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Eric D. Stein
Matthew Cover
Clare O'Reilly
James J. Hayes
A. Elizabeth Fetscher
Richard Ambrose
Lisa S. Fong
Roxana Guardado
Christopher Solek
G. Matthias Kondolf
Chris Alford
Carolina Zuri

Southern California Coastal Water Research Project

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Prepared for the State Water Resources Control Board

by:

Eric D. Stein[1], Matthew Cover[2], Clare O'Reilly[3], James J. Hayes[4], A. Elizabeth Fetscher[1] , Richard Ambrose[5], Lisa S. Fong[5], Roxana Guardado[2], Christopher Solek[1], G. Matthias Kondolf[3], Chris Alford[3] and Carolina Zuri[3]

[1]Southern California Coastal Water Research Project
[2]California State University, Stanislaus
[3]University of California, Berkeley
[4]California State University, Northridge
[5]University of California, Los Angeles

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Executive Summary

Localized armoring of stream channels is a common management response to a real or perceived threat to adjacent infrastructure or development from flooding or bank erosion. In many rural and suburban areas, short segments of channels may be armored with rock or concrete to direct flow away from roads, pipelines, or developed areas or to protect adjacent areas from the effects of overbank flow and/or channel migration. Despite their pervasiveness, the effects of reach-scale channel armoring have received less attention than major channelization projects or of regional scale hydromodification effects common in urban areas. Because of the somewhat isolated nature of localized channel armoring, their physical or biological effects are seldom monitored in a systematic way and are thus are less well understood.

The goal of this project was to begin to explore indicators of the relationship between channel bank armoring and physical and biological changes in the affected reach. The study had three components, each designed to address different questions. The first component was a mapping study designed to answer the question "*What is the extent of channel alteration in a pilot study area?*" The second component applied commonly used monitoring and assessment tools to six streams in Los Angeles and Ventura counties to answer the question "*How does the physical alteration of stream channels associated with channel armoring relate to physical and biological endpoints indicative of stream condition?*" For this component we used traditional geomorphic measures, the California Rapid Assessment Method (CRAM), benthic macroinvertebrates, and stream algae. The third component focused on the impact of channel restoration to address the question "*Does stream restoration result in recovery of biological condition based on applicable indicators?*"

Major conclusions of the three components of this study are:

- We were able to identify approximately 2,200 channel modification structures based on data available from major municipalities in Los Angeles and Ventura counties. However, comparison with intensive, ground-based mapping of structures in the Malibu Creek Watershed by Heal the Bay suggests that less than 5% of existing structures are accounted for in the local agency GIS layers. Extrapolation based on this finding translates to an estimated 50,000+ in-channel structures in the two county study areas.

- Most study sites exhibited localized changes in channel morphology in the armored stream segments. In general, armored segments were flatter (i.e., lower gradient), and contained more and deeper pools and fewer riffles. These flow conditions were also associated with increased sediment deposition. At several of the armored segments, we observed evidence of varying degrees of channel incision and toe bank failure, suggesting that bank hardening is contributing to localized incision at these sites.

- All biological indicators showed subtle, mechanistic responses to the physical changes in channel conditions in the armored segments. However, the response patterns were inconsistent among sites. Extreme heterogeneity between sites and presence of catchment-scale disturbances (e.g., fires, upstream flow control) made it difficult to ascribe observed patterns to channel armoring. General observed relationships included:

  - CRAM Biotic Structure scores were lower in the armored segments.
  - Results from two assessment tools commonly used in the European Union (River Habitat Survey and IDRAIM) showed that riparian vegetation and channel shading was more contiguous in upstream and downstream segments than in impact segments, due to the presence of a bank hardening structure, which prevents vegetation establishment.
  - Benthic macroinvertebrate diversity and tolerant taxa decreased in the armored segments. These patterns were associated with areas with higher sedimentation and lack of fast-flowing water.
  - Sediment-tolerant diatoms and soft-bodied algal taxa were more prevalent in armored segments that had higher deposition of fine-grained sediments

- Both benthic macroinvertebrate and algal taxa exhibited mechanistic responses to physical effects of armoring, but low sample size and differences between sites made it difficult to draw definitive conclusions. The data suggest that for local-scale effects, species-level or functional group-level metrics may be more sensitive tools than integrative indices of biotic integrity (IBIs).
- Neither physical nor biological effects appeared to be propagated to the downstream segments.
- The CRAM Biological Structure and Physical Structure attributes were higher at restored streams sites, suggesting that CRAM may be a good tool for monitoring restoration performance. However, it is insufficient to be used as a stand-alone tool because of the general nature of the assessment. Intensive assessment approaches will provide greater insight into ecological function and process, and hence long-term success potential of a restored site.
- Biologically based assessments hold promise for monitoring and evaluation of effects of hydromodification; however, additional work is necessary to refine relationships between physical stress and biological response.

Acknowledgements

We thank the teams from all intuitions that cooperated to successfully complete this project. Kristin Smith of SCCWRP was instrumental in site selection, reconnaissance and field work. We thank Jeff Brown and Greg Lyon of SCCWRP for assistance with field work and Raphael Mazor for overall technical assistance and advice over the course of the project. We thank Robert Thomas for his work compiling the spatial data and working through the many pitfalls of developing the geospatial database from the many diverse sources used in mapping stream channel modifications. Field assistance with BMI, algae, and PHAB sampling was provided by CSU Stanislaus students Veronica Menendez, Tamera Rogers, and Brittany Bjelde.

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1. Introduction and Background

Land use alteration associated with urbanization, agriculture and infrastructure development is often accompanied by changes in runoff and sediment discharge. Changes in the magnitude, relative proportions, and timing of sediment and water delivery can affect channels in a variety of ways including channel deepening, widening, changes in planform, and in some cases aggradation (Leopold 1968, 1972). In summarizing over 100 studies on the effects of urbanization on rivers, Chin (2006) concluded that urbanization has globally altered balances of water and sediment, with resulting impacts on river morphology. Stream channel degradation associated with changes in flow and sediment has been termed *hydromodification* (USEPA 1973). The processes and effects of hydromodification have been widely documented for both technical and non-technical audiences and numerous general information and background resources are available (Center for Watershed Protection 2003, Roesner and Bledsoe 2003, Susilo and Federico 2009).

A common management response to hydromodification-induced changes in channel form is to install bank armoring and grade-control structures. Such structures are intended to control velocities and direct flow to protect infrastructure that may be threatened by hydromodification effects. However, the effects of modified runoff and sediment yields are often further exacerbated by direct channel disturbances that increase stream power, decrease channel roughness, and reduce erosional resistance (Jacobson *et al*. 2001). Changes in water surface elevation, velocity, and bed scour may occur locally or propagate up or downstream from the bank armoring or grade control depending on the shape and slope of the channel and the nature of the installed structure (Kassem and Chaudhry 2005, Labbe *et al*. 2010).

Changes in flow and sediment, and the resulting shift in channel form associated with both hydromodification and subsequent channel alteration have the potential to modify physical habitat and affect instream ecological communities (Center for Watershed Protection 2003, Roesner and Bledsoe 2003). As early as 1973, USEPA recognized that alteration of flow and sediment patterns can result in degradation of water bodies and their associated beneficial uses (USEPA 1973, 2007). Altered channel morphology and bed material, and changes in the magnitude, frequency, and timing of sediment-transport events can adversely affect aquatic life and their life cycles (Waters 1995, Trimble 1997, Merritt and Cooper 2000, Konrad *et al*. 2005). Channel erosion can create a simplified stream environment, eliminating suitable substrate for macroinvertebrates and fish, and filling gravel beds with fine sediments from eroding banks. Excess erosion can also eliminate refuges in overhanging banks and reduce canopy shade which maintains cool water temperatures (Garie and McIntosh 1986, Yoder and Rankin 1997, Kennen 1999, Paul and Meyer 2001).

Although a general relationship between urbanization and instream biological endpoints is well established (Roy *et al*. 2003, Alberti *et al*. 2007, Gurnell *et al*. 2007, Cuffney *et al.* 2010), the direct connection between channel armoring and biotic response has not been well documented. Few studies have considered the specific mechanisms behind relationships between urbanization and biotic response (Paul and Meyer 2001) and fewer have considered using biological indices to evaluate whether restoration reverses the adverse effects of urbanization (Moerke and Lamberti 2004, Miller *et al*. 2010).

This is due in part to the fact that instream biological measures of conditions, such as invertebrate, fish, or algal communities, may be affected by many proximate causes that mask, mitigate, or alter the general effect of urbanization. Biological indices may be largely determined by local flow patterns, substrate size and type, slope, shading, and temperature patterns rather than directly by urban land uses (Fitzpatrick *et al*. 2005). These relationships may be particularly important when considering the effects of instream structures such as bank armoring and grade control (Nelson 2011).

Understanding the relationships between channel alteration (or restoration of degraded channels) is increasingly important because of the growth of biologically based monitoring and assessment programs. At least 75% of the states in the United States have active bioassessment programs. Bioassessment is also a primary tool used in the European Union's (EU) Water Framework Directive monitoring program and Australia's National Water Quality Management Strategy and associated Assessment of River Health. In several states and the EU, bioassessment is moving beyond monitoring and assessment to regulation based on biological endpoints (often called biocriteria or bioobjectives). California is one of the leaders in this area and has articulated a goal of establishing freshwater bio-objectives for all waterbody types using multiple biological endpoints (e.g., invertebrates, algae, riparian condition). Additional research is necessary to document more mechanistic relationships between channel alteration and the biological indices that are at the center of monitoring and regulatory programs.

This study begins to establish these connections by exploring the relationship between channel bank armoring, physical changes in the bed material and channel form, and ultimately changes in invertebrate and algal communities and riparian condition. This study represents a first step in testing the conceptual model of biological responses to channel alteration by exploring the following questions: 1) What is the extent of channel alteration in a pilot study area? 2) How does the physical alteration of the stream channel associated with channel armoring relate to physical and biological endpoints indicative of stream condition? 3) Does stream restoration result in recovery of the biological metrics used to assess condition?

The scope and budget of this study allowed for sampling only a limited number of sites/locations for each study element. Therefore, this project should be considered a pilot project which will provide initial data and insights into the effects of channel armoring on physical and biological stream conditions. The results of this pilot study can be used to inform decisions about future investigations into this topic.

2. Mapping of Channel Structures

An important first step to managing potential effects of channel armoring is determining their locations and distributions. Such information is critical for informing monitoring programs, assessing cumulative and indirect effects, and for prioritizing restoration activities. The objective of this portion of the study was to assess the spatial extent and distribution of in-stream structures in the study region (Figure 2-1). This exercise will allow an initial investigation of the degree of channel modification, types of streams most often affected, and most commonly used structures. This pilot study will provide a template for future compilation of comparable information for other watersheds in the region.

The primary questions addressed for this portion of the study were: 1) What data on channel modifications and structures (hereafter modifications) exist and are readily available for Los Angeles County and Ventura County (the study area)? 2) What types of modifications exist and where are they located? 3) How pervasive are channel modifications? 4) How well do existing and readily available data capture the true extent of channel modifications? Additionally this portion of the study set out to compile existing and readily available data into a spatial database that can be expanded in the future and used for monitoring and analysis of modifications.

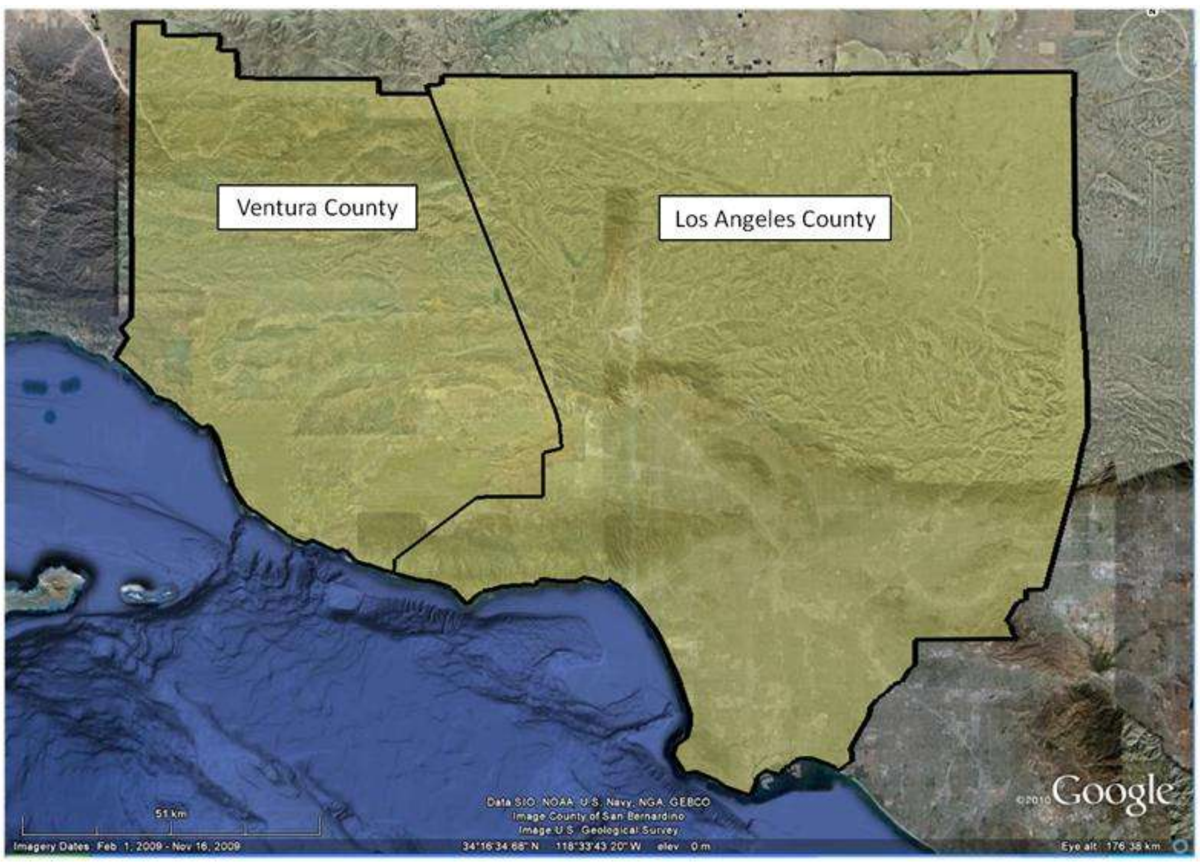

Figure 2-1. Study area for mapping analysis covering Los Angeles and Ventura counties.

2.1 Methods

Data availability on channel structures is generally poor across most municipalities. Therefore, we focused our efforts on areas of high data density in order to demonstrate an approach to compilation, mapping, and analysis of information on channel armoring. Analysis of areas of high data density also allows a generalized estimate of the degree of missing data in the rest of the study area.

Our initial approach was to determine which governmental and non-governmental agencies were in possession of spatial data describing stream-channel modifications. To help determine likely sources of data at the city-level, overlay analysis was conducted with city/county boundary files and existing simplified stream data from previous work done at the Center for Geographic Studies at California State University, Northridge (http://www.csun.edu/~centergs/). Initial internet searches were conducted to identify sources of online data, and where no online data were found, emails were sent to agencies requesting potentially relevant data layers. First steps were to develop a framework, or schema, for organization of a geodatabase, determine the common map projection to be used in the geodatabase, and process data layers as received to common standards to allow their combined use and cross-layer analysis.

2.1.1 Data Sources

Over 600 data layers were evaluated from over 20 primary sources (Table 2-1). Many of these layers were ancillary to direct channel modifications, but many were used as spatial reference to cull necessary data from other layers (i.e., other storm/sewer features not directly modifying stream channels or jurisdiction's base map layers (Table 2-2). In all, the data used in this project came from: eight city or county agencies, two local NGOs, six state agencies, and five federal agencies. Data sources included eight city or county agencies, two local NGOs, six state agencies, and five federal agencies.

One of the challenges with compiling multiple datasets from individual organizations is that some agencies recognize different categories or have different hierarchies of modification types. For instance, one city may group three different types into one layer called "modifications", while another city may map those same features in three different layers, one for each type. This often required data sets from multiple sources to either be combined, or broken into multiple layers depending on the sources involved and the types of features. Concomitantly there was a general lack of any standardized nomenclature or metadata across data sources (e.g., what are redlines and what are bluelines). In very few cases were we able to combine these datasets as they were provided. Thus, many data sets are not in this version of the database, because of the level of manual verification needed (segment by segment inspection) before features could accurately be determined to be of the same or different types (i.e., combined, or split into multiple layers).

Table 2-1. Data sources and layers obtained and used from each source.

Data Source	Total # of Layers	# of Layers Used
California Department of Conservation	1	1
California Department of Fish and Game	2	1
California Department of Boating and Waterways	220	4
California Department of Forestry and Fire Protection	6	0
California Department of Transportation	37	2
California Invasive Plant Council	27	1
Federal Emergency Management Agency	2	2
Federal Highway Administration	1	1
Natural Resources Conservation Service	1	1
U.S. Army Corps of Engineers	1	1
U.S. Bureau of Reclamation	1	1
U.S. Department of Agriculture- Forest Service	1	1
U.S. Geological Survey	14	4
Environmental Systems Research Institute, Inc	2	2
Los Angeles County	58	3
Ventura County	26	1
Heal the Bay	3	3
Los Angeles and San Gabriel Rivers Watershed Council	1	1
City of Ventura	64	4
City of Thousand Oaks	55	5
City of Simi Valley	23	0
City of Oxnard	58	2
City of Ojai	16	0
City of Camarillo	45	2
Cal State Northridge	12	4
Total	**677**	**47**

Table 2-2. Data sources and primary utility to the mapping of channel modifications. Features mapped from each data source are specified unless the data were primarily used for providing spatial or attribute context (i.e., reference).

Data Source	Features Used
Cal-Atlas	Portal-All Statewide Datasets
California Department of Conservation	Reference-Admin
California Department of Boating and Waterways	Invasive plants
California Department of Fish and Game	Reference-Hydro
California Department of Forestry and Fire Protection	Invasive plants and Reference -Admin
California Department of Transportation	Reference-Infrastructure
California Invasive Plant Council	Invasive plants
Federal Emergency Management Agency	Bridges
Federal Highway Administration	Reference-Infrastructure
Natural Resources Conservation Service	Reference
U.S. Army Corps of Engineers	Dams
U.S. Bureau of Reclamation	Reference- Admin and Hydro
U.S. Department of Agriculture - Forest Service	Reference
U.S. Geological Survey	NHD-Flowlines
Natural Resources Conservation Service	Reference
Environmental Systems Research Institute, Inc	Reference-Hydro and Infrastructure
Heal the Bay	All Mod Points
Los Angeles and San Gabriel Rivers Watershed Council	Invasive plants
Los Angeles County	HydroBasinPts
Ventura County	HydroBasinPts
City of Ventura	EnergyDissipators, HydroBasinPolys
City of Thousand Oaks	EnergyDissipators, HydroBasinPolys
City of Simi Valley	Not usable at this time
City of Oxnard	Not usable at this time
City of Ojai	Not usable at this time
City of Camarillo	EnergyDissipators, HydroBasinPolys
Cal State Northridge	Reference- Admin and Hydro

2.1.2 Data Layer Preprocessing

Since the data layers obtained came from different sources with different mapping standards, all layers were converted to match a single coordinate system and projection. For this project we used Universal Transverse Mercator (UTM) as the standard projected coordinate system and the North American Datum of 1983 (NAD83) as the spatial datum reference. These were chosen to allow the greatest compatibility with much of the previous work done for SCCWRP and the Regional Water Board by the Center for Geographic Studies at CSUN, which has used this projection and datum. For the UTM projection, the state of California is split into two zones, zone 10 (northern CA) and zone 11 (southern CA), we are using UTM Zone 11N; UTM uses meters as the standard measure. Additionally, the local reference datum, a model used to describe unknown points horizontally on the earth, is the North American Datum of 1983 (NAD83).

There were up to three major steps in the preprocessing stage: projection changes, datum transformation, or both. The most common projection change was from a version of State Plane coordinate system to UTM and the most common datum transformation was NAD 27 to NAD 83 or from WGS 1984 to NAD 83 (using NAD_1983_To_Nad_1983_NADCON or NAD_1983_To_WGS_1984_5)[1]. Depending upon how the data were received (individual shapefiles or geodatabase) projection changes were kept in those formats, to minimize any loss of data precision.

2.1.3 Data Compilation

Final data-type configuration was determined by comparing sizes and types available, determining which was the most common, and then creating new fields within intermediate datasets to begin matching up fields to the final layers. A crosswalk table was constructed to allow for cross-table queries and analysis of data from different sources. There were often several processing steps or spatial/table joins and intermediate layers created during the data compilation process. In addition, new fields were created for standardizing across all layers, including fields to identify the data source and fields needed for GPS verification. When data were ready for importing into the final geodatabase, field matching using crosswalk tables allowed for features to be paired with their correct attributes from the source data. A workflow diagram is shown in Figure 2-2.

The map data created for this project includes data from a number of sources (see Tables 2-1 and 2-2). We compiled data from the above sources into an ESRI Geodatabase containing Feature Datasets for "Administrative", "Hydrologic", and "Infrastructure" features. Each Feature Dataset includes ESRI Feature Class files containing spatial and attribute data for hydromodification features, the stream network, and study area boundaries with city and county boundaries (Table 2-3).

These Feature Classes and metadata are available for download via the CSUN Center for Geographical Studies: http://www.csun.edu/~centergs/

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[1] See http://resources.esri.com/help/9.3/arcgisengine/com_cpp/gp_toolref/data_management_tools/project_data_management_.htm for more detailed information

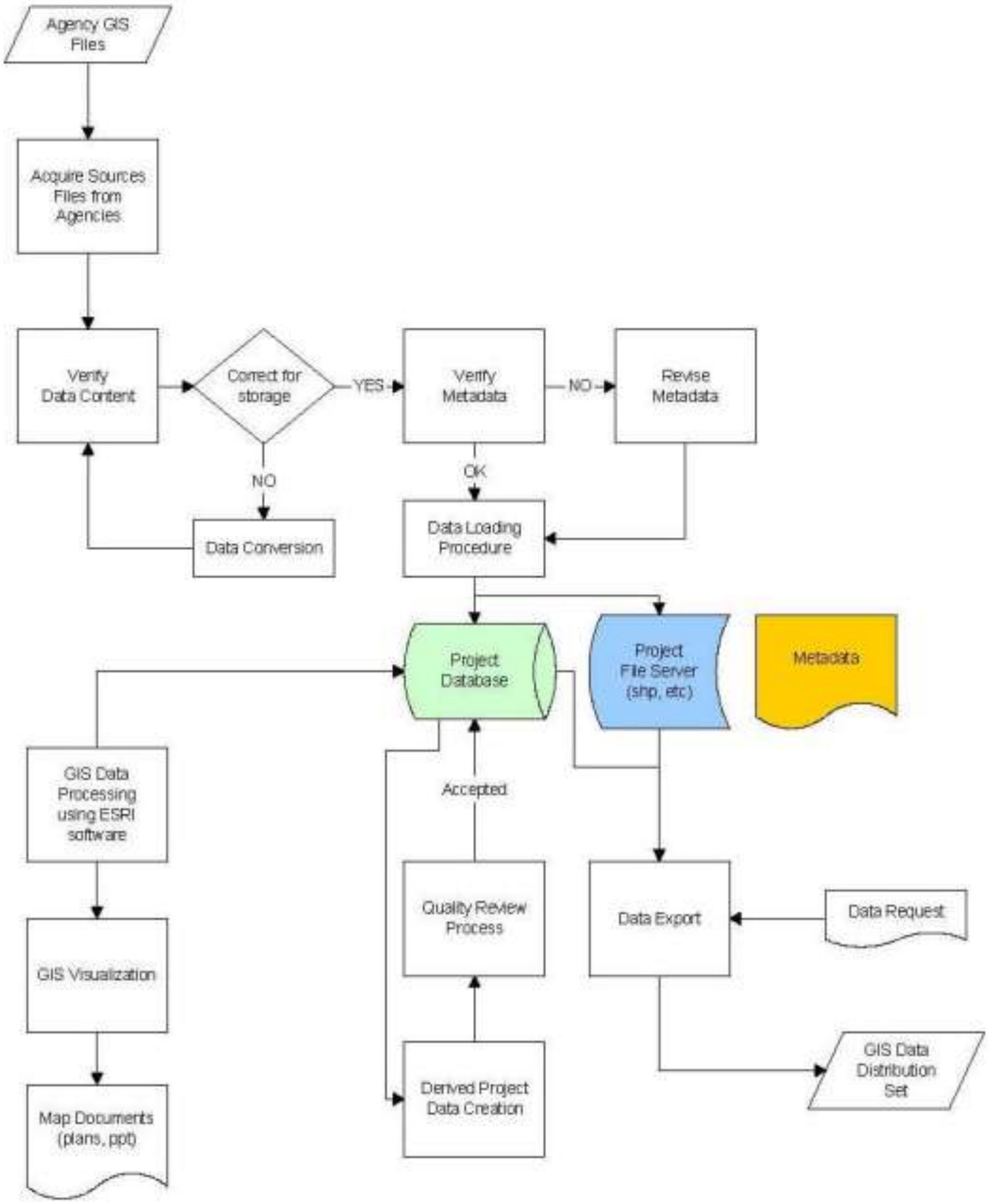


Figure 2-2. General GIS workflow diagram for mapping of channel structures.

Table 2-3. Hydromodification Geodatabase. Feature Datasets (column headings in bold) and Feature Classes.

Administrative	**Hydrologic**	**Infrastructure**
City_Limits	NHD_Hydro_Ln	Bridges
County_Boundary	HydroBasinPolys	Dams
Project_Data_Boundary	HydroBasinPts	
	EnergyDissipaters	
	ConcreteBoulder	
	ConcreteChannel	
	LooseBoulder	
	MiscAlterations	

2.2 Results

Currently available spatial data on the drainage network is lacking in many respects. The National Hydrography Dataset, medium resolution, used in this study is relatively complete and accurate though it is missing some highly modified channels in the Los Angeles Basin. The NHD also includes some artificial canals, and Pacific Ocean coastline and some reservoir boundaries. While these “non-stream” features can be easily removed and excluded from analyses, some features labeled as “canals” or “ditches” (“CanalDitch” in the database) appear to be part of the natural drainage network, however highly modified. These inconsistencies make it difficult to determine which features are relevant to a particular use and which are not. However, NHD does provide a good first estimate of the extent of major structures.

2.2.1 Dams

Many dams in the National Dam Inventory dataset are defunct, having been dismantled and their impoundments drained. We initially found 90 dams in the study area and deleted 12 from the source data to arrive at 75 currently in place and operational (Figure 2-3). Unfortunately a more up-to-date dataset is not currently available. Information on dam width (upstream-downstream dimension) was not available in this data set. If we were to assume an average dam width of 45 m, we would estimate the total stream length of dam structures in the study area to total about 3.5 km (2.2 stream-miles). This figure accounts for only the direct footprint of the dam and would not take into account the upstream effects of impounded water, and altered discharge rates downstream, which vary by dam.

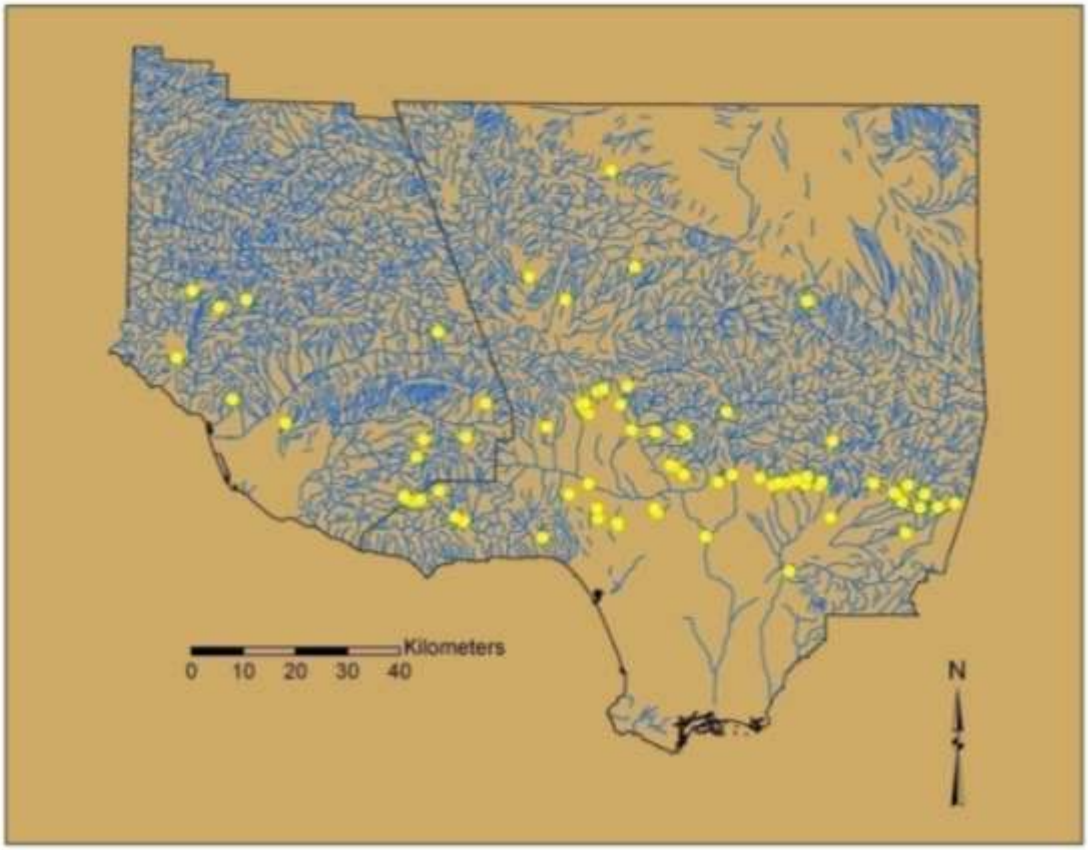


Figure 2-3. Location of all 75 dams in the study. Note that most dams are located in Los Angeles County and placed just upstream of major rivers such as the Los Angeles and San Gabriel Rivers.

The mean area impounded by dams in the study area was 57.7 ha (142.6 acres) per dam. The total area impounded by dams was 3,920.6 ha (9,688 acres). The smallest impounded area recorded was 0.4 ha (1 acre), and 1,092 ha was the largest (2700 acres). Coyote Creek has the largest impoundment behind the Casitas Dam in western Ventura County. While San Fernando Creek is reported as having the most dams (3) and a total of 191 ha (473 acres) impounded. Both the Upper San Fernando Dam and the Lower San Fernando Dam have had their impoundments drained, though the dams appear to still be in place and operational. The Los Angeles Reservoir Dam on San Fernando Creek remains in place with an active impoundment reported at 70.8 ha (175 acres).

2.2.2 Bridges

One thousand, eight hundred fifty-five bridges cross stream channels in Los Angeles and Ventura counties (Table 2-4; Figure 2-4). Bridges, their pilings or piers, and bank abutments directly affect approximately 35.5 km, or 22.1 stream miles (total of measured stream bed affect by each bridge width). The average bridge width is 19.2 m. Bridges span 151 different streams. The San Gabriel and Los Angeles rivers have the most bridges per stream at 149 and 146, respectively. The bridges on these two rivers account for 5.5 km (3.4 stream miles).

Table 2-4. The 10 "most-bridged" rivers.

RIVER	Count	Stream Miles	Mean Width (m)	Std. Dev. (m)
San Gabriel River	149	1.88	20.28	12.23
Los Angeles River	146	1.53	16.97	12.36
Santa Clara River	92	0.96	16.71	9.33
Coyote Creek	71	0.92	20.61	14.46
Dominguez Channel	66	0.92	22.37	13.27
Arroyo Seco	48	0.41	13.78	11.70
Verdugo Wash	39	0.53	22.02	12.09
Rio Hondo Creek	37	0.33	14.65	14.96
Ballona Creek	36	0.45	20.05	9.84
Compton Creek	35	0.41	18.99	11.77

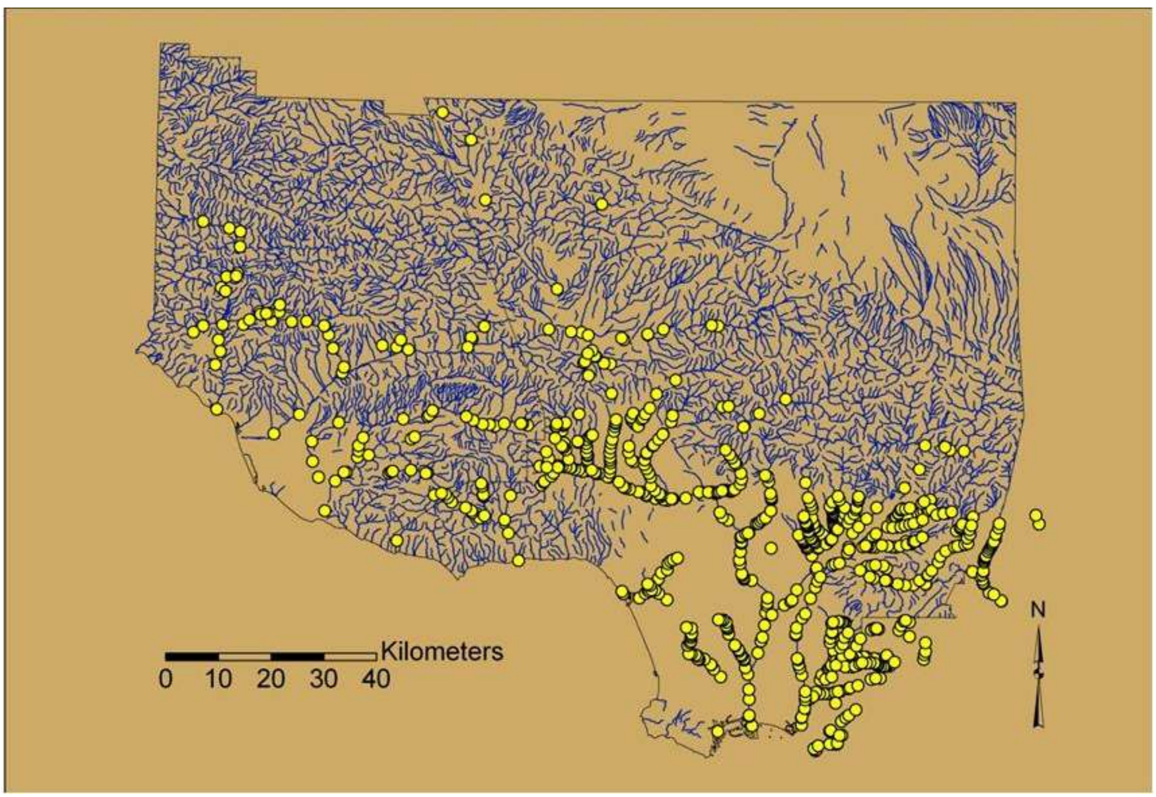


Figure 2-4. Spatial distribution of bridges spanning study area channels. Note the concentration in the south-half of Los Angeles County and southern Ventura County. This distribution is typical of most types of stream-channel modifications.

