*FINAL REPORT*

# Development and Implementation of Hydromodification Control Methodology

## Watershed Characterization Part 2: Watershed Management Zones and Receiving-Water Conditions

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Frontispiece: View north over the mountainous landscape of the southern Central Coast Region.

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# 1 INTRODUCTION

To date, products of the Central Coast Joint Effort for Hydromodification Control have included literature and data summaries (Task 1) and a preliminary, GIS-based characterization of the landscape and watersheds of the Central Coast Region (Task 2). Task 3 (originally titled "Receiving Water Classification") of the Joint Effort, the subject of this report, has three primary objectives:

1. Identify the set of "key watershed processes" that are likely to influence the condition of receiving waters and that are susceptible to the effects of human activity on the landscape;
2. Characterize the basic attributes of the "landscape zones" defined in Task 2 of this project (based on assigned categories of geology, topographic slope, and land cover), refining their definition and boundaries as needed to provide a useful and scientifically defensible stratification of the Central Coast Region from the perspective of key watershed processes; and
3. Use (and augment, as needed) the existing information on receiving waters compiled in Task 1 to identify a subset of water bodies that spans the range of geographic settings across the Region and has sufficient data to assess relationships between landscape zones, watershed processes, human disturbance, and receiving-water condition (this assessment will occur in Task 4).

These objectives have been pursued through a variety of methods, described in detail within each individual section of this report. Although all have a foundation in either data specific to the Central Coast or to scientific understanding of watershed processes, the primary effort of this Task comprised five weeks of field work (April–May 2011) across the entire Region, traversing every major (and many secondary) roads to make visual observations of the expression of watershed processes, both disturbed and undisturbed, within every landscape zone delineated in Task 2. Over 100 receiving water sites (streams, rivers, wetlands, marine nearshore, lakes, and groundwater basins) were also visited during the course of this field work. The findings of this report, which constitutes the deliverable product for Task 3, therefore represent the integration of raw data compilation (Task 1) and GIS-based analysis (Task 2) with synoptic field-based observations from the Central Coast Region within a science-based framework.

Several related tasks, most importantly the analysis of the "linkage" between landscape conditions, disturbance, key watershed process, and receiving-water conditions, is reserved for Task 4. We also defer to Task 4 a critical assessment of the importance of precipitation variability across the region in determining landscape and receiving-water conditions.

The goal of the Central Coast Joint Effort is to protect or restore key watershed processes that otherwise would be (or have been) adversely affected by human activity. The Joint Effort is focused most immediately on defining hydromodification control strategies for new and redevelopment, but the results of the landscape and receiving-water characterizations in this Task (and those preceding and following it) should also provide a foundation for achieving broader natural resource objectives. Because the natural balance of watershed processes in any area is dictated by the combination of intrinsic landscape attributes, weather and climate, and disturbance, these are the primary factors being carried forward throughout the individual tasks of the Joint Effort. Understanding the interactions between these factors, each of which vary across the Region, is judged to be essential to identify and apply appropriate management strategies to protect and enhance the watersheds and receiving waters of the Central Coast.

As noted during Task 2 (*Watershed Characterization Part 1: Precipitation and Landscape*), stratifying data of the natural landscape into discrete categories is a foundational principal of large-scale watershed characterization studies. It reduces the seemingly infinite complexity of such data into tractable groupings and allows an analysis to focus on the most important influences on watershed processes. For the purposes of the Joint Effort, the term "watershed characterization" entails the full stratification and grouping of our data (from both natural and disturbed parts of the landscape) into discrete categories that are broadly understood to influence local watershed processes most directly. This report, constituting Part 2 of the Watershed Characterization, documents the methods used and the results obtained from transferring the scientific understanding and map-based analyses of Task 2 to the observed field conditions as we find them across the Central Coast Region today, and their translation into a framework of key watershed processes that constitutes the foundational approach for the Joint Effort.

# 2 WATERSHED PROCESSES

The delivery, movement, storage, and loss of water within a watershed is one set of key watershed processes, most commonly represented by the hydrologic cycle (see the Task 1 report, *Literature Review*). Components of the hydrologic cycle constitute the fundamental hydrological processes that are active in any watershed: precipitation, surface runoff, infiltration, groundwater flow, return flow, surface-water storage, groundwater storage, evaporation and transpiration. Although present virtually everywhere across a watershed, these individual processes vary greatly in their importance to watershed "health" and functions of its physical, chemical, and biological processes. Recognizing their magnitude and spatial distribution has been a long-standing effort of landscape studies, of which the Joint Effort is merely the latest. Over four decades ago, for example, England and Holtan (1969) noted: "Soil properties significant to processes of infiltration, moisture storage, drainage, and the hydraulics of surface flow are related to topographic position. Areal and elevational distributions of soils provide a basis for interpretative grouping of soil mapping units in computations for watershed engineering."

Geomorphological processes are a second set of watershed processes that strongly influence watershed health and function. They broadly refer to the movement or deposition of sediment, driven largely but not exclusively by the movement of water, that affect the land surface—in the Central Coast region, these primarily include erosion, landsliding and other mass wasting, and sediment transport and deposition in stream channels. Their magnitude and distribution across different landscapes has also been the focus of much scientific study, albeit for not nearly as long as for their hydrological counterparts. These constitute the set of most immediately "visible" watershed processes; recent investigations in and adjacent to the southern part of the Central Coast Region (Warrick and Mertes 2009, Stillwater Sciences 2010a) provide ample basis for their characterization in this landscape.

## 2.1 Methods for Identifying Watershed Processes

Our prior literature review of approaches to hydromodification control, including prior assessments of watershed processes (Task 1, *Literature Review*), includes a number of references that list the "typical" watershed processes for temperate-region parts of the planet. Additional text references (e.g., Reid and Dunne 1996, Ritter et al. 2011) modestly augment these sources. Field review and common knowledge of the region can then guide the condensation of the original list down to those watershed processes that we judge to be important in some or all of the landscape zones of the Central Coast Region.

## 2.2 Results

Table 2-1 summarizes the outcome of this (largely literature-based) assessment of potential key watershed processes:

**Table 2-1.** Summary of literature-derived watershed processes likely to be important in the Central Coast Region.

| **Predominantly *hydrologic* processes (i.e., "water")** | **Predominantly *hillslope* processes (i.e., "sediment")** |
|---|---|
| Evapotranspiration | Creep |
| Overland flow | Sheetwash |
| Surface infiltration | Rilling and gullying |
| Shallow, lateral subsurface flow ("interflow") | Other mass failures ("landsliding") |
| Deep infiltration to groundwater ("groundwater recharge") | Tributary bank erosion |
| Transport of organic matter | Chemical, biological reactions in soil |
| **Within-waterbody processes** | |
| Fluvial transport and deposition; mainstem bank erosion | |
| Biological interactions (nutrient dynamics, trophic interactions) | |
| Chemical and biological reactions of sediment- and water-borne constituents | |

Note that most of the hydrologic processes (left-hand column) can only be inferred, given the limitations of one-time observation in non-rainy conditions. However, some of these processes are virtually certain to occur to *some* extent in every part of the landscape (e.g., evapotranspiration and surface infiltration); subsequent analyses, however, might be necessary to quantify their relative or absolute magnitude. In addition, the portions of the landscape where overland flow has (and will again) occurred are typically apparent, because any significant overland flow will give rise to persistent rills and/or gullies (Figure 2-1) on all but the most non-erosive of hillsides.

**Figure 2-1.** Rilling and gullying of weak sedimentary rock along the Maricopa Highway (SR 33) providing clear evidence of active overland flow during rain events, just south of Lockwood Valley in the southeastern part of the Region (in older Tertiary sediments, >40%).

In contrast, most of the "hillslope" processes (we recognize that runoff also occurs on hillslopes but use this term to identify those processes responsible for sediment movement and delivery) typically have direct field expression even if the process is not active at the time of observation. Gullies (Figure 2-1) are one such example; mass failures (Figure 2-2) are another. Creep is generally just inferred by the absence of other expression, but it is known to be ubiquitous across nearly all landscapes and can be the dominant sediment-delivery process where other modes of sediment movement are not active (Figure 2-3).

**Figure 2-2.** Mass failure (landslide) along Bitterwater Road, east of Paso Robles in the east-central part of the Region (in Quaternary sedimentary deposits, 10–40%).

**Figure 2-3.** Hillslopes dominated by creep, as evidenced by the lack of apparent rills, gullies, or discrete mass failures. Rates of sediment delivery from this landscape are likely one to several orders of magnitude slower than from those shown in Figures 2-1 or 2-2. Site is along Pacheco Pass Highway in the Diablo Range, east of Gilroy (in Franciscan mélange, >40%).

In-channel processes are not a primary focus of this stage of the Joint Effort study, because they are largely dependent on hydrologic and hillslope processes occurring farther upslope in the watershed. We include them for completeness here, and because the consideration of receiving-water conditions will need to reference the degree to which these processes have been affected by human disturbance.

# 3 LANDSCAPE ZONES

Task 2 of the Joint Effort (*Watershed Characterization Part 1: Precipitation and Landscape*) presented the process by which the GIS-based landscape of the Central Coast Region was subdivided into twelve distinct "landscape zones," based on the various combinations of geology, hillslope gradients, and land cover found across the Region. This preliminary landscape stratification (reproduced below in Figure 3-1) provided initial discrimination of the variety of landscape conditions, but the integration of attributes into subwatershed areas covering up to 50 $mi^2$ proved to be overly homogenous to discriminate critical attributes of the landscape that vary over finer spatial scales than that of the zones (e.g., Figure 3-2). Task 3 therefore has refined the zones first identified in Task 2, mapped the distribution and described the characteristics of the final landscape categories, and identified the dominant watershed processes associated with each.

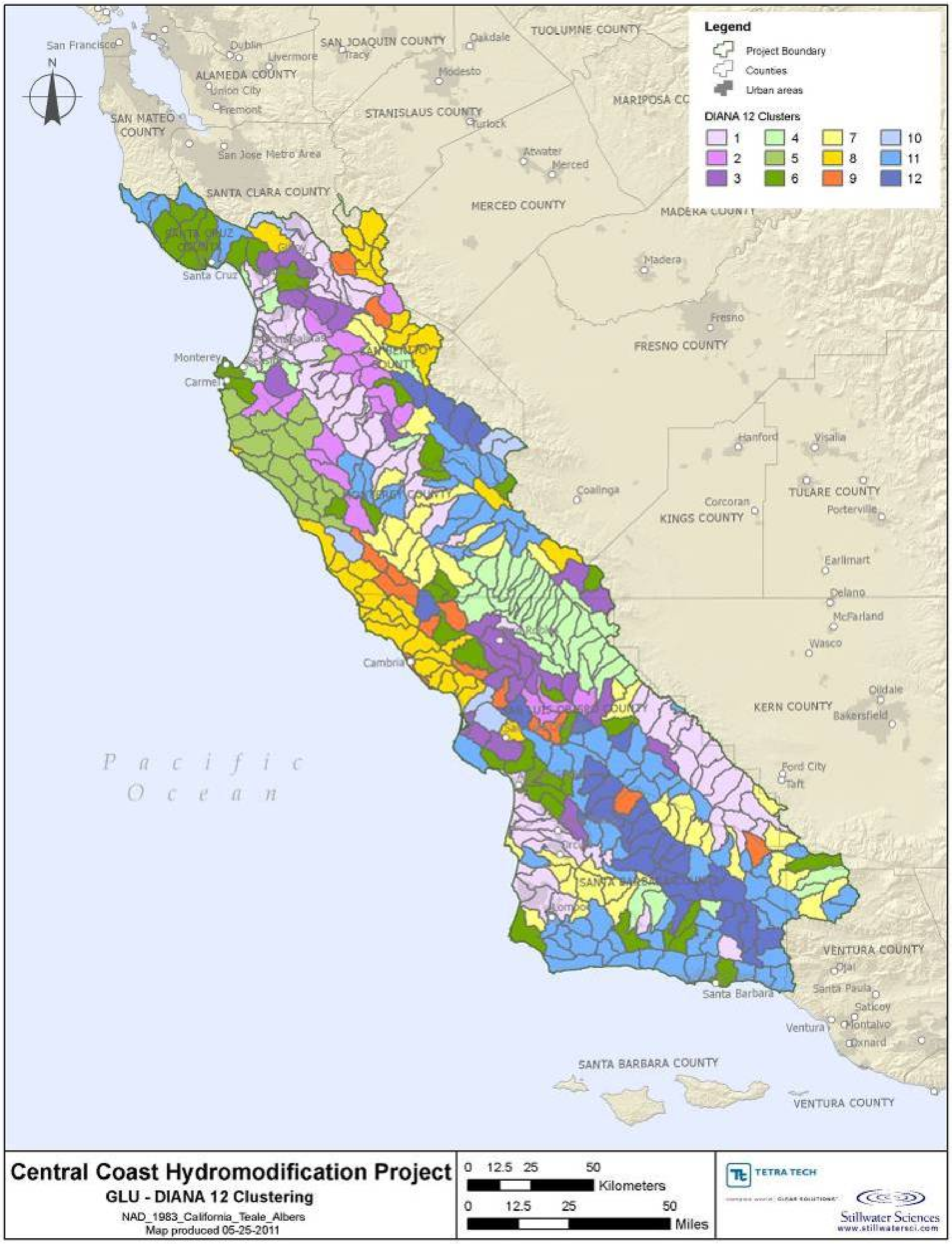


**Figure 3-1.** Initial landscape zones, identified by statistical analysis of GIS data within 406 sub-watershed areas (outlined colored polygons). The 12 "clusters" identify broadly similar areas with respect to geology, hillslope gradient, and land cover (reproduced from the Task 2 report, *Watershed Characterization Part 1: Precipitation and Landscape*; Figure 3-10).

**Figure 3-2.** View of the west side of the Carrizo Plain. This entire area is included in Cluster 1 (the light pink areas of Figure 3-1, here along the eastern edge of the Region near its south edge), but even a cursory inspection suggests that the watershed processes likely to dominate across the flat Quaternary sediments in the foreground are unlikely to correspond to those of the Tertiary mountains in the background.

