Carmel River Floodplain Restoration and Environmental Enhancement Project 35% Design Basis Report

BIG SUR LAND TRUST

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BSLT	Big Sur Land Trust
CAWD	Carmel Area Wastewater District
CLOMR	Conditional Letter of Map Revision
CSA-50	County Service Area 50
DOC	Dissolved Organic Carbon
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
GPS	Global Positioning System
HEC-RAS	Hydrologic Engineering Center – River Analysis System
HWM	High Water Mark
MFCA	Maintained Flow Conveyance Area
MPRPD	Monterey Peninsula Regional Park District
NAVD 88	North American Vertical Datum of 1988
NFIP	National Flood Insurance Program
NGVD 29	National Geodetic Vertical Datum of 1929
UBCRM	University of British Columbia Regime Model
USGS	United States Geological Survey
WY	Water Year

1. INTRODUCTION

Balance Hydrologics, Inc. (Balance) was originally contracted by the Big Sur Land Trust (BSLT) to provide technical assistance in assessing and identifying restoration alternatives along the Odello property located along the southern bank of the Carmel River Valley immediately upstream from Highway 1. This property, currently dedicated to agricultural production, has been identified as having the potential to substantially increase floodplain connectivity and natural riparian habitat within the lower end of the valley, while also addressing chronic flooding issues along the developed portions of the floodplain.

Preliminary findings were presented in a report titled Design Alternatives Analysis for Floodplain Restoration at the Odello Property, Lower Carmel River Valley (Balance Hydrologics, 2007).

A significant level of additional work has been completed since the 2007 report was released. A supplemental analysis was prepared in 2008 (Balance Hydrologics, 2008) with additional geomorphic and hydraulic detail. This supplemental analysis was prompted by the narrowing of the alternatives to a single, preferred design that includes agricultural preservation, removal of a portion of the existing south bank levee system, restoration of a dynamic floodplain environment, and construction of a new causeway in the embankment of Highway 1 south of the river to provide longitudinal floodplain connectivity and flood control benefits. This alternative has been evolving since 2008 and today is titled the Carmel River Floodplain Restoration and Environmental Enhancement Project (hereinafter “Project”).

This report summarizes the design basis for the geomorphic, hydrologic, and hydraulic aspects of the Project. As such, it provides a hydrologic background of the Lower Carmel Valley, an overview of the design goals and assumptions, a description of key features within the floodplain restoration design, a summary of the geomorphic issues, and recommendations for performance monitoring. Pertinent terms are defined in Section 7.

This report only briefly touches on the significant flood control benefits that would be associated with the Project. Detailed discussion of those benefits can be found in other reports prepared by the County of Monterey and County Service Area 50 (CSA-50).

This report is intended to inform other important design components associated with the overall Project such as the Restoration Management Plan, the causeway scour and hydraulic analyses, and trail layout and public access considerations.

2. HYDROLOGIC SETTING

2.1 The Carmel River Watershed

The Odello property is located at the downstream end of the Carmel River watershed, approximately one mile from its mouth at Carmel Bay. The Carmel River is a relatively large watershed for central coastal California, with a total watershed area of approximately 247 square miles at the United States Geological Survey (USGS) stream gage, located at the Via Mallorca Road crossing, approximately 1.4 miles upstream of the east end of the Odello Property.[1]

Although regulated by two dams in its headwaters, the river is still subject to very large seasonal and annual variations in total and peak discharge. The USGS gaging station often records no flow during the summer months, while exceptionally wet winter periods can see very significant peak discharge values. The peak flow of record at this gage was approximately 16,000 cubic feet per second (cfs) on March 10, 1995, estimated as just larger than a 30-year event. This peak flow is equivalent to 65 cfs/square mile and reflects the high rainfall totals in the mountainous upper reaches of the watershed. The 100-year flood event is estimated to be 22,700 cfs (92 cfs/square mile) by the Federal Emergency Management Agency (FEMA, 2009).

A major evolving aspect within the watershed is the future of the upstream San Clemente Dam, which is slated to be removed by 2016. The goal of that project is to provide a long-term solution to the public safety risk posed by the aging dam and to restore important aspects of the river's natural function by connecting the reaches upstream and downstream of the dam. Potential impacts of the dam removal with respect to the Project have been carefully considered and are factored into the design recommendations.

2.2 Existing Drainage Patterns

The Carmel River, as it runs through the lower end of its valley into the Pacific Ocean, has been significantly influenced by human activity, most notably through the construction of levees along both banks of the main channel. These levees, which run on both sides of the river from the Carmel Area Wastewater District (CAWD) treatment plant near the mouth of the river to the Rancho Cañada Golf Course approximately 1.2

[1] USGS gage #11143250 Carmel River near Carmel California.

miles upstream, have largely confined the small and moderate flow events to the main channel and limited the ability of the channel to interact with its adjacent floodplain.

During larger, less frequent storm events, flows escape the main channel and first spill into the south overbank area through low points in the levees. As water continues to rise, flow spills into the developed portions of the north overbank. Historically, the initial point of discharge into the north overbank has occurred along Val Verde Drive at the western end of the Rancho Cañada Golf course.

2.3 Historical Flooding

Large floods on the Carmel River in the historical period have occurred several times in the previous 150 years, such as those that occurred in 1862, 1911, and 1914.

In more recent history, flood flows along the Carmel River occurring in storms in January of 1995, March of 1995, and February of 1998 produced three of the highest flows on record and resulted in significant property damage along the lower valley. The March 1995 flood event (16,000 cfs) completely destroyed the Highway 1 Bridge and flooded much of the developed area contained within the north overbank levees including the Mission Fields neighborhood west of Highway 1 and the Crossroads commercial area to the east. Flood control projects and a new Highway 1 Bridge completed between the two storm events helped to significantly reduce the damage incurred during the somewhat smaller flow event in February of 1998 (14,600 cfs), but Highway 1 along the south overbank was still overtopped and Val Verde Drive came within a few inches of overtopping (L. Levine, personal communication, June 12, 2014).

2.4 FEMA Floodplain Mapping

Completed in 2009 by FEMA, the Flood Insurance Study (FIS) for Monterey County, California (FEMA, 2009) is of particular importance because it includes the most complete currently-effective estimates of the pertinent flood discharge values and flood elevations, with modeling extending upstream as far as San Clemente Dam. The hydraulic modeling and floodplain mapping are the effective FEMA flood hazard assessment for the project area under the National Flood Insurance Program (NFIP).

2.5 Community Service Area 50 Study

In October 2014, a team engaged by the County of Monterey prepared the Community Service Area 50 Final Lower Carmel River Stormwater Management and Flood Control Report (Balance Hydrologics, 2014). The Project was identified as a future scenario and this report concluded that the Project is expected to significantly reduce the flooding risk to the developed portions of the north overbank.

The much increased conveyance capacity in the restored floodplain and the construction of the Highway 1 causeway are predicted to reduce base flood elevations along essentially the entire length of the north overbank levee. The most pronounced impact is just upstream and downstream of the existing Highway 1 Bridge, reflecting the fact that the Project will function as an important natural means of relieving pressure on the main channel of the Carmel River. A direct result of the lowered water surface elevations in the main channel is the reduced need for perimeter protection measures for CSA-50[2].

[2] For example, in order to provide 100-year flood event protection to the Mission Fields neighborhood just downstream of Highway 1, the report identified a need for 1,300 linear feet of sheet pile floodwall at a cost of nearly $3 million. The Project lowers flood elevations such that no new perimeter protection is needed.

3. RESTORATION DESIGN GOALS

3.1 Restore Natural Floodplain Functions

The driving force behind the Project is to recover the natural functions and values that were present in the area prior to modern influences. Although it is unknown precisely how the south overbank looked and functioned in its natural state, it can be derived from a review of the existing geography that this area was once more closely hydraulically connected to the main channel of the Carmel River.

By increasing the frequency of overflow from the main channel, a more dynamic and diverse floodplain geometry is expected to evolve through a cyclical process of erosion and deposition of the silts and sands that predominately comprise the valley floor. This “reactivation” of the floodplain will subsequently result in the establishment of vegetation typical of river corridor environments, providing a denser and more diverse pallet of trees and plants than is currently found at the site. Storage and recharge of groundwater on the restored floodplain further ads to the restoration of natural floodplain functions.

3.2 Restore East-West Connectivity

A second goal identified for the Project is to increase the connectivity between the Carmel River Lagoon restoration west of Highway 1 and the proposed restoration east of Highway 1. In fact, this connectivity was identified one of the overarching long-term goals when restoration activities were undertaken to enhance the lagoon environment. More information can be found in Section 4.2.

3.3 Reduce Flooding Risk for North Overbank

The Project is expected to significantly reduce the flooding risk to the developed portions of the north overbank. As is the case with all river systems, when a portion of the floodplain is isolated from the remainder of the channel, flow is conveyed through a more confined area and higher water surface elevations typically result. Along the Carmel River, the south overbank levees currently cause water surface elevations in the main channel to rise higher during flood events, resulting in an increased frequency and magnitude of spilling into the north overbank. Although previous flood control projects have attempted to address this issue by lowering small portions of the south levee, it is a goal of this project to expand on that concept and to maximize the potential of this area to reduce flood risks along the developed portions of the river corridor downstream of Rancho Cañada.

3.4 Maintain Historical Farming Operations

An additional goal for the design is to maintain in part the historical farming operations that have persisted along the south overbank of the floodplain. The overall agricultural acreage of the floodplain will be significantly reduced to make room for the naturalized area, but roughly 23 acres will be retained along an elevated bench within the floodplain as an agricultural preserve.

4. FLOODPLAIN RESTORATION ELEMENTS

4.1 Channel-Floodplain Connectivity (Levee Removal)

In the most general sense, the primary goal of the project is to enhance connectivity between the main channel of the Carmel River and the south bank floodplain. This connectivity is critical to achieving a fundamental improvement in floodplain functions and values and to providing flood protection for the developed north overbank. At present, the only substantial point of connectivity to the floodplain is the so-called "Notch" in the existing south bank levee near the eastern end of the Odello property. In its present configuration, the "Notch" is roughly 300 feet in length, allowing limited access to the south overbank floodplain for flows from moderate to large floods.

In order to restore a very high level of channel-floodplain connectivity, the restoration plan envisions markedly reducing the confinement of the channel on the south bank of the river. This would be accomplished by removing five levee segments (see Plate 1), a total of 1,470 feet removed of the 4,650-foot length south bank levee (measured from Highway 1 to the most upstream end of the project limit). This equates to removal of roughly 30 percent of the existing levee run. The shortest individual levee segment to be removed is 250 feet, while the longest is 375 feet.

The levees would be cut to set top of bank elevations approximately equivalent to, or just slightly below, that of the 5-year flood event in the adjacent main river channel. The 5-year event was chosen after assessing a range of events 5- to 10-year in size and their ability to actively engage the floodplain. In general, the levee removal was constrained by the longitudinal floodplain geometry and its associated geomorphologic characteristics. The floodplain slope was set in part due to clearance requirements beneath the causeway and through the transition into the South Arm of the Carmel Lagoon and the amount of excess earthwork that could reasonably be accommodated by building up the already-elevated agricultural field. The geomorphically-stable slope of the resulting floodplain features a steeper slope than the energy grade of the 5-year event in the main channel of the Carmel River. These differential slopes mean that the most upstream levee openings can be engaged at the 5-year event, while the downstream levee openings will begin to be engaged at a flood between the 2- and the 5-year event. The present design balances the risk of full river avulsion (see Section 5.2.3 for more information about avulsion) with the desire to engage the floodplain during smaller events.

Removing the levee segments will provide multiple, continuous opportunities for interactions between the channel and floodplain regardless of patterns in sediment deposition and vegetation growth as the floodplain environment evolves. Furthermore, Plate 1 illustrates that the removed portions of the levee are on the upstream half of the floodplain. This helps to provide an early escape route for flood flows to enter the south overbank and relieves pressure on the main channel and the existing Highway 1 Bridge during large flow events, thus providing flood protection for the north overbank. It also leaves high quality riparian habitat on the westernmost levee area in place.

As mentioned, not all of the south bank levee will be removed. In fact, the majority of the levee will be left in place, and several sections will be maintained and expanded in roughly their current configuration, creating levee “islands” along the top of bank. More information on this topographic diversity can be found in Section 4.5.

The 1,800-foot long levee portion just upstream of Highway 1 is the longest segment to be maintained in its current configuration. This is preserved as such in order to protect the dense riparian vegetation along that length of levee and to provide significant protection from river avulsion risk (more information about this risk is provided in Section 5.2.3). As discussed later in Section 4.3, a geomorphically stable conform to the South Arm of the Carmel Lagoon requires a significant lowering of the floodplain elevation from existing grades both upstream and downstream of the new causeway. This design elevation is only a few feet higher than the elevation of the main channel Carmel River at the existing Highway 1 Bridge. Therefore, preserving this levee segment will play a key role in protecting the river from “short-circuiting” and choosing the shorter route to the Carmel Lagoon. Furthermore, fill will be added to the floodplain side of the levee in order to reinforce the existing structure by creating a wide levee top with gentle slopes down to the floodplain.

Removal of this length of confining levee represents a substantial change in flood flow patterns and will be transitioned by retaining small berms at the levee openings. This management strategy will assist floodplain vegetation establishment by limiting the volume and velocities of flows entering the floodplain during the first several flood seasons. The levee berms would be constructed out of fill over-excavated from the adjacent floodplain. Once vegetation has had the opportunity to establish on the floodplain, the berm material would be removed and return to the adjacent borrow areas, a fairly simple earthwork effort.

4.2 East-West Connectivity (Causeway)

Removal of the levees will result in direct connection of much of the south bank floodplain to the main channel. However, levee removal in and of itself will not significantly enhance longitudinal connectivity of the floodplain to other south bank areas downstream of the Highway 1 embankment. The May 2007 report on design alternatives (Balance Hydrologics, 2007) identified a number of benefits that could be realized if the present highway embankment were replaced (in part) by an elevated causeway section. The refined design has identified a 350-foot causeway as the preferred means of providing longitudinal connectivity through the south overbank (see Plate 1 for location). Hydraulic modeling indicates that the 350-foot length would be capable of conveying those portions of all floods that enter the floodplain, up to the 100-year event, with the required freeboard at the causeway, a marked improvement over existing conditions.

The re-establishment of floodplain vegetation, particularly expansion of the existing riparian corridor, has been balanced with the need to convey flood flows efficiently through the floodplain and under the causeway. See Section 4.10 for more information.