The existing data on bridges over streams in the area do not allow for assessment of degree of bank modification or in-stream obstruction such as pilings or piers. While the data do include information on an assessment of scour condition or the degree to which a bridge's foundation is stable or being degraded by water and debris scouring, 275 bridges have not been evaluated for scour and it is not clear if these bridges have structure in the water, on banks only, or above and beyond the stream channel. Further, scour assessment does not indicate if the bridge foundations are in-water foundations or bank-only foundations.

2.2.3 Debris and Detention Basins and Energy Dissipaters

Debris and detention basins are modifications to stream channels and adjacent land designed to trap and hold debris and sediment flowing downstream, as well as to temporarily hold water. Debris basins are not usually intended to hold water for extended periods, but slow it to allow debris to fall out of the stream flow. Detention basins hold water for longer periods which helps to mitigate storm-water flooding and acts as a sediment trap. Although each of these basin types have varying definitions and have been mapped in different ways by agencies, mapping them in this project was a priority due to their impact on stream environments. These basins usually involve significant alteration of natural banks and the course of streams. We were also able to make them a priority because of relatively good data availability. The data for these basins were however of poor spatial accuracy with many contradictory and redundant attributes across agencies. Compiling these layers were the most costly of the project.

Data at the county level were of lower quality than data collected by cities. County agencies mapped basins as points, while city-level data was precise enough to allow estimation of area for each basin. For Los Angeles County data for detention basins were not available or distinguishable from debris basin data. City-level data in Ventura County allowed identification of detention basins in addition to debris basins.

Energy dissipaters are basin-like features which may collect debris and sediment, but this is not necessarily their primary purpose. Energy dissipaters are intended to slow the flow of water down steep terrain, or where storm-water surges may be severe, to protect downstream environments from erosion and flooding. These features are modified banks and channels which allow water to spread out and take a longer course than the natural channel would have allowed. Energy dissipaters were relatively few in the data and generally well documented by the cities maintaining them.

In Los Angeles County 72 debris basins were mapped as points to indicate the approximate centroid of the basin. Ventura county data indicated 19 debris basins and 12 detention basins, which were also mapped as points. Within Ventura County, the cities of Thousand Oaks, Camarillo, and Ventura had mapped debris and, or, detention basins as polygons (Table 2-5). In all 21 basins were mapped as polygons. These cities also had mapped 8 energy dissipaters as points.

Table 2-5. Debris and detention basins and energy dissipaters in study area. Features mapped at the county-level are points. City-level data are polygons and area affected is shown parentheses.

City	Debris	Detention	Energy Dissipaters
Los Angeles Co.	72	Data not available	Data not available
Ventura Co.	19	12	See cities below
Thousand Oaks	-	15 (10.7 ha, 26.6 acres)	3 (area unknown)
Camarillo	-	3 (0.74 ha, 1.83 acres)	3 (area unknown)
Ventura	3 (0.80 ha, 1.98 acres)	-	2 (area unknown)

2.2.4 Detailed Mapping of Small Channel Modifications

Heal the Bay, a non-profit environmental group, mapped in-channel obstructions to stream flow and modifications to stream channels in the Malibu Creek watershed. Heal the Bay used GPS receivers to record position of any obstruction/modification found while walking stream routes. The result of this mapping was a highly detailed spatial data set of features which tend to not be represented in data sets found with county, state or federal agencies. Some features, such as bridges, which form part of the transportation infrastructure are exceptions.

Heal the Bay mapped a total of 987 in-stream alterations to stream channels affecting a total of 32.5 km (20.2 stream miles; Table 2-6). Within this data set we identified 3 major types of modifications: “concrete boulder”, “concrete channel”, and “loose boulder”. These 3 types comprised 71% of the modifications (Figure 2-5). Other common alterations mapped were “boulder weir” (45 features), “gabion” (44 features), “fill” (37 features), and “concrete pier” and “concrete wall” (35 and 23 features respectively). There were 30 other types of modifications mapped ranging from 1 to 14 occurrences.

Table 2-6. The most common channel modifications in Heal the Bay data.

Modification Type	Count	Stream Distance Affected (km/miles)
Loose Boulder	385	15.9/9.9
Concrete Boulder	173	4.3/2.7
Concrete Channel	145	12.7/7.9

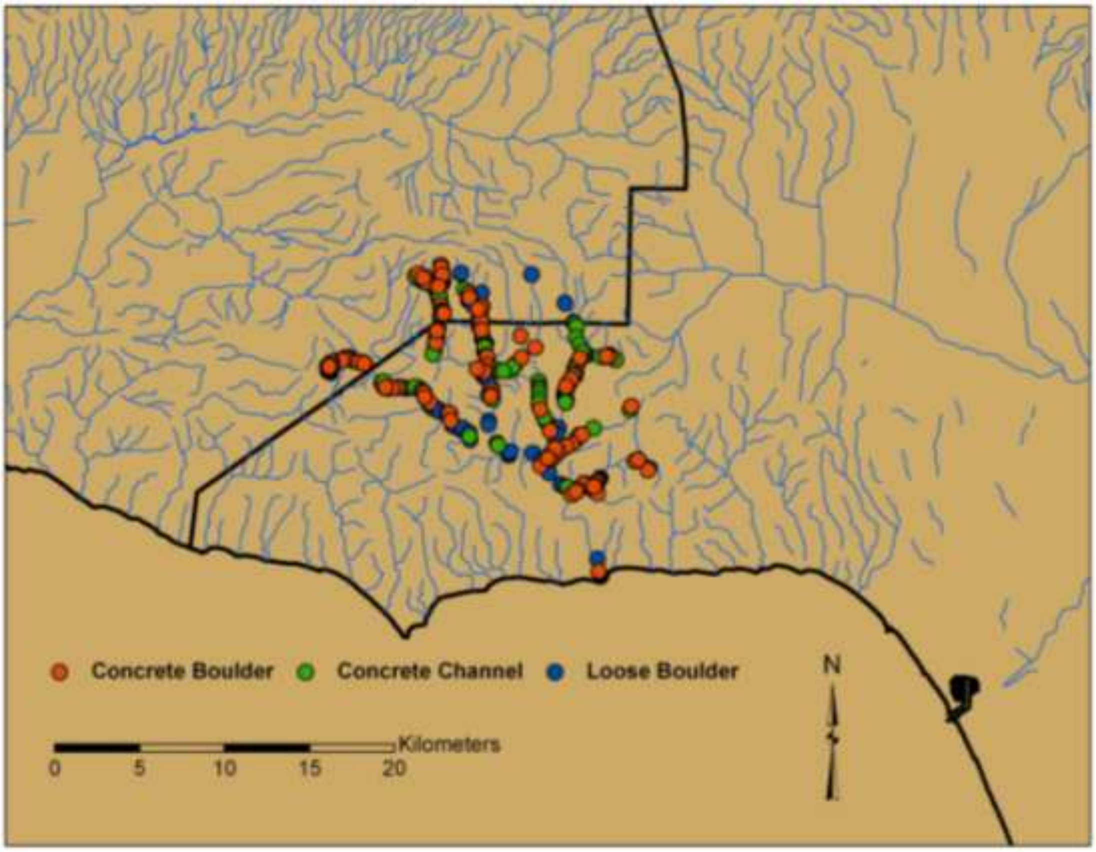


Figure 2-5. Three most commonly mapped features by Heal the Bay. These three types account for 71% of the features mapped by Heal the Bay, yet they are uncommon in other data sources.

2.2.5 Estimates of Confidence/Certainty in Existing Mapping

Heal the Bay mapped a total of 987 channel modifications or in-stream structures. Of these, other data sources had identified only 44, and these were limited to dams, bridges, and culverts. As such, "official" data sources represent approximately 4% of the stream-channel modifications identified in the Heal the Bay data. If this rate of mapping applies to the study area at large, we would expect an actual total of approximately 49,900 stream-channel modifications. To date, the data compiled for this project has identified only 2,225 modifications, not including the data compiled by Heal the Bay. It is recognized that Heal the Bay data cover only a small portion of the study area and this rate is not likely to be uniform across the study area; however, we lack other sites with similar detailed mapping to allow estimation of the variability of this ratio. While it appears that the most populated areas of the study area have the highest density of modifications, this may be misleading because we do not know what has not been mapped. The data from Heal the Bay indicate a high density of modifications in a relatively low population density portion of the study area. Although more modifications can be mapped in populated areas (bank armoring and storm-water outflows) very little is known about modifications upstream in less populated areas. Upper watershed areas may be relatively unmodified, but it is somewhat likely that property owners and land managers have added modifications to control erosion and discharge using a variety of methods that may not be showing up at the scale of interest to county and state agencies.

While the Heal the Bay data covers only a small subset of the study area, it suggests that existing mapping of these features in other parts of the county is missing a very large percentage of the features in place. The majority of features mapped are located in the lower potions of watersheds, in the most populated areas. Nevertheless, some of the most modified streams are not mapped in terms of modification. For instance, many streams in Los Angeles County have had bank armoring and concrete bottoms put in place, yet these features do not appear to have been mapped by any county or federal agency. The Los Angeles Department of Public Works and the Department of Water and Power were contacted for information about data on these channels, but no data could be identified. The Army Corp of Engineers has been contacted to inquire about any data that agency may have on these channel modifications, but no reply has been received to date. In the Malibu Creek watershed where Heal the Bay volunteers mapped 987 channel modifications, governmental agencies mapped 44. The cities of Agoura Hills and Calabasas have indicated that they do not have an inventory of modifications within their districts. The City Engineer of Agoura Hills noted that they have a goal of mapping modifications, but no concrete plan in place to do so at this time. Calabasas has information on the conditions of several streams within the city as part of environmental studies done on stream quality and restoration.

2.3 Discussion and Conclusions

Comprehensive data layers on widespread types of channel modification structures are not generally available. Based on the available data layers, approximately 2,200 structures exist in Los Angeles and Ventura counties, affecting approximately 72 km (45 miles) of streams (Figure 2-6). However, based on comparisons with intensive mapping in the Malibu Creek sub-basin conducted by Heal the Bay, we believe that the mapped features may represent less than 10% of the actual number of existing structures.

The most common type of structures mapped are bridges and in-stream flow and grade control structures such as the concrete channels and artificial and natural boulders placed in the Malibu Creek sub-basin. Most available data layers are for basic infrastructure, such as bridges, dams, storm-water basins. Many other types of modifications, including high-impact, and common ones such as bank armoring and channelized reaches, were missing from the available data.

Estimating the cumulative effects of the mapped modifications in this study is difficult due to the unknown extent of modifications that have yet to be identified. If trends revealed here hold it would appear that stream channels in the lower portions of the watershed are the most modified. Modifications vary from more substantial structures such as bridges, bank armoring, and channelization to less intensive such as placement of boulders or rip rap. The physical and biological effects of these structures will also likely vary with the type of modification; therefore, it is difficult to determine the overall effects of channel modifications at the watershed scale.

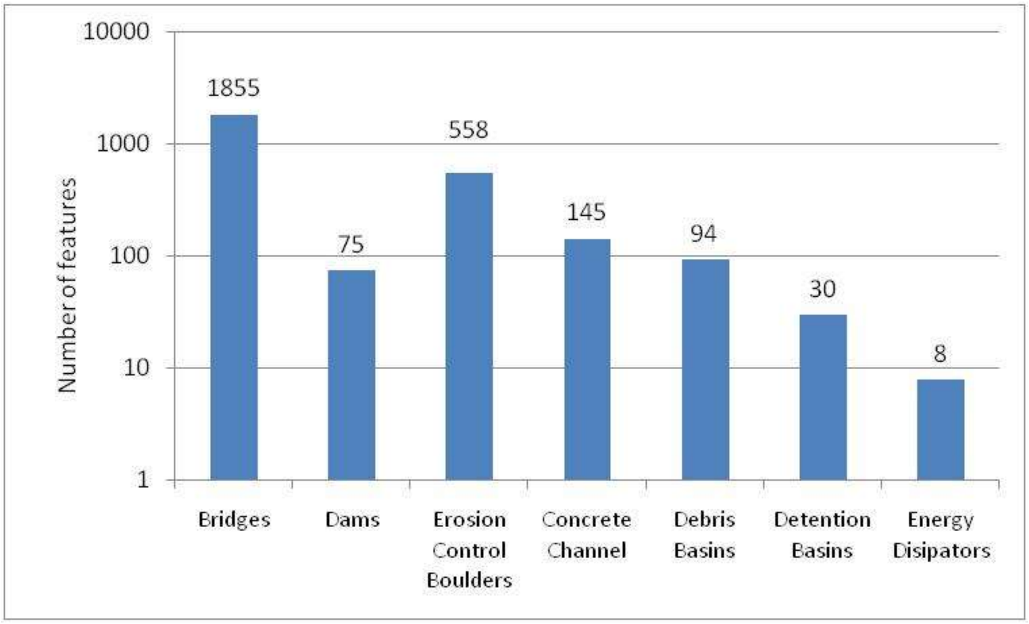


Figure 2-6. Frequency of each feature type in the study area. Note: second and third most common features (boulders and concrete channels) were mapped only in the Malibu Creek sub-basin by Heal the Bay. Vertical axis is logarithmic to allow ease of comparison between groups.

This effort was challenging because existing data are collected, stored, and used by a variety of agencies with overlapping interests, but without communication or a common data standard. Because of the lack of data standards, data are recorded at a range of spatial scales from highly detailed, fine scale mapping to highly generalized, coarse mapping. Agencies at multiple levels of government and even within one county's organization may be using different data standards, making it difficult to combine data layers or even to understand what was mapped. A common metadata standard for mapping modifications would facilitate data sharing among agencies and other interested parties.

The scale of data collection also has an enormous effect on the number and attributes of modifications recorded. At a generalized level, large features are identified using a large minimum mapping unit, perhaps dictated by regulations defining which features fall under the jurisdiction of a particular agency. At a detailed level, researchers walking the length of stream segments can identify and map many more features including objects difficult to classify using definitions of recognized stream channel modification practices. This discrepancy in a satisfactory scale of data collection, or minimum mapping unit, has led to a wide divergence in the amount of detail recorded with some areas having a great deal and others severely lacking.

The results of this project should be considered preliminary at best. It is clear that many more channel modification structures exist than have been mapped. While it may not be necessary or efficient to map every stream and tributary at the finest level of detail, it is necessary to map most streams and tributaries in more detail than has presently been done. A standard guideline or practice with respect to a reasonable minimum mapping unit would facilitate the collection of relevant data at the appropriate scale and coverage.

3. Physical and Biological Effects of Channel Armoring

The purpose of channel armoring is to limit or constrain the lateral movement of a stream in order to protect adjacent upland areas or infrastructure from damage due to overbank flooding and/or channel migration. Channel armoring with rock, concrete, geotextiles, or other materials results in obvious direct impacts such as loss of instream habitat, riparian areas, or adjacent upland buffers. Indirect effects associated with changes in slope, velocity, or general channel competence may be more subtle and difficult to detect. The objective of this portion of the study was to determine if tools commonly used to assess the physical or biological condition of streams respond to such indirect effects. The analysis is intended to test both the presence/severity of effects and the sensitivity of current assessment tools to such effects.

Physical effects of channel armoring were investigated using a series of traditional channel geomorphology measures (e.g., substrate size, slope, channel width) and the California Department of Fish and Game Physical Habitat (PHAB) protocols (Ode 2007). Several recently developed geomorphic assessment methods were also evaluated in terms of their ability to assess effects of bank armoring (Appendix A). Biological effects were investigated based on changes in instream benthic macroinvertebrate communities, diatoms, and soft-bodied algae (Ode 2007, Fetscher *et al*. 2009), and based on the California Rapid Assessment Method (CRAM) for wetlands (Collins *et al*. 2008).

The following hypotheses were tested under this portion of the study. Details are provided in subsequent sections:

<u>Physical Conditions</u>

1. Difference in flow patterns in armored stream segments will be associated with different sedimentation patterns, as evidenced by smaller grain/pebble size, relative to adjacent upstream segments.
2. Differences in flow and sedimentation patterns in armored stream segments will result in deeper pools and more simplified, planar channel beds relative to adjacent upstream segments.

<u>California Rapid Assessment Method</u>

1. The CRAM physical structure attribute and its associated metrics will be lower in armored segments than in adjacent upstream segments
2. The CRAM biological structure attribute and its associated metrics will be lower in the armored segment than in adjacent upstream segments
3. The CRAM buffer and hydrology metrics will be the same between the armored and upstream segments.

<u>Benthic Macroinvertebrates</u>

1. Differences in flow and sedimentation patterns will be associated with the Southern California IBI, *Coleoptera* Taxa, EPT Taxa, Predator Taxa, and % Intolerant Individuals scores being lower in the armored segments than in the upstream segments

2. Differences in flow and sedimentation patterns will be associated with the % Collector Individuals, % Non-insect Taxa, and % Tolerant Taxa scores being higher in the armored segments than in the upstream segments
3. The PHAB endpoints % pool, % sands and fines, and average water depth will be higher in the armored segments than in the upstream segments
4. The PHAB endpoints % vegetated groundcover, % canopy cover, and median grain size will be lower in the armored segments than in the upstream segments

Algae

1. Differences in flow will be reflected by differences in the algal community, such as the proportion of taxa that are tolerant vs. intolerant of high-velocity flows.
2. Differences in flow will be reflected by differences in the algal community, such as less biomass accrual in areas subject to higher-velocity flows.
3. Differences in sedimentation regime will be reflected by differences in the algal community, such as the proportion of benthic taxa that are either motile or otherwise tolerant of sedimentation

Overall

1. Effects of stream armoring will propagate downstream such that the downstream segment will exhibit changes in channel morphology and grains size comparable to those observed in the armored reach.
2. Effects of stream armoring will propagate downstream such that the downstream segment will exhibit changes in biological indicators comparable to those observed in the armored reach.

3.1 General Study Design

Effects of channel armoring were investigated by comparing conditions upstream, within, and downstream of segments that have been subjected to bank hardening (see Figure 3-1). The limited scope and budget of this project only allowed for sampling of six sites. Each of the six sites was considered an independent case study as opposed to a replicate in a larger study; conclusions are based on the presence, or lack, of consistent patterns among the six sites. The upstream reach of each site (A) was used as an internal control to test effects in the armored, or impacted, reach (B). Reach C was used to investigate whether any observed effects propagated downstream. Each reach was approximately 150m long to accommodate the biological sampling protocols.

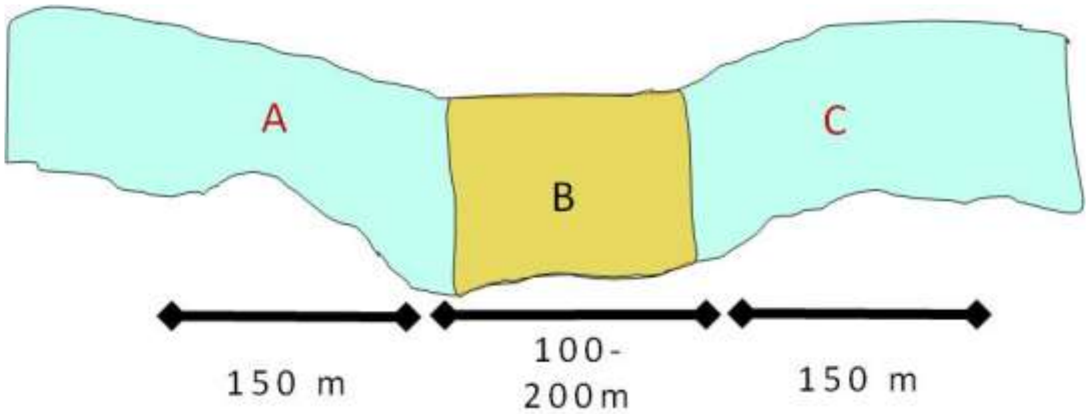


Figure 3-1. Conceptual sampling approach. The dark yellow area corresponds to the armored stream segment.

3.2 Site Selection

All study sites were located within the Los Angeles Regional Water Quality Control Board's jurisdictional area (generally Los Angeles and Ventura counties). To minimize the signal to noise ratio (i.e., maximize the opportunity to detect statistically valid relationships), we attempted to select sites with minimal confounding factors, i.e., no additional structures or features downstream of the armoring impact being investigated that could affect channel condition. Specific criteria used to guide site selection included:

- The site must include a reach of at least 100m of armoring on at least one bank, with unarmored (relatively natural) segments both upstream and downstream of the affected reach. The bank alteration should be at least five years old so that the channel is past the initial adjustment period.
- Perennial stream segments are preferred. However, at a minimum, the channel should have flow through late June and be sampleable for benthic invertebrate and algae measures using standard Surface Water Ambient Monitoring Program (SWAMP) protocols.
- The channel bottom through the study areas should be natural substrate with no anthropogenic hardening, filling, or paving. The preference is for gravel/cobble bed channels which will maximize taxonomic richness and hence maximize the ability to detect a response due to hydromodification.
- Sites should be free of systemic infestation with New Zealand Mud Snail or other ecosystem altering invaders.

Using the above criteria, we identified six sites; two each in the San Gabriel River, Los Angeles, River, and Calleguas Creek watersheds (Table 3-1; Figure 3-2).

Table 3-1. Summary of sampling sites.

Site ID	Site Name	County	Drainage Area (km^2)	General Site Characteristics
BH1	Big Tujunga Wash	Los Angeles	299	Unconfined, intermittent stream; flows regulated by Big Tujunga Dam and Reservoir; site is severely scoured (fire/flood damage)
BH2	West Fork San Gabriel River	Los Angeles	216	Confined perennial stream; flows regulated by Cogswell Dam
BH3	East Fork San Gabriel River	Los Angeles	205	Unconfined, natural perennial stream; not regulated. Site scoured from 2010 winter flow events
BH4	Arroyo Seco	Los Angeles	49	Confined, natural perennial stream, not regulated but flows influenced by upstream Brown Mountain Debris Basin; site severely scoured (fire/flood damage)
BH5	Arroyo Simi	Ventura	216	Unconfined, natural soft bottom channel; perennial flow due to urban runoff and pumped, shallow groundwater discharges to surface water
BH6	Conejo Creek	Ventura	198	Unconfined, natural soft bottom channel with rip-rap sides; perennial flow due to urban runoff and treated wastewater inputs

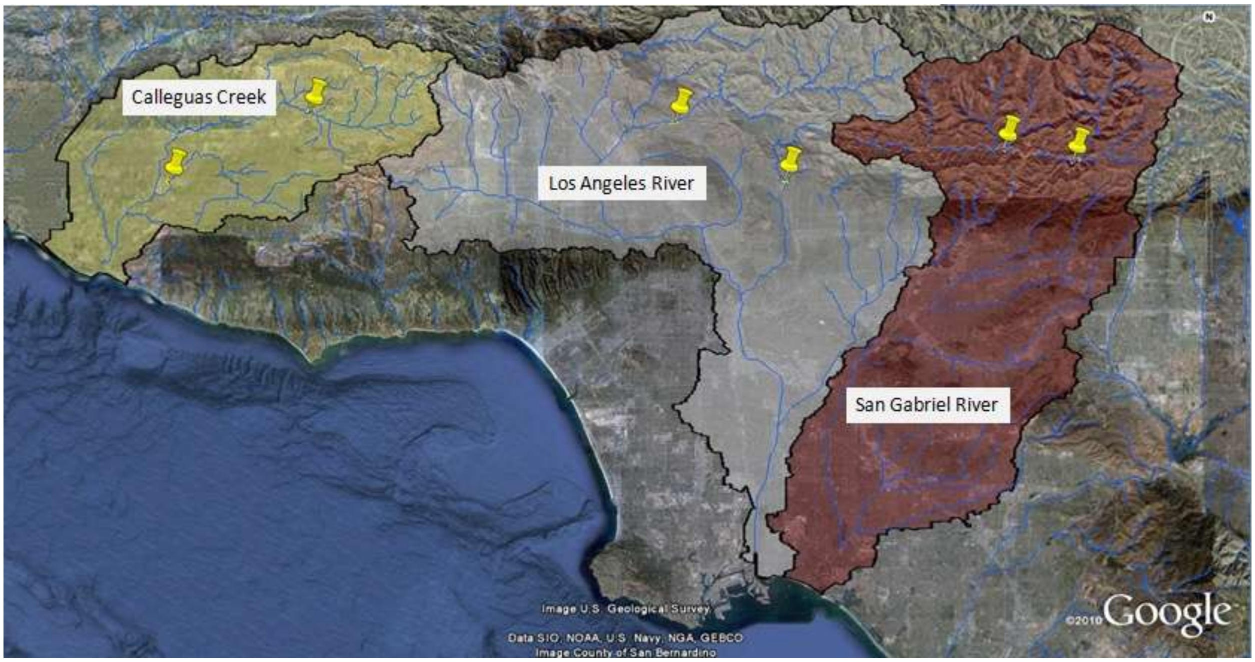


Figure 3-2. Location of sampling sites.

3.3 Methods

Sites were sampled to assess physical and biological conditions in three stream segments as described above. All sites were sampled during June and July 2010 while there was sufficient flow to meet critical condition requirements of the sampling protocols.

3.3.1 Assessment of Physical Condition

Physical assessment methods were used to evaluate how bank modification impacts channel geometry, by measuring features such as channel bed slope and cross sectional form and examining evidence of channel incision and planform change. Second, we evaluated how bank modification impacts in-stream and riparian habitat features, such as bed roughness, pool and riffle frequency, and presence of vegetation.

We used a combination of catchment characterization methods, traditional geomorphic field surveying methods and stream assessment tools to evaluate impacts of bank hardening at the study sites. Catchment analysis included reviewing geologic and topographic maps and hydrologic gauge records where available. Field methods included drawing facies maps, measuring average bed grain size, and surveying longitudinal profiles and representative cross sections in the upstream, armored, and downstream segments at each study site. Stream assessment tools from Europe and the United States were used to systematically record various features and classify the degree of modification and habitat quality impacts. We also assembled a photographic record of each site during field data collection.

3.3.1.1 Catchment Characterization

Using available GIS and hydrological data and paper maps, we characterized the catchment context of each study site. We relied upon the National Map Viewer 2.0 to view and download portions of the National Elevation Dataset (NED; Gesch 2007, Gesch *et al*. 2002) and the United States Geological Survey (USGS) National Hydrography Dataset (NHD; USGS 2009). We used catchment boundary shapefiles from NHD in ArcGIS to clip the topography data in NED for our study sites, and we measured valley width and approximate slope at the study sites. Data were converted for use in Google Earth, which was used to observe aerial imagery of the study site catchments. We also used geologic maps prepared by the California Geological Survey (CGS), including the interactive 2010 Geological Map of California (CGS 2010) and 1:250,000 scale paper maps (CGS 1977a,b) overlaid in Google Earth, to determine dominant bedrock geology formations in study site catchments. Hydrologic gauge data were collected from the USGS National Water Information System (http://waterdata.usgs.gov/nwis) for gauges located on study site streams, and were used in to analyze historic stream flow records. Mean annual precipitation amounts for study sites were recorded from the statewide GIS layer of mean annual rainfall zones from 1900-1960 (California Department of Forestry and Fire Protection 2010). Additionally, for sites in the Los Angeles River watershed we determined the approximate percent of upstream catchment burned in the 2009 Station Fire using the fire boundary delineated by the US Forest Service (USFS 2009).

3.3.1.2 Field Methods

Facies maps (i.e., sketches of the channel planform) provide a qualitative depiction of site characteristics and a basis for comparing sediment distribution and composition, channel form, and complexity among study segements. At each study site we drew a facies map that delineates locations of distinct sediment deposits, boulders, pool and riffle features, vegetation, woody debris, and other prominent channel features. Maps were hand drawn to scale onto gridded paper while in the field. Meter tapes placed along the channel centerline for the channel long profile were used as a longitudinal reference. Features noted on the facies maps and in geomorphic assessment and characterization tools (see Appendix A) were used to determine pool and riffle frequency within each reach. It is worth noting that bed features have likely changed since field data collection in July 2010.

The average surface particle size of a channel bed is an indicator of bed resistance and a determinant of bed surface roughness. Particle size can be used as an indicator of local channel velocity and habitat suitability for aquatic invertebrates and fish; changes in particle size are indicative of impacts due to changes in velocity or sediment discharge. We sampled bed surface particle size distributions (as a measure of bed conditions) by conducting pebble counts at select study segments using a modified version of the Wolman Pebble Count procedure (Wolman 1954). Pebble counts were not conducted where the bed was predominantly sand (Conejo Creek and Arroyo Simi sites) or predominantly large imbricated (overlapping in a common alignment due to flow) cobbles in deep water (West Fork San Gabriel site). Pebble counts were conducted by selecting particles at random from a representative patch located within the study reach. The intermediate-axis of each particle collected was measured with a ruler that was previously marked in “half-phi” classes. For embedded particles or those that were too large to move, we measured the shortest axis visible and recorded the particle as embedded. A minimum of 100 measurements were recorded at each study reach in order to quantify grain size distributions and median grain size (D50) at each site. All particles that measured less than 4mm were recorded as sand and included in the grain size distribution but were not included in the 100 particle count minimum.

We measured channel geometry at each study site by surveying the channel’s longitudinal profile and a representative channel cross-section with an auto-level, meter tapes, and a station rod. Benchmark locations were identified for all surveys in order to permit repeat surveying although benchmarks were not tied in to USGS surveyed benchmarks so all elevations recorded are relative elevations used to derive channel slope information. The longitudinal profile of each study reach was surveyed along the channel thalweg (deepest portion of the channel) at survey stations located at approximately 10-m intervals and/or at slope breaks to provide accurate information on overall channel gradient, riffle gradient, and pool depth. Channel elevation and water depth were recorded at all long profile stations and used to calculate average channel slope within each study reach. In addition to channel and water surface elevations, the height of observed high-water marks, primarily consisting of debris caught in trees, were recorded as an indication of the previous year’s maximum flow. Within each study reach we selected and surveyed a cross section representative of the general topographic character of the reach. The cross-section depicts quantitatively the steepness of the banks. Cross section survey stations were recorded at all topographic slope breaks. Major features such as bedrock outcroppings, vegetation, and channel thalweg were recorded in the notes.

3.3.2 Assessment of Biological Condition

Biological condition at the armored segments relative to the upstream and downstream segments was evaluated based on benthic macroinvertebrates, algae, and CRAM. Standard bioassessment protocols include an assessment of physical habitat (PHAB) as an explanatory measure to help interpret bioassessment results.

3.3.2.1 California Rapid Assessment Method (CRAM)

General condition of the stream and its adjacent riparian area were evaluated using the California Rapid Assessment Method (CRAM; Collins *et al*. 2008). CRAM assessments are based on four attributes of wetland condition: landscape context, hydrology, physical structure, and biotic structure. For the purposes of CRAM, stream and associated riparian areas are considered wetlands. CRAM attributes are evaluated based a set of metrics, or readily observable field indicators (Table 3-2). Each metric was evaluated over the entire 150-m reach based on a standardized set of mutually exclusive descriptions representing a full range of possible condition. Metrics are scored based on narrative descriptions, quantitative measures, or diagrams (depending on the metric). Scores range from 3 to 12 for each metric; metric scores can be aggregated to overall attribute scores and attribute scores aggregated to an overall index score based on simple combination rules. Attribute and index scores are expressed as percent possible, ranging from 25 (lowest possible) to a maximum of 100. The final part of the CRAM assessment involves indentifying key stressors that may affect wetland condition. Details of CRAM assessments can be found in the CRAM User's Manual (Collins *et al*. 2008) or on the CRAM web site at www.cramwetlands.org.

Table 3-2. CRAM attributes and metrics.

Attributes		Metrics
Buffer and Landscape Context		Landscape Connectivity
		Percent of AA with Buffer
		Average Width of Buffer
		Buffer Condition
Hydrology		Water Source
		Hydroperiod
		Hydrologic Connectivity
Structure	Physical	Structural I Patch Richness
		Topographic Complexity
	Biotic	Vertical Biotic Structure
		Interspersion and Zonation
		Number of Plant Layers
		Number of Codominant Species
		Percent Invasive Plant Species

Data Analysis

We performed statistical tests of the relationships between response variables (CRAM Overall Index and Attribute scores) and segment type (upstream, impact, and downstream segments). We hypothesized that CRAM physical and biotic structure attributes would show effects of hydromodification while the buffer and hydrology attributes would not. Because we proposed a hypothesis for each response variable, we considered p-values <0.05 to be statistically significant and did not perform a Bonferonni correction.

We used two different statistical approaches for bivariate statistical analyses. First, we used paired t-tests to compare means among the reach types. Results from paired t-tests should be taken with caution, however, as the data may not meet assumptions about normality, and there is uncertainty in assessing normality with a small sample size (n = 5 or 6).

3.3.2.2 Benthic Macroinvertebrates

Benthic macroinvertebrates (BMI) and physical habitat (PHAB) were sampled using the standard SWAMP methodology described in Ode (2007), with PHAB modifications described in Fetscher *et al*. (2009). Benthic macroinvertebrates were sampled using the multihabitat/reach-wide benthos sampling method. Both the BMI and PHAB sampling take place in a 150-m reach divided into 11 equidistant transects that are arranged perpendicular to the direction of flow. The downstream transect is sampled first, and sampling proceeds upstream. A standard 500-um mesh-top D-frame net was used to collect macroinvertebrates while disturbing the substrate for 30 to 60 seconds at each transect. The collection of benthic macroinvertebrates occurred simultaneously with algae collection, as described in Fetcher *et al*. (2009), in order to avoid disturbance of algae communities. Benthic macroinvertebrate samples were preserved immediately at the collection site using 100% ethanol, resulting in a final concentration of 70 to 80%. A minimum of 600 benthic macroinvertebrates were sorted and identified in the laboratory based on SWAMP protocols and following the taxonomic standards of the Southwestern Association of Freshwater Invertebrate Taxonomists (SAFIT).

