rate (cfs) on day of lowest WSE of dry season							18	0
Likely mechanism with greatest influence on process							Ocean	Ocean
End of WY								9/30/2002 23:45
Time (days) between final season closure and end of WY								118.5
Total days of lagoon closure in this WY (pre- and post-rainy season)								182.1
Totel days of closure including all partial closures								183.7

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in the Casagrande et al. 2001-02 CCoSW report

Table 12. WY 2001, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	Sustained breach*	Final Closure
Breach Type				
Mechnical, Natural, or Unknown			Mechanical	Natural
Dry Season Events	10/1/2000 0:00			
Date-Time of lowest lagoon WSE prior to breach	10/9/2000 10:30			
Lowest lagoon WSE during closure, this WY	6.82			
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0			
Date-Time of lowest WSE prior to significant increase in WSE		10/21/2000 16:30		
WSE (ft)		7.41		
Date-Time of highest WSE post-increase		10/26/2000 15:30		
WSE (ft)		9.08		
Increase in WSE (ft)		4.96		
Likely mechanism with greatest influence on WSE increase process		Wave overtopping		
Mean daily flow rate (cfs) on day of highest WSE		0		
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none			
Time (days) between start of WY and first seasonal breach	102.68			
Breachs and Closures during rainy season				
Date-Time of highest WSE at time of breach			1/11/2001 16:15	
WSE (ft)			14.78	
Date-Time of lowest WSE directly following breach			1/11/2001 20:30	
WSE (ft)			5.47	
WSE pre-breach minus post-breach (ft)			9.31	
Time difference (days)			0.18	
Time difference (hours)			4.25	
Rate of WSE decline (ft/hr)			2.19	
Mean daily flow rate (cfs) on day of breach			148	
Mean daily flow rate (cfs) on day of lowest WSE following breach			148	
Likely mechanism with greatest influence on breaching process			Mechnical/Riverine	
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours				
WSE (ft)				
Date-Time of lagoon WSE fills to > 11 feet				
WSE (ft)				
Date-Time of lagoon falls below WSE > 11 feet				
WSE (ft)				
Time (days) of WSE > 11 feet				
Time (hours) of WSE > 11 feet				
Mean daily flow rate (cfs) on day lowest WSE				
Mean daily flow rate (cfs) on day WSE > 11 feet				
Mean daily flow rate (cfs) on day WSE < 11 feet				
Likely mechanism with greatest influence on closure process				
Dry Season Closure				
Date-Time of highest WSE at WY closure				6/13/2001 5:30
WSE (ft)				9.87
Date-Time of lowest WSE during WY closure or following break				8/23/2001 5:45
WSE (ft)				5.58
Time (days) difference highest minus lowest WSE				71.01
Time (hours) difference highest minus lowest WSE				1704.25
Highest WSE at closure minus lowest WSE during closure in this WY				4.29
Rate of decrease in WSE (ft/day)				0.003
Mean daily flow rate (cfs) on day of highest WSE at closure				8.5
Mean daily flow rate (cfs) on day of lowest WSE of dry season				0
Likely mechanism with greatest influence on process				Ocean
End of WY				9/30/2001 23:45
Time (days) between final season closure and end of WY				109.8
Total days of lagoon closure in this WY (pre- and post-rainy season)				212.4
Totel days of closure including all partial closures				212.4

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Some breaching and/or closure events were reported in the Watson et al. 2000-01 CCoSW report

Table 13. WY 2000, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	Sustained breach*	Early Closure	Final Closure
Breach Type					
Mechnical, Natural, or Unknown			Mechanical	Natural	Natural
Dry Season Events	10/1/1999 0:00				
Date-Time of lowest lagoon WSE prior to breach	10/6/1999 18:00				
Lowest lagoon WSE during closure, this WY	5.93				
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0				
Date-Time of lowest WSE prior to significant increase in WSE		10/25/1999 4:45			
WSE (ft)		6.23			
Date-Time of highest WSE post-increase		10/28/1999 18:00			
WSE (ft)		10.07			
Increase in WSE (ft)		3.84			
Likely mechanism with greatest influence on WSE increase process		Wave overtopping			
Mean daily flow rate (cfs) on day of highest WSE		0			
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none				
Time (days) between start of WY and first seasonal breach	115.1				
Breachs and Closures during rainy season					
Date-Time of highest WSE at time of breach			1/24/2000 2:15		
WSE (ft)			14.05		
Date-Time of lowest WSE directly following breach			1/24/2000 22:30		
WSE (ft)			6.85		
WSE pre-breach minus post-breach (ft)			7.2		
Time difference (days)			0.84		
Time difference (hours)			20.25		
Rate of WSE decline (ft/hr)			0.36		
Mean daily flow rate (cfs) on day of breach			1000		
Mean daily flow rate (cfs) on day of lowest WSE following breach			1000		
Likely mechanism with greatest influence on breaching process			Mechnical/Riverine		
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours					
WSE (ft)					
Date-Time of lagoon WSE fills to > 11 feet					
WSE (ft)					
Date-Time of lagoon falls below WSE > 11 feet					
WSE (ft)					
Time (days) of WSE > 11 feet					
Time (hours) of WSE > 11 feet					
Mean daily flow rate (cfs) on day lowest WSE					
Mean daily flow rate (cfs) on day WSE > 11 feet					
Mean daily flow rate (cfs) on day WSE < 11 feet					
Likely mechanism with greatest influence on closure process					
Dry Season Closure					
Date-Time of highest WSE at WY closure				4/24/2000 11:15	5/6/2000 2:30
WSE (ft)				10.35	10.70
Date-Time of lowest WSE during WY closure or following break				5/2/2000 18:45	9/16/2000 10:45
WSE (ft)				8.11	5.67
Time (days) difference highest minus lowest WSE				8.31	133.34
Time (hours) difference highest minus lowest WSE				199.50	3200.25
Highest WSE at closure minus lowest WSE during closure in this WY				2.24	5.03
Rate of decrease in WSE (ft/day)				0.011	0.002
Mean daily flow rate (cfs) on day of highest WSE at closure				102	65
Mean daily flow rate (cfs) on day of lowest WSE of dry season				75	0
Likely mechanism with greatest influence on process				Ocean	Ocean
End of WY					9/30/2000 23:45
Time (days) between final season closure and end of WY					147.9
Total days of lagoon closure in this WY (pre- and post-rainy season)					263.0
Totel days of closure including all partial closures					271.3

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
No record of breaching and/or closing events for WY 2000

Table 14. WY 1999, Riverine Dynamics of Breaches and Closures

Breach Type	Sustained closure	WSE increase while closed	Temporary breach	In-season Closure	Temporary breach	In-season Closure	Temporary breach	In-season Closure	Sustained breach*	In-season Closure	Temporary breach	In-season Closure	Temporary breach	In-season Closure	Sustained breach	Early Closure	Temporary breach	Final Closure
Mechnical, Natural, or Unknown			Mechanical		Mechanical		Mechanical		Mechanical		Mechanical		Mechanical		Mechanical	Natural	Natural	Natural
Dry Season Events	10/1/1998 0:00																	
Date-Time of lowest lagoon WSE prior to breach	10/1/1998 0:00																	
Lowest lagoon WSE during closure, this WY	10.01																	
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	23																	
Date-Time of lowest WSE prior to significant increase in WSE		10/24/1998 9:45																
WSE (ft)		10.71																
Date-Time of highest WSE post-increase		11/3/1998 12:00																
WSE (ft)		12.75																
Increase in WSE (ft)		2.04																
Likely mechanism with greatest influence on WSE increase process		Riverine																
Mean daily flow rate (cfs) on day of highest WSE		22																
Date-Time of most recent WSE > 11 ft prior to breach, this WY	10/25/1998 9:15																	
Time (days) between start of WY and first seasonal breach	33.5																	
Breachs and Closures during rainy season																		
Date-Time of highest WSE at time of breach			11/3/1998 12:00		11/10/1998 18:15		11/19/1998 13:00		11/26/1998 13:00		1/2/1999 15:45		1/8/1999 17:45		1/16/1999 18:45		6/17/1999 20:00	
WSE (ft)			12.75		11.86		12.65		12.59		12.13		12.55		12.70		12.50	
Date-Time of lowest WSE directly following breach			11/4/1998 6:30		11/11/1998 4:30		11/19/1998 22:00		11/27/1998 0:30		1/2/1999 22:45		1/10/1999 1:00		1/16/1999 23:30		6/18/1999 13:30	
WSE (ft)			5.00		5.02		5.19		5.26		5.40		5.05		6.67		5.27	
WSE pre-breach minus post-breach (ft)			7.75		6.84		7.46		7.33		6.73		7.50		6.03		0.73	
Time difference (days)			0.77		0.43		0.38		0.48		0.29		1.30		0.20		17.50	
Time difference (hours)			18.50		10.25		9.00		11.50		7.00		31.25		4.75		7.23	
Rate of WSE decline (ft/hr)			0.42		0.67		0.83		0.64		0.96		0.24		1.27		0.41	
Mean daily flow rate (cfs) on day of breach			21		24		24		25		13		10		10		27	
Mean daily flow rate (cfs) on day of lowest WSE following breach			21		31		24		27		13		10		10		26	
Likely mechanism with greatest influence on breaching process			Mechanical		Mechanical		Mechanical		Mechanical		Mechanical		Mechanical		Mechanical		Mechanical	
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours				11/4/1998 6:30		11/11/1998 4:30		11/19/1998 22:00		12/28/1998 1:45		1/2/1999 22:45		1/10/1999 1:00				
WSE (ft)				5.00		5.02		5.19		5.40		5.40		5.05				
Date-Time of lagoon WSE fills to > 11 feet				11/8/1998 2:15		11/14/1998 9:30		11/22/1998 13:15		12/31/1998 16:15		1/5/1999 4:45		1/13/1999 8:00				
WSE (ft)				11.00		11.00		11.02		11.00		11.00		11.00				
Date-Time of lagoon falls below WSE > 11 feet				11/10/1998 20:15		11/19/1998 15:00		11/26/1998 14:00		1/2/1999 17:15		1/8/1999 18:45		1/16/1999 21:00				
WSE (ft)				10.80		10.98		8.60		9.97		9.46		10.89				
Time (days) of WSE > 11 feet				2.75		5.15		3.99		1.98		3.54		3.45				
Time (hours) of WSE > 11 feet				66.00		123.50		95.75		47.50		85.00		82.75				
Mean daily flow rate (cfs) on day lowest WSE				21		31		24		17		13		10				
Mean daily flow rate (cfs) on day WSE > 11 feet				24		22		22		15		11		10				
Mean daily flow rate (cfs) on day WSE < 11 feet				24		24		25		13		10		10				
Likely mechanism with greatest influence on closure process				Ocean		Ocean		Ocean		Ocean		Ocean		Ocean				
Dry Season Closure																		
Date-Time of highest WSE at WY closure																5/27/1999 0:00		7/4/1999 6:00
WSE (ft)																9.20		10.52
Date-Time of lowest WSE during WY closure or following break																6/12/1999 17:30		8/18/1999 13:00
WSE (ft)																8.06		5.38
Time (days) difference highest minus lowest WSE																16.73		45.29
Time (hours) difference highest minus lowest WSE																401.50		1087.00
Highest WSE at closure minus lowest WSE during closure in this WY																1.14		5.14
Rate of decrease in WSE (ft/day)																0.003		0.005
Mean daily flow rate (cfs) on day of highest WSE at closure																53		7.2
Mean daily flow rate (cfs) on day of lowest WSE of dry season																34		0
Likely mechanism with greatest influence on process																Unknown		Ocean
End of WY																		9/30/1999 23:45
Time (days) between final season closure and end of WY																		88.74
Total days of lagoon closure in this WY (pre- and post-rainy season)																		122.2
Totel days of closure including all partial closures																		159.8