4.3 Conform to the South Arm of the Carmel Lagoon

The project team met with California State Parks (State Parks) representatives early on in the design process to identify issues related to the floodplain restoration and causeway and how the two would best interface with the Carmel Lagoon system, particularly the ecologically important restored South Arm (see Plate 1). State Parks staff indicated that geomorphic stability and control of sedimentation to the South Arm of the lagoon were important concerns. These discussions noted that the new hydraulic connection between south-bank floodplain flows and the lagoon can rejuvenate and/or expand the lagoon environment by removing excess sediment that is currently tending to fill the lagoon through tidal action. Expansion and/or rejuvenation of the lagoon will likely be beneficial for lagoonal fauna, especially critical life stages of threatened anadromous fish species. However, concern was expressed that flood flows could also impair the lagoon should inflows from the main channel carry excessive amounts of sediment, or if significant velocities are achieved that can re-mobilize sediment from the floodplain and redistribute it to the lagoon (see Section 5.2.6 for further discussion).

As such, Balance performed detailed geomorphic modeling (described in Appendix A) in order to assess the short- and long-term sedimentation risk. The results of the modeling effort informed several design decisions including:

- Lowering the existing grade upstream and downstream of the causeway. The floodplain restoration design, in order to minimize sedimentation risk, will lower existing ground just upstream of the causeway. Originally at an elevation of approximately 18 feet NAVD, the floodplain will be lowered to approximately 14 feet NGVD. This design directly interacts with the grading of the South Arm "lip" described below and provides a stable slope configuration on the floodplain (see Appendix B for a profile view of the design).

- Grading of the South Arm "lip." The most fundamental geomorphic constraint between the proposed causeway and the South Arm of the Lagoon is the abrupt change in grade at the end of the lagoon, the "lip", with elevations dropping quickly from roughly 17 feet NAVD down to South Arm bottom elevations of 8 feet NAVD and lower (see Appendix B for the existing and proposed grades). If left in place, the grade break would not be stable once the floodplain is fully engaged. The transition zone, if not modified, would experience rapid erosion due to high velocities as flood flows pass over the grade break. The sediment mobilized by this erosion would largely be deposited in the lagoon. Ongoing erosion over subsequent flood events would potentially result in headcutting progressing to the east as the floodplain attempted to find a stable slope configuration. The associated erosion would generate additional sediment that would be deposited in the lagoon. Existing riparian vegetation would likely be undermined, damaged, or uprooted. Arresting any tendency to headcutting would require a physical barrier such as a rock cut-off wall that would be an artificial element in the floodplain and eventually create a large armored drop that is incompatible with east-west floodplain connectivity. Therefore, an overall floodplain restoration design has been proposed that provides a multi-channel configuration with slopes that are predicted to be stable over a full range of anticipated flood magnitudes.

- Continuing the distributary channel network into the lagoon. The distributary channel network, discussed below in Section 4.4, extends from the floodplain, underneath the causeway, and into the lagoon, providing a more natural pattern of floodplain connectivity. The range of elevations in the proposed channels and bars immediately adjacent to the upstream end of the South Arm would allow the lagoon environment significant additional horizontal and vertical space to adjust to over time to outside drivers such as sea level rise.

- Establishing vegetation. Willow plantings will be strategically placed between the distributary channels in order to provide a root network and bank stability. Overall, restoration of the transition zone will be greatly supplemented by many acres of new riparian vegetation. The ecological synergy of the transition zone with the existing Carmel River riparian corridor will naturally be further leveraged by the main channel-floodplain connectivity provided upstream and restoration of flood flows under the causeway.

- Lining the channels. In order to stabilize channel geometry while vegetation takes hold and to minimize erosion upstream of the lagoon, the design proposes a 2-foot layer of cobble bed fill material to line the bottom of the distributary channels from approximately the causeway to just upstream of the lagoon. The bed fill material will be made up of a combination of rounded river cobble and gravel consistent with the existing bed in the main river channel in the vicinity of Highway 1. In addition to providing increased stability during the grow-in period of the restoration plantings, the bed material will further emulate the substrate that would be expected from relict channels on the floodplain.

- Providing sediment sequestration elements. As discussed in Section 4.6, several sediment sequestration features have been included in the design in order to give flood flows sufficient opportunity to shed coarse sediment before reaching the lagoon, particularly during the first several years after project completion when vegetation is still becoming established.

A primary consideration during the course of design was the avoidance of any tendency for wholesale deposition of coarse sediment in the lagoon itself. Although this design requires relatively extensive grading on State Parks land, ultimately this approach will result in better integration of the restoration of the floodplain with the restoration of the South Arm of the lagoon and provide for a collaborative natural resources project with landscape-scale restoration on both sides of the highway.

4.4 Distributary Channel Network

The overall floodplain restoration project encompasses a relatively large area at a location in the Carmel River watershed where overbank flows can be expected to be very large. In fact, the previously discussed hydraulic modeling indicates that overbank flow rates greater than 10,000 cfs are likely at the peak of large flood events. Natural floodplains of this scale and conveyance capacity typically manifest a number of geomorphic features that reflect the evolution of the specific environment in response to factors such as flood discharge, flooding frequency, and sediment load. Although continuing evolution of the floodplain is to be expected, a primary design objective is to begin with a geomorphically appropriate configuration so that the river system can more readily achieve natural conveyance pathways and geometries. This need was one of the primary drivers and objectives of the geomorphic modeling summarized in Appendix A.

The geomorphic modeling showed that, along this reach of the Carmel River, the central tendency will be to form a multi-thread channel network, specifically one characterized by two distributary channels. The modeling indicated a generally shallow channel depth, on the order of one to two feet, with a typical top width of approximately 60 feet, a typical bottom width of approximately 25 feet, and 8:1 horizontal to vertical side slopes. This channel geometry has been incorporated into the restoration grading concept both upstream and downstream of the proposed Highway 1 causeway (see Plate 1) as a key component of the new landscape, integrally configured to provide connectivity between the removed levee sections, sediment sequestration areas, causeway, and ultimately the South Arm of the lagoon.

4.5 Topographic Diversity

The floodplain design includes several features that aim to create topographic diversity on the floodplain (see Plate 1). The central portion of the floodplain includes multiple areas of high ground, which serve three main purposes:

- Separate distributary channels. Some separation between the north and south distributary channels helps to keep each channel functioning independently while the floodplain stabilizes over the first few large flood events. Ensuring the existence of more than one distributary channel helps to return the floodplain to its historical function through a multi-thread channel network.

- Regulate flows. The high ground “island” features act to control the flood flows entering through the removed levee sections. The features reduce flow velocities and help direct the flows that are entering perpendicular to the general direction of flow on the floodplain.

- Provide refuge. The “islands” will provide a dry refuge for wildlife within the floodplain during large flood events.

As discussed in Section 4.1, in order to minimize avulsion risk, levee removal has been designed such that the longest individual segment is 375 feet in length. This limits the amount of water that can enter the floodplain through any one opening, thus discouraging the river from changing its course. Maintaining the dimensions of the openings is therefore important for the overall stability of the floodplain environment. The project proposes to reinforce the remaining levee portions by adding fill to the floodplain side of the retained levee segments (see Plate 1). The fill will be placed such that the flow leaving the main river channel is oriented towards the direction of flow on the floodplain. These retained levee island features will preserve important areas of existing vegetation that will support colonization and expansion of riparian plant communities on the floodplain. Additionally, the islands will provide new intact vegetative cover along the banks at points where the tendency for main channel bank erosion is expected to be highest.

4.6 Sediment Sequestration Elements

An increase in sediment deposition is expected on the floodplain (more information in Sections 5.2.4 and 5.2.6). However, removal of the most upstream portions of the south bank levees will allow for such deposition to occur well upstream of the South Arm of the Lagoon, with a considerable spatial separation between the overflow points and the lagoon itself. Along with a gentle slope conducive to sediment shedding, the design provides several sediment sequestration elements for redundancy (see Plate 1). Each distributary channel has a dedicated sediment sequestration depression near the upstream end of its reach and two additional shared depressions. The largest depression is located approximately 200 feet upstream of the causeway in order to provide an additional location for sediment to settle out before reaching the South Arm of the Carmel Lagoon.

Each depression contains a positive outlet[3] in order to address the potential for fish stranding. Section 5.2.5 explains that stranding is unlikely because of the high degree of longitudinal flow connectivity, timing of juvenile hatching and migration, and short duration of flood flows through the south overbank. Steelhead smolt will be migrating after most flood flows occur, and adults tend to migrate during the rising and falling limb of the hydrograph. Each of the depressions on the floodplain will be carefully graded to provide a defined flow outlet such that migrating fish are able to sense the falling limb and, therefore, vacate along with the flood flow downstream.

It is also important to note that the depressional areas within the floodplain are expected to play an important role in enhancing recharge of the underlying groundwater system by retaining both a portion of flood flows and runoff from local watershed areas (see below). Enhanced recharge of the local aquifer has been identified as a factor in preserving freshwater input to the downstream lagoonal

[3] A positive outlet is a location through which the depression can drain by gravity flow without residual ponding.

environment, in particular during the summer period when flow in the river itself often ceases entirely.

4.7 Restoration and Enhancement of Tributary Channels

As noted elsewhere in this report, the overall design is such that substantial inundation of the floodplain is not expected for Carmel River floods less than the 5-year event. Therefore, in the majority of years the only significant sources of surface water to sustain the floodplain environment will be direct rainfall and runoff from the local south bank watershed immediately adjacent, with small potential additions from tailwater return flow from the agricultural preserve. In this regard, it is important to note that the south bank watershed is not insignificant, encompassing a total of 300 acres ranging up to elevations over 800 feet within Palo Corona Regional Park, which is owned by the Monterey Peninsula Regional Parks District (MPRPD). Much of the watershed is underlain by shallow soils over steep bedrock, with substantial runoff potential, particularly in years of above average rainfall. Past practices have resulted in most of this runoff being confined to narrow toe ditches along the edge of the existing agricultural operations for conveyance around the floodplain. Therefore, the Project represents an important opportunity to increase hydrologic support for the floodplain through restoration and enhancement of these local tributary systems.

The overall existing south bank watershed can be divided into three separate sub-watersheds. From west to east these include:

- Seasonal creek at the Palo Corona Barn. A well-defined seasonal creek channel descends from the adjacent ridges, flowing just to the north of the Palo Corona Barn before being intercepted by toed ditches and entering the Odello property. This sub-watershed has an area of 115 acres and already supports healthy riparian vegetation along the reaches upstream of the Barn.

- Hillslope runoff. East of the seasonal creek sub-watershed lies an area of 122 acres that is characterized by terrain that descends from the ridgeline without clearly defined channels. Runoff from this area is characterized by sheet flow that is also currently intercepted by narrow ditches along the floodplain fringe.

- Eastern “hollow” and wetland. The easternmost sub-watershed draining to the south bank is characterized by a topographic “hollow” that generates sufficient surface and sub-surface flow to support the existing wetland at the southeast corner of the Odello property. This sub-watershed has a total area of 63 acres, rising to ridgeline elevations of over 700 feet. This area and its associated wetland are discussed in Section 4.8.

A key component of the Project plan is restoration of the functions and values of these floodplain tributaries. Core to this restoration will be the replacement of the narrow and confined toe ditches with intermittent drainage corridors of sufficient width to allow for both low-flow channels and tributary floodplains, comprising areas that will experience surface runoff in all but the most severe drought years.

The restored intermittent drainage corridor will begin near the eastern end of the agricultural field and flow to the west, forming a border between the agriculture operations and the Palo Corona lands to the south. The longest intermittent drainage reach will be located on the south side of the agricultural access road and will collect runoff from the adjacent hillslopes along its 3,000-foot length. It will feature a sinuous low-flow channel with an average width of 10 feet, bordered on either side by floodplain benches that would vary between 8 and 49 feet in combined width (see Figure 1 below). The variable floodplain width will allow ample opportunities for plantings and additional topographic diversity (such as shallow wetlands) as components of the overall restoration plan.

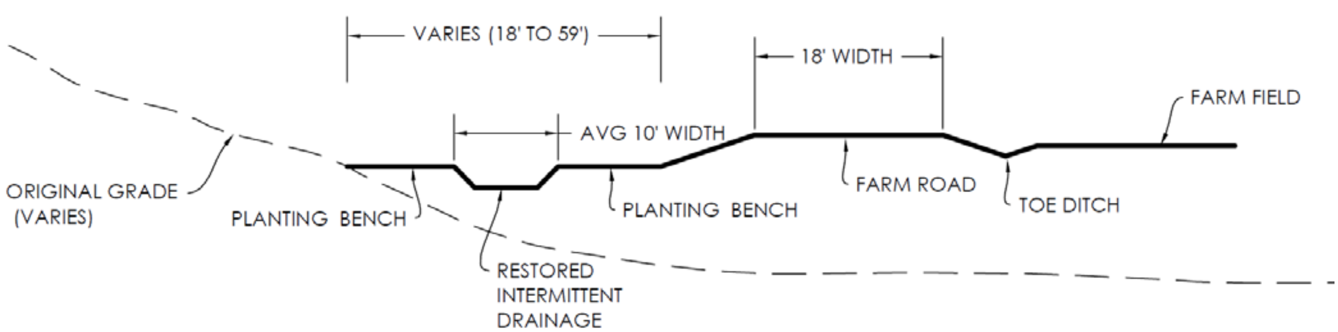

Figure 1 Intermittent Drainage Cross Section

The drainage corridor will extend westerly to a new confluence with the existing seasonal creek that comes down past the Palo Corona barn. The remaining gradient down to the restored floodplain will be quite steep and will be accommodated by a series of three boulder step-pools that will make up the grade difference between the confluence point and the floodplain floor. Once on the floodplain the combined tributary creek will flow through a 600-foot long channel joining the southern floodplain distributary channel before entering the final sediment sequestration area upstream of the causeway. Therefore, the restored tributary creek system will direct runoff from nearly 240 acres of the local watershed to the restored floodplain not far to the east of the South Arm of the lagoon, maximizing potential for freshwater augmentation to that feature as surface and/or groundwater inflow.

4.8 Connectivity to and Expansion of Existing Wetlands

As mentioned above, an existing, approximately 1.4-acre wetland exists south of the floodplain, near the upstream portion of the restoration. The wetland has formed where runoff from eastern "hollow" area reaches the former floodplain area and likely results from berms used to keep flow off the farm fields. The restoration project proposes to expand the wetland area to the north and the west, providing a wide, gently-sloping outlet over which water is allowed to leave as sheet flow onto the floodplain and join the southern distributary channel.

4.9 Agricultural Preserve and Associated Water Quality Pond

Another goal of BSLT's long-term management of the south overbank is to maintain an active agricultural operation on a portion of the land. The restoration plan achieves this goal by elevating a 24-acre area along the southern fringe of the valley above the active floodplain (see Plate 1). Fill was already placed in much of this area as part of California State Parks' Carmel Lagoon project downstream of Highway 1. However, the restoration plan envisions reducing the north-south width of the farm field to provide additional floodplain area. The elevation of the agricultural field will sit approximately 10 feet above the adjacent floodplain. Hydraulic modeling indicates that this elevation would be sufficient to protect the fields from inundation from floods as large as the 100-year event.