Benthic macroinvertebrate samples were preserved immediately, at the collection site, using 95% - 100% ethanol (EtOH; non-denatured) at a ratio of 5 parts EtOH per 1 part sample. For all samples, 95% EtOH was replaced with fresh 95% EtOH within 24 to 48 hours, again using a ratio of 5:1. Samples stored for more than one week were refreshed with fresh ethanol on a weekly basis.

PHAB measurements made at each transect and/or inter-transect included: wetted width; flow habitats; a pebble count including water depth, coarse particulate organic matter (CPOM), and algae cover for each pebble; cobble embeddedness; slope; sinuosity; canopy cover; riparian vegetation; instream habitats; human influence; bank stability; and bankfull dimensions. Certain PHAB measurements were also made at ten additional transects (designated “inter-transects”) located between the main transects to give a total of 21 transects per reach. Please refer to Ode 2007 for details on how each component is measured. Fetscher *et al*. 2009 provides additional instruction on measuring algal cover along transects.

Data Analysis

We performed statistical hypothesis tests of the relationships between response variables (selected BMI metrics and PHAB endpoints) and reach type (upstream, impact, and downstream segments).

Hundreds of possible metrics and endpoints describing BMI and PHAB data can be calculated. If we were to perform tests on all of these endpoints (i.e., a "statistical fishing expedition"), there is a greatly increased chance of incorrectly rejecting the null hypothesis, resulting in many false positives. To avoid the problems inherent in this type of exploratory data analysis, we selected a subset of potential variables *a priori* for which we had proposed specific hypotheses. Variables were selected based upon existing information that indicated they are responsive to hydromodification or general anthropogenic disturbance. Because we proposed a hypothesis for each response variable, we considered p-values <0.05 to be statistically significant and did not perform a Bonferroni correction. The *a priori* selected variables (and direction of predicted response to hydromodification) were:

- The Southern California IBI (-), and the seven individual metrics that comprise the IBI: Coleoptera Taxa (-), EPT Taxa (-), Predator Taxa (-), % Collector Individuals (+), % Intolerant Individuals (-), % Non-insect Taxa (+), and % Tolerant Taxa (+).
- A subset of PHAB endpoints currently being developed for SWAMP bioassessment analyses, including % pool (+), % vegetated groundcover (-), % canopy cover (-), % sand+fines (+), median grain size (-), average water depth (+).

If the predicted response to hydromodification for a variable was positive (+), our alternative hypotheses stated that (1) the impact reach had higher values (+) than the upstream reach.

We used two different statistical approaches for bivariate statistical analyses. First, we used paired t-tests to compare means among the reach types. Results from paired t-tests should be taken with caution, however, as the data may not meet assumptions about normality, and there is uncertainty in assessing normality with a small sample size (n = 5 or 6). Consequently, we also compared relative changes between reach types by performing the nonparametric equivalent of the paired t-test, the Wilcoxon signed-rank test, which ranks the absolute value of differences among pairs of data, sums the positive and negative values of signed ranks, and compares these sums to a critical value in order to test the null hypotheses.

We also performed an analysis of BMI and PHAB data using multivariate ordinations. We used non-metric multi-dimensional scaling (NMS) in order to determine dissimilarity of BMI communities among sites and segments. NMS was run in PC-ORD software (McCune and Grace 2002) with the Sorensen distance measure and "slow and thorough" autopilot mode, which runs initial ordinations to determine the best dimensionality (stability criterion of 0.00001, maximum of 6 axes, 40 runs with real data, and 50 randomized runs) and a second round of ordinations using the selected dimensionality (stability criterion of 0.00001, 1 run with real data, up to 400 iterations). We used untransformed taxa densities (individuals/m^2) for all ordination analyses. We examined the correlation of environmental variables with the ordination of taxa densities as well as the correlation coefficients between each taxon and the axes of the final ordination. We used minimum correlation (r) values of 0.5 (PHAB) and 0.6 (BMI) as criteria for moderate or strong correlation.

3.3.2.3 Algae

At each study reach, stream algae were sampled using the standard operating procedures (SOP) of California's Surface Water Ambient Monitoring Program (Fetscher *et al*. 2009).This entailed concurrently sampling benthic macro- and micro-algae (including diatom and soft-bodied taxa, as well as cyanobacteria) from a variety of stream substrata within the study reach. The same 11 transects used for the BMI and PHab sample and data collection were used for sampling algae. Specifically, at an objectively identified location along each transect (i.e., 25, 50, or 75% of the way across the stream), a sample of algal material was collected from whatever substrate type was present there (e.g., cobble, gravel, sand, boulder, bedrock), using a sampling device of known area. This procedure was repeated at each of the 11 transects, and each time, the collected material was added to a "composite sample" mixture. Once specimens were collected from all 11 transects, the composite was homogenized and aliquoted into several sample types: 1) for diatom taxonomic identifications and enumeration, 2) for soft-bodied algal and cyanobacterial taxonomic identifications and enumeration, and 3) for biomass analyses.

Field samples were analyzed for diatom, soft-bodied algae, and cyanobacteria. For diatoms, raw samples were cleaned of organic matter and the resulting material was used to make permanent diatom slides. Then 600 objectively selected diatom valves were identified to the lowest taxonomic category possible (species, variety, or form.) Observations were made with research-grade light microscopes, using oil immersion lenses. Major taxonomic references for species identification included Patrick and Reimer (1966, 1975), Krammer and Lange-Bertalot (1986, 1988; 1991a,b) and taxon-specific references (primary literature, books and monographs) where applicable and necessary.

For soft-bodied algae and cyanobacteria, a total of 300 "counting units" were identified and enumerated at 200-1000x magnification (as needed) under a research-grade compound microscope. Both multicellular taxa (colonies or filaments) and individual unicells were considered to be one counting unit. This procedure enabled objective characterization of algal assemblages that have a broad range of morphological forms and sizes. Then volumetric measurements were used to estimate total biovolume of each taxon. All specimens were identified to the lowest taxonomic level possible (usually species or variety, except where sexual reproduction was necessary for identification to species level (*e.g.*, *Oedogoniales* and *Zygnematales*). Major taxonomic references included recent general monographs, such as John *et al*. (2002) and Wehr and Sheath (2003), as well as taxon-specific references, including those given in each chapter of Wehr and Sheath (2003).

Total soft-algal biomass was determined using a combination of water-displacement and volumetric measurements under a microscope in order to determine biovolume represented in the sample, as well as extrapolated up to an assessment at the level of the stream reach. Ash-free dry mass (AFDM), an alternative estimate of biomass, was determined by homogenizing and filtering known volumes of composite sample, drying the filters to a constant weight, oxidizing them at 500°C, and reweighing them to determine the mass of organic carbon in the sample.

Data Analysis

To test the three hypotheses related to algae listed in Section 3, we conducted multivariate analyses of community composition using nonmetric multidimensional scaling (NMS) on normalized diatom count data and cubed-root-transformed soft algal absolute biovolume data. The goal was to identify structure within the dataset based on community composition, thus providing a means to compare sampling locations in terms of the algal taxa recorded from each sampling site.

A second approach to data analyses involved characterizing each taxon in terms of features hypothesized to confer differential responses to hydromodification. For the diatoms, this included motility and growth form. Motility was classified as either “non motile”, “moderately motile”, or “highly motile”. With respect to growth form, diatom taxa were classified based on whether they tend to be attached to substrata or not, and of the attached forms, whether they generally maintain low vertical profiles within the stream (prostrate), which presumably would render them more resilient to high-velocity flows, or extend more upwardly into the water column (stalked). Soft-bodied taxa were characterized according to their ability to tolerate sedimentation, and according to their tendency to prefer habitats with slower-moving water vs. faster. National databases (e.g., EMAP and NAWQA), literature, and personal communications with the expert phycologists who identified the specimens were used to assign these characters to each taxon.

Once all taxa were assigned characters, a number of simple indices were created and applied across each of the sampling sites in order to look for consistent patterns relative to hydromodification. For some indices, this was done by assigning factors of varying magnitude to the different categories, then weighting the proportion of all taxa in each category by that factor, and summing the resulting products for each site. For example, for the “diatom motility index”, the highly motile diatoms were weighted by a factor of 3, and the moderately motile were weighted by a factor of 2, such that a higher the overall score at a given site, the greater the inferred ability for the diatom community to tolerate sedimentation, and therefore the greater the likelihood that sedimentation had been occurring at that site. All of the indices were calculated using both relative abundance data and species richness data. Table 3-3 provides a list of all the indices and how they were calculated.

We employed two measures of stream algal productivity: total soft algal biovolume and ash-free dry mass, to examine the possible relationship between channel armoring and biomass accrual within each study segment. Analysis of variance (ANOVA) with site and segment (A, B, C) as main effects was used for evaluating the significance of algal community responses to armoring.

Table 3-3. Algal indices developed for examining relationships between diatom and soft-bodied algal communities and potential effects of hydromodification, and how they were calculated.

Index	Calculation
%motileDiatoms_ab	proportion of counts corresponding to moderately, or highly, motile diatom taxa
%motileDiatoms_sr	proportion of diatom taxa that are moderately, or highly, motile
%hightlyMotileDiatoms_ab	proportion of counts corresponding to highly motile diatom taxa
%hightlyMotileDiatoms_sr	proportion of diatom taxa that are highly motile
diatomMotilityIndex_ab	(proportion of counts of diatom taxa that are highly motile * 3) + (proportion of counts of diatom taxa that are moderately motile * 2) + proportion of counts of diatom taxa that are non motile
diatomMotilityIndex_sr	(proportion of diatom taxa that are highly motile * 3) + (proportion of diatom taxa that are moderately motile * 2) + proportion of diatom taxa that are non motile
diatom%SedimentationTolerant_ab	proportion of counts corresponding to moderately motile or highly motile diatom or unattached taxa
diatom%SedimentationTolerant_sr	proportion taxa that are moderately motile or highly motile diatom or unattached
softSedimentationIndex_ab	(proportion of total soft-bodied algal biomass comprised of taxa that are deemed sedimentation-tolerant*2.5)+proportion of total soft-bodied algal biomass comprised of taxa that are deemed sedimentation-intolerant
softSedimentationIndex_sr	(proportion of total soft-bodied algal taxa that are deemed sedimentation-tolerant*2.5)+proportion of total soft-bodied algal taxa that are deemed sedimentation-intolerant
diatomFlowToleranceIndex_ab	(proportion of counts of diatom taxa that are prostrate * 3) + (proportion of counts of diatom taxa that are stalked or erect * 2) + proportion of counts of diatom taxa that are unattached to substrata
diatomFlowToleranceIndex_sr	(proportion of diatom taxa that are prostrate * 3) + (proportion of diatom taxa that are stalked or erect * 2) + proportion of diatom taxa that are unattached to substrata
softFlowToleranceIndex_ab	(proportion of total soft-bodied algal biomass comprised of taxa that are deemed to prefer median flows * 3) + (proportion of total soft-bodied algal biomass comprised of taxa that are deemed to prefer median-to-low flows* 2) + proportion of total soft-bodied algal biomass comprised of taxa that are deemed to prefer low flows
softFlowToleranceIndex_sr	(proportion of soft-bodied algal taxa that are deemed to prefer median flows * 3) + (proportion of soft-bodied algal taxa that are deemed to prefer median-to-low flows* 2) + proportion of soft-bodied algal taxa that are deemed to prefer low flows

3.4 Results

3.4.1 Catchment Characterization

The six study sites were all located within the Ventura Basin of the Transverse Ranges geomorphic province of southern California. This province is characterized by west-trending valleys and ridges formed by a parallel series of anticlines, synclines, and faults. The San Andreas Fault is the dominant tectonic feature in this region.

The study sites are located in three characteristically different areas: the San Gabriel Mountains (East and West Forks San Gabriel River, Arroyo Seco), the base of San Gabriel foothills (Big Tujunga), and Simi Valley (Conejo, Arroyo Simi). Sites located in the San Gabriel Mountains are situated in steep gorges and each have at least some reach portions confined by bedrock. The Big Tujunga study site receives granitic sediment deposits from the San Gabriel Mountains, but is located within an alluvial fan at the base of the San Gabriel foothills where the floodplain widens. The Conejo Creek and Arroyo Simi study sites are located in valleys and are dominated by marine and non-marine sedimentary material (Table 3-4). The majority of the catchment upstream of the Big Tujunga and Arroyo Seco study sites burned in the 2009 Station Fire. The West Fork of the San Gabriel River was also impacted by the Station Fire, however sediment transport in the upper portions of the watershed are largely dampened by Cogswell Dam.

Table 3-4. Catchment characteristics of the study sites.

Stream	Drainage Area (kn2) Upstream of Site	Upstream Dams	Dominant Bedrock in Catchment	Landform Type	Catchement-scale Disturbance
BH1 Big Tujunga	298	Flood Control Reservoirs (Big Tujunga Reservoir - 7,350,000m3 capacity)	Mezozoic Plutonic granitics, Paleozoic Plutonic granitics and Pre-Cambrian intrusives	proximal alluvial fan	Virtually all of the catchment burned in Station fire August 2009
BH2 San Gabriel - West Fork	215	Cogswell Dam	Mezozoic Plutonic granitics and Pre-Cambrian intrusives	gorge	Most of the catchment above Cogswell Dam burned in Station fire August 2009
BH3 San Gabriel - East Fork	205	none	Mezozoic Plutonic granitics and Pre-Cambrian intrusives	montane alluvial valley, channel flanked by terraces, transitioning to gorge	none
BH4 Hahamunga (Arroyo Seco)	49	small debris dams	Mezozoic Plutonic granitics, Paleozoic Plutonic granitics and Pre-Cambrian intrusives	gorge	Virtually all of the catchment burned in Station fire August 2009
BH5 Arroyo Simi	215	none	Tertiary marine and non-marine sedimentary	montane alluvial valley (between Santa Susanna and Simi Hills)	none
BH6 Conejo	197	none	Northern half catchment: cenozoic marine sediments, Southern half: volcanics	wide alluvial valley	none

3.4.2 Characteristic Changes to Channel Geometry

At most sites, with the exception of Conejo Creek, measured bed slope was steepest in the upstream "natural" reach (A), less steep in the downstream reach (C), and least steep in the middle "impact" reach (B). Measurements of cross sectional geometry, including wetted channel, primary channel, and floodplain widths, did not display consistent trends between upstream, impact, and downstream reach channel form among study sites (Table 3-5). We hypothesize that this is due to variation in physiographic setting among the study sites, and localized disturbances.

We observed evidence of varying degrees of channel incision in the armored segments at all sites. We also observed bank toe failure (undercutting) in the armored segments at the San Gabriel River sites and Conejo Creek, suggesting that bank hardening is contributing to localized incision at these sites.

Table 3-5. Summary of physical properties of each study site.

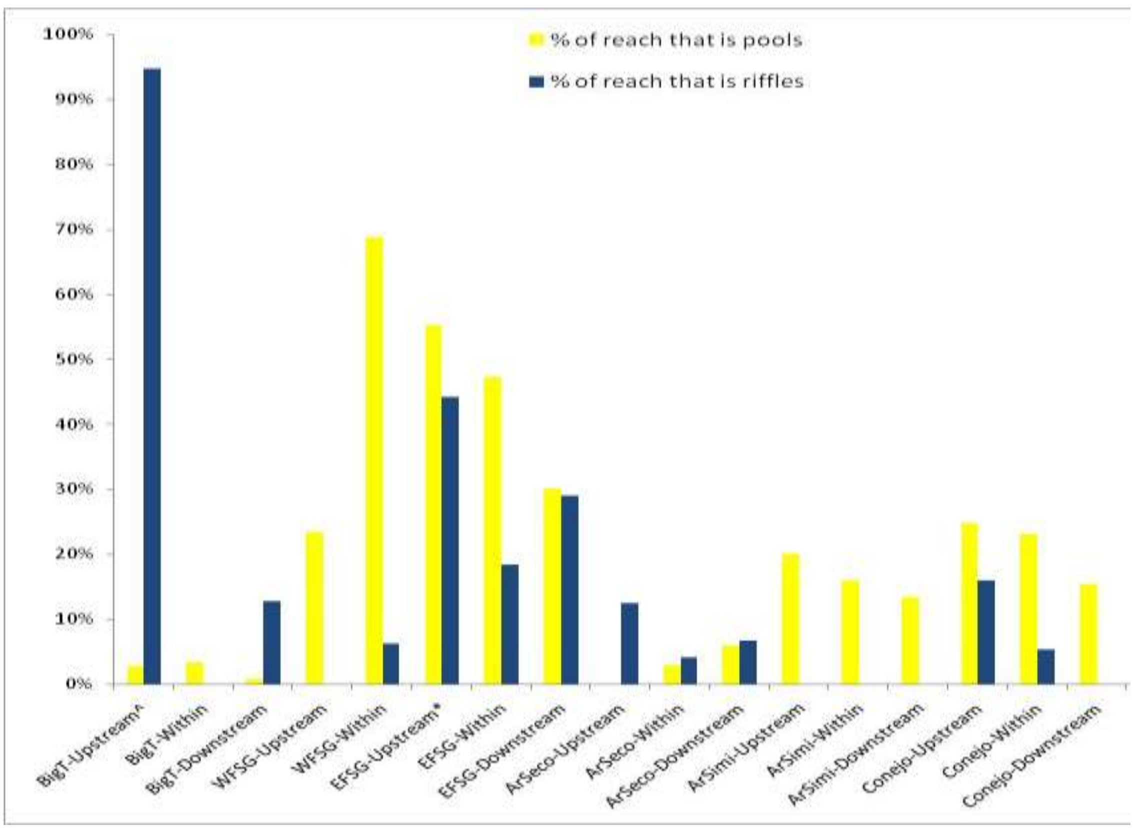
Study Reach	Reach length (m)	Location of Cross Section	slope (%)	embedded (%)	D50	HWM Avg. (m)	Critical Boundary Shear Stress	Wetted Channel Width (m)	Primary Channel Bankfull Width (m)	Floodplain Width (m)
BH1-A	150	94.9m	2.94	17.31	32	-	519.15	3.7	6.8	178
BH1-B	143.4	351.3m	0.97	27.48	<4	-	171.28	2.4	6.6	121
BH1-C	123.6	750m	1.27	33.97	22	1.8	224.26	4.8	29.9	97
BH1 All		-	1.39			1.8	245.45			
BH2-A	159	119.7m	2.34	-	-	-	-	8.7	18	0
BH2-B	77.5	46.4m	1.03	-	-	-	-	9.4	19	0
BH3-A	100	28.4m	1.99	17.65	32	-	-	10.5	29	87
BH3-B	125	43.8m	1.26	14.55	47.7	-	-	8.5	24.25	57.2
BH3-C	98.5	52m	1.53	17.82	31.5	-	-	11.8	23.3	34
BH3 All		-				-	-			
BH4-A	119.5	40m	2.8	10.4	4	2.63	722.41	1.5	7.3	50
BH4-B	116	230.5m	2.18	6.17	8	-	562.45	1.9	6.6	26.5
BH4-C	180	390.6m	2.4	10.71	16	-	619.21	3.2	11.8	40
BH4 All		-	2.64			2.63	681.13			
BH5-A	80	33.6m	0.28	-	<4	-	59.06	3.75	6	>30
BH5-B	113.2	205m	0.08	-	<4	2.15	16.87	5.3	10.6	>30
BH5-C	117	276m	0.17	-	<4	-	35.86	3.8	10.7	>30
BH5 All		-	0.24		<4	2.15	50.62			
BH6-A	130	69m	0.07	-	<4	-	20.60	5.8	11.2	37
BH6-B	119.5	256.5m	0.44	-	<4	3	129.49	5.8	7.3	34
BH6-C	180	~410m	0.08	-	<4	-	23.54	6.8	8.2	30
BH6 All			0.12		<4	3	35.32			

Based on field observations and examining surrounding topography and aerial photographs, we interpret that the planform of most of our study sites did not change over time. Exceptions to this were Big Tujunga and Conejo Creek. All of the sites in the San Gabriel Mountains are confined by steep valleys, which limit the extent of planform change. Bank reinforcement imposes a degree of confinement on Conejo Creek and Arroyo Simi, which are incised into the wide alluvial valley floor. The alluvial fan upon which Big Tujunga is situated is confined by the bank reinforcement, yet there is enough space for Big Tujunga to actively rework the surrounding floodplain. Detailed observations for each of the study sites are provided in Appendix B.

3.4.3 Instream Features

Instream habitat complexity in upstream, armored, and downstream segments did not vary consistently among sites. Thus, our hypothesis that armored reaches would have the least instream habitat complexity (more pools due to channel scouring, decreased grain size, little riparian vegetation) was not generally supported at all sites. However, several sites did exhibit reduced instream complexity in armored reaches, but catchment processes, local disturbances, and/or natural features prevented us from directly attributing these observations to the presence of a hardened bank (e.g., exposed bedrock in some segments can function similarly to an artificial bank-hardening structure). Investigation at additional sites will help better define these relationships.

There were no consistent patterns in the distribution of riffles and pools between upstream and armored segments (Figure 3-3). Individual sites did exhibit some differences(e.g., there was a significant decrease in riffle presence in the armored reach at Big Tujunga and East Fork San Gabriel compared to the upstream segments) but it is difficult to attribute these changes to the channel armoring as opposed to other site-specific factors that may be influencing channel morphology.



^reach included braided channel with two wet channels, both with long riffles
*suction dredging equipment observed in this site may distort # of pools

Figure 3-3. Percent of reach length that is in pools or riffles.

There were no consistent trends in grain size distribution among the study segments, largely due to heterogeneity between sites. At some sites, the inherent site conditions did not lend themselves to observing effects. For example, pebble counts were not conducted at Conejo Creek or Arroyo Simi because both beds were composed primarily of sand. River beds at West Fork San Gabriel study segments were composed primarily of large imbricated cobbles. In contrast, at Big Tujunga, the armored segment has the smallest median bed grain size compared to upstream and downstream reaches (Figure 3-4).

Results from the River Habitat Survey and IDRAIM showed that riparian vegetation and channel shading were more contiguous in upstream and downstream segments than in impact segments, due to the presence of a bank hardening structure which prevented vegetation establishment (see Appendix A for additional details).

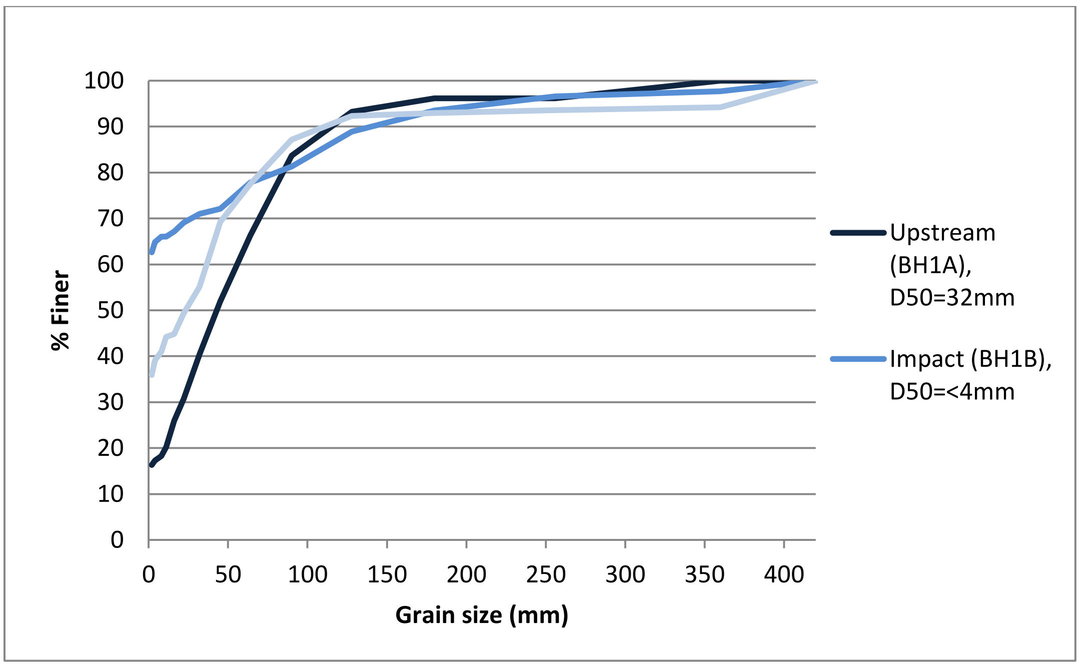


Figure 3-4. Grain size distribution plots for Big Tujunga.

3.4.4 CRAM Assessment

There was a general trend toward lower CRAM index scores in the armored stream segments relative to the upstream segments. However, there were no downstream effects with CRAM index scores for downstream segments being comparable to those upstream of the armoring (Figure 3-5). At the individual attribute level, our hypothesis that the physical and biotic structure attributes would show effects while the buffer and hydrology attributes would not was only partially supported. The most pronounced difference was for the Biotic Structure attribute, which was consistently lower in the armored segment than in the upstream control segment (Figure 3-5); with these differences being significant at the p<0.05 level based on paired t-tests (Table 3-6). This result is likely reflective of the loss of riparian vegetation and instream habitat associated with construction of bank armoring. Our hypothesis that Physical Structure attribute scores would be lower in armored segments was not supported as there were no statistically significant differences between the three segments. The one exception was for Big Tujunga (BH1) where there was a lower score for the Physical Structure attribute in the armored segment. This is consistent with the observations for this site base on the channel structure evaluation (see above). The Hydrology attribute scores were slightly lower in armored segments than in upstream segments; however the differences were generally within the 5% error range associated with CRAM attribute scores. There was a statistically significant difference between the armored and downstream segments in terms of the Buffer and Landscape Connectivity and Hydrology attributes at the p≤0.05 level based on paired t-tests, reflecting the differences in the landscape setting of the armored reaches vs. the downstream reaches (Table 3-6).

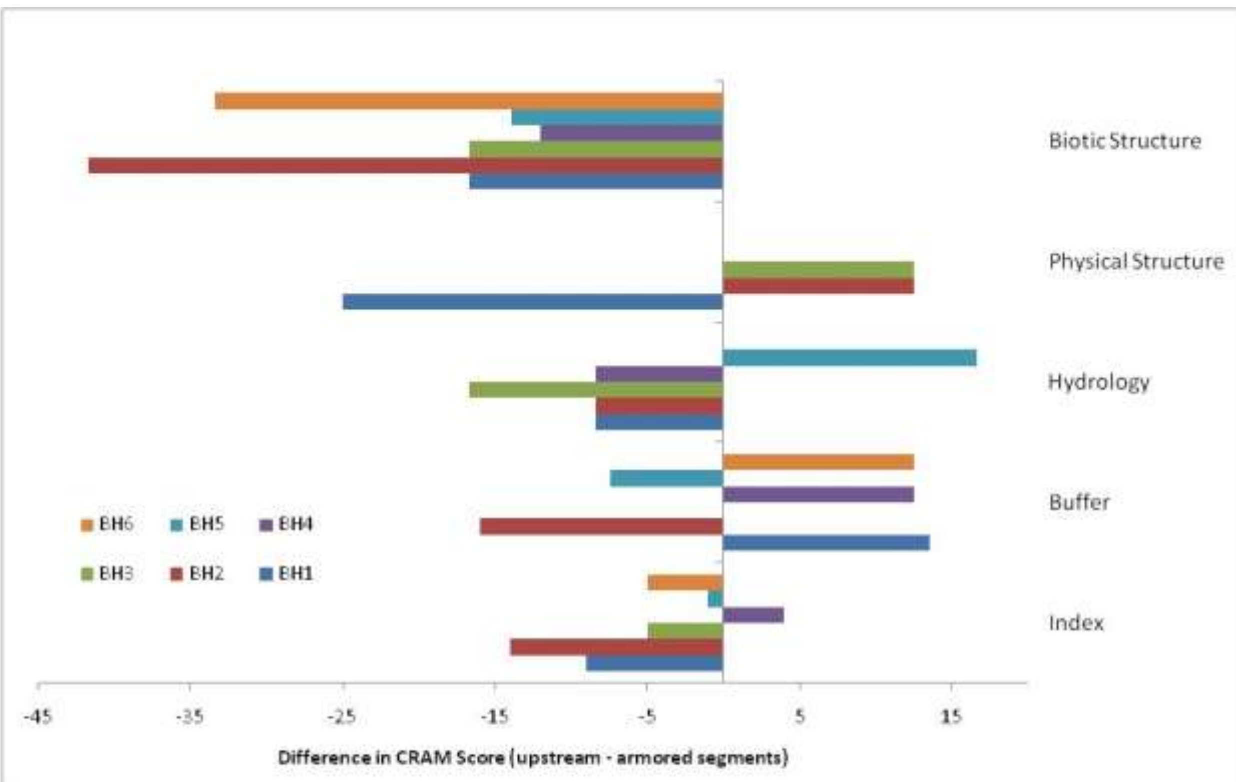


Figure 3-5. Differences in CRAM Index and Attribute scores between upstream and armored segments.

Table 3-6. Results of one-tailed paired t-tests for CRAM Overall Index and Attribute scores among treatments. Expected responses (in parentheses) apply to comparisons. Comparison A is based on n = 6 paired sites per treatment; comparisons B and C are based on n = 5 paired sites per treatment.

	A. Upstream/Impact Avg/Avg (p-value)	**B. Upstream/Downstream Avg/Avg. (p-value)**	**C. Impact-Downstream Avg/Avg (p-value)**
CRAM Scores			(opposite expected responses)
Overall Index	70.0/65.0 (0.05)	68.4/68.2 (0.45)	65.2/68.2 (0.07)
Buffer/Landscape Context Attribute	78.3/80.8 (0.32)	80.4/77.4 (0.07)	**86.6/77.4 (0.01)**
Hydrology Attribute	73.7/69.5 (0.21)	70.0/76.6 (0.25)	**66.8/76.6 (0.02)**
Physical Structure Attribute	60.5/60.5 (0.50)	60.0/65.2 (0.09)	57.6/65.2 (.11)
Biotic Structure Attribute	**67.7/49.0 (0.03)**	63.4/53.4 (0.30)	49.4/53.4 (0.07)

3.4.5 Benthic Macroinvertebrates and PHAB

There were no statistically significant differences between the three segments (upstream, armored, downstream) in terms of benthic macroinvertebrate metrics or indices. None of the paired, one-tailed t-tests comparing selected biological metrics or PHAB variables statistically supported our *a priori* hypotheses ($\alpha = 0.05$; Table 3-7). For example, although the impact segments had slightly lower average SoCal IBI scores (36.4) than the upstream segments (40.2), this difference was not statistically significant. In fact, comparisons of average values among the three segments exhibited responses in the hypothesized direction for only slightly more than half (60%; 25/42) of the tests (Table 3-7).

Two *a priori* hypotheses were supported at the $\alpha = 0.05$ level using the nonparametric Wilcoxon sign-rank test. The median grain size at impact segments was significantly smaller than in upstream segments (p = 0.039) and downstream segments (p = 0.047). There were no significant relationships among BMI metrics using the sign-rank test.

Although sites did not exhibit strong, consistent responses to channel armoring in terms of macroinvertebrate metrics, a subset of individual sites did exhibit predicted responses. For example, IBI scores decreased from upstream to armored segments at 4 of the 6 sites; however, the magnitude of change at two of the sites was substantial (West Fork San Gabriel, 63.6 to 49.3; East Fork San Gabriel, 62.1 to 49.3). The main constituent metrics responsible for the lower IBI scores in armored segments at two sites were decreases in Coleoptera Taxa and increases in Percent Non-Insect Taxa and Percent Tolerant Taxa metrics.

Table 3-7. Results of one-tailed paired t-tests for selected metric scores and PHAB variables among treatments. Expected responses (in parentheses) apply to comparisons. Comparison A is based on n = 6 paired sites per treatment; comparisons B and C are based on n = 5 paired sites per treatment. Comparisons with p values <0.10 are shown in bold.