## 3.1 Methods for Identifying Landscape Zones and Watershed Characteristics

### 3.1.1 GIS analyses

GIS processing for this step made direct use of the data layers compiled during Task 1 and utilized in Task 2. Only geology and topographic data were used, reflecting the technical team's decision to produce a final landscape stratification during this Task based on the "intrinsic" properties of the landscape (namely, without considering the presence of subsequent human disturbance as reflected in the land-cover data). The team also considered the use of soils data but judged that the overlap between geologic and soil data would provide little additional information relevant to this Task and needlessly complicate the analysis. The team also judged that geologic data would likely provide the most useful information on watershed processes (particularly groundwater recharge) at the scale of the entire region; some comparisons of geologic units and soil types in selected areas were made in GIS to evaluate this judgment (see below).

As with the initial landscape stratification (Figure 3-1), the data were much too "grainy" to be directly useful for a regional application. The digital geologic data from the California Geological Survey (based on Jennings et al. 1977, 1:750,000 scale) were thus aggregated into the same five lithologic units as for Task 2 (Franciscan mélange, Mesozoic metasedimentary rocks, pre-Quaternary crystalline rocks, Tertiary sedimentary rocks, and Quaternary sediment deposits). For extracting slopes, the original topographic data source (USGS/NED, 1-arc second) required "smoothing" in order to be useful, even after grouping into the three slope classes first defined in Task 2 (0–10%, 10–40%, and >40%). Both datasets where projected into NAD 1983 California Teale Albers prior to analysis. Slope-zone geoprocessing was carried out in ESRI ArcGIS 10

Platform and based on Spatial Analyst and ArcInfo supported toolboxes, supported by custom Python scripts.

The following steps were followed to create the final set of slope-based areas:

1. Class boundary filtering: used for cleaning ragged edges between slope classes, based on ‘expand and shrink’ method on the slope raster data.
2. Neighboring cell filtering: replacing cells in the slope raster based on the majority of their contiguous neighboring cells. This filtering process was based on eight neighboring cells (a 3-by-3 window) using a ‘majority’ replacement threshold (three out of four or five out of eight connected cells must have the same value before replacement occurs), and was applied 50 times.
3. Raster-to-vector conversion: the filtered slope raster was converted into polygons without polygon generalization.
4. Sliver polygon filtering: eliminating “small” polygons by merging them with the neighboring polygons with the largest area or the longest shared border. For our purposes, areas smaller than 12 hectares (0.12 square kilometers, equivalent to a square 345 m on a side) were flagged as ‘sliver polygons’ and so eliminated. This threshold was chosen on the basis of positional accuracy of the data (±125 m), the likely scale of the final map products (presumed 1:250,000), and judgment about the overall appearance and usability of alternative results using different thresholds.

Once the final set of smoothed slope polygons were defined, they were overlaid with the geology polygons to define fifteen unique “topographic–lithologic” units (i.e., 3 slope classes and 5 geology units) plus open water, exactly analogous to this stage of the analysis in Task 2. In contrast to Task 2, however, these areas were *not* then grouped into watershed areas: the natural boundaries, be they topographically or lithologically based, were retained.

### 3.1.2 Field work

In the original scoping for Task 3, field work was targeted at “selected subwatersheds” under the assumption that data collection would be overly time-consuming for the schedule and budget of this task. Early in the field campaign, however, it became apparent that near-comprehensive coverage of the Region was feasible, given excellent road access throughout most of the Region (Figure 3-3) and the ability of simple visual observations to generate the (relatively basic) information necessary for subsequent application in the Joint Effort. This judgment, however, does not extend to the assessment of receiving-water conditions (see Section 4).

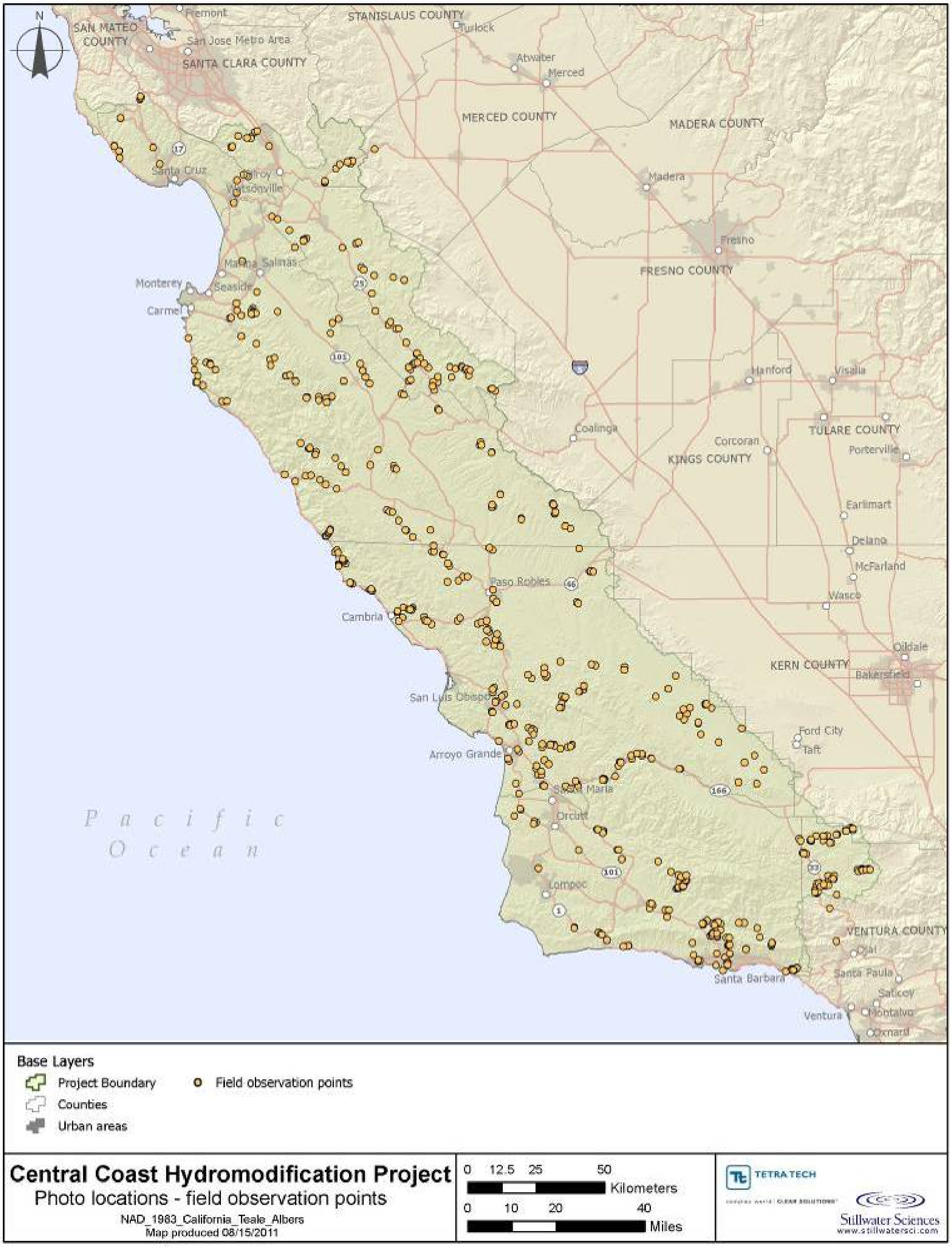


**Figure 3-3.** Observation locations (photo points) from the spring 2011 field work.

Field work was organized geographically, with teams of two geomorphologists working within a given portion of the Central Coast Region for 4- or 5-day periods. To the extent that truly "comprehensive" on-the-ground coverage would still be infeasible, the original 12-fold clustering of Task 2 (Figure 3-1) was used to ensure that every such region would be visited in multiple locations. These sites emphasized broad geographic diversity across the Region to inform future assessments, particularly whether Region-wide precipitation gradients documented in Task 2 are expressed in the *type* (as opposed to simply the magnitude) of watershed processes.

Observations generally consisted of visible indicators of specific watershed processes (or their absence, also indicative of certain processes). The degree of disturbance (human, bovine, or other) was also noted; although the emphasis in this Task is on undisturbed watershed processes, the condition of disturbed landscapes will be quite relevant to subsequent tasks of the Joint Effort. GPS-referenced photographs were taken and archived in both spatial (GoogleEarth) and tabular (MS Excel) files. They were grouped by the 15 topographic–lithologic units defined by the GIS analysis (henceforth, termed "Watershed Management Zones," or WMZ's) and used to describe the general characteristics, range of variability, and observed watershed processes in each. These observations were also used to reevaluate the initial WMZ categories and to determine whether combining multiple WMZ's with similar attributes, or conversely subdividing a mapped WMZ that nevertheless showed systematic variations, was warranted.

## 3.2 Results

### 3.2.1 GIS analysis

Geoprocessing of the slope data translated directly into the final boundaries of the initial WMZ's, and so the results of this procedure merit inclusion here. They are best illustrated by example of the changes that result from the two main steps of the procedure described above, namely the class-boundary and neighboring-cell filtering (the "raster filtering" of Figure 3-4) and the removal of small slivers ("vector filtering").

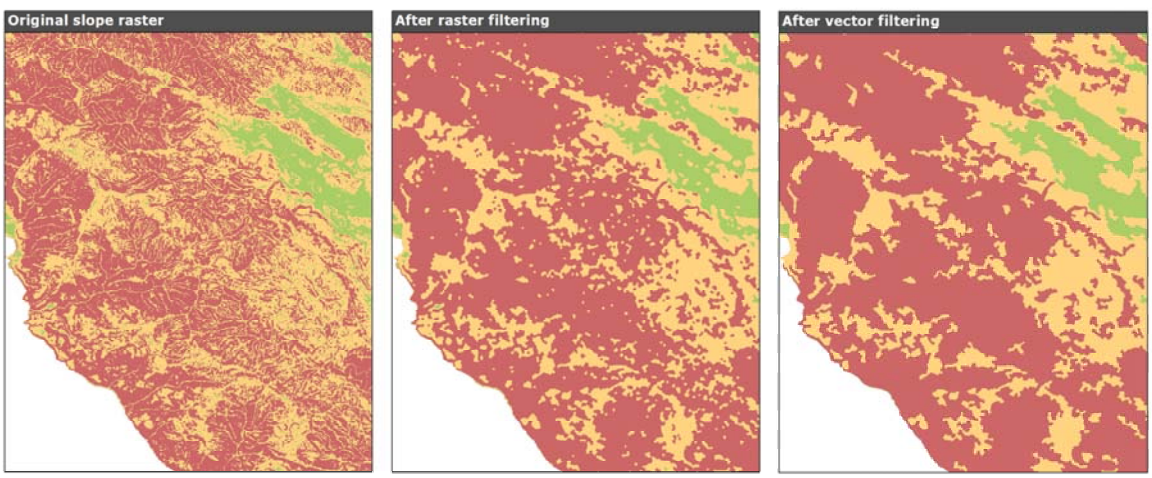


**Figure 3-4.** Progression from the original slope classes determined from the "raw" topographic data (left-hand panel), through the raster and vector filtering steps described in the text, to the final result (right-hand panel) used to create the provisional Watershed Management Zones (Figure 3-5).

Following the development of this smoothed slope layer, its combination with the generalized geology layer produced the map of initial or "provisional" WMZ's (i.e., not field-checked or assessed for providing useful discrimination of key watershed processes). A thumbnail of that map is displayed in Figure 3-5.

As noted above, the horizontal accuracy of the smoothed slope-category boundaries is ±125 m (410 ft). The positional accuracy of the final WMZ boundaries, however, are set by the least precise source data, which in this case is are the geologic units, originally mapped at 1:750,000 scale. Based on USGS map-accuracy standards (1/50” at map scale; see http://egsc.usgs.gov/isb/pubs/factsheets/fs17199.html) this value is ±1250 feet. This precision is sufficient for representing patterns and relationships of landscape conditions across the Central Coast Region as a whole, but it is obviously too coarse to specify regulatory requirements at a parcel or site scale without more precise definition. This need will be addressed as part of Task 5 of the Joint Effort.

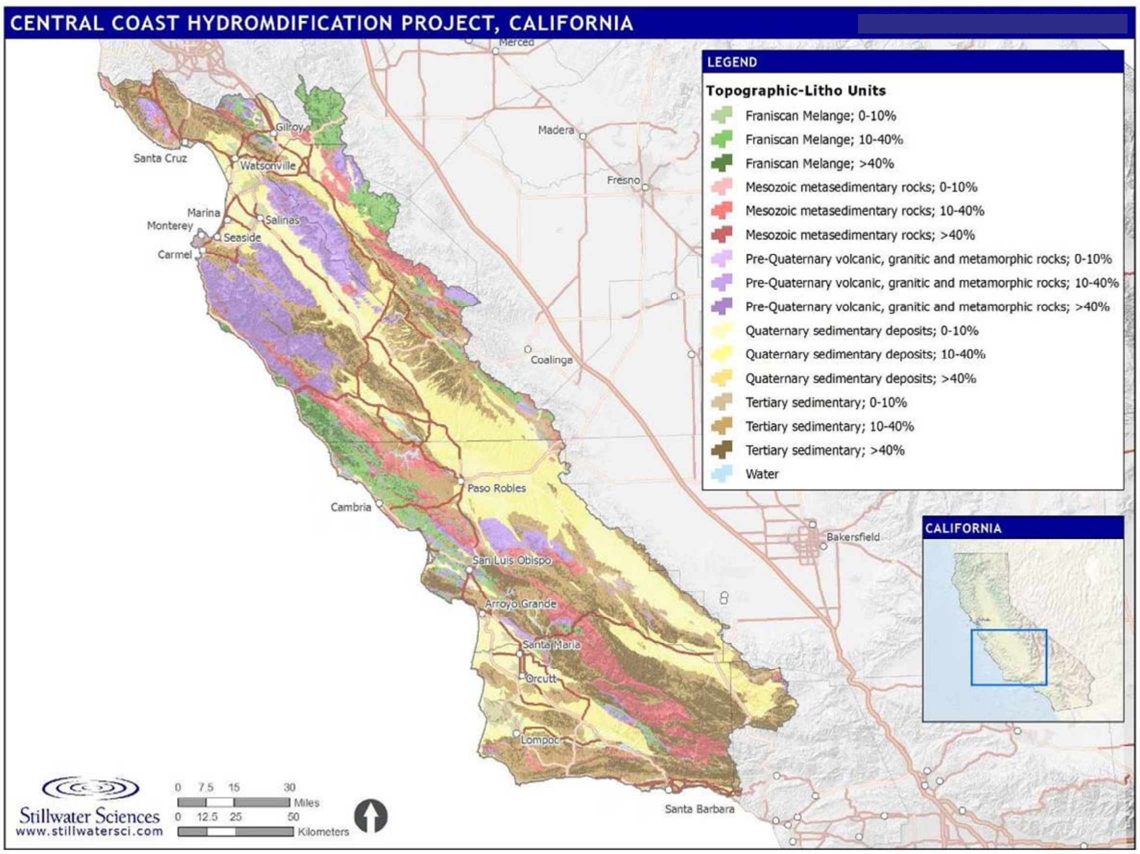


**Figure 3-5.** Preliminary map of the provisional Watershed Management Zones, based on the smoothed slope polygons and the generalized geology units of Jennings et al. (1977). The broad belts of coastal and interior mountains are readily visible in this map, together with the intervening valleys of young, low-gradient sedimentary deposits (yellow shades) in which most of the cities and towns of the region are located.

