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San Clemente Dam Removal and Carmel River Reroute Monitoring Plan: Carmel, CA

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Executive Summary

This study was conducted as part of a class project by students in the Advanced Watershed Science and Policy (ENVS660) course at California State University at Monterey Bay (CSUMB). The goal of this paper was to create a monitoring plan to record and quantify impacts of dam removal and river reroute on the Carmel River along the California Central Coast.

California's dams are aging, and many will need to be decommissioned over the coming decades. While the impacts of dam construction are well documented by volumes of scientific literature, we have limited understanding of both short and long-term environmental impacts of dam removal. This imbalance reflects the insufficient number of dam removal monitoring studies. Each new instance of dam removal offers an invaluable opportunity for scientific study within the context of a "natural laboratory." The results of such studies can be used to predict the impacts of subsequent dam modifications in the state and beyond.

The 91-year-old San Clemente Dam (SCD), which is impounding sediment of the upper Carmel River, is scheduled to be fully decommissioned by 2016 because of seismic safety issues. This event provides the next opportunity to assess the impacts of dam removal on related biological and physical systems of the watershed. This example of decommissioning is unique from previous examples because the great volume of sediment currently stored in the reservoir will be engineered and stabilized in place rather than released downstream. Simultaneously, the Carmel River will be permanently rerouted through a nearby tributary to prevent displacement of the stabilized sediment.

Watershed systems susceptible to change due to dam removal were analyzed using literature reviews and also presentations by regional resource managers and scientists. The watershed systems considered in this monitoring plan are divided into two overarching categories. First order changes (hydrology, fluvial geomorphology, coastal geomorphology) are

measurable changes in the generally abiotic systems of the watershed. Second order impacts (aquatic, terrestrial and marine ecosystems) within the biological systems of the watershed are hypothesized to result from the first-order changes.

For each system we discuss the processes that may lead to physical or biological change. Based upon those discussions, we specify testable hypotheses that can be evaluated by comparing pre- and post-dam data sets. We cite the locations of pre-existing data sets and propose detailed monitoring strategies for both pre- and post-dam time periods. While we anticipate that some systems might show significant impacts soon after dam decommissioning begins, we have also planned for longer time frames of monitoring for systems that might react more slowly.

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1 Introduction

1.1 Background

Dams provide valuable services including municipal water supplies, irrigation, hydroelectric power, improved navigation, flood protection, and expanded recreation opportunities (Graf 1999). While dams provide valuable services, undesirable ecosystem changes have become apparent over numerous scales (Graf 1999; Doyle et al. 2003). Common impacts include fish migration barriers, recruitment of invasive species, downstream channel degradation, beach erosion, and water quality degradation.

In general, dam and reservoir impacts have been well documented, but the impact of decommissioning dams is still unclear, with few examples or large scale removals to draw upon. In recent years, the Marmot Dam (Podolak 2010) and Elwha Dam (Winter and Crain 2008) were decommissioned for chiefly environmental reasons, but published accounts of the related impacts are still sparse. According to the Association of State Dam Safety Officials, the average life expectancy of a dam is 50 years at which point material and structural integrity may be considered compromised (ASDSO 2000). Over 30% of dams in the United States are over 50 years old (ASDSO 2000), underscoring the need for scientific studies that illuminate the long- and short-term environmental impacts of dam removal. San Clemente Dam (SCD) offers the opportunity to study dam removal impacts in the Carmel watershed of the California Central Coast (Fig. 1).

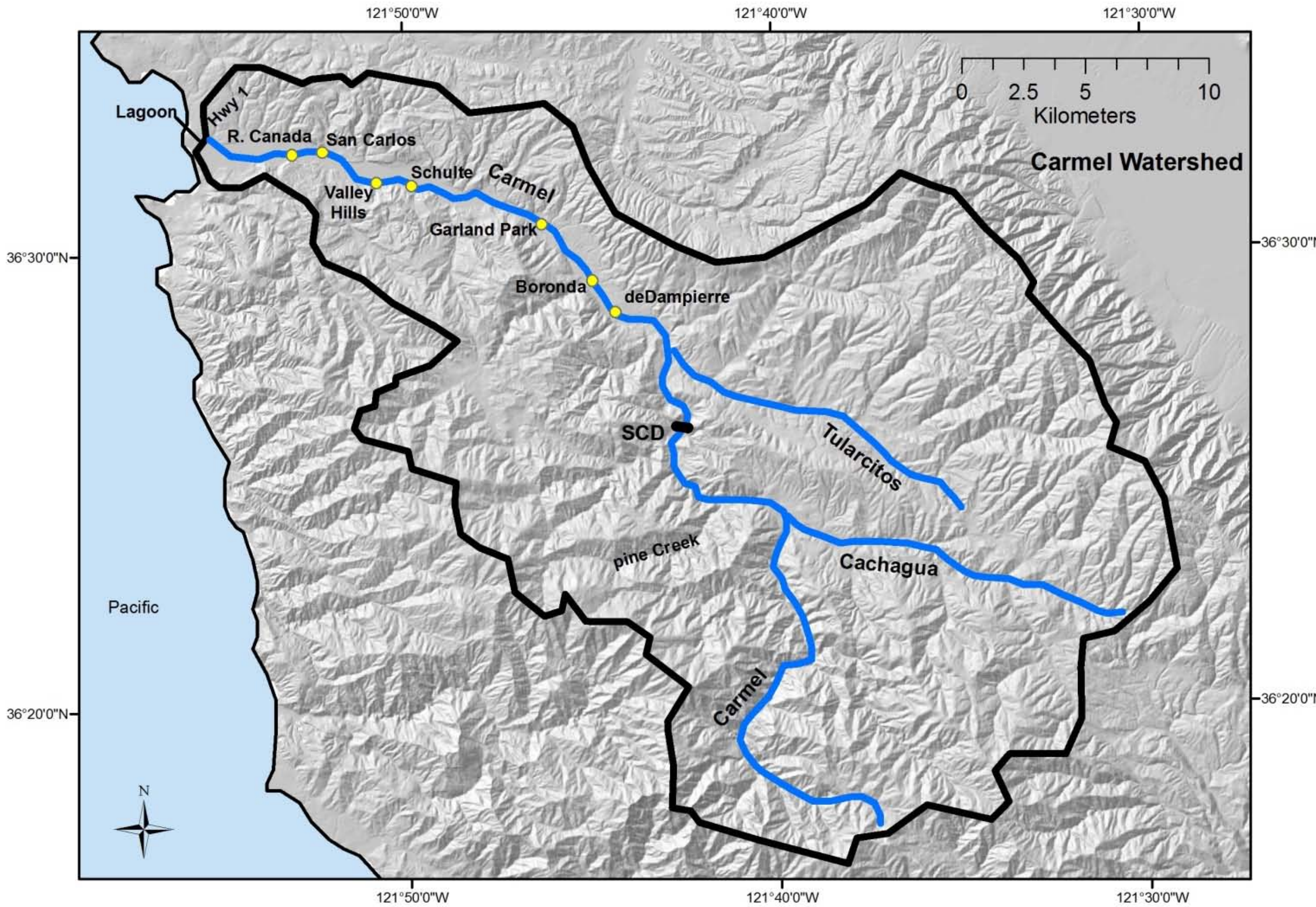

Figure 1. Carmel River watershed, Monterey County, CA. The black polygon indicates the Carmel River watershed boundary, while blue denotes the river location and a few primary tributaries. San Clemente Dam (SCD) is indicated.

Constructed in 1921, SCD is a 106-foot-high concrete-arch dam located approximately 18.5 miles from the Pacific Ocean on the Carmel River in Monterey County, CA (Capelli 2007; Fig. 2). When constructed the San Clemente reservoir had a storage capacity of 1,425 acre-feet of water, but as of 2008, it was 90% filled with 2.5 million cubic yards of sediment (SCDRP 2012). The SCD is situated between several seismically-active fault zones including the Cachagua and Tularcitos faults (Fig. 3). The California Department of Water Resources (Division of Safety of Dams) determined that the SCD would not withstand the seismic loading from a Maximum Credible Earthquake or endure a Probable Maximum Flood (Capelli 2007).

Figure 2. SCD on the Carmel River, CA. (Xasuan, 2012)

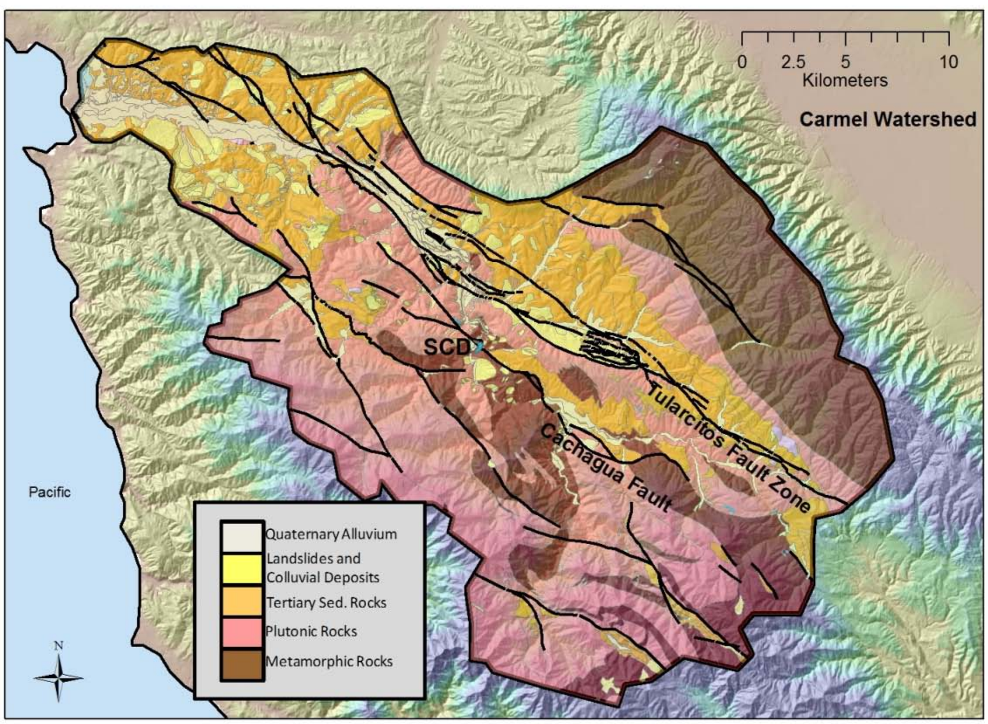

Figure 3. Geologic map of the Carmel River watershed (Geologic data from Rosenberg, 2001).

In response, the dam owner (California American Water Company) hired URS Corporation to create a plan to decommission the dam. The plan is unique from other projects because it stabilizes the reservoir sediment in place, and reroutes the Carmel River into an existing adjacent channel that circumvents the sediment. The current Carmel channel will be rerouted, into the historic channel of San Clemente Creek, where the combined flow will pass around the sediment wedge, utilizing the historic San Clemente channel (Fig. 4).