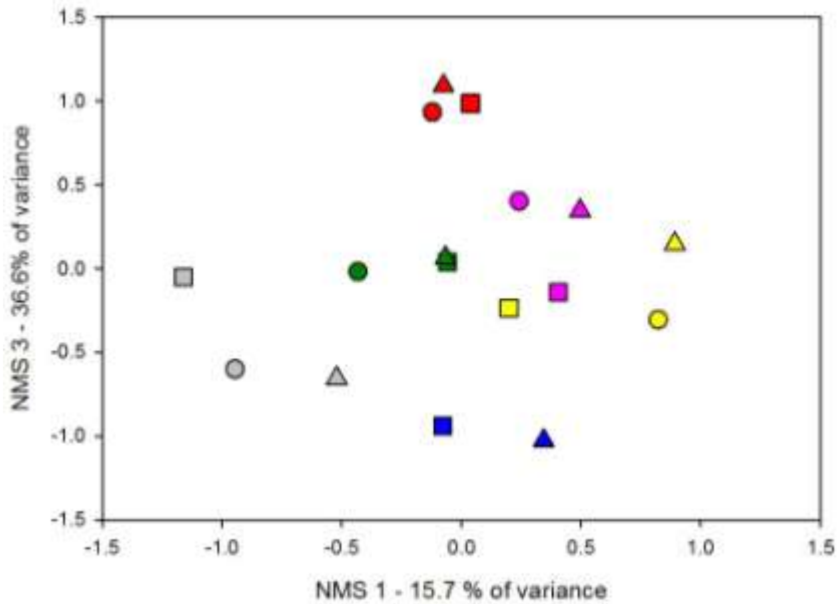
	A. Upstream/Impact Avg/Avg (p-value)	B. Upstream/Downstream Avg/Avg (p-value)	C. Impact-Downstream Avg/Avg (p-value)
BMI Metrics (expected response)			(opposite expected responses)
SC-IBI Score (-)	40.2 / 36.4 (0.19)	35.5 / 37.3 (0.64)	33.8 / 37.3 (0.22)
Coleoptera Taxa (-)	**1.5 / 0.5 (0.055)**	0.8 / 0.8 (0.5)	0 / 0.8 (0.81)
EPT Taxa (-)	6.7 / 6.7 (0.50)	5.2 / 5.8 (0.85)	5.8 / 5.8 (0.5)
Predator Taxa (-)	4.8 / 5.8 (0.89)	4.2 / 4.4 (0.57)	5.2 / 4.4 (0.75)
% Collector Individuals (+)	80.0 / 81.0 (0.36)	79.0 / 81.2 (0.17)	80.6 / 81.2 (0.62)
% Intolerant Individuals (-)	5.0 / 3.0 (0.18)	1.8 / 2.4 (0.74)	1.8 / 2.4 (0.19)
% NonInsect Taxa (+)	25.8 / 23.0 (0.78)	26.2 / 18.8 (0.84)	21.2 / 18.8 (0.26)
% Tolerant Taxa (+)	**21.3 / 25.8 (0.08)**	22.0 / 23.0 (0.43)	26.8 / 23.0 (0.14)
PHAB Endpoints (expected response)			
% Pool (+)	3.7 /12.8 (0.27)	3.3 / 4.3 (0.39)	7.2 / 4.3 (0.23)
% Vegetated Groundcover (-)	18.4 / 15.3 (0.27)	18.0 / 19.0 (0.67)	**15.8 / 19.0 (0.06)**
% Canopy Cover (-)	6.9 / 5.0 (0.18)	6.2 / 5.2 (0.14)	4.6 / 5.2 (0.36)
% Sand+Fines (+)	39.5 / 44.0 (0.36)	39.6 / 50.6 (0.30)	46.2 / 50.6 (0.73)
Median Grain Size (mm) (-)	**80.8 / 52.1 (0.07)**	37.0 / 29.3 (0.21)	**24.5 / 29.3 (0.07)**
Average Water Depth (cm) (+)	16.8 / 17.1 (0.34)	13.9 / 10.7 (0.91)	12.7 / 10.7 (0.20)

The NMS analysis resulted in a stable, 3-dimensional solution, based on plots of stress versus number of axes. Final stress for the 3-dimensional solution was 7.82935, and the final instability was 0.00001. The three axes accounted for 67% of the overall variation in BMI communities (axis 1, r^2 = 0.157 ; axis 2, r^2 = 0.149; axis 3, r^2 = 0.366). Axes 1 and 2 were moderately correlated r^2 = 0.257), while the other axes were essentially uncorrelated with one another ($r^2 < 0.01$). Variation among sites was generally much greater than the variation among segments within sites, as evidenced by the generally close clustering of segments within sites (Figure 3-6). Generally, the East Fork and West Fork San Gabriel River sites were more similar to one another, as were the Arroyo Simi and Conejo Creek sites (Figure 3-6).

Several sites exhibited consistent differences in ordination values among treatment segments. For example, Axis 1 values increased by an average of 0.29 (14% of total range of Axis 1) from upstream segments to armored segments, with the largest differences at Conejo Creek (0.69), East Fork San Gabriel River (0.64), and West Fork San Gabriel River (0.42) (Figure 3-7). Differences in ordination values between upstream and impact segments for Axis 2 and Axis 3 were inconsistent among sites, and average differences were near zero (Axis 2, -0.02; Axis 3, 0.05). Based on the known characteristics of the taxa associated with each ordination axis, Axes 1 and 3 are likely negatively correlated with cool, clean water or good habitat conditions (Table 3-8). This would suggest that a higher axis 1 score in the armored reaches represents more tolerant taxa. For example, only one taxon, the generalist and moderately tolerant midge *Tanytarsus*, was positively correlated (r = 0.601) with Axis 1; however, 7 taxa exhibited moderate or strong negative correlations with Axis 1, including sensitive and cold-water taxa such as the perlid stonefly *Calineuria californica* (-0.628), the mayfly family Heptageniidae (-0.728), the riffle beetle *Narpus* (-0.624), and the ephemerellid mayfly *Ephemerella maculate* (-0.754). Likewise, several taxa considered to be more sensitive to pollution and habitat degradation were negatively correlated with Axis 3, including the ephemerellid mayflies *Drunella coloradensis* (r = -0.684) and *Serratella micheneri* (-0.608). The ecological significance of the taxa positively correlated with Axis 3 is less clear because some taxa include many species that may have a wide range of pollution tolerance (e.g., *Simulium*, *Hydroptila*, Libellulidae). Only two taxa were correlated with Axis 2 (*Eukiefferiella*, 0.639; *Pericoma*/*Telmatoscopus*, -0.619), making interpretation of this axis less clear than for Axis 1.

Several physical habitat variables were correlated with the NMS ordination axes (Table 3-9). The correlations suggest that the armored segments were characterized by more pooling and correspondingly higher fine grained substrate. Percent sand and fines on the streambed was negatively correlated with Axis 2 and positively correlated with Axis 1. Correspondingly, percent fast-flow habitats was negatively correlated with Axis 1. Total canopy, the average vegetation densities of the upper and lower canopies, was negatively correlated with Axis 2, with the highest vegetation densities at Arroyo Simi. Percent pool habitats and water depth were both negatively correlated with Axis 3, with the highest values for both variables at the East Fork and West Fork San Gabriel River sites.

A)



B)

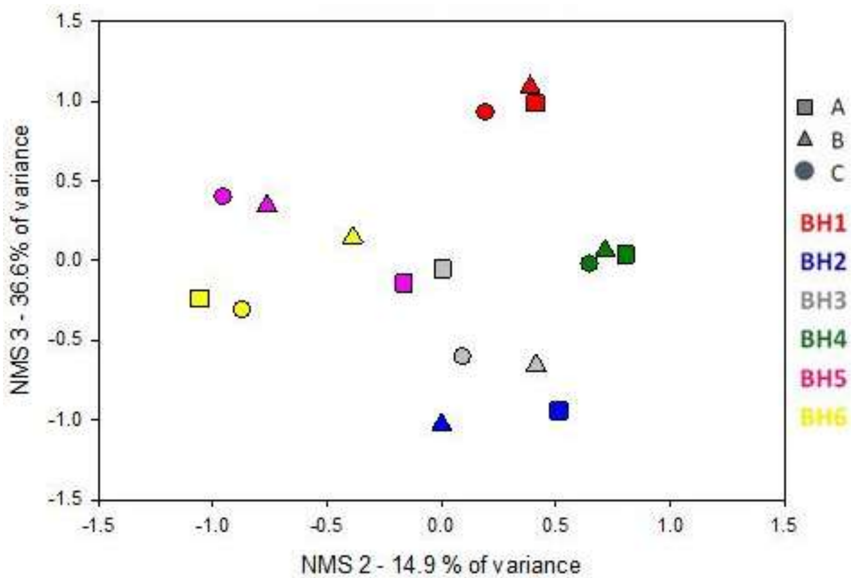


Figure 3-6. NMS ordination plots of raw taxa densities. Axis1 and Axis 3 (A); Axis 2 and Axis 3(B).

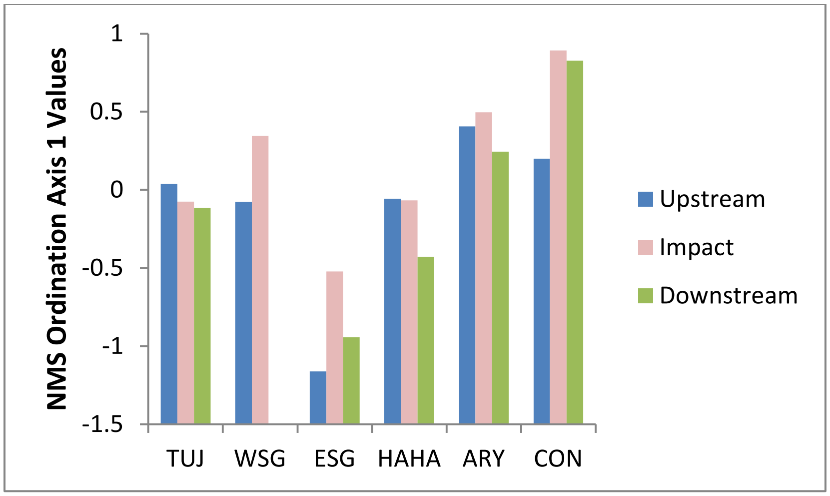


Figure 3-7. NMS ordination axis 1 values for each site and reach.

Table 3-8. Correlations (r) of benthic macroinvertebrate taxa with NMS ordination axes. Only taxa with r values > 0.6 are shown.

Axis 1	**r**
Tanytarsus (D: Chironomidae)	0.601
Protzia (Arachnida: Trombidiformes)	-0.607
Narpus (adults) (C: Elmidae)	-0.624
Calineuria californica (P: Perlidae)	-0.628
Stempellina (D: Chironomidae)	-0.674
Helicopsyche (T: Helicopsychidae)	-0.696
Heptageniidae (E)	-0.728
Ephemerella maculata (E: Ephemerellidae)	-0.754
Axis 2	r
Eukiefferiella (larvae) (D: Chironomidae)	0.639
Pericoma/ Telmatoscopus (D: Psychodidae)	-0.619
Axis 3	r
Hydroptila (T: Hydroptilidae)	0.767
Baetis adonis (E: Baetidae)	0.751
Simulium (larvae) (D: Simuliidae)	0.73
Libellulidae (O)	0.726
Eukiefferiella (pupae) (D: Chironomidae)	0.722
Simulium (pupae) (D: Simuliidae)	0.721
Serratella micheneri (E: Ephemerellidae)	-0.608
Eukiefferiella (larvae) (D: Chironomidae)	-0.609
Hydropsyche (T: Hydropsychidae)	-0.61
Cheumatopsyche (T: Hydropsychidae)	-0.62
Baetis tricaudatus (E: Baetidae)	-0.634
Neoplasta (D: Empididae)	-0.637
Atractides (Arachnida: Trombidiformes)	-0.656
Drunella coloradensis (E: Epehemerellidae)	-0.684

Table 3-9. Correlations (r) among physical habitat variables and NMS ordination axes. Only variables with r values > 0.5 are shown.

	Axis 1	Axis 2	Axis 3
% Fast Flow Habitats	-0.630		
% Pool Habitats			-0.647
Average Total Canopy		-0.715	
% Sand and Fines	0.572	-0.700	
Water Depth			-0.698

3.4.6 Algae

For both the diatom and soft-bodied algae, NMS ordinations did not show consistent differences between the three sampling positions (upstream, armored, downstream; Figure 3-8). However, there were strong taxonomic groupings of study segments by site (with the exception of Big Tujunga Wash for the soft-bodied assemblage). Because in this study we were less concerned with the taxonomic composition at the study sites (upon which the ordinations were based), and more interested in the roles that the various taxa might play relative to flow and sedimentation, we also examined relationships between hydromodification and groupings of taxa based on flow and sedimentation tolerances. Appendix C provides lists of all the diatom and soft-bodied algal taxa recorded in the study and their assigned characteristics with respect to these qualities. The scores for each of the indices calculated based on these characteristics are provided in Table 3-10. As with the NMS ordination, most of the variance in index values was explained by site and not segments within sites.

The possibility of relationships between the diatom and soft-bodied algal communities in terms of flow and sedimentation responses was also explored. Algal communities aligned well in terms of sedimentation response both between and within sites (Figure 3-9). Sediment tolerant taxa were more prevalent in armored segments that had higher deposition of fine grained sediments. In addition, the two sites (East and West Fork San Gabriel River) with the lowest sedimentation indices based on diatoms were also the lowest sites based on soft-bodied algae. Consistency between assemblages was also apparent at the higher sedimentation-response sites (Simi Valley and Conejo Creek). No relationship was apparent between assemblages in terms of flow response.

From the standpoint of biomass, neither soft-bodied algal total biovolume nor ash-free dry mass exhibited significant relationships with channel armoring. As with the other types of analyses presented, between-site variance far exceeded within-site. However ash-free dry mass was highest at segment A (upstream of the armoring) in 5 of the 6 sites, and the effect of “segment” in a two-way ANOVA with “site” and “segment” as effects was nearly significant (F-ratio = 3.85; df=2; p = 0.06).

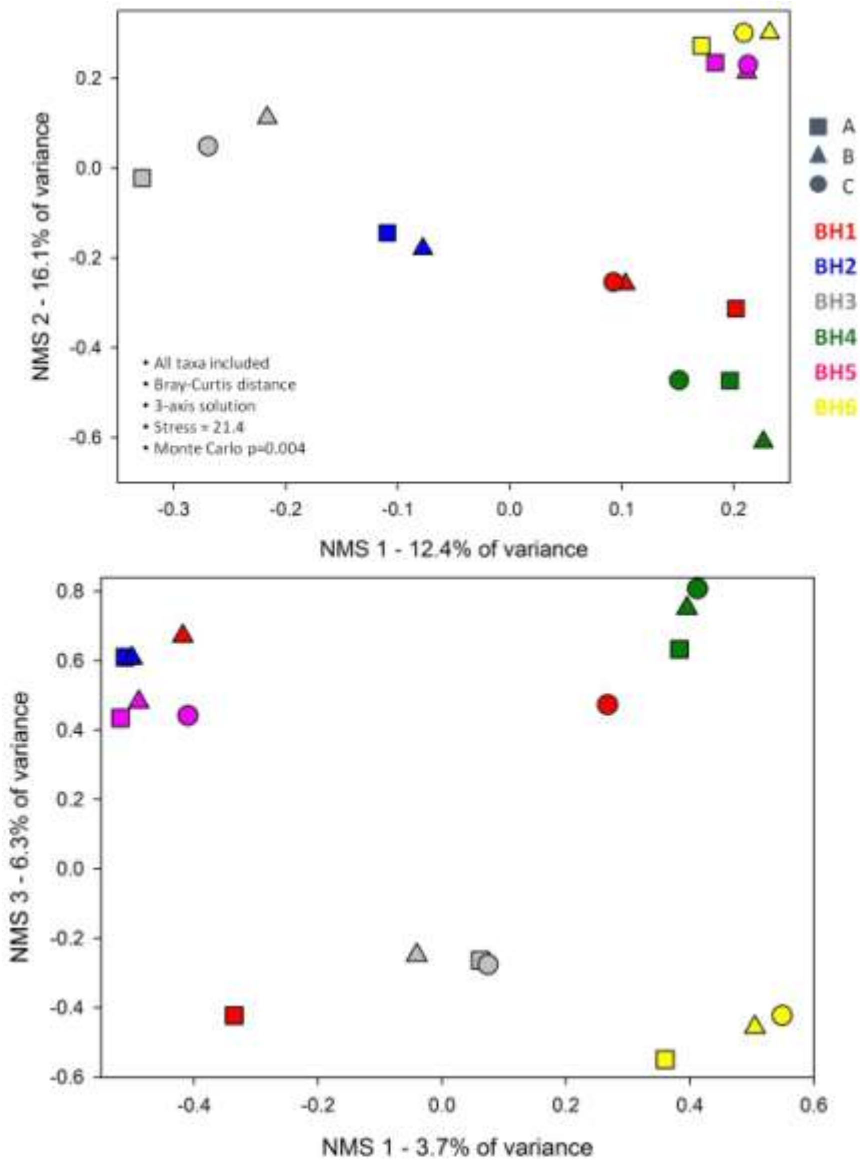


Figure 3-8. Relationships between nonmetric multidimensional scaling (NMS) axis scores based on diatom community composition (top) and soft-bodied algal community composition (bottom).

Table 3-10. Index values calculated for each site's sampling segment. "Ab" indicates that the metric was calculated based on relative abundance of counting units. "Sr" indicates that the metric was calculated based on percent of species.

Index	BH 1 A	BH 1 B	BH 1 C	BH 2 A	BH 2 B	BH 3 A	BH 3 B	BH 3 C	BH 4 A	BH 4 B	BH 4 C	BH 5 A	BH 5 B	BH 5 C	BH 6 A	BH 6 B	BH 6 C
%motileDiatoms_ab	0.47	0.42	0.49	0.18	0.22	0.03	0.00	0.02	0.19	0.24	0.27	0.42	0.38	0.40	0.44	0.69	0.65
%motileDiatoms_sr	0.61	0.64	0.57	0.50	0.45	0.36	0.20	0.35	0.57	0.62	0.61	0.52	0.52	0.53	0.64	0.65	0.62
%hightlyMotileDiatoms_ab	0.29	0.13	0.29	0.01	0.07	0.01	0.00	0.00	0.07	0.13	0.10	0.19	0.26	0.24	0.25	0.39	0.39
%hightlyMotileDiatoms_sr	0.25	0.25	0.27	0.15	0.21	0.14	0.00	0.00	0.29	0.38	0.22	0.18	0.15	0.17	0.22	0.27	0.26
diatomMotilityIndex_ab	1.76	1.54	1.79	1.19	1.29	1.05	1.00	1.02	1.26	1.37	1.36	1.60	1.64	1.64	1.69	2.07	2.04
diatomMotilityIndex_sr	1.86	1.89	1.83	1.65	1.66	1.50	1.20	1.35	1.86	2.00	1.83	1.70	1.67	1.70	1.86	1.92	1.87
diatom%SedimentationTolerant_ab	0.51	0.46	0.53	0.19	0.23	0.04	0.01	0.02	0.25	0.27	0.30	0.42	0.41	0.45	0.51	0.72	0.65
diatom%SedimentationTolerant_sr	0.64	0.68	0.63	0.55	0.48	0.43	0.30	0.41	0.62	0.67	0.65	0.58	0.56	0.60	0.69	0.73	0.67
softSedimentationIndex_ab	1.00	1.02	1.00	1.00	1.00	1.00	1.00	1.00	1.38	1.25	1.55	1.00	1.00	1.60	2.40	2.49	2.48
softSedimentationIndex_sr	1.00	1.38	1.00	1.00	1.00	1.00	1.00	1.00	1.75	1.38	1.50	2.09	1.95	2.20	1.96	1.86	1.96
diatomFlowToleranceIndex_ab	2.66	2.63	2.63	2.64	2.69	1.93	1.96	1.92	2.76	2.84	2.78	2.68	2.70	2.61	2.59	2.83	2.84
diatomFlowToleranceIndex_sr	2.75	2.68	2.60	2.55	2.55	2.21	2.10	2.29	2.81	2.76	2.74	2.55	2.59	2.57	2.69	2.70	2.64
softFlowToleranceIndex_ab	1.29	1.99	2.00	2.00	2.00	2.00	2.00	2.00	1.75	1.83	1.63	2.00	2.00	2.00	1.95	1.99	1.97
softFlowToleranceIndex_sr	1.67	1.75	2.00	2.17	2.00	2.00	2.00	2.00	1.50	1.75	1.67	1.27	1.36	1.27	1.57	1.57	1.43

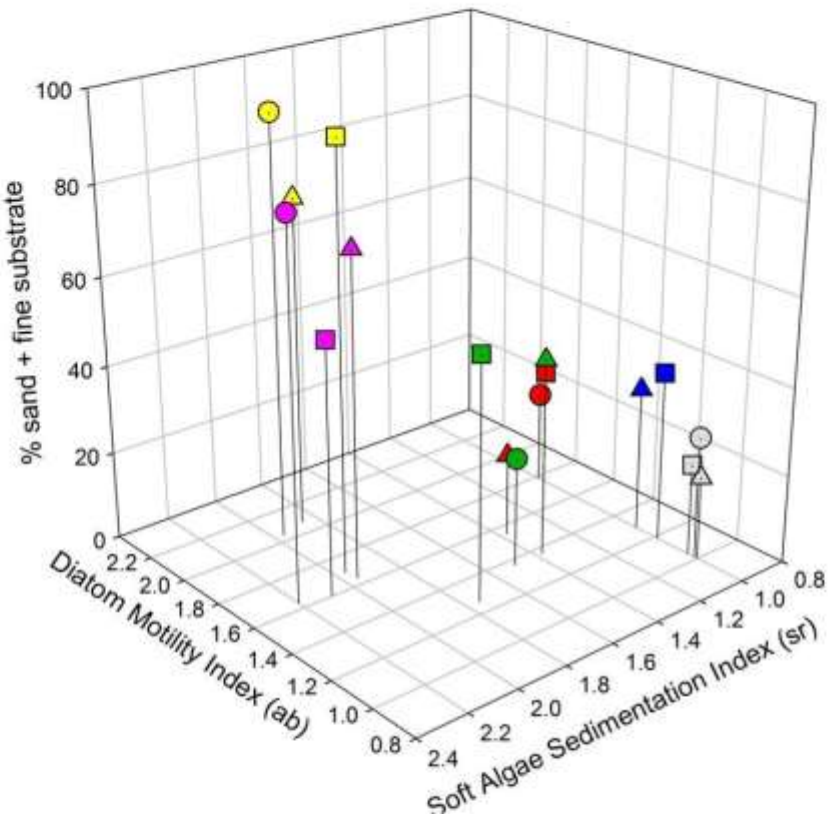


Figure 3-9. Relationship between stream % sand + fine substrates and diatom and soft-bodied algal assemblages in terms of index scores for sedimentation and motility.

3.5 Discussion

The results of this study suggest that stream channel morphology responds to channel armoring and that these physical responses in turn subtly affect instream biological communities that are often used as indicators of general condition. Changes in flow and sedimentation patterns in armored reaches can result in deposition of fine grained material and/or expansion of lower velocity pools or glides. These physical changes favor colonization by benthic invertebrates and algae that are tolerant of these conditions. Although the exact patterns of response varied among the six sites sampled in this study, consistent, subtle patterns were observed that suggest channel response mechanisms may be occurring. However, these responses may be difficult to discern from other factors (such as upstream dams, discharges, or recent fires) influencing the sites. Each of the study sites was distinct from the others in terms of both its physical and biological characteristics. NMS ordinations showed that between-site differences were much greater than differences within the sites associated with the effects of bank armoring. Therefore, the sites could not be considered as replicates, limiting the statistical power of our data set. In no cases did we observe any propagation of effects to the downstream segments.

Despite the lack of consistent patterns, several of the study sites did show evidence of changes in channel morphology in the armored segments relative to the upstream reach. These changes were also observed in lower CRAM attribute scores for biotic structure, which is likely reflective of the direct effects of removing streamside vegetation to construct armoring. In particular, Big Tujunga, West Fork San Gabriel, and East Fork San Gabriel exhibited increased bed scouring and decreased habitat complexity within the armored segments. This finding correlates with the conceptual model of river response to bank hardening. During high flows, water will move fastest along a hardened bank or bedrock surface where there is the least amount of friction, resulting in incision into the stream bed. Streams that are naturally confined by geology, such as the West and East Forks of San Gabriel, are predisposed to decreased riffles and larger and deeper pools in the armored segments. In addition, several sites were scoured in the armored segments, likely due to the constricting effects of the bank armoring. However, it is important to note that we cannot conclude that our observations and measurements can be solely attributed to the presence of a hardened bank. Site-specific conditions as well as natural and anthropogenic influences affect the extent to which hardened bank structures influence channel form and bed complexity as well as the ability to decipher these impacts. Channel incision observed in impact segments (specifically, toe failure), and in some downstream segments, can be partially attributed to catchment-scale processes and other upstream structures, such as dams, that may affect channel geometry and instream features at the study sites (Ligon *et al*. 1995, Gordon and Meentemeyer 2006). In addition, recent disturbances, such as the 2009 Station Fire, or recreational activities, are likely affecting channel features. The assessments we employed provide a "snapshot" of impacts observed during summer when stream flow is low; repeat cross sections following subsequent winter rains would help validate these findings and begin to discern the influence of local vs. watershed-scale influences.

Response of benthic invertebrates to changes in flow and sedimentation is well documented (Moyle 1976, Poff and Ward 1989, Waters 1995). The ability of biological metrics or indices to detect physical change is a determined by the severity of the impact and the spatial and temporal variability of the site (Milner *et al*. 2005, Beche *et al*. 2006). Given the low number of sites in this study and the high variability among the study sites with regards to geomorphic setting and upstream land use, consistent responses to bank armoring of benthic macroinvertebrate communities, as measured by the IBI and its constituent metrics, may be unlikely even if physical and biological responses are large in magnitude. However, the subset of sites where physical effects were most pronounced, i.e., East and West Forks of San Gabriel River, did exhibit many predicted biological and physical responses. These two sites had both lower IBI scores and large, consistent shifts in ordination space at impact segments.

Past studies have been mixed in their ability to show relationships among stream habitat indices and biological metrics with urban development. While some show a clear relationship, other studies show no relationship (Booth and Jackson 1997, Paul and Meyer 2001, Rogers *et al*. 2002, Fitzpatrick *et al*. 2005). Habitat indices are not always good indicators of geomorphic responses to urbanization, possibly because the component metrics respond to factors confounded with geomorphic processes and (or) different metrics respond in different ways, and central tendency of their combination mutes response (Fitzpatrick *et al*. 2005). This suggests that more sensitive indicators, perhaps at the species or functional group level, may be necessary to detect effects of channel alteration (Poff *et al*. 2006, Chessman *et al*. 2007). This is particularly applicable to small, heterogeneous data sets where effects may be dampened at the metric level. Consistent with this phenomenon, increased Axis 1 values, as was observed at the two sites, is interpreted to represent a decrease in benthic macroinvertebrate diversity and overall biological integrity, based on the negative correlations of pollution-sensitive taxa. In terms of changes to the physical environment, these biological shifts may be related to an increased extent of pools and less fast-water habitat resulting from channel armoring.

Specific aspects of stream algal communities also have the potential to reflect flow regime and sediment transport, both of which are potentially altered by channel armoring. For example, some benthic diatom genera, such as *Nitzschia* and *Surirella*, are able to propel themselves, and this quality is could render them less susceptible to burial by sedimentation. Indeed, some workers have found motile diatoms to be more frequent in stream segments subject to high levels of sedimentation, such that these taxa are sometimes considered sedimentation indicators (Pan *et al*. 1996, Fore and Grafe 2002). With respect to flow, some taxa, such as *Lemanea fluviatilis* and *Hydrurus foetidus* (Wehr and Sheath 2003), have growth forms and/or preferred habitats that suggest that they are more tolerant of high flows than other forms that are only loosely attached to stream substrates and or have an extensive vertical profile, and therefore tend to be found in quiet pools or slow-moving waters.

Like the benthic invertebrates, more subtle shifts in algal species were observed that suggest a potential mechanistic response. The clearest outcome of this study was the relationship between the diatom and soft-bodied algal communities as indicators of sedimentation. With the exception of the Big Tujunga Wash site, there was a tendency for sites with high sedimentation based on diatom evidence to exhibit the same response in terms of soft algae. This same pattern was apparent using a variety of different sedimentation indices. The algal community clearly reflects increases in sedimentation observed at some of the armored segments and at lower gradient sites. Congruence between the two assemblages provides weight of evidence and suggests that our hypotheses, our assumptions in assigning taxon-specific characteristics (e.g., tolerance to sedimentation), and our approach to creating preliminary indices, have merit.

Finally, the lack of observed downstream effects in either the physical or biological indices suggests that effects of armoring are localized and may not propagate downstream. This is consistent with the findings of other researchers who have similarly observed that macroinvertebrates respond to local stream conditions by utilizing refugia with suitable flow requirements thereby allowing communities to recover quickly from the deleterious effects of habitat alteration (Negishi *et al*. 2002). Furthermore, macroinvertebrates can recolonize over tens of meters from upstream by drifting (Waters 1972); therefore, once suitable conditions resume, indices often return to reference levels.

The overall weight of evidence of the biological indicators, and their concordance with the physical effects observed, suggest that the instream biological communities are responding to scour and sedimentation patterns associated with bank armoring. This study should be considered a preliminary “pilot” study that tests the ability of commonly used measures of instream physical and biological integrity to detect effects of channel armoring. The low sample size and extreme variability between sites makes it difficult to discern consistent patterns. Nevertheless, past studies have shown that local geomorphology and related physical parameters influence the structure of invertebrate functional group composition (Wohl *et al*. 1995, Suttle *et al*. 2004, Cover *et al.* 2008). A functional trait approach, such as that described by Poff *et al*. (2006) may be more sensitive to changes in local channel characteristics, such as those associated with bank armoring, whereas overall indices, such as IBIs, may be more sensitive to catchment-scale effects. Future efforts should continue to elucidate mechanistic responses at the species and functional group levels, with a goal of producing more sensitive indicators to local-scale effects.

4. Effect of Stream Channel Restoration

Channel alteration through armoring, grade control, or encroachment is a ubiquitous feature in urban and suburban landscapes. Such activities can affect both the physical and biological structure of the armored reach through higher flow velocities, bed scour, and loss of bank or adjacent vegetation. Reversal of these effects through stream restoration is often a priority for both regulatory and grant-funded programs. Success of stream restoration is typically evaluated through assessment of the physical condition of the channel or by assessment of re-established streamside riparian habitat. Such monitoring is often focused on site-specific indicators. In-stream indicators typically used for ambient or watershed monitoring programs are often not included in restoration performance monitoring. Improving the connection between ambient and site-based performance monitoring will provide better context for evaluating the success of stream restoration and its contribution to overall watershed recovery. The objective of this portion of the study was to evaluate several stream restoration case studies using biological endpoints to determine if the desired effects of the restoration can be detected using similar endpoints as are used to assess impacts during routine or ambient monitoring. The focus of this analysis was on using the California Rapid Assessment Method (CRAM) as an indicator of biological recovery. We focus on CRAM because it is one of the few assessment tools used for both ambient and project-based assessments. In contrast, indicators such as detailed vegetation assessment are only used for site level evaluation whereas indicators such as benthic macroinvertebrates are typically used for ambient assessment, but not for project monitoring.

4.1 Methods

4.1.1 Study Sites

Restored stream reaches in and around the Santa Monica Mountain Range in Southern California were evaluated in terms of their biological condition. Restricting sites to the same general area reduced confounding factors associated with different geology, rainfall patterns etc. Study reaches were located on Medea Creek (4 reaches), Las Virgenes Creek (5 reaches), Cold Creek (1 reach), Dry Canyon Creek (2 reaches), and Las Flores Creek (1 reach; total n = 13). All reaches are in the Malibu Creek watershed except for Dry Canyon Creek and Las Flores Canyon Creek , which are in the Los Angeles River and Santa Monica Bay watersheds, respectively restored sites were compared to local reference sites and channelized/armored reaches, as described below (Figure 4-1; Table 4-1).

Completed stream restoration projects were located by polling local agencies and non-governmental organizations. Reaches where artificial, hard channel lining was removed were selected to represent the 'Restored' category for this study. Reference reaches were selected according to the criteria that they were located in habitat similar to the restored reaches (sometimes even on the same stream), but had not experienced direct channel armoring or obvious negative impacts from surrounding land use change. Channelized reaches were chosen based on their proximity to the restored sites. The channelized reaches were all concrete side, concrete bottom channels with the exception of the Las Virgenes Creek North reach, which appeared to have a soft bottom. It should be noted the Las Virgenes Creek South restoration and channelized sites were matched to the Paramount Ranch reference site located on Medea Creek. Paramount Ranch was chosen because there was not a sufficiently large selection of reference sites available on or close to Las Virgenes Creek that matched the Las Virgenes Creek South restored site. Medea Creek and Las Virgenes Creek are similarly situated and in the same watershed (Malibu Creek Watershed), so the Paramount Ranch reach was deemed an appropriate reference site. Las Flores Creek did not have corresponding reference or channelized sites because appropriate sites did not exist in a similar setting to the restored reach.

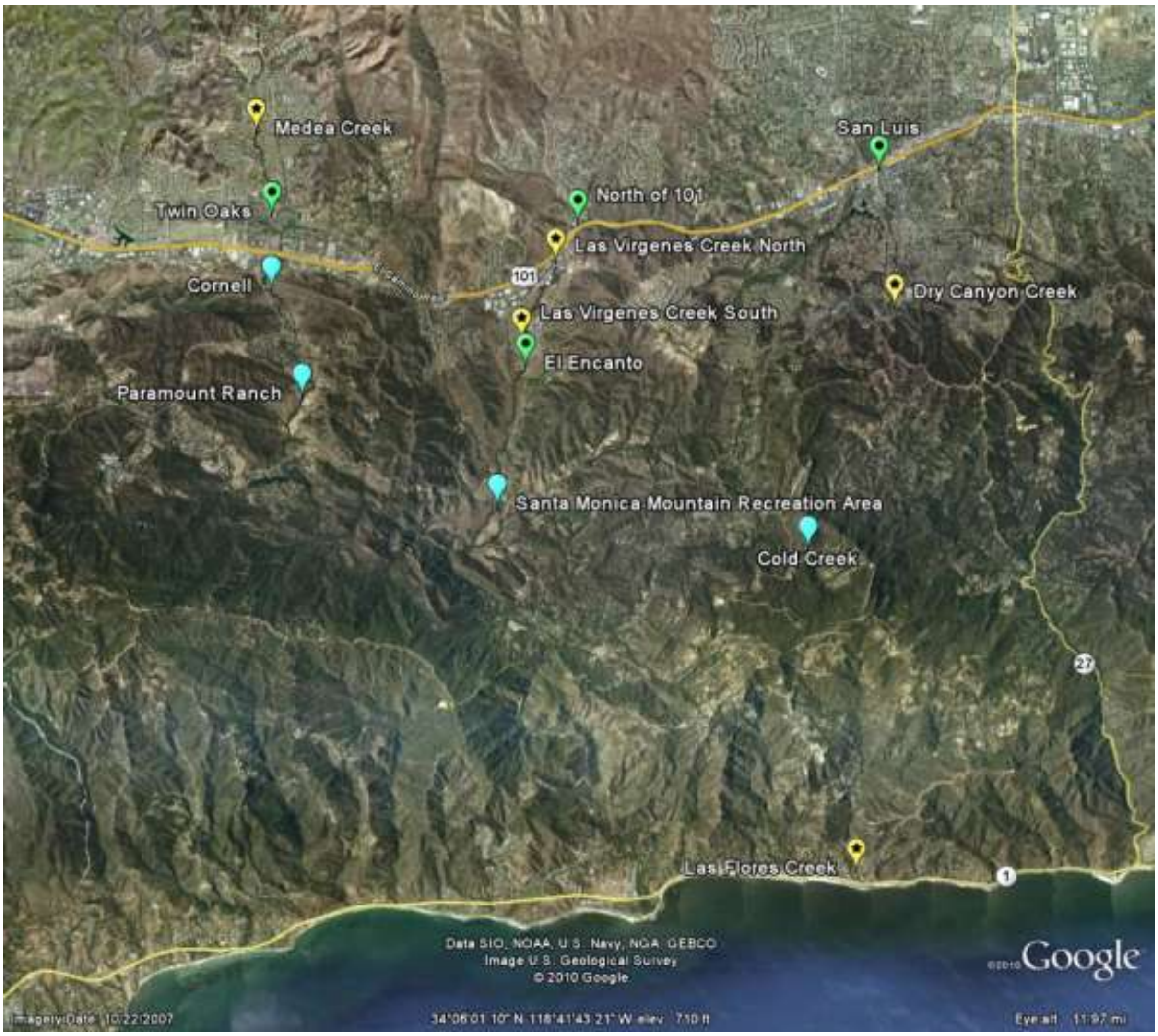


Figure 4-1. Map of all study reach locations: Restored reaches are marked with stars, Reference reaches are denoted with blanks, and armored reaches are marked with circles.