As noted in the Methods (Section 3.1), consideration was given to the use of soils data (in the form of hydrologic soil groups) to supplement (or replace) geologic data as representation of the material properties of the landscape. Theoretical considerations about the relevance of these two data sets to subsurface processes, and the scale over which they would be applied, suggested that the geologic data is more appropriate for the current application. This judgment appears to be confirmed by a GIS analysis of the different categories where they each intersect within the Region-designated "groundwater basins" of the Central Coast (which in total cover ~4000 $mi^2$ of the Central Coast Region). Table 3-1 displays these results, which show a very strong overlap between the identified groundwater basins and mapped Quaternary deposits, an association that would be expected given the relatively high permeability of these recent, unlithified and mainly granular sediments. In contrast, the soils data (NRCS 1994) show no systematic relationship; nearly half of the mapped soils in the groundwater basins are either hydrologic soil classes "C" or "D," classes normally associated with impermeable layers at shallow depth or overall non-infiltrative deposits. Such a characterization may be useful at a site scale (since hydrologic soil categories include numerical ranges for infiltration rates, necessary for engineering design) but does not appear to provide information that is readily incorporated at the more regional scale of the present Task.

**Table 3-1.** Relative areas of hydrologic soil groups (upper) and geologic units (lower) that overlap the mapped groundwater basins of the Central Coast Region. These basins, in total, constitute about 4000 $mi^2$, nearly one-third of the Region's area as a whole. The relationships displayed by the geologic data align with typical expectations for the deposits constituting a groundwater basin; the soil groups, however, do not intuitively correspond to regions of broadly high infiltration.

| **Hydrologic soil groups: percent total of groundwater basins** | |
|---|---|
| **Hydrologic soil group (A,B,C,D)** | **Area in GW basin** |
| A | 8.9% |
| B | 41.2% |
| C | 25.5% |
| D | 20.5% |
| n/a* | 3.9% |
| **Grand total** | **100.0%** |
| * this class includes water and other features lacking an soil-group code | |
| **Geologic units: percent total of groundwater basins** | |
| **Geologic unit** | **Area in GW basin** |
| Franciscan mélange | 0.7% |
| Mesozoic metasedimentary rocks | 0.3% |
| Pre-Quaternary crystalline rocks | 0.8% |
| Quaternary sedimentary deposits | 87.5% |
| Tertiary sedimentary rocks | 10.4% |
| Water | 0.3% |
| **Grand total** | **100.0%** |

### 3.2.2 Field work

The primary products of the field work in the landscape zones of the Central Coast Region are notes and observations associated with 949 georeferenced photographs (an additional 251 georeferenced photos associated with a variety of receiving waters across the region are discussed in the next section). A narrative report such as this can only provide a skeletal summary of the findings, but it still offers a sense of the general trends that are apparent across the landscape within a systematic structure. We organize this presentation by the five major geologic categories originally identified in Task 2, but as noted below this field effort led us to combine two of them for lack of any significant observed differences in their condition or response to disturbance, and to make a further subdivision of another.

#### 3.2.2.1 Franciscan mélange

By geologic definition, a "mélange" is a heterogeneous collection of very different but typically resistant rock types within a matrix of weaker material that has filled the spaces between the resistant clasts. Those clasts can range from meters to kilometers across and be separated from one another by similar scales—and so generalizations with respect to this geologic unit are notoriously difficult to make without detailed map data far beyond the scope of the present effort. Nonetheless, some generalizations with respect to dominant watershed processes can be made because of the weak mechanical properties of the pervasively sheared matrix that constitutes the bulk of the Franciscan. In addition, this geologic unit includes a less common but very characteristic rock, serpentine (which is, incidentally, the official California state rock). Serpentine-derived soils are an inhospitable growing medium for many native plants, and slopes underlain by serpentine are typically landslide-prone, owing to the weakness of both the primary minerals and their weathering products.

Little evidence of watershed processes active at the surface (e.g., overland flow, rilling, etc.) are visible on flat slopes underlain by Franciscan mélange, many of which may be mantled with a layer of more granular, recently deposited sediments that may permit surface infiltration. The underlying rock, however, is likely to be poorly infiltrative because many of its primary weathering products are clay. Though a weak material, little sediment production is likely unless offsite channeled runoff incises into the surface layers. In contrast, steeper slopes display local shallow soil slips (locally termed "melted ice cream topography") and local, deeper seated failures. Surface runoff can be well developed, particularly lower on slopes where drainage from upslope has accumulated.

This lithology covers 8% of the Region, of which virtually all is exposed on slopes steeper than 10%. A total of 66 photographs record landscapes associated with this lithology, with outcrops scattered from within 10 miles of the Region's southeast boundary to its northernmost tip (Figure 3-6). Its largest, continuous belt stretches north-northwest from the Santa Barbara–San Luis Obispo county line, along the coastline (western flank of the Santa Lucia Range), and into southern Monterey County (Figure 3-5). Other outcrops are identified along the mountain ridges forming the eastern spine of the Region and (of course) at Franciscan Rocks along the coast near Big Sur.


**Figure 3-6.** Franciscan mélange: 0-10% (upper left), 10–40% (upper right), and >40% (lower panels). A roadcut of serpentine is well exposed at lower right.

#### 3.2.2.2 Mesozoic metasedimentary rocks; pre-Quaternary volcanic, granitic, and metamorphic rocks

Although these two groupings of rock types are distinguished in the mapping of Jennings et al. (1977) and were originally separated in Task 2, they share many of the same material properties (indeed, the Mesozoic Era is simply one period within the pre-Quaternary, and metasediments are but one type of metamorphic rock). After abundant field review, we found no basis to discriminate them on the basis of lithology or resulting watershed processes, and so we have combined them both for purposes of this presentation and for subsequent analysis. They are collectively termed “pre-Quaternary crystalline rocks.” The dominant rock types contained in this group are Mesozoic granites of the Salinian Block—a displaced assemblage sharing its origin with the Sierra Nevada batholith—and Cretaceous sandstones.

As a group, these rocks are the most resistant of those found in the Region, and so hillslopes underlain by them (and stream channels cut into them) display evidence only of those watershed processes that are active in the thin overlying soil layer (Figure 3-7). In contrast to the Franciscan mélange, youngest Tertiary sedimentary, and Quaternary sedimentary rocks, deep-seated landslides are extremely rare; even on steep slopes, vegetation cover is very good except where the unweathered rock crops out or the slopes have been extensively grazed. Sediment production by all processes is low; deep infiltration to groundwater is probably minimal.

This lithology crops out over about one-quarter of the Region, about evenly divided between slopes 10–40% and those >40%; virtually no flat ground is included in this unit. A total of 95 photographs record landscapes associated with these lithologies. Belts of these resistant rocks form the core and underlie most of the highest peaks of the northwest-trending mountain belts of the Central Coast Region (e.g., Santa Lucia and Gabilan ranges), lying just east of the Franciscan outcrops along the western side of the region, flanking the Salinas River valley, and interspersed with Franciscan rocks along the Region's eastern divide.

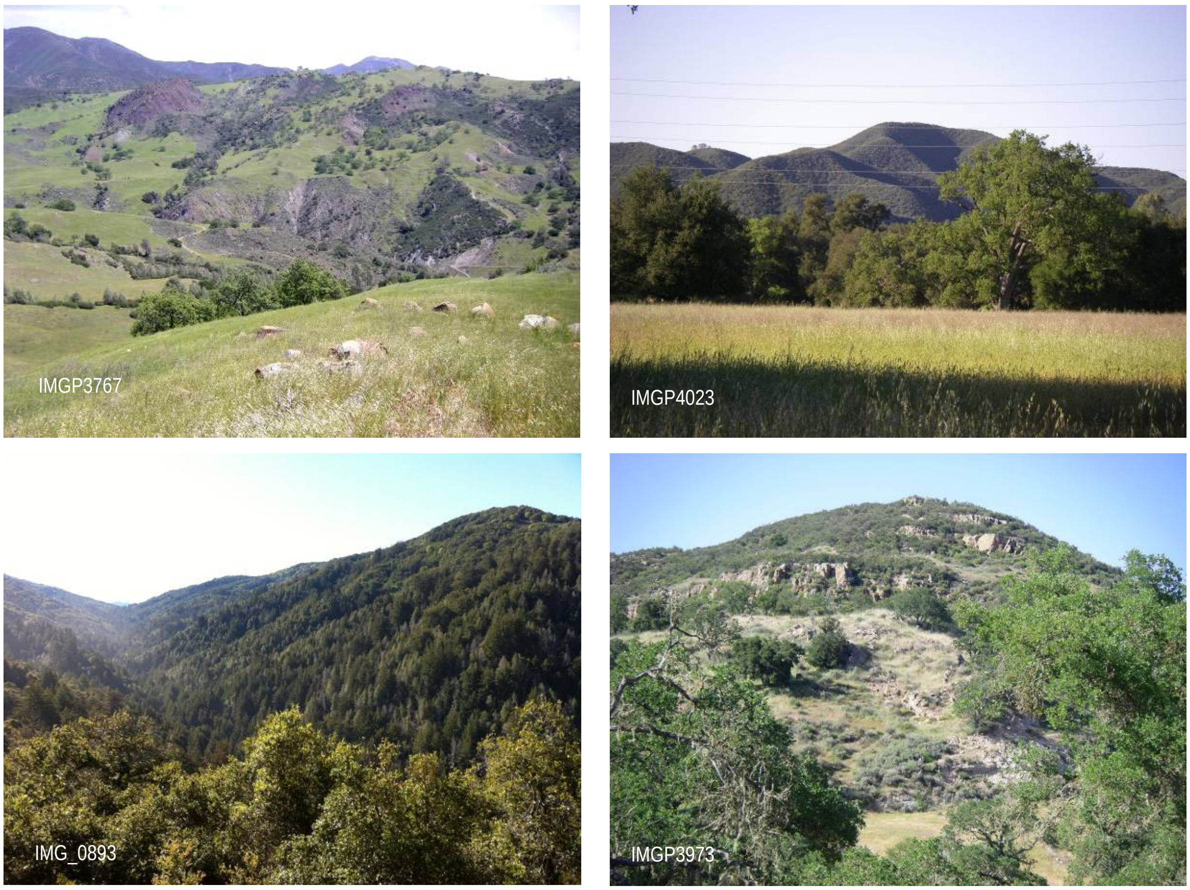


**Figure 3-7.** Pre-Quaternary crystalline rocks: 10–40+% (upper panels; note flat Quaternary valley fill, foreground of upper right panel), and 10–40% (lower panels)

#### 3.2.2.3 Early to Mid-Tertiary sedimentary rocks

In Task 2 of this project, the entire sequence of sedimentary rocks of Tertiary age (approximately 2 to 65 million years old) was lumped into a single geologic unit for purposes of this analysis. Field work rapidly demonstrated, however, that rocks in the older part of the section were significantly more erosion-resistant, as a group, than their younger counterparts (a finding anticipated by Warrick and Mertes 2009). We therefore excluded the youngest Tertiary rocks from this group and address their distribution and properties in the next section.

This lithologic group comprises both sandstones (cemented sand and, locally, conglomerate gravel) and shales (lithified silt and clay). The sandstones are typically well-cemented and hard;

they form the highest ridgetops of the Santa Ynez Range and the flatirons along US Highway 101 along the Gaviota Coast, and the brilliant outcrops ("the Indians") in Los Padres National Forest north of Hunter Liggett Military Reservation (Figure 3-8). The shales are much weaker but are generally interbedded with sandstone, creating a sedimentary "sandwich" of rocks with quite variable properties over relatively short distances. At the scale of the present effort these variations cannot be resolved, but they are a reminder that local investigations may identify divergences from the more general, regional patterns most commonly associated with this lithologic group.

Watershed processes in this lithologic group are as varied as the materials themselves, with a predominance of well-cemented sandstones that are relatively resistant to most erosive processes and weather to produce sandy soils with good infiltration and moderate susceptibility to gullying on moderate and steep slopes, particularly where devegetated. Most of these strata have been tipped, folded, and fractured, providing abundant preferential pathways for infiltrating groundwater. However, the less well-consolidated sediments, particular those with a high silt or clay fraction, exhibit abundant surface runoff and associated rilling and gullying. Examples of both sets of watershed processes are illustrated in Figure 3-8.

The Early to Mid-Tertiary sedimentary rocks as a whole are the most extensive lithologic group in the Central Coast Region; this subdivision of that group crops out over 30% of the Region, with only a modest representation on flat ground and slightly more than half in the 10–40% slope range. We have compiled 235 photographs of these rocks from every quadrant of the Region. About half of the images are also in the 10–40% slope category and the balance split between flatlands and steeplands, reflecting their ubiquitous distribution across the varied terrain of the Central Coast. They form the bulk of the Transverse Ranges that traverses east-to-west across southern California, and whose western-most expression is the Santa Ynez Range above Santa Barbara. Rocks of equivalent age and composition bend north along the California coastline and stretch from the extreme southeast edge of the Region to the Monterey Peninsula in a near-unbroken strip. A parallel belt of the same rock types lies a few tens of miles to the northeast and continues north to the very northwestern tip of the Region; in between these two ridges of (largely) Tertiary rock lies the Salinas River valley, the largest and most extensive lowland in the entire Central Coast.