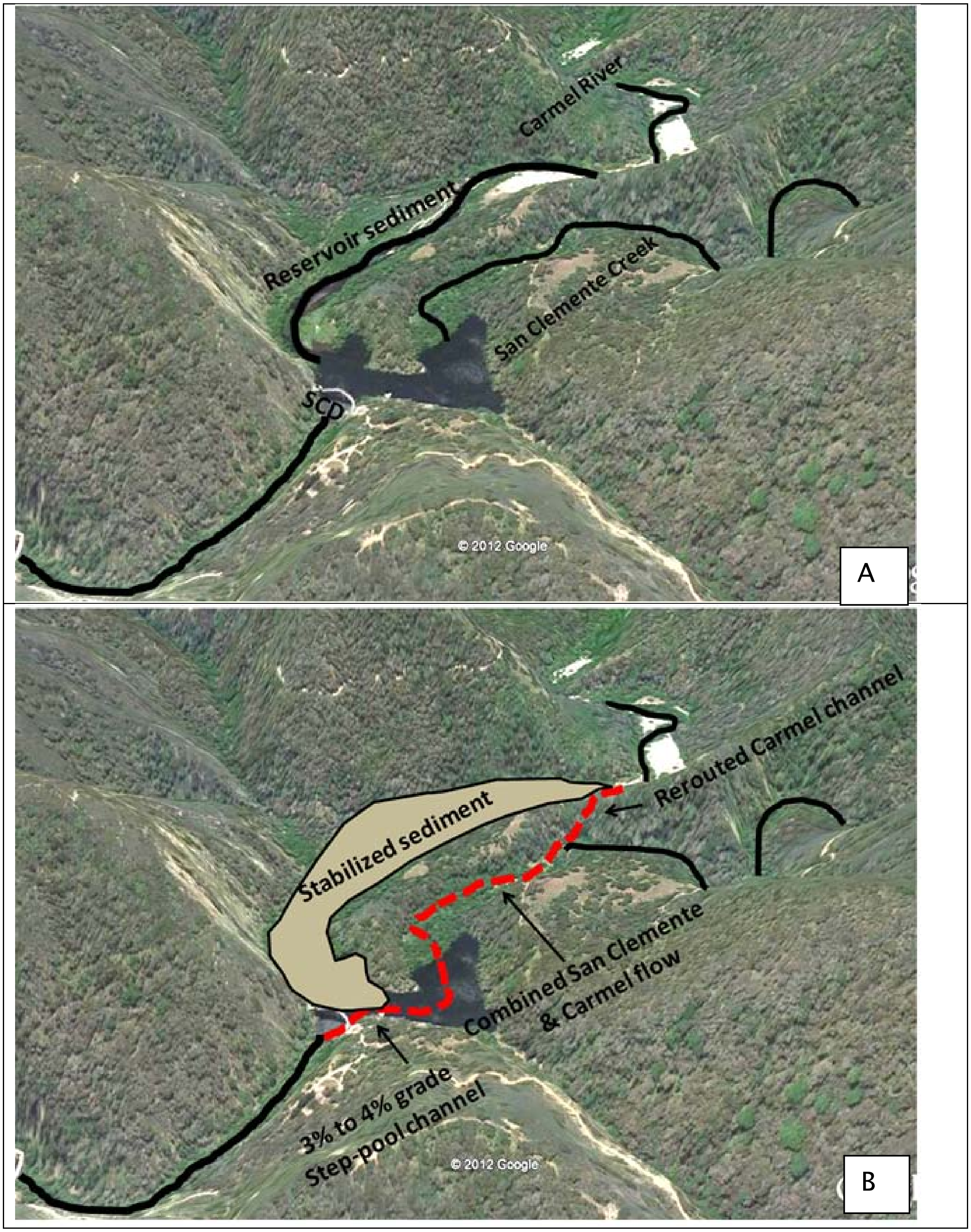

Figure 4. Schematic of channel geometry before (A) and after (B) SCD removal and Carmel River reroute. Background is oblique aerial photographic view in upstream direction (Google Earth).

The technical, legal, regulatory, and economic processes required to remove the SCD are nearly complete. This historic dam removal will be one of just a handful of larger dam removals to have occurred worldwide. The paucity of real-world examples of dam removal means that the short and long-term consequences of removal are only poorly understood. While dam removal projects may achieve the immediate goals of improved fish passage or improved safety, the dynamic nature of river processes dictates that other unintended positive and negative impacts will certainly occur. The ultimate effects of future dam removal projects would be less uncertain if there were a synthesis of the collective knowledge of past dam removal projects. In this regard, we present a monitoring plan that is specific to the climatic, geologic, ecological, and land-use context of the Carmel watershed.

1.2 Study area – Carmel Watershed

The Carmel watershed lies within the Santa Lucia Mountains at the apex of several fault zones. It is underlain by poorly consolidated marine sediments as well as metamorphic and granitic formations with a drainage area of 255 square miles (Capelli 2007; Fig. 3). The watershed ranges in elevation from slightly greater than 4,000 feet to sea level. The Carmel River is 36 miles long, beginning in Los Padres National Forest and draining into the Pacific Ocean near Carmel, CA. The central California coast has a Mediterranean climate with moderate year-round temperatures. Virtually all precipitation falls between November and April, with 60% falling between December and February (Kondolf and Curry 1986). The Carmel River watershed developed into a highly dynamic system, experiencing large seasonal variability in flow levels with subsequent variation in sediment transport from the upper watershed to the lagoon and ocean (PWA 2007). Species of concern include the steelhead trout (*Oncorhynchus mykiss*) and California red-legged frog (*Rana aurora draytonii*), both of which are currently listed as threatened at federal and state levels. Portions of the lower Carmel River floodplain have been developed with a variety of residential, commercial, and recreational (including golf courses) uses, some of which are subject to periodic inundation from the Carmel River (Capelli 2007).

1.3 Goal

The overarching goal of our study was to create a hypothesis-driven monitoring plan that can quantify the physical and biological changes related to the removal of SCD. The focus of this plan was to capture physical changes to the system that can influence ecosystem function or cause risk to property.

1.4 General Methods

We divided the monitoring plan into first-order changes (hydrology, fluvial geomorphology, coastal geomorphology) and consequential second-order biological impacts (aquatic, terrestrial and marine ecosystems). We proposed null hypotheses representing the status-quo for the Carmel River, with alternate hypotheses being detectable change between the pre-removal and post-removal time periods.

The Carmel River has naturally high background variability in hydrology and sediment supply through space and time, with the system varying dramatically on a decadal scale. Lack of baseline data characterizing this variability presented difficulties in the formation and investigation of hypotheses. As this may be the first attempt to reroute a river around impounded reservoir sediment, interpreting data and literature from previous dam removals was also problematic. In each case, the existing data from the literature were considered and supplemented by personal communication with local and regional watershed experts before an hypothesis was created. Hypotheses and monitoring strategies were improved through this feedback with watershed experts from the MPWMD, NOAA, and the USGS.

2 First-Order Changes

2.1 Hydrology and Water Quality

2.1.1 Background

Hydrologic conditions on the Carmel River are primarily driven by precipitation frequency, intensity and spatial distribution. Regional climactic conditions are primarily driven by proximity to the ocean and mountainous regions as well as pressure zone pathways. Climate conditions are commonly referred to as Mediterranean, where seasonal rain can supply highly variable annual, seasonal and spatially distributed rainfall. The SCD has historically received from 3-46" of precipitation over any particular winter season. Regional climate variability, geomorphic characteristics, and modified floodplains have dramatically altered the natural state of the river. Physical and chemical water quality (WQ) degradation resulting from prolonged water residence time, land use change, channel modification, and both surface and groundwater extraction have occurred throughout the Carmel River watershed since the mid-1800's (MPWMD 2003). Subsequently, anthropogenic modifications of water quality and quantity have affected invertebrates, amphibians, fish and riparian vegetation.

2.1.2 Hypotheses

Disturbance, modified hydrologic conditions, and seasonal fluctuations in annual precipitation each influence WQ and quantity conditions over different temporal and spatial scales. Unavoidable change in temperature, dissolved oxygen (DO), turbidity, and pH are anticipated during the construction and reroute phases of dam removal. In addition, constituents including iron, manganese, fecal coliform, specific conductivity and total dissolved solids (TDS) may differ from previously collected data. The null hypothesis suggests no change in water parameter concentrations will occur due to the Carmel River dam removal and reroute. An alternative hypothesis suggests that both short-term (ST) and long-term (LT) dissimilarities will be observed.

H_0: No change in mean diel temperature
H_a: ST–Increased mean surface water temperature
LT–Stabilization of water temperature around new mean and new variance

H_0: No change in mean turbidity
H_a: ST– Increase in daily mean turbidity below SC dam
LT– Change in daily mean turbidity

H_0: No change in dissolved oxygen (DO) concentrations
H_a: ST– Decreased daily mean DO
LT– Negligible difference to slight increase in DO

H_0: No change in mean pH
H_a: ST– Increase in pH mean and variance
LT–No difference in pH from baseline data values

H_0: No change in hydrogen sulfide (H_2S) daily mean or variance
H_a: ST– Increase in H_2S mean concentrations and variance
LT– Slight decrease in H_2S mean

H_0: No change in nutrient concentrations
H_a: ST– Increased mean and variance of nutrient levels
LT– Similar nutrient concentrations as baseline data values

H_0: No change in hazardous/toxic substances
H_a: ST– Increase in occurrence and concentrations of toxic analytes
LT– No change in hazardous/toxic substances

2.1.3 Existing Data Sets

Previous WQ monitoring participants include: Cardno Entrix, Monterey Peninsula Water Management District (MPWMD), Mussetter Engineering Inc. (MEI), Denise Duffy & Associates, California State University Monterey Bay (CSUMB), Surface Water Ambient Monitoring Program (SWAMP), and Central Coast Ambient Monitoring Program (CCAMP). Table 1 displays public WQ monitoring documents and resources relevant to future post-SCD removal and river reroute. Table descriptions contain relevant pages, parameters analyzed, year, and in some cases, location. Although this is not a comprehensive list, it does provide substantial documentation of pre-dam removal WQ conditions. Understanding the background variation is fundamental to determine variability resulting from the SCD Removal and Reroute activities.

Table 1. Existing hydrology and water quality data sets.

Subject	Summary	Reference
Precipitation	Mitigation Program Annual Reports, Annual Precipitation as flow (Q), precipitation, stream flow, lagoon water Level monitoring (II-1,6,7; IV-5)	MPWMD 2000-11
	Physical and hydrologic assessment of the Carmel River watershed	Smith et al. 2004
	Precipitation, geospatial precipitation data	AMBAG webpage
Discharge/Stage	Annual Discharge, Lagoon stage (II-4) 1992-present	MPWMD Mitigation Program Annual Reports
	MPWMD Surface water resource data report 2004-2008. Precipitation, discharge, historic tree-ring analysis	James 2010
	USGS Carmel River gage sites	MPWMD 2005-12
Flood	Flood inundation mapping and flood hazard evaluation. Model includes dam to estuary, 100-year flood plain inundation, water surface elevation, stage elevation, sediment transport model, downstream impact analysis of the Carmel river reroute and removal option for the San Clemente	MEI 2007
	Potential effects of groundwater extraction on the Carmel lagoon, stage height, groundwater	Watson and Casagrande 2004

	extraction wells	
	Physical hydrology characterization including precipitation, surface and groundwater resources. Pg. 24-40. Physical and hydrologic assessment of the Carmel River watershed	Smith et al. 2004
Water Quality	Mitigation Program Annual Reports, RM-27, 25.4, 18.5, 17.1,10.8 ,0.1, semi-annual WQ monitoring: pH, temp, DO, WSE, Conductivity, Turbidity, CO2 (III-1 to 4) 1991-present	MPWMD 1991-2012
	Sonde measurement of water quality temporal variation. Lagoon profiles and isographs of salinity, temperature, DO, chlorophyll *a*, light	ENVS 2010
	Dam removal WQ impacts (Sect 4.2.2), SCD seismic safety project: Draft supplemental EIR #2 SCH#2005091148	URS and MPWMD 2012
	Biological Opinion (BO), Water quality relating to dewatering sediment & reservoir (Pg. 24, 25)	NOAA and NMFS 2012
	Evaluating good WQ habitat for steelhead in Carmel Lagoon	ENVS 2010
	Pg. 28-35, Physical and hydrologic assessment of the Carmel River watershed	Smith et al. 2004
	Evaluating good WQ habitat for steelhead in the Carmel lagoon- salinity, temperature, DO, light, chlorophyll *a*	ENVS 2010
	Final SEIR SCD Seismic Safety Project: Chpt. 1, 2, 3, 4, 6 WQ. 4.3-1 to 4, Alternate 3: Carmel River reroute & dam removal (3.5-1), Alkalinity, pH, Conductivity, Ions, Metals, Turbidity. 2002 Cardno Entrix data included	CDWR 2012
	Data available from 1991 - 2012: contamination, septic leak, aquifer quality, semi-annual and annual sampling, chloride, 12.52, 13.65, 14.38, and 8 Lower Reach sites, SEC (IV-3 to 10)	MPWMD 2012
	Potential effects of groundwater extraction in the Carmel Lagoon	Casagrande and Watson 2003
	WQ and aquatic wildlife monitoring	Larson et al. 2005 Perry et al. 2007
	WQ parameters, groundwater quality and quantity data. 12-50 semi-annual wells sampled based on necessity	Bulletin 118: California's Groundwater 2004