Table 4-1. Study reaches along with the reference sites and associated channelized sites used for comparison. All sites are located in the Malibu Creek watershed unless indicated otherwise.

Reference Sites	Restored Sites	Channelized Sites
Santa Monica Mountain Recreation Area	Las Virgenes North	101 Freeway
Cold Creek	Dry Canyon Creek[1]	Ave. San Luis
Paramount Ranch	Las Virgenes South	El Encanto
Cornell Road	Medea Creek	Twin Oaks Shopping Center
	Las Flores Canyon Creek[2]	

[1]Located in the Los Angeles River watershed
[2]Located in the Santa Monica Bay watershed

4.1.2 Data Collection

Documents pertaining to restoration projects were collected from parties involved with the various projects. These included the Mountains Restoration Trust (Calabasas, CA), The City of Malibu, The City of Calabasas, the Resource Conservation District of the Santa Monica Mountains (Agoura Hills, CA), and Questa Engineering (Richmond, CA). Several of the documents obtained were plans for restoration written prior to the project construction periods. We corroborated statements in these documents with reports written after the completion of construction and with parties involved in the projects.

California Rapid Assessment Method was used to evaluate restored sites as well as corresponding reference and channelized sites. We performed CRAM as outlined in the Riverine Wetlands Field Book associated with the CRAM for Wetlands version 5.0.2. The CRAM assessments took place between November 18 and December 16, 2010. This season is not optimal for conducting CRAM because several plant species have already abscised their leaves by this time, making them difficult to identify. It is generally recommended that CRAM for riverine wetlands be performed late in the growing season of the plant community and near the onset of base flow (Collins *et al*. 2008) so the maximum possible amount of information about the plant community will be available, and the flows will be relatively low for the safety of the assessors. Although our assessments took place outside of the recommended assessment window, the relationships between the scores should not be greatly altered by the timing. Because species accounting constitutes only two sub-metrics within a metric of the Biotic Structure attribute, we were not concerned that the late fall season timing of our assessments would drastically alter the final CRAM scores (see Table 3-2). Furthermore, for present purposes, we were more concerned with the difference in CRAM scores between matched restored, channelized, and reference reaches than the absolute CRAM scores themselves.

4.2 Results

4.2.1 Restored Site Descriptions

Each restoration site used for this portion of the study is described below. Additional details and site photographs are provided in Appendix D.

4.2.1.1 Dry Canyon Creek

- Location: Calabasas, CA
- Lead Agency: Mountains Restoration Trust

Dry Canyon Creek is located in the Santa Monica Mountains in western Los Angeles County. The restoration project area is in the City of Calabasas, California. Dry Canyon Creek is a headwater tributary to the Los Angeles River system by way of Calabasas Creek. The mainstem of the creek flows perennially, and runs through mostly private property. Land use within the vicinity of the project site is predominantly open space and undeveloped hillside, and there are two single-family residences onsite. Less than twenty percent of watershed upstream from the project site is developed.

Four habitat types were identified in the immediate vicinity of the project area prior to construction: Oak woodland (upland), palustrine scrub-shrub wetland, palustrine forested wetland, and riverine intermittent streambed. Natural habitat in the area exists in small, discontinuous patches, so properties acquired by MRT around Dry Canyon Creek are important for providing connectivity between the upper and lower portions of the watershed, a broad range of habitats, and potential sites for habitat restoration. Based on field assessments, Dry Canyon Creek is considered potential fish habitat, although no native fish were found associated with it by studies performed in preparation for the restoration project.

Prior to restoration, the reach had a concrete bottom, with a stone wall stabilizing part of the bank. The channel was a steep-sided trapezoidal shape, with portions that were rectangular. The channel was also filled with foreign materials such as cement and metal debris.

Restoration Objectives

The main goals set forth for this project were to enhance and/or create existing or new wetlands and riparian areas at the site, improve ecological conditions, and provide educational opportunities for the public.

The mitigation objectives were to

- Restore natural channel morphology
- Restore native plant communities
- Improve stream flow
- Improve riparian and floodplain ecosystem functions

The construction objectives were to

- Recontour steep bank gradients to gentler slopes
- Remove previously placed fill and hard structures within the channel
- Create floodplain benches
- Remove invasive plant species
- Revegetate the area with native riparian plants

Restoration Measures

Restoration activities on this reach of Dry Canyon Creek took place in 2007. The concrete lining, rock retaining wall, and extra cement and metal debris were removed from the channel. Banks were pulled back to a more natural grade and height. Floodplain benches were restored to provide more area for riparian habitat and improve floodplain connectivity. In places where benching was not feasible, slope steepness was reduced to facilitate revegetation success.

In addition to the retaining wall, two other large items were removed: A corrugated metal culvert between the Masson House (a historical building on the property) and MRT Administrative Areas was removed and replaced with a free-span bridge crossing the channel. This alteration was intended to improve flood conveyance, restore sediment and debris transport, and improve wildlife accessibility. A guy-wired bridge downstream of the MRT Administrative Area with piers that stood in the channel was removed and replaced with a wooden footbridge with piers wholly outside of the channel.

The graded area totaled approximately 0.76 acres. During construction, 2,890 cubic yards (CY) of material were moved. Of that, 350 CY were used for fill on the project, and 2,540 CY were removed from the site.

Exotic plant species removed included the Greater Periwinkle (*Vinca major*), Giant Reed (*Arundo donax*), and Virginia Creeper (*Parthenocissus inserta*), which are prevalent invasives along Dry Canyon Creek. Native plants were planted in a four-zone organization system that consisted of a wet zone, riparian zone, riparian ephemeral zone, and upper terrace riparian zone. Collectively, 32 native plant species were planted. Brush mattresses over coir coconut fiber matting with live fascines and rock toes at the bank base were implemented in planting as well as aluminum hardware cloth plant protection for seedlings and pole cutting plantings.

4.2.1.2 Medea Creek

- Location: Agoura Hills, CA
- Lead Agency: Morrison Entity

Medea Creek is a perennially flowing stream that runs through Simi Valley, CA (Ventura County) and Agoura Hills, CA (Los Angeles County). The restored reach is located in Agoura Hills along Shadycreek Drive between 1600 ft south of the Laro Drive bridge crossing and 740 ft north of the Fountainwood Street bridge crossing. The surrounding area is mostly urban and residential land use.

In 1982 the site was illegally channelized into a storm drain culvert by Morrison Entity, a housing developer. Subsequently, the removal of the trapezoidal concrete channel and restoration to more natural conditions was mandated. As part of construction on the stream, measures were also taken to protect the surrounding neighborhood from flooding.

Restoration Objectives

The primary goal of this project was to restore riparian and wetland habitat. Successful completion of the project was also expected to produce benefits associated with habitat restoration:

- Improved water quality
- Improved beneficial uses
- Stormwater runoff reduction and increased recharge of the local aquifer due to increased ground absorption rates

Restoration Measures

Based on a review of permit applications, we estimate project construction took place in 1993 or 1994. The entire length of the project was 5,230 feet. Approximately 15,000 CY of gunite lining along 3,000 linear feet of existing channel were removed. An additional 25,000 CY of earth were moved during grading and excavation to restore the streambed to a more natural condition. Streambed elevations and cross sections were altered. Area from an adjacent grassbelt (0.6 acres) was incorporated into the reconstructed streambed.

Special measures were taken to improve streambed stabilization (thereby reducing erosion) and improve flood protection. A low flow channel was created at Laro Drive to allow flow discharges to be contained within channel banks. Two reinforced structures were constructed north and south of the Laro Drive crossing for flood protection. These structures were composed of 110 CY of concrete. An additional 7,000 CY of ungrouted rip rap was placed at the Laro Drive and Fountainwood Street crossings.

Several native species of plants were re-established along the project length including Arroyo Willow (*Salix lasiolepis*), Black Willow (*Salix nigra*), Sandbar Willow (*Salix interior)*, Red Willow (*Salix laevigata)*, Sycamore (*Platanus* spp.), Cottonwood (*Populus* spp.), White Alder (*Alnus rhombifolia*), Coast Live Oak (*Quercus agrifolia*), Canyon Live Oak (*Quercus chrysolepis*), Scrub Oak (*Quercus ilicifolia*). Drip irrigation was used to maintain plantings for 5 years, and survival was monitored. A minimum 80% survival was required after the first year, 75% cover after three years, and 90% cover after five years. The restoration operator was responsible to replace plantings to achieve goals if any cover requirements were not met.

4.2.1.3 Las Virgenes Creek South

- Location: Calabasas, CA
- Lead Agency: Resource Conservation District of the Santa Monica Mountains

Las Virgenes Creek is located in west-central Los Angeles County. The City of Agoura Hills is to the east of it, and the City of Calabasas to the west. The southern restored site exists within the City of Calabasas, and is located on eastern side of Lost Hills Road between Meadow Creek Lane and Cold Spring Street.

The surrounding area is urban and generally residential land use. Prior to restoration, the creek bottom had dense vegetation cover but banks had little vegetation. No other information could be found further describing the context of the restoration.

Restoration Objectives

The only goal presently known was to reduce erosion and sediment yield by stabilizing streambanks. Successful completion of the project was expected to produce benefits associated with bank stabilization:

- Positive impacts to water quality
- Increased beneficial uses associated with erosion reduction

Restoration Measures

This project was likely completed February 1997. Approximately 23,000 CY of sandy-gravel fill was removed from a 500 foot long reach of the west bank. The bank was recontoured from a 1:1 to a 3:1 slope. A wide, flat toe was constructed in an area where the bank previously had a cliff-like structure. A V-shaped trench along the stream was excavated, and a geotextile fabric-cased cut-off wall was built along the southern 120 feet of the reach. Flow constriction was removed upstream of the bank stabilization.

Following the slope contouring, the bare surface was covered with erosion blankets and replanted with native riparian vegetation. The adjacent channel area was intended to resemble a lateral channel bar and be vegetated with native willow species. Additionally, two small terraces planted with native riparian woodland species were planned for remaining slope area.

The project implementation temporarily impacted 1.5 acres of streambed and 3,000 ft^2 of riparian vegetation. It also removed approximately 0.07 acre of vegetation on the slope. Mitigation for these impacts included planting disturbed portions of stream bed, bank, and channel with native riparian vegetation in addition to the restoration of the 24,000 ft^2 area within the Las Virgenes Creek streambed.

4.2.1.4 Las Virgenes Creek North

- Location: Calabasas, CA
- Lead agency: City of Calabasas

Las Virgenes Creek is located in west-central Los Angeles County. The City of Agoura Hills is to the east of it, and the City of Calabasas to the west. The restored site at the north end of the creek exists within the City of Calabasas. It begins approximately 500 feet south of a point where U.S. Highway 101 crosses the creek west of the Las Virgenes Road junction and ends at the Agoura Road Bridge.

The surrounding area is urban and mostly commercial land use. Bedrock is approximately 60 feet below the surface and is overlain by sand and silt, which is easily transported or eroded. Because of the urban location, several utilities within the project area needed to be avoided or relocated to accommodate the channel restoration. These included a water main, sewer main and sewer lines, gas line, telephone pole, and electrical lines.

The restoration was proposed for a reach approximately 500 ft long. This length was divided into 3 portions: an upstream channel that was classified as 'natural' prior to restoration activities, a middle concrete trapezoidal channel approximately 370 ft long, and a portion below the Agoura Road Bridge that was 92 ft long. Half of the Agoura Road Bridge portion was lined on both sides with grouted riprap. Concrete bridge piers supporting the bridge were also in the channel below it.

As the formerly existing concrete channel was free of vegetation, it could convey high flows in its small area. There was concern that restoring the area would alter the efficacy of the channel to convey flood flow, raising flood levels. To address this issue, planners proposed either installing flood protection measures or enlarging the channel outside of its existing top of bank limits to accommodate high flows. Enlargement of the channel would have resulted in loss of parking spaces in adjacent parking lots. Because property on either side of the stream at this location was privately held for commercial use, the city would have needed to arrange for additional land and/or easement right-of-ways if any channel widening or bank-top modifications had taken place.

This project was a high priority for watershed protection because it would help to reduce some habitat fragmentation in the area. The Malibu Creek Watershed is highly urbanized, but it is thought that the Las Virgenes Creek tributary and Malibu Creek could potentially serve as a wildlife corridor between the pristine coastal scrub habitat of the Ahmanson Ranch area in the upper watershed and the Southern Steelhead Stream habitat below Rindge Dam extending to the Malibu Creek Lagoon. At the time of restoration, there were no known migratory fish within the project area. However, there were potential suitable spawning and rearing areas above the project reach. The restoration of this parcel of Las Virgenes Creek would be one step towards opening this corridor for future wildlife movement, as well as re-establish connectivity between the non-concreted reaches directly upstream and downstream of it.

Restoration Objectives

The overarching goal for the project was to have stable compound channel morphology with significant native riparian vegetation.

The following project goals were set forth by the City of Calabasas:

- Restore a native creekside habitat
- Increase the wildlife corridor

- Enhance the biological environment
- Plant native vegetation
- Create and extend the riparian zone
- Protect existing infrastructure
- Maintain the same level of flood control
- Create a community amenity; display the importance of environmental stewardship to the community's youth

The following project design concepts were proposed by Questa Engineering:

- Utilize compound channel geometry
- Maintain existing right-of-way
- Protect in-place existing utilities
- Use steps or grade breaks to reduce channel slopes
- Provide long-term scour protection for bank slope stability

Restoration Measures

Construction began on July 27th, 2007 and was completed by December 18th, 2007. Over 3,600 square yards of concrete were removed from the hard-bottomed reach.

To control flooding, retaining walls were used to maintain the channel area and flood walls were built to provide capital flood protection and maintain FEMA freeboard requirements.

To reduce risk of erosion along the channel bed and banks, coir coconut fiber blocks and rock were installed at the toe of bank slopes. Large (2 to 4 ton) boulders were placed in trenches to keep the channel from wandering. Willow stakes and rock and dirt chinking were used to fill in around the boulders. Additionally, five rock weirs connecting the parallel trenches were installed to further ensure long-term channel stability. Erosion protection was important for the prevention of utility line damage.

The area was planted with an assemblage of flora native to Southern California. The planting scheme was designed to quickly create a dense channel canopy cover. Deep willow pole plantings were installed during trenching operations and drought- tolerant plants were utilized in the upper bank zones. A temporary irrigation system was installed to ensure adequate irrigation during the vegetation establishment period. An inspection was scheduled for the following fall season to assess plant establishment and prescribe re-planting of some vegetation and erosion repair, if necessary. Annual reports on revegetation success, canopy development, and erosion conditions were mandated to determine whether any remediation activities would be necessary.

4.2.1.5 Las Flores Creek

- Location: Las Flores Canyon, Malibu, CA
- Lead Agency: City of Malibu

Las Flores Creek is located in Las Flores Canyon in Malibu, CA. The canyon is part of the Santa Monica Mountain Range, and local terrain is steep, rugged and unstable. The creek exists in a steep, rocky channel typically bounded by steep, dry slopes on one side and remnant floodplain on the other. The creek discharges directly into the Pacific Ocean approximately 150 feet downstream after flowing under the Pacific Coast Highway (PCH).

The flow of Las Flores Canyon Creek is intermittent in summer and low-flow months. Large flows occur in the winter following storm events, and consistent flows may persist into late spring or early summer. A floodplain analysis concluded that Las Flores Canyon Road, located on the east side of the creek, becomes a secondary flow path for channel overflow during large storm events.

Land cover near the creek is mostly open, natural space interspersed with residential and recreational development (i.e., tennis courts and a playground) and adjacent roads. The habitat is characterized as coastal sage scrub on steeper hillsides, dominated by California buckwheat (*Eriogonum fasciculatum*) and other shrub species; willow riparian along lower portion of creek, dominated by various willow species (*Salix* spp.) and mulefat (*Baccharis salicifolia*); and sycamore woodland on higher creek bank elevations and remnant floodplains, dominated by western sycamore (*Platanus racemosa*) with some coast live oak (*Quercus agrifolia*).

With respect to biota in Las Flores Canyon Creek, the area is considered potential habitat for two federally endangered fishes, the tidewater goby (*Eucyclogobius newberryi*) and southern steelhead (*Oncorhyncus mykiss*), due to its proximity to Malibu and Topanga Canyon creeks, where these fishes occur. No fish were found in the creek in a survey conducted in 2006.

The watershed is considered highly disturbed, due to both natural conditions and human presence. The area has experienced fire, periodic flooding, debris flows, and landslide. Prior to the start of the restoration project, the Rambla Pacifico landslide on west bank of Las Flores Canyon Creek pushed material into the channel, causing increased erosion on the opposite bank and severely confining the channel in a portion of the project area.

The restoration project is located along approximately 2,415 linear feet of Las Flores Canyon Creek, extending upstream from the PCH. It is bounded by the PCH to the south, Rambla Pacifico Road on the west, Las Flores Canyon Road on east, and scattered residences and open space to the north. The creek restoration covered 3.7 acres. Restoration of 4.4 acres of a city park adjacent to the creek was also undertaken through the same project.

<u>Restoration Objectives</u>

The project was intended to restore and repair degraded habitat along Las Flores Canyon Creek banks and stabilize the creek channel.

Project restoration objectives were summarized by the City of Malibu:

- Exotic plant species removal and control
- Increased native riparian vegetation extend and diversity
- Bank stabilization
- Improved flow conveyance and capacity
- Improved aquatic habitat
- Integration of long term management and control of exotic vegetation

The City of Malibu also listed several items it called 'specific objectives':

- Restore habitat for riparian, upland, and in-stream habitats
- Improve fish and aquatic habitat
- Preserve open space
- Avoid aggravating landslide situation or further destabilizing slope
- Avoid furthering any bank instability adjacent to private property
- Naturalize creek channel and riparian zones
- Stabilize creek corridor and promote channel equilibrium (e.g., arrest active incision, eliminate bank erosion, etc.) where feasible
- Reduce excess sedimentation going into Santa Monica Bay where possible

Restoration Measures

Instream demolition included the removal of: grouted riprap banks that were undercut in some locations and inhibited growth of a riparian canopy, a failing concrete foundation wall, a grouted rock weir structure that was inappropriately angled with respect to stream flows and thus potentially promoted erosion on the bank opposite it, and a concrete V-ditch weir that was replaced with a natural drainage swale. Instream, approximately 1,800 CY of grouted rip rap and about 77 CY of concrete were removed from approximately 482 linear feet of the creek's east bank. Additionally, approximately 77 CY of concrete were removed in total.

Structures including riprap and grouted rock were left in place on the west bank so to not aggravate the historic landslide or steep slopes. Grouted riprap and other structures on private property were removed only when necessary for project design and where landowner agreements were in place. The floodplain and bank were enhanced by cutting back new slopes from existing slopes. These were intended to increase conveyance, reduce erosion, support canopy-forming vegetation, and generally improve ecological conditions.

Geotechnical bank stabilization in the form of rock slopes and toe protection were installed in places where high stability was needed to protect private property or infrastructure, and at transitions to grouted riprap banks that were not removed due to private property limitations. A weir/step pool complex was constructed to arrest down-cutting and stream incision. Weirs were constructed from large boulders, and step pools composed of 3-ft diameter rock. Large woody debris were embedded into banks to reduce bank shear stress and enhance fisheries habitat by creating pools and cover, and otherwise increasing complexity.

4.2.2 California Rapid Assessment Method Results

California Rapid Assessment Method index scores were highest at the reference sites (75.5 ± 3.0; mean ± standard error), followed by the restoration sites (57.6 ± 3.6), and the channelized sites (29.3 ± 1.5) had the lowest scores (Table 4-2). There were no overlaps in the ranges of scores between reference, restored, and channelized reaches. Las Flores Creek achieved the highest score of all the restoration sites, and was not matched directly with reference and channelized sites.

CRAM attribute scores followed the same general pattern, in which reference sites scored highest, followed by restored, and then channelized sites. The greatest difference in mean scores between the reference and restored sites was found in the Buffer and Landscape Context attribute (Δ = 37.6), followed by the Physical Structure attribute (Δ = 16.3), and then the Hydrology attribute (Δ = 10.9). The Biotic Structure attribute exhibited the smallest difference (Δ = 6.8).

Although mean attribute scores were lower for restored sites than for the reference sites, there was overlap in the ranges of scores indicating that in many cases restored sites were approaching reference condition. The exception was for the Buffer and Landscape Attribute where there was little overlap in the ranges of scores. For the Hydrology attribute Las Flores Creek and Las Virgenes South restored reaches scored within the same range as reference reaches, and the El Encanto channelized reach scored within the range of the restored reaches. Las Flores Creek and Las Virgenes South restored reaches also scored within the same range as reference reaches in the Physical Structure attribute. Las Virgenes North and Dry Canyon Creek restored reaches exhibited Biotic Structure attribute scores within the same range as reference reaches. There was no overlap in ranges of scores with the channelized sites, which consistently scored within 10 points of the lowest possible attribute scores.

With respect to the comparison of matched reference, restored, and channelized reaches, the same pattern was seen as with mean CRAM scores: reference reaches scored highest, followed by restored, then channelized for each set. However, the Dry Canyon Creek restored reach exhibited a better biotic structure score than its complementary Cold Creek reference reach. Also, the Las Virgenes South restored reach, which exhibited the highest Hydrology score of all the restored reaches, exhibited the same Hydrology score as its complementary Paramount Ranch reference, as well as the Cold Creek and Cornell reference reaches.

Table 4-2. California Rapid Assessment Method Scores for reference, restored, and channelized sites. Abbreviations in parenthesis are for the restored site that corresponds to each reference or channelized site.

Site	Buffer and Landscape Context	Hydrology	Physical Structure	Biotic Structure	CRAM Index Score
Reference					
Santa Monica Mountain Recreation Area (LVN)	85.4	91.7	75	83.3	83.9
Cold Creek (DCC)	78.4	75	62.5	72.2	72.0
Paramount Ranch (LVS)	82.9	75	75	69.4	75.6
Cornell (Medea)	77.7	75	62.5	66.7	70.5
Mean ± SE	81.1 ± 1.8	79.2 ± 4.2	68.8 ± 3.6	72.9 ± 3.6	75.5 ± 3.0
Restored					
Las Virgenes North (LVN)	37.5	66.7	50	69.4	55.9
Dry Canyon Creek (DCC)	42.2	50	50	80.6	55.7
Las Virgenes South (LVS)	45.4	75	62.5	61.1	61.0
Medea Creek (Medea)	25	66.7	37.5	58.3	46.9
Las Flores Canyon Creek	67.2	83.3	62.5	61.1	68.5
Mean ± SE	43.5 ± 6.9	68.3 ± 5.5	52.5 ± 4.7	66.1 ± 4.1	57.6 ± 3.6
Channelized					
North of 101 (LVN)	25	33.3	25	36.1	29.9
San Luis (DCC)	25	33.3	25	25	27.1
El Encanto (LVS)	25	58.3	25	25	33.3
Twin Oaks Shopping Center (Medea)	25	33.3	25	25	27.1
Mean ± SE	25.0 ± 0.0	39.6 ± 6.3	25.0 ± 0.0	27.8 ± 2.8	29.3 ± 1.5

4.3 Discussion

The analysis in this phase of the study suggests that CRAM has utility in assessing the performance of restoration sites, but would need to be supplemented with other measures that provide additional insight into ecological function. From comparing the four attributes of CRAM, it appears restoration projects have more potential to influence the Physical and Biotic Structure attributes than the Hydrology and Buffer Landscape Context attributes. This relates to the results of the assessment of impacts of channel armoring (see Section 3), which showed that (from a CRAM perspective) the most pronounced impacts were to Biotic Structure and to a lesser extent Physical Structure. Restoration practitioners have little to no control over surrounding land use and hydrology; however, they can influence the physical and biotic structure of projects; therefore, it makes sense that these two attributes would be most affected by restoration.

With the exception of Las Flores Creek, the urban land use context of the restored sites prohibited them from scoring highly in the Buffer and Landscape Context attribute. Streams chosen for restoration are often surrounded by urban development, which becomes a constraint on visions to alter channel paths or widen the streams. For example, at the Las Virgenes North restoration site, where a widening on the channel would have required permission from the adjacent land owners, the restoration was constrained to the boundaries of publicly held land.

At Medea Creek, the grass strip adjacent to the stream led to a very low Buffer Landscape Context score. By non-CRAM standards, one could argue the grass to be a legitimate buffer. It provides space around the stream that would prevent flooding of local residences if water levels were to rise above the top of bank during periods of high stormflow. However, grass does not contribute to the ecology of the stream in the same manner as natural riparian habitat. Despite the social, aesthetic, or maintenance reasons for including a grass buffer, its presences reduces the overall ecological condition of the restoration site.

Although the topographic complexity of restored reaches was not generally comparable to that of reference reaches, it was much better than in the cement-lined channels. Among the restored reaches, Las Flores Creek had decent topographic complexity, which indicated that complexity is achievable with artificial bank restoration. The goal is for restored sites to develop more topographic complexity over time as flow regimes sort bed materials and contour the stream beds. Las Virgenes South was one of the more topographically complex among the restored reaches, possibly for this reason. However, an absence of information for the site did not allow us to further investigate whether present-day conditions are the result of construction or natural processes.

Of all the reaches assessed, those with higher Physical Structure scores (Santa Monica Mountain Recreation Area, Paramount Ranch) had much wider floodplains. The larger areas were able to accommodate excellent topographic complexity. Narrowly confined reaches will inherently have lower scores because of the natural constraints on their ability to develop complex structure.

As the natural physical increases structure over time, the expectation is that diversity of patch types will increase. While neither the restored or reference sites exhibited excellent structural patch richness, we expected Medea Creek, which has been in its restored state for the longest period of time, to have high patch richness; in contrast it had the worst Patch Richness score. One might predict that longer reaches where natural processes are not space limited are more likely to develop greater patch richness than short reaches. Las Virgenes North is an example of a restored reach where the ability to create a rich diversity of physical habitat was likely limited by its short length. At Medea Creek there is ample space, both length and width-wise, to have created or facilitated structural diversity. Due to the poor Physical Structure with little meandering and no riffles in the assessed reach, we speculated that the initial design of the restoration was not planned with a focus on patch richness.

Following the restoration of Medea Creek, a five-year vegetation maintenance scheme was prescribed. The site's current relatively poor Biotic Structure score could be attributable to one of the following: 1) attention was not devoted to planning vegetation diversity when the site was restored, or 2) five years of management was not sufficient time to support the new vegetation scheme and a longer period should have prescribed, as recommended by Kondolf (1995). However, we could not access sufficient information to infer why the project did not meet expectations.

4.3.1 Utility of CRAM for Restoration Assessment and Planning?

California Rapid Assessment Method is a useful tool for restoration planning because it provides an assessment of general condition with a modest level of effort (e.g., 2 to 4 hours in the field). However, CRAM should not be a stand-alone test of ecological health for assessing restored streams. More specialized studies of ecosystem components (e.g., biological, geomorphic) are important to determine the current health of an ecosystem, and to see how the health has changed over time. Specific information is especially vital if a restoration project is one step towards some greater ecological goal. For example, if fish re-introduction is a long-term goal, water quality and geomorphic studies are necessary to determine whether a stream reach would be able to sustain fish populations. CRAM would not be sufficient to evaluate progress toward these goals.

Furthermore, CRAM is based on ecological principles and knowledge of specific wetland systems but it has not been correlated with empirical measurements of ecosystem function (e.g., productivity, nutrient cycling). Several of the restoration case studies implied they hoped to achieve an improvement in ecological function. CRAM does not have the capacity to gauge how successfully those projects have met all of their goals, since it focuses on the structure of systems.

4.3.2 Lessons from the Santa Monica Mountain Area Stream Restoration Projects

In addition to ideas drawn from the use of CRAM, the case studies brought to light a few other noteworthy items.

1. *The restoration of ecological connectivity is a process.* One of the goals of the Las Virgenes North restoration was to restore ecological connectivity. However, the area under the Agoura Road Bridge was left lined with concrete, which blocks potential fish passage, a focus of the connectivity goal. Although passage for fish was not immediately obtained through this project, the restoration of the reach is a step towards establishing ecological connectivity. Should steelhead or other fish be re-introduced at some future time, only the portion under

the Agoura Road Bridge would need to be re-constructed. Additionally, improving water quality (e.g., reducing total maximum daily loads), shading the creek to reduce water temperatures, and incorporating habitat features to prepare for potential fish re-introduction far before fish become part of the system will allow for post-restoration water quality and habitat assessment. These are vital for determining whether the restored stream would be able to sustain the fish populations.

2. *Baseline data is valuable.* The more recently undertaken restoration projects we investigated (i.e., Las Flores Creek, Las Virgenes North, Dry Canyon Creek) all gathered baseline ecological data such as plant species lists, geomorphic analyses, and aquatic fauna. At Dry Canyon Creek MRT sponsored a hydrogeomorphic assessment, a rapid assessment focused on indicators of wetland function, prior to restoration activities. Gathering baseline data is valuable because it can contribute to the design of the restoration project by helping planners identify the degrees of improvement that would benefit various components of a pre-restored ecosystem. This knowledge can facilitate the development of realistic ecological goals in restoration planning.

3. P*ost-restoration monitoring and studies are important and should take place more often.* Out of five restoration projects for which we gathered documents, we were only able to obtain one post-restoration report (for Las Virgenes North from the City of Calabasas). Some of the pre-restoration reports required follow-up monitoring on planted vegetation, but otherwise there were no required plans for follow-up studies after restorations took place. Post-restoration studies should be implemented to see how ecological structure and function compare to baseline data. Information from these types of studies could be used to improve restoration design and technique, and thus refine the discipline of stream restoration.

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Appendix A: Comparison of River Assessment Methods

Each study site was evaluated with several river assessment and characterization tools that have been developed in Europe and the United States. The objectives were to 1) evaluate and compare the utility of each tool to assessment of armored segments in southern California streams and 2) provide an overall assessment of river "health" in armored vs. unarmored stream segments. The following methods were used:

<u>River Habitat Survey</u>

The River Habitat Survey (RHS) was developed in the United Kingdom to characterize and assess physical structure of rivers and streams (UK Environment Agency et al, 2003). The survey was designed to provide a contextual framework for geomorphic and bio-indicator surveys through field observation of stream features (Raven et al, 1998). The relationship between physical variables, channel modifications, and habitat features is documented through survey form completion at regularly spaced ("spot check") intervals with a study segment, and an overall summary of segment features ("sweep up") (Raven et al, 1998). Data are used to determine a Habitat Quality Assessment Score (HQA), quantified based on the diversity of features recorded, and a Habitat Modification Score (HMS), based on recorded presence of stream hydromodifications (Raven et al, 1998).

We used the survey form and guidance presented in the 2003 Version of the Field Survey Guidance Manual. We applied the method to pre-determined study segments, all of which were shorter than the RHS recommended 500m length. Therefore, we modified the distance between spot checks from 50m to 20m. Field data were entered into the RAPID 2.1 database (Center for Ecology & Hydrology, 2007) to determine HQA and HMS values for study segments.

<u>Fluvial Audit</u>

The Fluvial Audit was also developed in the United Kingdom with the purpose of characterizing and assessing geomorphic conditions on the catchment scale, as opposed to the RHS which is designed for application on the segment scale. Using a combination of field surveys, historical maps, and archival data (hydrologic gauge records, etc), Fluvial Audit attempts to identify sediment sources, storage, and transfer routes within a catchment (Sear et al, 2003). A subjective and adaptive multi-criteria assessment (MCA) process was developed for application to the River Nar in an effort to develop a segment scale indices for channel modification, function (sediment source or sink), and "naturalness" (Sear et al, 2009).

Given our segment-scale study design, we did not conduct a full catchment analysis as defined in the original Fluvial Audit design (Sear et al, 2003). We used the field survey form developed for the River Nar to record field observations (Sear et al, 2005), although it should be noted that field survey forms for other Fluvial Audit case studies were developed for recording catchment-specific features. We then developed a weighted multi-criteria analysis to quantify the degree of channel modification and used field observations recorded on the field survey form to determine scores for each study segment.

<u>Southern California Hydromodification Screening Tool</u>

The Hydromodification Screening Tool was developed by SCCWRP, Colorado State University, and Stillwater Sciences as a tool to “rate streams in terms of their potential susceptibility of response to planned changes in watershed land use, hydrology, and sediment yield.” (Bledsoe et al., 2010a). The tool includes a field assessment of channel stability in the vertical and lateral dimensions and a “desktop screening” where quantitative inputs (drainage area, mean annual precipitation, etc) are used to set parameters for decision trees which guide field observations and data. Local data from southern California streams were used to calibrate the probabilistic models for braiding, incision, and bank instability risk in both vertical and lateral directions. We applied the Hydromodification Screening Tool based on the guidance provided in field manual (Bledsoe et al, 2010b), with adaptation of the applied pebble count method according to the modified Wolman Pebble Count.

IDRIAM

Given a lack of suitable assessments for stream hydromorphology available for application it Italy, IDRAIM was developed from the collaboration between the University of Florence and the environmental agency Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). The general framework of the assessment is composed of two parts. The first phase provides a general setting of the physical conditions of the river and carries out an initial classification in relatively homogeneous segments based on the identification of physiographic units, degree of channel confinement, and channel morphological units. The second phase involves an analysis of segments defined in the first phase, focusing on continuity (longitudinal and lateral) of river processes, channel morphological conditions (channel pattern, cross-section configuration, and bed structure and substrate) and vegetation presence and structure. These aspects are analyzed according to three components: geomorphological functionality, artificiality, and morphological channel changes. All indicators are investigated using specific evaluation forms to determine a Geomorphic Quality score for the site, which is used to classify the site. We modified this assessment to apply it to previously delineated study site segments. The method was initially designed to examine morphological patterns and processes in study segments between 3-5km, as opposed to the 300-400m segments used in this study. Despite this difference, many of the features evaluated by IDRAIM are relevant to the Southern California Mediterranean-climate context.