**Figure 3-8.** Early to Mid-Tertiary sedimentary rocks: upper (>40%) and lower (10–40+%) left panels showing outcrops of well consolidated sandstone outcrops; minimally erosive vegetated and bare-rock outcrops 0–10% (upper right) contrasted with sandy less well-consolidated material in roadcut with relatively high erodibility (lower right)

#### 3.2.2.4 Late Tertiary sedimentary rocks

These lithologic units were identified from Jennings et al. (1977) as marine and nonmarine sediments of Pliocene age, which covers that last three million years of the Tertiary Era. These sediments are geologically relatively “young” and as such are typically only weakly cemented and so quite erosion-prone. Studies elsewhere in the region have also identify these rocks as the most erosive widespread deposit, with sediment-production rates about an order of magnitude greater than those of the most resistant rocks on equivalent slopes (Warrick and Mertes 2009, Stillwater Sciences 2010b), reflecting the activity of rilling and gullying (typically the most productive of the sediment-generating processes) along with abundant landsliding in this weak material.

Because of this lack of cementation, they are typically stable only on low slopes; where more steeply exposed, commonly a result of stream erosion or (along the San Andreas Fault) tectonic uplift, they are readily eroded (Figure 3-9). Sand-dominated deposits have good permeability and show little evidence of overland flow where un-eroded, but once flow concentration begins it can readily expand rills and gullies. Despite this intrinsic weakness, moderate slopes underlain by this deposit with an undisturbed vegetative cover persist with little evidence of either gullying or landsliding, and no surface channels. This demonstrates the intrinsic permeability of the material in these areas; the contrast with its eroding state (commonly in immediately adjacent areas) emphasizes the importance of avoiding the initiation of surface runoff and the rapid, positive feedback that runoff can provide, giving rise to an entirely new suite of watershed processes.

This lithologic group is not widespread in the Region; where we have observed it, typical constituents are interbedded sand and silt. It is most widely exposed northeast of Santa Cruz, along the San Andreas Fault zone east of King City along Highway 25, and on the hills between the lower reaches of the Santa Ynez and Santa Maria rivers. It crops out over 6% of the Region, with virtually all recognized exposures on slopes above 10%. We have recorded 38 photographs of the terrain underlain by this unit, of which two-thirds are of intermediate slope.


**Figure 3-9.** Late Tertiary sedimentary rocks: >40% (upper panels), 10–40% (lower panels). Note the lack of expression of surface runoff on the uneroded hillslopes (left-side panels), in contrast to the severity of gullying where surface runoff has occurred

### 3.2.2.5 Quaternary sedimentary deposits

The Quaternary Period covers the most recent 2.4 million years of earth history, and so sediments of this age are geologically “young.” Typically, this is not enough time for significant burial, lithification, and exhumation to have occurred—and so these deposits are generally the least resistant to erosion by running water, or to disturbance that increases any downslope stresses imposed on them. They are also most common in topographic lowlands and depressions, where their constituent sediments, eroded from the older rocks, have been transported predominantly by running water.

Because of their lack of cementation, they are typically stable only on flat slopes, where their lack of consolidation and cementation enhances permeability (Figure 3-10, upper panels). For this reason they are strongly associated with groundwater basins of the Region, providing both ready access for water into the subsurface and a high-permeability reservoir in which that subsurface water is stored. On slopes, however, their lack of consolidation makes them very prone to surface erosion (particularly where unvegetated), generally expressed as intense rilling and gullying (Figure 3-10, lower panels). Even though they are permeable, episodic rainstorms in the region are sufficiently intense to exceed infiltration capacities and initiate channels; once this occurs, runoff is further concentrated and the surface erosion process (and associated surface runoff) will continue.

Quaternary sedimentary deposits are the single most abundant geologic material in the Region, cropping out across one-third of the Region. This is almost certainly an underestimation, since narrow stream valleys and the toeslopes of most hills are also mantled in Quaternary-age sediments but are rarely mapped as such, particularly at a regional scale. These deposits generally underlie the coastal terraces and river valleys that separate the mountain belts formed of older, more resistant material. Indeed, over 80% of the flat (i.e., <10% slope) land of the Region is underlain by this deposit (the balance is almost exclusively Tertiary sediments). We have 185 photographs recording this deposit; in contrast to the other units, about two-thirds of these are of flat (0–10%) topography, where the unit is most commonly expressed. Because of its intrinsic weakness, steep natural deposits are not common and cover only 1% of the area of the Region; they typically exist only where either natural (e.g., river erosion) or human (e.g., road cuts) processes are actively creating a steepened face (Figure 3-9, lower panels).


**Figure 3-10.** Quaternary deposits: 0–10% (upper panels), 10–40+% (lower panels)

### 3.2.3 Summary of findings

Based on observed conditions across the broadly undisturbed landscape areas of the Central Coast Region, we judge that five geologic categories, well-defined at a regional scale, provide a useful basis for discriminating dominant watershed processes. The overlay of three slope zones is a somewhat artificial but nonetheless worthwhile stratification of the landscape that appears to correspond relatively well to the expression of differing degrees of surface runoff, surface erosion, and landsliding (although the same conditions do not necessarily occur on the same slopes in different geologic categories). In combination, these fifteen combinations of slope and geology have led us to a minor modification of the Watershed Management Zones developed in Task 2 and mapped above in Figure 3-5. The relative proportion of these revised zones in the Central Coast Region is tabulated in Table 3-2; their distribution across the Region is displayed in Figure 3-11.

These categories reflect the influence of the two factors that both theory and observation guide us to judge are the primary determinants in the “natural” (i.e., undisturbed) landscape—slope and geologic material. In contrast to prior analyses of this type (e.g., Stillwater Sciences 2010a), vegetation is absent from this list because this step of the Joint Effort is intended to characterize processes in relatively undisturbed regions. We review the effects of disturbance in the next section. Other factors of potential relevance, including the spatial variability of precipitation and the influence of different vegetation types in undisturbed watersheds (e.g., trees vs. shrubs vs. grasslands in progressively drier parts of the Region) will be assessed during the linkage analysis of Task 4.

**Table 3-2.** The WMZ areas as a proportion of the Central Coast Region (determined by GIS analysis).

| Watershed Management Zone | % of total area | |
|---|---|---|
| Franciscan Melange; 0-10% | 0.5% | 8% |
| Franciscan Melange; 10-40% | 5% | |
| Franciscan Melange; >40% | 2% | |
| Pre-Quaternary crystalline rocks; 0-10% | 1% | 23% |
| Pre-Quaternary crystalline rocks; 10-40% | 11% | |
| Pre-Quaternary crystalline rocks; >40% | 11% | |
| Early to Mid-Tertiary sedimentary; 0-10% | 2% | 30% |
| Early to Mid-Tertiary sedimentary; 10-40% | 16% | |
| Early to Mid-Tertiary sedimentary; >40% | 12% | |
| Late Tertiary sediments; 0-10% | 1% | 6% |
| Late Tertiary sediments; 10-40% | 4% | |
| Late Tertiary sediments; >40% | 2% | |
| Quaternary sedimentary deposits; 0-10% | 18% | 33% |
| Quaternary sedimentary deposits; 10-40% | 14% | |
| Quaternary sedimentary deposits; >40% | 1% | |
| Water | 0.4% | 0.4% |

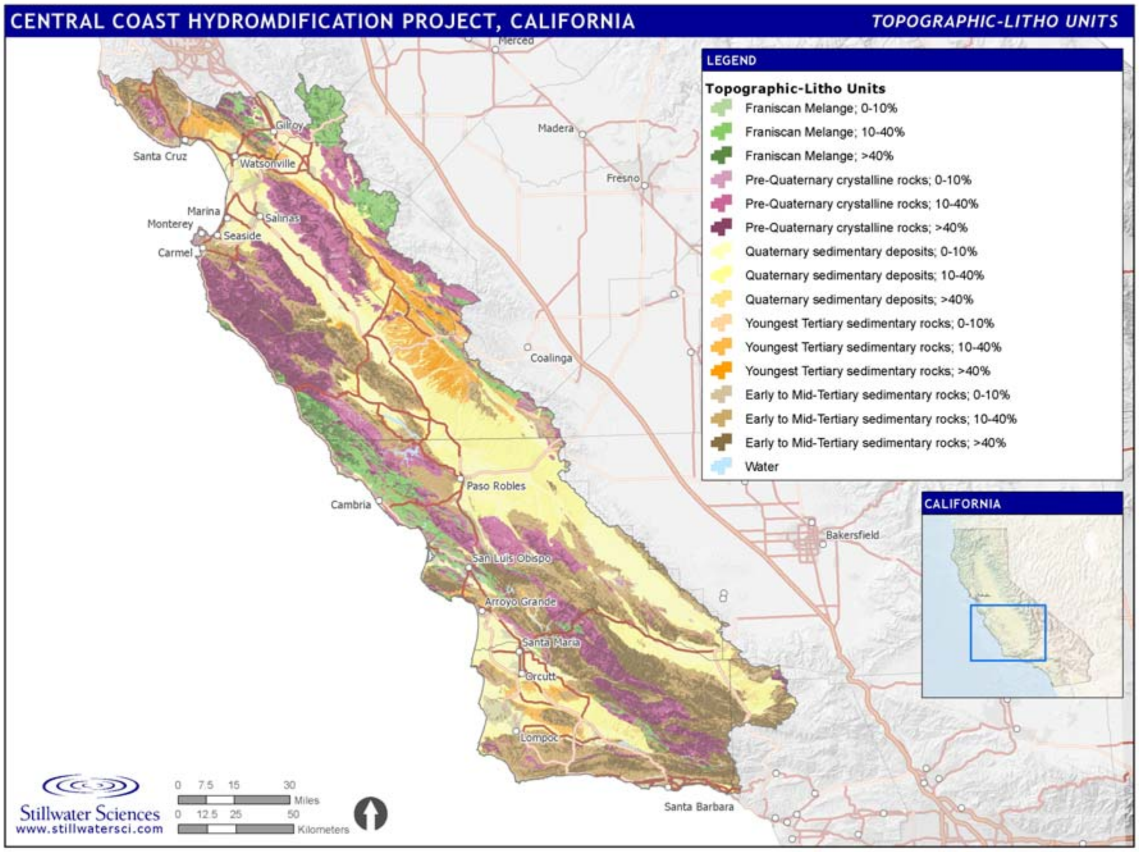


**Figure 3-11.** Final map of the Watershed Management Zones, based on the smoothed slope polygons and generalized geology units of Jennings et al. (1977) as developed from undisturbed watersheds with relatively intact vegetation cover. Final lithologic groupings have been informed by the results of the Task 3 field work. Relative areas as tabulated in Table 3-2.

Although the watershed processes that dominate on any given hillside obviously will depend on more factors than simply "slope" and "geology," our observations confirm geomorphic theory that these are critical determinants of those processes, and that a regional-scale stratification of the landscape based on these properties is a useful and defensible starting point for watershed management, including but not limited to addressing the potential impacts of urban development and hydromodification. These observations can be broadly generalized as shown in Table 3-3.

**Table 3-3.** Tabular summary of inferred and observed watershed processes in undisturbed settings, as discriminated by Watershed Management Zones. The assigned ratings (for "Low," "Medium," and "High") are relative and apply only to a particular column; so, for example, a "H" (high) rate of creep processes will not necessarily produce as much sediment as a high rating for rilling and gullying (indeed, the opposite will be true), but it will be inferred to produce more sediment within that WMZ than an "L" rating for creep in a different zone. The ratings are based on prior studies, observations, professional judgment, and common sense, but they do not reflect a systematic, quantitative evaluation of each process in each WMZ.

| Slope class | Geologic unit | Overland flow (incl. sheetwash) | Infiltration | Interflow | Groundwater recharge | Creep | Rilling and gullying | Landsliding |
|---|---|---|---|---|---|---|---|---|
| 0–10% | Franciscan mélange | M | L | L | L | L | L | L |
| | Pre-Quaternary crystalline | L | M | M | L | L | L | L |
| | Early to Mid-Tertiary sed. | L | H | M | H | L | L | L |
| | Late Tertiary sediments | L | H | M | H | L | L | L |
| | Quaternary deposits | L | H | M | H | L | L | L |
| 10–40% | Franciscan mélange | M | L | L | L | M | M | M |
| | Pre-Quaternary crystalline | M | L | L | L | L | L | L |
| | Early to Mid-Tertiary sed. | L | M | M | M | L | L | L |
| | Late Tertiary sediments | L | H | M | H | M | M | L |
| | Quaternary deposits | L | H | M | H | M | H | M |
| >40% | Franciscan mélange | H | L | L | L | H | M | H |
| | Pre-Quaternary crystalline | M | L | L | L | L | M | L |
| | Early to Mid-Tertiary sed. | M | M | M | M | L | M | L |
| | Late Tertiary sediments | H | M | M | M | M | H | H |
| | Quaternary deposits | M | M | M | M | M | H | H |

By inspection of this table, a few general patterns emerge. Of the two primary elements, slope is the major determinant of sediment-production processes (the "hillslope processes" of Table 2-1). However, relative sediment-production rates of the two youngest deposits (Late Tertiary and Quaternary) on moderate and (especially) steeper slopes are markedly greater than for the other lithologies, and from quantitative studies elsewhere in the region (Warrick and Mertes 2009, Stillwater Sciences 2010b) we expect those maximum rates to be over an order of magnitude greater than those of the other rock types. In contrast, lithology is the strongest determinant of infiltration and groundwater recharge; slope is presumed to have only a secondary influence (see, for example, Risser 2008).

Other observed patterns are expressed in this table. The markedly different susceptibility to landsliding between the "strong" rocks (crystalline and older Tertiary sedimentary rocks) and their weaker counterparts is only imperfectly mirrored by their propensity to rilling and gullying; we did not observe this latter form of sediment production in the Franciscan rocks as pervasively as in the youngest sediments.