The agricultural field is designed in such a way that it slopes away from the floodplain and drains towards the southwest corner of the field. Agricultural runoff will be collected in a drainage ditch that runs along the north side of the agricultural field access road (see Plate 1), specifically designed to keep agricultural runoff from flowing into the restored intermittent drainage on other side of the road. At the eastern terminus of the agricultural runoff ditch, the runoff will be conveyed via a 36-inch culvert into a water quality pond for settling and percolation. An outlet riser will be included in order to protect the water quality pond levees from erosion due to overtopping during large events.

4.10 Maintenance, Access, and Future Trail Clearance

The central design feature of the floodplain restoration is the ability for flows to enter onto the floodplain. Maintained Flow Conveyance Areas (MFCAs) will be established along each removed levee section and upstream and downstream of the causeway in order to maintain proper conveyance on the floodplain. These areas are shown in Plate 1 and will need to have an explicit maintenance plan. Planting in the MFCAs is limited to vegetation that will not impede flows during flood events.

A network of access roads is included as part of the design and will tie into the proposed trail network on the floodplain. The access road begins at Highway 1 south of the causeway and follows the south boundary of the land owned by BSLT. One branch of the access road continues onto the southern boundary of the agricultural field and rejoins the floodplain at the eastern end of field, near the existing wetland. A second access road branches off west of the agricultural water quality pond, traverses the floodplain in the north-south direction over one of the topographic diversity islands, and provides maintenance access to the north portions of the restored floodplain, the removed levee sections, and the existing well on the north side of the property. See Plate 1 for a schematic of the access road network.

A clearance of a minimum of 10 feet has been provided underneath the causeway, near the north abutment, for a future trail connection between the east and west portions of the floodplain. Additionally, the maintenance access roads have the ability to function as dirt trails, if required.

4.11 Overall Cut-Fill Balance

The latest grading for the floodplain and agricultural preserve incorporates a number of adjustments to previous conceptual grading plans, and results in a site that is balanced from an earth moving perspective. Although the project requires a substantial effort with respect to earthwork, the design is one that balances on site with only a small import of material for channel enhancements and step-pool construction.

5. GEOMORPHIC ASSESSMENT AND CONSIDERATIONS

Restoring critical landscape elements on lowland floodplain rivers in central California requires an examination of design opportunities and challenges that outline the feasibility and benefits of geomorphic restoration in the context of a multi-use, dynamic environment. This chapter reproduces information provided in the Supplemental Analyses for Floodplain Restoration at the Odello Property report (Balance Hydrologics, 2008) and discusses the functions provided by reconnecting the floodplain with the main channel.

5.1 Design Opportunities

Various ecosystem functions will ultimately be provided to the lower Carmel River system by the proposed reconnection of the floodplain through partial levee removal. While the list is not exhaustive, the following functions are most pertinent to the Project:

- Flood mitigation, including reducing flood elevations and the extent with which floods affect urban areas along the north overbank;
- Habitat enhancement afforded by recruitment of sediments and organic material onto the floodplain combined with a restored (or partially restored) hydroperiod;
- Nutrient cycling in floodplain sediments and in the water column associated with flood events, including the potential for carbon sequestration, and;
- Restoration of geomorphic function on the lower floodplain and in the main stem Carmel River through re-establishment of a more natural flood regime.

The work carried out as background for the restoration design relies in part on a very successful and well-documented floodplain restoration project on a large, lowland floodplain river in a semi-arid/temperate climate—the Cosumnes River in the Central Valley of California. The restoration research conducted on the lower Cosumnes River has served as a long-standing pilot project under the auspices of CALFED as an example of how semi-passive restoration techniques may be applied to a partially-cultivated and urbanized lowland riverine landscape while providing opportunities for improved management. The rich literature on the Cosumnes restoration work is supplemented by first-hand experience of intentional levee removal, sand-splay complex development, and vegetational succession on the Cosumnes River by

Balance staff as well as their (and others') work along channels approaching lagoons or impoundments throughout the state.

5.1.1 Flood Mitigation

Reconnecting the lower Carmel River with its floodplain will achieve significant reductions in flooding risk. By removing a portion of the levee system along the south bank on the Odello Property, water surface elevations and flooding risk for both moderate and large floods, particularly along the north bank, will be reduced compared with existing conditions. Flood flows along the main stem from Rancho Cañada downstream will no longer be constrained by a leveed channel insufficiently-sized to transmit moderate to large events. Flow velocities in the main stem will also be reduced as increasing proportions of flows move onto the southern floodplain.

Design features that address flood mitigation are levee removal and the causeway and are discussed in Sections 4.1 and 4.2, respectively.

5.1.2 Habitat Enhancement

Restoring connectivity to the floodplain is a means through which semi-passive habitat enhancement may be performed on the lower Carmel River. Connectivity of floodplains to river systems creates and maintains a mosaic of habitats that foster primary productivity, aids the reproductive cycle of various fish species, engenders nesting and foraging activity of birds, regenerates riparian vegetation, and provides a sustained source of beach nourishment. Small-scale reorganization of the floodplain surface combined with re-colonized terrestrial vegetation provides seasonal habitat for wildlife of all types.

Opening up the southern floodplain will re-establish a more natural flow regime in this episodic riverine system—one that seeks to emulate more closely the historical recurrence of flooding on the lower Carmel, which will tend to favor native fisheries and fauna that have adapted to, respond to, and reap benefits from a floodplain that receives infrequent and potentially widespread flood waters. Hecht (1993) highlights the necessity of abrupt, episodic disruption in semiarid central Californian streams, where riparian environments are rejuvenated at widely spaced intervals (shorter than those needed for mature woodland to develop). Thus, the episodicity of flooding events that once prevailed in the lower Carmel River may be a hallmark of its successful development and function—a trait that can be re-established through the proposed floodplain restoration work.

Design features that address habitat enhancement are levee removal, east-west connectivity, conform to the South Arm of the Carmel Lagoon, topographic diversity, enhancement of tributary channels, and connectivity to existing wetlands. These are discussed in greater deal above in Section 4.

5.1.3 Nutrient Cycling and Sequestration

Much recent research has complemented the growing field of biogeochemistry with studies on nutrient cycling, storage, and mobilization associated with aquatic environments, and notably, floodplains. Floodplains are incredibly important reservoirs, processing centers, and distribution hubs for biologically important nutrients and biogeochemical constituents in riverine systems, and historic separation of floodplains from their main channel by levees has reduced the ability of lowland rivers to support native plant and animal assemblages while simultaneously restricting ecosystem diversity.

Design features that address nutrient cycling and sequestration are levee removal, the distributary channels, sediment sequestration elements, and salvage and placement of woody material from the levee removal. These are discussed in Sections 4.1, 4.2, 4.4, and 4.6. More information about the three primary biogeochemical functions afforded by the Project can be found below.

5.1.3.1 Dissolved and Particulate Organic Carbon

Dissolved organic matter, and particularly dissolved organic carbon (DOC)[4], has been suggested as one of the most important factors contributing to the biotic functionality of riverine ecosystems (McDonald and others, 2007, and references therein). Dissolved organic carbon is important for energy flow, and heterotrophic[5] bacteria are almost exclusively responsible for DOC overturn.

McDonald and others (2007) suggest that floodplain water bodies in arid and semiarid environments play an important role in nutrient storage and exchange between the main channel and the floodplain. Specifically, riverine ecosystems and the food web of naturally-functioning floodplain-wetland systems may be revitalized by re-establishing

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[4] DOC is operationally defined as the fraction of organic matter that passes through a 0.45 µm filter, and consists mainly of organic acids like fulvic acid.

[5] Heterotrophic describes organisms that require energy from primary producers (those organisms that can photosynthesize sunlight into their own energy—autotrophs) or from other heterotrophs to sustain themselves through respiration.

episodic connection between the river and floodplain lakes and lagoons because there are likely important differences in the molecular weight, complexity, and type of aquatic DOC in different parts of the riverine environment.

Wigginton and others (2000) support the notion that organic matter in floodplain soils are essential in facilitating exchange of nutrients and energy between soil and plants, and that the sustenance of a restored floodplain forest-wetland system depends heavily on the delivery and maintenance of this organic matter from flood flows. Furthermore, storm flows tend to elevate DOC exports from headwaters, which are then transferred to floodplains downstream where prolonged residence time in low energy waters offers microorganisms more opportunity to transform the DOC into a useful subsidy for the aquatic food web. And, flood flows often deliver high concentrations of organic carbon to floodplain lakes and surfaces, where they are buried and retained for subsequent processing (Moreira-Turcq and others, 2003). This also suggests that restoration of the lower Carmel River floodplain may contribute to a small, but importantly growing trend of lowland floodplain restoration projects that include floodplain carbon sequestration and global warming mitigation as a distinct, salient benefit locally and globally.

5.1.3.2 Denitrification

Dissolved inorganic nitrogen is a nutrient in riverine systems that can affect water and habitat quality, and in the lower Carmel River, may impact nearshore environments in the Carmel and Monterey Bays. Dentrification in riverine systems describes a process whereby dissolved inorganic nitrogen can be converted to atmospheric nitrogen and removed from the river network. Restored floodplains provide this service through native plant uptake and microbial denitrification by bacteria that are subjected to anaerobic conditions associated with inundation/submersion, which are then forced to use nitrate rather than oxygen to break down dissolved organic carbon (Lymburner and others, 2006, and references therein).

Ahearn and others (2006) document complex hydrologic mixing behavior on floodplains that establish localized and temporary zones of hypoxia that favor anaerobic microbial denitrification. Anaerobic denitrification may also occur in semiarid floodplain environments as nitrogen-rich water enters the root zone of riparian vegetation during the rising limb of a hydrograph, spends some time there, and then is returned to the river channel during the falling limb (Lymburner and others, 2006)[6].

Prolonged flooding will favor denitrification and reduction in nutrient load to the Carmel River Lagoon and Monterey Bay—more than 3 days are generally required for denitrification to begin, while 8 days is required for all available reserves of water soluble carbon to be consumed (Lymburner and others, 2006). The service of denitrification has long been curtailed in the lower Carmel River, not only because of infrequent river-floodplain connection during only the most extreme flood events that overtop or breach levees, but because agricultural areas (such as the historically cultivated floodplain) have essentially no potential to denitrify flood waters due to low amounts of water soluble carbon and the presence of nitrogen fertilizers (if any have been used). Thus the delivery of both soluble organic carbon and nitrogen-bearing flood waters accomplished by opening up the floodplain to flood flows offers biogeochemical services: principally, the exchange and processing of nutrients are what make healthy, functioning floodplains among the most productive and diverse ecosystems.

5.1.3.3 Algal Biomass and Nutrient Exchange

Downstream and floodplain aquatic ecosystems benefit greatly from periodic connection of floodplains with the main channel (Mueller-Solger and others, 2002; Ahearn and others, 2006; Gallo and others, 2004, 2004b, 2004c, Gallo and others, 2003, Gallo and others, unpubl.). Floodplains function as a source of concentrated suspended algal biomass for downstream aquatic ecosystems by processing deposited organic materials over time: spatial variability in floodplain surface roughness and water velocity, afforded by a restored floodplain, promotes woody debris and particulate deposition. Restored floodplains may then allow subsequent biological processing of particulate and dissolved detritus (Ahearn and others, 2006). Floodplains are then organic carbon sinks (as suggested earlier), which export in-situ carbon to the river channel and downstream ecosystems (Ahearn and others, 2006, and references therein). The constant reorganization of floodplain features during storms and floods also creates complex mixing of waters and biogeochemical constituents, some of which may be exported from the floodplain, while others are simply redistributed, further enhancing the organized but complex patterns of plants and animals established on connected floodplains. Such complexity gives rise to dynamic zones of phytoplankton (algae) production on the floodplain, which may be absent in the river

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[6] Gallo and others (unpubl. data) present data that attest to this drop in total nitrogen and nitrate from the Cosumnes River floodplain during draining.

channel itself (Ahearn and others, 2006). This "nested" process (immediate delivery and flushing, transient storage and draining, long-term storage and nutrient cycling) has led to the characterization of floodplains as "productivity pumps" by Ahearn and others (2006), where waters of higher nutritional value (i.e., higher algal biomass) are stored, processed, and re-delivered to the river system.

Chlorophyll *a* (Chl *a*), a proxy measurement of the amount of phytoplankton, is one of three forms of very important floodplain organic carbon, and is more nutritious than the other two (DOC and coarse particulate organic matter). The duration and frequency of floodplain connection with the main stem determined the response of Chl *a* concentrations in floodplain waters, and a residence time of at least 2 days was required for Chl *a* levels to increase enough that subsequent flood waters could deliver highly nutritious waters from the floodplain to downstream reaches during flushing activity (Ahearn and others, 2006). Removing a portion of the levees along the restored floodplain will accommodate this exchange of Chl *a* between floodplain and channel zones, and should greatly enhance the efficiency of biogeochemical cycling of nutrients and algal biomass in the lower Carmel. Gallo and others (2003, 2004, 2004b, 2004c) also suggest that phytoplankton and zooplankton production increases in floodplain water bodies with increased residence time, and indeed their data document higher productivity in floodplain ponds and grasslands than in the associated river channel. Gallo and others (2004c) recommend water residence times on the floodplain on the order of several weeks with recurrent flooding on the scale of weeks. Ultimately, flow conditions and channel morphological adjustments will dictate the frequency with which the restored floodplain is inundated with flood flows, but the proposed restoration plan makes such activity feasible in a system that has been without nutrient exchange for decades.

5.1.4 Geomorphic Function

One important component of floodplain restoration involves maintaining soil quality, and proper geomorphic function is required in lowland floodplain rivers for this maintenance to occur. Flooding accelerates the decomposition of leaf litter and other woody debris on the floodplain, which, once decomposed, provides mulch that protects the underlying soil from dehydration and sunlight (Clinton, 2003). The decomposing mulch also supports bacteria which supply nutrients to plants, while flood waters deliver sands and silts rich in nitrogen and phosphorus. Flood waters also establish stagnant ephemeral pools during hydrograph recession, supporting the leaf litter of riparian floodplain meadows. In areas where organic debris is sparse, algal mats function as floodplain mulch, supporting bacterial communities and the supply of nutrients to floodplain plants and soil. Algal mats also harbor invertebrates that are healthy for the soil, and ultimately the food web as a whole.