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
No record of breaching and/or closing events for WY 1999

Table 15. WY 1998, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	Sustained breach*	In-season Closure	Temporary breach	In-season Closure	Sustained breach	Final Closure
Breach Type								
Mechnical, Natural, or Unknown			Mechanical		Mechanical		Mechanical	Unknown
Dry Season Events	10/1/1997 0:00							
Date-Time of lowest lagoon WSE prior to breach	10/29/1997 21:00							
Lowest lagoon WSE during closure, this WY	7.34							
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0							
Date-Time of lowest WSE prior to significant increase in WSE		11/9/1997 17:45						
WSE (ft)		8.16						
Date-Time of highest WSE post-increase		11/15/1997 12:00						
WSE (ft)		10.65						
Increase in WSE (ft)		2.49						
Likely mechanism with greatest influence on WSE increase process		Ocean						
Mean daily flow rate (cfs) on day of highest WSE		0						
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none							
Time (days) between start of WY and first seasonal breach	66.4							
Breachs and Closures during rainy season								
Date-Time of highest WSE at time of breach			12/6/1997 10:15		12/30/1997 16:45		1/3/1998 17:30	
WSE (ft)			12.36		12.66		12.12	
Date-Time of lowest WSE directly following breach			12/7/1997 0:45		12/30/1997 22:15		1/3/1998 23:30	
WSE (ft)			6.57		5.40		5.36	
WSE pre-breach minus post-breach (ft)			5.79		7.26		6.76	
Time difference (days)			0.60		0.23		0.25	
Time difference (hours)			14.5		5.5		6	
Rate of WSE decline (ft/hr)			0.40		1.32		1.13	
Mean daily flow rate (cfs) on day of breach			112		12		29	
Mean daily flow rate (cfs) on day of lowest WSE following breach			135		12		29	
Likely mechanism with greatest influence on breaching process			Mechanical/Riverine		Mechanical		Mechanical	
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours				12/26/1997 18:45		12/30/1997 22:15		
WSE (ft)				5.45		5.40		
Date-Time of lagoon WSE fills to > 11 feet				12/28/1997 14:30		1/2/1998 15:45		
WSE (ft)				11.00		11.00		
Date-Time of lagoon falls below WSE > 11 feet				12/30/1997 18:30		1/3/1998 18:45		
WSE (ft)				9.88		10.10		
Time (days) of WSE > 11 feet				2.17		1.07		
Time (hours) of WSE > 11 feet				52.0		25.7		
Mean daily flow rate (cfs) on day lowest WSE				18		12		
Mean daily flow rate (cfs) on day WSE > 11 feet				15		11		
Mean daily flow rate (cfs) on day WSE < 11 feet				12		29		
Likely mechanism with greatest influence on closure process				Ocean		Ocean		
Dry Season Closure								
Date-Time of highest WSE at WY closure								6/12/1998 0:00
WSE (ft)								8.85
Date-Time of lowest WSE during WY closure or following break								8/31/1998 2:30
WSE (ft)								7.16
Time (days) difference highest minus lowest WSE								80.10
Time (hours) difference highest minus lowest WSE								1922.50
Highest WSE at closure minus lowest WSE during closure in this WY								1.69
Rate of decrease in WSE (ft/day)								0.001
Mean daily flow rate (cfs) on day of highest WSE at closure								172
Mean daily flow rate (cfs) on day of lowest WSE of dry season								23
Likely mechanism with greatest influence on process								Unknown
End of WY								9/30/1998 23:45
Time (days) between final season closure and end of WY								110.99
Total days of lagoon closure in this WY (pre- and post-rainy season)								177.4
Totel days of closure including all partial closures								180.7

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
No record of breaching and/or closing events for WY 1998

Table 16. WY 1997, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	Sustained breach*	Final closure	WSE increase while closed
Breach Type					
Mechnical, Natural, or Unknown			Mechanical	Natural	
Dry Season Events	10/1/1996 0:00				
Date-Time of lowest lagoon WSE prior to breach	10/4/1996 11:15				
Lowest lagoon WSE during closure, this WY	6.10				
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0				
Date-Time of lowest WSE prior to significant increase in WSE		10/4/1996 11:15			9/17/1997 23:45
WSE (ft)		6.10			6.16
Date-Time of highest WSE post-increase		10/8/1996 9:30			9/25/1997 22:00
WSE (ft)		9.20			10.48
Increase in WSE (ft)		3.10			4.32
Likely mechanism with greatest influence on WSE increase process		Ocean			Ocean
Mean daily flow rate (cfs) on day of highest WSE		0			0
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none				
Time (days) between start of WY and first seasonal breach	69.6				
Breachs and Closures during rainy season					
Date-Time of highest WSE at time of breach			12/9/1996 13:15		
WSE (ft)			12.34		
Date-Time of lowest WSE directly following breach			12/10/1996 4:30		
WSE (ft)			8.34		
WSE pre-breach minus post-breach (ft)			4		
Time difference (days)			0.64		
Time difference (hours)			15.25		
Rate of WSE decline (ft/hr)			0.26		
Mean daily flow rate (cfs) on day of breach			27		
Mean daily flow rate (cfs) on day of lowest WSE following breach			879		
Likely mechanism with greatest influence on breaching process			Mechanical		
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours					
WSE (ft)					
Date-Time of lagoon WSE fills to > 11 feet					
WSE (ft)					
Date-Time of lagoon falls below WSE > 11 feet					
WSE (ft)					
Time (days) of WSE > 11 feet					
Time (hours) of WSE > 11 feet					
Mean daily flow rate (cfs) on day lowest WSE					
Mean daily flow rate (cfs) on day WSE > 11 feet					
Mean daily flow rate (cfs) on day WSE < 11 feet					
Likely mechanism with greatest influence on closure process					
Dry Season Closure					
Date-Time of highest WSE at WY closure				5/18/1997 23:00	
WSE (ft)				9.89	
Date-Time of lowest WSE during WY closure or following break				7/31/1997 16:00	
WSE (ft)				5.51	
Time (days) difference highest minus lowest WSE				73.71	
Time (hours) difference highest minus lowest WSE				1769.00	
Highest WSE at closure minus lowest WSE during closure in this WY				4.38	
Rate of decrease in WSE (ft/day)				0.002	
Mean daily flow rate (cfs) on day of highest WSE at closure				13	
Mean daily flow rate (cfs) on day of lowest WSE of dry season				0	
Likely mechanism with greatest influence on process				Ocean	
End of WY				9/30/1997 23:45	
Time (days) between final season closure and end of WY				135.0	
Total days of lagoon closure in this WY (pre- and post-rainy season)				204.6	
Totel days of closure including all partial closures				204.6	

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
No record of breaching and/or closing events for WY 1997