### 3.2.4 Landscape disturbance and watershed processes

Although a systematic evaluation of the effect of landscape disturbance on watershed processes (and resulting receiving-water conditions) is reserved for Task 4, much of the Central Coast Region exhibits some degree of human impact. Thus, our observations provide ample and varied expression of these impacts, of which grazing and the associated loss of woody and/or chaparral vegetation is the most widespread in the Region. Not surprisingly, slope remains an important determinant of the response of hillslope processes to disturbance (even intensive grazing on flat ground creates few if any additional landslides, for example), but we observed consistent patterns of grazing and gullying on both moderate and steep slopes in all but the most resistant of terrains (i.e., pre-Quaternary crystalline and older Tertiary sedimentary rocks). Even those areas are not immune to changes in dominant process, but such changes are limited primarily to where a thick soil mantle has accumulated over the bedrock.

The effects of urbanization on watershed processes are normally best expressed in the receiving waters (see next section), but the consequences of the activities normally associated with this group of disturbances—increased surface runoff, decreased infiltration, vegetation removal, soil disturbance, regrading of hillslopes—can be readily inferred in the context of the region's WMZs. Changes in the ratio of surface runoff to infiltration will be most significant where infiltration is normally the dominant hydrologic process. This is particular true of the low- and mid-gradient Quaternary deposits, which (awkwardly) are also host to most of the Region's current (and projected) population. On slopes of almost any magnitude, these deposits and their slightly older Tertiary counterparts are highly susceptible to dramatic increases in the rates of hillslope processes (particularly rilling and gullying) that produce high sediment loads and tend to be efficiently transported downslope to receiving waters (Figure 3-12). Landsliding in areas underlain by these deposits, together with those underlain by Franciscan mélange (see, for example, Ellen et al. 2007, Stark et al. 2010, Mackey and Roering 2011), pose a significant hazard (albeit a well-regulated one, particularly in urban areas) wherever topographic contours are altered.


**Figure 3-12.** Examples of altered watershed processes in response to disturbance. Upper panels, Tertiary deposits express landsliding west of Twitchell Reservoir (left) and gullying south of Guadalupe (right) in response to vegetation changes and soil compaction from grazing; lower panels show effects of concentrated runoff in the form of severe gully-cutting through Quaternary deposits above the Santa Maria River (left) and debris flows below a service road in Franciscan mélange north of Arroyo Grande (right).

# 4 RECEIVING WATERS

The US Environmental Protection Agency defines receiving waters as "A river, lake, ocean, stream or other watercourse into which wastewater or treated effluent is discharged" (http://www.epa.gov/OCEPAterms/rterms.html; accessed August 7, 2011). For purposes of the Joint Effort we also include groundwater aquifers and wetlands; and because land-based runoff is the primary focus of this study (as opposed to wastewater treatment plant outfalls), for "oceans" we consider only the marine nearshore instead of the entirety of the Pacific Ocean.

We have conducted this investigation of receiving-water conditions in the Central Coast Region within a different spatial framework from that of the "landscape zones" and their associated watershed processes described in the preceding section. For the latter, we approached the Region comprehensively, compiling GIS data and acquiring field data for landscape conditions across the *entire* region. For the former, however, the original scope of the Joint Effort anticipated the value of collecting broadly representative, but not necessarily comprehensive, data on receiving-water conditions. Based on inspection of the receiving-water data acquired from local municipalities during Task 1 and the overall goals of the Joint Effort, the technical team has embraced the framework of "*selected* receiving waters" (and their associated sub-watersheds) with the intention that they can provide broad representation of conditions across the Region. The list of the receiving waters so reviewed, however, is by no means comprehensive.

The linkage between WMZ's, key watershed processes, human disturbance, and receiving-water conditions—both as empirically demonstrated, using the selected subset of locations presented in this section, and as generalized across the Region as a whole—will constitute Task 4 of this project.

## 4.1 Selecting Receiving Waters and Evaluating "Quality"

In choosing receiving waters for more intensive analysis during this Task, the team placed the highest priority on those receiving waters with good hydrologic data (i.e., long USGS gage records) and systematically (and consistently) collected and analyzed biological data. Our focus in the following discussion is therefore on streams (and a few larger rivers) of the Region, where these data are sufficient to support future analysis. Other types of receiving waters (marine nearshore, lakes and wetlands, groundwater) have much less complete and inconsistently compiled data, and so their inclusion and review is less systematic in the following discussion. The region's larger rivers (the Salinas, Santa Maria, Cuyama, Sisquoc, Pajaro, Estrella, and Santa Ynez rivers, for example, all drain more than 400 $mi^2$) encompass such a diversity of watershed conditions, disturbances, and flow modifications that their inclusion in this analysis would be unlikely to illuminate the relationship between watershed processes land-use disturbance that are most immediately relevant to the goals of the Joint Effort.

No single metric for "receiving-water quality" is broadly recognized. Even from any single discipline-specific perspective, little consensus exists over what should reflect the "quality" or the "health" (or, conversely, the magnitude of degradation) of a waterbody. The Clean Water Act calls out "physical, chemical, and biological integrity," suggesting at minimum that no single metric, and no single discipline, should be used to make such an assessment. The Joint Effort in general, and this Task in particular, is also limited by practical constraints of schedule and budget—and so we do not include here a treatise on the effects of urbanization on downstream receiving waters (for such a compendium, the reader is directed to several excellent recent review articles such as Paul and Meyer 2001 or Walsh et al. 2005).

In streams, the scientific literature for more than a decade has shown that biological metrics are typically the most sensitive to the earliest impacts of urbanization (Booth and Jackson 1997, Karr and Yoder 2004, King et al. 2011), with multimetric indices based on benthic macroinvertebrates being the most common quantification of instream biological health. Hydrologic changes in urbanizing streams have been recognized for even longer (e.g., Hollis, 1975), but there is less agreement on the appropriate hydrologic metric(s) to discern the "signal" of urbanization in the contributing watershed.

We have also reviewed, but have not systematically included, results from the California Rapid Assessment Methodology (CRAM; http://www.cramwetlands.org/, accessed September 29, 2011). CRAM offers a uniform, systematic, field-based evaluation of wetlands (including "riparian wetlands," or streams) designed to generate a consistent evaluation of observed conditions for waterbodies throughout the state. The history of rapid assessment techniques is no less extensive than that of biological metrics; the primary difference between them is that the former infers "function" from observed *conditions*, whereas a biological assessment evaluates one of those key functions (namely, biological health) directly. For this Task of the Joint Effort, the latter is likely to be most informative and so is emphasized in this report.

Both assessment approaches depend on the definition of reference conditions—for CRAM, it is wide, continuous buffers of native vegetation; no evidence of artificial water sources or impoundments; a regular, sinuous channel morphology with pools, riffles, and flanking perennial vegetation; varied topographic cross-sections with a diverse plant community. Similarly, biological metrics also require the specification of attributes using reference conditions, but in contrast to CRAM they are determined by identifying undisturbed sites in the region in question and measuring those conditions directly, rather than by making an *a priori* assumption of what high-quality conditions should look like. The challenge for both approaches is that the choice of what is "good" depends on either a conceptual model (for CRAM) or place-based reference sites (for a biological index) that are truly appropriate for the subject sites. Although proponents of both approaches normally assert widespread applicability, the history of all such assessments suggests that their results need to be evaluated with caution.

## 4.2 Other Indicators of Receiving-Water Conditions

Konrad and Booth (2005) evaluated hydrologic indicators with likely ecological effects (addressing high-flow frequency, distribution of water between stormflow and baseflow, daily flow variability, and low-flow magnitude) in 12 USGS-gaged watersheds across the United States with drainage areas from 12–356 $km^2$ (5–137 $mi^2$), selected for either their stable (i.e., control sites) or increasing population density from 1920 to 2000. None of these latter "urbanizing" watersheds showed a statistically significant change in *all* hydrologic metrics; and the one gage in southern California (San Francisquito Creek, about 60 miles east of the southeast boundary of the Central Coast Region) showed a statistically significant change in only one metric, baseflow discharge (and this an *increase*, not a decrease), despite having one of the greatest increases in population density of the entire set.

In contrast, Hawley and Bledsoe (2011) evaluated 43 USGS-gaged flows between the Ventura County line (i.e., immediately south and east of the Central Coast Region) and the Mexican border draining watersheds <250 $km^2$ (97 $mi^2$) with at least 15 years of record. They found a statistically significant relationship between total impervious area in the contributing watershed (TIA) and instantaneous peak-flow rates at the 1.5- and 2-yr recurrence intervals, as well as between TIA and the durations of all "geomorphically important" flows. They quantified the relationship between impervious area and flow increases by use of a regression model (rather than before–after flow data); their model results suggest that the 2-year peak discharge may increase by a factor of 2–3 with 10% TIA and 4–6 with 20% TIA.

In other types of receiving waters, neither biological metrics nor (particularly) hydrologic metrics are nearly as useful because of the fundamental nature of these waterbodies (e.g., gage data are irrelevant for a lake or the marine nearshore). We are compiling available chemical data on selected lakes, marine nearshore areas, and groundwater bodies of the region because these other types of receiving waters are of equal concern to streams under the protective goals of the Joint Effort. To date, however, these data are much more limited than those pertaining to streams, and they do not characterize the conditions of these other receiving waters to the same degree of quantification.

## 4.3 Methods

### 4.3.1 Selection of receiving waters

Our approach to site selection sought to optimize the following attributes of each location, to the extent that such data are available:

- High-quality, long-duration flow records from USGS gaging stations likely to show effects of any land-use change (i.e., with contributing drainage areas less than a few hundred square miles);
- Existing benthic data, ideally integrated into interpretive indices and/or quality ratings and spanning multiple sample years; and
- Adequate site access for making first-hand observations (normally addressed by virtue of existing flow or biological data).

The availability of chemistry (i.e., "water-quality") data was not used as a criterion for primary site selection, but any such data was acquired for the receiving waters otherwise chosen.

After an initial list of sites was identified based on available hydrologic and (or) biological data, the distribution and patterns of sites and receiving waters were evaluated to further refine the selection. Additional site(s) along the same stream were added if additional biological sampling sites could provide potential insight into the effects of different land uses along a single watercourse. The distribution of selected sites was compared to the Task 2 clustering of subwatersheds across the Region to evaluate whether all major "DIANA-12" groups were represented, and if not then what biomonitoring sites could fill in any such gaps. Similarly, the geographic distribution of sites north-to-south and dry-to-wet was reviewed on a map, with any gaps filled in as possible with one or more additional biomonitoring sites. Finally, we reviewed the data provided by the Regional Board and local jurisdictions to determine if any other receiving water(s) held the promise of being so well characterized by available data that their inclusion in this review would likely provide additional insight to the goals of the Joint Effort.

The approach used in each of these steps is described in greater detail below.

### 4.3.2 USGS gage data

All USGS daily average flow records within the study area were retrieved from the USGS web site (www.usgs.gov) and stored in a WRDB project file. There were 183 stations that were initially used to begin the investigation. The stations ultimate selected had to have observed daily average flow records for two 10-year periods, under the rationale that by spanning a 10-year period there would be a reasonable chance that wet, average, and dry periods will occur. The first period was 1981–1990 which surrounds 1985, the year of the historical land-cover GIS coverage assembled during Task 2. Likewise, the second period was 2001–2010, the most recent decadal period around the more recent 2006 land-cover coverage.

The entire period of record was evaluated at each gage, with the objective of selecting stations with relatively low impairment and long temporal records, because stations of this nature will have a greater chance of capturing hydrologic changes for flow duration trend analysis.

A polygon coverage was developed to represent the drainage area of the USGS stations that were selected, ensuring that these polygons differed by no more than 5% from the reported drainage area by USGS. Annual rainfall totals for each drainage area was determined from the

PRISM dataset by area-weighting the PRISM values per grid cell with the respective intersected drainage basin. These data were summarized by year as well as by period of interest. A statistical test was performed to determine whether rainfall over the two periods (1981–1990 and 2001–2010) could be considered sufficiently "similar" to exclude climatological variations from any changes that were subsequently recognized.

Similarly, the variability and the average of annual runoff values were summarized from the online data for each of the USGS gages selected. Annual runoff means in the two periods (1981–1990 and 2001–2010) were also compared to each other and to rainfall totals from the two periods to determine whether meaningful relationships between watershed conditions (particularly those associated with hydromodification) and streamflow could be drawn to support future analyses under the Joint Effort.

### 4.3.3 Existing biological data

The most comprehensive collection of biological data in the Central Coast Region is compiled and maintained by staff of the Regional Board. It includes data collected as part of the state's Surface Water Ambient Monitoring Program (SWAMP) and other data developed by the Regional Board (in total more than 600 unique sites). Because of its geographic extent, we used other criteria (availability of flow data, geographic "holes" in the coverage) to identify sites from this compendium for use in the characterization of receiving-water condition.

Detailed, high-quality benthic macroinvertebrate data are also available from the City of Santa Barbara and compiled into annual reports (most recently Ecology Consultants 2010, 2011; available at http://www.sbprojectcleanwater.org/waterquality.aspx?id=66#bioassess; accessed August 7, 2011). We took advantage of several paired sites with multiple years' biological data showing consistent trends, strategic placement up- and downstream of urban development, fully interpreted results, and (in several cases) correspondence with flow data.

### 4.3.4 Field investigations

During the five weeks' field work for the observation and evaluation of landscape zones, disturbance, and watershed processes, we had ample opportunity to visit the full range of receiving waters present in the Central Coast Region (except groundwater; streams, rivers, wetlands, lakes, and marine nearshore areas were all included). Because of challenges with the sequencing of tasks for the overall Joint Effort project, the initial round of visits was not keyed to the specific receiving waters selected as part of this task. However, a much larger number of sites were field-visited (over 100) than have been anticipated for final selection, and the schedule includes additional time for return visits to any selected receiving waters that were not directly observed during the initial round of field work but should be useful during Task 4.

Reflecting the focus of the other data sources, the visited sites were overwhelmingly streams. Observations were made of the general geomorphic character, specifically the substrate size and embeddedness, general channel morphology, and the presence or absence of bank erosion. Significant macrophyte (algae) growth was noted, and in many cases the presence or absence of benthic macroinvertebrates was noted, albeit not under any systematic sampling protocol. The goal was not to specify the "condition" of the stream (a single dry-weather observation at a single location along a channel can never achieve this) but rather to characterize the very general quality of the channel (particularly significant physical degradation, which is generally easy to recognize where present) and to complement any other available data of a more quantitative nature. All field observations were made by teams of two geomorphologists having two to more than four decades of experience between them. We consider the results broadly qualitative but reliable as to basic characterization of (most commonly in-stream) conditions. Although in many settings the "cause" of observed degraded conditions was readily apparent or easily inferred on the basis of surrounding human activities or land use, the primary purpose of these observations was simply to provide an observational basis for systematic consideration of linkages in Task 4.

