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Current Conditions and Restoration Scenarios for the Carmel River and Riparian Corridor at the Rancho Cañada Parcel of Palo Corona Park: Carmel Valley, CA

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Disclaimer:

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Executive Summary

In 2018 the Monterey Peninsula Regional Parks District (MPRPD) obtained 185 acres of the former Rancho Cañada Golf Course in Carmel Valley, CA. This recent acquisition provides an opportunity to improve overall ecosystem function of this reach of the Carmel River through channel realignment, floodplain creation, and restoration of native vegetative habitat ranging from wetland obligate to oak-woodland species. The goal of the project is to foster the rebound of steelhead utilization of the Carmel River and to create more and diverse native habitat for wildlife in the park.

As part of California State University at Monterey Bay's (CSUMB) Environmental Science, Technology & Policy 660 Fall 2018 class, we examined the historical background of Palo Corona at Rancho Cañada, measured current conditions, and proposed potential restoration scenarios that the Regional Parks District, policy makers and stakeholders could consider.

Through historical, geospatial, field and quantitative analysis, we aimed to answer the following questions:

1. What are the current geomorphological and riparian vegetation conditions along the Carmel River at Palo Corona?

2. What restoration scenarios have potential to improve the current stream conditions?

Current conditions include impaired fluvial geomorphology and locally-important invasive riparian plant species. The Carmel River at the Palo Corona Rancho Cañada site is an incised, eroding channel with low sinuosity. This channel lacks a geomorphic floodplain and related environmental benefits such as habitat for fish and riparian ecosystem. This reach does not contain essential bed habitat heterogeneities such as large woody debris and scour holes, however grain size characteristics in riffles may currently be suitable for steelhead spawning. The channel banks have been armored with rip-rap, constraining its lateral movement. The riparian zone contains a variety of native grasses, herbaceous plants, shrubs, and trees, as well as invasive species such as cape ivy (*Delairea odorata*) that may cause future erosion. The environmental impairments listed above can be easily improved and would have local and regional benefits. We recommend excavation and enlargement of the floodplain and adding sinuosity and physical complexity to the channel. This restoration strategy would have the following benefits:

- foster steelhead at all life stages, would
- allow natural formation of ponds and wetland habitat
- improve water quality
- add floodwater accommodation space.

The additional flood accommodation space at the project site would reduce upstream backwater effects, thereby reducing flood risks for residents in Carmel Hacienda and stand-alone homes located upstream from this project. Additionally, we recommend invasive species be removed and native species be planted along the riparian corridor with species selected to match the anticipated soil wetness and shade.

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1 Introduction

1.1 Background

1.1.1 Palo Corona Regional Park 2018 Expansion

In April 2018, the Monterey Peninsula Regional Parks District (MPRPD) obtained 185 acres of the former Rancho Cañada Golf Course in Carmel Valley, CA to be incorporated into Palo Corona Regional Park (PCRP) (Fig. 1). In July 2016, the golf course was set to close and went up for sale. The Trust for Public Lands acquired it for $11 million in 2018 and transferred it to the MPRPD (MPRPD 2018). The former golf course will serve as the new primary entrance to PCRP, allowing for easier public access compared to the initial limited access entrance from Highway 1 and the South Bank Trail. This new land acquisition creates a novel opportunity to improve a large riparian corridor that includes both aquatic habitat of the Carmel River and the associated vegetative ecosystem. The property also encompasses a 1-mile stretch of the Carmel River. The existing paved golf cart paths will be incorporated into the new trail system and will link up to the South Bank Trail and the trails leading to Inspiration Point in the southern portion of the park (called the Front Ranch). The District's vision is to enhance public connectivity to the open space and provide passive recreation opportunities that engage residents and visitors (MPRPD 2018). This section of land is integral to the long-term goal of creating an interconnected network of public lands extending from the Los Padres National Forest up to Jack's Peak County Park or Fort Ord National Monument.

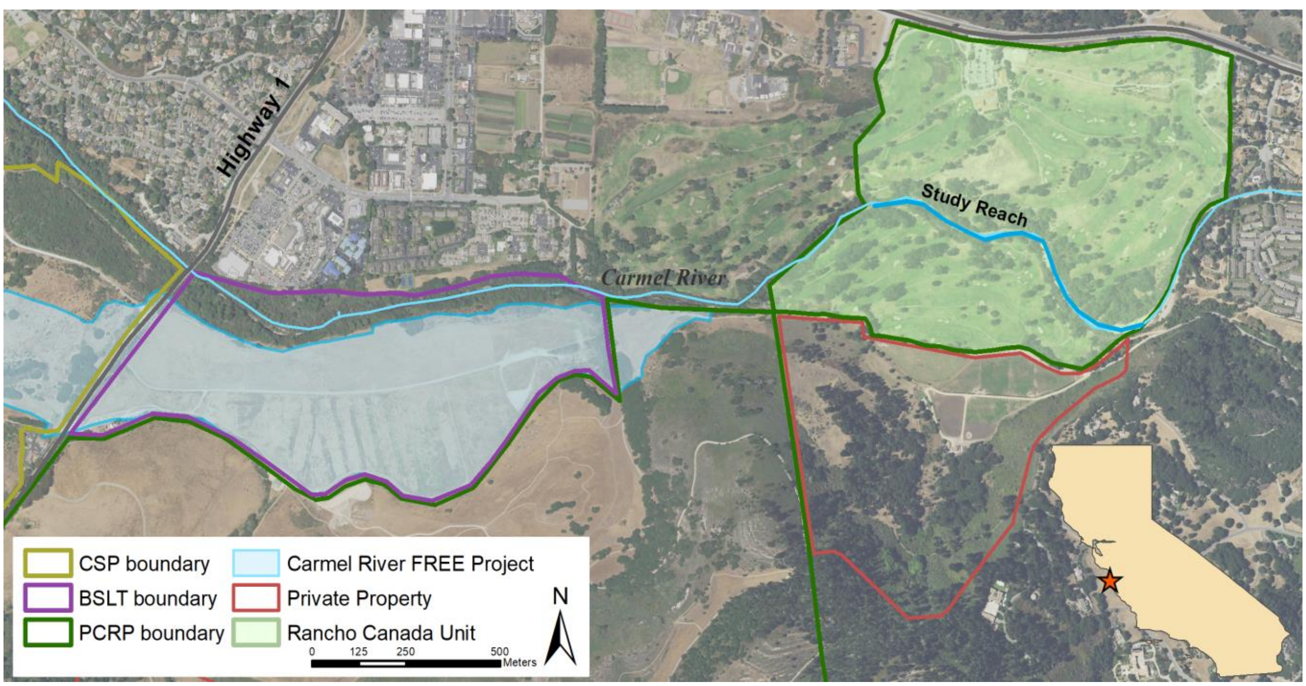

Figure 1. 185-acres of the former Rancho Cañada golf course were added to the 4,300 acres of PCRP in 2018. Other organizations downstream of the study reach are in the process of river restoration.

1.1.2 Project Area

The northeast portion of PCRP, formerly the Rancho Cañada Golf Course, is currently managed by the MPRPD. The site is located near the mouth of Carmel Valley on the central coast of California, in the lower Carmel River Watershed. This region exhibits a temperate, Mediterranean climate, composed of dry summers and winters that are unpredictable and highly variable in terms of rainfall. The new section of PCRP is bound on the north by Carmel Valley Rd, on the East by the Hacienda Carmel housing community, and in the south by private ranch property. It connects up to the larger Front Ranch portion of PCRP in the south-west corner of the property. The site is in a low gradient reach of the Carmel Valley and is floristically situated near the boundary of the Central Coast and San Francisco Bay Area sub-regions of the California Floristic Province (Nomad Ecology 2014).

1.1.3 MPRPD's Mission and River Context

The MPRPDs mission states that the PCRP is to be maintained for public enjoyment and its natural resources protected in perpetuity, and must provide recreation, educational, and research opportunities while conserving the land's valuable natural resources.

The Carmel River has many organizations involved with its management, restoration, and conservation (Figure 1). In addition to the MPRPD, the new section of the Palo Corona Regional Park has a portion of land that will be managed as a wildlife corridor by the Santa Lucia Conservancy (SLC), which is a non-profit land trust located about one mile upriver from PCRP. The Big Sur Land Trust (BSLT) is another non-profit land manager that is heavily involved in restoration work on the lower Carmel River near the study site. The BSLT is far along in a terrace restoration project immediately downstream from the PCRP river reach called the Carmel River Floodplain Restoration and Environmental Enhancement (FREE) Project (Big Sur Land Trust 2018). The Carmel River FREE Project is planned for the Odello property by Balanced Hydrologics. This project is one mile from the mouth of the Carmel Bay. The primary goal of this restoration effort is to restore floodplain connectivity, as the Carmel River is an incised channel. To do this, five levee segments will be removed, achieving a 30 percent reduction in levee channelization. The remaining levees will provide protection to the existing riparian habitat. The FREE project will be flooded at a five-year flood rate (or greater) at the most upstream reach of the project (Balance Hydrologics 2015).

Hacienda Carmel and other private homes adjoin the upstream boundary of the Rancho Cañada reach of the PCRP.

Other stakeholders that are involved in restoration work along the lower Carmel River include:

California Department of Fish and Wildlife (CDFW)
California State Parks (CSP)
Carmel River Steelhead Association (CRSA)
Carmel River Task Force (CRTF)
Carmel River Watershed Conservancy (CRWC)
Monterey Peninsula Water Management District (MPWMD)
National Marine Fisheries Service (NOAA NMFS)
Trout Unlimited
Nearby home and business owners

1.2 History of the Lower Carmel River

1.2.1 Endangered and Sensitive Species

The decline of the Central California steelhead (*Oncorhynchus mykiss*) population over the last 35 years has been the catalyst for most of the restoration work along the Carmel River. Steelhead were listed as a threatened species under the Endangered Species Act (ESA) in 1997, final critical habitat maps were designated in 2005, and respective areas are now managed to foster the population recovery. Since the late 1980's, process-based habitat restoration has become the guiding principle for Central California Coast (CCC) steelhead (and other salmonid) population support. While process-based population recovery naturally takes a long time, direct interventions, such as fish relocations in low-flow summers, have also been enacted by the Monterey Peninsula Water Management District (MPWMD). Riparian restoration informed by the natural process of the Carmel River give the CCC steelhead more opportunity to successfully confront many other problems they face, such as changing ocean conditions, increased temperatures and extremes in precipitation due to climate change, and predation by invasive species.

Riparian restoration along the Carmel River, though frequently targeted towards CCC steelhead recovery, also helps other species of concern in the region. This includes the California red-legged frog, another obligate riparian species that is listed as threatened under the ESA. Another herptile that benefits from restoration along the Carmel River is the Western pond turtle, a Californian species of special concern. Yellow warblers, a bird species of special concern in California, uses the riparian habitat extensively and benefits from structurally complex riparian vegetation components. Tricolored blackbirds have recently been listed as a threatened California species and, while their breeding colonies are rather ephemeral, have been breeding just upstream of the PCRP portion of the Carmel River on SLC lands. This blackbird species benefits from seasonal ponds associated with the river. The Carmel River and Point Lobos are jointly considered an Important Bird Area by California Audubon (Audubon 2018). Other sensitive bird species that benefit from a healthy riparian habitat in this location are the white-tailed kite and yellow-breasted chat. Western red bats are one more species of special concern that roosts in cottonwood trees and have been included for analysis in EIRs for nearby projects (Michael Brandman Associates 2004).

1.2.2 Water Extraction

Some of the first attempts at irrigation in the Carmel Valley began during the founding of the San Carlos Carmel Mission. Evidence of the ditches that were dug to irrigate gardens in the mission can still be seen on the Carmel Valley Golf and Country Club (CRWC 2010).

With the decrease in cattle ranching in the 1870's, agriculture increased and with it, the need to irrigate. Establishing water rights and right-of-ways then started in earnest. In 1883, the Pacific Improvement Company (PIC) built the Old Carmel River dam. They also drilled the first wells in Carmel Valley, six near the end of Laureles Ranch (~9 mi upriver of the PCRP site), capable of drawing 2M gallons per day. San Clemente Dam, constructed in 1921, provided water to develop the Monterey Peninsula. The PIC eventually become Monterey County Water Works but was bought by California Water and Telephone Company in 1935. In 1965, this company was bought out by California American Water (Cal-Am), an American Water Works company.

This portion of the river experienced extensive erosion in the 1969, 1995, and 1998 floods. In 1984, MPWMD began to re-vegetate and irrigate portions of the riparian corridor of the Carmel River to help improve critical habitat for the CCC steelhead.

In 1995, it is estimated that Cal-Am pumped 14,106 afy from the Carmel Watershed. This was 10,730 afy over their legal right. Cal-Am had rights to 3,376 acre-feet per year from the Carmel River. In response, the State Water Resources Control Board (SWRCB) issued Order 95-10. This ordered Cal-Am to reduce consumption through enacting and promoting conservation practices. In 2009, the SWRCB had to issue Cease and Desist Order WR

2009-0060, since Cal-Am was still overdrawing water. Nearly 71% of the water provided to the Monterey District, which includes the cities of Monterey, Carmel-by-the-Sea, Del Rey Oaks, Pacific Grove, Sand City, and portions of Seaside, comes from the Carmel River watershed. Water extraction still proves to be one of the biggest challenges to restoration of the Carmel River and improving CCC steelhead numbers.

With the conversion of the golf course to a natural landscape, it is estimated that 170-190 acre feet of water will be conserved annually (MPRPD 2018).

1.2.3 Land Use History

The site was first "owned" on paper in 1839. It was gifted to a soldier in the Mexican army through a land grant program by the Mexican government. It was called Rancho Cañada de la Segundo. The land has housed a cattle ranch, a dairy operation and an artichoke farm. A large portion of the parcel that was south of the river and up against the hills was dominated by tree-cover (Fig. 2). Anthony Lombardo leased the land from the Hatton family in order to develop the Rancho Cañada Golf course in the 1970's. With the impending closure of the golf course in 2017, the land went up for sale again. A portion was purchased by the Trust for Public Land and is now the Rancho Cañada Unit of PCRP. The Western portion of the golf course was purchased by Clint Eastwood and Alan Williams for the purpose of developing residential housing (Golf Digest 2016). This has been called the Rancho Cañada Village project and is in the beginning stages of an Environmental Impact Report (EIR) process.

Approximately 15,000 people inhabit the Carmel River watershed (Water Management Group 2014) stressing the natural resources, and creating a cumulative impact from roads, homes, and recreation. The mouth of the river experiences the heaviest impacts of urbanization, but the entirety of the river is affected.

1.2.4 Hydrology of Lower Carmel River

The Carmel River is 35 miles long and its watershed is 255 sq. miles in total. It flows northwest from its headwaters in the Santa Lucia Mountains and enters Carmel Bay near the town of Carmel-by-the-Sea. Annual average rainfall is approximately 17 to 41 inches (PRISM 2007).

Figure 2. Comparison of forested portion in the south area of the Rancho Cañada Unit from 1947 to 2016. Tree species cannot be determined from the 1947 imagery.