Table 17. WY 1996, Riverine Dynamics of Breaches and Closures

	Sustained closure	Sustained breach*	In-season closure	Temporary breach	In-season closure	Temporary breach	In-season closure	Sustained breach	Final closure
Breach Type									
Mechnical, Natural, or Unknown		Mechanical		Mechanical		Mechanical		Natural	Natural
Dry Season Events	10/1/1995 0:00								
Date-Time of lowest lagoon WSE prior to breach	11/12/1995 10:15								
Lowest lagoon WSE during closure, this WY	7.12								
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	2.50								
Date-Time of lowest WSE prior to significant increase in WSE									
WSE (ft)									
Date-Time of highest WSE post-increase									
WSE (ft)									
Increase in WSE (ft)									
Likely mechanism with greatest influence on WSE increase process									
Mean daily flow rate (cfs) on day of highest WSE									
Date-Time of most recent WSE > 11 ft prior to breach, this WY	12/13/1995 2:45								
Time (days) between start of WY and first seasonal breach	73.8								
Breachs and Closures during rainy season									
Date-Time of highest WSE at time of breach		12/13/1995 18:30		12/24/1995 19:30		12/27/1995 22:30		1/2/1996 9:45	
WSE (ft)		11.68		11.74		12.01		11.91	
Date-Time of lowest WSE directly following breach		12/14/1995 0:15		12/24/1995 22:30		12/28/1995 2:15		1/2/1996 14:30	
WSE (ft)		5.65		5.86		6.95		5.37	
WSE pre-breach minus post-breach (ft)		6.03		5.88		5.06		6.54	
Time difference (days)		0.24		0.13		0.16		0.20	
Time difference (hours)		5.75		3		3.75		4.75	
Rate of WSE decline (ft/hr)		1.05		1.96		1.35		1.38	
Mean daily flow rate (cfs) on day of breach		36		35		28		25	
Mean daily flow rate (cfs) on day of lowest WSE following breach		36		35		24		25	
Likely mechanism with greatest influence on breaching process		Mechanical		Riverine		Riverine		Riverine	
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours			12/21/1995 19:30		12/24/1995 22:30		12/29/1995 0:15		
WSE (ft)			5.36		5.86		6.30		
Date-Time of lagoon WSE fills to > 11 feet			12/23/1995 15:00		12/26/1995 10:00		12/31/1995 16:45		
WSE (ft)			11.00		11.00		11.00		
Date-Time of lagoon falls below WSE > 11 feet			12/24/1995 20:45		12/28/1995 0:00		1/2/1996 12:30		
WSE (ft)			10.64		10.69		10.77		
Time (days) of WSE > 11 feet			1.24		1.58		1.82		
Time (hours) of WSE > 11 feet			29.8		38.0		43.8		
Mean daily flow rate (cfs) on day lowest WSE			34		35		24		
Mean daily flow rate (cfs) on day WSE > 11 feet			35		28		27		
Mean daily flow rate (cfs) on day WSE < 11 feet			35		24		25		
Likely mechanism with greatest influence on closure process			Ocean		Ocean		Ocean		
Dry Season Closure									
Date-Time of highest WSE at WY closure									7/1/1996 0:15
WSE (ft)									10.37
Date-Time of lowest WSE during WY closure or following break									8/28/1996 19:00
WSE (ft)									5.49
Time (days) difference highest minus lowest WSE									58.78
Time (hours) difference highest minus lowest WSE									1410.75
Highest WSE at closure minus lowest WSE during closure in this WY									4.88
Rate of decrease in WSE (ft/day)									0.003
Mean daily flow rate (cfs) on day of highest WSE at closure									8.5
Mean daily flow rate (cfs) on day of lowest WSE of dry season									0
Likely mechanism with greatest influence on process									Ocean
End of WY									9/30/1996 23:45
Time (days) between final season closure and end of WY									91.98
Total days of lagoon closure in this WY (pre- and post-rainy season)									165.8
Totel days of closure including all partial closures									170.4

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
No record of breaching and/or closing events for WY 1996

Table 18. WY 1995, Riverine Dynamics of Breaches and Closures

	Sustained closure	Sustained breach*	Final Closure	WSE increase while closed
Breach Type				
Mechnical, Natural, or Unknown		Mechanical	Natural	
Dry Season Events	10/1/1994 0:00			
Date-Time of lowest lagoon WSE prior to breach	10/1/1994 21:15			
Lowest lagoon WSE during closure, this WY	5.96			
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0			
Date-Time of lowest WSE prior to significant increase in WSE				9/6/1995 9:30
WSE (ft)				5.59
Date-Time of highest WSE post-increase				9/24/1995 0:30
WSE (ft)				10.43
Increase in WSE (ft)				4.84
Likely mechanism with greatest influence on WSE increase process				Wave overtopping
Mean daily flow rate (cfs) on day of highest WSE				
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none			
Time (days) between start of WY and first seasonal breach	101.3			
Breachs and Closures during rainy season				
Date-Time of highest WSE at time of breach		1/10/1995 6:15		
WSE (ft)		10.51		
Date-Time of lowest WSE directly following breach		1/12/1995 1:15		
WSE (ft)		6.39		
WSE pre-breach minus post-breach (ft)		4.12		
Time difference (days)		1.79		
Time difference (hours)		43		
Rate of WSE decline (ft/hr)		0.10		
Mean daily flow rate (cfs) on day of breach		6070		
Mean daily flow rate (cfs) on day of lowest WSE following breach		746		
Likely mechanism with greatest influence on breaching process		Mechanical/Riverine		
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours				
WSE (ft)				
Date-Time of lagoon WSE fills to > 11 feet				
WSE (ft)				
Date-Time of lagoon falls below WSE > 11 feet				
WSE (ft)				
Time (days) of WSE > 11 feet				
Time (hours) of WSE > 11 feet				
Mean daily flow rate (cfs) on day lowest WSE				
Mean daily flow rate (cfs) on day WSE > 11 feet				
Mean daily flow rate (cfs) on day WSE < 11 feet				
Likely mechanism with greatest influence on closure process				
Dry Season Closure				
Date-Time of highest WSE at WY closure			8/9/1995 0:00	
WSE (ft)			9.73	
Date-Time of lowest WSE during WY closure or following break			9/6/1995 9:30	
WSE (ft)			5.59	
Time (days) difference highest minus lowest WSE			28.40	
Time (hours) difference highest minus lowest WSE			681.50	
Highest WSE at closure minus lowest WSE during closure in this WY			4.14	
Rate of decrease in WSE (ft/day)			0.006	
Mean daily flow rate (cfs) on day of highest WSE at closure			3.7	
Mean daily flow rate (cfs) on day of lowest WSE of dry season			3	
Likely mechanism with greatest influence on process			Ocean	
End of WY			9/30/1995 23:45	
Time (days) between final season closure and end of WY			52.99	
Total days of lagoon closure in this WY (pre- and post-rainy season)			154.3	
Totel days of closure including all partial closures			154.3	

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
Mechanical breach on January 9, 1995 in anticipation of flood flows, James, 2005 (p 10)

Table 19. WY 1994, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	Sustained Breach*	In-season closure	Temporary breach	In-season closure	Temporary breach	Final closure
Breach Type								
Mechnical, Natural, or Unknown			Mechanical		Natural		Natural	Natural
Dry Season Events	10/1/1993 0:00							
Date-Time of lowest lagoon WSE prior to breach	10/3/1993 12:00							
Lowest lagoon WSE during closure, this WY	5.44							
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0							
Date-Time of lowest WSE prior to significant increase in WSE		11/6/1993 8:15						
WSE (ft)		7.43						
Date-Time of highest WSE post-increase		11/13/1993 10:45						
WSE (ft)		8.87						
Increase in WSE (ft)		1.44						
Likely mechanism with greatest influence on WSE increase process		Ocean						
Mean daily flow rate (cfs) on day of highest WSE		0.00						
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none							
Time (days) between start of WY and first seasonal breach	139.9							
Breachs and Closures during rainy season								
Date-Time of highest WSE at time of breach			2/17/1994 22:15		3/18/1994 15:00		3/27/1994 17:00	
WSE (ft)			11.69		11.62		12.15	
Date-Time of lowest WSE directly following breach			2/19/1994 15:45		3/19/1994 14:30		3/27/1994 20:00	
WSE (ft)			6.45		7.80		5.81	
WSE pre-breach minus post-breach (ft)			5.24		3.82		6.34	
Time difference (days)			1.73		0.98		0.13	
Time difference (hours)			41.5		23.5		3	
Rate of WSE decline (ft/hr)			0.13		0.16		2.11	
Mean daily flow rate (cfs) on day of breach			106		22		20	
Mean daily flow rate (cfs) on day of lowest WSE following breach			203		22		20	
Likely mechanism with greatest influence on breaching process			Mechanical/Riverine		Riverine		Riverine	
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours				3/13/1994 9:00		3/19/1994 15:45		
WSE (ft)				5.6		7.8		
Date-Time of lagoon WSE fills to > 11 feet				3/16/1994 20:30		3/24/1994 7:45		
WSE (ft)				11.00		11.00		
Date-Time of lagoon falls below WSE > 11 feet				3/18/1994 17:45		3/27/1994 18:00		
WSE (ft)				10.93		10.05		
Time (days) of WSE > 11 feet				1.89		3.39		
Time (hours) of WSE > 11 feet				45.3		81.3		
Mean daily flow rate (cfs) on day lowest WSE				31		22		
Mean daily flow rate (cfs) on day WSE > 11 feet				24		20		
Mean daily flow rate (cfs) on day WSE < 11 feet				22		20		
Likely mechanism with greatest influence on closure process				Ocean		Ocean		
Dry Season Closure								
Date-Time of highest WSE at WY closure								4/3/1994 3:45
WSE (ft)								10.66
Date-Time of lowest WSE during WY closure or following break								8/29/1994 16:45
WSE (ft)								5.44
Time (days) difference highest minus lowest WSE								148.54
Time (hours) difference highest minus lowest WSE								3565.00
Highest WSE at closure minus lowest WSE during closure in this WY								5.22
Rate of decrease in WSE (ft/day)								0.001
Mean daily flow rate (cfs) on day of highest WSE at closure								8.2
Mean daily flow rate (cfs) on day of lowest WSE of dry season								0
Likely mechanism with greatest influence on process								Ocean
End of WY								9/30/1994 23:45
Time (days) between final season closure and end of WY								180.83
Total days of lagoon closure in this WY (pre- and post-rainy season)								320.8
Totel days of closure including all partial closures								326.0

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
No record of breaching and/or closing events for WY 1994