	Surface water monitoring by hydrologic sub-area: pH, conductivity, turbidity, DO, temperature, nitrate, nitrite, fecal coliform bacteria, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), $CaCO_3$, chloride, ortho-phosphate	SWAMP 2002
	Surface water flow and yield data report: Water Years: 2000-2003, 1996-1999, 1992-1995, 1991-1994, 1991-2005	James 1994, 1996, 1999, 2005
	Ambient WQ criteria for DO	Chapman 1986
	Carmel river basin surface WQ data report: Water years 2004-2008. Contains data tables and sample site photos/characterization 2004-2008. Measured parameters: pH, turbidity, temp, conductivity, salinity, carbon dioxide	Hamilton 2010 (unpublished)
	GIS CA Clearinghouse # 2005091148. WQ mitigation practices and mitigation measures during dam reroute and removal	DWR 2012
Groundwater/Pore water	Final SEIR SCD Seismic Safety Project: Chpt. 1, 2, 3, 4, 6. CAW Drawdown: 4.3-1 to 29, surface water sample locations, pore and groundwater samples: DO, turbidity, temperature, pH	CDWR 2012
Lagoon	Surface water dynamics at the Carmel Lagoon water years 1991 through 2005	MPWMD 2005
	In situ depth profiles over time, isopleths, on site lab analysis of physical samples, TSS, turbidity, salinity, temp, DO, chlorophyll *a*, pH, CO_2, Suspended Sediment Concentrations (SSC), H_2S. Lagoon subdivision including monitoring locations	Larson and Watson 2006;Watson and Casagrande 2002, 2003, 2004; ESSP 2007; ESSP 2008; ENVS 2010

2.1.4 Methods

Complex biogeochemical interactions may occur. We propose stratified, zone-specific sampling based on the detection and exceedance of parameter thresholds for the following reasons: fixed monitoring infrastructure, limited access, budget constraints and appropriate allocation of limited resources.

The timing and spatial location of anticipated impacts is important to consider before designing a monitoring strategy (Table 2). Sub-division of the Carmel River watershed for the purpose of stratified sampling based on impact detection will support increased higher frequency of data. WQ analysis should take place within eight zones including:

1) Reference sites upstream of SC reservoir in SC Creek and Carmel River
2) Reservoir pore and surface water
3) Designed reroute channel
4) Below SCD to the Old Carmel River Dam
5) Below the Old Carmel River Dam
6) Below the Old Carmel River Dam to the lagoon
7) The lagoon
8) Post-breach marine sampling

WQ changes will first be detected in Zones 3 and 5. Initial monitoring should be concentrated in Zones 1-5 for the purpose of capturing and analyzing short term impacts. Our goal is to capture impacts at the finest resolution while also capturing spatial effects as the WQ parameters are transported to receiving water. Leveraging *in-situ* YSI data, in-stream continuous loggers and physical monitoring should provide data that can be statistically analyzed. The following sites are going to be used: (Fig. 5).

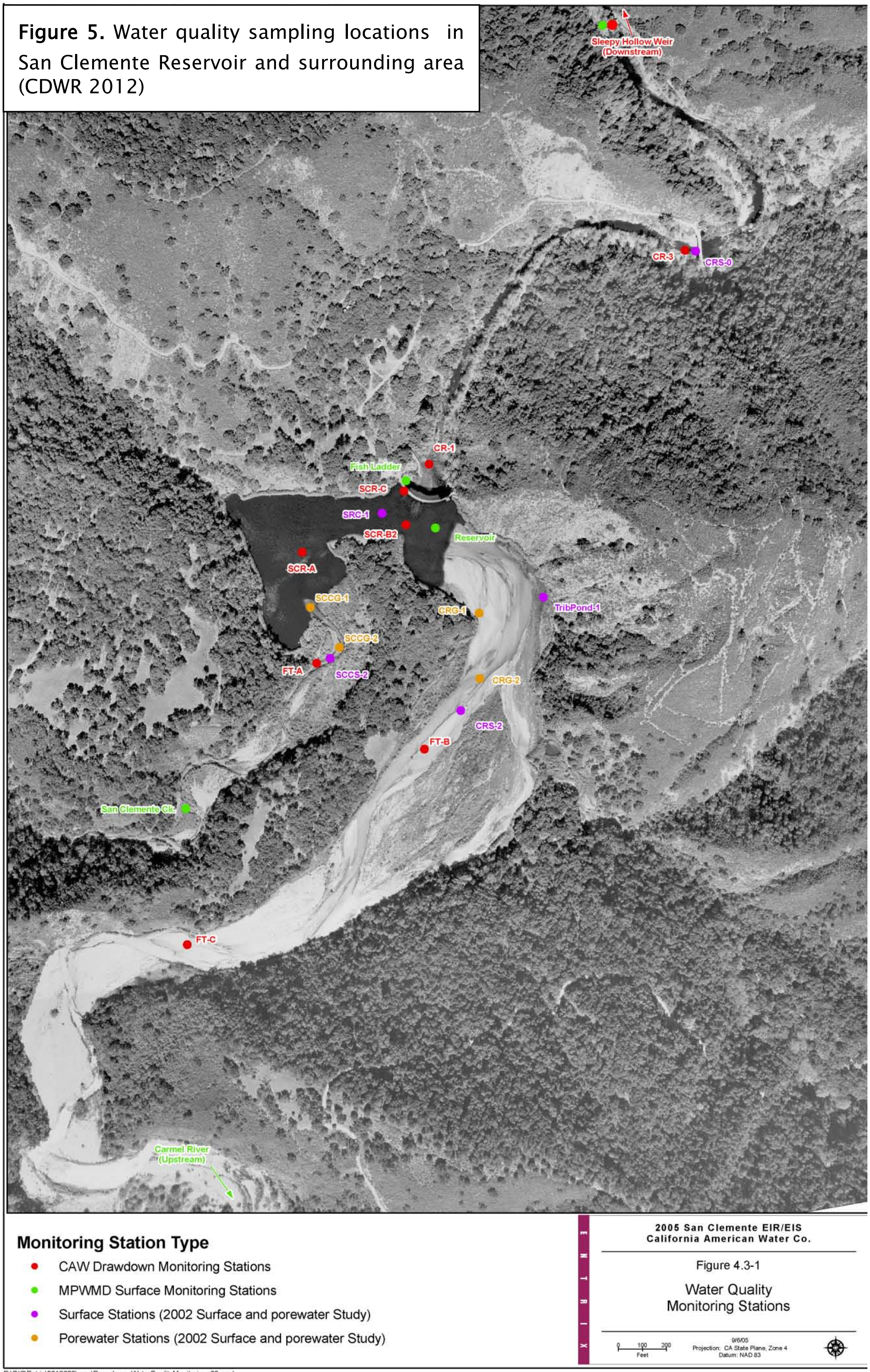

Figure 5. Water quality sampling locations in San Clemente Reservoir and surrounding area (CDWR 2012)

Table 2. Hydrologic monitoring methods.

Subject	Predicted Change	Implications	Methods	Location	Frequency
Temperature (T)	**ST**: Similar to previous levels	• key physical driver of habitat in aquatic ecosystems • Important environmental determinant of water chemistry, especially DO • Fundamental constraint to supporting aquatic ecosystems • Stressor	*In situ* YSI Environmental Multiprobe System and physical snap-shot samples. Create reference sites above dam site, compare to previous data	Control site, locations outlined in SEIR, previously MPWMD sites, in Zones 1-4	Continues *in-situ* or diel monitoring
	LT: Slight decrease		*In situ* YSI Environmental Multiprobe System and physical snap-shot samples, compare with previous data	USGS gage sites, MPWMD collection sites, in Zones 1- 6	Weekly or monthly sampling regime
Dissolved Oxygen (DO)	**ST**: Decreased concentration	• Factor in atmospheric reaeration and photosynthetic activities of aquatic plants. • Determinant of chemical and biological reactions in ground water and surface water • Inversely correlated: higher water temperature and turbidity resulted in lower DO • Metabolic state of steelhead and rainbow trout	*In situ* YSI Environmental Multiprobe System and physical snap-shot samples, amperometric, or spectrophotometric method. Compare with previous MPWMD, URS, CCAMP datasets	Control site, SEIR locations for both surface and groundwater	*in-situ* continuous monitoring
	LT: Stabilization to post-1949 Los Padres Dam construction levels		*In situ* YSI Environmental Multiprobe System, amperometric, or spectrophotometric method, or continuous data logger installation	USGS gage sites, MPWMD collection sites	Daily or bi-weekly

pH	**ST**: Change at SCDRR site change due to unweathered geologic exposure	• Determines solubility and biological availability of chemical constituents, measure of the relative amount of free hydrogen and hydroxyl ions in the water	*in-situ* YSI Environmental Multiprobe System and physical snap-shot samples	Control site, below SCDRR site, MPWMD sites, estuary	Daily
	LT: Stabilization to post-1949 Los Padres Dam construction		*in-situ* YSI Environmental Multiprobe System and physical snap-shot samples	Control reach, SC Creek, below SCDRR	Weekly
Conductivity	**ST**: Minimal change	TDS decreases may indicate introduction of pollutants into system Proportional to major ion concentrations and hydroxyl ions in the water	*In-situ* YSI Environmental Multiprobe System and physical samples	Control site, below SCDRR site, MPWMD sites, estuary	Daily
	LT: Reduction of Total Dissolved Solids (TDS)		Physical samples	Control reach, SC Creek, below SCDRR	Bi-Monthly
Nutrients	**ST**: Increase	• Inorganic and organic nutrients are characterized as limiting growth factors aquatic flora and fauna	*in-situ* YSI Environmental Multiprobe System and physical snap-shot samples, SEIR previously defined locations of both surface and groundwater	Upstream of coffer dam, detention pond discharge sites, pore water, control site, SC Creek, reroute channel, below dam construction, estuary	Daily
	LT: Reduction		*in-situ* YSI Environmental Multiprobe System and physical snap-shot samples. Further analysis of water samples for specific constituents	Control site, below SCDRR, estuary, MPWMD previous locations	Bi-weekly or weekly

Turbidity	**ST**: Increase	• Fine sediment transport • Microfauna death • Above thresholds fish fatality may occur	Turbidimeter, YSI handheld multi-parameter instrument, physical grab samples	Control site above SC reservoir, reroute channel, below dam site, previous collected sites throughout watershed, detention pond discharge	Daily
	LT: Decrease		Turbidimeter, *in-situ* YSI Environmental Multiprobe System and physical snap-shot samples, compare with previous data	Control site, reroute channel, SC creek, old Carmel river dam, previous sites, estuary	Weekly
Hydrogen Sulfide (H_2S)	**ST**: Increase in short term occurrence and severity	• Toxic to nervous and respiratory systems of aquatic organisms • Fatal for invertebrates • Reduces DO concentrations	Field water samples due to rapid dissolution	Control site above SC reservoir, reroute channel, below dam site, previous collected sites, detention pond discharge	Hourly during construction activities near the or stream bank margin
	LT: Decrease		Field water samples due to rapid dissolution	Zones 4-6	Weekly
Hazardous & toxic substances	**ST**: Significant	•Can be catastrophic to local flora and fauna • Pose both short and long term affects to both surface and groundwater resources • Are difficult to capture using physical 'grab sample techniques, must be mitigated	Specialized lab analysis of physical sample	Random samples below construction sites, emergency sampling	Daily or weekly; dependent upon substances present
	LT: No change		Unknown	Unknown	Post construction bi-monthly or monthly