We used IDRAIM to rate morphological quality for study segments (see TableA-1). Classification was determined based on analysis of physiographic units, historical aerial photos, and field observations. Degree of confinement within physiographic units dictates which features are scored and evaluated. Similar to the adapted MCA analysis for Fluvial Audit, features were assigned weighted scores to determine a classification of geomorphic quality.

Application of Assessment Methods

The results of applying the various river assessment and characterization tools are summarized in Table A-1. Descriptive results for each study site and evaluation of their applicability in Southern California follows.

River Habitat Survey (RHS)

In general, armored segments had the highest Habitat Modification (HMS) scores, which correspond to the lowest overall condition (Figure A-1). The exception was for Arroyo Seco and West Fork San Gabriel where HMS scores were slightly higher in the upstream segments. This is likely due to the notation of a hardened bank structure in all segments at these study sites, although at varying distances from the active channel (not a feature recorded in the RHS form).

The diversity of features recorded in RHS is an indicator of channel complexity in that the more types of features recorded, the more complex the habitat is considered to be (that is, it achieves a higher HQA). Our hypothesis was that the upstream segments would have the highest HQA, the armored segments the lowest HQA, and the downstream segments an intermediate HQA. Our results at Big Tujunga, East Fork San Gabriel and West Fork San Gabriel correspond with this hypothesis (although there was no downstream segment at West Fork San Gabriel). Results from Arroyo Seco correspond with our observation that bank and channel features varied significantly upstream and downstream of the bridge in the downstream segment. The presence of guide vanes in the impact segment of Arroyo Simi resulted in localized sinuosity, and more diversity among recorded bed features (Table A-1).

The design of RHS has several limitations for application in Southern California. RHS was developed in the UK (Raven et al 1998), a more temperate climate system than in Southern California. It has been applied extensively throughout Europe (Buffagni & Kemp, 2002), and studies were done to adapt the survey design to Mediterranean climates where braided channels and other features are commonly present in episodic channels (Raven et al, 2009). However, a survey form with fields to record episodic channel features is not yet available for public use, although work is underway to develop one in Portugal (Samantha Hughes, personal communication, 9/29/10). The available survey form from the UK Environment Agency is designed for use on single thread channels, and we observed several multi-thread channels and dry flood channels at our study sites. We concur with Buffagni and Kemp's recommendation that future survey forms should include fields for recording features found in both dry and wet sub-channels. Additionally, incorporating fields for floodplain activity observations should be considered in developing a survey for flashy Southern California streams, which can modify adjacent floodplains during winter flows. Certain features important for evaluations in Southern California, like exotic vegetation species, should also be considered if such a survey were to be carried out again in Southern California. We also recommend including a distinction between exotic and native vegetation presence in recording bank vegetation.

This is the first study that we are aware of in Southern California employing RHS; thus, we did not have a set of reference sites to calibrate HMS and HQA scores, and we relied upon calibration included in the

RAPID 2.1 database that we used to analyze our results. Our scoring was based upon HMS score quintile for the UK reference set, thus these classifications may not be accurate within a Southern California context.

Determining the degree of habitat modification and habitat quality is the primary objective of RHS, and while geomorphic conditions are an integral part of these assessments, they are not identified as a significant contributing influence on habitat quality in the current RHS design. Diversity of habitat elements such as channel substrata and features are considered to be indicators of high habitat quality, and these elements are subject to frequent change in a Mediterranean climate and active geological setting, as found in our region. Southern California streams frequently exhibit periods of intermittent flow, and thus determining flow types can be difficult. Attention should be given to sequences of flow types (pool->riffle->glide), and not just the presence of a flow type in a given segment (that is, recording number of riffle pool sequences, and not just numbers of riffled and pools).

Fluvial Audit

Results of the Fluvial Audit Multi-Criteria Analysis (MCA) generally correspond with our hypothesis that armored segments would exhibit the highest degree of channel modification (Figure A-2). Downstream segments did not always show signs of impact from upstream bank hardening based on the criteria we selected. Scores reflect the degree of modification at each site based upon evidence of channel incision, bank material alterations, planform change, and instream channel features. Features were weighted based on the degree to which they indicate direct hydromodification related to bank hardening.

Fluvial Audit is intended for application on a catchment scale, including GIS-based catchment scale analysis of sediment sources and sinks. Once these segments are identified, a multi-criteria analysis is developed to identify priority segments for restoration actions, such as increasing channel stability (Sear et al, 2009). Although we did some of the catchment characterization recommended in Fluvial Audit documentation (e.g., review of historical photos, catchment topography), conducting a full catchment analysis of sediment sources and sinks was beyond the scope of this study. We recommend that future development of geomorphic assessment tools on the catchment scale incorporate Fluvial Audit sediment source analysis, especially reviewing catchment changes over time.

As with RHS, we did not have an extensive set of Southern California reference sites with which to contextualize our results. However, we did use data from Bledsoe et al 2010a to score select reference sites used in that study according to our MCA system.

IDRAIM (Stream Hydromorphological Evaluation, Analysis, and Monitoring System)

Morphological quality was rated as “good” to “very good” for all study segments (see TableA-1). The slight differences among quality ratings at segments can be attributed to the presence of a hardened bank. Segment dimensions for IDRAIM are intended to be larger (3-5km) than our study sites (300-400m). Therefore, it is difficult to distinguish subtle changes between study segments, hence the similar classifications between segments. Changes in the upstream catchments, such as the presence of dams, which influence sediment supply to downstream segments, are accounted for in the IDRAIM analysis, unlike other analyses we applied.

Southern California Hydromodification Screening Tool

Bank susceptibility to failure was found to be in the "high" to "very high" range for both vertical and lateral response segments at sites with channel beds composed primarily of sand and fine gravels (Big Tujunga, Arroyo Seco, Arroyo Simi, Conejo Creek). There was little variation in ratings among segments at these sites, with the exception of the impact segment at Conejo Creek, where the segment is confined against a hillslope and within a hardened bank, resulting in a "low" lateral rating. Both San Gabriel sites received "low" lateral response ratings, which can be attributed to their confinement within bedrock gorges. West Fork San Gabriel study segments also received a "low" vertical response rating, while East Fork San Gabriel received "medium" to "high" rating due to the presence of recreational dams, which act as intermediate grade-control structures, some of which had failed. Summarized results are presented in Table A-1.

We compared the 10 year flood frequency interval discharge (Q10) predicted by the regional rating curve incorporated into the Hydromodification Screening Tool Desktop Tool version 1.0 (see Bledsoe et al, 2010a) with the 10 year flood frequency interval discharge determined based on historic gauge records and calibrated based on drainage area (Table A-2). Study sites with upstream dams have predicted Q10s that were much higher than indicated by the gauge record (Big Tujunga and West Fork San Gabriel), likely related to the flood control function provided by these dams. Gauges on Arroyo Seco and Arroyo Simi were used to calibrate the regional rating curve developed by Hawley and Bledsoe, and thus Q10 results from flood frequency analysis using the gauge record are comparatively close to those predicted in the Hydromodification Screening Tool. Predicted Q10 was within an order of magnitude of the gauge record Q10 for East Fork San Gabriel and Conejo Creek.

We also tested how the "valley width index" changes based on changes to the valley width, which is a user input in the "Desktop" sheet of the Hydromodification Screening Tool. The input guidance recommends using the "valley bottom width at site between natural valley walls as dictated by clear breaks in hillslope of NED raster, irrespective of potential armoring from floodplain encroachment, levees, etc." Big Tujunga, Arroyo Simi and Conejo Creek are all set within wide alluvial valleys, yet they are confined within the valley floor by the presence of a hardened bank. Thus, we hypothesized that natural slope breaks as detected on an NED raster would overstate valley width. However, when changing the valley width input for these sites to reflect their confined setting, there was no consistent response in vertical and lateral ratings, suggesting that the valley width input does not significantly affect valley width index ratings.

We were among the first field teams to apply the Hydromodification Screening Tool in Southern California to sites beyond those used in the development and initial testing of the tool. Based on our experiences, we recommend reconsidering how bank characterization is incorporated in the tool. All of our study sites had one bank hardened, not both banks. In "Form 4-Lateral" within the desktop version of the tool (see Appendix 1), "Primary Lateral States" are presented to characterize both stream banks, without distinction between banks. At some of our field sites, opposite banks were composed of very different materials with different cohesive properties. For example, in the impact segment of Arroyo Seco, the left bank was composed of a cemented stone wall, and the right bank of sand terraces. While the left bank is best described as “fully armored,” the right bank is best described as “poorly consolidated,” creating somewhat of a contradiction in the lateral rating.

Other user inputs could be modified to facilitate more accurate calculation of vertical and lateral risk of failure. As recommended in guidance documents, we entered the mean annual precipitation for the area-weighted polygon containing our study site, not for the study site’s entire watershed. In some watersheds where precipitation amounts can vary substantially from the headwaters to the lowlands, such as steep watersheds in the San Gabriel Mountains, it may be worth providing additional user guidance on how to properly input mean annual precipitation for a varied watershed. With respect to grain size, “Form3-Pebble-Count” is designed to allow the user to input measurements for individual grains, instead of by phi-classes, to produce results for median grain size and percent sand. This prevents recognition of a bi-modal distribution among grains and the degree of embeddedness. The form limits the number of grains for which measurements can be recorded to 200, which should be expanded for situations where the sampler counts more than 100 sand particles.

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Table A-1. River Assessment and Characterization Tools Results Summary

Study Site	Study Reach	Morphological Quality Index (IDRAIM)	River Habitat Survey Habitat Modification Classification	River Habitat Survey Habitat Modification Score	River Habitat Survey Habitat Quality Assessment Score	Hydromod Vertical Rating	Hydromod Lateral Rating	Fluvial Audit Multi-Criteria Assessment for Modification
BH1 Big Tujunga	BH1-A	Good (2)	Predominantly Unmodified (2)	75	50	9 = High	Very High	6.5
BH1 Big Tujunga	BH1-B	Good (2)	Significantly modified (4)	725	32	Very High	Very High	17
BH1 Big Tujunga	BH1-C	Good (2)	Pristine/Semi-natural (1)	0	39	9 = High	Very High	10.5
BH2 West Fork San Gabriel	BH2-A	Good (2)	Significantly modified (4)	640	79	Low	Low	3
BH2 West Fork San Gabriel	BH2-B	Good/Moderate (2/3)	Obviously modified (3)	480	46	Low	Low	18
BH3 East Fork San Gabriel	BH3-A	Very Good (1)	Significantly modified (4)	660	53	6.8 = medium	Low	5
BH3 East Fork San Gabriel	BH3-B	Very Good (1)	Severly modified (5)	2050	30	7.3 = high	medium	14
BH3 East Fork San Gabriel	BH3-C	Very Good (1)	Severly modified (5)	1400	44	8.1 = high	low	4
BH4 Arroyo Seco	BH4-A	Very Good (1)	Significantly modified (4)	990	43	Very High	high	7.5
BH4 Arroyo Seco	BH4-B	Good (2)	Significantly modified (4)	680	38	Very High	High	13
BH4 Arroyo Seco	BH4-C	Very Good (1)	Significantly modified (4)	665	52	8.1 = high	high	4
BH5 Arroyo Simi	BH5-A	Good (2)	Predominantly Unmodified (2)	190	55	Very High	Very High	15.5
BH5 Arroyo Simi	BH5-B	Good (2)	Severly modified (5)	1590	66	high	High	9
BH5 Arroyo Simi	BH5-C	Very Good (1)	Predominantly Unmodified (2)	150	56	Very High	Very High	3.5
BH6 Conejo	BH6-A	Good (2)	Severly modified (5)	2140	28	Very High	High	9
BH6 Conejo	BH6-B	Good (2)	Severly modified (5)	3760	23	Very High	Low	19
BH6 Conejo	BH6-C	Good (2)	Pristine/Semi-natural (1)	860	23	Very High	High	11.5
			1 Pristine/Semi-Natural 2 Predominantly unmodified 3 Obviously modified 4 Significantly modified 5 Severely modified					0 = unmodified 25 = most modified

Table A-2. Q10 Comparison using gauge record results and Hydromodification Screening Tool predictions.

Site	Drainage Area (sq mi)	Predicted Q10 (cfs)	Actual Q10 (cfs)	Calibrated Q10 (cfs) based on site drainage area	2009-2010 WY peak (cfs)	Peak flow of Record (cfs)
BH1A	115	12,518.00	4,719.00	5,119.67		8,600 (1922)
BH1B	115	12,518.00	4,719.00	5,119.67		
BH1C	116	10,537.00	4,719.00	5,119.67		
BH2A	83	13,140.19	10,860.00	8,667.12		34,000 (1938)
BH2B	83	13,140.19	10,860.00	8,667.12		
BH3A	79	10,454.26	8,801.00	8,218.43		46,000 (1938)
BH3B	79	10,454.26	8,801.00	8,218.43		
BH3C	80	10,569.29	8,801.00	8,322.46		
BH4A	19	2,593.00	2,815.00	3,342.81	455 (02-06-10, .6 exceedance probability = ~Q2) (P)	8,620 (1938)
BH4B	19	2,593.00	2,815.00	3,342.81		
BH4C	20	2,711.00	2,815.00	3,518.75		
BH5A	83	6,129.00	6,243.00	7,339.50		10,700 (1983)
BH5B	83	6,129.00	6,243.00	7,339.50		
BH5C	83	6,129.00	6,243.00	7,339.50		
BH6A	76	4,992.00	17,380.00	5,326.13	1,790 (01-20-10, .85 exceedance probability = ~Q1.1) (P)	25,300 (1980)
BH6B	76	4,992.00	17,380.00	5,326.13		
BH6C	77	5,049.00	17,380.00	5,396.21		

*note actual Q10 is from "systematic record" result in PeakFQ using annual maxima

*calculated by dividing "systematic record" Q10 with gage DA, then multiplying that number by site DA

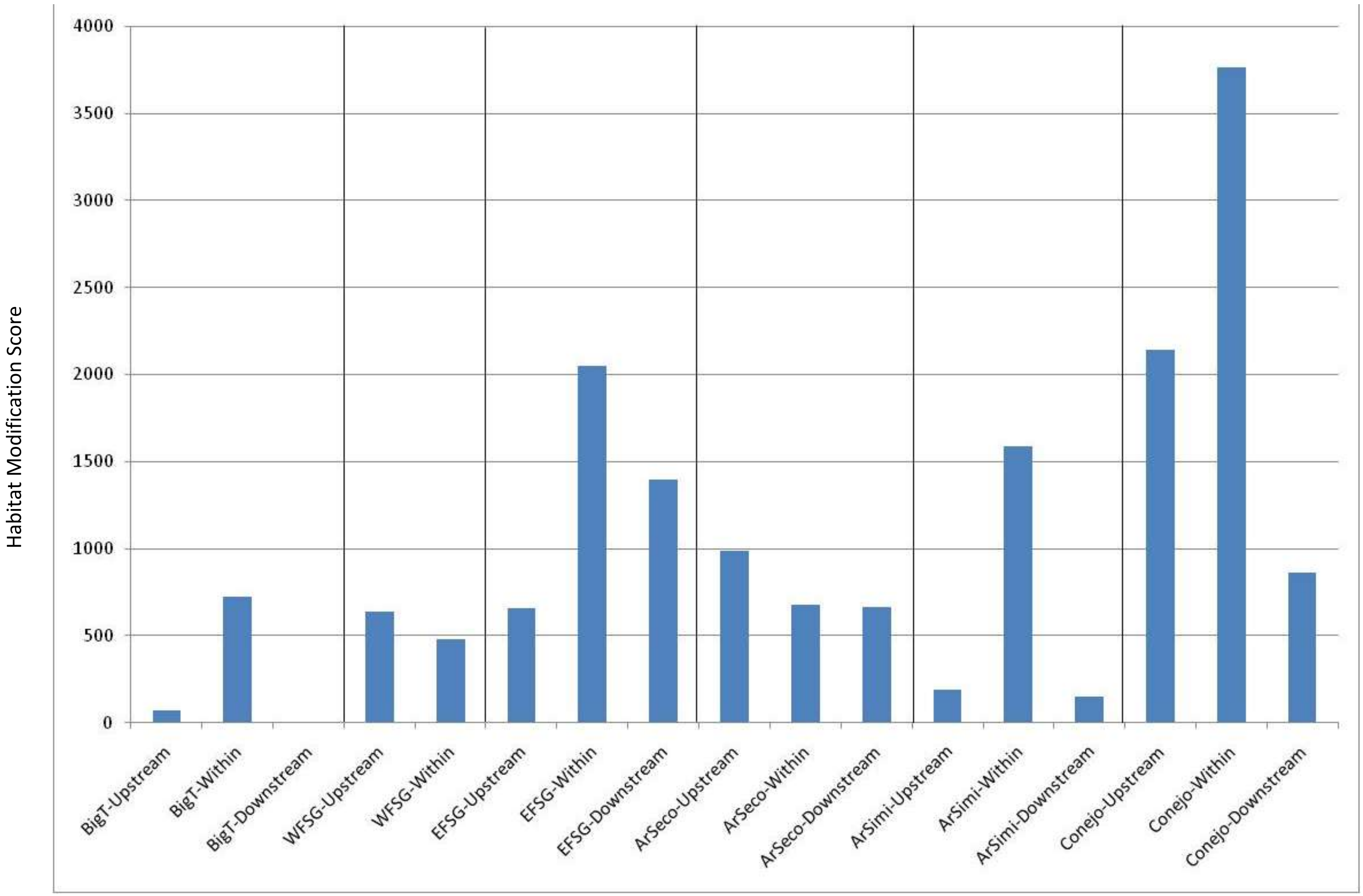


Figure A-1. River Habitat Survey, Habitat Modification Scores for each site.

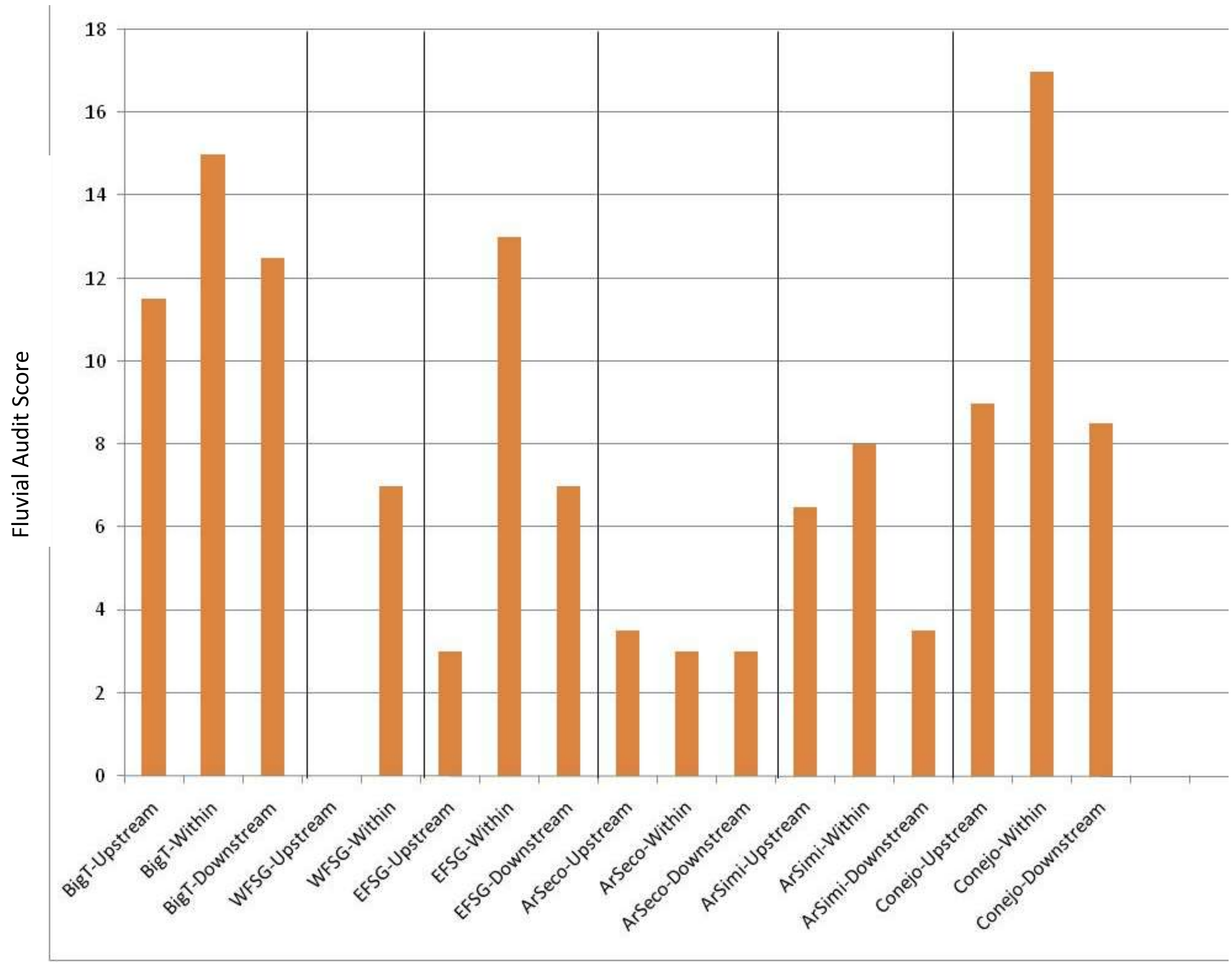


Figure A-2. Fluvial Audit Multi-Criteria Assessment for Modification. Scores are shown relative to a maximum possible score of 30.

Appendix B: Detailed Descriptions of Study Sites

Descriptions of channel geometry and measurement of instream features and observations from each study site follow. Right and left are used to refer to sides of the bank when facing downstream.

Big Tujunga (BH1)

Big Tujunga can be characterized as the most geomorphically complex study site, with substantial evidence of recent high flow events which have altered channel and floodplain features visible on aerial imagery available in Google Earth (dated November 14, 2009). The floodplain throughout the study area is wide (~90-130m), with the far right limit bounded by a steep hillslope. The low flow channel runs along the hardened (concrete wall) left bank in the impact segment (BH1-B), which forces the channel to turn towards the right. The active channel(s) trends more towards the center of the floodplain in the upstream and downstream segmentes. Secondary channels at both lower and upper terraces are visible in all segmentes. Secondary channels have low flow in the upstream segment and no flow in the impact and downstream segmentes.

Sediment input, primarily in the form of fine-grained sediment (<4mm), is currently abundant in the wetted low-flow channel throughout all survey segmentes of Big Tujunga. At the time of the field assessment (July 2010), active sand bedload transport was visible throughout the study site. The high sediment load is primarily due to erosion of sediment in the upper watershed after the 2009 Station Fire. The recent influx of sand deposition and subsequent channel incision is most visible in the middle survey segment (BH1-B), which is a low gradient segment (<1% slope) compared to the upper segment which has a slope of almost 3%. Sediments in dry upper terrace channels on the right bank floodplain consist of mixed sand and cobble with scattered large boulders, some of which are embedded. This coarser bed is likely typical in the active channel under non-disturbance conditions.

<u>Big Tujunga Upstream (BH1-A):</u> This is the most complex segment at the study site. The main low-flow channel in the upstream-most portion of the segment is confined by a bridge that constricts the main channel against the hillslope. An active side channel enters the segment near the left bank. Downstream of the bridge, multiple low-flow channels are present and are separated by terraces approximately 1m high. For the purposes of our study, we surveyed our long profile along the channel that appeared to have the highest discharge, but we did include bed features for all channels in our facies map. The longitudinal channel profile of this segment is characterized by some small step pools in the upstream-most section, a long and relatively flat sand channel, and then followed by a series of step-pools (some formed by recreational dams) as the slope becomes steeper. A wide, dry flood channel is present in the right floodplain, separated from the rest of the floodplain and active channel by a bank with well established vegetation. The active channel and adjacent dry side channels primarily consist of a sand bed except in riffles where cobbles and scattered boulders are present. Bed surface materials on channel banks in this segment are comprised of poorly sorted gravels and sporadic large boulders. Grain size sampling was conducted on the right bank of the low flow channel near the upstream most section of the segment, and grains were moderately embedded.

Big Tujunga Armored (BH1-B): This segment occurs where the floodplain turns towards the right. The hardened left bank (concrete wall) prevents the active channel from moving any farther to the left. A recently deposited sand bed approximately 20m wide occupies the lower elevations of the channel, and active sand bedload transport appeared to be moving fastest in this relatively flat segment. A single low flow channel is actively downcutting through these sand deposits and vegetation (primarily willows) has emerged along the edge of the recent sand deposits and adjacent, coarser, bed material. Terracing is visible on the right bank, and evidence of multiple flood channels is present in the right floodplain. The lowest terrace on the right bank primarily consists of sand and embedded cobbles with little riparian vegetation. Upper terrace topography and surface material are similar to those found in the upstream segment (BH1-A). No side channels, terraces, or vegetation are present on the left bank due to the presence of the hardened bank structure. This segment is distinctly less complex than the upstream segment.

Big Tujunga Downstream (BH1-C): The single active low flow channel continues through this segment, with some larger grains providing increased channel complexity when compared to the impact segment, but not as much complexity as the upstream segment. This segment contains a series of small riffles and pools as well as some sand and small gravel bars. Some large boulders, similar to those found in the upper segment provide additional channel complexity. A secondary flood channel is located on the right bank and sand/gravel terraces are present on both banks. Sediment in the low-flow channel primarily consists of sand and small gravels with significant levels of embeddedness.

Overall Assessment: Big Tujunga displayed characteristics of our expected response to bank hardening: high channel complexity in the upstream segment, minimal channel complexity in the impact segment, and increasing channel complexity in the downstream segment. Channel form in the impact segment is evidently influenced by the armoring, as the low-flow channel in this segment runs straight along the hardened bank while it meanders in the upper and lower segmentes. Some of the difference in channel form in the upstream and downstream segmentes may be attributed to the absence of a bank hardening structure which imposes a limited (in comparison to other study sites) degree of confinement on the floodplain and channel.

The recent flux of sediment supplied by areas burned during the 2009 Station Fire had a potentially significant influence on channel dynamics at Big Tujunga. The mostly sandy bed with varying degrees of embeddedness of larger grains is evidence of recent bed aggradation. Due to the recent flux of sediment, it is difficult to attribute the low-flow channel bed complexity solely to the hardened bank structures.

Figure B-1. Big Tujunga

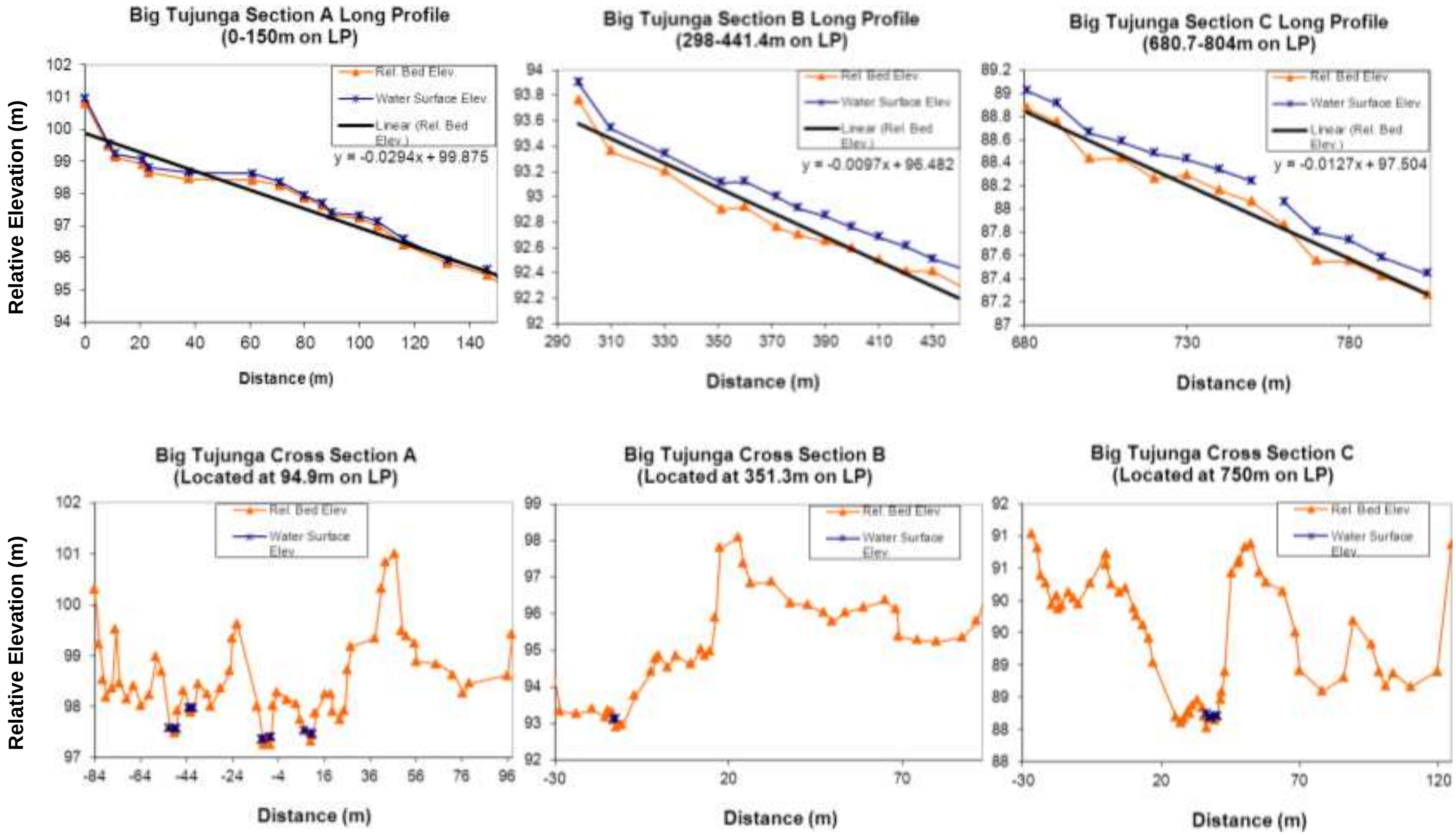


Figure B-1. Continued

West Fork San Gabriel (BH2)

The channel is located in a bedrock gorge ~30m wide. The low flow channel has a bankfull width of approximately 16-20m wide. The channel bed material primarily consists of large cobbles and boulders, many of which are imbricated. Exposed bedrock is visible in many areas along the channel bed and banks. A road runs along the top of the right bank for the entire length of the study site, and the upper portion of the right bank is reinforced in the upstream segment, and the entire right bank is reinforced in the impact segment. Several sites on the right bank of the upstream segment and left bank of the impact segment are used as access sites for fishing and general recreation. A parking lot and stairs located on the left bank in the impact segment (BH2-B) provides direct access to the river and concentrates recreational use in this area. A bridge is located immediately downstream of BH2-B, so there is no study segment downstream of the impact segment. The 2009 Station Fire burned the upper ridges of the study site catchment, and all areas burned in the watershed were above Cogswell Dam (~11km upstream of upstream segment).

<u>West Fork San Gabriel Upstream (BH2-A)</u>: The low flow channel in this segment is bound on either side by a densely vegetated sand terrace that is approximately 2-3m above the channel bed. The sand terrace on the left bank ranges from 6-12m wide and is flanked by an almost vertical bedrock wall. The sand terrace on the right bank ranges from 0-5m wide and is abutted by a steeply sloped, unconsolidated bank that is approximately 5m above the channel bed. The active channel contains several cascade pool sequences along with sporadic large woody debris. The bed material is very coarse and imbricated. No pebble count was conducted in this segment due to deep water and imbricated bed material. Fly fisherman were observed throughout this segment although physical in-channel disturbance (i.e. deliberate re-positioning of cobbles) is minimal.

<u>West Fork San Gabriel Armored (BH2-B):</u> The channel in this segment is confined by a concrete/rip-rap on the right bank slope and a moderately vegetated terrace and steep, unconsolidated left bank slope. A large pool located downstream of large boulders and exposed bedrock dominates this segment. No pebble count was conducted in this segment due to deep water and large bed material. The hardened right bank is undercut by up to 1m in some locations. There is significant recreational activity occurring in this segment. Recreational dams have been created at several areas along the left bank and understory vegetation on the left bank is primarily absent, likely due to trampling.

<u>Overall Assessment</u>: The presence of a large pool in the impact segment is consistent with our expected response, but the presence of large boulders and exposed bedrock within the confined segment are more likely to cause pool scouring than the hardened right bank. This structure was likely put in place to protect the road on top of the right bank, and somewhat limits the channel's ability to move within the already confining bedrock gorge. Due to the site location within in a gorge with exposed bedrock slope toes, any influence that the hardened bank may have on channel conditions (directing flow, lack of vegetation, etc) is likely to resemble conditions created by a bedrock outcropping. Additionally, the bed of the active low-flow channel was below (~1m) the toe of the hardened right bank throughout the impact segment, indicating that bed incision occurred since the period in which the bank was reinforced.

This is may be related to limited sediment supply from the upstream catchment due to Cogswell Dam. Cogswell Dam is also likely to have dampened influx of sediment from upstream areas impacted by the Station Fire.