Table 20. WY 1993, Riverine Dynamics of Breaches and Closures

	Sustained closure	WSE increase while closed	Sustained Breach*	In-season Closure	Sustained Breach	Final Closure
Breach Type						
Mechnical, Natural, or Unknown			Mechanical		Natural	Natural
Dry Season Events	10/1/1992 0:00					
Date-Time of lowest lagoon WSE prior to breach	10/19/1992 6:00					
Lowest lagoon WSE during closure, this WY	6.19					
Mean daily flow rate (cfs) on day of lowest WSE prior to 1st reported breach	0					
Date-Time of lowest WSE prior to significant increase in WSE		10/24/1992 8:30				
WSE (ft)		7.38				
Date-Time of highest WSE post-increase		10/28/1992 17:00				
WSE (ft)		10.06				
Increase in WSE (ft)		2.68				
Likely mechanism with greatest influence on WSE increase process		Wave overtopping				
Mean daily flow rate (cfs) on day of highest WSE		0				
Date-Time of most recent WSE > 11 ft prior to breach, this WY	none					
Time (days) between start of WY and first seasonal breach	98.5					
Breachs and Closures during rainy season						
Date-Time of highest WSE at time of breach			1/7/1993 11:00		6/3/1993 13:30	
WSE (ft)			12.74		12.07	
Date-Time of lowest WSE directly following breach			1/7/1993 19:30		6/3/1993 19:30	
WSE (ft)			6.23		5.71	
WSE pre-breach minus post-breach (ft)			6.51		6.36	
Time difference (days)			0.35		0.25	
Time difference (hours)			8.5		6	
Rate of WSE decline (ft/hr)			0.77		1.06	
Mean daily flow rate (cfs) on day of breach			697		47	
Mean daily flow rate (cfs) on day of lowest WSE following breach			697		47	
Likely mechanism with greatest influence on breaching process			Mechanical		Riverine	
Date-Time of lowest lagoon WSE prior to next WSE > 11 feet for > 24 hours				5/28/1993 15:00		
WSE (ft)				5.46		
Date-Time of lagoon WSE fills to > 11 feet				6/2/1993 3:30		
WSE (ft)				11.02		
Date-Time of lagoon falls below WSE > 11 feet				6/3/1993 14:50		
WSE (ft)				8.66		
Time (days) of WSE > 11 feet				1.47		
Time (hours) of WSE > 11 feet				35.3		
Mean daily flow rate (cfs) on day lowest WSE				28		
Mean daily flow rate (cfs) on day WSE > 11 feet				53		
Mean daily flow rate (cfs) on day WSE < 11 feet				47		
Likely mechanism with greatest influence on closure process				Ocean		
Dry Season Closure						
Date-Time of highest WSE at WY closure						7/3/1993 1:00
WSE (ft)						8.77
Date-Time of lowest WSE during WY closure or following break						9/30/1993 23:30
WSE (ft)						5.52
Time (days) difference highest minus lowest WSE						89.94
Time (hours) difference highest minus lowest WSE						2158.50
Highest WSE at closure minus lowest WSE during closure in this WY						3.25
Rate of decrease in WSE (ft/day)						0.002
Mean daily flow rate (cfs) on day of highest WSE at closure						4.9
Mean daily flow rate (cfs) on day of lowest WSE of dry season						0
Likely mechanism with greatest influence on process						Ocean
End of WY						9/30/1993 23:45
Time (days) between final season closure and end of WY						89.95
Total days of lagoon closure in this WY (pre- and post-rainy season)						188.4
Totel days of closure including all partial closures						189.9

Notes

Water year (WY) is defined as the time period beginning October 1st of a given year and ending September 30th the following year
All WSE elevations are in NAVD88, feet
Breach types are based on professional judgement, available records, and personal communications with staff knowledgeable of breaching operations
* indicates breach data used for rate of lagoon draining in Table 3
Sustained closure is defined from October 1st of each water year until the first breach
Temporary breach is defined as lagoon being open to tidal influence for < 7 consecutive days
Sustained breach is defined as the lagoon remaining open to tidal influences for > 7 consecutive days
In-season closure is defined as the time period during the wet season (approximately October - May of each WY) when lagoon WSE > 11 feet persists for > 24 hours
Early closure is defined as lagoon closing due to mechanical or ocean processes shortly (approximately 1 week to 1 month early) before a final closure
Final closure is defined as lagoon closed to ocean processes until the following water year
Significant increase in WSE is defined as an increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Wave overtopping is defined as increase in lagoon WSE of > 1 foot when flows are zero and lagoon is closed to the ocean
Total days of lagoon closure included days between start of WY and 1st breach, days between final season closure and end of WY, and days of in-season closures
No record of breaching and/or closing events for WY 1993

Memo

To: Erin Harwayne, Denise Duffy & Associates

From: Scott Brown

Date: July 29, 2016

Subject: Carmel River Lagoon EPB- Potential impacts to the CAWD wastewater treatment facility and Mission Ranch.

You have asked that Balance assess selected potential hydrologic impacts of the proposed Ecosystem Protective Barrier (EPB) project on the CAWD Wastewater Treatment Plant located just south of the Carmel River, west of Highway 1. Specifically, you have asked that we address the change in flood water surface elevation and the potential for associated significant impacts, increases in seepage through the uncertified levee (or berm) that surrounds the facility, and additional inundation of areas that may impact CAWD operations or the Mission Ranch area.

Background

The EPB is a proposed wall structure planned along the perimeter of the northern portion of the Carmel River Lagoon intended to reduce flood impacts to adjoining neighborhoods during periods when water levels in the lagoon are at or near their peak (typically due to closed barrier beach conditions at the mouth of the lagoon, though could also affect high water levels during flood stage of the River, as discussed below). The proposed EPB alignment is shown in Figure 1.

The CAWD water treatment facility is located adjacent to and south of the Carmel River and west of Highway 1. The facility is separated from the River and from the floodplain to the south by uncertified levees that protect the facility, at least in part, from inundation during flooding events of the Carmel River.

The Mission Ranch property is located upstream of the proposed EPB alignment along the northern side of the eastern end of the lagoon and, in part, north of an uncertified levee that separates the area from the Carmel River. The potentially impacted area includes a large open field, currently used occasionally as a pasture for sheep grazing, a parking lot, a tennis clubhouse and "quadplex" buildings, and six tennis courts (Whitson, 2013).

Carmel River and Lagoon flood impacts

Two aspects of the EPB project have the potential to increase flood levels and cause significant impacts. First, changes in management of the barrier beach would allow higher sustained water elevations within the lagoon, which would increase the area subject to flooding, potentially affecting low-lying buildings and other facilities adjacent to the lagoon (those not protected by the new EPB).

Second, the proposed EPB would constrict flood inundation areas on the north side of the Carmel River, and as such, would have the potential to result in increased flood water surface elevations. In order to analyze the magnitude and location of these potential increases, Balance Hydrologics modeled pre- and post-project conditions under several different scenarios, and prepared a summary of the results (Riedner and Ballman, 2013). While that memo generally described the magnitude and location of increases, it did not specifically assess the potential impact related to the uncertified levee that surrounds the CAWD facility or structures on the Mission Ranch property.

The following discussion addresses these two issues for both the CAWD Wastewater Treatment Facility and the Mission Ranch property, building in part on results presented in the earlier memorandum[1].

CAWD

The CAWD Wastewater Treatment Facility ('CAWD facility'), is located adjacent to the main Carmel River channel, separated from the channel by an uncertified levee with a top elevation of about 18 feet NAVD. Elevations within the facility typically range from about 15.5 to 18 feet NAVD, though one depression on the property is as low as 13.6 feet NAVD. Water level in the lagoon has risen as high as 15.4 feet NAVD in the past (Whitson, 2013), and as such, changes in management of the barrier beach that result in higher lagoon water elevations could result in increased flooding at the project site.

Prior to 2011, the barrier beach was typically mechanically breached when the lagoon reached a level of about 12.7 feet NAVD, and since 2011 a sand plug has been left in place with a top elevation of 12.7 feet NAVD to facilitate a more natural river over-topping and breaching at that elevation (Whitson, 2013). Estimates of a typical elevation for fully natural beach dynamics and breaching cover a wide range, but would likely fall within the range of 13 to 16 feet NAVD (Whitson, 2013). The elevation of the top of the uncertified levee that surrounds the CAWD facility is greater than 16 feet NAVD along the full perimeter, though some sections are as low as 17 to 18 feet NAVD. As such an increase in breaching elevation to 16 feet would not cause surface flooding at CAWD. However, there is uncertainty in the estimates of natural breaching elevation, and it may be possible that the elevation would be greater than 16 feet in some years, which could cause flooding at the CAWD facility if the berm were overtopped. This potential impact could be reduced to less-than-significant by:

a. setting an emergency action trigger elevation that would provide a better constraint on the maximum lagoon elevation relative to the CAWD facility, or alternatively,
b. by raising the level of the berm surrounding the CAWD facility.

In addition to potential flooding related to beach barrier management, the EPB would constrict the flood plain, potentially raising flood levels in the Carmel River at the location of the CAWD facility. Table 1 presents an excerpt of the previous modeling results (Riedner and Ballman, 2013), showing the magnitude of the predicted increase in the base flood elevation (BFE) on the

[1] For brevity, the details of the modeling effort are not discussed in the current memo. For specifics, see the Hydraulic Model Description section of Riedner and Ballman, 2013.

Carmel River per hydraulic modelling using the currently-effective FEMA HEC-RAS model base.[2] The CAWD facility is located between cross-sections 27+85 and 39+86 along the main channel of the Carmel River. As discussed in the earlier memo, changes in BFE as a result of the EPB are predicted to be small overall (less than an inch). Specifically, the maximum increase in main channel BFE (0.02 feet) is predicted at Station 22+06, downstream from the CAWD Treatment Plant, with projected increases adjacent to the plant of 0.01 feet or less (Stations 29+72 to 41+96; see Figure 1 for cross-section locations).