1.2.5 Flood Events

Flooding has historically burdened the residents of Carmel (Fig. 3). In 1911, flow at the Old Carmel River Dam reached 18,000 cfs before the gage was swept away. The dam tender estimated flow reached 20,000 cfs, exceeding the 100-year event at this site. In late 1931, a dramatic five-day downpour caused a 25-foot water level rise behind the San Clemente Dam in just 15 hours which exceeded its capacity. In 1943, 5.5 inches of rain fell in two days on the San Clemente Dam bringing the Carmel Valley to the upper reaches. In 1958 the Carmel River overflowed its banks, flooding many homes within the Carmel Valley and washing out Schulte Road. In 1969 Monterey County was declared a disaster area as storms swept through, causing 6.5 million dollars' worth of damage from flooding of the Carmel and Salinas River combined. In 1984 Monterey County joined the National Flood Insurance Program because the Carmel River was such a high risk to the community (Monterey County Water Resources Agency 2015). In January 1995, massive flooding to Monterey County occurred again with a 10 to 20 year event. The four most impacted areas in the Carmel Valley were: "Camp Stephani, the Robles Del Rio area of Carmel Valley Village, the Rio Road area adjacent to Highway 1, and Mission Fields" ("Historical Flooding" 2018). The county government began to improvement disaster response by creating "Carmel Valley Coordinated Emergency Response Plan" and designated the Mission Fields and Rio Road region as areas at risk. Following this event, more flooding occurred in March of 1995 where 2,500 people were evacuated from Carmel Valley, and 400 homes and 68 businesses were damaged. The flood blocked 63 roads in the Valley including the Highway One bridge and caused untreated sewage to spill into the Carmel River ("Historical Flooding" 2018 and Monterey County Water Resources Agency 2015). An El Nino event in 1998 flooded Carmel at Highway One, washed out the 10th and 12th fairways and well at the Rancho Cañada east course, damaged the power panel at the Cal-Am well located on the east course, and caused a massive failure of the levee protecting the Hacienda Carmel retirement community. In 2008, 30 homes were damaged by flooding in the Carmel Lagoon area (Monterey County Water Resources Agency 2015). As of 2014, 44% of the flood insurance policy holders in the county reside in Carmel with an additional 12% in the Carmel Valley (Monterey County Water Resources Agency 2015). History has proved that flooding is an inherent risk when developing on a river floodplain. Alternatively, broad floodplain creation, with land-use restrictions, can reduce the risk of loss elsewhere along the river while providing enhanced environments for native species and recreationists.

Figure 3. Comparison of aerial imagery from 1947 and 2016 showing area in southeast area of the Rancho Cañada Unit that was the site of gravel mining operation into the 1960's. The low-lying, denuded area (circled) would flood after high rainfall events (Larry Hampson pers. comm.).

1.2.6 San Clemente Dam Removal

The San Clemente Dam on the upper Carmel River was removed in 2015 due to the risk caused by an active fault running through it (Boughton et al. 2016). The dam was also losing its storage capacity from sediment buildup and was a barrier to steelhead passage. With the removal of the dam came the construction of pools and riffles to encourage fish passage. Dam removal impacts have been felt downstream such as sedimentation (Chow et al. 2016a, Harrison et al. 2018, Steinmetz and Smith 2018) which should be monitored and noted for any downstream restoration plans.

1.3 Project Goals

During the acquisition process of Rancho Cañada, the Rancho Cañada Carmel River Protection and Instream Flow Enhancement Project established several goals and objectives, including future restoration of the incised Carmel River channel (MPRPD project narrative). Incised channels exhibit several hydrologic and ecologic issues such as increased downstream flooding, excess erosion, reduced wetland habitat, polluted water, and compromised fish viability (Harvey and Watson 1986). Our project evaluates the current geomorphic and vegetative conditions of the Carmel River at Rancho Cañada and provides a conceptual design for future restoration of the channel, floodplain and attendant vegetative ecosystem.

Following evaluation of current conditions, our report provides a conceptual stream design using elements of natural channel design principles (Rosgen 2007). Natural channel design is based upon the premise that a stream channel will reach steady-state equilibrium with watershed conditions once it can just transport the sediment supplied without net aggradation or degradation while maintaining geomorphic shape as measured over many hydrologic cycles. The channel will be designed to produce frequent floods onto an adjacent newly constructed floodplain. We also provide initial HEC RAS hydraulic evaluation including sediment transport competence and flood frequency.

The conceptual restoration design is finalized by recommending the palette of native plants that would be typical of all the continuum of microenvironments from floodplain wetland ponds to drier oak woodlands of the adjacent terraces.

2 Existing Conditions

We performed baseline surveys of both physical and vegetative conditions to document the level of impairment and to develop plans for improved conditions.

2.1 Geomorphology

2.1.1 Cross Section Methods

Four benchmarked cross sections were surveyed using standard autolevel methods (Harrelson et al. 1994) to capture existing cross-sectional geometry of pools and riffles (Figs. 4 and 5). At each transect, pebble counts were performed at 5 equally spaced intervals along the transect starting at the left bankfull. We used quadrats with 20 sampling points and measured the substrate samples using a gravelometer, resulting in approximately 100 pebble samples at each cross section, this same methodology was used for several years on other locations on the Carmel River (Steinmetz and Smith 2017, Harrison et al. 2018).

A 2017 7 cm/pixel orthophoto was used to measure existing planform geometry, including sinuosity, radius of curvature, and meander belt width. The older imagery was augmented by a 2 cm/pixel orthophoto and digital surface model of the study reach acquired by unmanned aerial system on September 23, 2018. The existing longitudinal channel slope was obtained from a 2017 survey (Monterey Peninsula Water Management District 2017).

2.1.2 Cross Section Results

Survey shots were taken every two meters starting at the left benchmark for each cross section, and at changes in slope. Benchmark GPS locations were taken for each cross section transect using Trimble Juno GPS (Fig. 5, Table 1). Approximate GPS locations were post-processed using Pathfinder Office which corrected to a 3-5 m resolution using the California State University at Monterey Bay base station.

(a)  (b) 

Figure 4. (a) Riffle cross section (b) Pool cross section

Figure 5. Left and right benchmarks (LBM and RBM respectively).

Table 1. Distance downstream in the reach for each cross section. Thalweg elevations were obtained from the Monterey Peninsula Water Management District Carmel River Thalweg Survey (2017).

Transect	Reach Distance	Elevation
PC1	0 m	28.41 ft
PC2	223 m	27.90 ft
PC3	606 m	23.10 ft
PC4	690 m	21.75 ft

2.1.3 Cross Section Dimensions

Bankfull channel geometry was difficult to determine because the system lacks a floodplain. Cross section locations were selected, in part for the presence of nascent floodplains that might represent bankfull surfaces. Nascent floodplains from the field were interpreted as bankfull surfaces for the calculation of current bankfull dimensions, however, HEC modelling shows that these surfaces are likely too low for the annual flow. The average bankfull depth (D_{bkf}) was calculated ($D_{bkf} = A_{bkf}/W_{bkf}$) and applied to determine an average width to depth ratio (W_{bkf}/D_{bkf}) of 21.82 m across all cross sections (Table 2). Maximum depth (D_{max}) was measured from the river thalweg to the identified bank full elevation and was found to be 1.55 m, 1.67 m, 1.53 m, and 1.49 m for cross sections 1-4 respectively (Table 2). An average flood-prone width (W_{fp}) of 32.50 m was measure at an elevation of twice the height of D_{max} (Rosgen 1994). Floodprone width was used to estimate flood accommodation space using the entrenchment ratio (ER) (W_{fp}/W_{bkf}). Entrenchment ratios throughout the study area varied from 1.37 to 1.55 (Table 2), which is less than typical of Rosgen class C4 streams, that would be expected to exist at the study site (Rosgen 1994). The total linear distance of the channel cross section in contact with water (wetted perimeter (WP)) at the established modeled flow was found to be 21.15 m on average (Table 2). This information was used to estimate hydraulic radius (R) ($R = A_{bkf}/WP$) in order to evaluate stream efficiency based on channel shape. The average calculated R values for the surveyed reach was 0.92 m, ranging from 0.88 m to 0.97 m deviating 0.04 m between individual values (Table 2). The current channel dimensions demonstrate that the channel is incised within the alluvial fill of the Carmel Valley, and lacks the typical flood accommodation space of lowland rivers (Figures 6-9).

Table 2. Cross-sectional river dimensions and bedload characteristics calculated from field observations of the study site conducted on Sep. 14, 2018. Calculations are based on nascent floodplains that are likely too low for the annual flow. List of abbreviations; bank full width (W_{bkf}), area of bank full (A_{bkf}), bank full depth (D_{bkf}), width to depth ratio (W_{bkf}/D_{bkf}), max depth (D_{max}), flood-prone width (W_{fp}), entrenchment ration (ER), wetted perimeter (WP), hydraulic radius (R), median grain size (D_{50}), the 84th grain size percentile (D_{84}), and standard deviation (St. Dev.).

Cross Section	W_{bkf} (m)	A_{bkf} (m^2)	D_{bkf} (m)	W_{bkf}/D_{bkf}	D_{max} (m)	W_{fp} (m)	ER	WP (m)	R (m)	D_{50} (m)	D_{84} (m)
1	22.55	20.96	0.93	24.26	1.55	32.00	1.42	23.13	0.91	0.011	0.055
2	22.28	20.01	0.90	24.81	1.37	35.00	1.57	22.69	0.88	0.029	0.052
3	19.57	18.86	0.96	20.31	1.53	33.00	1.69	20.25	0.93	0.020	0.058
4	17.98	18.06	1.00	17.90	1.49	30.00	1.67	18.54	0.97	0.014	0.038
Average	20.60	19.47	0.95	21.82	1.49	32.50	1.59	21.15	0.92	0.019	0.051
St. Dev.	2.20	1.27	0.05	3.29	0.08	2.08	0.12	2.15	0.04	0.008	0.009

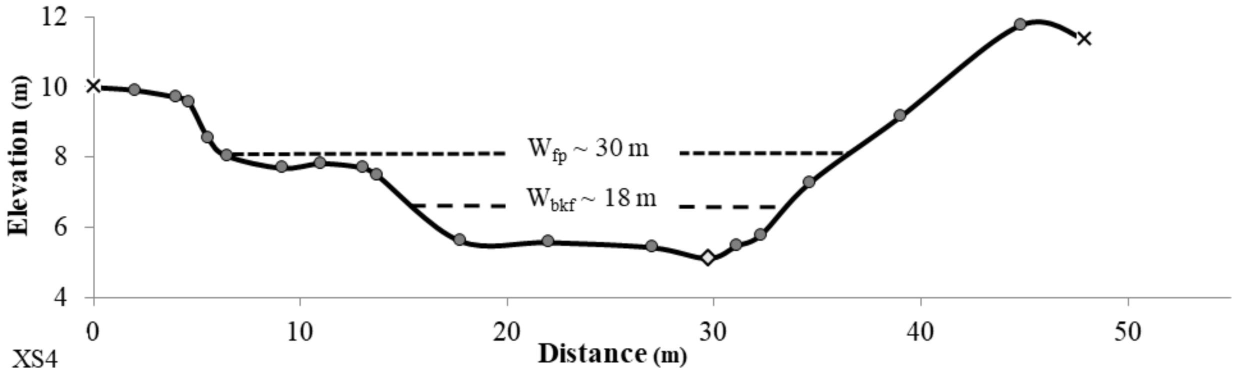

Figure 9. Cross Section 1 current channel dimensions surveyed on September 14th, 2018 measured at established benchmarks (X) from the left to right river back looking downstream with indicated distances for flood-prone width (W_{fp}) and bank full widths (W_{bkf}) calculated from maximum channel depth (D_{max}) determined at the thalweg (◊).

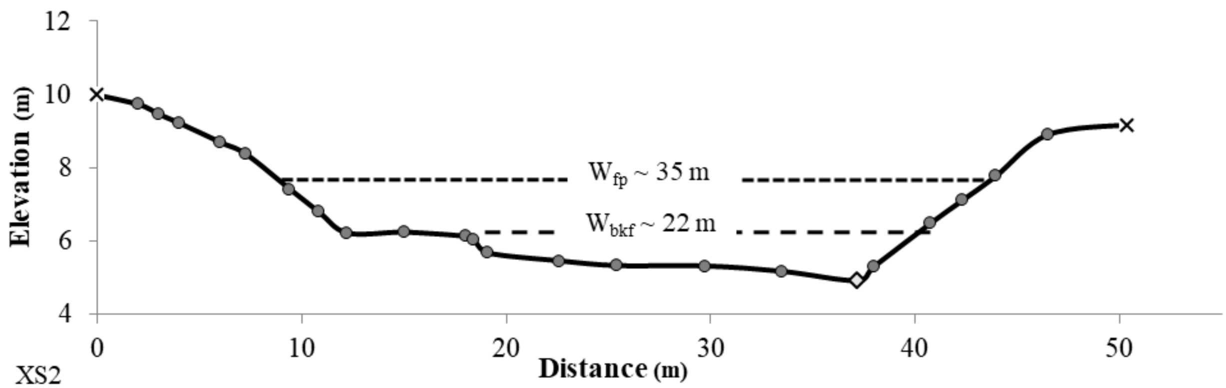

Figure 7. Cross Section 2 current channel dimensions surveyed on September 14th, 2018 measured at established benchmarks (X) from the left to right river back looking downstream with indicated distances for flood-prone width (W_{fp}) and bank full widths (W_{bkf}) calculated from maximum channel depth (D_{max}) determined at the thalweg (◊).

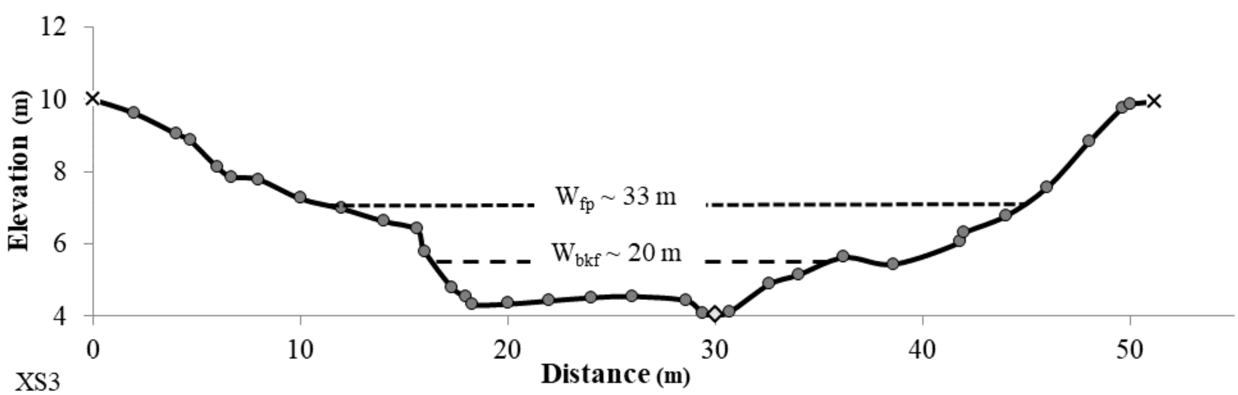

Figure 8. Cross Section 3 current channel dimensions surveyed on September 14th, 2018 measured at established benchmarks (X) from the left to right river back looking downstream with indicated distances for flood-prone width (W_{fp}) and bank full widths (W_{bkf}) calculated from maximum channel depth (D_{max}) determined at the thalweg (◊).