Fecal Coliform (FC)	**ST**: Negligible change	• Can be used as proxy for pathogens in water system	Field water sample requiring filtration-incubation and colony counts	Control sites, below SCDRR	Daily
	LT: Reduction		Physical water sample requiring filtration-incubation and colony counts	Control sites, below SCDRR	bi-weekly or monthly
Dissolved manganese and iron	**ST**: Increase	• Affects pH, demand by biological organisms and chemical equilibrium within the system	Field water sample, *in-situ* YSI Environmental Multiprobe System and physical snap-shot samples	Control site, SEIR defined samples sites for pore water, detention basin discharge, stormwater runoff below reservoir sediments, SC Creek	Daily or following storm events
	LT: No Change		Physical sample, YSI multi-probe meter	Control, pore water, detention basin discharge, stormwater runoff below reservoir sediments, SC Creek	Bi-weekly, with increased frequency following precipitation events
Stage height	Increase in stage height for a given discharge	Increased flood frequency, causing threat to near-shore infrastructure	In stream measurements to calculate gage specific stage-discharge curve, gage height, Multi-reach variable flow HEC-RAS model, LiDAR or other accurate transects, aerial imagery	All USGS gages, at beginning and end of reroute channel, Carmel Lagoon	Standard frequency at USGS gages

2.2 Fluvial Geomorphology

2.2.1 Background

The Carmel watershed lies within the Santa Lucia Mountains at the apex of several fault zones; it comprises poorly lithified marine sediments and highly-fractured metamorphic and granitic rocks (Capelli 2007; Figure 3). The river flows through the alluvium-filled Carmel Valley, where sediment depths range from 15 to 20 m before emptying into the Carmel Lagoon (Kondolf and Curry 1986). The river channel has stretches of meandering flow, steep constrained reaches of bedrock, and a few short braided reaches (Kondolf 1996). River valley width and slope are two contributing factors to river behavior that are of particular interest in the Carmel River.

The SCD has retained 2.5 million cubic yards of bedload and large woody debris (LWD) since its construction, depriving the lower river of sediments and LWD for almost 100 years (MEI 2008a). Rivers that have been deprived of natural sediment inputs from upstream of dam sites often compensate by eroding sediments from the lower floodplain below the dam (Draut et al. 2011). Armoring along the river has been, and still is, used to combat the sediment starved reaches of the river from eroding banks and widening the river valley. Mussetter Engineering, Inc. (2002) found that up to 40% of the river's banks from the mouth to Rosie's Bridge (RM 30) have been artificially hardened to protect infrastructure from erosion. Hardened banks have prevented sufficient compensational erosion from taking place in the lower floodplain, causing the river to degrade and narrow (Kondolf 1986). Previous studies indicate that background variation of channel bed elevation in the upper watershed ranges from 10-50 cm, while fluctuations in the lower watershed are much greater (Kelly 2012; MEI 2008a).

2.2.2 Hypotheses

Changes in sediment load to the downstream floodplain of the Carmel River after the SCD removal and reroute has significant consequences for the Carmel River ecosystem and the surrounding infrastructure. This monitoring plan pursues multiple hypotheses regarding the effects of dam removal and river reroute on geomorphology of the river channel. The following hypotheses are:

H_0: No change in LWD density and size
H_a: Increased LWD density and size

H_0: No change in bed elevation
H_a: Increased bed elevation

H_0: No change in thalweg profile
H_a: Change in thalweg profile

H_0: No change in bed material size distribution
H_a: Increase in fine sediments (sands and gravels)

H_0: No change in bed load volume
H_a: Increase in bed load volume

H_0: No change in suspended sediment load volume
H_a: Increase in suspended sediment load volume

H_0: No change in embeddedness
H_a: Long-term increase in embeddedness

2.2.3 Existing Data Sets

Previous studies of the geomorphology of the Carmel River were collected to provide insight for a comprehensive monitoring plan (Table 3). Mussetter Engineering Inc., on behalf of the Monterey Peninsula Water Management District, conducted predictive modeling regarding sediment loading and changes in channel morphology after SCD removal and reroute. LWD monitoring has been conducted by California State University Monterey Bay. It is recommended that the previous studies be used to help facilitate future sampling locations and monitoring techniques.

Table 3. Existing geomorphology data sets.

Subject	Summary	Reference
Bank erosion	• Characterization of bank erosion 1911-1980 • Used historic surveys, photographs, and topographic maps • Relocated and re-surveyed 30 cross- sections surveyed in 1965 by US ACE (not georeferenced) • Classified slope, grain size, degree of bank stability and collected bed/bank sediment samples	Kondolf and Curry 1986
Sediment	• Sediment transport analysis of proposed reroute using computer models • Bed sediment size distribution • Predicted timing, volume, distribution of sediments transported by new channel and mean bed elevation changes • Appendix C1 contains computed average suspended sediments concentrations • Appendix D contains temporal change in median grain size	MEI 2008a
	• Potential failure models of the bypass channel including: • Channel modification that could cause a partial or total barrier to upstream migration of adult steelhead • Temporary disassembly of channel morphology • Predicted excessive floodplain scour and removal of riparian habitat	MEI 2005
	• Predicted reduction of sediment loads to Pacific Ocean with/without dam	Willis and Griggs 2003
	• Stream gauge locations • Post-dam sand fluxes • Estimated sand flux and sediment loading	Slagel and Griggs 2008
	• Predicted effects of step-pool design of reroute on sedimentation • Predicted future aggradation in step-pool system • Description of river reroute plans	USSD 2011

	• Surveyed six cross-sections in the upper river and conducted pebble counts at 8 reaches to assess bed elevation changes and grain size distribution	Kelly SA 2012
	• Contains georeferenced cross-sections in Carmel Lagoon (1994-2011)	MPWMD 2012
	• Topographic mapping of 19 river miles below SCD at 2ft contour intervals • Sediment transport model for same 19 RM • Observed geomorphic conditions (bed material grain size, average gradient, length of bank with hardening protection, annual sediment supply, suspended load estimates) and took sediment samples along same 19 RM	MEI 2002
Longitudinal profile	• Bathymetric profile of thalweg in lagoon	Castorani et al. 2008
	• Surveyed the longitudinal profile from river mount to the Robinson Canyon Bridge and in Carmel Valley Village reach • Surveyed cross-sections at main bridges • Compared 2007 surveys with previous longitudinal profiles • Contains survey control points used	GMA 2007
	• Thalweg profiles along Carmel River • Thalweg survey locations	Chaney *pers. comm.*
LWD	• 7 survey reaches with: GPS location of each piece of LWD, average density, length and width • Evaluated physical function of LWD in terms of bank protection/bed scour	Smith et al. 2003
	• 13 survey reaches with: GPS location of each piece of LWD (some tagged), average density, length and width of LWD • Evaluated physical function of LWD in terms of bank protection/bed scour	Smith and Huntington 2004
	• Re-located Smith and Huntington (2004) tagged LWD to assess distribution and movement	Price 2005
Predicted post-dam removal geomorphology	• Potential issues of upstream/San Clemente creek diversion (erosion, channel morphology, landslides, etc)	MEI 2008b
Embeddedness	• Visual embeddedness estimates	MPWMD 2010
	• Characterization of embeddedness throughout stream channel	Sylte and Fischenich 2002

2.2.4 Methods

We propose to monitor the impacts of the SCD removal and reroute on geomorphological processes by surveying cross-sections within multiple reaches of the river, creating a longitudinal profile, sampling bedload, tagging and tracking LWD, and analyzing embeddedness of bed material. We have suggested five reaches for intensive study that represent the diversity of the Carmel River channel and are likely to exhibit change after dam removal (Figure 6). Cross-sections and study areas from previous research are also used and are cited below (Table 4).

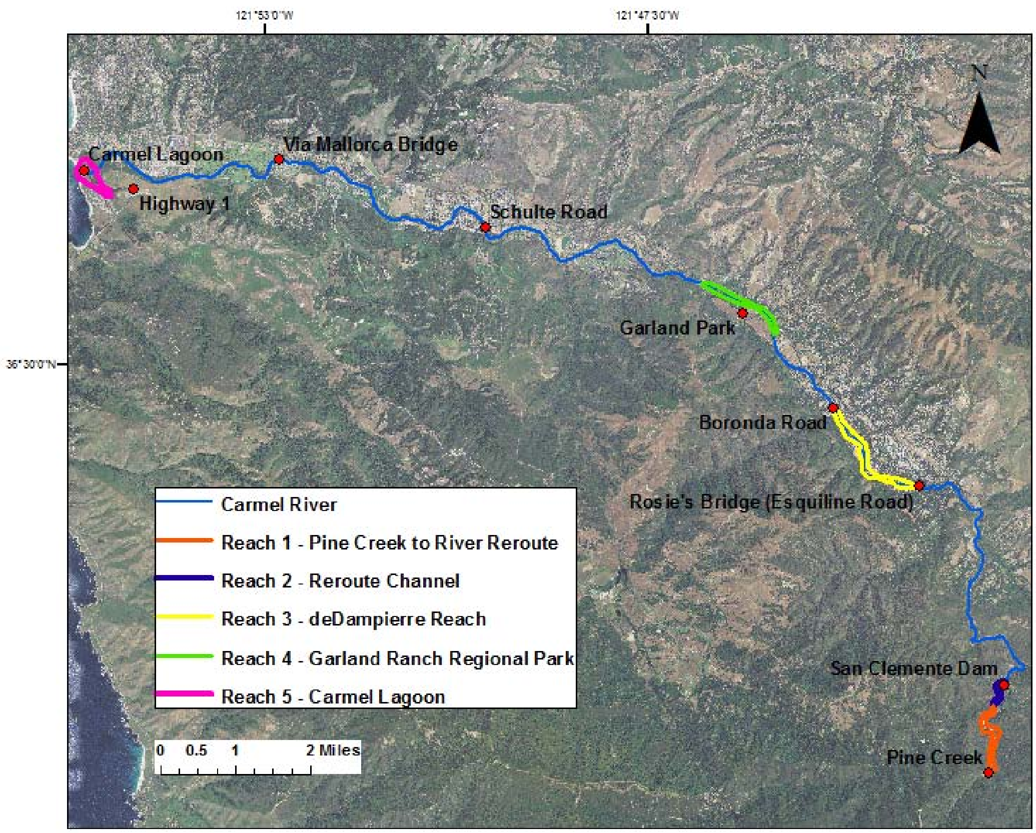

Figure 6. Proposed reaches for geomorphic monitoring.

Table 4. Fluvial geomorphology monitoring methods.

Variable	Predicted Change	Implications	Methods	Location	Frequency
Bed elevation	Bed elevation will increase and channel will become more braided	Influences flood stage, channel migration, fish habitat, bank erosion, lagoon breaching frequency	Benchmarked channel cross- section surveys	Five suggested reaches, using pre-established cross sections for the lagoon (MPWMD 2012). Reaches include: 1. Pine Creek to reroute channel 2. Rerouted channel 3. DeDampierre Reach, between Esquiline Rd and Boronda Rd 4. Garland Ranch Regional Park 5. The lagoon	Annually for first 5 years, then every 5 years for up to 40 years
Thalweg profile	Gradual aggradation	Potential negative impacts on fish habitat, changes in channel migration, bank erosion	Use total station surveying equipment according to (GMA 2007)	From river mouth to Pine Creek	

Large woody debris	Increased density and average size	Added diversity to stream habitat, offered bank protection, supplied nutrients to aquatic ecosystem. There was also concern with negative impacts to in-stream structures such as bridges	Complete survey of reaches for LWD, tagging LWD when detected, recording designated parameters (Smith et al. 2003, 2004) and recovering GPS coordinates with a handheld unit	Smith et al. 2003 and 2004 survey reaches, plus additional reach at base of river reroute site	
Bed material size distribution	Increase in fine sediments (sands & gravels)	Increased spawning habitat for fish, potential negative impacts on benthic macroinvertebrates, change in Carmel beach grain size	Conduct Wolman Particle Count	Longitudinal profile and cross-sections	
Bed load	Long-term increase in bed load volume	Impact on spawning habitat for steelhead, aggradation/degradation, flood stage	Helley-Smith bedload sampler	MEI (2008) benchmarked bridges and at mouth of each major tributary	
Suspended load	Increase in suspended load volume	Impacts on fish habitat, aquatic vegetation, aggradation in lagoon, increased turbidity	Nilsson Sediment Sampler	MEI (2008) benchmarked bridges and avoid locations directly below tributaries as this can cause heterogeneity in grain-size distribution	

Embeddedness	Long-term increase in embeddedness	Improved fish spawning habitat	Complete embeddedness survey according to Platts/Bain method (Sylte and Fischenich 2002)	One area within each reach	

2.3 Coastal Geomorphology

2.3.1 Background

The Carmel River State Beach, governed by the California Department of Parks and Recreation, is one mile long and extends between two granodiorite outcrops from Abalone (Carmel) Point to Granite Point. The beach receives the majority of its sediment from the Carmel River during winter storm events. The beach has historically experienced sediment loss through anthropogenic processes along the Carmel River. Between the 1920's and 1970's, sand and gravel mining depleted sediment from both the river and the beach. Construction of the SCD in 1921 and the Los Padres dam in 1949, further interrupted sediment supply, which is evident through the mound of impounded sediment behind the dam. Floodplain development in Carmel Valley and bank stabilization projects has also reduced sediment supplied to the beach by the river.