Figure B-2. West Fork San Gabriel

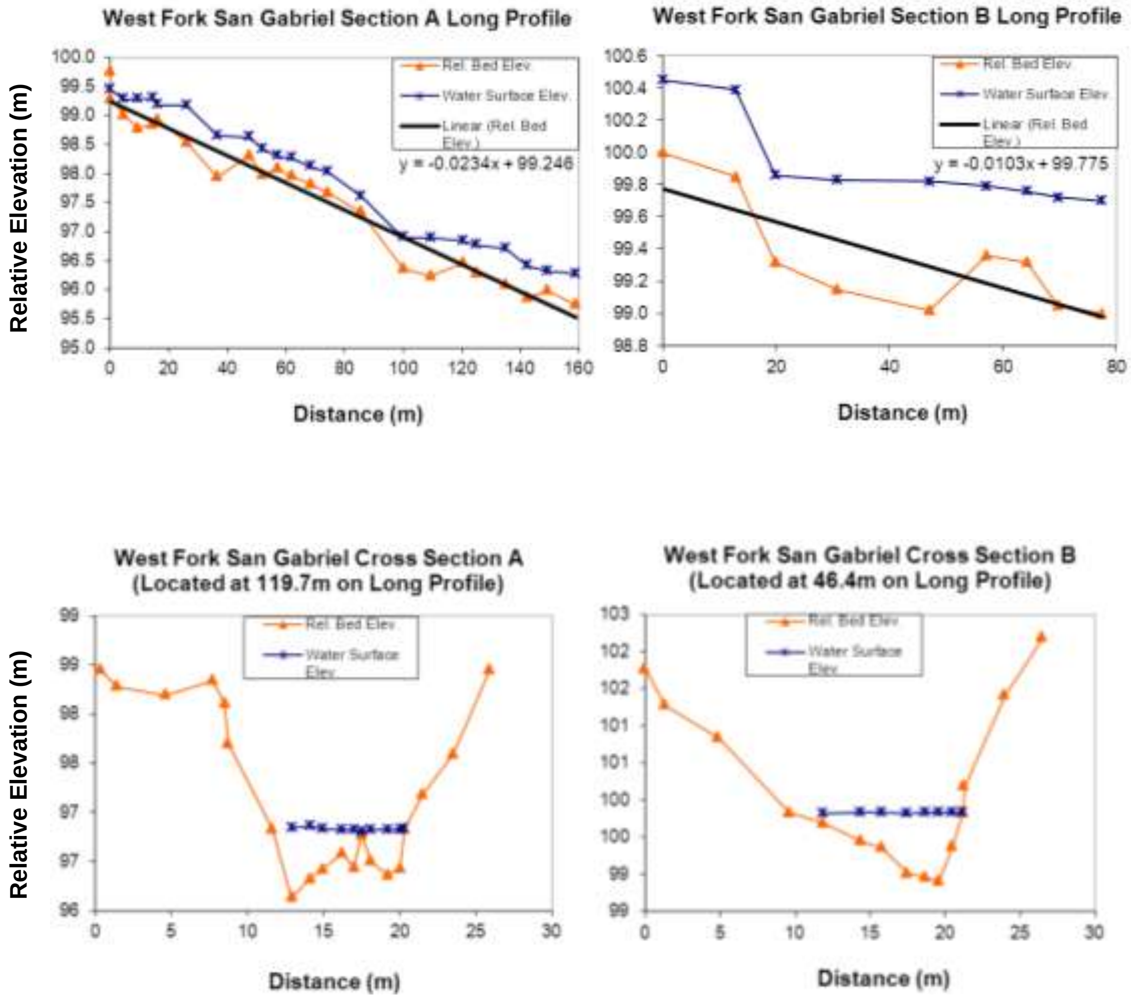


Figure B-2. Continued

East Fork San Gabriel (BH3)

East Fork San Gabriel is also confined within a bedrock gorge in the San Gabriel Mountains, approximately 90m wide in the upper segment and 30-60m wide in the two lower segmentes. Parent material of in-channel sediment primarily consists of large coarse-grained granitics from steep slopes in the upper watershed. The sediment load is coarse with similar grain size distributions (D50 = 30-47mm) and channel slopes (1.2-2%) among the three segments. A road runs along the top of the left bank for the entire length of the study site, and is farthest away from the study site in the upstream segment (~55m between the road and the left channel edge). A parking lot located adjacent to the road in the impact and downstream segmentes provides direct access to the river and concentrates recreational use in this area. This area is heavily used for recreation as evident by the recreational dams and garbage located in all segments, although mostly concentrated in the impact and downstream segmentes.

<u>East Fork San Gabriel Upstream (BH3-A):</u> The segment is located between two recreational dams made of large cobbles, with the upstream dam reinforced by a large log that spans the channel. The active channel in this segment is characterized by large riffle-pool sequences. Approximately a third of the pools appear to be formed by recreational dams, some of which were previously segmented. Smaller pools along the edge of the channel have fine sediment covering the cobble bed surface. The bed material primarily consists of cobbles (D50=32), many of which are embedded. The banks of the low flow channel are lined with established riparian vegetation (alders and willows). Two secondary channels approximately one meter higher than the main channel bed elevation are located on the lower floodplain terrace on both sides of the main channel. A second floodplain terrace, approximately 15-17m wide, and 2.5m above the main channel bed is located on the right bank.

<u>East Fork San Gabriel Armored (BH3-B):</u> The channel in this segment flows along the base of the concrete/rock hardened left bank, which is mostly undercut or failing. There is an extensive network of recreational dams in this segment. Pools behind dams are fairly deep (>1m). Riffles between dam sites primarily consist of large cobbles (D50=48), some of which are embedded, although many have been moved by the river's flow or by people. There are several small, shallow channels on the right bank that are divided by gravel bars. Alternate flood channels are present on the lower and upper right bank terrace, approximately 1.5m and 2.5m above the channel bed. There is very little vegetation in this segment although there is some willow recruitment on the edge of the right bank along the alternate channels.

<u>East Fork Downstream BH3-C:</u> This segment is confined by a road on the left bank and bedrock on the right bank. The upper portion of the left bank is hardened, and the bank is currently separated from the active low flow channel by a 20m wide gravel/sand terrace. There are several recreational dams that span the width of the channel. Deep pools are located behind a few recreational dams.There are fewer recreational dams in this segment than in the impact segment. Large riffle sequences with embedded cobbles (D50=32) are present between, and downstream of, dams.

<u>Overall assessment</u>: The percentage of the segment characterized by riffles is less in the impact segment than in the upstream and downstream segments, consistent with our expected response. We also observed channel incision and active undercutting of the hardened bank structure. However, the

high level of recreational activity, especially recreational dam building to create pools, prevents us from attributing this pattern to the presence of a hardened bank. The hardened bank was likely put in place to protect a road that runs along the left bank of the river channel at a place where the gorge naturally narrows. While the bank hardening does limit the channel's ability to move within the gorge, it is not significantly changing its channel form due to its location in a narrowing gorge. Additionally, a bridge located just beyond the downstream end of the downstream segment restricts the channel more than the hardened bank by forcing it through a narrow concrete corridor. Our observations and measurements suggest that the most significant anthropogenic disturbance at this study site is the creation of recreational dams, which dramatically alter the channel bed form. Additional recreational activity has limited the establishment and survival of riparian vegetation in the two lower segmentes.

Figure B-3. East Fork San Gabriel

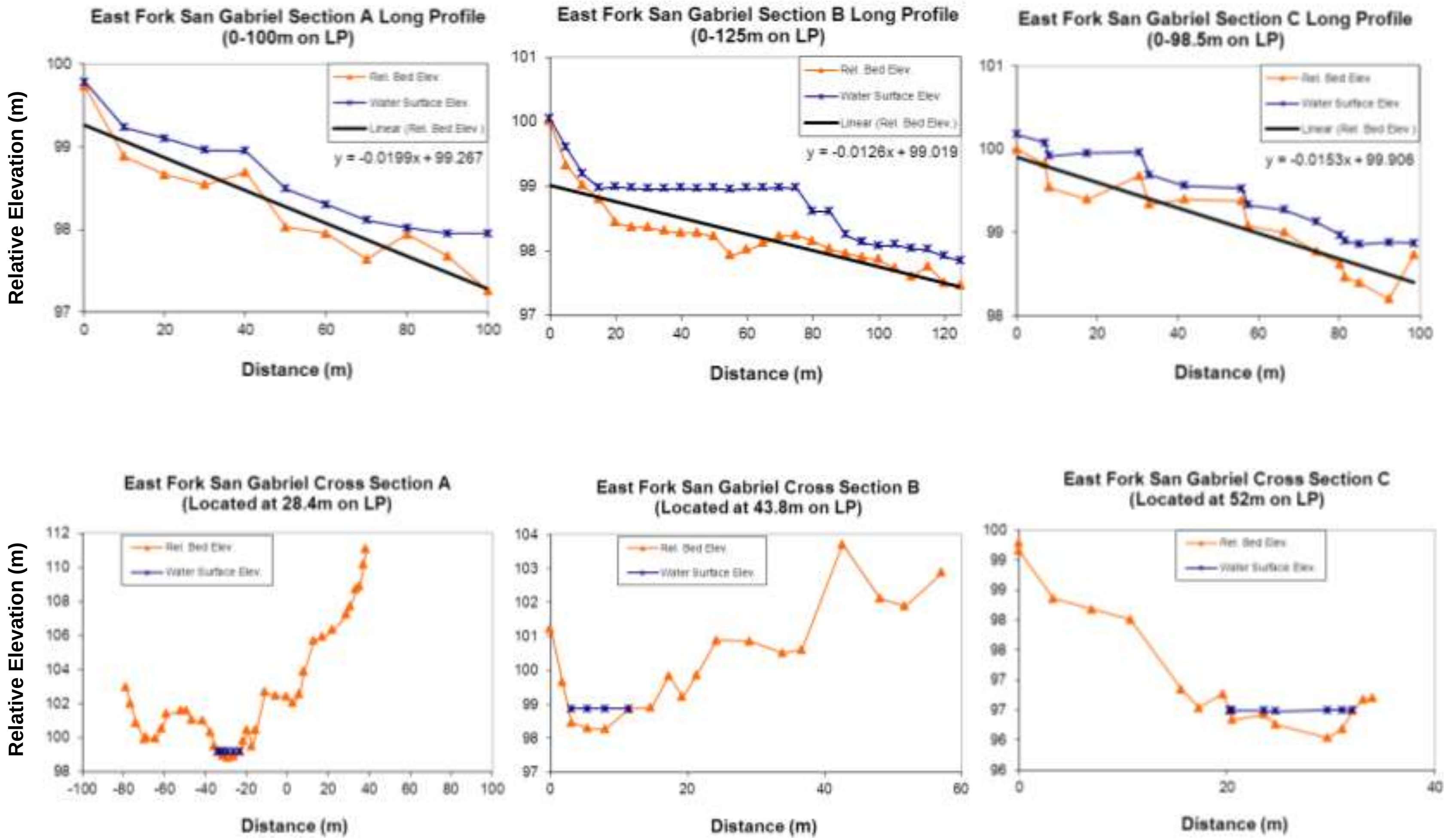


Figure B-3. Continued

Arroyo Seco (BH4)

The study site is located within a confined channel in a gorge in the foothills of the San Gabriel Mountains. The channel is located in a gorge ~40-50m wide, and the low flow channel has a bankfull width of approximately 6.5-12m wide. The channel bed material primarily consists of sand and small gravels although large, embedded boulders were also present. Parent material of in-channel sediment primarily consists of large, coarse-grained granitics from steep slopes in the upper watershed. Exposed bedrock is visible along the channel banks in all three segmentes. A road runs along the top of the left bank in the upstream segment, on the top of the right bank in the impact segment, and crosses from the right bank to the left bank in the downstream segment. The hardened bank structure at this site consists of a 4m high rock wall on the left bank in the impact segment. A rock wall is also present on the far left bank of the flood channel in the upstream segment , and on the left bank in the downstream segment where it is 10m from the low flow channel.

Arroyo Seco Upstream (BH4-A): Channel movement in the upper segment of the study site is confined to a corridor 35-50m wide, which is confined by a road on the left bank and exposed bedrock and a steep hillslope on the right bank. A wide, deep (bankfull estimate of ~10m wide, ~1.5m deep) alternate channel is located between the active low flow channel and the left bank. The alternate channel may have previously functioned as the primary channel, as it contains large patches of woody debris and high water marks approximately 2.5-2.7m above the channel bed, however it is currently cut off at the upstream end by a sediment pile. Based on observations of recent excavation at the base of the debris basin immediately upstream of the upstream segment, we hypothesize that the sediment pile was likely pushed in place by bulldozers to prevent flow from entering the channel and eroding the left bank and the road on top of it. The left bank and base of the road are reinforced by a stone wall and bedrock. Mature trees are growing on the large gravel bar that divides the active and alternate channels. The bed surface of the active low flow channel primarily consists of poorly sorted sand and small gravels with some embedded cobbles (D50=4mm).

Arroyo Seco Armored (BH4-B): This segment begins below a bridge crossing, which acts as a channel constrictor during high flows. The left bank of this segment is a vertical rock wall approximately 4m high. The right bank has one large (~6-8m wide) and several smaller sand terraces, and the upper portion of the bank is composed of unconsolidated material extending at a ~45 degree angle up to approximately 4.5m above the channel bed. A road is located at the top of the right bank. The active low flow channel runs close to the base of the rock wall on the left bank. It contains some large embedded gravels although the majority of the bed surface sediment consists of sand and small gravels (D50=8mm). There is evidence of recent sand deposition throughout the segment and woody debris is wrapped around alder trees at the base of the right bank. Alders appear to be recovering from a recent disturbance – there was little leaf growth in the canopy when we took field observations in July 2010.

Arroyo Seco Downstream (BH4-C): This segment is more complex than the two upstream segments, particularly below the bridge crossing the segment, where the channel slope steepens and large boulders are present. Riffle pool sequences and gravel bars are present throughout the segment and the low flow channel meanders around large embedded boulders. The average grain size is slightly larger in this segment (D50=16mm) compared to upstream segmentes, although the percent of embedded particles is similar to other segmentes (~10%). The upper portion of the segment contains a rock wall on the left bank and a sand gravel slope with a road on top on the right bank although the active low flow channel is > 10m from either of these structures. Sand terraces are present on either side of the active low flow channel. An alternate high water channel is located on the left bank terrace. Below the bridge, the right bank is confined by a steep slope with some exposed bedrock, while the left bank contains several terraces and small alternate flood channels.

Overall assessment: Field observations and measurements do not correlate with our expected channel response to bank hardening. The recent pulse of sediment and debris due to the 2009 Station Fire, which burned nearly all of the upstream catchment, and winter rains appear to have significantly altered the channel based on our observations of sand terraces, larger boulders, and woody debris caught on trees. Recent channel modifications (sediment removal and piling of sediment) in the upstream segment make it difficult to assess the segment as an ‘unimpaired’ site for comparison. Additionally, the presence of stone walls and exposed bedrock in all study segmentes, albeit at varying distances from the channels, makes it difficult to attribute channel features to bank hardening.

Figure B-4. Arroyo Seco

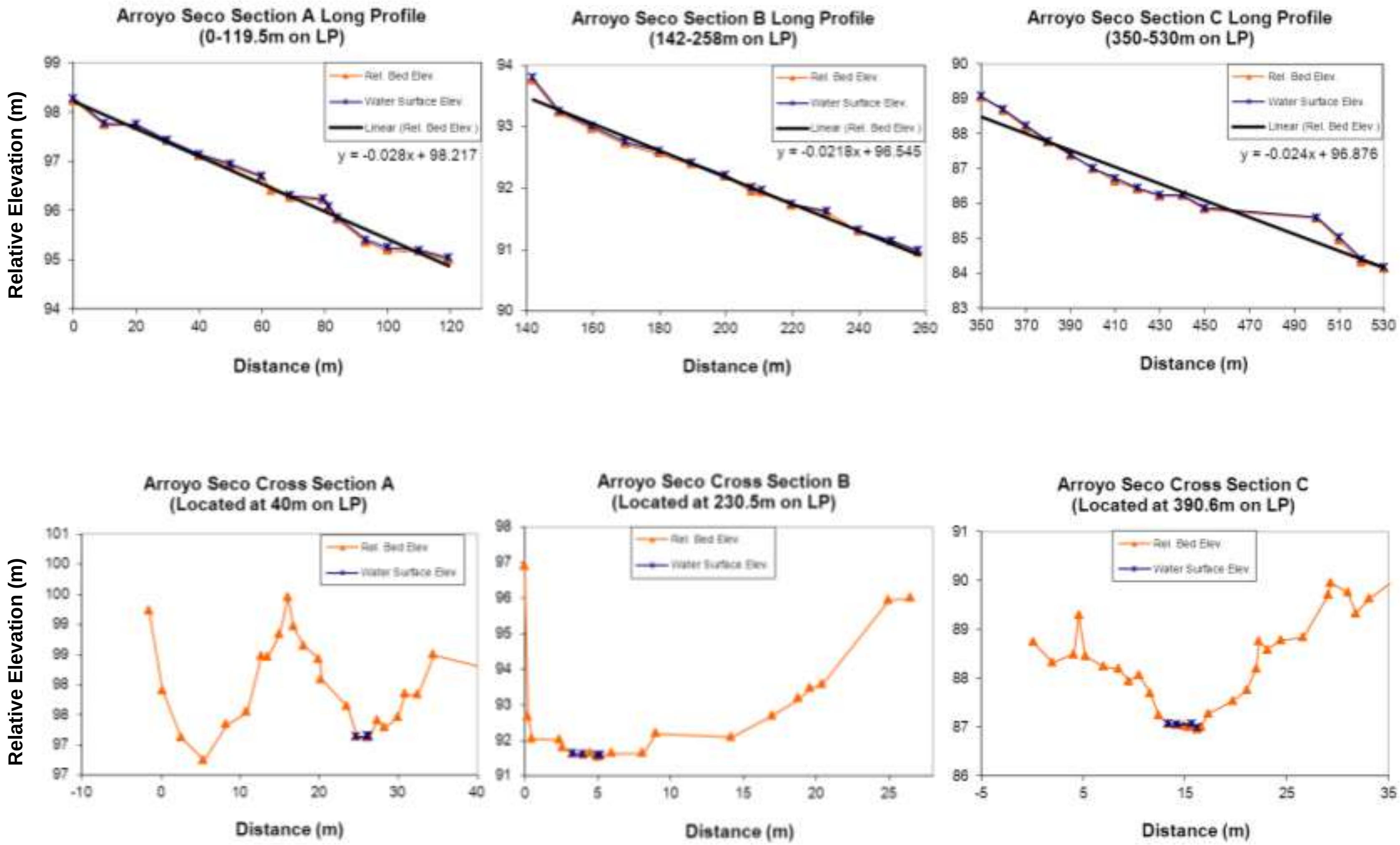


Figure B-4. Continued

Arroyo Simi (BH5)

The study site is located in the bottom of an alluvial valley which has experienced significant urban development. Interpretation of surrounding topography suggests that the channel historically had access to a large floodplain, yet is now confined by a reinforced (grouted concrete) levee structure along the far right bank, which is protecting a wastewater treatment plant and several industrial facilities. Floodplain width varies from approximately 85m in the upstream and impact segmentes to approximately 130 meters in the downstream segmentes. The reinforced levee structure (~6-8m high) is closest to the active channel in the impact segment, and several “guide vanes” (I-beam and cable racks, ~3m tall x ~6m wide) were installed perpendicular to the reinforced bank between the date of imagery available in Google Earth (September 30, 2007) and fieldwork in July 2010. We interpret these structures as an attempt to deflect the channel away from the hardened bank to prevent undercutting, which we observed at several other study sites. The hillslope extending from the base of the left floodplain appears to have been graded for roads and drainage, and a 1964 USGS map indicates that this hillslope was once a gravel pit.

Bed material in this bottomland channel primarily consists of sand with some fine gravel. Parent material of in-channel sediment primarily consists of tertiary marine and non-marine sediments. No pebble counts were conducted due to the dominance of sandy bed material. Channel bed slope is low in all segmentes, ranging between 0.08-0.28%. Base flow in the channel is strong and clear, possibly indicating that water is pumped in upstream or groundwater is a significant water source. Given the highly urbanized upstream catchment, we expected substantial debris and higher turbidity than was observed. Low flow water depth averaged between 0.2-0.4m. Cattails and willow roots hold almost vertical 0.1-0.3m sand banks in place in many areas of the site, particularly in the upstream segment. Mature vegetation is present along the low flow channel banks in most areas, although some sites were cleared for tent encampments. High water marks in trees are approximately 1.5-2m above the channel bed.

<u>Arroyo Simi Upstream (BH5-A):</u> The upper half of the low flow channel in this segment is dominated by cattailsand confined to a corridor ~2m wide. Steep banks are present along the left side of the channel, with evidence of slumps in some areas. The channel bed is primarily a smooth sandy bed with some fine to medium gravels. Approximately 40m downstream from the segment beginning, the channel widens and enters a single large pool ~0.5m deep. The lower half of the segment has mature willows on both banks. High flow alternate channels are present on the sand terrace on the right bank. Dense clumps of giant reed have formed sand bars between the high flow alternate channels.

<u>Arroyo Simi Armored (BH5-B):</u> The active low flow channel is located along the guide vanes and rock groins at the base of the hardened right bank. The debris racks impose some localized channel sinuosity with riffles and small pools. Debris trapped by the guide vanes indicates that the 2009/2010 peak winter flows were approximately 2m above the channel bed. Mature willows 10+m tall line the left bank in a manner similar to the downstream portion of segment BH5-A. A sandy high water alternate channel is present on in the left bank terrace. Vegetation is patchy between debris racks and boulders on the right

bank. Mature vegetation was likely cleared on the right bank during debris rack installation. Algal growth is visible on cobbles located in sun-exposed areas near the right bank.

Arroyo Simi Downstream (BH5-C): The floodplain expands in this segment as the main channel moves farther away from the reinforced levee. We continued surveying the low flow channel that was continuous from the impact segment, although based on our interpretation of aerial imagery, we suspect that there are other low flow channels in the mature riparian forest between the surveyed channel and reinforced levee. This segment contains mature willows on both banks near the edge of the low flow channel. Few small in-channel bars of sand and fine gravel are present. The high-water channel with a sandy bed surface continues from the impact segment on the left bank terrace. A large patch of cattail occupies the channel in the downstream portion of the segment, and a fallen tree across the channel prevented long profile surveying to continue to the farther downstream end.

Overall assessment: There were no trends consistent with our expected channel response to bank hardening. We observed more complex instream features in the impact segment than in the upstream segment due to localized sinuosity imposed by the guide vanes. Proximity to the hardened bank in the impact segment limits shading of the channel and temperature regulation. Floodplain complexity on the right bank terrace is greater in the upstream and downstream segmentes because the channel is farther away from the hardened levee.

Figure B-5. Arroyo Simi

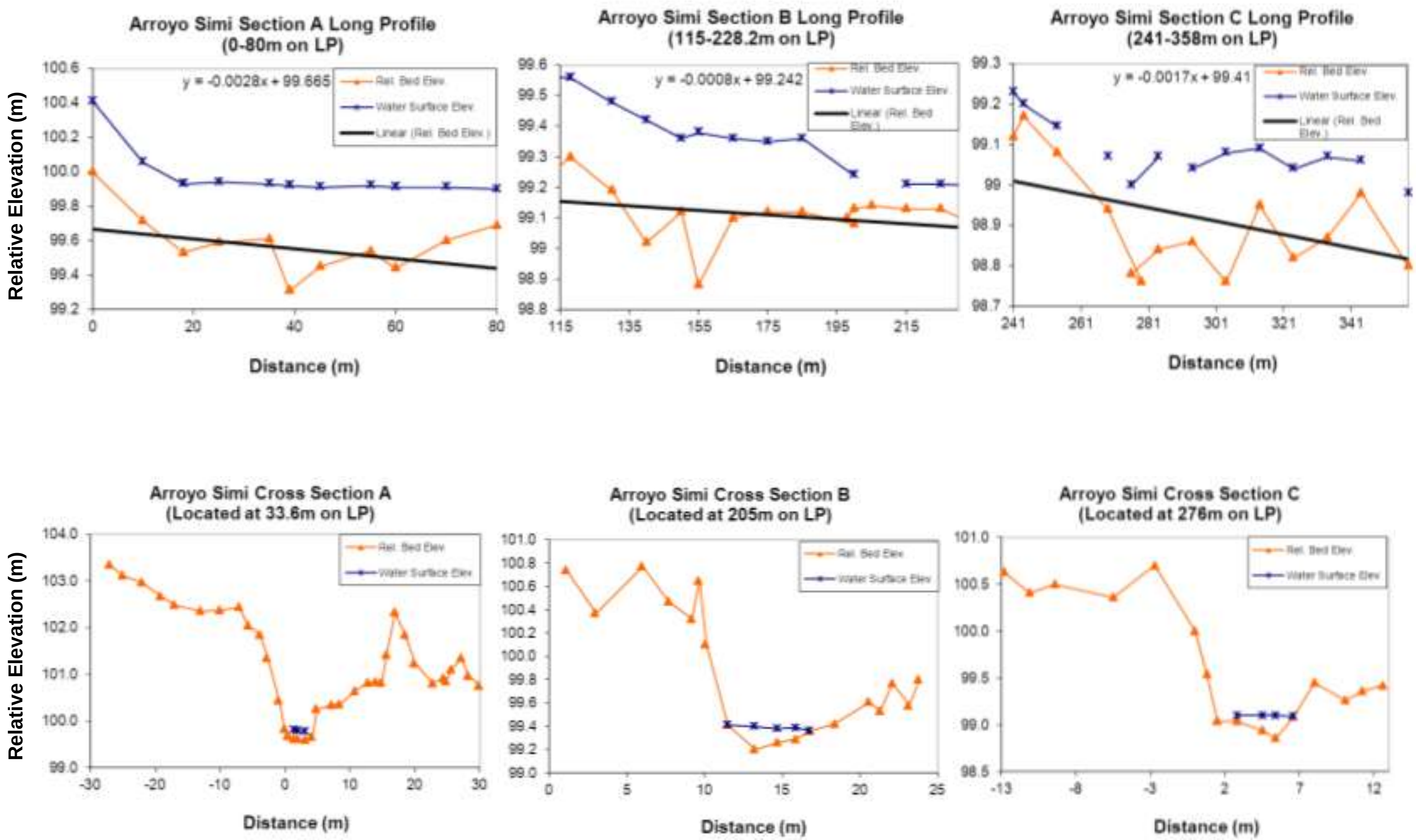


Figure B-5. Continued

Conejo Creek (BH6)

This study area is within a wide, low gradient, agricultural valley. The stream has been confined to a 30-38m wide channel between two levees (~4-5m high), and it is cut off from its natural floodplain and has consequently incised. The channel abuts a hillside to the east (left bank), and extensive agricultural fields on the west (right bank) with a dirt road present on top of both levees. Based on our interpretation of the valley form, we suspect that Conejo Creek was likely moved and channelized to this location to accommodate adjacent agricultural development.

The entire channel within this study area has a sand bed, with the exception of a cobble and broken concrete riffle located immediately upstream of the impact segment (BH6-B) where the low flow channel makes an abrupt turn from the left bank to the right bank. In the impact segment, the right bank of the channel was hardened with a concrete/rock mixture along the outside curve likely to protect the levee against the agricultural fields. No pebble counts were conducted due to the dominance of sandy bed material. Low slopes are present throughout, ranging between 0.44% and 0.07%. Through most of the study segment, there is a single active channel which alternates along the bottom of the banks, with a secondary channel running parallel along the base of the opposite bank and separated by a mid-channel bar with established vegetation (cattails, willows, and mature trees). The single active channel runs along the left bank in the upstream segment (BH6-A) and along the right bank in the impact and downstream study segmentes (BH6-B and BH6-C). Vegetation is present on all channel banks except for the hardened bank in the impact segment, although during the field survey we were informed that in-channel herbicide spraying was planned later in the week for "weed clearance."

<u>Conejo Creek Upstream (BH6-A)</u>: The active channel is separated from the alternate channel in this segment by a large, vegetated sandbar. Some water is present in the alternate channel's pools due to seepage through the sand bed substrate, although no water is flowing in the alternate channel. Bed material in the low flow channel is primarily sand, while the bed material in the alternate channel is sand with a layer of silt. Aquatic vegetation is present on the water, and common riparian vegetation such as willows and cattail are present on the sandbar and both channel banks.

<u>Conejo Creek Armored (BH6-B):</u> After passing over the aforementioned riffle, the active low flow channel runs along the base of the hardened right bank. Exposed roots of mature trees on the large sandbar and undercutting of the hardened bank throughout the entire segment (up to 1m deep) are evidence of channel incision. Lack of vegetation on right bank leaves the channel exposed to sun mid-day and afternoon, potentially leading to warmer water temperatures. Fish were observed utilizing undercut portions of the concrete/rock bank as cover. The channel bed consists of a relatively uniform sand bed with a single deep pool located at approximately 210m on the long profile. High water marks in mature willow trees ~2-3m above the channel bed are evidence of recent high flows.

<u>Conejo Creek Downstream (BH6-C)</u>: The single low flow channel divides into two channels around a large vegetated sandbar, although the alternate channel along the left bank contains very little water. Several concrete pieces in the channel, likely broken off from the undercut portion of the upstream

hardened bank, have created scour pools. Sandbar vegetation is dense and aquatic vegetation is present, similar to the upstream segment (BH6-A).

<u>Overall assessment</u>: The hardened bank in segment BH6-B prevents vegetative growth on the right bank, greatly increasing sun exposure to the active channel. Other than the presence of concrete located in the downstream segment, which provides some channel bed complexity, the hardened bank seems to have little geomorphic impact on the downstream segment during low-flow conditions, particularly because the channel has incised below the depth of the hardened bank structure throughout most of the segment. During high flows, the hardened bank structure directs flows away from the agricultural fields, preventing the channel from migrating across its natural floodplain. The hardened bank primarily acts to reinforce the channel constriction created by the levees that confine the channel.

Results generated from peak flood and flood frequency analysisfor all sites are presented in Figure B-7. Hydrologic record analysis results for all sites are summarized in Table B-1. Peak flows in the winter of 2010 were approximately equivalent to the 1.1 – 2 year flood discharge based on the flood frequency analysis.

Figure B-6. Conejo Creek

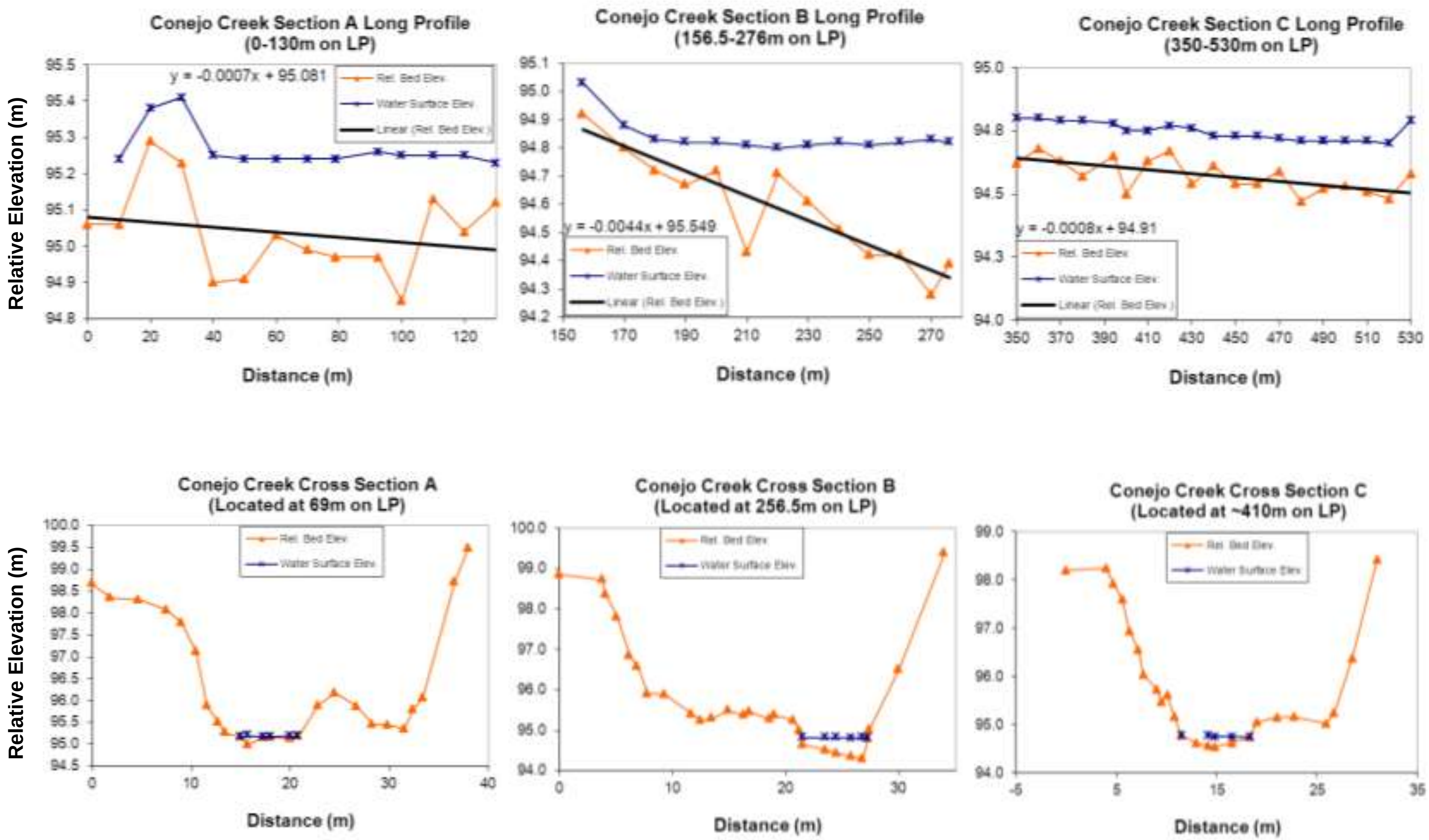


Figure B-6. Continued

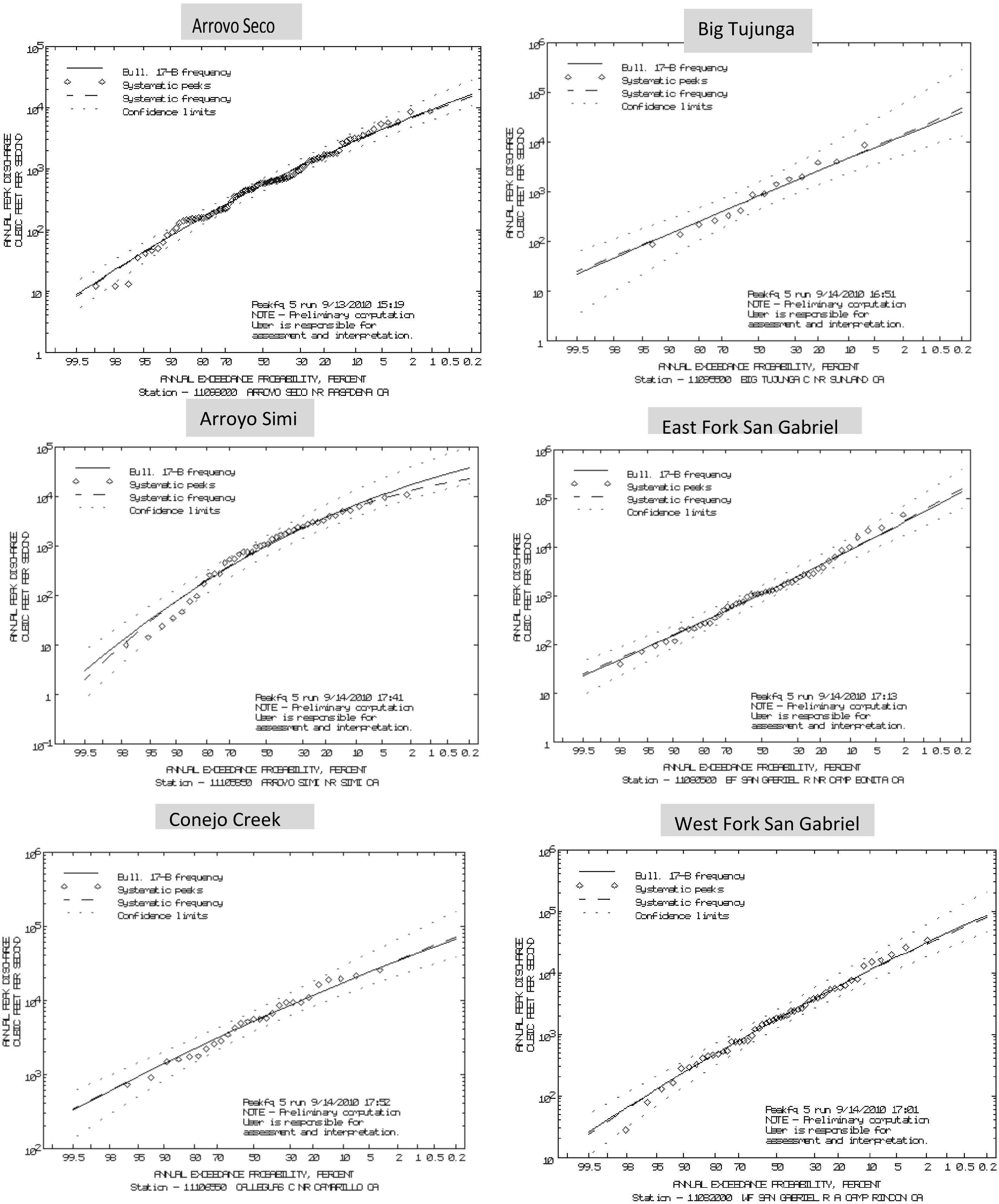


Figure B-7 – Flood frequency curves for all study sites

Table B-1. Hydrologic Record Analysis. Table displays average annual precipitation from 1900-1960, the 10 year flood discharge (Q10) based on data available from USGS gauge records, the calibrated 10 year flood discharge based on the drainage area of our study sites, the 2010 water year peak flow (where available), the peak flow of record, and information about the gauge where data was recorded.