Table 1 presents the elevation of the top of the uncertified levee on the main channel side of the CAWD facility at the location of each cross-section, and estimates the pre- and post-project freeboard for the 100-year flood based on the calculated BFE from the previous modeling[3]. As shown, the greatest anticipated increases in BFE are in the downstream portion of the CAWD facility, where the uncertified levee has and would continue to have freeboard. Upstream of section 33+89 there are two locations where the pre-project flood level exceeds the elevation of the levee (at 36+78 and 39+86), but at these locations there is not expected to be an increase in BFE as a result of the proposed EPB project.

Mission Ranch

As stated in the EPB Feasibility Report (Whitson, 2013), portions of Mission Ranch lie within the 100-year floodplain and may be affected by increased flood levels as a result of floodplain constriction caused by the EPB. Under the EPB (no extension) scenario, there is a predicted slight increase (0.01 feet) in the 100-year flood elevation in the area of Mission Ranch (Riedner and Ballman, 2013). That impact seems to be entirely confined to the area within the open fields (‘sheep field’), and doesn't extend upstream as far as the tennis courts. As such, the slight increase in BFE in that area does not represent a significant impact.

The Mission Ranch area could, however, be impacted by sustained higher lagoon water elevation as a result of changes in beach barrier management allowable under the EPB scenario. Post-project, sustained lagoon water levels may reach as high as 16 feet NAVD. The feasibility report (Whitson, 2013) states that the ground surface immediately adjacent to some buildings near the tennis courts and parking lot are at 15.9 feet, and thus may be impacted by higher sustained lagoon water levels. The potential impact could be mitigated through implementation of either of the following measures:

a. Establishment and implementation of emergency action levels that would allow for barrier beach management when lagoon water level approaches trigger elevations that would impact Mission Ranch infrastructure.
b. Construction of an EPB extension that would protect facilities within the Mission Ranch area.

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[2] The BFE is defined by FEMA as the water surface elevation for the 1-percent chance flood event (also known as the “100-year flood”).

[3] For the purposes of this assessment, we used the maximum potential increase as a result of the EPB. The previous memo included analysis of an extension of the EPB surrounding Mission Ranch which is not part of the current proposed project, but provides a conservatively high estimate of the potential flood elevation impact, and is therefore appropriate for an EIR-level analysis.

It is important to note that the 'sheep field' to the west of the Mission Ranch infrastructure is at a lower elevation (about 12.5 to 13.5 feet NAVD) and would be inundated more frequently and to a greater extent than under current conditions. Increased inundation in this area, however, would not specifically threaten built infrastructure.

Groundwater impacts

The ground surface at the CAWD facility (within the perimeter levee) is predominantly between 15.5 and 18 feet NAVD, though at one spot in the southwest corner there is a depression with a bottom elevation at 13.6 feet NAVD. In this regard it is appropriate to consider potential impacts from higher sustained water levels in the lagoon that may result in higher groundwater levels at the CAWD facility, which could impact CAWD operations and/or infrastructure. For example, in a comment letter to Carl Holm (Buikema, 2013), CAWD states that "elevating groundwater levels within 20 feet of the surface in and around the Treatment Plant property may have an effect on both the future construction of facilities as well as maintenance costs."

Groundwater data from several wells near CAWD suggest that local, shallow groundwater elevations closely track water level in the lagoon (Woyshner and others, 2015), and as such higher groundwater levels at CAWD are likely as a result of higher sustained water level in the Lagoon. A monitoring well adjacent to the CAWD facility (MPWMD 'CAWD dewater'; located near the northeast corner of the treatment plant grounds) suggests that existing groundwater levels adjacent to the lagoon and CAWD facility already reach an elevation of over 14 feet NAVD, less than 4 feet below ground surface at the location of the well (Figure 2)[4]. This suggests that CAWD may already need to dewater in order to maintain groundwater levels at their stated 20' below ground surface, though no information was available as to whether there is, or is not, an active dewatering program at CAWD.

Figure 3 compares the water level measured at the 'CAWD dewater' well against the concurrent water level reported for the Lagoon, as recorded by MPWMD[5]. Because water level in the lagoon can fluctuate rapidly (after a breach or when open to tidal effects) there is considerable scatter in the data at lower lagoon elevations (below about 10 feet NAVD). However, at higher lagoon water elevations, the scatter converges toward a near one-to-one relationship. In fact the sharp break at the lower-right edge of the data represents a clear indication of the "hydraulic floor" effect caused by the lagoon relative to water levels in the well. Given these conditions, we expect that higher sustained lagoon elevations as a result of the EPB would correspond directly to higher water levels in the CAWD dewater well.

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[4] It is important to note that the monitoring well has a depth of 50 feet, with an unknown screened interval. As such, water elevations in the monitoring well at 6 feet below ground surface suggest only that groundwater has the potential to be that close to the surface within the CAWD facility, barring no significant obstruction to groundwater flow in the vertical direction (as might be expected in the compacted fill on which the facility was constructed). Buikema (2013) states that geotechnical investigations within the facility (no date or citation provided) found groundwater between 25 and 55 feet below ground surface. In order to provide a conservatively high estimate of the impact, we assume that groundwater level measured at the CAWD dewater well corresponds to the actual depth to groundwater within CAWD.

[5] Raw lagoon water surface elevation datalogger files, provided by Monterey Peninsula Water Management District, are provisional and subject to revision.

Post-project, estimated maximum sustained lagoon water elevation may reach as high as 16 feet[6], raising groundwater levels adjacent to the CAWD facility by a similar amount, and potentially resulting in seepage at the ground surface in locations where elevations within the facility are less than 16 feet. The following analysis offers a first approximation estimate of the magnitude of the potential impact, and estimates the effort that would be required to maintain water levels near the CAWD dewater well at pre-project levels[7].

Figure 2 shows monthly monitoring data from the 'CAWD dewater' well. While water levels have been as high as 14.2 feet NAVD (in 2005), levels more regularly reach only to about 12 feet NAVD, and this number is used as a representative baseline condition of an average annual maximum. Post-project, sustained water levels have the potential to approach 16 feet NAVD. In order to maintain water levels adjacent to and within the CAWD facility at pre-project levels, some amount of pumping would likely be required during periods when lagoon water levels are between 12 and 16 feet[8].

Design of a full-scale dewatering plan to mitigate this potential impact is outside the scope of this analysis, and would need to be coordinated with CAWD in order to meet and mesh with their operational needs. However, we can estimate the effort that would be needed to maintain water level near the CAWD well below 12 feet NAVD under a potential post-project 16 foot elevation high-stand in the lagoon. A simple conceptual model of the post-project groundwater conditions at CAWD can be represented by a bounded aquifer scenario, where the lagoon represents a 'constant head' boundary (i.e. a boundary at which no drawdown would occur as a result of pumping from the aquifer; see Figure 4a). Standard hydrogeologic equations can be used to estimate the amount of pumping that would be needed to maintain groundwater levels at 12 feet NAVD (near the CAWD dewater well) when the lagoon is at 16 feet NAVD, as discussed below.

The CAWD dewater well is approximately 60 feet from the open water of the Lagoon on the opposite side of the levee. When groundwater is pumped from a well adjacent to a constant head boundary, induced recharge from the open-water feature will tend to suppress the amount of drawdown (water-level drop) that occurs relative to a case in which groundwater is pumped from a non-bounded aquifer. The recharge effect can be calculated by modeling a condition where the open-water feature is represented by a 'recharge image well' of equal distance from and on the opposite of the recharge boundary, injecting water to the aquifer at a rate equal to the discharging

[6] Whitson (2013) provides a summary of the estimated 'natural breach height' concluding that this elevation would vary between 13 and 16 feet NAVD 1988. For the purpose of this analysis, we use the upper end of that range in order to provide a conservatively high estimate of potential groundwater pumping needed to mitigate the impact of the higher water level at the CAWD facility.

[7] As explained below, we use the CAWD dewater well as an index for the purposes of assessing the potential feasibility of mitigation. A full dewatering plan would involve additional wells and/or perimeter drains and would need to be coordinated with CAWD in order to meet all of their operational goals and/or mesh with their existing dewatering operations, to the extent that they exist.

[8] We have no formal documentation that CAWD currently requires dewatering to reduce impacts under existing conditions, though it is certainly possible. If so, the simplified analysis herein would be considered additional capacity above and beyond what is already being provided. A more detailed analysis can and should be provided prior to design of potential mitigation strategies. The analysis herein is simply for EIR impact analysis and assessment of feasibility that the potential impact could be mitigated.

well (Figure 4b). Total drawdown at a given observation point is a result of the difference between the independent drawdown of the primary (discharging) well and the image (recharging) well, represented by the following equation (after Ferris and others, 1962):

$$s_t = \frac{Q}{4\pi T} * [W(u)_p - W(u)_i]$$

Where:

$s_t = total\ drawdown\ at\ observation\ point$
$Q = rate\ of\ discharge/recharge$
$T = transmissivity\ of\ the\ aquifer$
$W(u)_{p,i} = 'well\ function'\ of\ pumping, image\ well$

And:

$$u_p = \frac{r_p^2 S}{4Tt}$$

$$u_i = \frac{r_i^2 S}{4Tt}$$

Where:

$r_{p,i} = distance\ from\ observation\ point\ to\ pumping, image\ well$
$S = storativity\ of\ the\ aquifer$
$T = transmissivity\ of\ the\ aquifer$
$t = time\ since\ beginning\ of\ pumping$

Solving the above equation for Q results in:

$$Q = \frac{s_t 4\pi T}{[W(u)_p - W(u)_i]}$$

In this case, all values are known or can be estimated except for the rate of discharge needed to produce a four-foot drawdown (16 feet minus 12 feet NAVD) near the CAWD dewater well. There are no readily-available estimates of transmissivity (the ease at which groundwater can move through an aquifer) for the berm surrounding CAWD or the material on which the facility was constructed. However, as a first-order assessment, we can use estimates derived for other nearby wells to approximate conditions at the CAWD facility. Fugro (1993) conducted 72-hour pump test of a well near Rio Road (about 0.85 miles east of the CAWD facility). They concluded that transmissivity of the aquifer in which the well is screened (50-150 feet below ground surface) is approximately 120,250 gallons per day per foot of saturated aquifer (gpd/ft), or 0.186 square feet per second. The same aquifer test yielded an estimate of storativity of 0.00153 (storativity is a unitless value).