For those sites discussed below, we also looked for any available results of CRAM evaluations (via http://www.californiawetlands.net/tracker/cc/map; accessed September 29, 2011) and have noted their findings as available.

### 4.3.5 Geographic distribution of sites

Following the review of hydrologic, biological, and field data, prospective sites were plotted on a map in GIS and evaluated with respect to gross geographical distribution and relationship up- and downstream of known urban areas. Their drainage areas were also plotted and evaluated with respect to PRISM annual rainfall, Watershed Management Zones (Figure 3-11), and the DIANA-12 clusters identified in Task 2 (that is, the 406 subwatersheds of the Region each classified into one of 12 statistically defined groups on the basis of geology, topography, and land cover). The objective of this review was to achieve, as much as possible given available hydrologic and/or biological data, a broad and representative distribution of sites with respect to geography, rainfall, WMZ's, and urbanization. We also sought any receiving waters where their location, configuration, and available data might allow a particularly clear example of the relationship of watershed characteristics, landscape disturbance, and receiving-water condition.

## 4.4 Results—Site Selection

### 4.4.1 USGS gage data

Of the entire population of 183 USGS gage stations, 36 had ample coverage of good-quality data for the period of interest (1951–2010). Average annual rainfall totals in the watershed upstream of each gage (based on the PRISM dataset) were evaluated for the entire period of record (Figure 4-1) and the two decadal periods coinciding with the selected land-use profiles (1981–1990 and 2001–2010) (Figure 4-2). Because the period of time for the decadal comparison is relatively short (10 years, versus 61 years for the entire period of interest), the 95% confidence intervals are relatively wide. A statistical test suggests that no individual station has a significantly different annual average rainfall totals between the two decadal periods, because the confidence intervals overlap at every station.

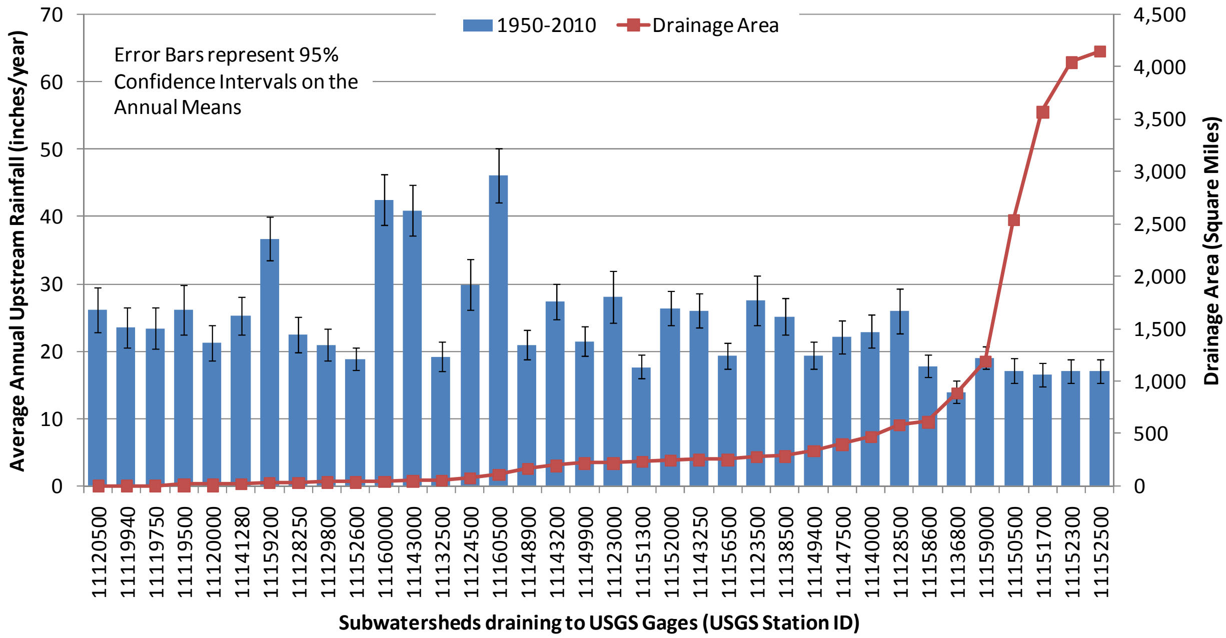


**Figure 4-1.** 61-year average annual rainfall (blue bars, LH axis) and drainage area (red squares, RH axis in mi$^2$) for the 36 selected USGS gages in the Central Coast Region. Error bars show 95% confidence intervals on the annual average rainfall.

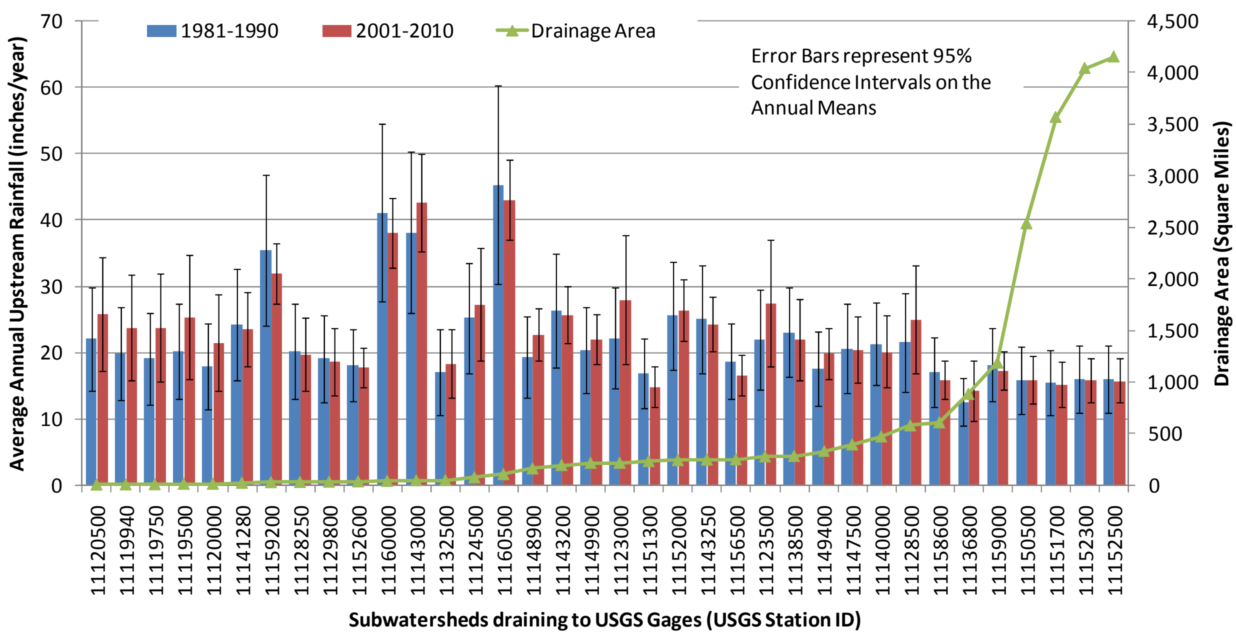


**Figure 4-2.** 10-year mean annual rainfall totals (with 95% confidence intervals on annual mean rainfall) and cumulative area upstream of each USGS gage (green triangles).

For streamflow, the data across the two decadal periods also showed too much variability to draw meaningful conclusions. There was not a consistent relationship between streamflow and observed precipitation, for various possible reasons. For example, there may be other unfactored conditions or activities upstream of each gage, such as inter-basin transfers, reservoirs, or other hydraulic modifications.

### 4.4.2 Selected subwatersheds

Based on data availability and watershed size, a preliminary set of streams were selected, based first on the size of the drainage area contributing to a USGS gage site with high-quality, long-term records (Table 4-1)

**Table 4-1.** Initial set of receiving-water sites based (only) on hydrologic data availability and drainage basin size.

| Stream name | USGS gaging station | Drainage area ($mi^2$) |
|---|---|---|
| Maria Ygnacio Ck (Goleta) | 11119940 | 6 |
| San Jose Ck (Goleta) | 11120500 | 6 |
| Mission Creek | 11119750 | 8 |
| Carpinteria Creek | 11119500 | 13 |
| Atascadero Creek | 11120000 | 19 |
| Lopez Ck (Arroyo Grande) | 11141280 | 21 |
| Scott Ck | 11162000 | 27 |
| Corralitos Creek | 11159200 | 28 |
| Alamo Pintado Ck (Solvang) | 11128250 | 29 |
| Zaca Creek (Buellton) | 11129800 | 33 |
| Gabilan Creek (Salinas) | 11152600 | 37 |
| Soquel Ck | 11160000 | 40 |
| Big Sur R | 11143000 | 46 |
| Salsipuedes Creek | 11132500 | 47 |
| Santa Cruz Ck (Santa Ynez) | 11124500 | 74 |
| San Lorenzo R (Santa Cruz) | 11160500 | 106 |
| Nacimiento River | 11148900 | 162 |
| Carmel River | 11143200 | 193 |
| San Antonio River | 11149900 | 217 |
| San Lorenzo Ck (King City) | 11151300 | 233 |
| Arroyo Seco | 11152000 | 244 |

Additionally, Orcutt Creek (northern Santa Barbara County) and the upper Cuyama River (eastern San Luis Obispo County) were added to capture an underrepresented watershed "cluster" of Figure 3-1 (namely, that typified by flat groundwater basins) and the dry eastern side of the Region. Abundant biological data also led us to include three others (Aptos, Chorro, and Santa Rosa) in the final list. In total, the receiving waters evaluated for this Task of the Joint Effort are as follows (Table 4-2). They are mapped in Figure 4-3.

**Table 4-2.** Final set of selected receiving-water sites.

| Stream name | Drainage area ($mi^2$) | DIANA-12 cluster (see Figure 3-1) | USGS gaging station* |
|---|---|---|---|
| Maria Ygnacio Ck (Goleta) | 6 | 11 | 11119940 |
| San Jose Ck (Goleta) | 6 | 11 | 11120500 |
| Mission Creek | 8 | 6 | 11119750 |
| Aptos Creek | 25 | 6 | (11159690, 11159700) |

| Stream name | Drainage area ($mi^2$) | DIANA-12 cluster (see Figure 3-1) | USGS gaging station* |
|---|---|---|---|
| Carpinteria Creek | 13 | 11 | 11119500 |
| Atascadero Creek | 19 | 5 | 11120000 |
| Orcutt Creek | 19 | 1 | (11141050) |
| Lopez Ck (Arroyo Grande) | 21 | 1,6 | 11141280 |
| San Simeon Creek | 26 | 8 | (11142300) |
| Corralitos Creek | 28 | 1, 3 | 11159200 |
| Alamo Pintado Ck (Solvang) | 29 | 6, 11 | 11128250 |
| Zaca Creek (Buellton) | 33 | 11 | 11129800 |
| Gabilan Creek (Salinas) | 37 | 1, 2 | 11152600 |
| Soquel Creek | 40 | 6 | 11160000 |
| Chorro Creek | 45 | 11 | - |
| Big Sur River | 46 | 5 | 11143000 |
| Salsipuedes Creek | 47 | 6, 11 | 11132500 |
| Santa Rosa Creek | 47 | 6 | - |
| Santa Cruz Ck (Santa Ynez) | 74 | 12 | 11124500 |
| San Luis Obispo Creek | 84 | 10 | - |
| Upper Cuyama River | 90 | 7, 11 | (11136500, 11136600) |
| San Lorenzo River (Santa Cruz) | 106 | 5 | 11160500 |
| Nacimiento River | 162 | 1, 4, 11 | 11148900 |
| Carmel River | 193 | 5, 6 | 11143200 |
| San Antonio River | 217 | 8 | 11149900 |
| San Lorenzo Creek (King City) | 233 | 8 | 11151300 |
| Arroyo Seco | 244 | 1, 11 | 11152000 |

* USGS gage numbers in parentheses were not part of the hydrologic analysis by virtue of insufficient length and/or quality of record.

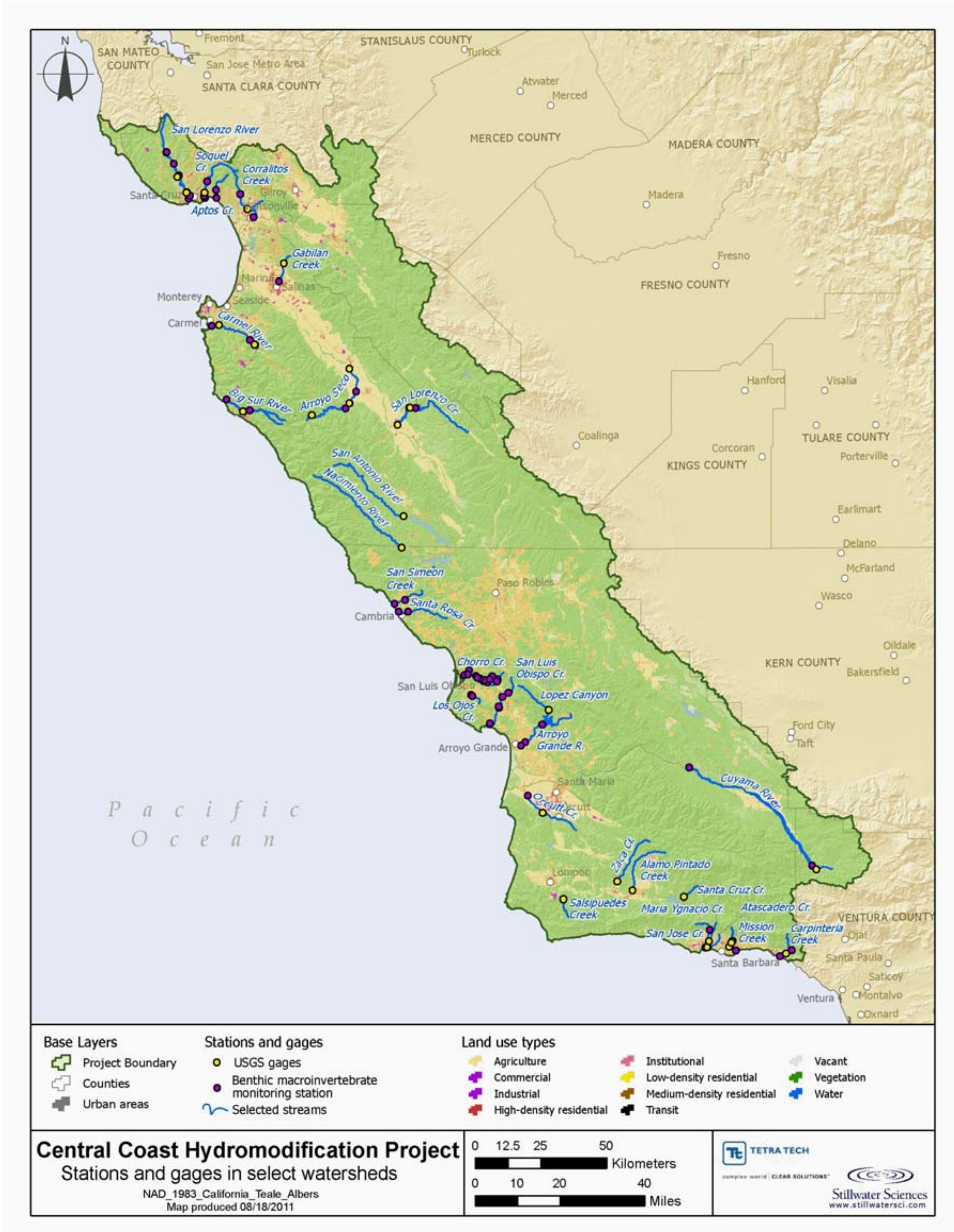


**Figure 4-3.** Map of selected receiving waters and locations of data.

## 4.5 Results—Receiving-Water Conditions

We present the results of this investigation in two parts—a summary compilation of data for those streams listed in Table 4-2 that have biological and, in most cases, also hydrologic information (Section 4.4.1, organized geographically), and additional regional data originally compiled and presented by others that do not directly apply to our selected waterbodies but which nevertheless provide useful insights for the upcoming work of Task 4 (Section 4.4.2, below).