Lowering a significant proportion of the levees along the south overbank will reduce pressure on the main stem of the Carmel River, allowing flood flows to be directed away from built areas while providing the necessary hydrologic and sedimentologic behavior to sustain a vibrant and visually diverse floodplain-wetland environment. Proper geomorphic function through periodic inundation of the floodplain results in reorganization of the floodplain surface, providing pockets where algal mats can establish, which will support the requirements of autotrophic and heterotrophic organisms. Flood flows also carry sands and silts laden with organic material, including seeds of native plants, providing for soil hydraulic conditions that foster native plant growth. This delivery of fines to floodplains rather than to lower energy depositional locales in the channel or near its margins also favors proper sediment transport and bedform organization behavior to which the river was originally accustomed.

It is a misnomer that floodplains are flat, relatively featureless components of riverine systems, simply straddling a hydrologic artery. Both the geologic record and modern day observation attest that floodplains are ornamented by subtle variations in topography related to periodic inundation and reworking of floodplain deposits. It is this subtle variation in topography, established by episodic inundation and exchange of material, which defines a well-functioning riverine-floodplain system.

Design features that address geomorphic function are levee removal, causeway, conform to the lagoon, distributary channel network, topographic diversity, and sediment sequestration elements. These are discussed in detail in Section 4 and Appendix A.

5.2 Design Challenges

Floodplain restoration as part of the Project raises several geomorphic questions, which collectively provide the opportunity to assess restoration feasibility at the site. This section works through the following five geomorphic/systems-based topics:

- Observed and historic channel geometry;
- Susceptibility of future channel avulsion along the lower Carmel River;
- Susceptibility of future channel bed aggradation along the lower Carmel River;

- Potential impacts to native species and fisheries; and
- Considerations of future potential effects to the South Arm of Carmel Lagoon.

In discussing each topic highlighted above, this report draws extensively from the rich literature base which exists for the Carmel River watershed as a whole, and specifically the lower reaches in the vicinity of the restoration site. The local literature was supplemented with: a) investigations focused on levee breaches and floodplain restoration activities completed along the lower Cosumnes River, b) research focused on describing avulsion potential in lowland rivers, and c) ongoing work focused on describing sea level conditions over the past 50 to 100 years and potential sea level trends in the future. This report builds on the 2007 and 2008 Balance Hydrologics' reports, which were developed to present the big picture elements. These elements have been expanded upon during this report.

The geomorphic findings presented in this section helped to inform a restoration plan that considers channel planform stability along the lower river and the stability and functionality of the South Arm of the Carmel Lagoon.

5.2.1 Physical Description of the Lower Carmel River

The geomorphic assessment focuses on the section of the lower Carmel River[7] extending from Valley Greens Bridge to Highway 1, a distance of approximately 3.7 miles measured along the main channel. This reach exhibits a sinuous planform geometry, and is characterized by a reach-average gradient of approximately 0.2 percent (10 feet/mile). Alternate bars become visible at low flows, and the channel bed generally consists of alluvium ranging from sand to fine gravel. Bulk bed sediment samples collected by Mussetter Engineering, Inc. (MEI, 2002) show downstream fining, ranging from median sizes of:

- 21 mm (fine gravel) near the Valley Greens Bridge, to
- 2 mm (sand) just upstream of the Via Mallorca Bridge, to
- 1.7 mm (sand) upstream of the Highway 1 overcrossing, near the Rancho Cañada Golf Club.

[7] The Carmel River is often subdivided into lower, middle, and upper portions in the literature; the lower Carmel extends from its mouth to a bedrock constriction 10 miles upstream ("the narrows"), and the middle Carmel extends from "the narrows" to San Clemente Dam. The upper Carmel extends from the San Clemente Dam to the headwaters.

Downstream from the Rancho Cañada Golf Club, the river is confined by levees along both sides of the channel and ranges from 300 to 450 feet of levee-confined width. Hardened bank protection lines 40 percent of the total bank length between the Valley Greens Bridge and Highway 1 (MEI, 2002). The reach extending from Highway 1 to the mouth exhibits two largely straight, equal-length sections joined by an approximately 90-degree bend. Average channel gradient downstream of Highway 1 is approximately 0.1 percent (5 feet/mile), and hardened bank protection in this section is nearly continuous. The channel is sandy, well-incised, and bordered by thick riparian forest. This reach interfaces with the Carmel River Lagoon, which forms an estuary bounded by a bedrock outcrop and seasonally-deposited barrier bar at its mouth. The bedrock outcrop forms a positive vertical control at the mouth of the river, while the mouth is seasonally blocked during the low-flow season due to development of the barrier bar at the beach. During the high-flow season, the barrier bar is reworked (or opened manually) and migrates seaward, forming a nearshore bar as the river mouth is reconnected with the sea. The previously completed lagoon restoration project on California State Parks land has provided for an additional lagoon arm which extends to the south from the present-day location of the Carmel River mouth – this area of the lagoon is referred to as the South Arm.

5.2.2 Overview of Observed and Historic Channel Geometry Dynamics

Kondolf and Curry (1984; 1986) have done extensive work on the Carmel River system and documented planform changes along the lower and middle reaches of the river from sources dating back to 1858. Their analysis extends through 1980, and their documented channel pattern changes have been digitized in Figure 2.

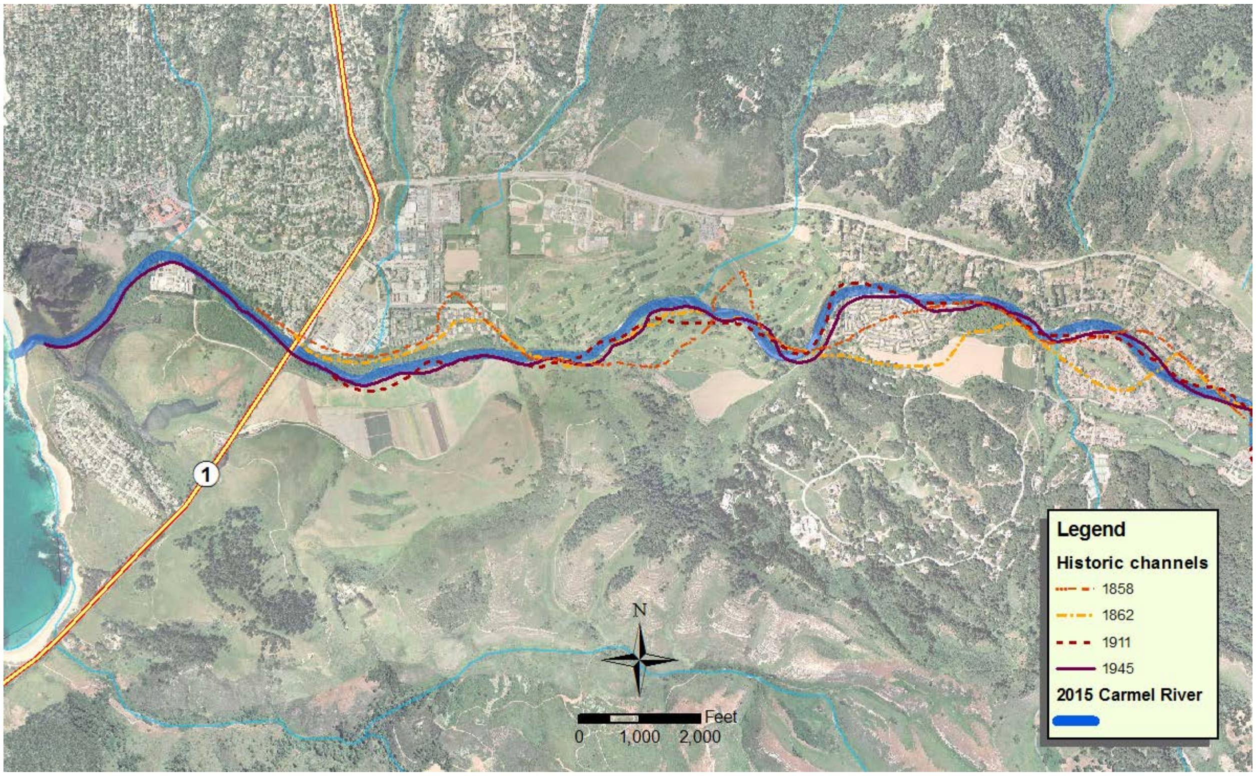

Figure 2 Historical channel alignments

The map illustrates nine locations where lateral channel migrations of 820 to 1,640 feet have occurred during the period between 1858 and 1945, presumably due to the large floods of 1862, 1911, and 1914. It is also significant to note that a separate historic map from 1876 depicts an anastomosing[8], multi-thread, relatively high-sinuosity river channel along the reach that borders the future restored floodplain (PWA, 2002).

Channel planform changes were poorly documented following the 1862 flood, but the 1911 flood caused extensive bank erosion and channel migration, as shown by

[8] Anastomosing streams are characterized by an interconnected network of low-gradient, relatively deep and narrow channels separated from one another by relatively stable, vegetated floodplain islands. The individual channels within the network can be straight, sinuous, or braided. These channel systems are also called ‘anabranching’; branches, or channels, form primarily by avulsion, or the abandonment of a former channel for a new one at a lower elevation.

comparison of the 1858 and 1911 channel traces in Figure 2, and as evidenced by personal accounts such as those by Fannie Meadows and Roy Martin who lost 10 acres and a pear orchard to channel migration (Kondolf and Curry, 1984). The flood of 1914 caused fewer channel changes, although Kondolf and Curry (1984) do not explicitly state the relative magnitude of change between the 1911 event and that in 1914.

Kondolf and Curry (1984) report a lack of major floods in the decades following the 1911 and 1914 floods. The 1911 flood registered approximately 17,000 cfs near San Clemente Dam before the staff gage was swept away (with an estimated peak around 21,000 cfs), and the 1914 flood was likely of similar magnitude (Kondolf and Curry, 1984). USGS streamflow records extending from the late 1950’s and early 1960’s to the present indicate that flows near Robles Del Rio and Carmel, significantly downstream from the San Clemente Dam site gage, have only approached this magnitude twice. Peak flows of ~14,700 to 16,000 cfs occurred in 1995 and 1998, respectively, at both sites. This reduction in major flooding episodes, exacerbated by ground-water withdrawals in the lower Carmel River that often cause flows to decrease downstream, coupled with the construction of San Clemente Dam in 1921 plus gravel mining during the 1950s and 1960s in mid-valley, resulted in a reduction of coarse bedload sediment supply (by an estimated 60 percent) to the lower reaches of the river. This reduction in bedload is thought to have resulted in significant channel bed incision along reaches below the dam down to Highway 1 (mean incision of approximately 13.1 feet) including a loss of previously observed planform dynamics through the lower reaches of the Carmel River documented by Kondolf and Curry (1986). Historical photos from 1918 of the lower reaches show a wide, sandy, braided channel, whereas photos from 1939 illustrate the development of a single-thread, entrenched channel form along the lower reaches and the retention of a braided pattern farther upstream. Channel planform geometry was disrupted along the middle Carmel due to the floods of 1978 and 1980 when bank erosion was significant along this reach (Kondolf and Curry, 1984). Bank erosion was particularly severe near the Schulte Road Bridge, where channel width increased from 43 to 115 ft as roughly 130,000 cubic yards of material was eroded from the banks between 1965 and 1980. Bank erosion along the middle Carmel was reportedly linked to riparian vegetation die off and severe stress induced by depressed ground-water elevations due to aquifer overdraft (Kondolf, 1982).

The drought of 1976-77, however, did not affect riparian trees downstream of Valley Greens Drive, where none of the high-capacity water-supply wells existed, and the aquifer is finer-grained and more complex, and retained sufficient water to sustain their growth. The lower Carmel below the Schulte Road Bridge remained relatively unaffected by the large storm flows of 1978 and 1980. It is well established that in the absence of vegetation, coarse-grained bank and channel substrate are easily mobilized (c.f.,Murray and Paola, 2003). Thus, vegetation plays a primary role in defining channel shape and pattern in bedload-dominated, lowland rivers. The planform stability of the middle and lower Carmel is, therefore, likely affected by adjustments in vegetation cover and density. Bank stabilization structures have progressively supplemented the effects of vegetation along the lower and middle reaches of the Carmel.

Few studies have described or otherwise documented bed elevation changes to the middle and lower Carmel River system with the notable exception of 1) Kondolf (1982), who revisited previously surveyed sections conducted by the U.S. Army Corps of Engineers during his graduate work of the early 1980's, and 2) a thalweg survey performed for the Monterey Peninsula Water Management District by Graham Matthews and Associates in late 2007. The data collected by GMA is compared in their report with data and vertical control points (unavailable to us) established in 1995 by Central Coast Surveyors. Cross-section data presented by Kondolf (1982) illustrate that from 1965 to 1982, relatively little change (possible 0.3 feet aggradation) occurred to bed elevations near the project site, close to Highway 1. However, channel bed elevation data from cross-sections upstream of the project site (near Via Mallorca Road and Rancho San Carlos Road) suggest that the channel aggraded by up to 1.3 feet during the same time period, but Kondolf acknowledges that these data may reflect the passage of a sediment slug rather than long-term bed dynamics. Further upstream, bed degradation characterized the middle reaches of the river.

GMA's data and analysis depicts a different and more dynamic story during the years following Kondolf's resurveys and is based on channel thalweg surveys rather than discrete cross section surveys. In addition, a direct comparison of bed elevation changes between Kondolf's and GMA's data may not be entirely possible because the two surveys were not consistent in their use of benchmarks and vertical control. Nevertheless, GMA's data show downcutting of two to three feet in the reach extending from the Highway 1 Bridge to Via Mallorca Road since 1978. This trend is generalized for the reach and does not contradict Kondolf's data (extending to 1982) suggesting 1.3 feet of aggradation at the Via Mallorca Bridge; GMA's data at the Via Mallorca Bridge show aggradation of approximately one foot from 1978 to 1984, while the rest of the reach extending to Highway 1 decreased in elevation from 1978 to 2007. Continuing upstream, the reach extending between Via Mallorca and Rancho San

Carlos Bridges was vertically static between 1978 and 1984[9]. Between 1984 and 1994, incision in this reach of approximately two feet ensued, until storms in 1995 and 1998, combined with upstream bank erosion, supplied sediment and restored bed elevations to levels obtained in 1984. Subsequent localized incision continuing until 2007 lowered bed elevations again to 1994 elevations in the same reach. Finally, the reach between the Rancho San Carlos Bridge and Valley Greens Drive also experienced incision of approximately two feet between 1984 and 2007. Several deep pools at the Schulte Road Bridge, and other deep pools a short distance upstream at “a well-known bedrock outcrop” underwent deepening of up to seven to nine feet between 1997 and 2007, further demonstrating a tendency to incise under more recent flow and sediment transport conditions.