For the calculation of u, we use the following values:

$r_p = 10\ feet$ *(theoretical observation point near the pumping well)*
$r_i = 110 feet$ *(distance to the image well)*

$S = 0.00153$
$T = 0.186\ ft^2/s$
$t = 86{,}400\ s$ *(10 days; assuming equilibrium by that time)*

Thus:

$u_p = 5.95 \times 10^{-7}$
$u_i = 3.15 \times 10^{-4}$

And[9]*:*

$W(u)_p = 12.55$
$W(u)_i = 7.94$

The needed discharge, then, to draw down water level to below 12 feet NAVD within an approximate 10-foot radius[10] of the CAWD dewater well when the lagoon is at 16 feet NAVD, is calculated as follows:

$$Q = \frac{s_t 4\pi \mathrm{T}}{[W(u)_p - W(u)_i]}$$

$$Q = \frac{4 * 4 * 3.14 * 0.186}{[12.55 - 7.94]}$$

$$Q = 2.0\ cubic\ feet\ per\ second\ (910\ gallons\ per\ minute)$$

Without developing a full dewatering plan it is difficult to estimate the total amount of pumping that would be needed at the site to fully dewater to 12 feet (or another trigger point that would meet CAWD operational goals). With additional testing of the CAWD dewater well and information about existing dewatering schemes (if any), as well as more specific information about the operation goals for groundwater at CAWD, a detailed plan could be developed using readily available groundwater modeling packages. The results of the preliminary analysis above, however, do suggest that groundwater pumping rates near the perimeter of the inside of the berm would not be unreasonably high such that they would preclude a successful mitigation strategy.

Additionally, it is important to note that the estimate above is likely conservatively high due to two factors. First, the transmissivity of the levee material (compacted fill) is likely lower than the estimate that was used, potentially by an order of magnitude. Performing a standard 72-hour pump test of the CAWD dewater well itself would help to refine the parameters, and should be included as part of the development of a mitigation dewatering plan. Second, the analysis assumes a sustained lagoon water elevation of 16 feet NAVD, when in reality this elevation

[9] Values for ‘W’ as a function of ‘u’ (calculated based on the above equations) were selected from tabulated W(u) values for Theis solution in Domenico and Schwartz, 1990.

[10] The calculation shown here provides an estimate of pumping needed to draw water down to 12 feet NAVD on the lagoon side of the well. Because the recharge effects of the lagoon diminish with distance, it would only take 1.8 cfs of pumping to draw down water level 10 feet from the CAWD dewater well on the opposite side from the lagoon.

would typically be sustained only for a short period just prior to the barrier beach naturally breaching.

For the purposes of this discussion, we are discounting potential seepage impacts related to increases in water level during river flood events, as the water surface increase is very small (see discussion above) and is not likely to be sustained for a long enough period of time to significantly affect groundwater seepage rates through the levee.

Closing

The results presented in this memo were intended for an EIR-level analysis to assess the mitigability of potential hydrologic impacts. Additional analysis may be required after project approval to provide guidance during final project design and to better refine mitigation strategies and implementation.

Do not hesitate to contact us if you have any questions or comments on the information presented in this memo.

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Buikema, B., 2013, Comments to Carl Holm in response to the feasibility discussion of the Carmel Lagoon Ecosystem Protective Barrier. Letter from Barbara Buikema, Carmel Area Wastewater District, dated May 13, 2013, 3p.

Domenico, P.A. and F.W. Schwartz, 1990, *Physical and Chemical Hydrogeology*, John Wiley & Sons, New York, 824 p.

Ferris, J.G., D.B. Knowles, R.H. Brown and R.W. Stallman, 1962, Theory of aquifer tests, U.S. Geological Survey Water-Supply Paper 1536 E, 174p.

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Woyshner, M., Parke, J., and Hecht, B., 2015, Baseline groundwater monitoring at the mouth of the Carmel River for the proposed floodplain restoration and enhancement project, water years 2012 through 2015, Monterey County, California. Consulting report prepared by Balance Hydrologics, Inc. for the Big Sur Land Trust, 22p.

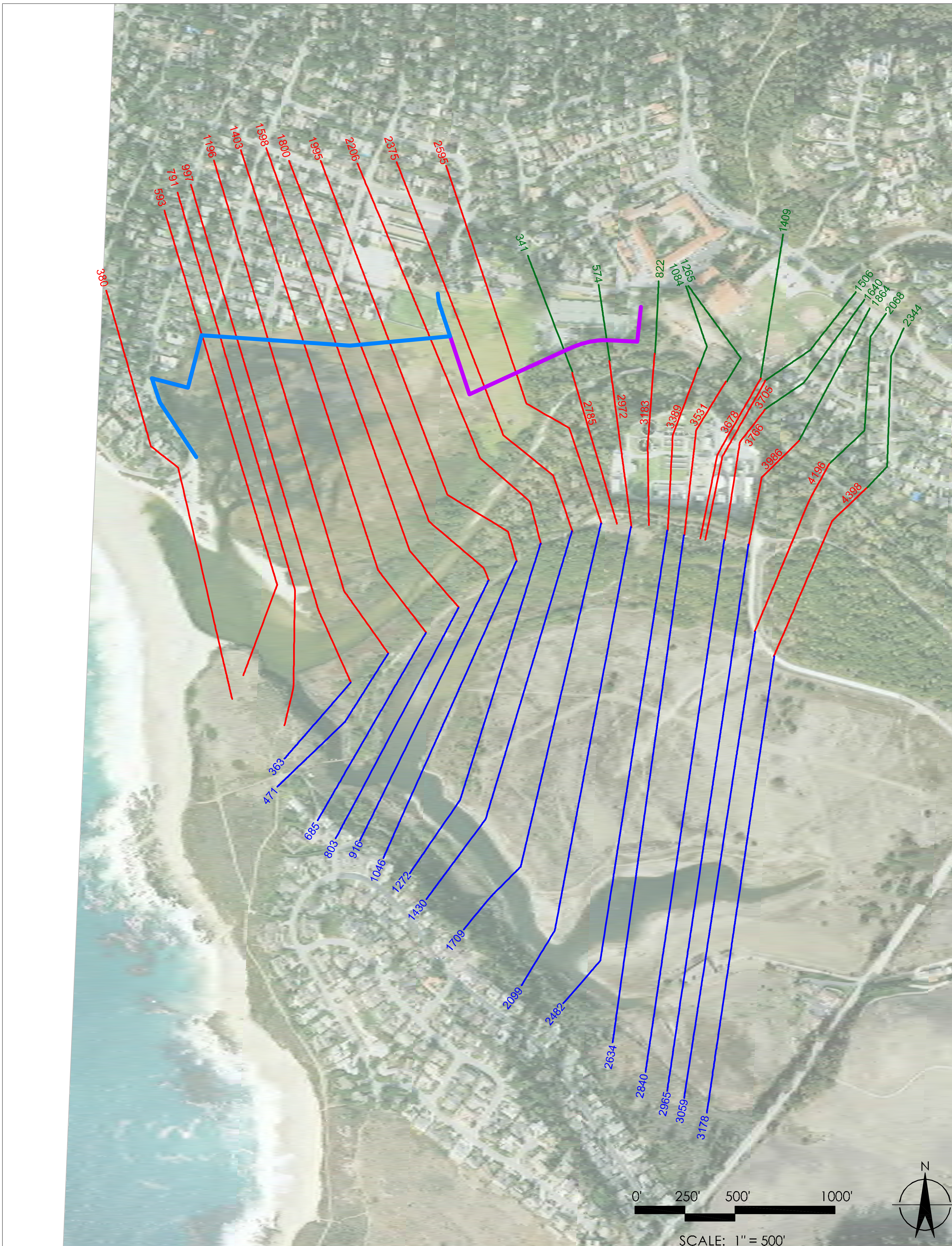
Table 1. Potential impact of EPB on flood elevations at the CAWD water treatment plant, Carmel, California.

Modeling results compiled from analysis by Riedner and Ballman, 2013.

Model cross-section station	Elevation of top of uncertified CAWD levee at cross section	Pre-project 100-year water surface elevation	Pre-project freeboard	Post-project 100-year water surface elevation[1]	Post-project freeboard	Change in flood elevation	Comments
(feet)	(feet NAVD)	(feet NAVD)	(feet)	(feet NAVD)	(feet)	(feet)	
15+98	--	15.62	--	15.62	--	0.00	
18+00	--	15.64	--	15.64	--	0.00	
19+95	--	15.67	--	15.68	--	0.01	
22+06	--	15.74	--	15.76	--	0.02	
23+75	--	15.75	--	15.76	--	0.01	
25+95	--	15.78	--	15.79	--	0.01	
27+85	--	15.93	--	15.94	--	0.01	just downstream of the CAWD uncertified levee
29+72	17.5	16.41	1.09	16.42	1.05	0.01	
31+83	18.0	17.18	0.82	17.18	0.8	0.00	
33+89	20.0	17.86	2.14	17.86	2.13	0.00	
35+31	19.0	18.50	0.50	18.50	0.5	0.00	
36+78	19.0	19.08	-0.08	19.08	-0.08	0.00	
37+05	20.0	19.12	0.88	19.12	0.87	0.00	
37+66	20.0	19.35	0.65	19.35	0.65	0.00	
39+86	18.0	19.47	-1.47	19.47	-1.47	0.00	
41+96	25.0	19.79	5.21	19.78	5.22	-0.01	upstream of CAWD facility
43+98	20.0	19.99	0.01	19.99	0.01	0.00	
45+86	--	20.17	--	20.17		0.00	

Notes:

[1] EPB alignment #2, as analyzed in Riedner and Ballman, 2013.