During the summer and fall months, the "bar-built estuary" constricts flow of the river from the lagoon into Carmel Bay due to a natural sand berm built by wind, waves, and low rainfall. During winter storm events, the Monterey County Department of Public Works routinely breaches the sand berm to prevent flooding of private residences along the floodplain ([CRTAC] 2007). An adaptive management plan for breaching the bar has included inlet channels engineered to shift the river flow to the north, the south, and perpendicular to the beach. An inlet channel position in the northern section of the beach threatens bluff erosion along Scenic Drive, while a southern inlet channel and perpendicular position drains the floodplain to water levels too low for certain lagoon species, such as steelhead, to survive.

2.3.2 Hypotheses

It is likely that rapid transport of suspended sediment from dam construction activities and post-construction geomorphic adjustments in the overall river system will reach the lagoon system prior to sand and gravel. An addition of sediment to the lagoon may raise the lagoon stage, decrease capacity of the lagoon basin, and increase the frequency of breaching the bar. Gradually, as material moves downstream, adding sand and coarser material to the nearshore system, the beach berm crest will shift seaward, increasing crest elevation, widening the beach, and reducing wave overtopping events.

H_0: No change in grain size in lagoon
H_a: Short term fining of lagoon substrate

H_0: No change in late summer beach berm crest position
H_a: Beach berm crest location shifts seaward

2.3.3 Existing Data Sets

Monitoring changes in beach morphology will determine the impact of the SCD removal and river reroute project due to sediment influx. We suggest mainly following protocols by Storlazzi and Field (2000) who analyzed textural and mineralogical properties of littoral sediments and morphologic and hydrodynamic properties of Carmel River State Beach. Storlazzi and Field (2000) also measured beach widths from 1949-1990 through aerial photography during the summer months. This study shows beach width shortening in the north and central sections while the southern section has had variable widths. More recently, Laudier (2009) measured beach slope, berm height and discussed wave run-up and wave overtopping models on the Carmel River Beach. Many datasets, provided in Table 5, contain Carmel Bay physical parameters, historical accounts of the breaching locations, and river mouth migration rates.

Table 5. Coastal geomorphology existing data sets.

Subject	Information Summary	Reference
Beach geomorphologic and hydrodynamic properties	• Beach slope • Berm height • Greatest historical change in width measured from aerial photography (1949-1990)	Storlazzi and Field 2000

	• Mean beach width (m) • Beach exposure (degrees) • Mean relative wave height • Modal beach state	
	• Beach slope • Berm height	Laudier 2009
Beach textural and mineralogical properties (littoral sediments)	• Mean, sorting, skewness • Percentages of quartz, feldspars, heavy minerals, shell material	Storlazzi and Field 2000
Carmel Bay Physical Parameters	• Wave height, peak period, peak direction, average period	Coastal Data Information Program
	• Daily/Monthly tides	NOAA Tides & Currents
	• Direction of longshore currents and sediment transport offshore	Thornton 2005
	• Topographic Laser Shoreline Mapping Data: 2 m resolution of shoreline mapping in Carmel Bay	CSUMB Seafloor Mapping Lab
Lagoon/Breaching Dynamics	• Susceptibility index for breaching from the lagoon side	Kraus et al. 2008
	• Location of river mouth opening (1880-2005) and river mouth migration rates	Thornton 2005
	• Date of first opening for water year (WY), maximum lagoon level on opening date, closing dates w/ lagoon levels	James 2005

2.3.4 Methods

Suggested monitoring methods include monitoring grain size distribution in the lagoon and monitoring the beach profile (Table 6). Monitoring grain size distribution through sieve analysis in the lagoon can determine the amount and size of sediment particles the river transports after dam deconstruction and river reroute. Using an RTK-GPS to track the berm crest position provides high vertical and horizontal accuracies to monitor the smallest changes in the beach profile (Lentz and Hapke 2011, Dawson and Smithers 2010).

Table 6. Coastal geomorphology monitoring methods.

Variable	Predicted Change	Implications	Methods	Location	Frequency
Grain size distribution/analysis	Short term fining in the lagoon	An increase in fine sediment may raise water levels and increase the threat of flooding to local residences	Sieve analysis (Storlazzi and Field 2000)	Sediment sample from the thalweg, channel center and 3 m locations on both sides of center line at 3 locations (Figure 7) : Site 1:mouth of the river Site 2: 200 m upstream of mouth Site 3: south arm	Every June during low-flow conditions
Beach profile	Beach berm crest shifts seaward	An increase in sediment on the beach will widen the beach, raise the berm elevation and increase earlier manual breaching events	RTK-GPS or total station (Lentz and Hapke 2011)	Along beach berm crest, from 100 m south of the lagoon to Scenic Drive	Every September before rainfall and annual breaching

Figure 7. Map of grain size distribution monitoring locations in the lagoon.

3 Second-Order Impacts and Consequent Biological Impacts

3.1 Aquatic Ecosystem

3.1.1 Background

The aquatic ecosystem of the Carmel River encompasses a diverse range of biota, which are all affected by anthropogenic changes throughout the watershed, including the SCD. Great emphasis has been placed on the endangered steelhead, a historic resource of the Carmel River that has been degrading over the past century. We are approaching this monitoring plan at an ecosystem-scale in an effort to encompass all physical and biological interactions of this aquatic habitat.

Steelhead populations (*Onchorhynchus mykiss*) in the Carmel River are of particular interest because fish in the river occupy a system near the southern limit of a distinct population segment, and are subject to environmental conditions very different to those of northern populations (Hayes 2008). The sandbar-closed lagoon that forms during low flow periods provides essential nursery habitat for juvenile steelhead. The seasonal closure of the lagoon may constrain the temporal emigration period of smolts to the ocean, as well as the delay the return of spawning adults to the river (Bond et al. 2008; Hayes et al. 2008). The SCD also presents a challenge to the emigration of fish from the upper watershed to the ocean. While the dam's fish ladder facilitates some movement upstream, for downstream migration fish have to swim over the edge of the dam and drop to the plunge pool below. This drop of over 100 feet into the pools may be responsible for the death of fish during their trip downstream to the ocean.

Steelhead display highly variable life history patterns as they are both facultatively anadromous, meaning that they choose if and when to return to the ocean, and iteroparous, meaning that they can spawn multiple times. Subtle changes in freshwater conditions, by natural or anthropogenic factors, may alter current life history trajectories, sending fish into alternative pathways resulting in changes in demographic rates within a population and the population's viability. Challenges in population monitoring, steelhead year class identification, and species management are well documented (Satterthwaite 2009).

Juvenile steelhead growth rate and life history trajectory varies in response to environmental differences, and has subsequent effects on marine survival and return of mature adults to spawning areas (Hayes et al. 2008). Growth is dependent on both food availability and on metabolic rate. Steelhead are poikilothermic, meaning their metabolic rate is determined by water temperature. High water temperatures increase energy allocation to catabolic processes, decreasing energy available for growth (Bell et al. 2011). Optimal temperatures for growth of juvenile steelhead are between 15°C and 19°C, and lethal temperatures are between 27.5°C and 29.6°C (Hayes et al. 2008). The removal of the SCD may affect temperature regimes, as discussed in the Hydrology section of this paper. Riparian vegetation may help mitigate this problem by providing shade that keeps water temperatures cools, in addition to providing a control for algal growth (Bell et al. 2011).

Another important function of riparian vegetation is to provide food for benthic macroinvertebrates (BMIs) and steelhead. BMIs use fallen vegetation from the riparian zone for both food and habitat, while steelhead eat insects that fall from the canopy (Allan et al. 2003, Rundio and Lindley 2008). BMIs are not only a food source for steelhead, they are an important indicator of stream health. The riparian zone also adds large woody debris (LWD) to the system, which improves habitat by creating deep pools that are utilized by steelhead as a refuge from predators. Installation of the SCD has reduced the input of LWD affecting the structure and dynamics of upstream and downstream aquatic and riparian habitats. Dams can also impede the natural flux of water, sediments, and nutrients (Thomson et al. 2005). Assessment of water quality can be made by analyzing both BMI and algal assemblage. This provides an indicator on how dams have affected water quality, if a reference reach is available.

Bed material size is another important feature for the aquatic ecosystem. Gravel is vital for successful steelhead spawning and BMI habitat (King 2010). High levels of interstitial fine sediment, which is predicted after dam removal, can clog gravel beds. Inhibiting the movement of gravels during redd construction attempts inhibits the ability of swim-up fry to incubate and emerge. Bed materials that are too coarse may be too large for the fish to move to dig redds, a problem common downstream of dams where supplies of smaller, mobile gravels are diminished or eliminated. It is believed that the optimal range of bed materials for spawning success ranges from 5.4mm to 78mm (Kondolf and Wolman 1993, Kondolf 2000). Increased sediment also blankets algae populations and inhibits photosynthesis.

3.1.2 Hypotheses

Sediment transport may change with the dam removal, as discussed in the Fluvial Geomorphology section of this report. If fine sediment transports increase then the areas for suitable redd habitat may decrease along with algae and BMI populations. Fine sediment can also be harmful to steelhead eggs, since fine sediment suffocates eggs. Alternatively if gravel transport increases then redd habitat would increase. Without the dam more fish will have easier access to spawn in upstream locations of the dam. If an increase in redd abundance occurs, Steelhead population should increase, while a decrease in redd abundance will lead to a decrease in population size.

H_0: No change in steelhead abundance or redd distribution

H_a: Change in steelhead abundance and redd distribution

H_0: No change in macroinvertebrate assemblage

H_a: Change in macroinvertebrate assemblage

H_0: There will be no change in algal assemblages attached to benthic substrate.

H_a: There will be an effect on algal assemblages attached to benthic substrate.

H_0: There will be no change in floating mat algal assemblages

H_a: There will be an effect on floating mat algal assemblages

3.1.3 Existing Data Sets

Records of adult fish counts along the Carmel River are available starting in 1949 and 1973 for juveniles (MPWMD 2004a). The juvenile and adult populations within the Carmel River are lower than historically observed. Currently there is a fish counter located at the SCD that automatically counts the population of steelhead migrating upstream. At the Los Padres Dam adults are trapped and trucked over the dam. Fish trucked over the dam are tallied to obtain the adult population size. See Table 7 for links to past population analysis. MPWMD also installed a dual-frequency identification sonar (DIDSON) to count steelhead within the Carmel River. The DIDSON was installed late 2011 early 2012 and was placed in a location that should capture a majority of the steelhead which utilize the Carmel River (Urquhart 2012). Though fish count data is not yet currently available, once the technology becomes further developed the DIDSON data will be more encompassing for fish counts within the Carmel River. The data currently being recorded with the DIDSON can be processed and compared with data post dam removal. Several areas within the Lower Carmel River have been surveyed for redd abundance. Past data suggests that 41% of redd habitat is between the Narrows and the SCD and 9% is between the Los Padres dam and the SCD (MPWMD 2004a). The region between the Highway 1 bridge and Stonepine Bridge historically has had higher redd counts than areas closer to the SCD. This could be due to the inadequate sediment size location near the Dam.