In sum, it appears that reductions in sediment supply, the establishment of dense riparian vegetation along channel banks, and continuing increases in the length of bank hardening transformed a braided and more active lower Carmel River into a relatively fixed single-thread channel. Bank erosion and bed adjustment of the recent past seem to have been driven by reductions in bedload supply from the upper watershed coupled by locally weakened or dead riparian plant communities. Recent trends from repeated surveys suggest incision under current sediment supply and climatic conditions; however, sediment supply alterations from the imminent bypass of San Clemente Dam may cause distinct departures from the patterns currently documented. More information about San Clemente Dam can be found throughout this report.

5.2.3 Susceptibility of the Carmel River to Avulsion

The preferred restoration design includes removal of considerable lengths of the existing levee along the south bank of the river, as presented in Section 4.1. Given the historically active nature of the lower Carmel River, and the proposed reconnection of the floodplain to more frequent flooding, it is reasonable to consider the possibility of channel avulsion to the south into the re-established dynamic floodplain. Other sources support the notion that avulsion is a likely natural process on the lower Carmel River, especially near the Carmel Area Wastewater Treatment Plant (PWA, 1999). Planning level concerns with channel avulsion might include:

[9] At Rancho San Carlos Bridge, Kondolf’s cross section surveys record 1.3 feet of aggradation while GMA’s data at the same discrete location suggest 0.5 feet of incision. These differences in processes can perhaps be best understood if Kondolf’s data are interpreted as the transient passage of a sediment slug.

- Impacts to a newly-constructed Highway 1 causeway;
- Impacts to fish habitat in any abandoned length of river as well as within the newly established river course;
- Damage to any length of levee east of Highway 1, particularly on the south side, which is not removed as a part of the floodplain restoration;
- Damage or impacts to the agricultural uses; and
- Damage or impacts to the South Arm of the Carmel Lagoon.
- Inherent difficulty in predicting channel avulsion. There are currently no entirely deterministic ways to predict the conditions necessary to cause avulsion. A few studies, however, provide some guidance to consider in any assessment of avulsion on lowland floodplain rivers. Stability criteria separately developed by Slingerland and Smith (1998) and Jerolmack and Mohrig (2007), along with analysis presented by Ashworth and others (2004) have been used to assess the potential for avulsion at the project site (further outlined in Appendix A). The results of this analysis are contradictory: Slingerland and Smith's method suggests a tendency towards a stable channel configuration without avulsion, while Jerolmack and Mohrig's semi-empirical approach suggests that the lower Carmel might avulse episodically under present watershed conditions.

The contradictory and uncertain nature of the analysis conducted is a result of the following factors:

- Slingerland and Smith's method analyzes steady-state hydraulic conditions that might lead to avulsion under current channel and floodplain geometry;
- Jerolmack and Mohrig's method approaches avulsion with a more empirical perspective, relying on temporally-averaged rates of change to channel geometry (deposition and erosion recorded over the last few decades) that tend to reliably classify channels as avulsive or meandering;
- Inherent uncertainty in predicting flow conditions and changes to bed configuration.
- The lower Carmel River's morphology is not dominantly diagnostic of an avulsive or stable-channel configuration, which makes prediction using the currently available methods uncertain.

Two other factors specific to the Carmel River that may affect the probability of avulsion merit consideration:

- Significant increases in coarse sediment supply entering a reach of river will likely increase the tendency to avulse (c.f., Ashworth and others, 2004); periodic increases in sediment supply (for example, from re-establishment of bedload supply after San Clemente Dam removal, or from possible incision of northern tributaries to the Carmel River), or following episodic climatic or geomorphic events (Kondolf, 1982; Hecht, 2000) are possible contributors to these increases in supply.
- Large woody debris and logjams strongly affect channel behavior in the Carmel River, and (based on our observations of previous floods) may likely mute the tendency to avulse by accumulating at locations where breaches might or are beginning to develop.

Field observations from similar restoration activity in historically avulsive rivers (for example, the Cosumnes River) may help clarify design criteria, but observations even in entirely analogous systems should be interpreted with some caution. The geomorphic modeling completed (described in Appendix A) would suggest that the risk to avulsion following partial levee removal along the lower Carmel River is likely to be relatively low. However, levee strength at the margins between retained and removed sections is likely to be at its minimal value immediately following removal due to a loss of vegetation – this would increase the avulsion risk and suggests that practical design-based measures should be taken to promote the strength of remnant levee segments during the first several years following restoration. As discussed in Section 4.1, the restoration design takes the avulsion risk into account and has elected to keep the south overbank levee at the locations with the highest avulsion risk.

5.2.4 Susceptibility to Future Channel Bed Aggradation

As stated previously, Kondolf and Curry (1984; 1986) suggest that bed incision of up to 13 feet occurred along the lower reaches of the Carmel River in response to the 1911 flood and the closure of San Clemente Dam in 1921. Channel surveys extending up until 1982 suggest bed-elevation stability, with negligible bed aggradation in the vicinity of the project site of 0.3 feet that cannot be entirely attributed to long-term trends in transport and deposition. Surveys as recent as 2008 document channel incision in many sections of the lower Carmel River by as much as two feet, pointing to a recent relative trend of gradual removal of sediment; this potentially creates in-channel storage opportunity for future events. These data notwithstanding, there are at least four geomorphic drivers to consider that may influence bed aggradation rates in the lower Carmel River in the future:

- Anticipated sea level rise will elevate base level, potentially inducing deposition in the lowermost reaches, potentially both in the channel and on the floodplain;
- Long-term changes, such as the San Clemente Dam removal and re-establishment of sediment delivery to the lowermost Carmel River, which may result in river aggradation;
- Episodic climatic and geomorphic events will continue to occasionally surcharge the river with sediment;
- Proposed levee removals may promote bank destabilization as the temporary loss of vegetation enables non-cohesive sediments to mobilize and redeposit into the channel.

A commonly accepted sea level rise prediction for this area of the California coast is 36 inches by 2100. While this magnitude may seem small, shallowly sloping coastal systems may exhibit spatially widespread effects from small vertical ranges of process adjustment, not only because of geometry, but because sedimentation and erosion processes tend to be highly nonlinear (a small change in a driving force may result in disproportionately large response). This rise in base level could cause lower reaches of the Carmel River to aggrade as the river seeks a new equilibrium profile. Studies suggest that early in the geologic evolution of the Carmel River-Lagoon system sediment deposition kept pace with sea level rise, allowing the system to evolve at the same relative shoreline position (Williams and PWA, 1992). However, variations in sediment supply may affect the system's position, function, and form[10].

The removal of San Clemente Dam and the renewed sediment supply through the system to the lower reaches of the Carmel River will likely induce bed aggradation, unless the enhanced sediment supply can be conveyed through the system to the ocean without affecting channel geometry and average bed elevations. At this point, it is expected that a pulse of aggradation is likely along the lower Carmel River as San

[10] Seaward progradation would tend to eliminate the lagoon system as abundant sediment builds up the channel bed, fills the estuary, and creates a delta at the beach. Landward retreat would likely cause inundation and expansion of the lagoon and portions of the lower floodplain, despite complexities in sediment transport and deposition that could create both bed aggradation and incision in certain locations.

Clemente Dam is removed, given that the upstream sediment would be transmitted to reaches below the dam.

In the absence of bank stabilizing vegetation and hardening materials, the local channel substrate is loose, coarse, and highly mobile. The removal of such stabilizing materials from channel banks where the levees are removed for floodplain restoration may enhance the lateral redistribution of this material into the channel as flows erode loose sediments and allow the bank to assume slopes characteristic of sediments unsupported by roots and organic debris. The re-introduction of these materials may cause local widening, an increase in width/depth ratios, and localized braiding and/or bar formation on the floodplain. Should the reorganized materials elevate sediment supply above flow capacity, the bed will likely aggrade as flows a) redistribute material over the channel bottom or b) form bars, should braiding occur. As mentioned previously, the most likely effect of reduced vegetation at the margins of levee removal sites, however, would be a reduction in strength of the remnant levee segments at their edges—appropriate erosion control measures have been incorporated into the design to limit post-project levee erosion and avulsion risk.

The above scenarios are all highly dependent on climatic and project-specific conditions, and upstream effects at San Clemente Dam and in tributaries. Undocumented and/or unpredictable conditions in the evolving watershed post-restoration may create entirely new system trajectories not envisioned here. However, the responses articulated in this report are important and cognizant of as the restoration plan progresses and adaptive management techniques are applied. In terms of aggradation potential, 1.5 feet of aggradation should be assumed along the lower Carmel (main channel and floodplain). This is consistent with a finding from the 2008 Supplemental Report, which recommended that future designs include 0.5 to 2.5 feet of aggradation along the lower Carmel in response to resumption of full sediment delivery from upstream of San Clemente Dam (Balance Hydrologics, 2008). Long term, in a worst-case scenario, the floodplain degradation would not reasonably be expected to exceed 1.5 feet, which would give an elevation at the causeway equivalent to the existing main channel below the Highway 1 Bridge.

5.2.5 Potential Effects to Native Species and Fisheries

The Carmel River Lagoon, wetlands, and associated riparian corridor are very important for native wildlife and vegetation, since most of these types of environs in the Salinas Valley region have been converted to agricultural and municipal use (Williams and PWA, 1992). The thick riparian woodland that now exists along the Carmel River provides important habitat for migratory and resident birds. The local floodplain and lagoon habitat also supports (or has the potential to support) California red-legged frog, southwestern pond turtle, Monterey dusky-footed woodrat, white-tailed kite, and many other important species. The Carmel River and Lagoon also provide habitat for the South-Central California coast steelhead and also potential habitat for tidewater goby if they were to be reintroduced.

Opening the floodplain to more frequent inundation through removal of existing levees presents the potential to cause both beneficial and adverse impacts to local wildlife and vegetation. Levee removal will tend to restore diversity in physical structure to the floodplain through sand-splay complex formation and sustainable geomorphic function. Spatially variable sedimentation and channelization on the floodplain will encourage variability in inundation frequency and duration, sediment texture and thickness, and depth to ground water—conditions that will tend to promote rapid establishment of native floodplain vegetation and habitat.

Experience with floodplain restoration efforts through intentional levee breaching on the lower Cosumnes River in Sacramento County suggests that willows and other floodplain vegetation will take root following the first events that distribute fresh sediment and organic material across the floodplain (Florsheim and Mount, 2002; 2003). Variation in floodplain topography produced from sand-splay complex formation may also create refugia for fish during flooding, which may be enhanced if connection is established between the lagoon and submerged floodplain, affording aquatic species in the lagoon the opportunity to take shelter at multiple and varied locations. Stranding of fish in isolated floodplain ponds will likely not be an issue because of the likely degree of connectivity, timing of juvenile hatching and migration, and short duration of stranding. Steelhead smolts will be migrating after most flood flows occur, and adults tend to migrate during the rising and falling limb of the hydrograph, and therefore will likely be moving in the main stem rather than on the floodplain. However, even if ponding does occur, discontinuous floodplain ponds that seasonally desiccate would provide potential habitat for the California red-legged frog (Balance Hydrologics, 2008).

Hydraulic connection between south-bank floodplain flows and the lagoon may also rejuvenate and/or expand the lagoon environment by removing excess sediment that is currently tending to fill it through tidal action. Expansion and/or rejuvenation of the lagoon will likely be beneficial for steelhead, southwestern pond turtle, or a reintroduced tidewater goby (PWA and others, 1999). However, flood flows may also choke the lagoon with sediment should inflows carry excessive amounts of suspended material or woody debris, or if significant velocities are achieved that can re-mobilize floodplain sediments from the Odello site and redistribute them to the lagoon.

The re-establishment of floodplain vegetation, particularly expansion of the existing riparian corridor and formation of new floodplain forest vegetation, will need to be balanced with the need to convey flood flows efficiently through the southern floodplain. Thus, continued assessment, along with hydraulic model refinement, may be necessary as floodplain habitat develops and roughness elements become more variable and important, although our current modeling endeavors incorporate a healthy margin of conservatism in setting roughness coefficients for flood routing through the lower Carmel River system (see Appendix A).

5.2.6 Incision or Infilling of the Carmel River Lagoon

Studies assessing hydrologic conditions in the Carmel River watershed (Smith, 2004) have highlighted that continuing sedimentation in the lagoon from tidally-driven fine-sediment flux may reduce the lagoon's longevity under current conditions. In theory, any existing tendency for the lagoon to fill with sediment may either be exacerbated or reversed by the proposed floodplain restoration. For example, it is conceivable that more sediment may enter the lagoon from upstream as enhanced flood flows admit sediment to the floodplain and rework deposits, potentially re-depositing them in the deeper waters of the lagoon. However, enhanced flood flows may also serve to increase velocities through the lagoon, providing the forces necessary to periodically scour away deposited sediment and promote channel network expansion. Occasional scouring flood flows could also improve water quality in the lagoon by removing accumulated organic matter on the bottom (which can depress dissolved oxygen levels or grow pathogens) and reducing winter salinity stratification.

As an example of how the South Arm may adjust to a restored system, hydraulic modeling of the proposed conditions suggests an increase in flow velocity compared to existing conditions, which would tend to scour material and open the lagoon's channel system. Such increases in velocity can be considered likely for all flood events, particularly due to the increased conveyance of the proposed Highway 1 causeway.

For comparison, it is interesting to note that a mitigation pond excavated downslope of an intentional levee breach on another restored California river of comparable size (the lower Cosumnes River) only served to receive flood-transported sediments, and no scour was evident, despite its closer proximity to the breach site (Florsheim and Mount, 2002; 2003) than that proposed between levee removal sites and the lagoon at the project site. In the Cosumnes system, flood flows entering the floodplain through the breach site formed convex channel profiles resulting from scour just beyond the breach site and deposition farther out on the floodplain (and close to the mitigation pond). This depositional pattern is likely in the newly restored floodplain as part of the Project as well. However, removal of the most upstream portions of the south bank levees will allow for such deposition to occur well upstream of the lagoon, with a considerable spatial separation between the overflow points and the lagoon itself. Sediment sequestration features have thus been provided as part of the design and are explained in Section 4.6.

Nonetheless, long-term conditions may see lower- intensity floods transporting sediment to distal portions of the lagoon channels, while less frequent, larger events episodically scour lagoon sediments. This generalized picture will be made more real and complex by natural variability in the sediment delivery to the lagoon, by the introduction of large wood – an important feature in most coastal California lagoons – and by the complexities of flow beneath Highway 1 or such logjams that may form on the floodplain. The existing evidence indicates that this would more approximate conditions that prevailed before the 1800's.

5.3 Geomorphic Summary

The following is a bulleted synopsis of the points made in the preceding discussion on design challenges and design opportunities associated with the proposed restoration project. The list begins with geomorphic and hydraulic considerations and progresses through the ecological and biogeochemical aspects of the site and effects of the proposed work.