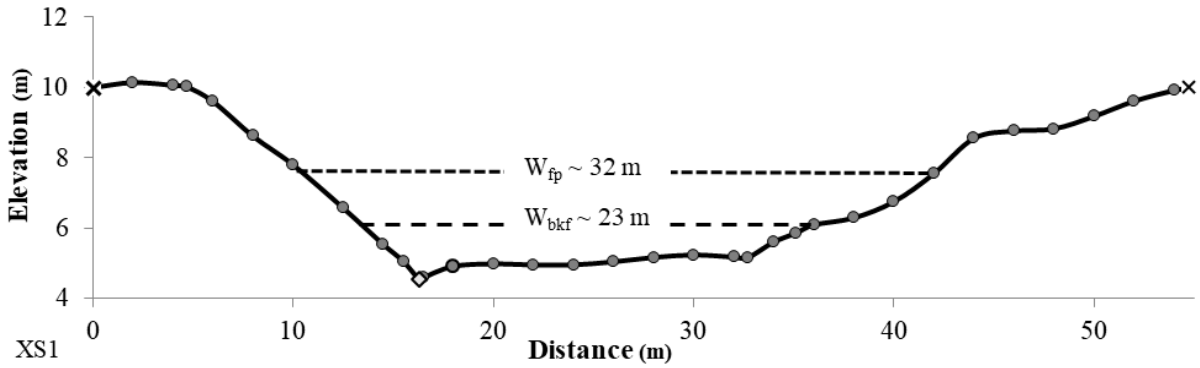

Figure 6. Cross Section 1 current channel dimensions surveyed on September 14th, 2018 measured at established benchmarks (X) from the left to right river back looking downstream with indicated distances for flood-prone width (W_{fp}) and bank full widths (W_{bkf}) calculated from maximum channel depth (D_{max}) determined at the thalweg (◊).

2.1.4 Pebble Count Methods and Results

A quadrat was used to measure the intermediate axis of 20 random pebbles at five equally spaced locations within each cross section, for a total of 100 pebbles per cross section. Grain size percentiles were estimated by eye from cumulative percent plots. Each cross section was also classified as a riffle or pool segment based on observed stream channel characteristics at that location. The total number of each grain size identified at riffle (Cross Sections 1 and 3) or pool (Cross Section 2 and 4) was combined and used to assess bed material variation between pools and riffles A D_{50} of 0.016 m and D_{84} 0.058 m were determined for riffle segments and a D_{50} of 0.022 m and D_{84} of 0.048 for segments classified as pools (Appendix A). Grain size data for all cross sections in the reach were combined for an overall cumulative percent plot (Fig. 10).

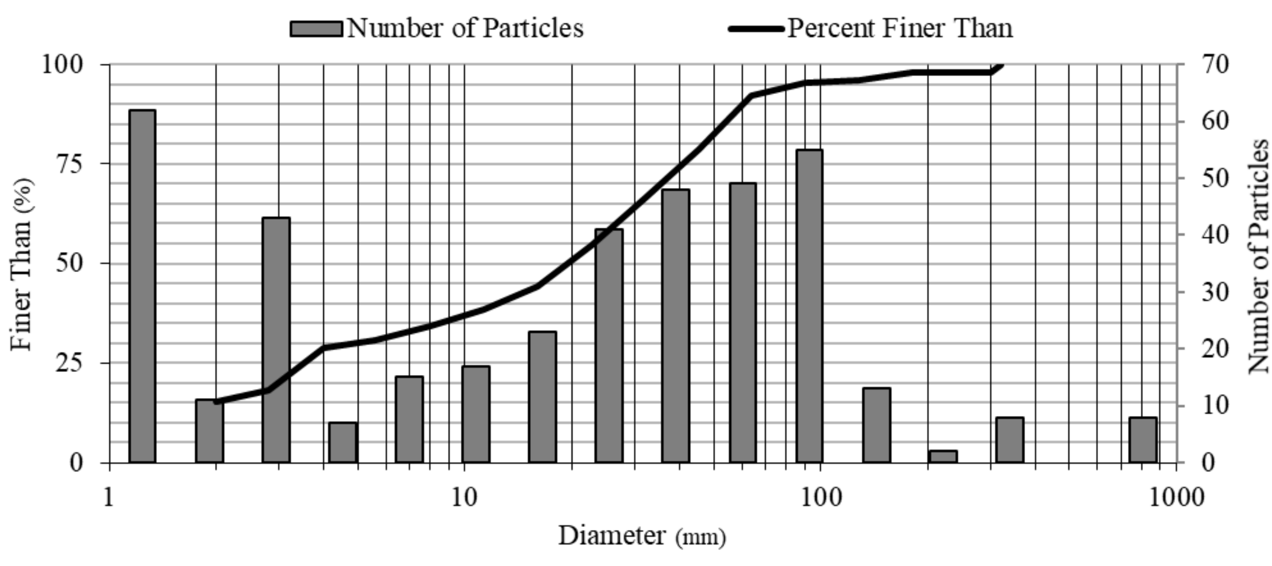

Figure 10. The cumulative total number of particles sizes measured throughout all surveyed cross sections on September 14th, 2018 and the calculated value of the percentage of substrate particles finer than any given particle size observed at any location.

2.1.5 Existing Pattern

Steps were taken to examine the current pattern, dimension and profile of Palo Corona Park. We designated a study portion of the Carmel River on Palo Corona of about 28,000 square meters (-121.889, 36.536 to -121.882, 36.539).

The degree to which a stream meanders is defined by a ratio of channel length to valley length. Other important stream parameters include meander wavelength, radius of curvature, belt width and amplitude (Rosgen 1985).

Using ArcGIS Mapping we calculated the current average radius of curvature to be about 101 m and a beltwidth of approximately 324 m (Fig. 11, Table 3).

The current sinuosity is 1.11, which is low for natural low gradient rivers (Rosgen 1994).

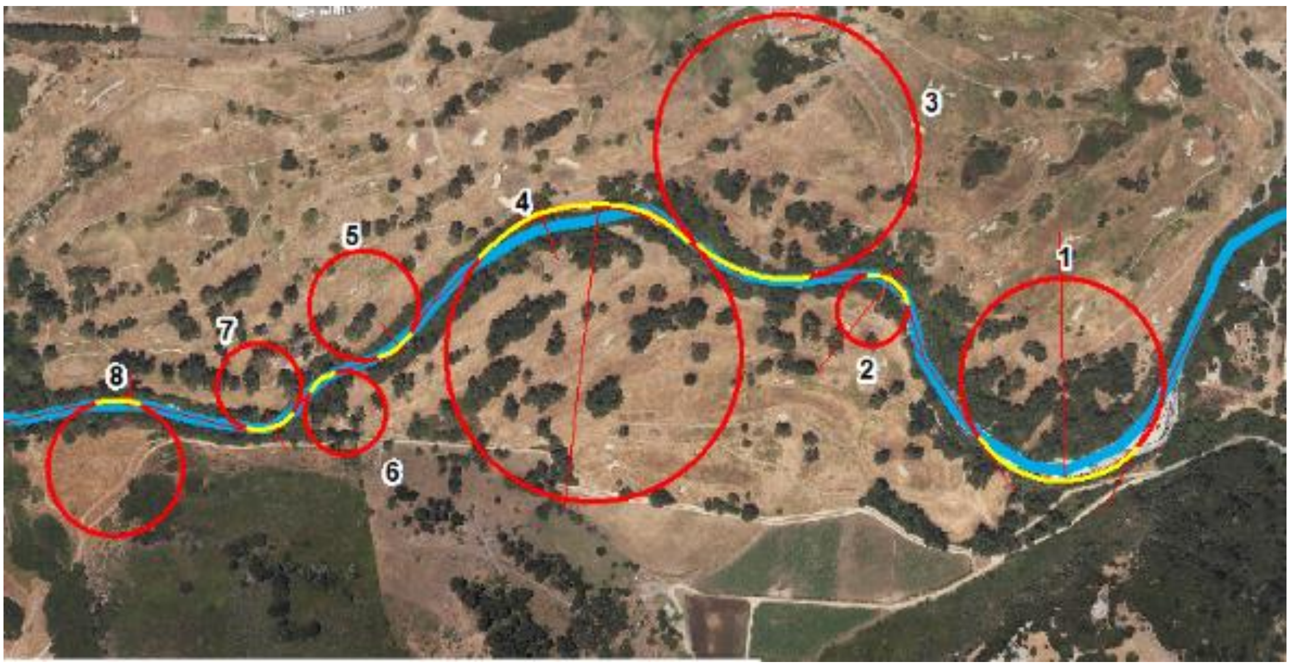

Figure 11. Current pattern of the study reach.

Table 3. Current geomorphic parameters

Parameter	Value	Units
Average Bankfull Width	20.6	m
Average Radius of Curvature	101	m
Average Beltwidth	324	m
Number of Meanders	6	
Sinuosity	1.11	
Valley Slope	0.0038	

2.2 Riparian Vegetation Existing Conditions

We conducted fieldwork along four transect locations as shown on Figure 4 on September 14th and 15th, 2018. The transects were measured and surveyed prior to the vegetation survey by the geomorphology survey crew. A Line Point Intercept (LPI) survey was conducted for plant species composition in relation to elevation above the thalweg. A relevé survey was implemented to classify the range of diverse plant cover over a larger area of the Carmel River (CNPS 2007). We conducted surveys in late summer when many flowering plants were not currently blooming which made some plants unidentifiable. The field datasheet for the LPI surveys can be found in Appendix B.

2.2.1 Survey Methods

Line Point Intercept

We assessed riparian plant species composition in relation to elevation above the thalweg using the Line Point Intercept (LPI) transect survey method adapted from the USDA Forest Service National Riparian Vegetation Monitoring Core Protocol. We implemented the protocol according to previous vegetation surveys (Merritt et al. 2017, Missaghian et al. 2015). The LPI survey sheets used to record data can be found in Appendix B. The LPI protocol is efficient and repeatable and requires less time to sample when compared to quadrat transect sampling.

LPI surveys were implemented at each cross section of the Carmel River in Palo Corona Regional Park that were measured and studied initially by the geomorphology survey crew. Transects ranged from 48.5 m to 51.5 m in horizontal length crossing the Carmel River. GPS coordinates of the benchmarks and endpoints for each transect were recorded along with the lengths. A meter tape was extended between the endpoints that represented the approximate floodplain width of the river.

The sampling interval along the transects was 0.5 m for a total of approximately 100-110 sampling points per transect. For each transect, we recorded fluvial setting (channel, transition, floodplain, terrace) as well as ground cover (leaf litter, bare sand, silt, gravel, cobble, boulders, basal vegetation, and wood). At every sample point along the transect, a visual assessment of plant species composition was conducted using a metal flag pin at three plant cover locations: understory, middlestory, and overstory. Vegetation located in the understory was <1.5 m above the ground, middle story was 1.5-5 m above the ground, and overstory was >5 m above the ground. For reproducibility, the data recorder stood on the right side of the tape and the sampler sampled on the left, minimizing the trampling of plants (Misshaghain et al. 2015). Each sample point involved the visual assessment and identification of plants that touched the flag pin. A single species could only be recorded once per cover location (understory, middlestory, or overstory) but could be in each cover location. For example, one sample point could have one plant species three times, once each in the understory, middlestory, and overstory. We used "The Plants of Monterey County: An Illustrated Field Guide" (Mathews and Mitchell 2015) to aid in identifying unfamiliar plant species.

Relevé

Relevé surveys were used to provide a semiquantitative method for recording percent vegetation types along the riparian corridor. We adapted the protocol and data sheets from California Native Plant Society (CNPS 2007). Relevé surveys have been used for over five decades as an efficient and more comprehensive assessment of overall plant cover classification. These surveys indicate locations of beneficial native plants and harmful invasive species. Relevé plant cover percentages are subjective and therefore not to be used for probability statistical analysis (Minnesota Department of Natural Resources 2013).

Relevé surveys were conducted on September 15th, 2018 between transects 1 and 4 as shown in Figure 5. Eight relevé sites were selected using the subjective plot placement method: a site was chosen by the surveyor when a plant species visibly dominated an area. Other areas along the Carmel River with the same dominant species were categorized according to the respective relevé site, for a total of 18 sites. GPS points were taken at each site and the site area, soil surface, and plant cover percentage were visually estimated.

2.2.2 Existing Vegetation Conditions

The LPI and relevé surveys resulted in 48 identifiable plant species and genera and five plants that could not be determined to family, genus, or species. The identified species and genera are listed in Table 4. Of the observed vegetation for LPI surveys five species were trees, three shrubs, 30 herbaceous, and seven grasses, rushes or sedges. The vegetation for the relevé surveys included five tree, four shrub, 31 herbaceous, and seven grass, rush or sedge species. There were 36 native species and 12 non-native species.

Line Point Intercept

The LPI surveys resulted in a mix of both native and non-native species. All surveys had at least 30% cover of willows and black cottonwoods, essential riparian trees. However, three of the four surveys had at least 23% cover of cape ivy, a highly invasive species. LPI 1 was the only survey without cape ivy (Table 5). LPI 2 was the only survey without black cottonwood trees (Table 6). LPI 3 had the greatest cover percentage of black cottonwoods (Table 7). LPI 4 had the greatest species diversity with 18 identified plants (Table 8).

Plant species in Tables 5 through 8 are organized according to average elevation above the thalweg relative to the benchmarks established for each cross section. Grasses and cottonwood trees were generally found at higher elevations while small weedy herbaceous plants were found throughout the channel bottom. Willows were found at both high and low elevations. In all surveys except LPI 3 there was minimal vegetation cover in the overstory, especially close to the river channel.

Organic ground cover was dominated by leaf litter in LPI surveys 2, 3, and 4, and by dead wood in LPI survey 1 (Table 9). Inorganic ground cover varied between each cross section, but the highest percentages included bare silt or clay, pebbles, and cobbles.

Table 5. LPI survey at cross section 1. Color intensity is proportional to magnitude.

	Species	Approx. Avg. Elevation Above Thalweg (m)	% Understory	% Middle	% Overstory
Native	Black cottonwood	9.97	0.0%	0.0%	1.8%
	Mule fat	9.61	0.9%	0.0%	0.0%
	Coyote brush	8.01	4.5%	7.3%	0.0%
	Swamp sedge	7.71	10.9%	0.0%	0.0%
	Terragon	7.16	1.8%	0.0%	0.0%
	California blackberry	6.49	8.2%	0.9%	0.0%
	California mugwort	6.49	2.7%	0.0%	0.0%
	Western goldenrod	6.30	1.8%	0.0%	0.0%
	Willow	5.93	10.0%	20.0%	0.0%
Non-native	Grass	9.94	11.8%	0.0%	0.0%
	Poison hemlock	8.77	0.0%	0.9%	0.0%
	Black mustard	6.93	7.3%	0.0%	0.0%
	Fennel	6.58	0.9%	0.9%	0.0%
	White sweet-clover	5.17	0.9%	0.0%	0.0%

Table 4. Observed plant species within the study reach in Palo Corona Regional Park. Asterisk (*) indicates invasive species.