### 4.5.1 Selected receiving waters

#### 4.5.1.1 Santa Cruz area

**San Lorenzo River** is the largest river system flowing into the Santa Cruz urban area. The headwaters are flanked by lush vegetation, including redwood trees, and cascading streams tumbling from the resistant geology composing the hillsides. The river drains an area of 106 square miles at the long-term USGS gage in the system, located approximately 2.5 miles upstream of the Pacific Ocean. A large portion of the river's length is flanked by at least a modest level of residential development, with increasing density in the general downstream direction. As the river enters the core of urban Santa Cruz it becomes increasingly straighter and confined. Two USGS gages with an extensive period of record occur along the San Lorenzo River. BMI monitoring stations have been established along much of the length of the river, providing an opportunity to compare those sites downstream of varying levels of urbanization with those upstream of all but a few, relatively small residential zones. In all, nine BMI monitoring stations provide varying levels of data covering the previous 10 years. For example, the lower-most (304LOR) reported an average of 1 EPT taxa over 6 years of monitoring; only 1.6 miles away (but above most though not all urban development) at station 304RIV, the average was a better (though still depauperate) 5. Between these two sites, a CRAM assessment captures some degree of degradation in every metric though perhaps understates the degree of biological impairment suggested by the BMI results.

**Soquel Creek** is situated in the northwestern corner of the Central Coast, extending upstream from the City of Santa Cruz into the Coast Range mountains. The creek encompasses a drainage area of approximately 40 square miles at the site of the USGS gage (11160000), approximately 1.6 miles upstream of the mouth of the creek at the Pacific Ocean. The upper reaches of the watershed are moderately steep hillsides with residential development interspersed with lush, dense forest. Thick forests blanket the hillslopes in the upper extent of the water, while urban development expands in area as the creek progresses to the mouth. Eventually, Soquel Creek winds its way through the eastern flanks of the city of Santa Cruz, with the associated impacts of confinement and straightening as it progresses downstream. The long-term USGS gage now lies completely within the urban corridor. An upper BMI station is located downstream of relatively little development and/or agriculture, and two additional BMI stations have been established near the mouth in the urban center. The upstream BMI station (304SOU), above most development and agricultural influence (but not above an open-pit mine) reported 16–17 EPT taxa and a total taxa richness of 27–31 across the two years monitored (2005–2006); the lowermost BMI station (304SOQ) reported a widely varying 0 to 19 EPT taxa and a total richness between 24 and 27 for the years 2001–2004. Near the lower BMI station, a CRAM assessment also reported degraded conditions, particularly with respect to buffer integrity and hydrologic alteration.

**Corralitos Creek** is located in the southeastern portion of Santa Cruz County; the watershed includes the eastern side of the City of Watsonville. Corralitos Creek flows approximately 13 miles before its confluence with the Pajaro River. At the USGS gage, a few miles upstream of the Pajaro River, Corralitos Creek drains approximately 28 square miles. Its headwaters are primarily forested, but downstream the creek flows through agricultural zones and finally through the densely populated urban area of Watsonville. Corralitos Creek was listed on the 2006 Federal Clean Water Act section 303(d) List of Water Quality Limited Segments. A BMI station (305COR2) lies significantly upstream of the USGS gage, while another site (305COR) lies in the midst of development (Figure 4-4). Visually, the creeks are deeply incised and impaired by an enormous influx of fine sediment and agricultural runoff; and all channels in the lower reach are confined and straightened and many are leveed. A CRAM evaluation near 305COR2 inferred significantly altered hydrology and compromised buffers.



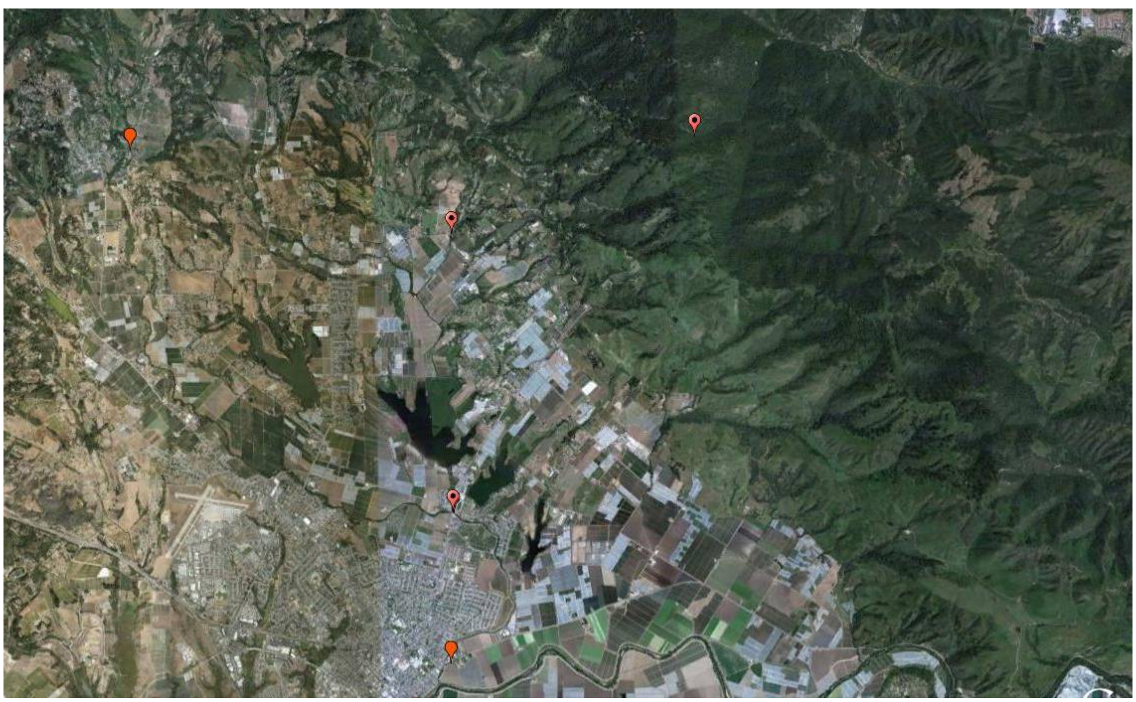

**Figure 4-4.** Corralitos Creek and the city of Watsonville (urban area at lower edge of bottom image, from GoogleEarth). Upper left red pin is BMI station 305COR2; downstream about 10 river miles is station 305COR. Upper left photo is of the lower river (red pin with black dot, between the two BMI stations and just southwest of Kelly Lake); upper right photo taken at the pin in the mountains to the north-northeast of town.

**Aptos Creek** empties into the northern edge of Monterey Bay after draining 24.5 square miles of mostly mountainous terrain. The area is highly influenced by the large amount of annual precipitation, and this is largely expressed in the abundant vegetation of the area, including coastal redwoods. Almost half of the watershed is a designated State Park (Nisene Marks). Two USGS gages (11159690 and 11159700) were operational in the watershed on the two main tributaries for more than a decade each, but the last was discontinued in 1983. Two BMI monitoring stations provide an opportunity to compare a largely undisturbed system with that of one experiencing increasing urban expansion, although the reported data do not clearly support preconceived expectations. The uppermost BMI monitoring station, 304APS, drains an area dominated by the State Park, some roadways, and otherwise densely vegetated hillsides; the averages from 2 sampling events in in 2005 and 2006 present a picture of good, but by no means exceptional biological conditions: 12 EPT taxa, 2% tolerant taxa, and 3% intolerant taxa. The lowermost station, 304 APT, is located less than 0.5 mile from the coast, just below Highway 1 in the heart of downtown Aptos; the averages from four sampling events from 2001–2007, however, differed only modestly from those farther upstream: 8 EPT taxa, 15% intolerant taxa, and 12% tolerant taxa. The watershed was listed as impaired by sediment and pathogens in 2003.

#### 4.5.1.2 South (and east) of Monterey Bay

**Gabilan Creek** drains westward from the resistant granitic slopes of Fremont Peak, through grazing and agricultural zones, and finally through the City of Salinas where it is channelized and straightened before reaching the Salinas Reclamation Canal. The entire creek length is approximately 22 miles. The upper reaches consist of steep canyons of forested terrain, as well as grazing. After Old Stage Road the creek begins flowing through a narrow cultivated valley for approximately 3 miles before ultimately reaching the heavily cultivated Salinas Valley. Gabilan Creek has an accumulated a drainage area of 37 square miles at the site of a long-term USGS gage (#11152600) which remains upstream of the reach of urbanization but wholly within an agricultural production zone. No BMI stations have been established upstream of the gage, but one is located within the town of Salinas, and another on the adjacent tributary Natividad Creek on the edge of the urban growth. Several BMI stations and another USGS long-term gage are located downstream of the Gabilan Creek–Salinas River confluence in the Salinas River Reclamation Slough. BMI monitoring at both the Gabilan Creek and Natividad Creek, for all years monitored (2005–2009), yielded ratings of very poor.

**Carmel River** is an elongate east–west trending river draining the steep, resistant granitic and metasedimentary slopes of the Santa Lucia Range. Though the river is partially constrained by roads following the narrow floodplain along much of its course, the Carmel River watershed as a whole has relatively less land-use impairment than other rivers in the region. Two BMI stations, closely associated with USGS gage stations, have been established along the mainstem—one upstream of essentially all development (307CMU, with gage 11143200) and one 11 miles downstream at the US Highway 101 crossing (307CML, gage 11143250; see Figure 4-5). Despite rather modest land-use impacts, both sites reported consistently "very poor" biological conditions through two (upper) and six (lower) years of monitoring. In contrast, CRAM assessments report near-average conditions near the lower BMI site and above-average conditions near the upper site.


**Figure 4-5.** Aerial view of the lowermost 6 miles of the Carmel River (from GoogleEarth), showing most of the land-use disturbance that contributes runoff to BMI station 307CML (at red pin near left edge of image). Nearly all of the rest of this 247-$mi^2$ watershed is minimally disturbed by human activity.

**Big Sur River** drains approximately 46 square miles, dominated by a granitic geology. The Big Sur watershed is relatively unimpacted through most of the area (Figure 4-6), with moderate levels of human land use only close to the mouth. Monitoring for benthic macroinvertebrates and water quality by both Central Coast Long-term Environmental Assessment Network (CCLEAN) and Monterey Bay National Marine Sanctuary (MBNMS) has been conducted at two sites over the past decade. The upstream-most biological monitoring station lies above the development in the basin at the USGS gage. The lower site lies below several developments, including a state park and the section of the river adjacent to the coastal highway. The upstream site shows predictably high-quality conditions, with 14–19 EPT taxa in 2002 and 2003. Our field visit to this locale revealed a free-flowing cobble-bed river with clear water and stable channel boundaries. Even the lower site showed between 6–15 EPT taxa between 2002 and 2007, with comparative values for tolerant and intolerant taxa; they suggest measurable impacts from even this low level of human disturbance, but with significantly less consequences than seen in the more urban or agricultural landscapes elsewhere in the region. Somewhat counterintuitively, CRAM assessment scores for these two sites report an inverse relationship between them, with the downstream site reporting significantly better conditions than the upstream site.


**Figure 4-6.** Big Sur River (left panel, from GoogleEarth), with the downstream and upstream BMI sites (red pins, upper left corner and middle right). Photo in right panel taken at red pin with black dot; the two BMI stations are about 5 miles apart.

#### 4.5.1.3 Santa Luis Obispo and vicinity

**San Simeon Creek** drains a 35-$mi^2$ watershed originating in the Santa Lucia Range, just north of the coastal town of Cambria (Figure 4-7). The watershed is primarily underlain by Franciscan mélange, a rock mixture that allows little infiltration and is prone to erosion. Human land uses are limited to roads and ranching in the upper watershed, although some agriculture in the form of grape growing occurs in the South Fork San Simeon Creek. The nearest population center, Cambria, is in the neighboring watershed of Santa Rosa Creek. The creek has two main forks, the north and south, which converge at about stream mile 6.2. There is no USGS gage in the basin. A BMI monitoring station is located in the upper watershed that drains an area mostly used for ranching and grazing; the lower BMI station is located downstream of both grazing, but also some fields with row crops and very low-level residential development. Sampling results from the two stations are similar: EPT taxa were 15 for both; percent intolerant averaged 32% at the upper (310SSU) and 22% at the lower (310SSC). Tolerant taxa, however, differed more—10% at the upper and 29% at the lower. CRAM evaluations in the vicinity of the two sites also returned similar scores to each other, but identified the lower as having slightly better conditions than the upper one.