- Prior to 1914, the lower Carmel River exhibited a highly dynamic planform geometry—a sinuous single- or multi-threaded channel with some tendency towards braiding behavior.
- Reduced flooding frequency combined with reduced bedload sediment supply via closure of San Clemente Dam in 1921 permitted widespread channel incision in lower reaches and the conversion of a more freely migrating planform to a more fixed, single-threaded channel. The potential to locally revert to a wider, more mobile planform following San Clemente Dam construction has historically stemmed from excessive local ground-water withdrawals that caused riparian vegetative die off and bank instability. This highlights the sensitivity of the lower Carmel's planform geometry and bank erodibility to vegetative cover.

- Bed elevation changes in the lower Carmel between 1965 and 1982 generally showed minimal signs of aggradation, while selected reaches extending from the Highway 1 Bridge upstream to Valley Greens Drive Bridge show repeated episodes of cut and fill since roughly 1980, in response to large storm events and longer-term sediment transport conditions.

- Bed aggradation is likely in coming decades, principally because of rising sea level, the bedload sediment increase as a result of San Clemente Dam removal, and local weakening of bank materials associated with episodic flood flows onto the newly-opened southern floodplain. The magnitude of bed configuration change will depend upon the extent to which the channel's longitudinal profile can keep pace with rising sea level, and if additional supply from upstream can be swept through the system. Local effects on bank stability can be closely monitored, and appropriate management can reduce and/or eliminate disturbed levee and bank segments.

- Avulsion potential is relatively low, although the stability criteria used to assess the likelihood of avulsion are uncertain. An assessment of avulsion risk has been included as part of this restoration project and particular attention has been focused on vegetative stabilization of bank and levee surfaces that might be disturbed from grading activity and subsequent reworking by flood flows.

- Reorganization of the lagoon may occur through either scour or deposition from flood flows. It will be important, however, to monitor the South Arm in particular, to ensure that sufficient depth and connectivity with the rest of the lagoon is maintained to support saltwater adaptation and survival of steelhead.

- The proposed restoration will reduce flooding risk along the northern, urbanized floodplain by admitting a much higher proportion of flood flows onto the restored Odello Property than is currently possible under pre-project conditions.

- Restoring connectivity to the floodplain is a multi-faceted means through which semi-passive habitat enhancement may be performed—a mosaic of geomorphic surfaces and habitat elements, from riparian corridor to floodplain wetland and marsh, will encourage primary productivity and the development of a healthier river-floodplain ecosystem. Spatial and temporal complexity in sand-splay complex formation from floodplain flows, and the reorganization of a revitalized floodplain are forecast to deliver mostly positive effects for local flora and fauna. Stranding of steelhead in disconnected floodplain ponds is not likely due to positive release features embedded in the design.

- Floodplains are incredibly important reservoirs, processing centers, and distribution hubs for biologically important nutrients and biogeochemical constituents in riverine systems, and the historic separation of the lower Carmel floodplain from its main channel by levees has likely reduced its ability to support native floral and faunal assemblages while simultaneously restricting ecosystem diversity. Reconnecting the lower floodplain to the lower Carmel River presents the opportunity for restoration of these biogeochemical ecosystem services—including denitrification, carbon storage and processing, and algal biomass production and nutrient exchange.

As can be surmised from the preceding list and discussion, it is unjust to analyze geomorphic function, nutrient cycling, habitat enhancement, and flood mitigation as mutually exclusive benefits of reconnecting a floodplain to its master channel. Removing portions of the south-bank levee along the Odello Property will accomplish many goals at once. However, close monitoring must accompany the transition from a confined lowland river to a healthier riverine-floodplain ecosystem to ensure that re-introduced dynamics afforded by a more open and malleable floodplain system do not result in unintended consequences. Although this shift will not be immediate, our analysis suggests that the environmental and societal benefits of opening the southern floodplain are significant, and that attentive monitoring and adaptive management will provide a means with which to address design challenges outlined above.

6. SUCCESS CRITERIA AND MONITORING

The Project will be subject to a multi-faceted program of monitoring once construction is complete. The project team expects that monitoring associated with the subject matter of this Design Basis Report will be divided into three main categories: hydrologic, geomorphic, and flood control conveyance. Specific details of the monitoring plan are likely to change as the project evolves and is finalized, but the overall goals and objectives are clear.

6.1 Hydrologic Monitoring

Two stream flow gages exist on the Carmel River near the project site, conveniently bounding the project upstream and downstream. The upstream gage at Via Mallorca Road is located approximately 1.4 miles upstream of the eastern end of the project and is operated and maintained by USGS. It provides a reliable period of record reaching as far back as WY 1963. This gage will provide the most accurate estimate of the flow at the northeast corner of the project area as there are no major tributaries between its location and the project. Additionally, the fact that Val Verde Road was raised in 1997 will be an added assurance that the full streamflow will reach the project without being lost to the north overbank, except under exceptionally large flood events.

A second gage exists at the Highway 1 Bridge. This gage is owned and operated by Monterey Peninsula Water Management District, but is it unclear how often the associated rating curve is calibrated and revised. Regardless, this gage will serve as a measure of the remaining flow in the main stem of the Carmel River downstream of the new connection points to the Odello floodplain. The difference in flow between the two gage readings can be assumed to have entered the floodplain restoration.

A permanent monitoring gage is not recommended at the newly constructed causeway due to the fact the floodplain will not be continuously engaged by flows year round. Instead, a stilling well will be installed on one of the causeway pier bents after construction. A pressure gage will be deployed prior to predicted flood events and will be retrieved after flows retreat. This gage will provide stage information that can then be used to estimate the floodplain flow through the causeway. This measurement can be compared to the sum of the estimated floodplain flow via the two Carmel river gages and the estimated intermittent drainage flow. A deviation between this sum and the value measured at the causeway will provide one estimate of groundwater recharge.

As noted above, a permanent stream gaging station will be installed at the culvert that connects the intermittent drainage step pools to the floodplain valley floor. This will serve as a way to monitor the functionality of the restored creeks year round as well as a way to document the amount of flow the local watersheds to the south are contributing to the total flow onto the larger restored floodplain.

In addition to the amount of flow that enters the floodplain restoration during each event, it will be important to monitor the functionality of the levee openings. A visual inspection of each of the five levee openings is expected after peak flow events during the first ten years of project operation, with the first inspection occurring after the first flood event that engages the floodplain. During inspection, high water marks (HWMs) will be recorded, and these can then be translated to flow rates using methodologies such as the USGS slope-area computation method (Dalrymple and Benson, 1967). It will be important to assess the peak flow rate passing through each levee opening and to assess whether all five openings were engaged during each flood event in order to evaluate whether the openings are functioning as designed.

Finally, after the first flood event, a visual inspection of the floodplain should occur. During this visual inspection, high water marks will be recorded on foot using a Global Positioning System (GPS) throughout the restoration area. High water marks will be recorded on the basis of debris wrack lines and sediment deposits. The collected data will be used to map the efficacy of the project design in conveying and distributing overbank flows as envisioned.

6.2 Geomorphic Monitoring

The GPS inspection will also serve several purposes with regards to geomorphic monitoring. A sediment performance metric will be an important way to gauge the performance of the floodplain in the geomorphic sense. During the first event that engages the floodplain, the project team expects the distributary channels to retain their shape and for flood flows to deposit fine sediment onto the floodplain valley floor. In subsequent events, the distributary channel network is are expected to evolved as the floodplain returns to its natural functions. The presence, shape, and sinuosity of the distributary channels will be monitored as part of the GPS walk-through. New distributary channels can be mapped as they form.

Two baseline survey cross-sections will be established: one between the causeway and the lagoon and one midway along the floodplain west of the causeway. The reference cross-sections will undergo a detailed survey after every flood event that engages the floodplain for the first ten years of the project. These surveys will provide a mechanism to monitor the lateral migration of the designed distributary channels, the formation of additional distributary channels, and will provide a sense of spatial distribution and presence of any major shift in floodplain geometry.

Additional geomorphic monitoring will take form in the installation of sediment plates in each of the four sediment sequestration elements in order to quantify the cumulative depth of sediment shed along the floodplain. Sediment depth at each location will be recorded after every flood event that engages the floodplain.

6.3 Flood Control Conveyance Monitoring

One of the central design features of the floodplain restoration is maintaining the ability for flows to enter and pass through the floodplain as this provides a significant flood control benefit to the north overbank. In order to monitor the functionality of the established MFCAs, ten transects will be established. These transects will be located along each removed levee section and upstream and downstream of the causeway and will be identified with GPS coordinates and bearings. Each transect will be visually inspected by a qualified engineer or hydrologist who will assess changes in floodplain roughness and vegetation cover as they impact overall roughness and conveyance capacity of the floodplain. Inspections will occur annually, most likely in the late spring or early summer, so that remedial maintenance work can be scheduled and completed prior to the subsequent winter storm season.

7. TERMINOLOGY

Aggradation – The increase in land or riverbed elevation due to the deposition of sediment. This occurs in areas in which the supply of sediment is greater than the amount of the material the system is able to transport.

Anadromous - An anadromous fish, born in fresh water, spends most of its life in the sea and returns to fresh water to spawn. Salmon, smelt, shad, striped bass, and sturgeon are common examples.

Anastamosing Steam – Refers to a stream characterized by an interconnected network of low-gradient, relatively deep and narrow channels separated from one another by stable, vegetated floodplain islands.

Autotrophic/Heterotrophic – Autotrophic organisms, such as plants, can obtain energy from sunlight. Heterotrophic organisms must consume other plants and organisms to obtain energy.

Avulsion – The rapid abandonment of a river channel and the formation of a new river channel.

Bedload – Sediment particles rolling, sliding, or tumbling along the streambed.

Bed – The bottom of a channel.

Biotic – Of, relating to, or resulting from living things, especially in their ecological relations.

Causeway – An elevated road, usually across a body or water or a wetland.

Channel Geometry – Refers to the configuration of the channel cross-section (channel width, bank slopes, channel slope, etc.).

Connectivity – Describes the transfer of matter, energy, and organisms by water within and between all components of the stream ecosystem including the main channel, floodplain, and groundwater aquifer.

Denitrification - Describes a process whereby dissolved inorganic nitrogen can be converted to atmospheric nitrogen and removed from the river network.

Distributary – A stream that branches off and flows away from a main stream channel. The opposite phenomenon is a tributary which flows into and joins a main stream channel.

Drainage/Basin/Watershed – A geographical area which contributes surface runoff to a particular concentration point.

Erosion/Deposition – Erosion is the action of water removing soil and rock from one and transporting it to another location where it is deposited.

Floodplain Function – Floodplain functions include the temporary storage of sediment and floodwater. Floodplains may also provide diverse habitat for both aquatic and terrestrial wildlife, support riparian vegetation, and they may be movement corridors for larger mammals.

Geomorphology – The science of landforms with an emphasis on their origin, evolution, form, and distribution across the physical landscape.

Grading – Any excavation, filling, or combination thereof that change the natural topography or drainage pattern of an area.

Hydraulics – A topic dealing with the mechanical properties of water. Hydraulic studies assess how a volume of water moves through a watercourse focusing on depth, width, velocity, duration, and energy.

Hydrology – The scientific study of the movement, distribution, and quality of water. Hydrologic studies assess the distribution of rainfall, how it is converted to runoff, and the volume of water that makes it to the watercourse.

Incision – Refers to the downward cutting of the riverbed that often happens when the energy and velocity of a flow exceed that which the soil particles can handle.

Intermittent/Ephemeral – Lasting for a short time, often seasonal or in direct response to precipitation.

Overbank – Interchangeable with floodplain, refers to the flat-lying areas adjacent to the main river channel where flood flows spill once they reach the channel banks.

Planform – Shape and layout as viewed from above. The most common categories are straight, meandering, and braided.

Positive Outlet – A location through which a depression can drain by gravity flow without residual ponding.

Reach – A stream segment.

Riparian – Often refers to riparian vegetation or vegetation situated on the banks of a river or adjacent to wetlands.

Runoff – The flow of water that occurs when excess stormwater flows over the ground surface.

Scour – The process due to which particles of soil or rock is eroded and removed, usually when the velocity of the flowing water increases or crosses the limiting value that the soil particles can handle.

Sediment – Solid material that is moved and deposited to a new location. It can be as small as a grain of sand (suspended sediment) to small rocks (bedload) and boulders. Sediment moves from one place to another through the process of erosion.

Sinuosity – the meandering of a river.

Slope – Also known as grade, it is the unitless ratio of vertical drop or gain over a horizontal distance.

Substrate – The material at the bottom of the channel.

Tailwater – The downstream elevation of a modeled river reach that sets the hydraulic gradient. The tailwater condition for the Carmel River is the water surface elevation in the Carmel Lagoon when the beach isn't breached and the Pacific Ocean when it is.

Thalweg – The longitudinal profile line or the line connecting the lowest points along a streambed.

Toe Ditch – A long, narrow excavation running along the base (toe) of slope used for draining water.

Woody Debris – Logs, limbs, and rootwads found in streams. Woody debris plays an important role in stream ecosystems by increasing boundary roughness and flow resistance, providing storage areas for sediment and organic material, providing fish refuge, and controlling grade.

8. LIMITATIONS

This report was prepared in general accordance with the accepted standard of practice existing in Northern California for projects of similar scale at the time the investigations were performed. No other warranties, expressed or implied, are made. Should a higher level of certainty or precision than described be required, Balance Hydrologics should be contacted to prepare supplementary work plans.

As is customary, we note that interpretation and evaluation of factors affecting the hydrologic context of any site is a difficult and inexact art. Judgments leading to conclusions and recommendations are generally made with an incomplete knowledge of the conditions present. If the client wishes to further reduce the uncertainty beyond the level associated with this study, Balance should be notified for additional consultation.

We have used standard environmental information -- such as flow records, topographic mapping, and soil mapping -- in our analyses and approaches without verification or modification, in conformance with local custom. As updated information becomes available, the interpretations and recommendations contained in this report may warrant change. To aid in revisions, we ask that readers or reviewers advise us of new plans, conditions, or data of which they are aware.

Concepts, findings, interpretations and recommendations contained in this report are intended for the exclusive use of the Big Sur Land Trust in the study area under the conditions presently prevailing except where noted otherwise.

Finally, we ask once again that readers who have additional pertinent information, who observed changed conditions, or who may note material errors should contact us with their findings at the earliest possible date, so that timely changes may be made.