LEGEND

1265 (green line)	NORTH OVERBANK FEMA CROSS-SECTION AND LABEL	(light blue line)	ECOSYSTEM PROTECTIVE BARRIER ALIGNMENT #2
3389 (red line)	MAIN CHANNEL FEMA CROSS-SECTION AND LABEL	(purple line)	ECOSYSTEM PROTECTIVE BARRIER EXTENSION #3A
2840 (blue line)	SOUTH OVERBANK FEMA CROSS-SECTION AND LABEL		

Balance Hydrologics, Inc.

Figure 1. Location of proposed Ecosystem Protective Barrier and hydrologic modeling cross sections relative to the CAWD Wastewater Treatment Facility and the Mission Fields area. Note that EPB Extension #3a was analyzed previously, but is not proposed as part of the current project.

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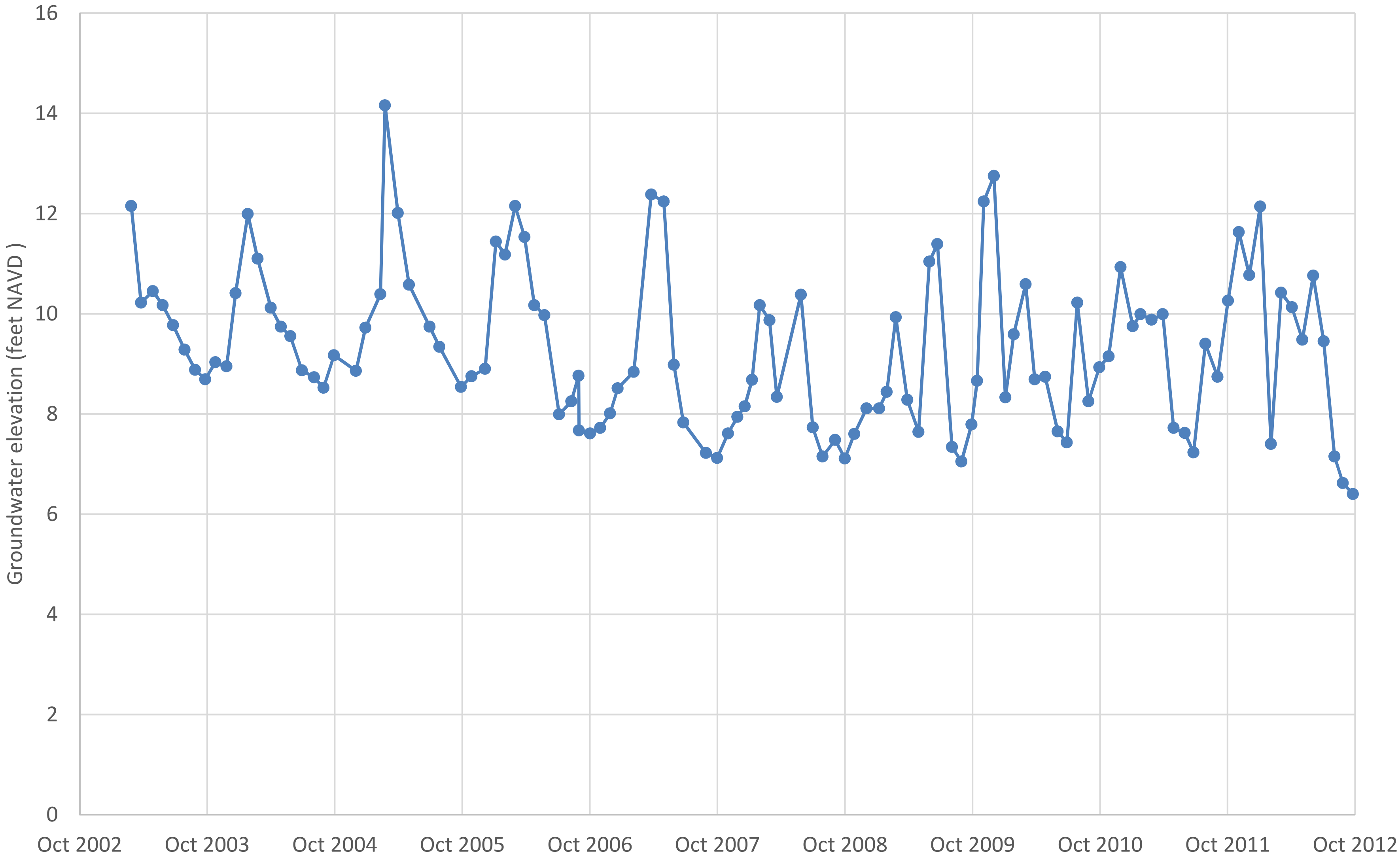

Balance Hydrologics, Inc.®

Figure 2. Groundwater elevations as measured at the 'CAWD dewater well', adjacent to the CAWD Water Treatment Facility, Carmel, California. Ground surface at the well is approximately 18 feet NAVD. Note that groundwater elevation regularly exceeds 12 feet NAVD. Groundwater monitoring data provided by MPWMD.

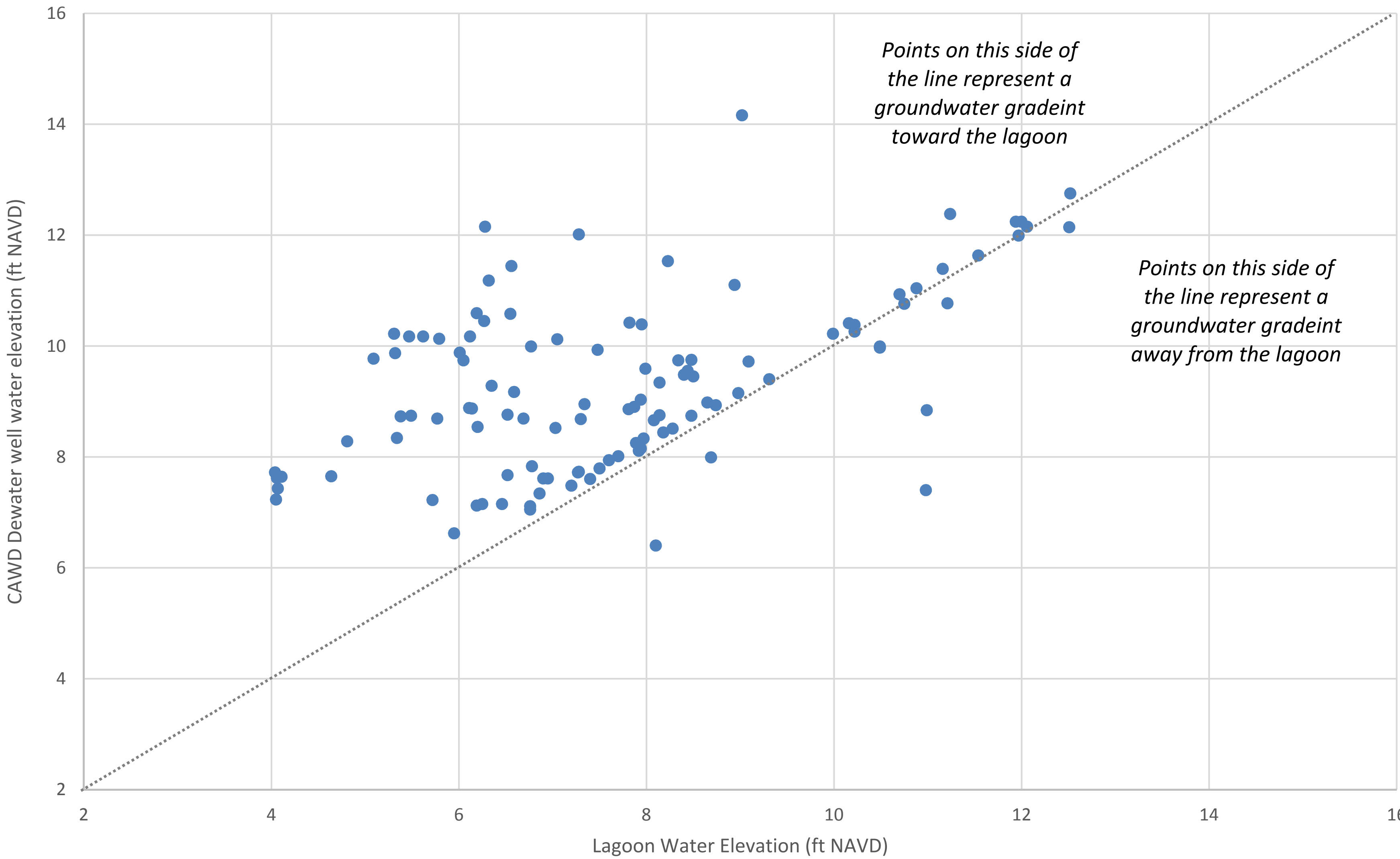

Figure 3. Water elevation in the Carmel Lagoon compared to groundwater elevations as measured at the 'CAWD dewater well', adjacent to the CAWD Water Treatment Facility, Carmel, California. Graph shows data (approximately monthly) for 2003 to 2012. There is considerable scatter at lower lagoon water elevations, but the data converge toward a near one-to-one correlation at high lagoon water elevations.