Based on previous data, Carmel has low BMI assemblage downstream of the SCD, though the taxa of insects present may supply a sufficient food source for salmonids (King, 2010). Furthermore, the BMI assemblage diversifies and the index of biological integrity (IBI) values increases further downstream of the dam. The 10-Year Summary of the MPWMD Bioassessment Program discusses the BMI assemblage and IBI values found within the Lower Carmel River and also suggests one component of the recently drafted SWAMP stream algae procedure could be added to assess amounts of algae along site transects (Table 7). The report does not definitively state why BMI assemblage is worse downstream of the dam but believes higher water temperature and substrate sizes are they key influencing factors. Table 7 highlights the past studies conducted and where the data can be found.

Table 7. Existing aquatic ecology data sets.

Subject	Information Summary	Reference
Redd Count	Reach surveyed Via Mallorca Rd. bridge to Los Padres Dam in 2003	MPWMD 2003
	Reach surveyed Highway 1 bridge to Los Padres Dam in 2004	MPWMD 2004b
	Reach surveyed Highway 1 bridge to SCD in 2008	MPWMD 2008
	Reach surveyed Highway 1 bridge to SCD in 2009	MPWMD 2009a
	Highway 1 bridge to Schulte Rd. bridge	CRSA 2012
Juvenile Population Density	Red Rock to Cachagua sampled from 1990 to 2009	MPWMD 2009b
	Wetted Front to Los Padres Dam sampled between 1973 to 2009	MPWMD 2009c
Adult steelhead Count	Los Padres Dam sampled from 1949-2011	MPWMD 2011a
	SCD sampled from 1954 to 2011	MPWMD 2011b
Benthic macroinvertebrates	Red Rock to Los Padres Dam sampled from 2000-2009	King 2010
Algae - Attached	Collected samples 2002-2003, 2008-2009 from 4 different monitoring sites (Schulte Rd, HWY 1, Nason Rd Community Park, Esquiline Rd)	Central Coast Ambient Monitoring Program 2012
Algae - Floating Mats		

3.1.4 Methods

Suggested monitoring methods for the aquatic ecosystem of the Carmel River are summarized in Table 8. With the removal of the dam more fish should be observed migrating upstream of the SCD location. This is because the SCD is acting as a barrier for upstream migration and may be a factor leading to the decline in steelhead population. To observe the population changes after the dam removal, fish counts should occur at the reroute location and Los Padres Dam. Obtaining a fish count will also help establish if there have been significant changes in population size post dam removal. Redd surveys should occur when spawning is most likely to take place, historically between February and April, and when the sandbar at the Carmel Lagoon is open.

Following King's (2010) recommendations, we propose conducting future bioassessments using the Surface Water Ambient Monitoring Program (SWAMP) protocol as opposed to the CSBP methods used in the study. Since invertebrates surveyed within a BMI assessment largely consist of terrestrial adults and aquatic larvae, sampling should coincide with when insects are in their larval stage. King (2010) found no seasonal variation between fall and spring sampling. Sampling post-dam removal should continue during only the fall to allow for the comparison of post and pre-dam conditions while keeping sampling costs at a minimum.

In regards to algal sampling, we propose to collect quantitative algal assemblages, both floating mats and attached to benthic substrate, in free flowing reaches above and below the site of the dam removal and reroute and at various reaches along the river. Sampling will be divided into three stages: pre-removal/reroute, during removal/reroute, and post removal/reroute with biomass comparison before and after each stage.

Methods will be followed according to the SWAMP bioassessment procedures for collecting stream algae samples (Fetsher et al. 2010) The variables to be compared for both attached and floating algal mats are:

- Biomass
- Chlorophyll a concentrations
- Diatom species richness
- Diatom siltation index

Table 8. Aquatic ecology monitoring methods.

Variable	Predicted change	Implications	Methods	Location	Frequency
Redd abundance	Increased access to spawning upstream of SCD	Increased redd abundance	Compare redd count and location data before and after dam removal using standard methods (Gallagher et al. 2007)	From Highway 1 bridge to Los Padres Dam	Annually between February and April when the sandbar at the lagoon is open
Adult Fish Count	Increased adult fish count at the Los Padres Dam, possible increase fish count at stream reroute location	Increased adult fish count at the Los Padres Dam indicates increased upstream migration while increased fish count at the reroute locations indicates increase in population size	Compare fish count data before and after dam removal using fish count obtained from the DIDSON sonar if available or electrofishing and snorkeling surveys and fish count of steelhead trucked past the Los Padres Dam	Los Padres Dam and stream reroute location	Annually during fish migration
Juvenile fish count	Increase juvenile population	Increased juvenile fish counts indicates improved habitat for steelhead	Compare juvenile fish count data before and after dam removal using seining, electrofishing and/or visual surveys	Between the Narrows and Los Padres Dam	Spring
Benthic Macroinvertebrate Index	Possible Increase in invertebrate assemblage or no change	Increased benthic macroinvertebrate assemblage and diversity indicates improved aquatic conditions	SWAMP	Locations illustrated in the 10 year BMI report (King 2010)	Annually during the fall

Algal Biomass	Concentrations increasing after 1 year	Changes in water quality and amount of sunlight reaching the river bottom	Compare algal biomass concentrations in attached and floating mats using standard collection methods (Bushaw-Nelson et al. 2002; Fetscher et al. 2010)	SCD/ Reroute (above and below), Schulte Rd, the Narrows, Nason Rd Community Park, Carmel Lagoon	Biannually during the fall in conjunction with BMI sampling
Chlorophyll *a* biomass		Increased algal abundance, steelhead food supply, and habitat suitability	Compare chlorophyll a concentrations before, during, and after removal using standard methods (Thomson et al. 2005); (Clarke and Warwick 1994)		
Diatom species richness			Compare diatom species richness before, during, and after removal using standard methods (Thomson et al. 2005)		
Diatom siltation index		Bioindicator of turbidity and siltation	Compare abundance of silt tolerant diatoms before, during, and after removal using standard methods (Bahls et al. 1992)		

3.2 Terrestrial Ecosystem

3.2.1 Background

Vegetation is a key element determining river pattern and profile through processes of bank stabilization and sediment capture (Urquhart *pers. comm.).* The lower Carmel reaches are characterized by more stable meanders versus braided mid-river reaches, largely due to sustained erosion control by a combination of structural protection and vegetation (Hampson *pers. comm.*). Spatial variability in geology and channel morphology between upper, middle, and lower reaches of the Carmel generates high spatial heterogeneity in vegetation patterning, thus affecting terrestrial community composition (Smith et al. 2004). Over the past century, development and channel erosion have degraded riparian habitat, impacting aquatic and terrestrial biota (MPWMD 2004c). Terrestrial streamside inhabitants, such as the threatened California red-legged frog (*Rana aurora draytonii*), western pond turtle, and numerous resident and migratory bird species, depend on vegetated riverbanks to provide protection, habitat for breeding, and to maintain water quality. Heavily vegetated stream reaches may supply up to 1000g/m^2 of organic matter, and can generate up to 99% of annual energy budgets for headwater streams (Bray and Gorham 1964, Fisher and Likens 1973).

The Carmel River provides riparian wetland habitat ideal for the California red-legged frog (CLRF), including channel ponds located in the SCD reservoir (MPWMD 2004c). In the Carmel River Valley, several riparian communities of interest have been identified as "high priority" habitats (CNDDB 2006):

- Central coast cottonwood (sycamore riparian forest)
- Arroyo willow series (central coast arroyo willow riparian forest)
- California sycamore series (sycamore alluvial woodland)
- Narrow-leaf willow series (central coast riparian scrub)
- White alder riparian forest
- California bay series (California bay forest)

- Mulefat scrub
- Bulrush-cattail series (coastal and valley freshwater marsh)

The cottonwood and willow series are considered vital indicators of riparian health (Christensen and Geisler 2008). Artificially lowering the groundwater table is one of the largest adverse impacts to riparian vegetation along the Carmel River (Hampson *pers. comm.*).

In 1996, the US Fish and Wildlife Service (USFWS) listed the CRLF as a threatened species. In 2001, the USFWS designated "critical habitat" for the CRLF, which included most of the Carmel River watershed (Jones and Stokes 2003). CRLFs have been observed in the slow-moving backwaters, adjacent-pools and tributaries to the Carmel River as these areas provide ideal breeding habitats (EWCG 2001; MPWMD 2004c; Reis 2002; Reis 2003). Riparian vegetation provides foraging ground and refuge while emergent vegetation has been shown to play a crucial role in egg mass attachment (Chubb 1999). The SCD creates a barrier to CLRF dispersal, and currently no CLRFs are found immediately downstream of the dam near the plunge pool (SEIR 2012). Additionally, annual drawdowns at SCD historically have presented risks to CRLF larval stages. Another negative pressure on the CRLFs is the introduced American bullfrog. The American bullfrog competes for CRLF habitat and preys upon tadpoles and adults (MPWMD 2004c). CRLF tadpole survival rates of less than 5% have been documented with the co-occurrence of bullfrog tadpoles (Lawlor 1999). Bullfrog eradication during CRLF surveys has benefited CRLF populations over the past decade (SEIR 2012).

3.2.2 Hypotheses

Dam removal is not anticipated to affect vegetation downstream of the SCD, but may cause loss of vegetation upstream due to decreased water availability (Urquhart *pers. comm.*). If the Carmel River cuts headward through sediment left in the upper portion of the reservoir, the water table may drop slightly. This effect could lead to loss of sensitive riparian vegetation, such as white alder, that are rooted on the sand and gravel bars (Christensen *pers. comm.*). However, the riparian vegetation will likely reestablish fairly quickly at a slightly lower elevation as the channel form stabilizes (Christensen *pers. comm.*). A comparable dam removal on the Elwha River, WA, with a similar partially sediment-filled reservoir, has had upstream effects of bank head-cutting (Amy Draut p*ers. comm.*). Downstream impacts of dam removal on the terrestrial ecosystem should be minimized as the 1,500,000 m^3 of sediment behind the dam will be stabilized, revegetated, and covered with geotextiles to prevent catastrophic sediment release downstream due to flooding (Hecht 1977). Such releases would likely reduce food chain length and decrease the amount of energy available to CRLF and other riparian species (Marks et al. 2000). However, an overall increase in fine sediment loading is anticipated below the dam site after removal. This could increase substrates for emergent vegetation and habitats for terrestrial and aquatic species. The floodplain and bank width of the Carmel River could also become wider and increase lateral riparian habitat space. Bed aggradation could increase groundwater availability to streamside vegetation, reconnecting vegetation to elevated groundwater stores (Groeneveld and Griepentrog 1985). Increased delivery of LWD downstream will affect channel geomorphology, which will likely alter vegetative cover and composition (See Section 2.2).

Potential changes in geomorphology and vegetation have key implications for the habitat of the CRLF. Currently, CRLF populations are highly abundant along and upstream of the SCD reservoir, in areas with low gradient slope and bordering vegetative cover (SEIR 2012). This habitat extends at least to the edge of the deposited sediment bed. Since the reroute will occur 2,500 feet above the dam, there will be viable habitat loss once the reservoir dewatering occurs. While the reroute plans include step-pool reaches and off-channel pools, it is predicted that the natural channel migration and sediment deposition will make constructed off-channel pools temporary (MEI 2008). CRLF rescues from drying pools can mitigate this problem in the short-term, but long-term habitat viability is largely unknown. However, the population may benefit from connectivity and adapt to the new habitat.