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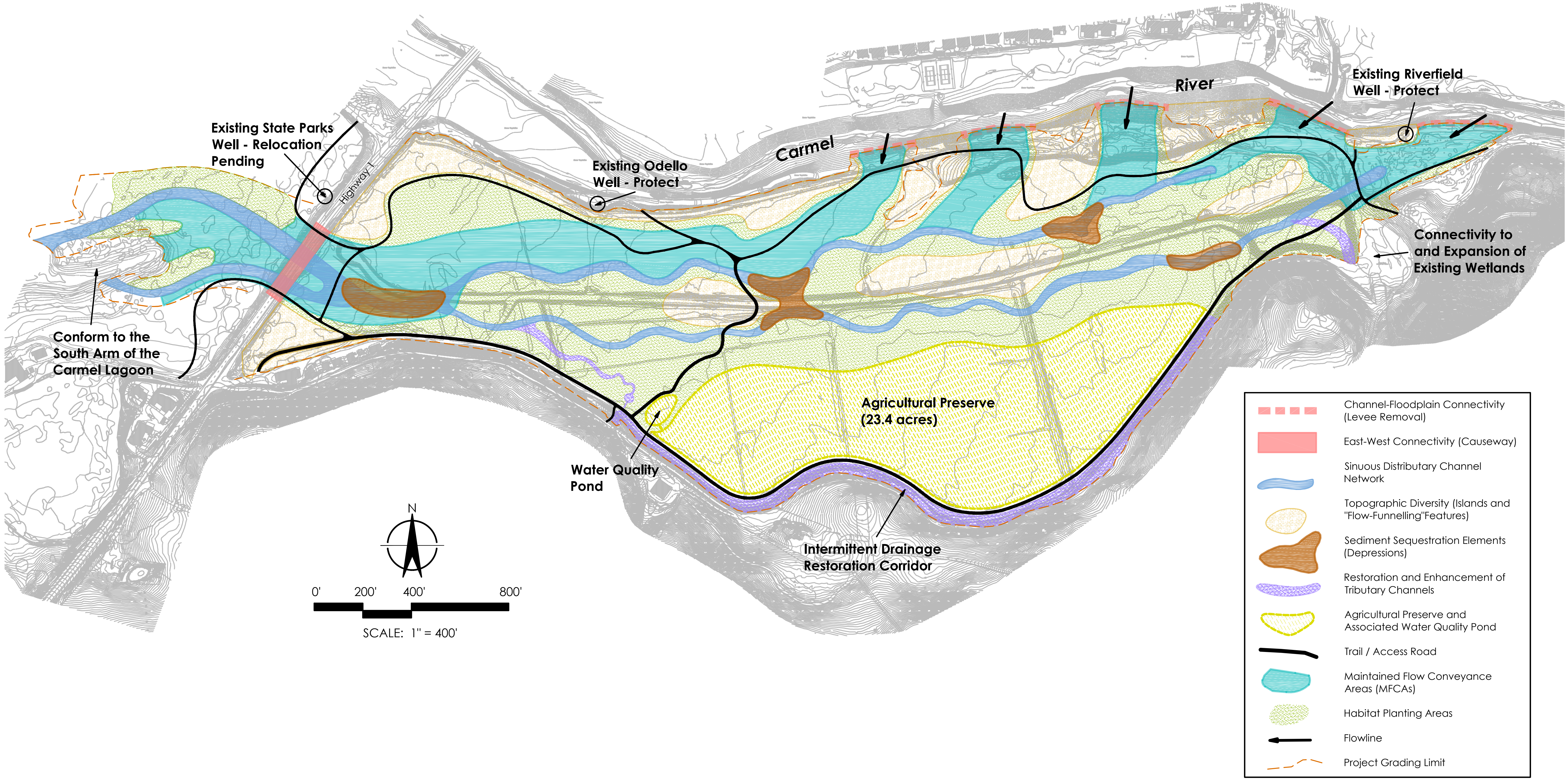
PLATES



Balance Hydrologics, Inc.

Plate 1 . Restoration Design Features, Carmel River Floodplain Restoration and Environmental Enhancement Project, Monterey County, California.

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APPENDICES

APPENDIX A

Numerical Modeling

A1. Hydraulic Modeling

Hydraulic modeling used to assess design alternatives was completed using the U.S. Army Corps of Engineers' HEC-RAS software package. This modeling platform was selected due to its previous use along the river reach, particularly in FEMA's currently-effective Flood Insurance Study (FIS) (FEMA, 2009) and in the report prepared for CSA-50 (Balance Hydrologics, 2014). Additionally, the HEC-RAS package was chosen to facilitate processing of an anticipated future Conditional Letter of Map Revision (CLOMR) through FEMA. The effective FEMA model was compiled after the 2007 and 2008 floodplain restoration studies and is the most recent approximation of the channel and floodplain geometry. The sections below describe the existing and proposed conditions models and the associated results.

A1.1 Assumptions and Limitations

The HEC-RAS model, as provided by FEMA, uses a one-dimensional calculation scheme that is not necessarily suited for the complex flow patterns along the Lower Carmel River. To address the inherent limitations of the one-dimensional model architecture, a number of simplifying assumptions have been made to account for the complex interaction between the main channel and the adjacent overbank areas. These assumptions provide for an appropriate assessment of the flooding conditions along the reach, and more importantly, provide a solid basis of comparison between existing conditions and the proposed design geometry.

Primary among the assumptions used in the model is the splitting of the lower Carmel into two distinct flow paths defined as the main channel and the south overbank.[1] This split begins at the most upstream end of the proposed Project grading limit (see Plate 1 for grading limit line), continues across the restored south floodplain, underneath the causeway, past the CAWD plant, and nearly to the mouth of the river where the flow paths recombine in the Carmel Lagoon. Lateral weirs are included in the FIS model downstream of Highway 1 to account for overtopping of the CAWD access road and have been retained in the proposed conditions model. Lateral weirs were also used to model the proposed levee removal segments. Where the HEC-RAS model could not solve the complicated weir flow geometry, a manual energy balance was performed between the energy grade line of the main channel and the floodplain, consistent with the practices used in the FEMA flood study.

Another significant, simplifying assumption is that the developed north overbank has been excluded from consideration in the model. Modeling from the CSA-50 report (Balance Hydrologics, 2014) concluded that a significant flood control benefit is expected for the north overbank, with reductions in flood elevations, even during a 100-year event, such that the existing north overbank levees (with associated auxiliary work)

[1] The full FEMA model build includes a third, additional flow path through the developed north overbank areas to account for potential flood risks due to failure of levees on the north river bank, but this was not used as described further on.

would be sufficient to provide protection from flooding[2]. Therefore, the Project hydraulic modeling was completed with the conservative assumption that future flood flows would be conveyed by only the main river channel and southern floodplain.

A1.2 Existing Conditions Model

The existing conditions model is the "Base Scenario" model from the CSA-50 study (Balance Hydrologics, 2014). The geometry is nearly identical to the one used in the FEMA FIS, but was revised to account for the changes that have occurred to the river and floodplain geometry since 2009. These include the removal of a large spoils pile called the "Blister" that was previously placed adjacent to the south bank levees with the resulting material used to create an elevated dirt road and fill pad in the floodplain. The model was run as a steady state flow application consistent with the flood insurance study.

The following modeling parameters were used:

- Peak flows. Flow values of 9,500 cfs for the 10-year event, 18,500 cfs for the 50-year event, and 22,700 cfs for the 100-year event were used. The 5-year event, while relevant to the floodplain restoration design, is not an event usually modeled in FEMA studies. Therefore, the record for the Carmel River at Carmel gage was reanalyzed using Bulletin 17B methodology (USGS, 1982) in order to assess the flow during a 5-year event.[3] The result is a flow of 6,000 cfs.

- Modeled geometry. As mentioned above, cross-sections were updated to include changes to the geometry that have occurred since 2009. The existing Highway 1 embankment is modeled as an inline structure.

- Tailwater condition. The beach at the mouth of the Carmel River is dymanic in that it does not provide connectivity for surface flows to discharge into the ocean except during wet water years or large storm events when the beach is overtopped and a breach is formed. The model uses the tailwater conditions provided in the FEMA FIS model, which are based on interactions of the lagoon and barrier beach at the river mouth. For the 100-year event, the model assumes a conservative pre-breach tailwater elevation of 14.6 feet NAVD 88.[4]

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[2] The existing north overbank levees, while providing protection, do not meet the standards associated with FEMA levee accreditation.

[3] For consistency with the period of record analyzed in the FEMA model, the 5-year event is estimated based on peak annual flows for Water Years (WY) 1963 through 2007. Perhaps counterintuitively, analyzing the full available record, which includes several years of drought, would have resulted in overall lower (less conservative) estimates for peak discharges at all reported flood frequencies due to a longer period of record in which no large annual floods occurred.

[4] Unless otherwise noted, all elevations reported herein are referenced to the North American Vertical Datum of 1988 (NAVD 88). It is important to note that the base modeling files provided

- Channel roughness. Manning's n values used to define the roughness of the channel were unchanged from the FEMA FIS model. The model used a roughness value of 0.04 for the south overbank, reflecting a relatively open flow path across the existing agricultural fields once water breaks out onto the floodplain.[5]

The existing conditions model predicts only 7,140 cfs entering the south overbank during the 100-year event. This is due to the presence of the south overbank levee system and the fact that the existing Highway 1 embankment performs as a transverse encroachment.

A1.3 Proposed Conditions Model

The driving force behind the project design is to recover elements of the natural functions and values that were present in the area prior to modern influences. By increasing the frequency of flow on the floodplain, a diverse floodplain geometry will evolve, diverse riparian corridor vegetation communities will be established, and a significant flood control benefit will be provided to the developed north overbank.

The following modeling parameters were used in the post-project model:

- Peak flows. Peak flows were left unchanged from the existing conditions model.

- Modeled geometry. The cross-sections used to define the proposed geometry were extracted from the 35% grading plan using an iterative process. Levees were "removed" on the upstream portion of the project limits in order to provide a route to the floodplain as early as possible. The causeway was modeled as a 350-foot wide bridge with 4.5-foot piers. More information about the levee removal location and the causeway can be found in sections below.

- Tailwater condition. The tailwater parameters were left unchanged from the existing conditions model.

- Channel roughness. A target floodplain roughness of 0.08 was included in the model with the distributary channels and the Maintained Flow Conveyance Areas having a roughness of 0.06.

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by FEMA are in the earlier National Geodetic Vertical Datum of 1929 (NGVD 29), though the Flood Insurance Rate Maps published in 2009 use the newer datum.

[5] The Manning's n provided by FEMA assumes a maintained agricultural field through the entire floodplain and does not account for the extensive vegetation that presently exists. Because the causeway presents such a significant change in the floodplain conveyance, comparing pre-project elevations (which are controlled by the "bathtub" effect of the existing Highway 1 embankment) with post-project elevations was not a key component of design. Because of this and in anticipation of a future CLOMR submittal, the roughness remained unchanged.

The proposed design accomplished the above goals and results in a floodplain that activates during approximately a 5-year event. During a 100-year event, the floodplain and the causeway convey 13,000 cfs with the required freeboard at the proposed causeway structure. This leaves 9,700 cfs in the main channel of the Carmel River, effectively reducing the 100-year event on the main stem to a 10-year flow.

Detailed explanations of floodplain restoration elements are provided in Section 4.

A2. Geomorphic Modeling

Floodplain restoration on the scale of the Project requires careful consideration of a wide range of design issues. Important considerations throughout project formulation and planning have included concerns over the geomorphic stability of a restored floodplain environment and the need to avoid wholescale sedimentation in the ecologically important Carmel Lagoon. Therefore, detailed geomorphic modeling was completed in order to:

- Identify functional floodplain channel dimensions;
- Identify the ideal number of functional floodplain channels;
- Examine the response of the floodplain and the lagoon to sediment; and
- Examine the response of the floodplain and the lagoon to sediment for different possible future conditions, such as sea level rise and main stem bed elevation change.

The University of British Columbia Regime Model (UBCRM) was the principal geomorphic modeling tool utilized. UBCRM formalizes the graded river concept[6] and couples it with hydraulic geometry to predict optimal channel dimensions. Model inputs include discharge, slope, 50th and 84th percentile grain size, and a rooting depth to represent the role of riparian vegetation. It uses a hydraulic resistance function and a bedload transport function to provide results.

A3. Channel Evolution Model and Results

A channel evolution model was used to predict long-term sediment transport and bed change. Assumptions included:

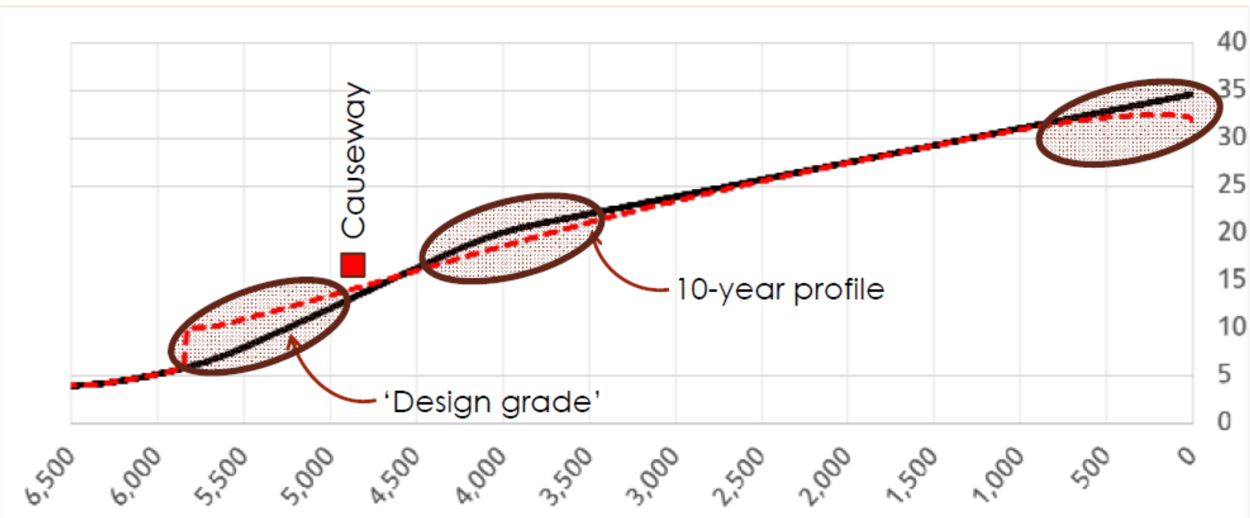
- One-dimensional examination is adequate to explore floodplain evolution;
- Suspended sediment is not a primary driver of channel evolution in this setting;
- All flow enters at the upstream end of the floodplain through the locations where the south bank levee will be removed; and

[6] The graded river concept postulates that, viewed over many years, a graded stream adjusts slope to provide a velocity profile sufficient for transportation of all of the sediment load supplied from upstream.