Lifeform	Common Name	Scientific Name	Code
Grasses, Rushes and Sedges	Awned cyperus	*Cyperus squarrosus*	CYSQ
	Kikuyu grass*	*Pennisetum clandestinum*	PECL
	Pacific rush	*Juncus sp.*	JU
	Pale spikerush	*Eleocharis macrostachya*	ELMA
	Rabbitsfoot grass	*Polypogon monspeliensis*	POMO
	Swamp sedge	*Carex senta*	CASE
	Tall cyperus	*Cyperus eragrostis*	CYER
Herbaceous	Black mustard*	*Brassica nigra*	BRNI
	Bull thistle*	*Cirsium Vulgare*	CIVU
	California man-root	*Marah fabacea*	MAFA
	California mugwort	*Artemisia douglasiana*	ARDO
	Cape ivy*	*Delairea odorata*	DEOD
	Cocklebur	*Xanthium strumarium*	XAST
	Common snowberry	*Symphoricarpos albus*	SYAL
	Dotted smartweed	*Persicaria punctata*	PEPU
	Duckweed	*Lemna sp.*	LE
	English plantain*	*Plantago lanceolata*	PLLA
	Fennel*	*Foeniculum vulgare*	FOVU
	Goosefoot	*Chenopodium sp.*	CH
	Greater water speedwell	*Veronica anagallis-aquatica*	VEAN
	Horseweed	*Erigeron canadensis*	ERCA
	Jersey cudweed*	*Pseudognaphalium luteoalbum*	PSLU
	Mule fat	*Baccharis salicifolia*	BASA
	Pennyroyale*	*Mentha pulegium*	MEPU
	Poison hemlock*	*Conium maculatum*	COMA
	Poison oak	*Toxicodendron diversilobum*	TODI
	Sneezeweed	*Helenium puberulum*	HEPU
	Stinging nettle	*Urtica dioica*	URDI
	Watercress	*Nasturtium officinale*	NAOF
	Western goldenrod	*Euthamia occidentalis*	EUOC
	Western stinging nettle	*Hesperocnide tenella*	HETE
	White nightshade	*Solanum americanum*	SOAM
	White sweet-clover*	*Melilotus albus*	MEAL
	Wild mint	*Mentha canadiensis*	MECA
	Wild radish*	*Raphanus sativus*	RASA
	Willow herb	*Epilobium ciliatum*	EPCI
	Willow weed	*Persicaria lapathifolia*	PELA
	Wood mint	*Stachys*	ST
	Terragon	*Artemisia dracunculus*	ARDR
Shrub	California blackberry	*Rubus ursinus*	RUUR
	Coyote brush	*Baccharis pilularis*	BAPI
	Himalayan blackberry*	*Rubus armeniacus*	RUAR
	Spreading gooseberry	*Ribes divaricatum*	RIDI
Tree	Black cottonwood	*Populus trichocarpa*	POTR
	Box elder	*Acer negundo*	ACNE
	Western dogwood	*Cornus sericea*	COSE
	Willow species	*Salix sp.*	SA
	White alder	*Alnus rhombifolia*	ALRH

Table 6. LPI survey at cross section 2. Color intensity is proportional to magnitude.

	Species	Approx. Avg. Elevation Above Thalweg (m)	% Understory	% Middle	% Overstory
Native	California mugwort	7.48	19.8%	0.0%	0.0%
	Wood mint	7.46	6.9%	0.0%	0.0%
	Willow	7.08	31.7%	27.7%	9.9%
	California blackberry	7.03	24.8%	5.9%	0.0%
	Common snowberry	6.88	4.0%	0.0%	0.0%
	Sneezeweed	6.46	1.0%	0.0%	0.0%
	Rabbitsfoot grass	5.66	2.0%	0.0%	0.0%
	Stinging nettle	5.66	1.0%	0.0%	0.0%
	Awned cyperus	5.35	7.9%	0.0%	0.0%
	White alder	5.31	1.0%	0.0%	0.0%
	Rumex	5.31	1.0%	0.0%	0.0%
	Dotted smartweed	4.90	5.0%	0.0%	0.0%
Non-native	Grass	9.86	5.9%	0.0%	0.0%
	Cape ivy	7.99	23.8%	6.9%	0.0%
	Poison hemlock	7.88	12.9%	13.9%	0.0%
	Black mustard	6.46	1.0%	0.0%	0.0%
	Pennyroyale	5.31	2.0%	0.0%	0.0%

Table 7. LPI survey at cross section 3. Color intensity is proportional to magnitude.

	Species	Approx. Avg. Elevation Above Thalweg (m)	% Understory	% Middle	% Overstory
Native	Willow weed	8.43	2.9%	0.0%	0.0%
	Cocklebur	8.25	1.0%	0.0%	0.0%
	White nightshade	7.45	2.9%	0.0%	0.0%
	Poison oak	7.25	11.7%	1.9%	0.0%
	Western dogwood	7.07	21.4%	13.6%	0.0%
	Black cottonwood	6.62	0.0%	35.9%	36.9%
	Willow	5.76	12.6%	15.5%	11.7%
	California blackberry	5.61	25.2%	2.9%	0.0%
	Greater water speedwell	4.89	1.9%	0.0%	0.0%
	Goosefat	4.53	1.0%	0.0%	0.0%
	Stinging nettle	4.53	1.9%	0.0%	0.0%
	Mule fat	4.46	1.9%	0.0%	0.0%
	Tall cyperus	4.03	1.0%	0.0%	0.0%
Non-native	Cape ivy	9.93	35.9%	8.7%	0.0%
	Wild radish	9.93	1.9%	0.0%	0.0%
	Poison hemlock	7.70	9.7%	0.0%	0.0%
	English plantain	5.02	1.0%	0.0%	0.0%
	Grass	4.56	5.8%	0.0%	0.0%
	White sweet-clover	4.55	1.0%	0.0%	0.0%
	Jersey cudweed	4.50	4.9%	0.0%	0.0%

Table 8. LPI survey at cross section 4. Color intensity is proportional to magnitude.

	Species	Approx. Avg. Elevation Above Thalweg (m)	% Understory	% Middle	% Overstory
Native	Black cottonwood	10.53	4.2%	8.3%	7.3%
	Horseweed	10.00	1.0%	0.0%	0.0%
	California man-root	9.75	2.1%	2.1%	0.0%
	Stinging nettle	9.59	2.1%	0.0%	0.0%
	Wild mint	9.08	10.4%	0.0%	0.0%
	Western dogwood	7.81	0.0%	3.1%	0.0%
	Spreading gooseberry	7.78	4.2%	4.2%	0.0%
	California blackberry	7.75	33.3%	0.0%	0.0%
	California mugwort	7.50	2.1%	0.0%	0.0%
	Willow	7.33	36.5%	30.2%	17.7%
	Willow weed	5.52	4.2%	0.0%	0.0%
	Tall cyperus	5.48	2.1%	0.0%	0.0%
	Willow herb	5.48	1.0%	0.0%	0.0%
	Western goldenrod	5.48	1.0%	0.0%	0.0%
	Awned cyperus	5.43	1.0%	0.0%	0.0%
	Wood mint	5.29	4.2%	0.0%	0.0%
	Watercress	5.26	5.2%	0.0%	0.0%
	Duckweed	5.12	1.0%	0.0%	0.0%
Non-native	Poison hemlock	9.49	6.3%	2.1%	0.0%
	Cape ivy	8.96	32.3%	7.3%	0.0%
	Black mustard	8.62	12.5%	2.1%	0.0%
	Grass	7.26	1.0%	0.0%	0.0%
	Jersey cudweed	5.60	7.3%	0.0%	0.0%

Table 9. Ground cover for LPI surveys at cross sections 1-4. Color intensity is proportional to magnitude.

	Ground Cover	XS1	XS2	XS3	XS4
inorganic	Bare silt or clay	0.00%	5.9%	16.5%	8.3%
	Bare sand	0.91%	0.0%	8.7%	0.0%
	Gravel	0.00%	2.0%	1.0%	0.0%
	Pebble	26.36%	0.0%	0.0%	0.0%
	Cobble	3.64%	41.6%	15.5%	25.0%
	Boulder	0.00%	0.0%	2.9%	0.0%
	Bedrock	0.00%	0.0%	0.0%	0.0%
	Water	0.91%	0.0%	0.0%	0.0%
organic	Basal vegetation	0.00%	4.0%	0.0%	0.0%
	Bryophyte	0.00%	0.0%	0.0%	0.0%
	Wood	48.18%	0.0%	2.9%	1.0%
	Litter	0.00%	46.5%	52.4%	65.6%

Relevé

Because the PCRP was a former golf course, each site was impacted by competition from exotics, erosion, groundwater pumping, altered flood regime, rip-rap, human caused channelization, and grazing. Specifically, relevé site 1 was highly eroded and had a steep bank on the transition zone. Relevé site 2 had a tall and steep transition zone. Details of each site can be found on Table 10 and locations of relevé sites with their respective plant cover percentages can be found in Figure 12.

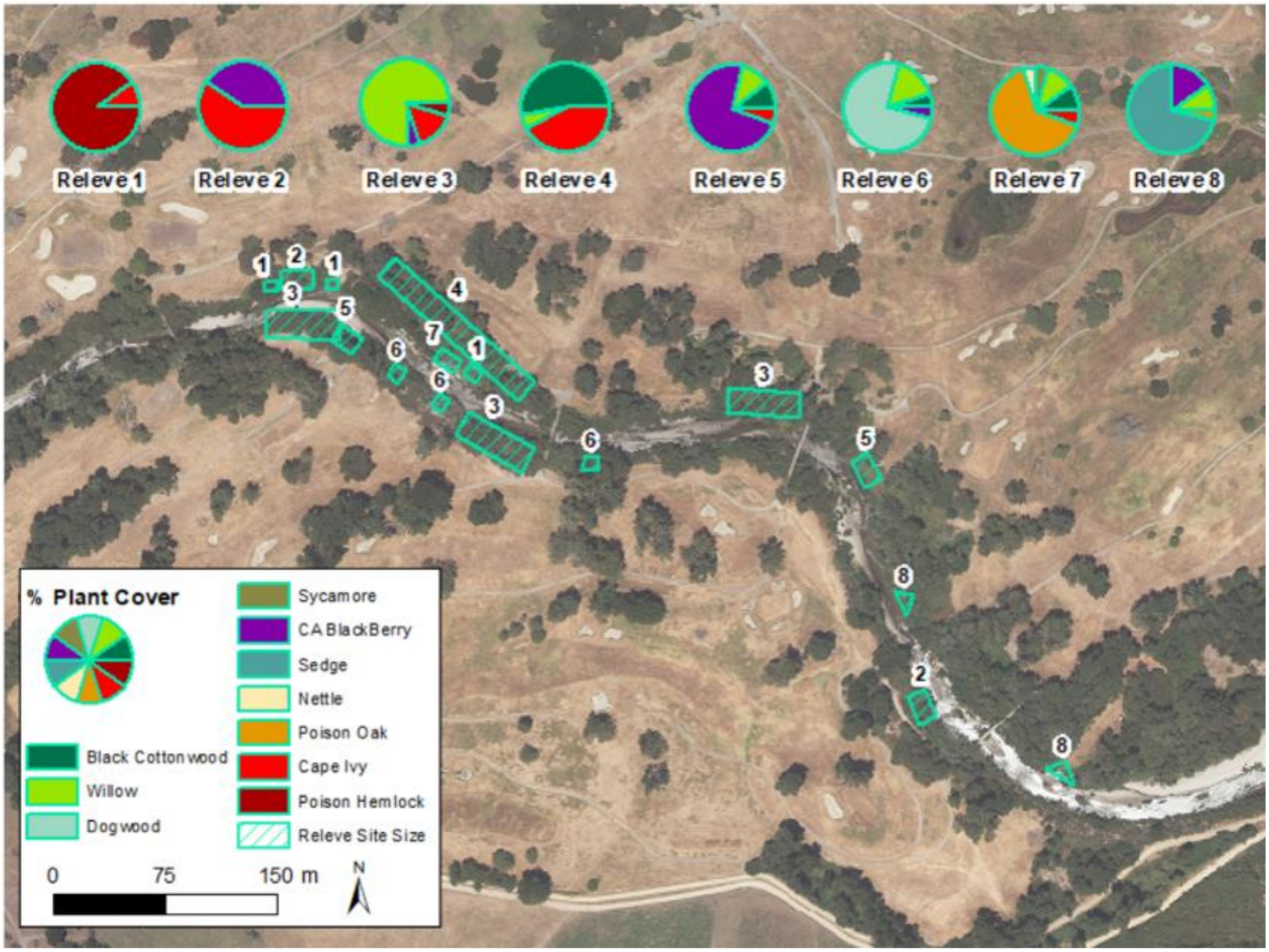

Figure 12. Visual representation of relevé survey showing plant species greater than 1% cover from each of the relevé sites.

Table 10. Relevé survey site summaries.

Relevé Site #	Dominant Species	% Cover of Dominant species	Invasive or Native	Soil Surface	% Soil Surface Cover	Other Plant Species	% Plant cover	Approx. Site Size (m^2)
1	Poison Hemlock	90	Invasive	Fine	25	Cape Ivy	10	81
				Litter	75			
2	Cape Ivy	50	Invasive	Fine	2	CA Blackberry	34.5	240
				Living stem	98	Black Cottonwood	5	
						Willow	10	
						Wild Mint	0.5	
3	Willows	75	Native	Fine	15	Poison Hemlock	5	900
				Litter	15	Cape Ivy	15	
				Living stems	70	CA Blackberry	4	
						Gooseberry, Mustard	<1	
4	Black Cottonwood	50	Native			Cape Ivy	40	10,000
						Willow	5	
						Poison Oak, Mugwort	<1	
						Poison Hemlock	<1	
						Wild Mint, Mustard	<1	
5	California Blackberry	70	Native	Fines	1	Willow	10	216
				Litter	4	Black Cottonwood	10	
				Living stem	95	Cape Ivy	5	
						Black Mustard	<1	
						Snow Berry	<1	
						Stinging Nettle	<1	
						Poison Oak	<1	
						Poison Hemlock	<1	
						Bull Thistle	<1	
						Sycamore	<1	
6	Dogwood	70	Native	Fine	2	Willow	15	80
				Boulders	<1	Black Cottonwood	5	
				Litter	2	CA Blackberry	4	
				Living stem	95	Wood Mint	<1	
						Western Goldenrod	<1	
7	Poison oak	65	Invasive	Fine	<1	Willow	10	120
				Gravel	<1	Black Cottonwood	10	
				Litter	3	Sycamore	5	
				Living stems	95	Cape Ivy	5	
						Stinging Nettle	4	
						Black Mustard	<1	
						Mugwort	<1	
						Poison Hemlock	<1	
8	Carex senta	70	Native	Fine	<1	CA Blackberry	15	125
				Water	<2	Willow	10	
				Living stem	98	Poison Oak	4	
						Sedge	<1	
						Nightshade	<1	
						Bull Thistle	<1	
						Mentha sp.	<1	
						Sneezeweed	<1	

Locations of Invasive Weed Patches

Problem sites include areas with large cover of invasive species and riprap. Figure 13 highlights some of the major areas that should be targeted for initial management.