H_0: No change in riparian vegetation
H_a: Loss of riparian vegetation (upstream)

H_0: No change in emergent vegetation
H_a: Increase in emergent vegetation (downstream)

H_0: No change in canopy cover and canopy rating
H_a: Increase in canopy cover and rating (downstream)

H_0: No change in accessibility and topographic area of CRLF habitat (ponds)
H_a: Net loss or temporary disruption in CRLF habitat

H_0: CRLF populations will not migrate between upper and middle reaches
H_a: CRLF will migrate between upper and middle reaches after dam removal

H_0: No change in CRLF population size
H_a: Decrease in CRLF population size

H_0: No change in bullfrog population
H_a: Increase in bullfrog population and negative impact to local CRLF populations

3.2.3 Existing Data Sets

Surveys for CRLF have been conducted on behalf of California American Water (Cal-Am) in order to mitigate the effects of annual SCD reservoir drawdowns and comply with the Endangered Species Act (ESA). However, significant survey bias has resulted from a lack of monitoring all CRLF life history stages within the main stem Carmel River. Therefore, expanded CRLF monitoring is strongly recommended. Areas surveyed for the CRLF through 2004 are delineated on the map in Figure 8. These surveys have provided valuable long-term datasets on the CRLF historic range and the response of vegetation to changes in groundwater, surface flow, channel migration, and sediment fluxes. Cal-Am has also conducted annual aerial surveys of the Carmel riparian corridor in conjunction with the Monterey Peninsula Water Management District (MPWMD) since 1958. MPWMD has performed several vegetation surveys employing canopy rating (CR) and monthly canopy rating (AMCR) along with tensiometer readings to detect change in canopy health and cover as a function of groundwater drawdown and seasonal water stress (Table 9).

Table 9. Existing terrestrial ecosystem data sets.

Subject	Summary	Reference
CRLF	Limiting factors by reach, i.e. bullfrog predation, water extraction, etc.	MPWMD 2004c
	Map of surveyed reaches for frogs and reproductive sites	MPWMD 2004c
	Population distribution GIS analysis in Carmel Valley	Wheeler 2004
	CRLF and Arroyo Toad Surveys	Hubbartt and Murphey 2005
	Frog and tadpole presence in 2002 at the De Dampierre restoration site; 2003 during CalAm water drawdown	Entrix 2003b, 2004, 2005, 2006
	Pond habitat along the Carmel River arm up to the SCD reservoir	Entrix 2003b, 2004, 2005, 2006
	2002-2006 annual surveys: CRLF reproduction documented inside-channel and off-channel pools up to 1.5 miles above SCD	Entrix 2003b, 2004, 2005, 2006
	CRLF presence in tributaries and in main stem in 1996	Jones and Stokes 2003
Emergent vegetation	Association between vegetation and CRLF at red rock ponds near Robinson Canyon Creek	Elkins 2000
Vegetation species diversity	Avifauna associated with increased diversity in riparian corridors	Williams and Williams 1988
Total Wooded Acreage	Total wooded acreage (riparian area) along the Carmel River from San Clemente Dam to the lagoon.	MPWMD 2004d

		Christensen 2003, 2004, 2007, 2009
Riparian restoration	Restoration efforts have increased riparian habitat in many areas of the Carmel River, as measured by aerial orthoimagery	Hampson 2005
Canopy ratings	Canopy cover has changed as a result of restoration and conservation efforts, water diversions, as measured by orthoimagery, walked transects, tensiometer and canopy stress indices	McNeish 1988; Christensen 2004, 2008, 2009
Riparian condition surveys	37 assessments of riparian condition along the Carmel, including photos and notes on plant species	MPWMD 2004e
Wetland Assessment	Assessment of wetland ponds off the upstream Carmel River above the SCD reservoir Jurisdictional wetlands were also assessed downstream of the reservoir with the largest delineation being 0.6 acres downstream of the plunge pool	Entrix 2005; Appendix W of 2012 SEIR

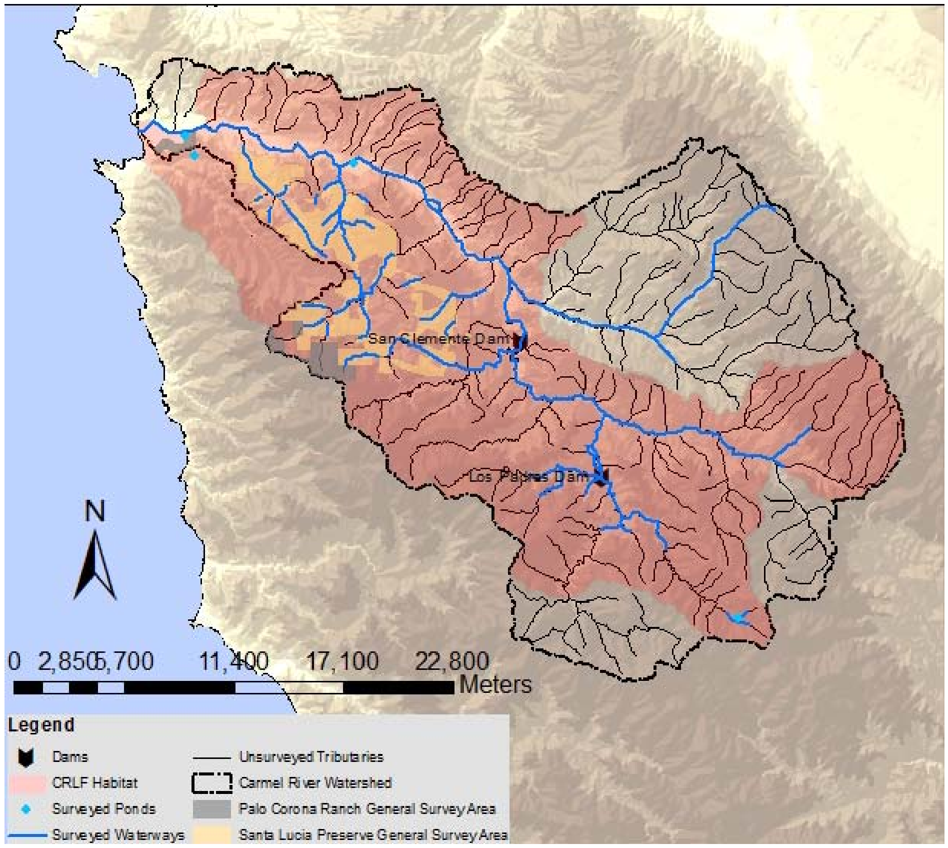

Figure 8. Documented habitats and sites of CRLF population in the Carmel River watershed (Wheeler 2004).

3.2.4 Methods

Annual aerial surveys (orthoimagery) by Cal-Am for the MPWMD can be used to identify reaches most affected by SCD removal and subsequent sediment delivery changes, especially reaches where the river has degraded or reaches with high bank erosion (Table 10). These surveys provide canopy cover data, helpful for determining where on-the-ground monitoring is most crucial. Aerial orthoimagery of the entire Carmel riparian corridor provides coarse-scale data for canopy cover in the Carmel watershed. Vegetation type can also be classified using available satellite imagery and the Normalized Difference Vegetation Index (NDVI) (Nagler et al. 2001).

Proper Functioning Condition (PFC) assessment data can be used to examine streamside vegetation and bank stability (MPWMD 2004d). Riparian trees (primarily *Salix* and *Populus*) can be monitored using the Canopy Rating Scale from the MPWMD Riparian Vegetation Monitoring Plan (2007) and should be selected randomly from previous vegetation monitoring sites and in areas where LWD currently exists. Keeler-Wolf (2004) provides extensive guidelines on protocols for assessing vegetation diversity in a riparian setting. These include vegetation counts and identification within pre-defined plots, line (point-intercept) and belt transects (Vaghti and Keeler-Wolf 2003). The California Native Plants Society (CNPS 2003) provides a rapid vegetation assessment technique. Photopoint monitoring can also be used to depict community-scale changes in vegetation health and cover. Archer and Fisher (2008) provide a discussion of the limitations of vegetation monitoring as related to hypothesis-testing and change measurement.

The monitoring protocol for CRLF within the Carmel River watershed should be conducted following the procedures described by the USFWS (USFWS 2005 and Haggard 2000). The study by Wheeler (2004) described in the existing data section, can also be referred to for general guidelines and recommendations.

Table 10. Terrestrial ecosystem monitoring methods.

Variable	**Predicted Change**	**Implications**	**Methods**	**Location**	**Frequency**
CRLF Migration	Local population migration to reroute, combined flow channel, and directly above/below SCD	Increased population connectivity and genetic diversity of population	Radio telemetry methodology described by Haggard (2000)	Proposed pools and 1000 feet up/downstream of the Combined flow reach and the reroute channel	Twice daily (morning and afternoon from January to May)
CRLF Habitat	Loss of current off-channel ponds upstream of SCD, including reservoir	Decrease in CRLF populations as a result of reductions in CRLF habitat	GIS Analysis: I. Data Sources II. Data Organization III. Data Analysis described by Wheeler (2004)	From SCD to 11 miles upstream	Collect data once pre and annually post dam removal
			USFWS (2005) data collection protocol	Main stem and 1000 feet up/downstream of the SCD removal	Annually
CRLF Reproductive Success	Decreased survival of egg masses and tadpoles	Decrease in current SCD CRLF population	Nocturnal and Diurnal Surveys (Juvenile and Adult) by USFWS (2005)	Mains tem and 1000 feet up/downstream the combined flow reach and the reroute channel	Minimum of 4 nights: Jan-May and 4 days: June-Sep
			Diurnal Surveys (Frog Egg Masses) by USFWS 2005		Once every two weeks for two months from Dec-Feb
			Larval frog surveys (USFWS 2005)		Minimum of 4 separate days from Jan-Sep

<table>
<tr><td>Riparian Vegetation Diversity</td><td>Increase in diversity of vegetation upstream</td><td>Increases in riparian vegetation health, bank strength and habitat value</td><td>Aerial and ground-based (photopoint) photography, multispectral automated imagery classification using NDVI transects, vegetative plots and vegetation tags</td><td rowspan="3">Downstream:
Below SCD (Sleepy Hollow), Boronda Rd., De Dampierre, Garland Park, Rancho Cañada, San Carlos, Valley Hills, Schulte Rd.

Upstream
Pine Creek downstream to reroute</td><td>Annually, during early fall</td></tr>
<tr><td>Canopy Rating</td><td>Increase in canopy rating</td><td rowspan="3">Changes in bank strength and habitat value</td><td>Manual assessment using AWCR from MPWMD protocol (Christensen 2009; RVMP 2009)</td><td rowspan="3">Seasonal, four times per year</td></tr>
<tr><td rowspan="2">Canopy Cover</td><td rowspan="2">Changes in total canopy cover upstream and downstream</td><td>Aerial orthoimagery, GIS classification using NDVI (Nagler et al. 2001), transect, plot diversity measures (alpha beta, gamma diversity) (Christensen 2009; RVMP 2009)</td></tr>
<tr><td>Multispectral satellite imagery, aerial remote sensing, GIS classification using NDVI, alpha beta, gamma diversity, (Nagler et al. 2001)</td><td>Pine Creek downstream to river reroute; Boronda Rd.</td></tr>
</table>

Emergent Vegetation	Increase in emergent vegetation	Increases in bank strength and habitat value, increased CRLF habitat	Aerial imagery survey (orthoimagery), ground-based photography	Downstream: Below SCD (Sleepy Hollow), Boronda Rd., De Dampierre, Garland Park, Rancho Cañada, San Carlos, Valley Hills, Schulte Rd. Upstream: Pine Creek downstream to reroute May also be recorded concurrent to thalweg surveys	Seasonal, four times per year

3.3 Marine Ecosystem

3.3.1 Background

Carmel Bay sits at the head of the Carmel Submarine Canyon which provides nutrients to support a diverse array of marine plant and animal life. High relief bedrock substrates, sandy and granite reef habitats, and canopy forming giant and bull kelp forests provide habitat for a variety of species including rockfish, surfperch, invertebrates, harbor seals and endangered southern sea otters (*Enhydra lutris*). Carmel Bay is within the Monterey Bay National Marine Sanctuary and is protected under numerous federal, state and local regulations to ensure preservation of this unique ecosystem. In the 1970's Carmel Bay was designated as an Area of Special Biological Significance (ASBS) to protect water quality and established as a State Marine Conservation Area (SMCA), which is now included in the network of Marine Protected Areas to prohibit take of marine resources. Other protection initiatives and regulations include designation as a Restricted Overflight Area, Prohibited Shark Attraction Area, California Sea Otter Game Refuge and Rockfish Conservation Area (MLPA 2005).