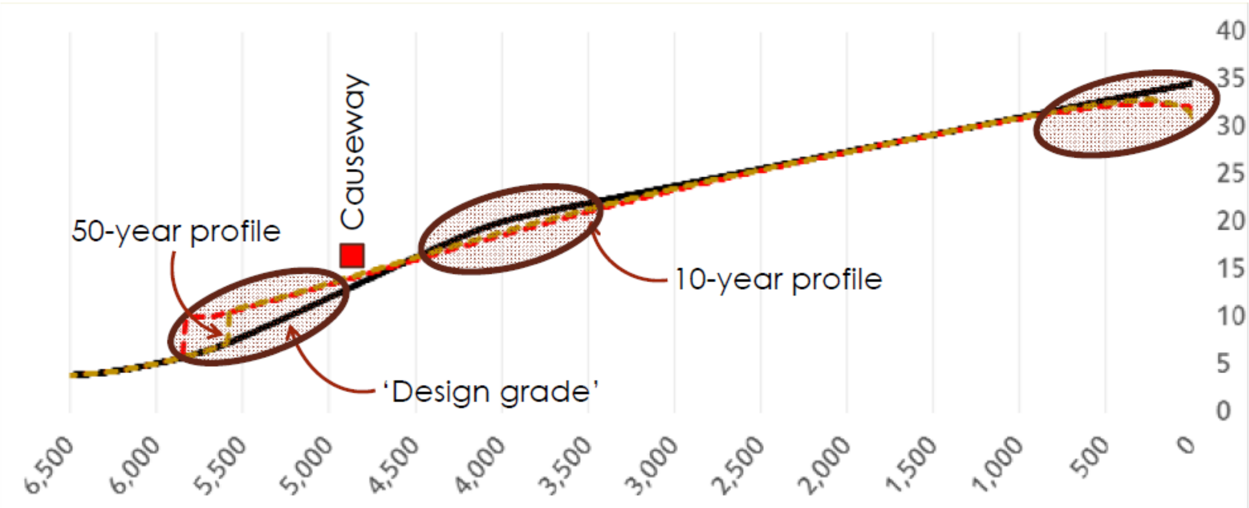
- Most of the sediment transported to the lagoon will travel through a distributary channel network.

The model was parameterized using a sediment loading rate from the USGS gage at Via Mallorca Road, a spatial resolution of 8 feet, and a temporal resolution of 2.5 seconds. USGS records indicate that the 10-year flood hydrograph has a duration of approximately one day for flows sufficient to have a bearing on floodplain geomorphology. The 10-year event was run for five consecutive 24-hour periods to assess that anticipated geomorphic evolution associated with multiple, moderately large events over a 50-year timespan. The 50-year event was also run for one 24-hour period to assess the impacts expected from a much larger flood.

During the 10-year event run, the model predicted one to three feet of degradation (erosion) at the upstream-most end of the floodplain, with additional degradation at a change in floodplain slope located approximately 1,000 feet upstream of the proposed causeway. Below the causeway and downstream into the lagoon the model predicts aggradation (see Figure below). This is in large part due to the fact that the lagoon system is backwater controlled using tailwater assumptions consistent with the FEMA modeling.



The 50-year future bed profile below is nearly identical to the 10-year profile underneath the causeway and along the floodplain. Less aggradation is predicted during the 50-year event because larger floods have the capacity to flush the lagoon of sediment.



As the floodplain profile trends toward a flatter slope, it is reasonable to expect some lagoon sedimentation, though periodic and cyclical flushing of the lagoon in large flood events is also to be expected.

A4. Numerical Model Details

A de-coupled numerical model of channel bed evolution has been developed generally following Parker (2007) and Wu (2008). The model consists of four components which taken together describe the basic physical processes governing channel evolution:

- Step 1: 1D non-uniform hydrodynamics (Saint Venant Equations);
- Step 2: Mixed grain sediment transport (Wilcock-Crowe, 2003);
- Step 3: Diffusive bed evolution (Exner Equation);
- Step 4: Bed sediment sorting and properties (Modified Exner Equation).

The model uses a finite differences scheme and bed evolution is solved sequentially over a 1D domain in the order presented above, with each step completed prior to moving to the next step. At the end of the four steps the model advances to the next time step and the calculations are completed again. Step 1 produces cross-sectionally and vertically averaged flow velocities, which in turn are used to compute shear stresses. Shear stress is fed into Step 2 where rates of bedload sediment transport are made. Spatial bed load transport rates are used to drive bed elevation adjustment, which in turn determines how and if the grain size distribution of the bed changes. Bed elevation and bed grain size characteristics determine the new channel bed profile and roughness, which are used to advance to the next time step and start the process again. The model is considered an approximate formulation of channel evolution, useful to explore and simulate the problem in a manner consistent with the assumptions used to develop the governing equations for each of the four model components. Principal aspects of channel evolution not addressed by the model include:

- Flow patterns characterized by lateral and/or vertical motions;
- Flow properties associated with time independent turbulent motions;

- Bedload sediment transport patterns defined by lateral motions;
- Interactions of flow with a rough channel bank;
- Bed stratigraphy for cycles of erosion and deposition;

Each of these model components will be presented after discussing model set-up and boundary conditions.

A4.1 Model Set-up and Boundary Conditions

The channel bed evolution model is computed following a finite difference numerical scheme. Determination of the spatial and time steps is subject to the Courant stability parameter where the mean flow velocity is used to compute the parameter value. Whereas the model computations are strictly de-coupled, the model solution reflects a coupling between the flow and the bed surface, both of which evolve through time. Specifically, sediment transport rates are coupled to channel bed evolution by:

$$\frac{\delta q_b}{\delta x} = \frac{b q_b}{3(1-\lambda)S}\frac{\delta^2 \eta}{\delta x^2} \qquad \text{(A1)}$$

The sediment transport gradient is specified by the Exner Equation as being dependent upon the rate of channel bed elevation change (discussed below). As a result Eq. A1 can be restated as a 1D linear diffusion equation describing the change of the bed surface profile over time:

$$\frac{\delta \eta}{\delta t} = \frac{b q_b}{3(1-\lambda)S}\frac{\delta^2 \eta}{\delta x^2} \qquad \text{(A2)}$$

The model requires one initial condition and two boundary conditions. The bed profile defines the model initial conditions. The first boundary condition specifies the water surface elevation at the downstream most computational node:

$$h(x_L, 0) = h_o \qquad \text{(A3)}$$

The term L is the length of the computational domain. The second boundary condition specifies the sediment transport rate at the upstream most computational node:

$$q_b(x_o, t) = q_{b_o} \qquad \text{(A4)}$$

A4.2 1D Non-uniform Hydrodynamic Model

The hydrodynamic model solves the 1D mass conservation and non-uniform steady-flow Saint-Venant equation. Assuming a flow of constant density and a unit width expression, the 1D mass conservation equation is stated as:

$$\nabla \cdot q = 0 \qquad \text{(A5)}$$

The Saint-Venant equation is derived from the Navier-Stokes equation:

$$\rho \frac{Du}{Dt} = -\nabla p + \mu \nabla u + F \quad \text{(A6)}$$

Equation A1 can be simplified based on four assumptions. First, the vertical and lateral components can be ignored because we assume that the channel evolution problem can be reasonably approximated as a 1D case. Second, the unsteady part of the substantive derivative can be eliminated because we are only concerned at this point with the steady flow problem. Third, the flow is assumed to be gradually varying in x (i.e. the length scale of the pressure term (L_x) is therefore assumed to satisfy $H/L_x << 1$), and hence the pressure force can be approximated as hydrostatic, with the channel bed surface defining the local datum. Fourth, the viscous stress term can be eliminated by providing a friction force within the body force term (this assumes the viscous stress is negligible). The friction force acts on the flow at the channel-bed flow interface.

From these assumptions Eq. A2 can be re-stated as the 1D open-channel momentum balance for steady flow:

$$u \frac{\delta u}{\delta x} = -g \frac{\delta h}{\delta x} + F_{g_x} + F_{f_x} \quad \text{(A7)}$$

The F_{g_x} term is the gravity force acting on a unit volume of water, which for small bed slopes equates to gS (S equates to $\partial \eta / \partial x = \tan \theta$). The F_{f_x} term is the friction force acting on a unit volume of water, represented by drag a type equation ($C_f u^2$), which is represented by gS_f (S_f is the specific energy and equates to $h + v^2/2g$). Upon rearrangement Eq. A3 takes the form of the backwater equation, used to solve for the water surface profile along a stream channel based on downstream boundary condition:

$$\frac{dh}{dx} = \frac{S - S_f}{1 - Fr^2} \quad \text{(A8)}$$

Equation A6 is limited by cases when the Froude number equals 1. To address this shortcoming, water depths for Froude numbers higher than ~0.75 are approximated by the quasi-normal momentum balance (Cui and Parker, 1997), for which $S = S_f$. Improvements to the model will include establishment of internal boundary conditions to facilitate the occurrence of flows with Froude numbers > 1.0. This is necessary to simulate pool-riffle formation in absence of external forcing to lateral flow concentration (Nicholas, 2010), or changes in w (de Almeida and Rodríguez, 2011; de Almeida and Rodríguez, 2012).

A4.3 Mixed Grain Sediment Transport Model

The Wilcock and Crowe (2003) transport function is used to estimate fractional rates of bedload transport for a poorly sorted sediment mixture:

$$W_i^* = \begin{cases} 0.002\phi^{7.5} & \phi < 1.35 \\ 14\left(\dfrac{1-0.894}{\phi^{0.5}}\right) & \phi \geq 1.35 \end{cases} \tag{A9}$$

$$\phi = \frac{\tau}{\tau_{ri}} \tag{A10}$$

The unit rate of sediment transport is computed from the sediment transport parameter W_i^*:

$$W_i^* = \frac{(s-1)\, q_{bi} g}{F_i u_*^3} \tag{A11}$$

Phi is a function of the hiding function, which specifies the mobilization stress of a particular size class *i* as:

$$\frac{\tau_{ri}}{\tau_{rsm}} = \left(\frac{D_i}{D_{s50}}\right)^b \tag{A12}$$

The exponent *b* is given by:

$$b = \begin{cases} 0.12 & \dfrac{D_i}{D_{sm}} < 1 \\ \dfrac{0.67}{1+\exp\left(1.5-\dfrac{D_i}{D_{sm}}\right)} & \dfrac{D_i}{D_{sm}} \geq 1 \end{cases} \tag{A13}$$

The reference stress for the means grain size of the bed surface is specified as a function of the bed surface sand fraction (specified in percent):

$$\tau_{rsm} = (s-1)\rho g D_{sm}\left[0.021 + 0.051\exp\left(-20F_s\right)\right] \tag{A14}$$

It is important to note because the water surface profile is computed from assumptions of non-uniform flow, the average boundary stress term of Eq. A6 is computed as the drag force equivalent. The friction factor of the drag force statement is a function of the Manning-Strickler coefficient (a value of 8.1) and the bed roughness, computed as the Nikuradse coefficient (a value of 2) times the 90th percentile grain size of the bed surface.

A4.4 Channel Evolution Model

Channel bed evolution is computed based on the 1D bed sediment mass conservation equation (Exner Equation):

$$\frac{\delta\eta}{\delta t} = -\frac{1}{(1-\lambda)}\frac{\delta q_b(t)}{\delta x} \tag{A15}$$

A4.5 Grain Sorting Model

The graining sorting model is based on the active layer concept developed by Hirano (1971), and as applied by Parker (1991) to the problem of bed surface sediment sorting and mass conservation of the various grain sizes present on the bed surface along a channel profile. The active layer is a relatively thin layer of surficial sediments that are conceptualized to participate in bedload transport, as well as bed evolution. The active layer length scale is commonly estimated as the 90^{th} percentile grain class of the bed surface times a constant, which ranges from a value of 1 to 2. The active layer grain size distribution changes due to erosion and deposition based on fractional bedload transport capacity. The model presently tracks the changing composition of active layer sediments due to erosion and subsequent deposition. Cycles of erosion and deposition can be handled, but presently are not.

The grain sorting model for a unit width of stream bed is computed as:

$$(1-\lambda)\left[L_a \frac{\partial F_i}{\partial t} + (F_i - f_{li})\frac{\delta L_a}{\delta t}\right] = -\frac{\partial q_{bi}}{\partial x} + f_{li}\frac{\delta q_b}{\delta x} \quad \text{(A16)}$$

The left hand side of Eq. A16 represents the mass of bed sediments within a control volume, and the right hand side reflects the net mass inflow rate of sediment. Exchange of sediments between the active layer and sediments below is controlled by the exchange fraction parameter:

$$f_{li} = \begin{cases} f_i\big|_{z=\eta-L_a} & \text{for bed erosion} \\ \alpha F_i + (1-\alpha)\,p_{bi} & \text{for bed deposition} \end{cases} \quad \text{(A17)}$$

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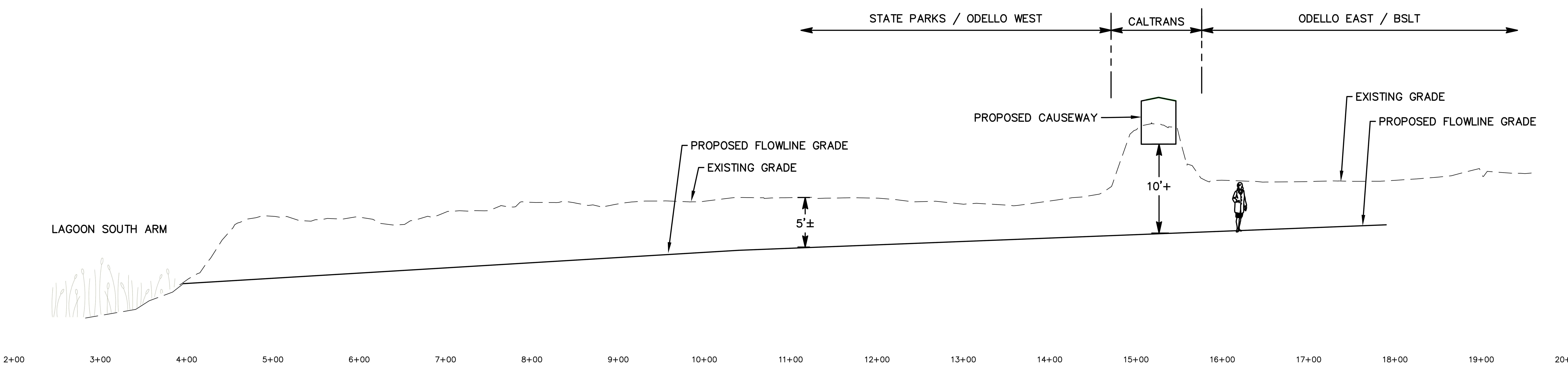
APPENDIX B

Profile View of South Arm Conform

10X VERTICAL EXAGGERATION
1" = 60' H   1" = 6' V



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CARMEL RIVER FLOODPLAIN RESTORATION AND ENVIRONMENTAL ENHANCEMENT PROJECT

FIGURE B

MONTEREY COUNTY, CALIFORNIA

60 0 60 120 180 Feet
SCALE: 1" = 60'

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Sheet 1 of 1

1" = 60'