Site	Drainage Area (mi2) Upstream of Site	Average Annual Precipitation (in) from 1900-1960	Gauge Systematic Record Q10 (cfs)	Calibrated Q10 (cfs) based on site drainage area	WY 2010 peak (cfs)	Peak flow of Record (cfs)
BH1 Big Tajunga	115	22.5	4,719.00	5,119.67	-	8,600 (1922)
BH2 San Gabriel - West Fork	83	35	10,860.00	8,667.12	-	34,000 (1938)
BH3 San Gabriel - East Fork	79	27.5	8,801.00	8,218.43	-	46,000 (1938)
BH4 Arroyo Seco	19	22.5	2,815.00	3,342.81	455 (02-06-10, .6 exceedance probability = ~Q2) (P)	8,620 (1938)
BH5 Arroyo Simi	83	13	6,243.00	7,339.50	-	10,700 (1983)
BH6 Conejo	76	11	17,380.00	5,326.13	1790 (01-20-10, .85 exceedance probability = ~Q1.1) (P)	25,300 (1980)

Appendix C: Benthic Invertebrate and Algal Taxa found at Study Sites

Table C-1. Diatom taxa found at the sampling sites and assigned attributes relating to motility and growth form.

Diatom Taxon	Motility	GrowthForm
Achnanthes coarctata (Brébisson ex W. Smith) Grunow in Cleve & Grunow 1880	non motile	stalked
Achnanthidium affine (Grunow) Czarnecki 1994	non motile	stalked
Achnanthidium deflexum (C.W. Reimer) J.C. Kingston 2000	non motile	stalked
Achnanthidium exiguum (Grunow) Czarnecki 1994	non motile	stalked
Achnanthidium jackii Rabenhorst 1861	non motile	stalked
Achnanthidium minutissimum (Kützing) Czarnecki 1994	non motile	stalked
Achnanthidium spp.	non motile	stalked
Amphora holsatica Hustedt 1930	moderately motile	prostrate
Amphora ovalis (Kützing) Kützing 1844	moderately motile	prostrate
Amphora perpusilla (Grunow in Van Heurck) Grunow in Van Heurck 1882-1885	moderately motile	prostrate
Amphora sp. (small) JPK	moderately motile	prostrate
Amphora spp.	moderately motile	prostrate
Asterionella formosa Hassall 1850	non motile	unattached
Aulacoseira granulata (Ehrenberg) Simonsen 1979	non motile	unattached
Bacillaria paradoxa Gmelin in Linneaeus 1788	highly motile	prostrate
Caloneis bacillum (Grunow) Cleve 1894	moderately motile	prostrate
Cocconeis disculus (Schumann) Cleve in Cleve & Jentzsch 1882	non motile	prostrate
Cocconeis pediculus Ehrenberg 1838	non motile	prostrate
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck 1885	non motile	prostrate
Craticula halophila (Grunow ex Van Heurck) Mann in Round, Crawford & Mann 1990	moderately motile	prostrate
Cyclotella meneghiniana Kützing 1844	non motile	unattached
Cyclotella ocellata Pantocsek 1902	non motile	unattached
Cymatopleura solea (Brébisson in Brébisson & Godey) W. Smith 1851	highly motile	prostrate
Cymbella hustedtii Krasske 1923	non motile	stalked
Cymbella spp.	non motile	stalked
Cymbella turgidula Grunow in Schmidt et al. 1875	non motile	stalked
Denticula kuetzingii Grunow 1862	moderately motile	prostrate
Denticula tenuis Kützing 1844	moderately motile	prostrate

Diatoma moniliforme Kutzing in litt., Kutzing 1833	non motile	unattached
Diploneis ovalis (Hilse in Rabenhorst) Cleve 1891	moderately motile	prostrate
Ellerbeckia arenaria (Moore ex Ralfs) Crawford 1988	non motile	unattached
Encyonema minutum (Hilse in Rabenhorst) Mann in Round, Crawford & Mann 1990	moderately motile	stalked
Encyonema spp.	moderately motile	stalked
Encyonopsis microcephala (Grunow) Krammer 1997	non motile	stalked
Fallacia spp.	moderately motile	prostrate
Fistulifera pelliculosa (Brebisson) Lange-Bertalot 1997	non motile	prostrate
Fragilaria capucina var. gracilis (Østrup) Hustedt 1950	non motile	unattached
Fragilaria capucina var. rumpens (Kützing) Lange-Bertalot in Krammer & Lange-Bertalot 1991	non motile	unattached
Fragilaria vaucheriae (Kützing) Petersen 1938	non motile	unattached
Geissleria decussis (Østrup) Lange-Bertalot et Metzeltin 1996	moderately motile	prostrate
Gomphoneis olivaceum (Hornemann) P. Dawson ex Ross & Sims 1978	non motile	stalked
Gomphonema affine Kützing 1844	non motile	stalked
Gomphonema kobayasii J.P. Kociolek & J.C. Kingston 1999	non motile	stalked
Gomphonema mexicanum Grunow in Van Heurck 1880	non motile	stalked
Gomphonema parvulum (Kützing) Kützing 1849	non motile	stalked
Gomphonema spp.	non motile	stalked
Hantzschia amphioxys (Ehrenberg) Grunow in Cleve & Grunow 1880	highly motile	prostrate
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski 1996	moderately motile	prostrate
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski 1996	moderately motile	prostrate
Karayevia clevei (Grunow in Cleve & Grunow) Round et Bukhtiyarova 1996	non motile	prostrate
Luticola mutica (Kützing) Mann in Round, Crawford & Mann 1990	moderately motile	prostrate
Luticola muticopsis (Van Heurck) Mann in Round, Crawford & Mann 1990	moderately motile	prostrate
Navicula arvensis Hustedt 1937	moderately motile	prostrate
Navicula cf. subminiscula JPK	moderately motile	prostrate
Navicula cf. tantula JPK	moderately motile	prostrate
Navicula gregaria Donkin 1861	moderately motile	prostrate
Navicula peregrina (Ehrenberg) Kützing 1844	moderately motile	prostrate
Navicula protracta (Grunow in Cleve & Grunow) Cleve 1894	moderately motile	prostrate
Navicula schroeteri Meister 1932	moderately motile	prostrate

Navicula sp. 200 JPK	moderately motile	prostrate
Navicula sp. 201 JPK	moderately motile	prostrate
Navicula spp.	moderately motile	prostrate
Navicula tripunctata (O.F. Müller) Bory 1827	moderately motile	prostrate
Navicula veneta Kützing 1844	moderately motile	prostrate
Navicula viridula (Kützing) Ehrenberg 1836	moderately motile	prostrate
Navicymbula pusilla (Grunow in A. Schmidt) K. Krammer 2003	moderately motile	prostrate
Nitzschia acicularis (Kützing) W. Smith 1853	highly motile	prostrate
Nitzschia amphibia Grunow 1862	highly motile	prostrate
Nitzschia cf. frustulum JPK	highly motile	prostrate
Nitzschia cf. palea JPK	highly motile	prostrate
Nitzschia communis Rabenhorst 1860	highly motile	prostrate
Nitzschia dissipata (Kützing) Grunow 1862	highly motile	prostrate
Nitzschia fonticola (Grunow) Grunow in Van Heurck 1881	highly motile	prostrate
Nitzschia inconspicua Grunow 1862	highly motile	prostrate
Nitzschia kotschii (Grunow) F.W. Mills 1934	highly motile	prostrate
Nitzschia linearis (Agardh) W. Smith 1853	highly motile	prostrate
Nitzschia microcephala Grunow 1880	highly motile	prostrate
Nitzschia palea (Kützing) W. Smith 1856	highly motile	prostrate
Nitzschia sinuata var. tabellaria (Grunow) Grunow in Van Heurck 1881	highly motile	prostrate
Nitzschia spp.	highly motile	prostrate
Planothidium delicatulum (Kützing) Round et Bukhtiyarova 1996	non motile	prostrate
Planothidium lanceolatum (Brébisson) Round et Bukhtiyarova 1996	non motile	prostrate
Planothidium lanceolatum var. omissum (C.W. Reimer) N.A. Andresen, E.F. Stoermer, & R.G. Kreis, Jr. 2000	non motile	prostrate
Pleurosira laevis (Ehrenberg) Compère 1982	non motile	unattached
Puncticulata bodanica (Grunow in Schneider) Håkansson 2002	non motile	unattached
Reimeria sinuata (Gregory) Kociolek & Stoermer 1987	non motile	prostrate
Rhoicosphenia abbreviata (C. Agardh) Lange-Bertalot 1980	non motile	stalked
Rhoicosphenia sp. 1 (coarse) JPK	non motile	stalked
Sellaphora bacillum (Ehrenberg) D.G. Mann 1989	moderately motile	prostrate
Sellaphora pupula (Kützing) Mereschkowsky 1902	moderately motile	prostrate

Staurosira construens Ehrenberg 1843	non motile	stalked
Staurosira elliptica (Schumann) Williams & Round 1987	non motile	stalked
Stephanodiscus hantzschii Grunow in Cleve & Grunow 1880	non motile	unattached
Surirella angusta Kützing 1844	highly motile	prostrate
Surirella ovalis Brébisson 1838	highly motile	prostrate
Synedra ulna (Nitzsch) Ehrenberg 1832	non motile	erect
Tabularia fasciculata (Agardh) Williams & Round 1986	non motile	unattached
Tryblionella hungarica (Grunow) Mann in Round, Crawford & Mann 1990	highly motile	prostrate

Table C-2. Soft-bodied algal taxa found at the sampling sites and assigned attributes relating to tolerance of sedimentation and preferred flow regime.

Soft-Bodied Algal Taxon	Sedimentation Tolerance	Preferred Flow Regime
Anabaena sp. 1	tolerant	low
Aphanothece minutissima (W.West) Komárková-Legnerová et Cronberg	tolerant	low
Calothrix epiphytica W.West et G.S.West	intolerant	median to low
Calothrix fusca (Kütz.) Bornet et Flahault	intolerant	median to low
Calothrix sp. 2	intolerant	median to low
Chamaesiphon polymorphus Geitler	intolerant	median to low
Chantransia sp. 1	intolerant	median
Chlamydomonas globosa J. Snow	tolerant	low
Chlamydomonas reinhardtii	tolerant	low
Chlamydomonas sp. 1	tolerant	low
Chlorella sp. 1	tolerant	low
Chlorogloea aff. novacekii	intolerant	median to low
Chroococcopsis epiphytica Geitler	intolerant	median to low
Chroococcopsis fluviatilis (Lagerh.) Komárek et Anagn.	intolerant	median to low
Cladophora glomerata (L.) Kütz.	intolerant	median to low
Clastidium rivulare (Hansg.) Hansg.	intolerant	median to low
Clastidium setigerum Kirchner	intolerant	median to low
Cosmarium subtumidum var. minutum (Krieg.) Krieg. et Gerloff	tolerant	low
Crucigeniella apiculata	tolerant	low
Cryptomonas erosa Ehrenb.	tolerant	low
Gloeocystis vesiculosa Nägeli	intolerant	low
Gongrosira sp. 1	intolerant	median to low
Gongrosira sp. 2	intolerant	median to low
Green coccoid 3	intolerant	median to low
Green coccoid 7	intolerant	median to low
Green filaments (3 cells)	intolerant	median to low
Heteroleibleinia kossinskajae (Elenkin) Anagn. et Komárek	intolerant	median to low

Homeothrix crustaceae	intolerant	median to low
Komvophoron constrictum (Szafer) Anagnostidis & Komárek	tolerant	median to low
Komvophoron minutum (Skuja) Anagn. et Komárek	tolerant	median to low
Leptolyngbya foveolara (Mont. ex Gomont) Anagn. et Komárek	intolerant	median to low
Leptolyngbya tenuis (Gomont) Anagn. et Komárek	intolerant	median to low
Merismopedia glauca (Ehrenb.) Kütz.	tolerant	low
Merismopedia punctata Meyen	tolerant	low
Monoraphidium arcuatum (Korshikov) Hindák	tolerant	low
Monoraphidium contortum (Thuret) Komàrková-Legnerová	tolerant	low
Oedogonium sp. 1	intolerant	median to low
Oocystis lacustris Chodat	tolerant	low
Pediastrum integrum Nägeli	tolerant	low
Phormidium ambiguum Gomont ex Gomont	intolerant	median to low
Phormidium chalybeum (Mert. ex Gomont) Anagn. et Komárek	tolerant	median to low
Phormidium sp. 2	intolerant	median to low
Scenedesmus abundans (Kirchn.) Chodat	tolerant	low
Scenedesmus aculeolatus Reinsch	tolerant	low
Scenedesmus aff. brevispina	tolerant	low
Scenedesmus bicaudatus (Hansgirg) Chodat	tolerant	low
Scenedesmus circumfusus Hortobágyi	tolerant	low
Scenedesmus ellipticus Corda	tolerant	low
Scenedesmus flavescens Chodat	tolerant	low
Scenedesmus microspina Chodat	tolerant	low
Scenedesmus opoliensis var. contacta	tolerant	low
Scenedesmus opoliensis var. mononensis	tolerant	low
Scenedesmus semipulcher Hortobágyi	tolerant	low
Spirulina major Kütz.	tolerant	low
Stigeoclonium sp. 1	intolerant	median to low
Trachelomonas hispida (Perty) F.Stein	tolerant	low
Vaucheria sp. 1	tolerant	median to low
Xenococcus minimus Geitler	intolerant	median to low

Table C-3. Benthic macroinvertebrate taxa found at the sampling sites and assigned attributes relating to pollution tolerance and functional feeding group (FFG). Note: P = predator, CG = collector gatherer, CF = collector filterer, SC = scraper, SH = shredder, MH = macrophyte herbivore, PH = piercer herbivore, OM = omnivore.

Benthic Macroinvertebrate Taxon	Life Stage	Tolerance Value	FFG
Arthropoda			
Hexapoda			
Insecta			
Coleoptera			
Dytiscidae			
Stictotarsus sp.	Larvae	5	P
Elmidae			
Narpus sp.	Adults	4	CG
Optioservus sp.	Adults	4	SC
Zaitzevia sp.	Adults	4	SC
Ordobrevia nubifera	Adults	4	SC
Narpus sp.	Larvae	4	CG
Optioservus sp.	Larvae	4	SC
Zaitzevia sp.	Larvae	4	SC
Ordobrevia nubifera	Larvae	4	SC
Ordobrevia nubifera	Larvae	4	SC
Hydrophilidae	Larvae	5	P
Psephenidae			
Eubrianax edwardsii	Larvae	4	SC
Psephenus falli	Larvae	4	SC
Diptera			
Ceratopogonidae			
Bezzia/ Palpomyia	Larvae	6	P
Atrichopogon sp.	Larvae	6	CG
Dasyhelea sp.	Larvae	6	CG
Ceratopogonidae	Pupae	6	P
Ceratopogonidae	Pupae	6	P
Chironomidae			
Chironominae	Larvae	6	CG
Chironomini	Larvae	6	CG
Apedilum sp.	Larvae	6	CG
Chironomus sp.	Larvae	10	CG
Cryptochironomus sp.	Larvae	8	P
Cryptochironomus sp.	Larvae	8	P
Dicrotendipes sp.	Larvae	8	CG

Paracladopelma sp.	Larvae	7	CG
Phaenopsectra sp.	Larvae	7	SC
Polypedilum sp.	Larvae	6	OM
Microtendipes pedellus group	Larvae	6	CF
Microtendipes rydalensis group	Larvae	6	CF
Cryptochironomus sp.	Pupae	8	P
Pseudochironomini			
Pseudochironomus sp.	Larvae	5	CG
Tanytarsini			
Cladotanytarsus sp.	Larvae	7	CG
Micropsectra sp.	Larvae	7	CG
Micropsectra sp.	Larvae	7	CG
Rheotanytarsus sp.	Larvae	6	CF
Rheotanytarsus sp.	Larvae	6	CF
Stempellinella sp.	Larvae	4	CF
Tanytarsus sp.	Larvae	6	CF
Micropsectra sp.	Pupae	7	CG
Rheotanytarsus sp.	Pupae	6	CF
Orthocladiinae			
Orthocladius complex	Larvae	6	CG
Brillia sp.	Larvae	5	SH
Cardiocladius sp.	Larvae	5	P
Cricotopus sp.	Larvae	7	CG
Cricotopus sp.	Larvae	7	CG
Eukiefferiella sp.	Larvae	8	OM
Eukiefferiella sp.	Larvae	8	OM
Euryhapsis sp.	Larvae	5	CG
Heterotrissocladius sp.	Larvae	0	CG
Krenosmittia sp.	Larvae	1	CG
Krenosmittia sp.	Larvae	1	CG
Limnophyes sp.	Larvae	8	CG
Parametriocnemus sp.	Larvae	5	CG
Parametriocnemus sp.	Larvae	5	CG
Rheocricotopus sp.	Larvae	6	OM
Synorthocladius sp.	Larvae	2	CG
Cricotopus bicinctus group	Larvae	7	CG
Cricotopus trifascia group	Larvae	7	CG
Cricotopus sp.	Pupae	7	CG
Eukiefferiella sp.	Pupae	8	OM
Krenosmittia sp.	Pupae	1	CG
Parametriocnemus sp.	Pupae	5	CG
Corynoneurini			
Corynoneura sp.	Larvae	7	CG

Thienemanniella sp.	Larvae	6	CG
Tanypodinae			
Pentaneurini			
Thienemannimyia group	Larvae	6	P
Zavrelimyia/ Paramerina	Larvae	7	P
Ablabesmyia sp.	Larvae	8	CG
Labrundinia sp.	Larvae	6	P
Pentaneura sp.	Larvae	6	P
Procladiini			
Procladius sp.	Larvae	9	P
Dolichopodidae	Larvae	4	P
Empididae			
Chelifera/ Metachela	Larvae	6	P
Hemerodromia sp.	Larvae	6	P
Neoplasta sp.	Larvae	6	P
Wiedemannia sp.	Larvae	6	P
Muscidae	Larvae	6	P
Psychodidae			
Pericoma/ Telmatoscopus	Larvae	4	CG
Sciomyzidae	Larvae	6	P
Simuliidae			
Simulium sp.	Larvae	6	CF
Simulium sp.	Larvae	6	CF
Simulium sp.	Pupae	6	CF
Stratiomyidae			
Caloparyphus/ Euparyphus	Larvae	8	CG
Euparyphus sp.	Larvae	8	CG
Nemotelus sp.	Larvae	8	CG
Tipulidae	Larvae	3	SH
Tipula sp.	Larvae	4	OM
Ephemeroptera			
Ameletidae			
Ameletus sp.	Larvae	0	CG
Baetidae			
Baetis sp.	Larvae	5	CG
Callibaetis sp.	Larvae	9	CG
Centroptilum sp.	Larvae	2	CG
Baetis adonis	Larvae	5	CG
Baetis tricaudatus	Larvae	6	CG
Diphetor hageni	Larvae	5	CG
Fallceon quilleri	Larvae	4	CG
Caenidae			
Caenis bajaensis	Larvae	7	CG

Ephemerellidae	Larvae	1	CG
Drunella coloradensis	Larvae	0	P
Ephemerella maculata	Larvae	1	CG
Serratella micheneri	Larvae	1	CG
Heptageniidae	Larvae	4	SC
Ecdyonurus sp.	Larvae	--	--
Epeorus sp.	Larvae	0	SC
Leptohyphidae			
Tricorythodes sp.	Larvae	4	CG
Hemiptera			
Corixidae	Larvae	8	P
Corixidae	Larvae	8	P
Corisella sp.	Larvae	8	P
Trichocorixa sp.	Larvae	8	P
Odonata			
Coenagrionidae			
Argia sp.	--	--	--
Argia sp.	Larvae	7	P
Gomphidae			
Progomphus borealis	Larvae	4	P
Libellulidae	Larvae	9	P
Paltothemis lineatipes	Larvae	9	P
Plecoptera			
Capniidae	Larvae	1	SH
Chloroperlidae			
Haploperla chilnualna	Larvae	1	P
Perlidae			
Calineuria californica	Larvae	2	P
Trichoptera			
Brachycentridae			
Micrasema sp.	Larvae	1	MH
Glossosomatidae			
Glossosoma sp.	Larvae	1	SC
Glossosoma sp.	Pupae	1	SC
Helicopsychidae			
Helicopsyche sp.	Larvae	3	SC
Helicopsyche sp.	Pupae	3	SC
Hydropsychidae	Larvae	4	CF
Cheumatopsyche sp.	Larvae	5	CF
Hydropsyche sp.	Larvae	4	CF
Hydroptilidae			
Hydroptila sp.	Larvae	6	PH
Hydroptila sp.	Larvae	6	PH

Neotrichia sp.	Larvae	4	SC
Ochrotrichia sp.	Larvae	4	PH
Hydroptila sp.	Pupae	6	PH
Lepidostomatidae			
Lepidostoma sp.	Larvae	1	SH
Lepidostoma sp.	Pupae	1	SH
Philopotamidae			
Wormaldia sp.	Larvae	3	CF
Psychomyiidae			
Tinodes sp.	Larvae	2	SC
Sericostomatidae			
Gumaga sp.	Larvae	3	SH
Gumaga sp.	Larvae	3	SH
Gumaga sp.	Pupae	3	SH
Crustacea			
Malacostraca			
Amphipoda			
Hyalellidae			
Hyalella sp.	--	8	CG
Ostracoda	--	8	CG
Chelicerata			
Arachnida			
Trombidiformes			
Hydryphantidae			
Protzia sp.	--	8	P
Hygrobatidae			
Atractides sp.	--	8	P
Lebertiidae			
Lebertia sp.	--	8	P
Sperchontidae			
Sperchon sp.	--	8	P
Torrenticolidae			
Testudacarus sp.	--	5	P
Torrenticola sp.	--	5	P
Annelida			
Clitellata			
Hirudinea			
Arhynchobdellida			
Erpobdellidae	--	8	P
Oligochaeta	--	5	CG
Mollusca			
Bivalvia			
Veneroida			

Corbiculidae			
Corbicula sp.	--	8	CF
Sphaeriidae	--	8	CF
Gastropoda			
Basommatophora			
Ancylidae			
Ferrissia sp.	--	6	SC
Lymnaeidae			
Lymnaea sp.	--	7	SC
Physidae			
Physa sp.	--	8	SC
Hypsogastropoda			
Hydrobiidae	--	8	SC
Nemertea			
Enopla			
Hoplonemertea			
Tetrastemmatidae			
Prostoma sp.	--	8	P
Platyhelminthes			
Turbellaria	--	4	P

Appendix D: Selected Photographs of Evaluated Restoration Sites

Dry Canyon Creek

Dry Canyon Creek is located in the Santa Monica Mountains in western Los Angeles County. The restoration project area is in the City of Calabasas, California next to the administrative office of Mountains Restoration Trust (MRT). The main stem of the creek flows perennially, and runs through mostly private property. Prior to restoration, the reach had a concrete bottom, with a stone wall stabilizing part of the bank. The channel was a steep-sided trapezoidal shape, with portions that were rectangular. The channel was also filled with foreign materials such as cement and metal debris.

In 2007, the concrete lining, rock retaining wall, and extra cement and metal debris were removed from the channel. Banks were pulled back to a more natural grade and height. Floodplain benches were restored to provide more area for riparian habitat and improve floodplain connectivity. A corrugated metal culvert was also removed and replaced with a free-span bridge crossing the channel. Also, a guy-wired bridge downstream of the MRT Administrative Area with piers that stood in the channel was removed and replaced with a wooden footbridge with piers wholly outside of channel. Exotic plant species were removed, and native species planted.

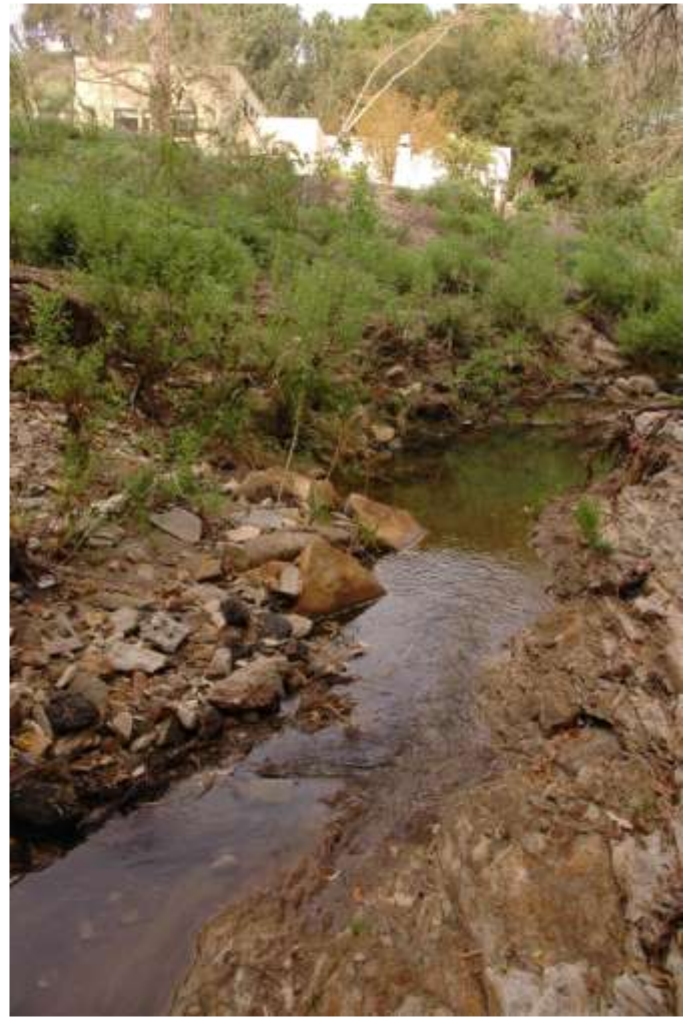
Dry Canyon Creek pre-restoration 2005, bridge with piers in channel, photo from MRT

Dry Canyon Creek pre-restoration 2005, photo from MRT

Dry Canyon Creek 2008, wooden footbridge after restoration, photo by Jessica Hall

Dry Canyon Creek pre-restoration 2005, stone wall, photo from MRT

Dry Canyon Creek pre-restoration 2005, photo from MRT


Dry Canyon Creek 2008, after restoration, photo by Jessica Hall


Dry Canyon Creek 2010


Dry Canyon Creek 2010

The reference reach for the Dry Canyon Creek restoration is located on Cold Creek near the intersection of Stunt Road and Cold Creek Road in Calabasas, CA.


Cold Creek reference 2010


Cold Creek reference 2010

The channelized reach matched to the Dry Canyon Creek restoration is located by Mulholland Drive and Avenue San Luis in Calabasas, CA.


Ave. San Luis reach 2010

Medea Creek

Medea Creek is a perennially flowing stream that runs through Simi Valley, CA (Ventura County) and Agoura Hills, CA (Los Angeles County). The restored reach is located in Agoura Hills along Shadycreek Drive between 1600 ft south of the Laro Drive bridge crossing and 740 ft north of the Fountainwood Street bridge crossing. In 1982 the site was illegally channelized into a storm drain culvert by Morrison Entity, a housing developer. Subsequently, the removal of the trapezoidal concrete channel and restoration to more natural conditions was mandated. No pre-restoration photos could be obtained for this area.

Project construction took place in 1993 or 1994. Gunite lining was removed, and the streambed was excavated and graded to restore it to a more natural condition. A low flow channel, two reinforced structures, and ungrouted rip rap were strategically installed for flood protection. Several native species of plants were re-established along the project length.

Medea Creek circa 1994, before vegetation plantings


Medea Creek 2010


Medea Creek 2010

Medea Creek 2010 grassbelt. View is facing north with the stream to the west (left) of the frame.

Medea Creek 2010, rip rap bank stabilization

The reference reach for Medea Creek restoration is located on Medea Creek next to Cornell Road, just south of Sideway Road, Agoura Hills, CA.


Cornell reference 2010


Cornell reference 2010

The channelized reach matched to the Medea Creek restoration is located by Twin Oaks Shopping Center where Medea Creek crosses under Kanan Road, Agoura Hills, CA.

Twin Oaks Shopping Center reach 2010

Las Virgenes Creek South

Las Virgenes Creek is located in west-central Los Angeles County. The City of Agoura Hills is to the east of it, and the City of Calabasas to the west. The southern restored site exists within the City of Calabasas, and is located on eastern side of Lost Hills Road between Meadow Creek Lane and Cold Spring Street. Prior to restoration, it was only noted that the creek bottom had dense vegetation cover but banks had little vegetation. No photos of the site prior to restoration could be acquired.

Around 1997, sandy-gravel fill was removed from the channel, and the bank was recontoured and stabilized. Native riparian vegetation was replanted along the slopes.


Las Virgenes South 2010


Las Virgenes South 2010


Las Virgenes South 2010


Las Virgenes South 2010


Las Virgenes South 2010


Las Virgenes South 2010

The reference reach for Las Virgenes Creek South restoration is located on Medea Creek at Paramount Ranch, Agoura Hills, CA.

Paramount Ranch reference 2010

The channelized reach matched to the Las Virgenes Creek South restoration is located by El Encanto Drive and Lost Hills Road in Calabasas, CA


El Encanto 2010


El Encanto 2010

Las Virgenes Creek North

The restored site at the north end of the creek exists within the City of Calabasas. It is between approximately 500 feet south where U.S. Highway 101 crosses the creek west of the Las Virgenes Road junction and ends at the Agoura Road Bridge. Prior to restoration, the channel was trapezoidal and concrete lined.

In 2007, concrete was removed from the bottom of the reach. Retaining walls were constructed for flood protection, and boulders and rock weirs were installed for erosion protection and channel stability. The area was planted with an assemblage of flora native to Southern California. A concrete path, wooden gazebo, observation deck, and educational boards were constructed for public access and education.


Las Virgenes North 2004, pre-construction


Las Virgenes Creek North, pre-construction

Las Virgenes North during construction (photo by Alex Farrassati)

Las Virgenes North 2007, post-construction (photo by Alex Farrassati)


Las Virgenes North 2010


Las Virgenes North 2010, walkway and gazebo


Las Virgenes North 2010


Las Virgenes North 2010

Las Virgenes North, beneathAgoura Road Bridge pre-construction

Las Virgenes North 2010, beneath Agoura Road Bridge post-construction

The reference reach for Las Virgenes Creek North restoration is located on Las Virgenes Creek approximately 300 feet south of Mullholand Highway near Las Virgenes Road in the Santa Monica Mountain Recreation Area, Calabasas , CA.


Santa Monica Mountain Recreation Area 2010


Santa Monica Mountain Recreation Area 2010

The channelized reach matched to the Las Virgenes Creek North restoration is located on Las Virgenes Creek just north of Interstate 101 in Calabasas, CA.

North of 101 Freeway 2010

North of 101 Freeway 2010

Las Flores Creek

Las Flores Creek is located in Las Flores Canyon in Malibu, CA. The creek is next to Las Flores Creek Park in a steep, rocky channel, and discharges directly into the Pacific Ocean approximately 150 feet down stream after flowing under the Pacific Coast Highway. This creek is the only intermittently flowing stream used in our study, and was dry at the time these photos were taken.

Restoration was completed in October 2008. Grouted riprap banks, a failing concrete foundation wall, a grouted rock weir structure and a concrete V-ditch weir were removed. Structures including riprap and grouted rock were left in place or installed so to not aggravate historic landslide or steep slopes, and to protect private property. A weir/step pool complex was constructed to arrest down-cutting and stream incision. The floodplain and bank were enhanced by cutting back new slopes from existing slopes. Exotic plant species were removed, and the area revegetated with native species.


Las Flores Creek 2010


Las Flores Creek 2010


Las Flores Creek 2010