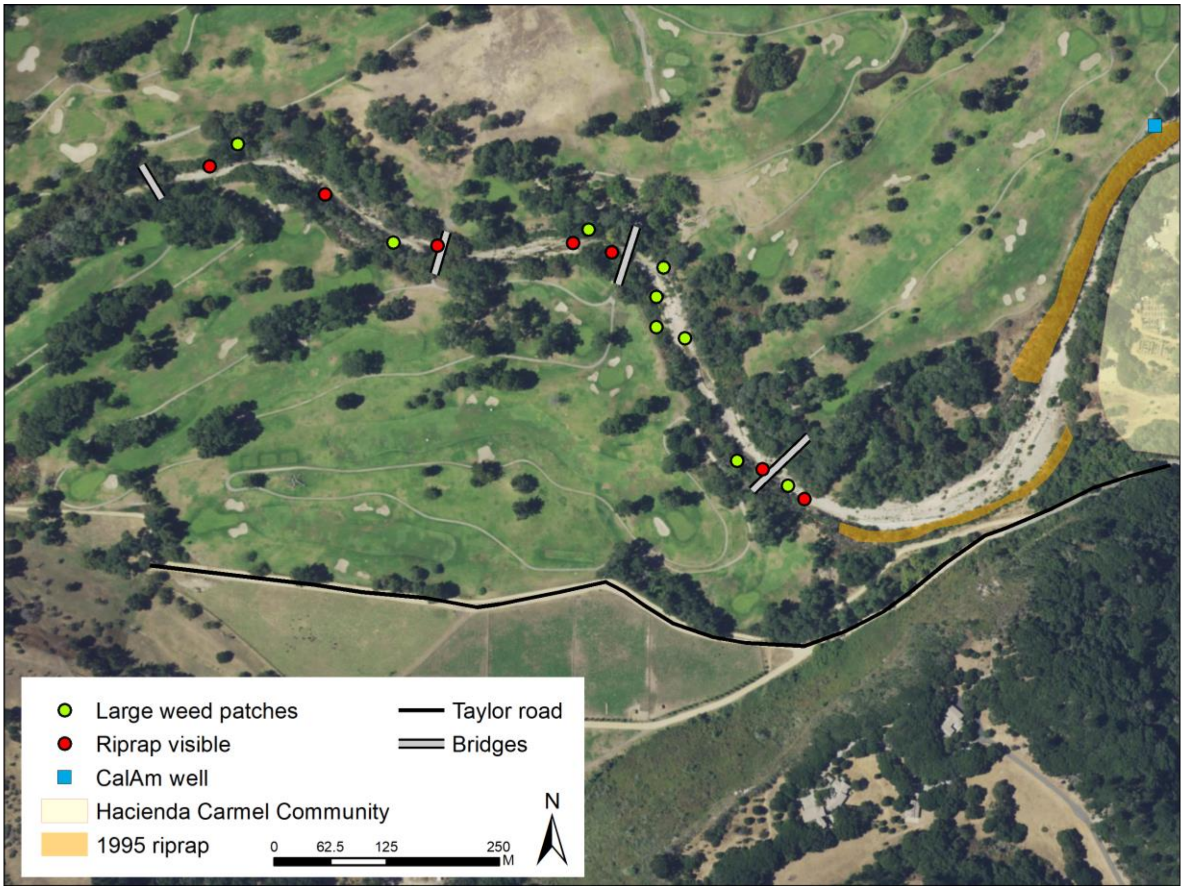

Figure 13. Large weed patches are composed of cape ivy, poison hemlock, and pampas grass. Visible riprap and the 1995 riprap were installed to prevent erosion but may need to be removed to restore natural channel flow in the future.

3 Conceptual Design

The existing conditions presented above indicate that the riparian corridor in the study area is impaired with respect to potential optimal geomorphic and vegetative conditions. Specific limitations include the lack of floodplain and attendant floodplain ecosystem services, limited large wood in the channel, and presence of non-native invasive plant species. We provide a conceptual model for improving riparian corridor ecosystem function in the study area through physical improvement of river morphology, planting site-appropriate plant groups, and managing non-native invasive species.

The physical river design includes a meandering channel within the context of a broad, vegetated wetland floodplain. The channel dimensions were developed so that the adjacent new floodplain would flood at least once each year (except for dry drought years). These dimensions are based upon flood frequency at the nearby USGS stream gage. The design channel widths are not greatly different from those found in other nearby reaches of the

Carmel River, so the design should not generate geomorphic instability upstream or downstream of the site. The chief physical difference is more overbank storage area for floodwater.

3.1 Planform Dimensions

Rivers develop a natural resonance between cross sectional geometry and planform geometry. Leopold and Wolman (1960) found that unmanaged rivers develop meander lengths that are related to the bankfull widths, such that Lm/W_{bkf} is between 10 and 15. We selected a value of 15 or our conceptual model. River bends are typically designed to conform to the arc of a circle with a specific radius of curvature (Rc). The radius of curvature for unmanaged rivers hovers near 3 times the bankfull width (e.g., Rosgen 2006). We selected a value 3.2 for the conceptual design.

3.2 Flow Frequency

The bankfull channel will be designed to flood with a near-annual frequency typical of natural rivers (Dunne and Leopoled 1978). We exercised multiple approaches to estimate a reasonable discharge range for the 1-1.5-year flow at Rancho Cañada for use in HEC RAS modelling. We used the 2000-2018 water year hydrographs from the nearby upstream USGS Carmel Near Carmel gage to assess the discharge value of frequent floods. While the annual maximum series is appropriate for estimating the frequency of high magnitude flows, it tends to underestimate frequent flood recurrence intervals because it only accounts for the maximum flow of each water year and ignores smaller flows which may be important for flood frequency analysis of frequent events (Dunne and Leopold 1978). The partial duration series is more appropriate for estimating frequent flows, such as those close to bankfull conditions (Smith et al. 2009). Along with the partial duration series, we visually estimated 1-1.5 year flows by finding a horizontal line that intersected the peak flow during at least 2/3 of the years from 2000-2018. Through the visual inspection of the hydrograph and partial duration analysis we recommend constructing a channel that can convey between 1600 cfs and 2300 cfs before flooding onto a broad floodplain (Fig. 14). For our design we selected 1700 cfs for our design Q_{bfk}.

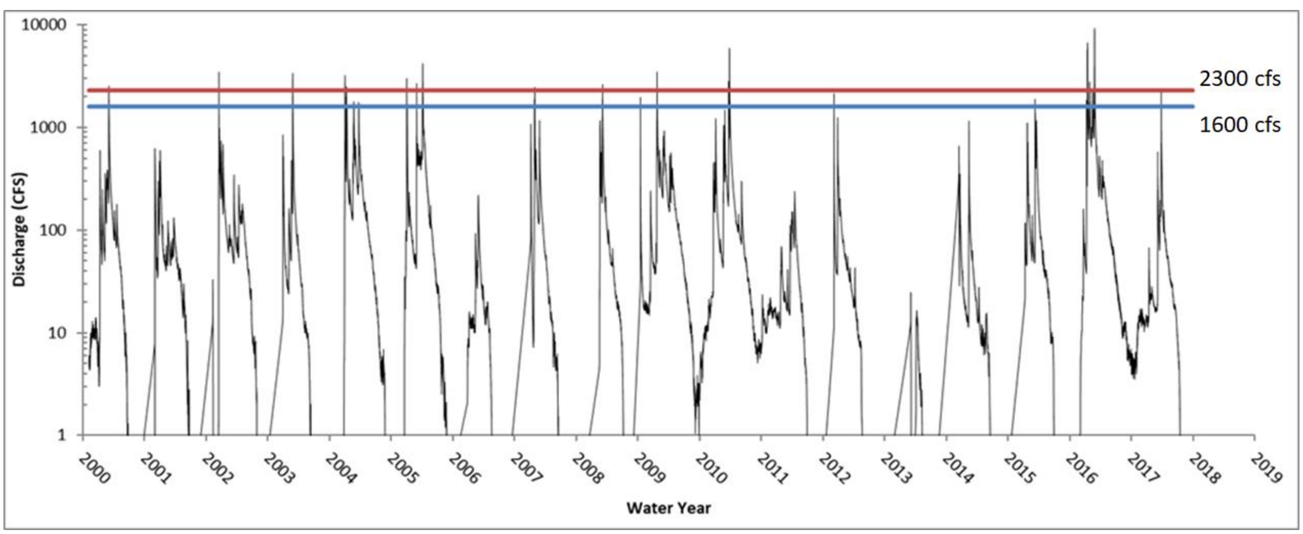

Figure 14. Hydrograph of the USGS Carmel Nr Carmel gage for water year 2000 to 2018. 1-year flow based on the partial duration series is shown in red, while the visual estimation of the 1-1.5 year flow is shown in blue.

3.3 Modeling

We modelled the annual flow in the surveyed cross-sections using the designed slope of 0.0028, which was derived from design sinuosity (see below) and existing slope. The modeled water surface elevation changes for a range of flows were compared to the nearby USGS stage information to validate the model. We based our designed bankfull channel dimensions on the portion of cross section 4 submerged by the annual flow (1700 cfs) as estimated by HEC RAS hydraulic modelling (Table 11). The modelled bankfull width and bankfull depth values are close to the dimensions suggested for a river of this drainage area by a published regional curve of bankfull geometry (Hecht et al. 2013). The constructed channel would also have a width to depth ratio of 14 (Table 11), in keeping with a C4 channel ($W_{bkf}/D_{bkf} > 12$; Rosgen, 1994). All other design parameters in this conceptual design conforms to C4 parameters. A review of published regional curves for bankfull geometry indicates that the width and average depth values (Table 11) are in agreement with less altered rivers in the region (Hecht et al. 2013).

3.4 Pattern

Table 11. Cross sectional bankfull dimensions of the restoration design based upon HEC RAS output table from 1700 CFS flow. A = area, W = top width, d = A/W, w/d = width to depth shape parameter, WP = wetted perimeter, R = hydraulic radius, tau = average boundary shear stress.

Dimension	Value	Unit
A	27	m^2
W	20	m
d	1.4	m
w/d	14	
WP	21	m
R	1.3	m
τ	36	N/m^2

The conceptual design is based upon the premise that a single-thread meandering channel would form here under unmanaged conditions. By constructing such a channel, rather than letting it incise naturally, we take away a great deal of uncertainty in river behavior, and perhaps produce a system that will not evolve and erode very quickly once constructed. Given that premise and the context of a gravel supply in a low-gradient alluvial valley, we recognize that the design might follow the parameters of a Rosgen C4 class stream. The bankfull meander length and radius of curvature were scaled from the modelled bankfull width Table 12. Sinuosity was measured from the map of the design. Sinuosity was calculated as: $K = \frac{Lc}{Lv}$, where Lc is the length of the curvy center line of the channel and Lv is the straight length of the valley where channel length was measured.

Table 12. Map view pattern parameters for the restoration design. K= sinuosity, Rc = radius of curvature, Lm = meander length.

Pattern	Value
K	1.4
Rc	63
Lm	296

Flows that exceed bankfull should flow onto a broad floodplain that supports a diverse semi-aquatic ecosystem. While the minimum entrenchment ratio for a C4 stream is 2.2 (Rosgen 1994), a broader floodplain would accommodate more opportunity for enhanced riparian ecology and produce a much lower risk stream design by mitigating the shear stress related to high flow events. A minimum flood-prone width of 45m was calculated to obtain a C4 classification. However, we selected a 100 m flood-prone width for our design to exceed the minimum 2.2 entrenchment ratio requirements. In order to produce a 100 m flood-prone width throughout the channel each surveyed cross section would need to be increased by approximately 68 m (Fig. 15).

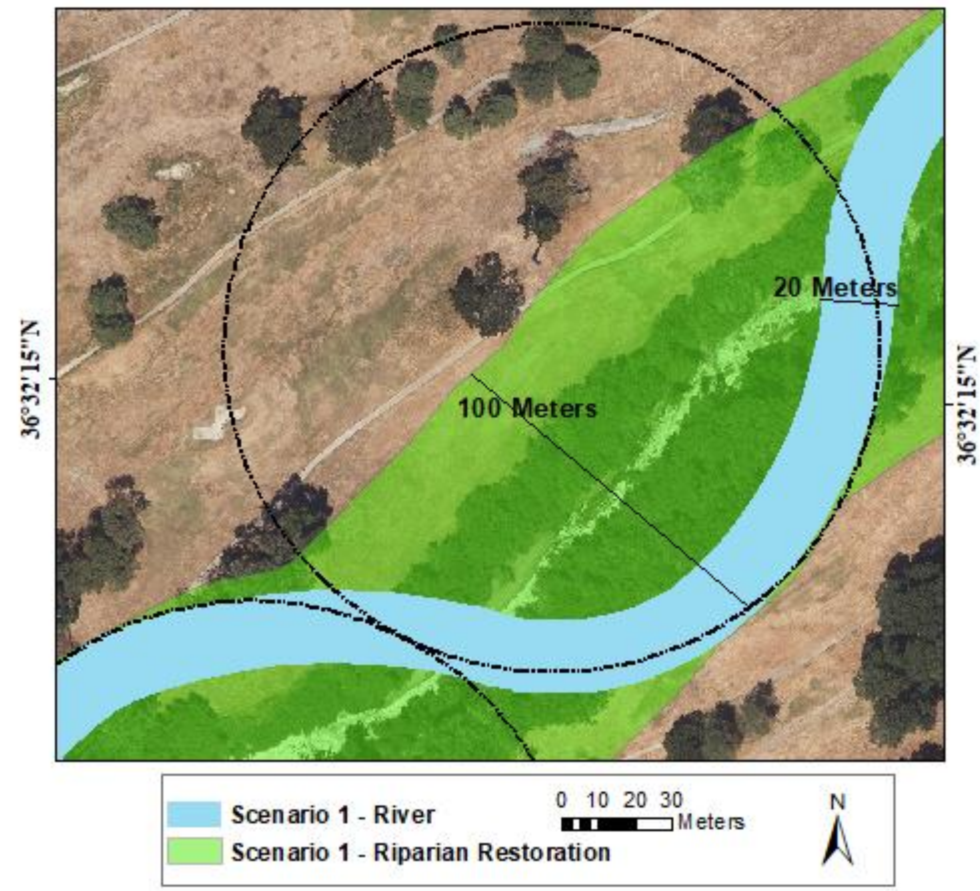

Figure 15. Detail of a portion of designed river meander pattern. Green corridor would be cut to provide a floodplain surface.

3.5 Sediment Transport Competence

River designs will fail if they are not tuned to the existing sediment transport regime. Rivers must be able to transport the sediment supplied to them, with the available shear stress from a range of flows. We tested the competence of the conceptual river design to move the 84th percentile of the riffle bedload material (53 mm) at bankfull conditions. Average boundary shear stress (τ) is the theoretical, down-valley pressure exerted by flowing water on a channel bottom. τ can be used to determine if there is enough stress to transport the existing sediment supply. We compared the theoretical available average boundary shear stress of the conceptual model τ (Table 11) to the theoretical resistance to motion of the 53 mm grain τ_c. The critical shear stress (τ_c) was estimated using the method of Andrews (1994) using the following equations:

$$\tau_c^* = 0.0384\left(\frac{\mathrm{d}i}{\mathrm{d}50}\right)^{-0.887}$$

$$\tau_c = \tau_c^*\,(\gamma_{\text{sediment}} - \gamma_{\text{water}})\,(\mathrm{d}i)$$

where

τ_c^* = dimensionless critical shear stress

τ_c = shear stress needed to move di

γ_{sediment} =Specific weight of sediment = $9.8\,\frac{\mathrm{m}}{\mathrm{s}^2} * 2650\,\frac{\mathrm{kg}}{\mathrm{m}^3}$

γ_{water} = Specific weight of water = $9{,}800\,\frac{\mathrm{N}}{\mathrm{m}^3}$

d*i* = d84

d50 = median grain size

The average reach d50 and d84 are 19 mm and 53 mm respectively (Table 2). Therefore, the minimum shear stress needed to move the d84 in this channel is just below $13\frac{N}{m2}$. Based on the HEC model, there is $36\frac{N}{m2}$ available as average boundary shear stress, which is sufficient to move the d84, and provide excess shear stress for broader gravel transport needs.