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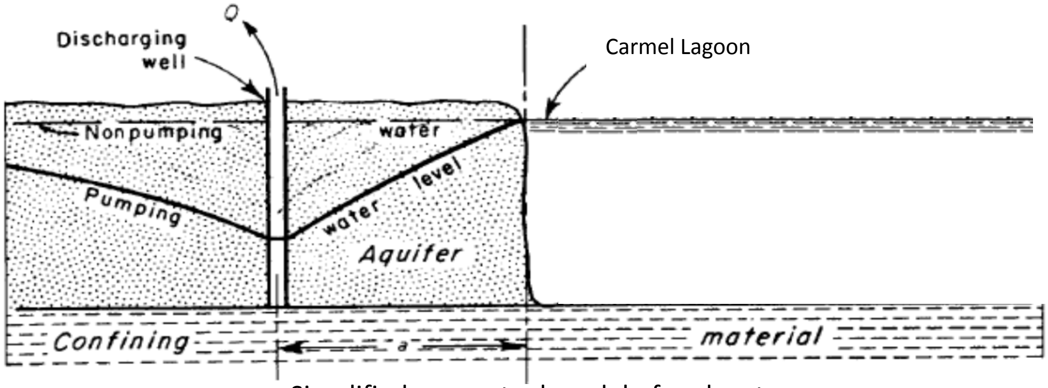
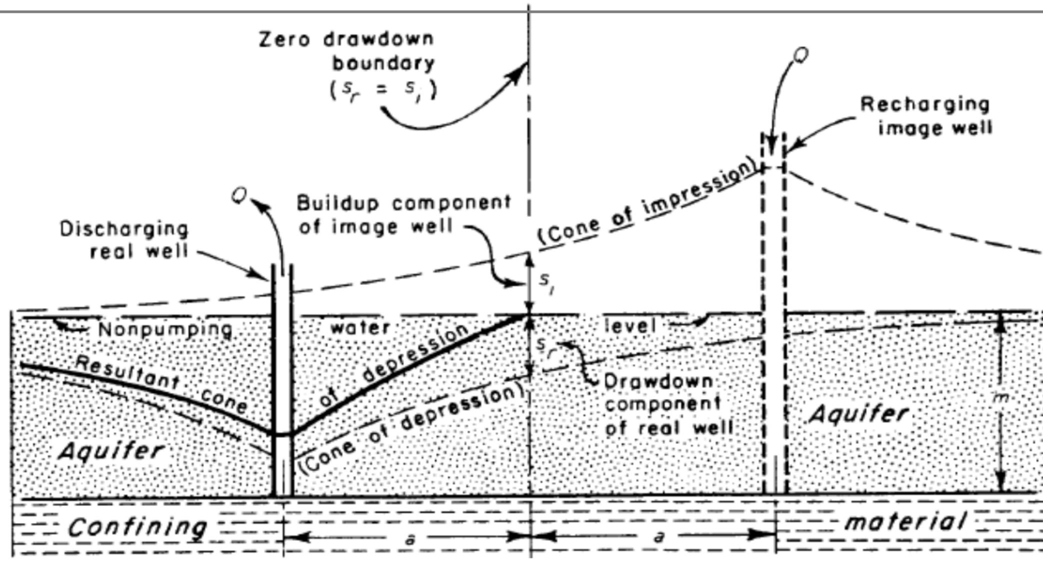


a. Simplified conceptual model of real system



b. Modeled representation or real system

(adapted from Ferris and others, 1962)

Figure 4. Simplified conceptual model of groundwater condtions near CAWD (a), and hydrogeologic representation for calculation purposes (b).

Memo

To: Josh Harwayne, Denise Duffy & Associates, Inc.

From: Eric Riedner, P.E. and Edward Ballman, P.E.

Date: August 7, 2015

Subject: DRAFT Summary of Estimated Interior Side Hydrologic Conditions, EPB Project, County of Monterey

The following memo summarizes the anticipated hydrologic conditions that would result after implementation of the proposed Ecosystem Protective Barrier Project (EPB). Our focus is on identifying the various factors that influence water levels on the interior side of the barrier, estimating the likely range of ponding depths, and qualitatively assessing potential water-quality impacts. Anticipated hydrologic conditions are characterized for both the winter rainy season and summer dry season.

Winter Rainy Season

During the rainy season both surface and shallow groundwater flows from the upland drainage area would be the primary contributor to ponding along the interior side of the EPB. These inflows would pond behind the EPB until discharged to the lagoon by seepage under the barrier, through culverts located along the barrier, and/or by pumping. Variability in the rate of seepage under the barrier would largely be a function of water levels in the lagoon which vary significantly during the winter months. Similarly, flow released through the culverts that penetrate the barrier would be controlled by flap gates that remain closed during periods of relatively high water levels in the lagoon. Pumps would be used to control the depth of ponding landward of the EPB during moderate to large storm events or during times of elevated stages in the lagoon.

Ponding depths during the winter months are anticipated to be variable and dependent on both the frequency and magnitude of storm events as well as the stage in the lagoon. During wetter than average years it is possible that water levels landward of the EPB remain at or slightly above the proposed culvert invert and pump trigger elevation of 10.5 feet[1] over extended periods of time (i.e. weeks or months). During periods of drought ponding depths would be comparable to dry season conditions described below and it would be possible for the water level to recede below elevation 7 feet, leaving the area interior of the EBP completely dry for short periods of time (i.e. days or weeks). Peak water elevations landward of the EPB could potentially reach as high as 13 feet (NAVD-88) during large storm events, but would be drawn down rapidly (i.e. hours) due to pumping.

Relative to existing conditions the EPB would slow the rate of flow towards the lagoon and potentially concentrate pollutants in areas subject to frequent ponding along the barrier. This potential impact could be mitigated through a range of water-quality treatment BMPs (e.g.

[1] All elevations in this memo are referenced to NAVD-88.

bioretention basins, vegetated swales, etc.) sited at the ends of the roads that route surface runoff towards the lagoon. With proper mitigation measures, overall pollutant loadings to the lagoon environment would be markedly reduced from existing conditions.

Summer Dry Season

During the dry season, groundwater would be the primary source of inflow to the inside of the EPB, with the groundwater gradient generally conveying flows towards the lagoon. However, a relatively rapid rise in lagoon stage during the summer months would have the potential to block seepage flows from upland areas or even reverse the direction of the groundwater flow from the lagoon toward the landward side of the EPB.

Water levels on the interior side of the EPB are anticipated to track very closely to water levels in the lagoon with a head differential expected to be less than one foot during periods of relatively static water surface elevations. A review of the MPWMD lagoon stage data indicates that water levels in the lagoon most frequently range between 5 and 9 feet during the summer months. This compares to a low elevation of 7 feet along the EPB that could remain inundated or desiccated for extended periods of time (i.e. weeks or months) dependent on conditions in the lagoon. Lagoon levels occasionally rise above 9 feet during the summer months, in which case water levels landward of the EPB could be expected to occasionally rise as high as the pump trigger elevation of 10.5 feet.

Dry season discharges to the landward side of the EPB would predominantly consist of shallow groundwater inflow that would pose minimal risk of contributing pollutants into the system.

Closing

In summary, during the rainy season, the proposed EPB project is anticipated to result in somewhat high water elevations on the landward side of the barrier relative to existing conditions. During the dry season, hydrologic conditions are expected to be comparable to existing, with water elevations generally well below the pump trigger elevation of 10.5 feet. Potential impacts of pollutant loadings to the area landward of the barrier are limited to winter stormwater runoff that can be readily mitigated through water quality treatment BMPs.

Carmel Area Wastewater District

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Barbara Buikema
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August 17, 2016

Ms. Melanie Beretti
Monterey County Resource
Management Agency
168 W. Alisal, 2nd Floor
Salinas, CA 93901

Dear Ms. Beretti:

Thank you, Melanie, for meeting with us last Friday, August 12, 2016. Prior to the meeting, you had provided us with a draft analysis of what the County called "Impact HYD-6" and proposed "Mitigation Measure HYD-6." The County's proposed measure HYD-6 would place numerous burdens on CAWD, including the determination of necessary infrastructure to mitigate impacts of flooding and seepage, and the proposed operation and funding of de-watering the CAWD facility in perpetuity.

This letter confirms CAWD's statement at that meeting that CAWD does not accept the proposed mitigation HYD-6. CAWD cannot accept a mitigation that would place burdens on CAWD to mitigate the flood and seepage impacts of the County's project.

CAWD is best positioned to provide information on the conditions at the CAWD facility. Based on our data we believe there is no question that the County's proposed EPB would cause flooding at CAWD.

At the meeting, the County provided a draft report from Balance Hydrologics dated June 23, 2016. We have looked briefly at the draft report. CAWD's position is that the analysis is inadequate and flawed in material ways. At a minimum, CAWD should have been consulted during the analysis. CAWD has not heard from the County on any substantive issues related to the EPB for more than a year.

The County's documentation continues to refer to a levee surrounding the CAWD facility. We have repeatedly rebutted that claim. There is no levee surrounding our facility. There is a roadway that runs the perimeter of the facility. It is not a certified levee. There is a levee on State Parks property. However, the CAWD treatment plant is on the wrong side of that levee for it to provide any protection from flooding.

CAWD again offers to work with the County on these issues. Feel free to contact me to set up a meeting at which CAWD can provide current information to the County's technical advisers.

Regards

B. Buikema

B. Buikema
General Manager

cc: Carl Holm, Mo. County RMA