Unlike most dam removal projects, the SCD removal and Carmel River Reroute project does not involve naturally releasing impounded sediments downstream (UCR [date unknown]). Sediment releases can create a large plume that flows to the ocean, impacting intertidal community structure (Duda et al. 2011). Stabilizing reservoir sediment and rerouting the river avoids the impacts and uncertainties of naturally releasing the sediment downstream (Capelli 2007). Due to possible changes in flow regime and sediment transport of the Carmel River, it is reasonable to expect sediment delivery to the ocean to increase over the long-term. Ocean conditions and beach dynamics have not been modeled or included in the Environmental Impact Assessment/Statement for this project so impacts to Carmel Bay are largely unknown (DWR 2008).

3.3.2 Hypotheses

Changes in sediment delivery to the ocean can cause both physical (first-order) and biological (second-order) changes with potential impacts at the community and ecosystem levels. Possible changes to increased suspended and deposited sediment include increased turbidity, altered substrate and habitat, and reduced density and diversity of intertidal species such as invertebrates, kelp and fish. Any increase in sediment load to Carmel Bay has potential to cause changes at the ecosystem level through covering of rocky substrates with fine sediments and subsequent effects on invertebrate and kelp (*Macrocystis pyrifera*) populations. Deposited sediments can smother invertebrates and kelp holdfast sites while suspended sediments can reduce overall kelp productivity (Thayer et al. 2005).

Reductions in kelp and invertebrate densities in Carmel Bay would have direct implications for the southern sea otter that relies on the kelp forests for protection and the associated invertebrates for food. The southern sea otter is a keystone species in kelp ecosystems as feeding on invertebrates keeps the population in check and prevents invertebrates such as sea urchins from eating holdfast sites and destroying kelp forests. Therefore, increased sediment delivery to Carmel Bay has potential to disrupt ecosystem balance and cause ecosystem collapse through direct impacts to the southern sea otter habitat and food source (NOAA 2011). The following hypotheses were derived from the above information and directly drive the monitoring methods suggested by this document:

H_0: No change in turbidity
H_a: Turbidity will increase

H_0: No change in availability of rocky substrates and habitats
H_a: Shift from rocky substrates/habitats to sandy substrates/ habitats

H_0: No change in kelp cover and productivity
H_a: Reduced kelp cover and productivity

H_0: No change intertidal diversity (fish and invertebrate density)
H_a: Reduced intertidal diversity (fish and invertebrate density)

3.3.3 Existing Data Sets

Existing data sets for Carmel Bay and supplementary information are provided to address the hypotheses listed above and to provide baseline data for future monitoring efforts (Table 11). Federal, state and local regulations within Carmel Bay have prompted a variety of research and monitoring studies. Designation as an MPA and inclusion in the Monterey Bay Sanctuary has resulted in baseline monitoring studies within the Carmel Bay SMCA and various research projects as part of sanctuary-wide monitoring efforts. Marine Life Protection Act stakeholder processes and meetings can also provide comprehensive information on specific MPAs. A comprehensive set of historic data in table format has been compiled for the Carmel Bay SMCA through this process (MLPA 2005). The Monterey Bay National Marine Sanctuary's Research and Monitoring website provides technical reports by staff members and projects funded by the Sanctuary, while the Sanctuary Integrated Monitoring Network (SIMoN) collects and integrates monitoring information for the Sanctuary into a searchable database and various data portals.

Table 11. Existing marine ecosystem data sets.

Subject	Summary	Reference
Turbidity	Annual reports (2000, 2001, 2003-2008, 2011-present): • Transparency/turbidity using transparency tube	CWC [date unknown]*
	Maps and text files (2001-2009): • Optical attenuation using underway data acquisition systems (UDAS)	MLML [date unknown]

Sediment/Substrate	GIS Data Portal (1994-2000): • Bathymetry, Surficial Sediment Samples and Sidescan Sonar	USGS 2006a
	GeoTiff, GRID or Shapefiles: • Shaded relief, Bathymetry , Rugosity, Substrate/Habitat Analysis, Topographic Position Index, Sidescan Sonar, Slope	CSUMB 2006*
	GIS Data Portal: • Bathymetry, Grain Size, Dominant Sediment and Bottom Type	USGS2006b*
	• Distribution of sediment and rock outcrops • See coastal geomorphology section for methods	Storlazzi and Field 2000
	• Bathymetry, Mean Grain Size, % sand, gravel, clay, silt using grab samples and gravity core	Carter 1971
Kelp	Shapefiles (1989, 1999, 2002-2009): • Kelp canopy cover using historic surveys, aerial photographs and Digital Multi-Spectral Video System	CDFG 2011
	Annual reports (2007, 2008): • Annual productivity and density using hyperspectral remote sensing from aircraft flown sensor	CICORE 2007, 2008*
	Publication: • Canopy cover and abundance using time series analysis of aerial photos (1985-1991)	Donnellan 2004*
Intertidal Diversity	Data Portal of MPA baseline data and Multi-Agency Rocky Intertidal Network (MARINe) data: • Intertidal Biodiversity and Subtidal Community Surveys • Includes diversity and abundance of invertebrates and fish using submersible and scuba surveys • Also includes rock type, vertical relief and macro algae	PISCO 2011*
	Data tables (2007-present): • Siting frequency and density scores of invertebrates and fish using scuba transects (Seaweed abundance also recorded)	REEF [date unknown]

* See SIMoN website for further details

3.3.4 Methods

The existing data sets aim to identify studies that can be used for future monitoring efforts and that could capture effects of dam removal in the future, as several initiatives are ongoing. While some of these studies can be used as a baseline for suggested monitoring methods, we recommend employing a before and after monitoring design if time permits. It is expected to take decades for the Carmel River to establish a more natural sediment regime and anywhere from 17-40 years for sand to reach the Carmel Lagoon according to modeling studies (Urquhart *pers. comm.*). Therefore, increased sediment and any physical and biological impacts are expected to take around the same amount of time to reach the ocean, if not longer. Due to this time lag, it would be possible to conduct a unique before and after monitoring study to assess the effects of this type of dam removal on the coastal environment. However, pre-dam removal monitoring should take place as soon as possible as downstream sediment movement can take place more rapidly than model predictions as seen on the Elwha River (Draut *pers. comm.*). The Elwha River monitoring plan employed a before and after monitoring approach with scuba surveys and can be used as a framework to monitor impacts of dam removal in Carmel Bay. Another recommendation is to use a remote sensing technique, such as hyperspectral imagery, combined with GIS to comprehensively assess key variables such as turbidity, substrate, kelp, and intertidal diversity (Table 12).

Table 12. Marine ecosystem monitoring methods.

Variable	Predicted Change	Implications	Methods	Location	Frequency
Turbidity	More turbid	Lower productivity of kelp, algae and benthic vegetation	Hyperspectral remote sensing with airborne sensor Environment for Visualizing Images (ENVI) for analysis and mapping in GIS Protocols: (Hennig et al. 2007) (Bissett and Zimmerman 2004)	Pascadero Point to Point Lobos Shoreline to ~0.25 mile offshore (~60 ft deep)	At least once before dam removal and every 5 years thereafter
Substrate Type	Shift from rocky substrates to fine sediments	Reduction of invertebrate habitats and kelp holdfast sites			
Surface kelp cover	Reduced kelp cover, benthic vegetation and biological diversity	Alteration of community structure, stability and risk of ecosystem collapse (i.e. southern sea otter)			
Intertidal Diversity					
Visibility	Decreased clarity	Impacts to research, recreation and potentially productivity	Scuba Diver Transect Surveys (30 m) Pearson's correlation coefficient and t-test for data analysis Protocol: (Duda et al. 2011)	Carmel Point to Point Lobos ~10 -60 ft deep	Annually for 5 years before dam removal and annually thereafter
Grain size	Smaller grain sizes (sand)	Smothering and burial of intertidal organisms and covering of rocky substrates			
Habitat Type	Shift from rocky intertidal to sandy habitats	Changes in community structure and risk of ecosystem collapse			
Kelp, invertebrate, fish densities	Decreased kelp, fish and invertebrate densities				

4 Discussion

The goal of this report was to create a hypothesis-driven monitoring plan that could identify the possible physical and biological changes related to the removal of the SCD. The focus of our proposed monitoring plan was to examine the physical changes to the river system and make inferences about how these changes may influence ecosystem function.

Natural variability of the Carmel River and the absence of baseline data characterizing this variability presented difficulties in the formation and investigation of hypotheses. As this may be the first attempt to reroute a river around impounded reservoir sediment, interpreting data and literature from previous dam removals was also problematic. In each case, the best possible conclusions based on existing data were investigated using scientific literature supplemented by personal communication with local and regional watershed experts before an inference was made. Null hypotheses, representing the status-quo for the Carmel River, and alternate hypotheses, representing detectable changes from historic conditions, were presented.

While rerouting the river and stabilizing the sediment is likely to minimize detrimental effects, changes in the physical and biological function of the river system are inevitable. Monitoring location and frequency are critical for quantitatively capturing changes before and after the SCD removal and reroute project. For hydrologic and water quality monitoring, stratified zone-specific methods are critical for plan development, resource allocation, and monitoring over both the short and the long-term. Hydrologic impacts, both chemical and physical, may result in changes in water quality and quantity over different spatial and temporal scales.

For fluvial geomorphology, monitoring of five distinct reaches of the river is suggested based on areas of high interest, available data and ease of access. In these reaches, it is hypothesized that bed load volume, fine sediment, and suspended sediment load will increase, causing channel movement and an overall increase in bed elevation. It is believed the observation of increased sediment transport will proceed slowly over time, and result in increased embeddedness downstream of the SCD. Density and size of LWD is expected to increase immediately.

Changes in these first-order parameters will initiate second-order impacts on ecological systems in the Carmel River. Increased LWD transport downstream of the dam may increase the diversity of habitat available to aquatic biota, resulting in greater species richness, diversity, population, and ultimately greater ecosystem resilience. However, increased embeddedness may cause a decrease in BMI abundance and decreased steelhead spawning habitat. The removal should increase access to habitat upstream of the current dam location, promoting development of steelhead populations in the upper Carmel watershed.

Riparian vegetation will also be affected by first-order changes, based on position relative to the SCD removal. Upstream sites may show reduction in vegetation cover and canopy due to reductions in groundwater status provided by the SCD reservoir. Reduction in riparian health and canopy cover may reduce bank integrity above the sediment reservoir, further reducing riparian habitat for terrestrial organisms such as the CRLF. However, CRLFs may benefit from increased habitat connectivity after the removal due to increased stream bank integrity via LWD.

The effects of the SCD removal on the coastal and marine environments will be observed last due to proximity to the SCD. The beach and the lagoon are dynamic systems, with sand constantly being shifted around by peak river flows, ocean waves and wind. Consequently, tracking changes in river and lagoon profile should be regularly performed to assess and predict future changes to the river within the coastal interface. Assessing these changes is imperative to ensure the protection of floodplain infrastructure and steelhead rearing habitat within the lagoon.

For the marine environment, it is important to establish comprehensive baseline data so changes in this unique ecosystem can be detected.

With numerous dams in the United States reaching the end of their functional lifespan, an increase in the number of removal projects is forthcoming. Because the dam removal process and understanding of their impacts are still in their infancy, it is important to monitor physical and biological changes. Our comprehensive monitoring plan provides a well-rounded framework for future dam removal monitoring efforts.

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