3.6 Riparian Vegetation

Recommended restoration efforts also incorporate the inclusion of vegetated banks, implementation of large wood structures and the development of artificial ponds (Fig. 16). The incorporation of these additional parameters has been found to promote channel stability through the anchoring of sediment, as well as provide vital habitat for a range of native wildlife, such as the California red legged frog (Alvarez et al. 2013, Osterkamp and Hupp 2010, Pess et al. 2012).

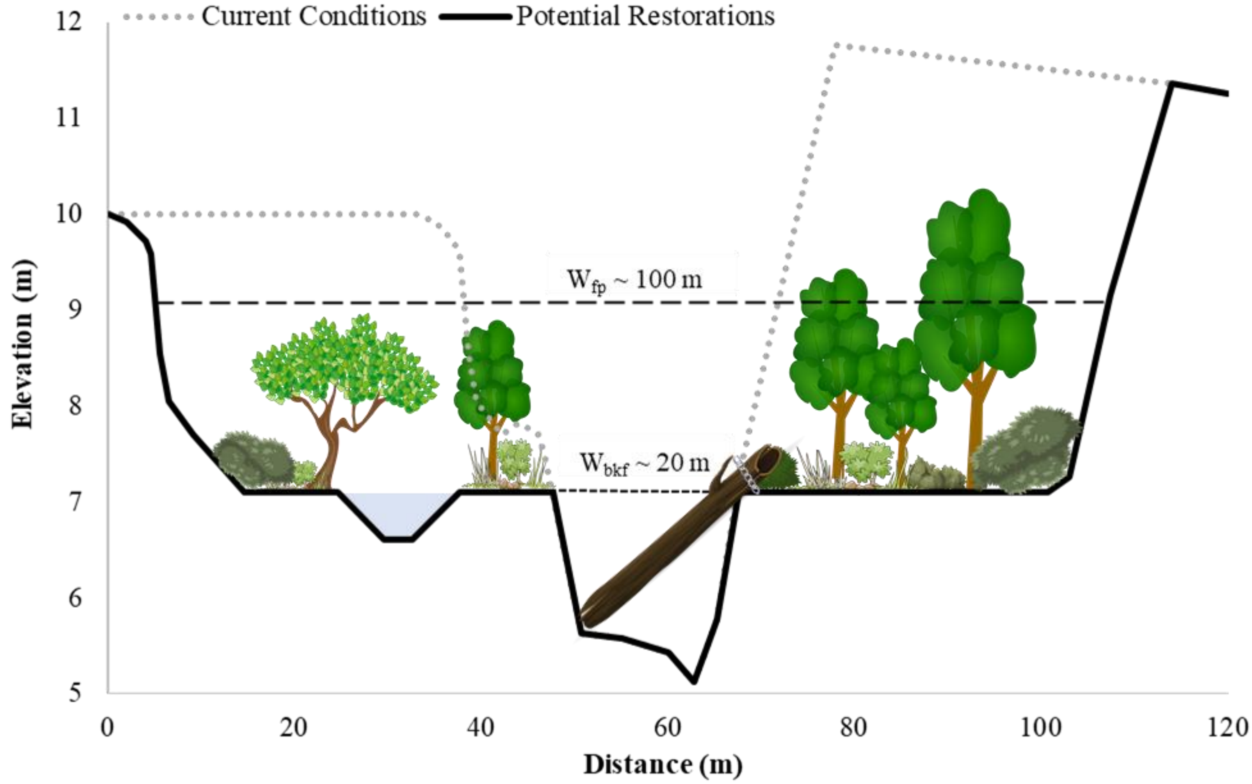

Figure 16. Recommended restoration at cross section 1 to achieve a 100m flood-prone width (W_{fp}) based on a bank full width (W_{bkf}) of 20m and minimum entrenchment ratio (ER) >2.2. Potential restoration design incorporates vegetated banks, the inclusion of an artificial pond and the implementation of a large wood structure. Note vertical exaggeration in figure.

4 Recommendations

4.1 Hydrologic Restoration Recommendations

We considered three design approaches.

- Leave the system as it is
- Fill existing channel and cut a new channel on existing terrace
- Leave channel at current elevation but add meanders and excavate a floodplain adjacent to the channel.

The first option of maintaining current river conditions is least expensive. Based on current conditions such as existing rip rap, and limited floodplain, there are several aspects that can be altered to enhance ecological benefits by providing more ecological habitat, flood prevention, and stability.

The second option is to fill the existing channel and relocate a new channel up on the existing terrace. The third is to leave the Carmel channel at its current elevation and excavate a floodplain on one side or the other at various locations. The most expensive and labor-intensive restoration scenario would call for a new channel to be designed on the existing terrace and the old channel be filled with sediments and create potential pond habitats (NCSRI 2007 and Fig. 17). Though we do recommend pond habitats, this scenario was not considered for this study as the change of slope it would create in the current Carmel River would worsen flooding immediately upriver. This did not seem reasonable as there is currently development above and below Palo Corona. In addition, this option would require the creation of a step-pool system at the downstream terminus of the project. Considering this construction would be very costly and could impact a large number of residents in Carmel Valley, we concluded that this restoration framework was unreasonable for Palo Corona.

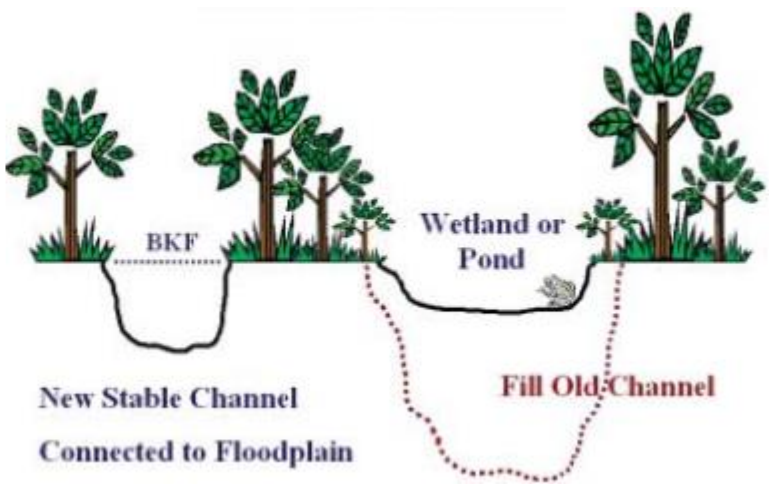

Figure 17. Figure taken from NCSRI detailing a restoration profile design.

An intermediate restoration plan, the third option, would best benefit this geomorphic system. The main objective of this restoration plan is to create a stable floodplain and stream at the current channel-bed elevation (Table 13 and Fig. 18). This scenario will allow us to alter the stream from current Rosgen F4 (impaired) morphology into a Rosgen class C4 stream, with a bankfull stage near the newly excavated floodplain. Such projects decrease regional flooding losses in adjacent river reaches (NCSRI 2007). There are other scenarios not mentioned in detail but that can be found in Table 13. Two scenarios are described further below. Scenario 1 includes a more sinuous channel and broad floodplain. Scenario 2 would expand a floodplain environment adjacent to the current Carmel River position.

Figure 18. Figure taken from NCSRI detailing a restoration profile design.

Table 13. Scenarios proposed in this study including their brief summaries of increased environmental benefits and risks in decreasing order of relative cost.

Scenario Description	Environmental Benefits	Risks
Create a floodplain and realign channel to have more natural sinuous pattern	Greatest instream habitat improvement, greater control on restorated vegetative ecosystem	Low risk, however protection of bridges and bends should be considered
Create a floodplain along existing invert pathway	High instream habitat improvement, some control on restorated vegetative ecosystem	Low risk of lateral migration, however protection of bridges and bends should be considered
Remove riprap and not provide new floodplain	Eventual complete passive restoration of riparian corridor as natural processes creates a "steady-state" equilibrium	Rapid widening and lateral migration compromises existing infrastructure, and possible upstream and downstream lateral erosion, difficult to predict behavior
No restoration plan implemented	None	No environmental quality improvements

Scenario 1

The first restoration scenario proposes excavation of the river valley to widen the floodplain to be approximately 100 m to contain a meandering 20 wide channel (Fig. 19). This scenario would restore the river to a Rosgen C4 type river. This scenario will enhance the meanders, increasing overall sinuosity from 1.23 to >1.4. We expect to see the increased environmental benefit for instream habitat improvement through this scenario. In addition, this would provide the most control for restoring the vegetative ecosystem.

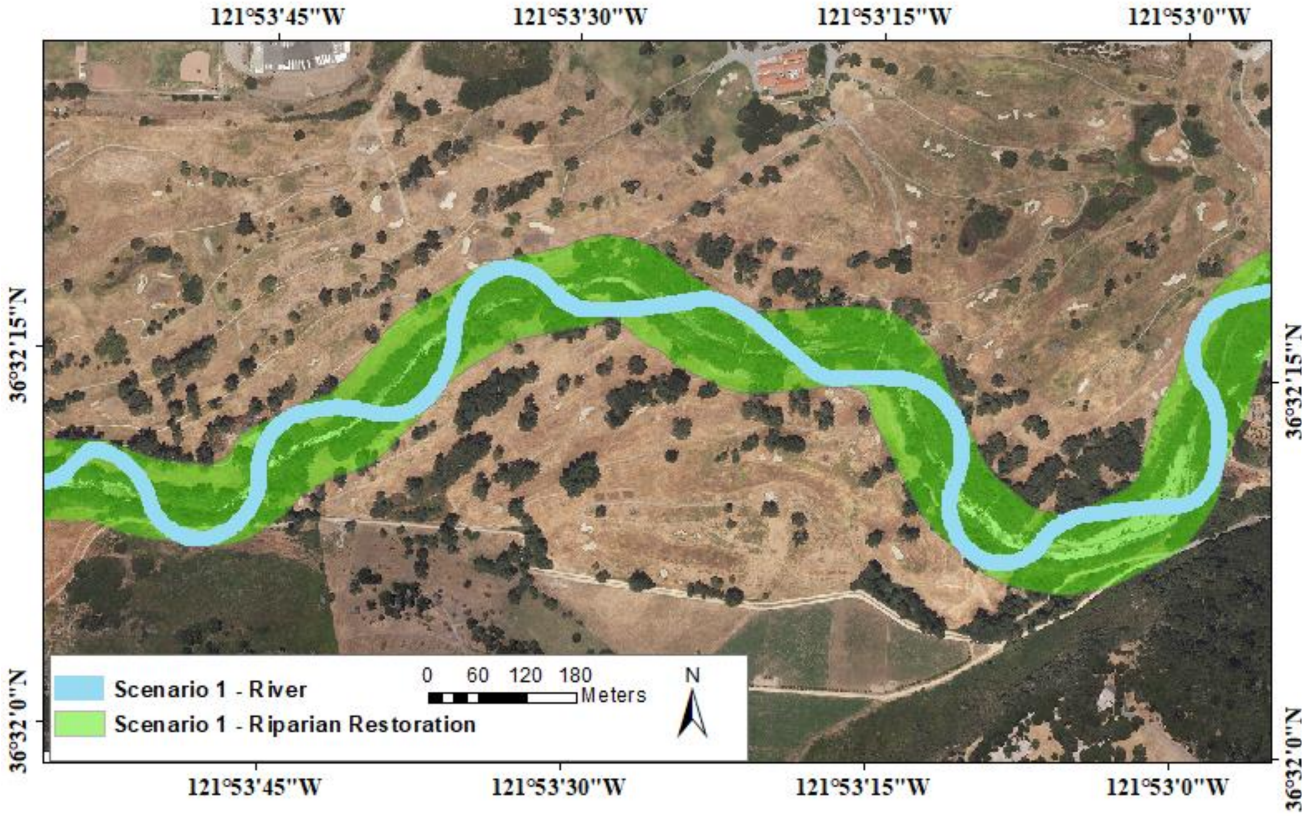

Figure 19. Scenario 1: Conceptual design of proposed floodprone width of original channel.

Scenario 2

The second restoration scenario also involves excavating the river valley to widen the floodplain but retains the existing channel pattern and sinuosity (Fig.20). As in Scenario 1, the river would be restored to a Rosgen type C4 river. This approach would not require a shift in the river channel, but rather over time the river would reach equilibrium conditions through movement and erosion within the new floodplain. Potential risks involved with this scenario include higher rates of lateral migration and erosion than scenario 1 and existing infrastructure will need protection (Table 13). That being said, the current sinuosity is not drastically different from the sinuosity of the conceptual design, suggesting that erosional events caused by allowing the river to create its own meanders might not be substantial.

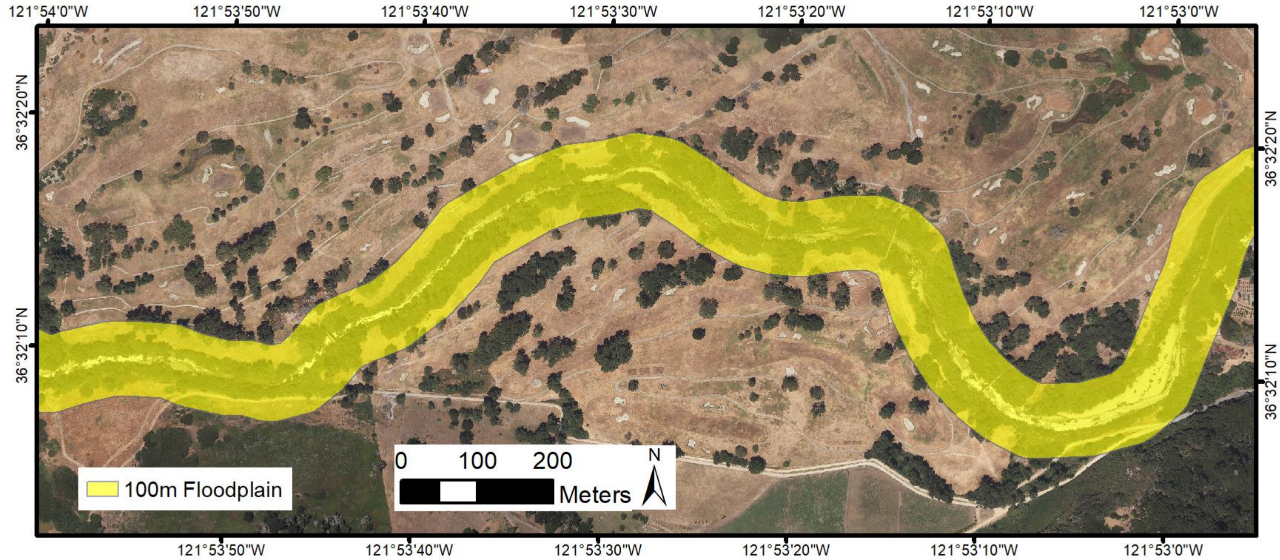

Figure 20. Scenario 2: Conceptual design of proposed floodprone width of original channel.

4.2 Vegetation Recommendations

Invasive plants, especially cape ivy, need to be managed. We recommend hand-pulling cape ivy twice a year and/or scorching. Hand-pulling invasive species is a common control method for non-native plants due to a relatively low cost, lack of required equipment, and does not involve chemicals (Flory and Clay 2009). Scorching, or burning, may remove invasive species quicker than hand-pulling, but may have negative long-term effects. Keeley et al. 2003 showed that both diversity and non-native species increased over the years after a prescribed burn, and frequent burning can alter vegetation balance in favor of non-natives. We therefore recommend hand-pulling as the best vegetation management strategy.

Native vegetation should be planted as soon as possible after invasive species removal. Emphasis should be placed on restoring major lifeforms of riparian vegetation by including trees, shrubs, herbaceous, and rushes/sedges in restoration plan (Fig. 21). For additional vegetation recommendations for the lower Carmel River see Chow et al. 2016b and the Conceptual Floodplain Revegetation Design for the Lower Carmel River and Lagoon Floodplain Restoration and Enhancement Project (2011).

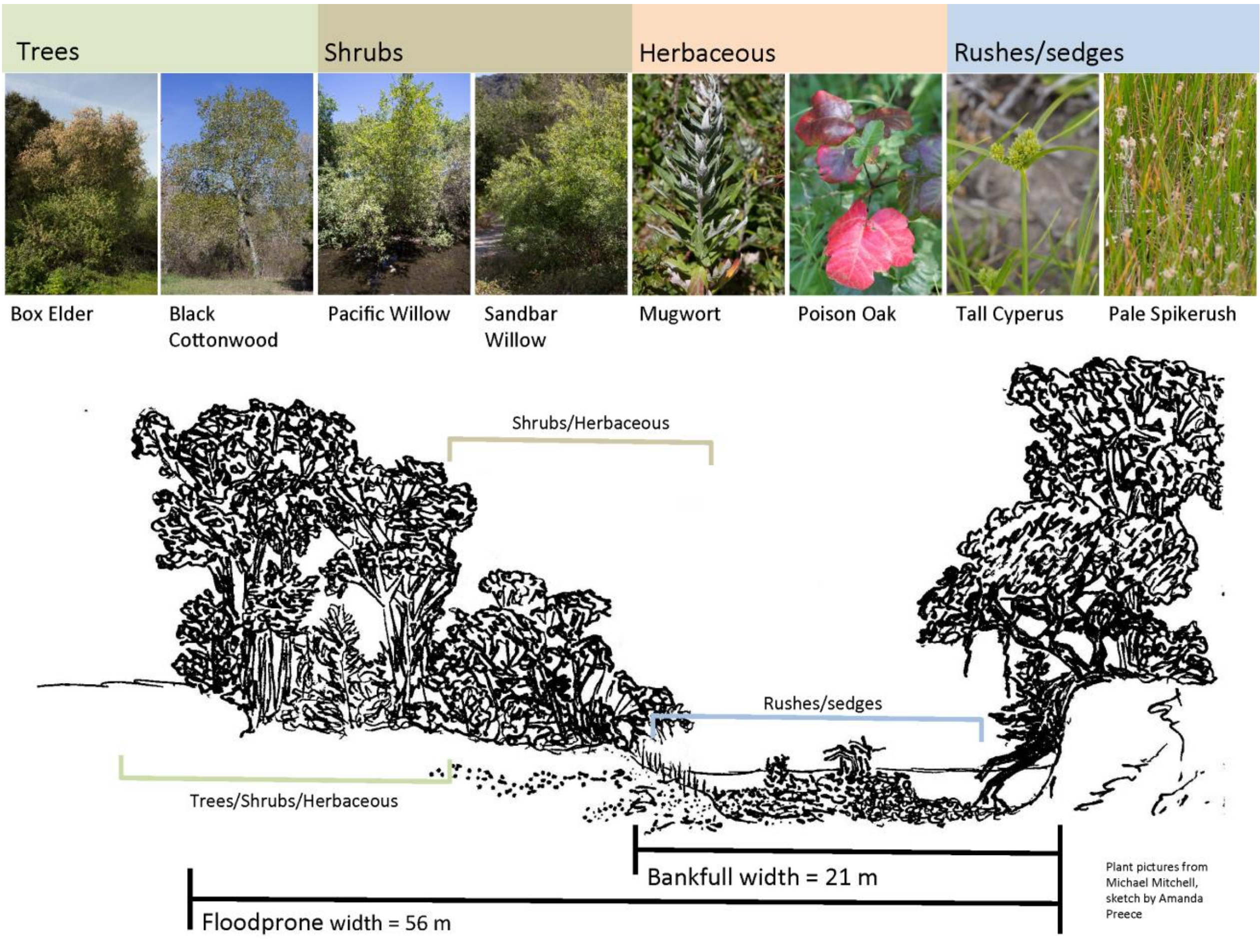

Figure 21. Recommendations of native plant species to use in restoration along study site and general planting locations along river.

5 References

Alvarez, J.A., Cook, D.G., Yee, J.L., van Hattem, M.G., Fong, D.R. and Fisher, R.N., 2013. Comparative microhabitat characteristics at oviposition sites of the California red-legged frog (Rana draytonii). *Herpetological Conservation and Biology*, *8*(3), pp.539-551.

Andrews ED. 1994. Marginal bed load transport in a gravel bed stream, Sagehen Creek, California, *Water Resour. Res.*, 30(7), 2241–2250, doi: 10.1029/94WR00553.

Audubon California. 2018. Carmel River/Point Lobos Bird Conservation Region. Retrieved Sept 24, 2018. From: https://netapp.audubon.org/iba/Reports/4638

Balance Hydrologics. 2015. "Carmel River Floodplain Restoration and Environmental Enhancement Project 35% Design Basis Report." Retrieved: Sept 4, 2018. From: https://www.co.monterey.ca.us/home/showdocument?id=13767

Big Sur Land Trust. 2018. "Carmel River Floodplain Restoration and Environmental Enhancement Project (Carmel River FREE)" Retrieved: Oct 3, 2018. From: https://bigsurlandtrust.org/carmel-river-free/

Boughton DA, East A, Hampston L, Kiernan J, Leiker, S, Mantua N, Nicol C, Smith D, Urquhart K, Williams T, Harrison L. 2016. Removing a dam and re-routing a river: Will expected benefits for Steelhead materalize in Carmel River, California? NOAA Technical Memorandum, NOAA-TM-NMFS-SWFSC-553. US Department of Commerce. Southwest Fisheries Science Center, Santa Cruz, CA. 89 pp.

Chow K, Fields J, Flores S, Hart K, Kleven A, Luna L, MacCarter L, and Smith D. 2016a. San Clemente Dam Removal Sediment Impacts: Year One Report. Watershed Institute, California State University Monterey Bay, Publication No. WI-2016-10, 38 pp.

Chow K, Fields J, Flores S, Hart K, Kleven A, Luna L, MacCarter L, and Burton R. 2016b. Developing Adaptive Management Tools for the Carmel River Floodplain Restoration and Environmental Enhancement Project. The Watershed Institute, California State University Monterey Bay, Publication No. WI-2016-12, 58 pp.

[CNPS] California Native Plant Society. 2007. Field Protocols & Guidelines. Retrieved 2018 September 28. From: https://www.cnps.org/plant-science/field-protocols-guidelines

[CRWC]. Carmel River Watershed Council. 2010. Carmel River History. Retrieved: Sept. 7, 2018. From: http://www.carmelvalleyassociation.org/assetts/docs/CV_Voices/Carmel_River_History.pdf

Dunne, T. and Leopold, L.B. (1978) Water in Environmental Planning. WH Freeman and Co., New York.

Flory, L.S. and Clay, K. 2009. Invasive plant removal method determines native plant community responses. Journal of Applied Ecology. Vol. 45, No. 2., pp. 434-442.

Golf Digest. 2016. Monterey Peninsula to lose two courses, despite efforts by Robert Trent Jones II. Retrieved Sept. 20th, 2018. From: https://www.golfdigest.com/story/monterey-peninsula-to-lose-two-courses-despite-efforts-by-robert-trent-jones-ii

Harman W., Smith Rachel. 2000. Using Root Wads and Rock Vanes for Streambank Stabilization. NC State Extension.

Harrelson, C.C., Rawlins, C.L. and Potyondy, J.P., 1994. Stream channel reference sites: an illustrated guide to field technique. *Gen. Tech. Rep. RM-245. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p.*, *245*.

Harrison, L.R., East, A.E., Smith, D.P., Logan, J.B., Bond, R., Nicol, C., Williams, T.H., Boughton, D.A., Chow, K. and Luna, L. 2018. River response to large-dam removal in a Mediterranean hydroclimatic setting: Carmel River, California, USA. Earth Surf. Process. Landforms. DOI: 10.1002/esp.4464.

Harvey MD, Watson CC. 1987. Fluvial processes and morphological thresholds in incised channel restoration. Journal of the American Water Resources Association. No. 86005.

Hecht B, Senter AE, Strudley M, Xu L. 2013. New bankfull geometry relations for Inland South Bay and Monterey Bay aeras. Central California: State of the Estuary Biannual Conference.

Kail J., Hering D., Muhar S., Gerhard M., Preis S. 2007. The use of large wood in stream restoration: experiences from 50 projects in Germany and Austria. British Ecological Society 44(6).

Keeley, J.E., Lubin, D., and Fotheringham, C.J. 2003. Fire and grazing impacts on plant diversity and alien plant invasions in the southern Sierra Nevada. Ecological Applications. Vol. 13, No. 5, pp.1355-1374.

Kondolf, G.M., and M.G. Wolman, 1993. The sizes of salmonid spawning gravels, Water resources research, Vol. 29, No. 7, pp. 2275-2285, July 1993

Mathews, M and Mitchell, M. 2015. The Plants of Monterey County: an Illustrated Field Guide, Second Edition. Retrieved 2018 September 28. 464 pp.

Merritt, David M, Manning, Mary E, Hough-Snee, Nate. 2017. The National Riparian Core Protocol: A riparian vegetation monitoring protocol for wadeable streams of the conterminous United States. Retrieved 2018 September 28. 37 pp. From: https://www.fs.fed.us/rm/pubs_series/rmrs/gtr/rmrs_gtr367.pdf

Michael Brandman Associates. 2004. Draft Revised Environmental Impact Report for the September Ranch Subdivision Project. Retrieved Sept 24th, 2018. From: http://www.landwatch.org/pages/issuesactions/carmelvalley/SeptemberRanch-DREIR-2004.pdf

Minnesota Deparment of Natural Resources. 2013. A handbook for collecting vegetation plot data in Minnesota: The releve method. 2nd ed. Minnesota Biological Survey, Minnesota Natural Heritage and Nongame Research Program, and Ecological Land Classification Program. Biological Report 92. St. Paul: Minnesota Department of Natural Resources.

Missaghian, J, Schulze, B, Neill, C. 2015. Lower San Lorenzo River Riparian Vegetation Study: an inventory and characterization of four city managed properties. Retrieved 2018 September 28. 37 p

Monterey County Water Resources Agency. November 24, 2015 “Floodplain Management Plan Monterey County, CA” Retrieved: Sept 4, 2018. From: http://www.co.monterey.ca.us/Home/ShowDocument?id=22597

Monterey County Government. 2018. “Historical Flooding.” Retrieved: Sept 4, 2018. From: http://www.co.monterey.ca.us/government/government-links/water-resources-agency/programs/floodplain-management/historical-flooding#wra

[MPRPD]. Board of Directors Meeting. 2018. Resolution #2018-04. Retrieved: Sept 20, 2018. From: https://www.mprpd.org/files/1097758c9/Item0218-11E_GrantAgmtCDFW.pdf

[MPRPD]. Design Workshop. 2018. Palo Corona Regional Park General Management Plan. Retrieved Sept 4th, 2018. From: https://www.mprpd.org/files/9fc5c8435/Item0818-7A_PCRPGDP_Attach2.pdf

[MPRPD]. Request for Proposal. 2018. Professional Structural Engineering Services for Safety Inspections of Pedestrian/Golf Cart and Vehicle Bridges Located at the former Rancho Cañada Golf Course, Carmel, CA. Retrieved: Sept 12, 2018. From: https://www.mprpd.org/files/298fe0233/GolfCartBridgeInspectionsRFP_0718.pdf

Monterey Peninsula Water Management District. 2017. Carmel River Thalweg Survey – Compiled Plan & Profile.

Nomad Ecology. 2014. Invasive Weed Management Plan for Palo Corona Regional Park. Retrieved Sept 12th, 2018. From: https://mprpd.specialdistrict.org/files/e951aaa49/PCRPWMP_052314.pdf

[NCSRI] North Carolina Stream Restoration Institute. 2007. Stream Restoration: A Natural Channel Design Handbook. North Carolina Sea Grant (5)50-61.

Osterkamp, W.R. and Hupp, C.R., 2010. Fluvial processes and vegetation—glimpses of the past, the present, and perhaps the future. Geomorphology, 116(3-4), pp.274-285.

Pess, G.R., Liermann, M.C., McHenry, M.L., Peters, R.J. and Bennett, T.R., 2012. Juvenile salmon response to the placement of engineered log jams (ELJs) in the Elwha River, Washington State, USA. *River Research and Applications*, *28*(7), pp.872-881.

PRISM. 2007. 103-Year High-Resolution Precipitation Climate Data Set for the Conterminous United States. Oregon State University.

Rosgen, D.L., 1994. A classification of natural rivers. Catena, 22(3), pp.169-199.

Smith, D.P., Diehl, T., Turrini-Smith, L.A., Maas-Baldwin, J, and Croyle, **Z**., 2009, River restoration strategies within channelized, low-gradient landscapes of West Tennessee, USA; in James, A., Rathburn, S., and Whittecar, R., eds, Management and Restoration of Fluvial Systems with Broad Historical Changes and Human Impacts: GSA Special Paper no 451, p. 215-229.

Smith E. 2016. Rip-Rap Repair, Structure Maintenance, and Creation of Fish Habitat in Pass (Norns) Creek 2015 – 2016. FWCP # F-F16-25 & F-F15-25.

Steinmetz C. and Smith D. 2018. 2017 Post-San Clemente Dam Removal Morphological Monitoring of the Carmel River Channel in Monterey County, California. The Watershed Institute, California State University Monterey Bay, Publication No. WI-2018-03, 51 pp.

Water Management Group. 2014. Draft, Monterey Peninsula, Carmel Bay, and South Monterey Bay Integrated Regional Water Management Plan (IRWM).

Appendix A – Pebble Counts

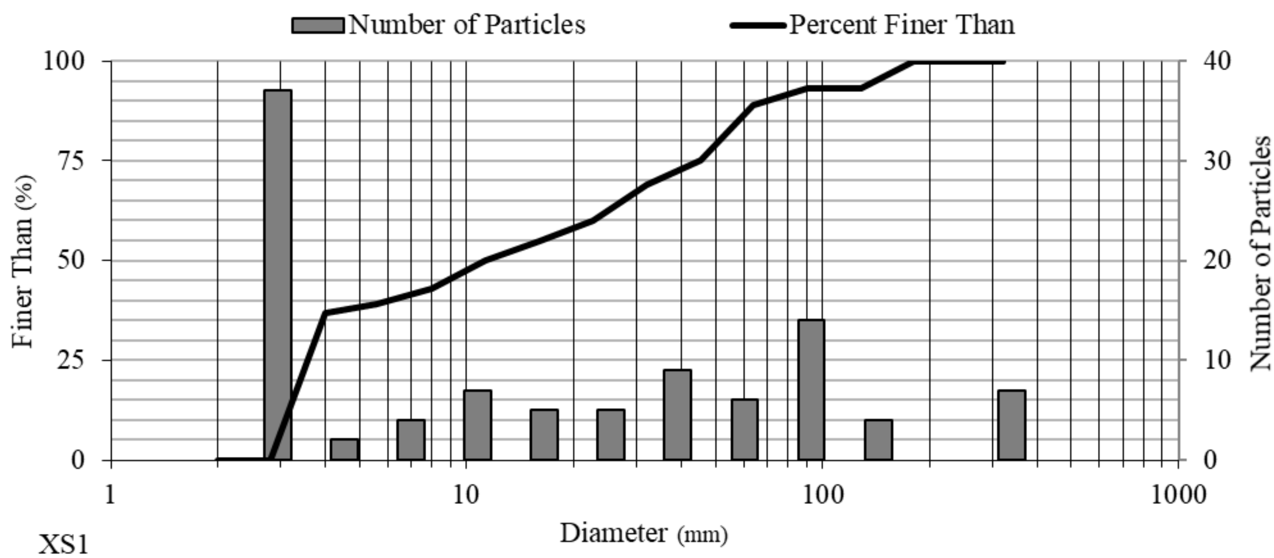

Figure 23. Pebble counts measured at cross section 1 on September 19th, 2018 and the calculated value for the percentage of substrate particles finer than any given particle size observed at this location.

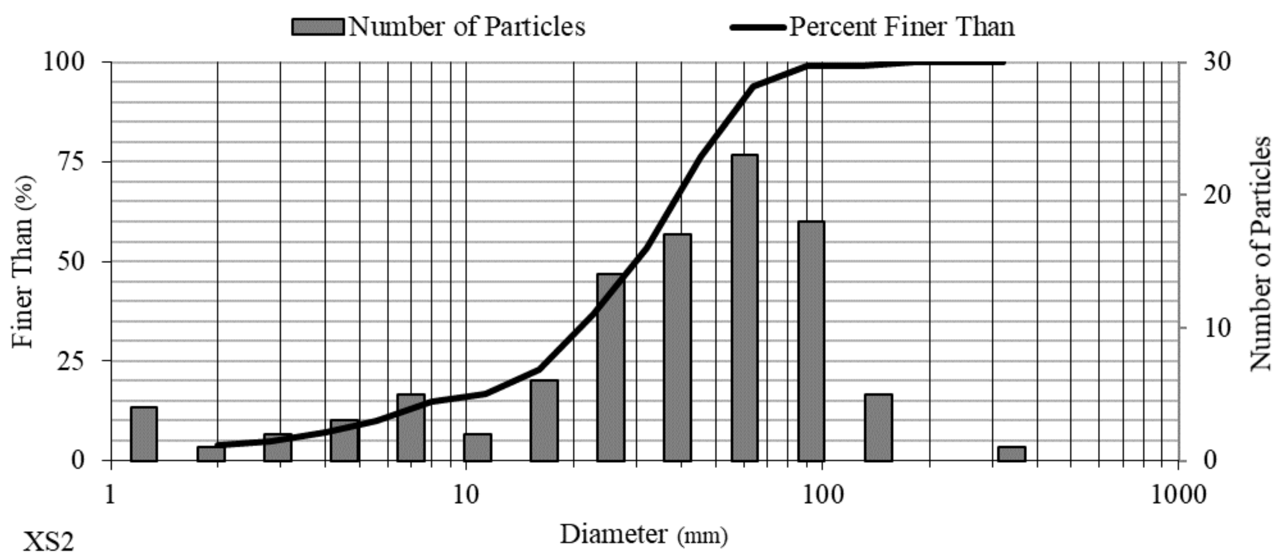

Figure 24 Pebble counts measured at cross section 2 on September 19th, 2018 and the calculated value for the percentage of substrate particles finer than any given particle size observed at this location.

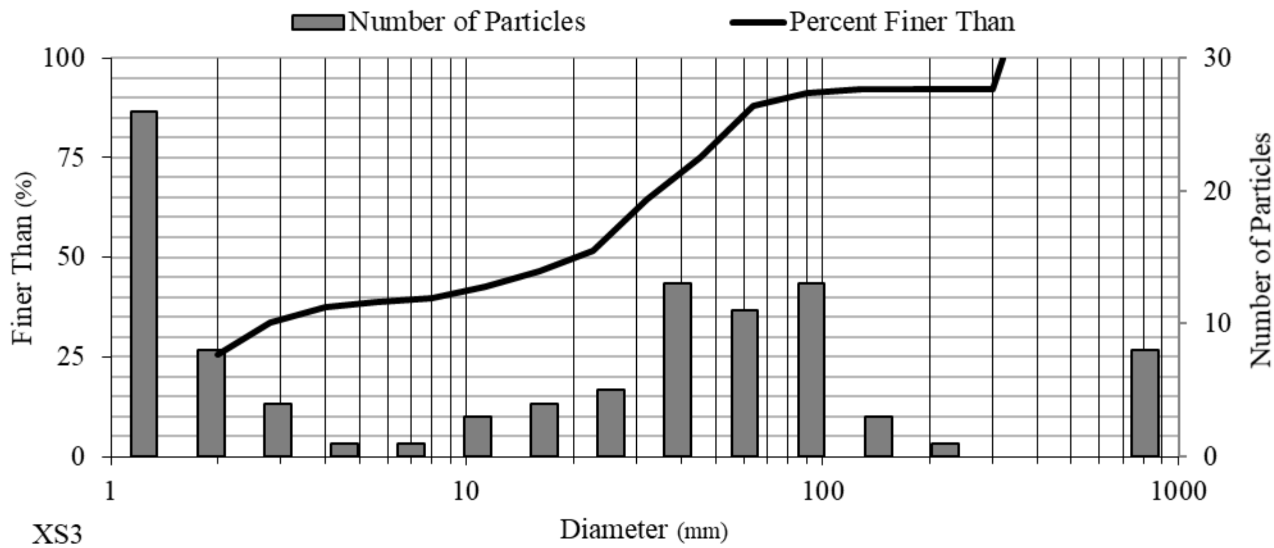

Figure 25. Pebble counts measured at cross section 3 on September 19th, 2018 and the calculated value for the percentage of substrate particles finer than any given particle size observed at this location.

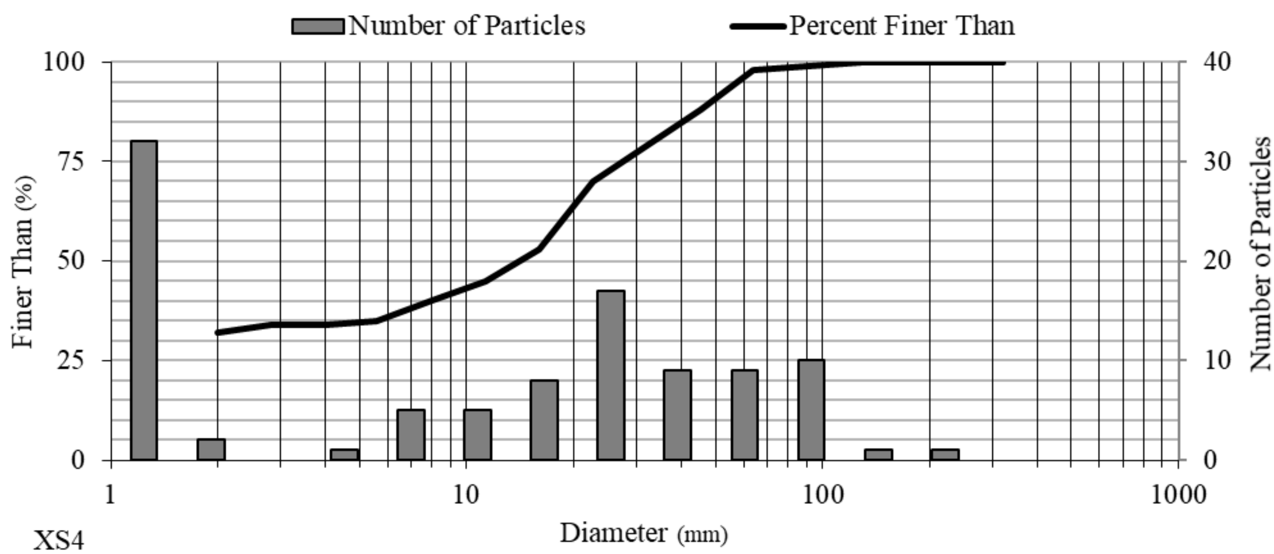

Figure 26. Pebble counts measured at cross section 4 on September 19th, 2018 and the calculated value for the percentage of substrate particles finer than any given particle size observed at this location.

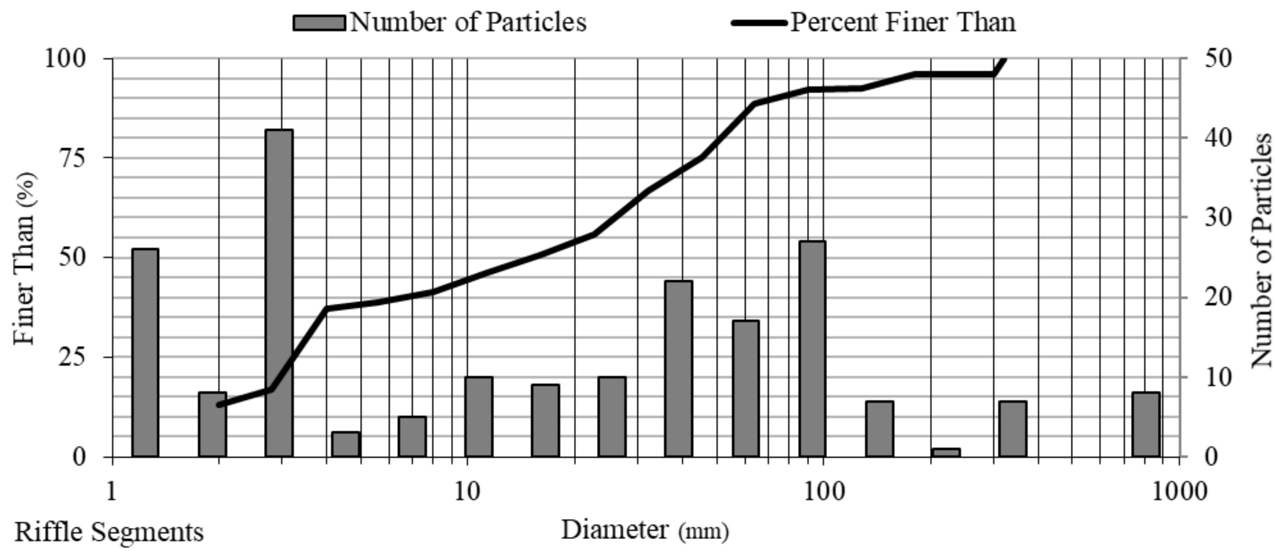

Figure 27. Pebble counts measured at riffle segments on September 19th, 2018 and the calculated value for the percentage of substrate particles finer than any given particle size observed at either location.

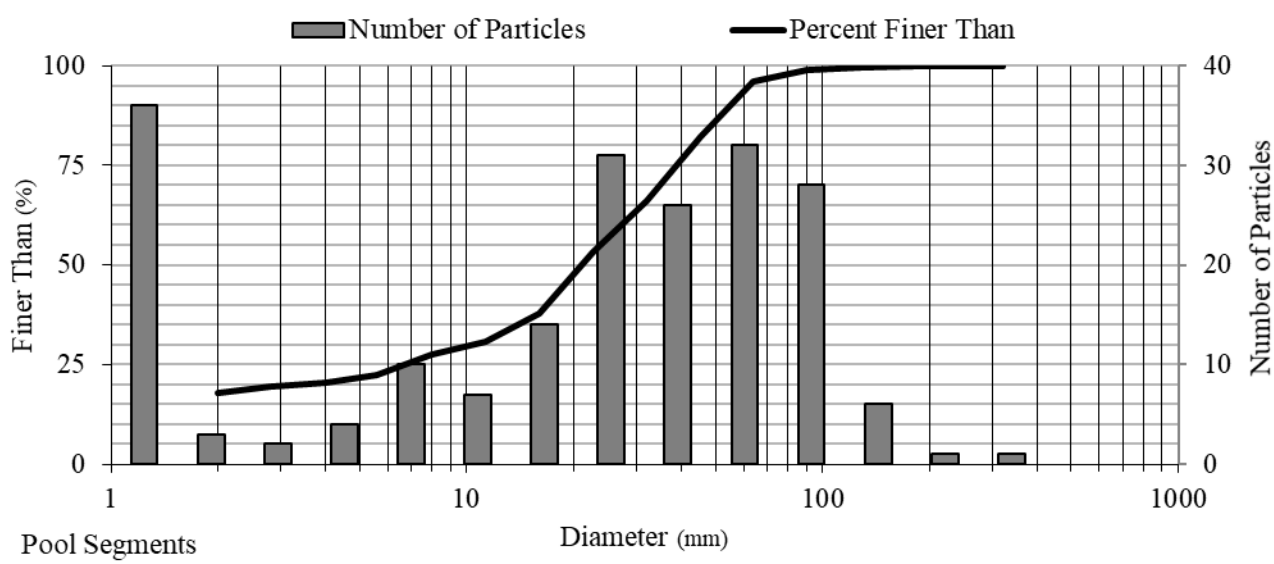

Figure 28. Pebble counts measured at pool segments on September 19th, 2018 and the calculated value for the percentage of substrate particles finer than any given particle size observed at either location.

Appendix B – LPI Field Datasheet

Obeservers: ________________ **Carmel River Rancho Canada** Page ___ of___

Xsect#: ____________________ **Datasheet: Line Point Intercept** Date:_________________

Base Xsect:	Bearing:	WP:	Lat:	Long:	Xsect (m):	Xsect (%):
Base Xsect Slope Breaks (dist, %, and Fluvial Setting):						

Point (m)	Ground Cover[1]	Understory <1.5 m				Middlestory 1.5 m to 5 m			Overstory > 5 m			Fluvial setting[2]	Notes
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1. Ground Cover: Si - bare silt or clay, Sa - bare sand, G - gravel, P - pebble, C - cobble, BL - boulder, BR - bedrock, Wa - water, BV - basal vegetation, BY - bryophyte, Wo - wood, L - litter

2. Fluvial setting: CH - channel, B - bank, FP1 - floodplain 1, FP2 - floodplain 2, T1 - terrace 1, I - island, BC - back channel, Tr - transition (record actual distance of breaks)

* Stand on left, sample on right