**Figure 4-7.** Watershed of San Simeon Creek (from GoogleEarth; upper boundary marked by yellow line, upper right corner). The two BMI sites (red pins) are about 4 river miles apart, with only modest disturbance occurring between them.

**Santa Rosa Creek**, not far south of San Simeon Creek, lies centrally along the Pacific coast in an expanding vineyard region, although the dominant land use (in terms of area) continues to be grazing. The small seaside town of Cambria is the only significant urban center in the watershed. The watershed is composed of multiple rock types, but the area is overwhelmingly dominated by Franciscan mélange, recognized for its instability and erosivity. There are no USGS gaging stations identified in Santa Rosa Creek, but a BMI assessment was conducted and a resultant report has been produced, a project funded by a California Department of Fish and Game (CDFG) grant received by Greenspace–The Cambria Land Trust (CCSE 2010). Six sites were sampled, both upstream and downstream of the town of Cambria. The Southern California Index of Biological Integrity scores for the sites upstream of Cambria reported good to fair conditions. Two lower sites, located within and downstream of town, both received scores of “poor”; but one downstream-most site suggested partial recovery of biological conditions and a rating of “fair.” Two CRAM assessment sites do not follow this trend, with that upstream of Cambria showing a lower rating than that located well within the urbanized area.

**Chorro Creek** comprises the northern half of the Morro Bay watershed in the west-central portion of the Central Coast Region, flowing through the Morro Bay Salt Marsh into the bay just upstream of the town of Morro Bay. Extensive ranching and farming, but little urban development, occupies the watershed. Although it has no USGS flow gage in the watershed, six BMI monitoring stations have been sampling at various locations in Chorro and Los Osos creeks since 2001. Three tributaries to Chorro Creek have been sampled at various times in the previous ten years. Two sites in Chorro Creek are located just upstream and just downstream of the small Chorro Creek dam; the remaining four sites are located downstream of ranching, development and row crops. The upstream site in Cattle Creek lies above the cattle enclosure (approximately 1 mile) and the downstream site lies above a golf course. Water quality monitoring for sediment and pollutants is being conducted by several entities, including the Irrigated Agriculture Program of the Central Coast Regional Water Quality Control Board, the US Environmental Protection Agency, the California Coastal Commission, the Central Coast Ambient Monitoring Program (CCAMP), the Morro Bay National estuary Program (MBNEP), and the Department of Fish and Game Wildlife Conservation Board. Over the past 15 years, stakeholders have made significant efforts to restore the Chorro Creek watershed. Once designated as an impaired system for sediment and pollutants, several water quality restoration efforts have been implemented in the watershed and the creek has now been removed from the state's 2008 CWA section 303(d) list of impaired waters for dissolved oxygen. Despite these efforts (and moderately high CRAM assessment scores accompanying them), biological data at the BMI sampling stations show almost uniformly "poor" to "very poor" conditions both upstream and downstream of the major restoration work (that at Chorro Flats, completed in 2002), both before and after implementation of the project, as assessed by the Southern California IBI (Ode et al. 2005).

**San Luis Obispo Creek** drains an 84 square mile area at the USGS gage, including the City of San Luis Obispo, before it meets the Pacific Ocean at Avila Beach. San Luis Obispo Creek originates in the Cuesta Grade area north of San Luis Obispo, on the western slopes of the Santa Lucia Range (Figure 4-8). Two mainstem stations and the tributaries of Stenner, Prefumo, and Davenport creeks have been monitored for BMI data sporadically over the past 9 years, with two years (2002 and 2003) well-represented in all data sets. The farthest upstream station, 310SLC in Cuesta Park, lies above most development zones; ranching does persist upstream of the station, and so this may serve as an indicator of conditions in response to predominantly agricultural (but not residential) land uses. EPT taxa were 10–13 in those two years of monitoring, with 7% intolerant taxa and 19–22% tolerant taxa. During our field visit, aquatic worms but no EPT taxa were seen in a cursory examination. Downstream in the center of the city (310SCN), the channel has been severely stabilized but some habitat features have been constructed; EPT taxa were 2–6 in the same two years, with 0–1% intolerant taxa and 33–41% tolerant taxa. Field observations showed very few individuals, but with less algae than the upstream site and a single mayfly/stonefly. Below most of the urban development (310SLV), the results were 0–1 EPT taxa, 0% intolerant taxa and 36–50% tolerant taxa; in the field, the bed was predominantly sand with heavy algae growth and no EPT taxa observed.

Conditions recover marginally at the BMI station at the mouth of the creek (310SLB, not shown in Figure 4-8), with the most extensive monitoring history. It has shown relatively few EPT taxa (1–6), low intolerant taxa (one sample at 22%, the others at 0%), and up to 35% tolerant taxa. The creek still has a Southern California IBI rating of "very poor" at this location, however, which provides a curious contrast with a CRAM assessment score that is close to the calibration data set's average here and is higher than every other site on the stream, including one upstream of nearly all urban development.


**Figure 4-8.** San Luis Obispo Creek, from its headwaters (ridgeline at extreme right in the GoogleEarth image) downstream through the town of San Luis Obispo (the large urban area at left-center). BMI stations shown with red pins, photo locations are red pins with black dot. Upper photos, upstream-most site (310SLC) with no upstream urbanization but significant grazing through Cuesta Park; lower left, through center of town (site 310SCN); lower right, below most urbanization (site 310SLV). Distance from upstream to downstream site is about 4 miles; downstream site is ~6 miles from Pacific Ocean.

**Arroyo Grande and Lopez creeks** both lie within the Arroyo Grande watershed, flowing from the Coastal Range into Lopez Reservoir. The USGS gage in Lopez Creek, above the reservoir, has been collecting flow information since 1956. The reservoir discharges into Arroyo Grande Creek, which ultimately drains the west flank of the coast range, along with the towns of Arroyo Grande, Pismo Beach, Avila Beach, Grover Beach and Oceano, all of which have grown substantially over the past decades, resulting in expanses of urban development and agricultural areas. Upstream of Lopez Reservoir, the Arroyo Grande Creek watershed is predominantly undeveloped land. Arroyo Grande Creek from Lopez Dam downstream to approximately Fair Oaks Boulevard, a distance of 10 miles, has a natural channel. A BMI station, 310AGB, is located just downstream of the reservoir at Bittle Park, and represents a reach impacted by the reservoir and agriculture, but as mentioned, little to no urbanization has occurred upstream of the reservoir. The lower reach of Arroyo Grande Creek, downstream of Fair Oaks Boulevard to the Arroyo Grande creek lagoon, a distance of approximately three miles, has been channelized for flood control protection.

The Central Coast Ambient Monitoring Program (CCAMP) program has been collecting BMI data at four monitoring stations, most within the lower half of Arroyo Grande Creek, and some since 2001. The lower sections of river have resulted in ratings of “poor” and “very poor” where ratings have been designated. The BMI station just below Lopez Reservoir shows an average % EPT of 16–31 and a total richness of 16–19 from sampling in 2002 and 2003. These values are slightly improved compared to those mainstem and tributary stations in the lower reaches, of which the lowermost has averaging % EPT of 14 and Total Richness of 13 from sampling in 2002–2007. CRAM scores for two sites on lower Arroyo Grande Creek similarly reflect degraded conditions, particularly with respect to inferred hydrologic alteration and the physical structure of the channel.

**Orcutt Creek** drains the western flank of the Santa Lucia Mountains through the Santa Maria Valley in northwest Santa Barbara County. The town of Orcutt is a suburb of neighboring Santa Maria to the north and is one of the fastest growing communities in the county. Much of Orcutt Creek is channelized and straightened as it flows through the town and the agricultural fields downstream. A USGS gage has been operating since 1982 and lies downstream of residential development and agricultural areas. Multiple BMI monitoring stations are active in the lower reaches of Orcutt Creek and smaller tributaries. The lowermost, Station, 312ORC, upstream of the confluence with the Santa Maria River estuary, lies adjacent to an aggregate mining operation; its one reported sample in 2001 found no EPT taxa and no intolerant taxa. Orcutt Creek is considered to be a major contributor of pollutants to the impacted Santa Maria Estuary, where fish tissues had detections of a number of different fungicides, herbicides, and pesticides, according to a 1996 study done by UC Davis Marine Pollution Studies Laboratory and the US Geological Survey (Huckaby 2011).

#### 4.5.1.4 South Coast

**Maria Ygnacio, San Jose, and Atascadero creeks** flow parallel to each other for much of their length, joining together to form Goleta Slough just south of the Santa Barbara Airport in the city of Goleta. All three streams have long-term USGS gage data dating back to 1970, 1940, and 1942, respectively. Although smaller in drainage area, Maria Ygnacio and San Jose creeks reach high up into the Santa Ynez Mountains, whereas the watershed area of Atascadero Creek is at much lower elevations (with proportionately much more urban development). In total, Ecology Consultants (2011) have collected and analyzed benthic macroinvertebrate (BMI) data at 11 sites, ranging from reference sites high up Maria Ygnacio and San Jose creeks (the latter achieving an index rating of "Good", the second-highest of their 5-category scale) to two sites on Atascadero Creek below most urban development in Goleta (and both with corresponding ratings of "Very Poor"). One measured site on San Jose Creek, several miles below the reference site but primarily affected by drainage from orchards and scattered residential development, had a rating of "Fair" (mid-point of the scoring range). Of these channels only San Jose Creek has a CRAM evaluation, yielding a modestly sub-average score with significant inferred hydrologic degradation.

**Mission Creek** drains a watershed whose physiography is similar to that of Maria Ygnacio and San Jose creeks, and overall is quite common along the Santa Barbara coast (and other coastlines farther north in the Region). The upper reaches begin in primarily resistant Early Tertiary sandstone that forms the ridges of the Santa Ynez Mountains, descending steeply to cross the urbanized coastal plain. Multiple USGS gauging stations have been operational since 1970, including three with real-time data available. Six BMI sampling sites have been established by the City of Santa Barbara along Mission Creek (Ecology Consultants 2011); at the lowest, the channel drains a watershed about 11 square miles in size. Benthic macroinvertebrate sampling at these and other sites along the channel network has occurred every year since 2002. Sampling results demonstrate that water quality and macroinvertebrate abundance and taxa are consistently lower at sites downstream of residential development as compared to the reference site high in the watershed, draining a relatively undisturbed area. The City's monitoring program has documented long-term "Good" ratings at the monitoring site below State Route 192, upstream of most residential development in Santa Barbara (it also documented a one-year drop to "Poor" in consequence of recent fires); it also shows a very persistent rating of "Very Poor" at the two downstream-most sites, below nearly all of the urban drainage delivered to the creek.

**Carpinteria Creek** lies about 8 miles east along the coast from Mission Creek and occupies a similar physiographic setting, with headwaters in the steep uplands of the mountains above the southern Central Coast Region, flowing through agricultural and then urban development before reaching the Pacific Ocean. In contrast to Aptos Creek discussed above, Carpinteria Creek displays a classic relationship between biological conditions and urban development (Figure 4-9): City of Santa Barbara site 315CAU lies at the Highway 192 crossing, above all but scattered large-lot residential development and orchards; sampling in 2001 and 2008 found 11–13 EPT taxa. Site 315CRP, a few hundred yards upstream of the coastline and below US 101 and the town of Carpinteria, found between 1 and 4 taxa over the same period. Using the index scoring ratings from Ecological Consultants (2011), the biological condition of the lowermost site (C1 in their report) is "Very Poor"; the upper site (C3), "Good."


**Figure 4-9.** Carpinteria Creek, downstream (upper left) and upstream (upper right) of the town of Carpinteria and US Highway 101. Lower image from GoogleEarth shows the location of the two photos (red pins) relative to the surrounding land cover; they are about 1.5 miles apart from each other.

#### 4.5.1.5 Interior drainages

**Arroyo Seco** drains the Coast Range to the east, eventually draining into the Salinas River just south of the town of Soledad. The watershed is approximately 244 square miles in size above USGS gage 1115200 and is composed of mostly Tertiary rocks with areas of Franciscan mélange in its headwaters. Grazing and agricultural production dominate the landscape. Very little development aside from sparse residential units exists in the watershed as a whole, and the production of row crops is limited to the floodplain adjacent to the lowermost 11 miles of channel below gage 11152000. Farther upstream, USGS gage 11151870 drains a 113-mi$^2$ area of high relief dominated by grazing and little development besides a small hot springs resort on Tassajara Creek. One BMI sampling data in 2006 at the lower gage (309SEC) found an average of 7 EPT taxa, no intolerant taxa, and 8% tolerant taxa. Curiously, sampling at one other station about 3 miles downstream within the agricultural Salinas Valley (309SET) found similar but slightly *higher* quality results (e.g., average of 11 EPT taxa). Two CRAM assessments upstream of the USGS gage report high-quality conditions; one below the lower BMI station and surrounded by agricultural fields has relatively low-quality conditions.

**San Lorenzo Creek** is a tributary to the Salinas River on the northeastern flanks of the Central Coast Region, a variable topography of steep hillsides composed mostly of sedimentary sandstone of the Tertiary age (although Franciscan mélange occurs in the lower watershed, a legacy of a past location of the San Andreas fault). Land use in the majority of the watershed consists of grazing and ranching, especially in the upper extents where cattle grazing flanks the channel along most of its length. In the lower third of the creek, land use transitions to more agriculture in the flatter floodplain and then to mid-level residential development as San Lorenzo Creek flows through the town of King City before reaching the confluence. The USGS gage and the upstream BMI monitoring station lie above most development and agriculture in the basin, but they are downstream of large tracts of ranching and several in-stream aggregate mining operations. The lowermost BMI station is used to sample the Salinas River, not San Lorenzo Creek, and thus no paired opportunity exists in this system.

**San Antonio River** watershed drains the eastern flank of the Coast Ranges, with a Wild and Scenic river corridor through the upper watershed; it then flows through the Hunter-Ligget military base, where it flows largely undisturbed until its lower reaches. The river is ideal as a reference channel because of the minimal impact through a large portion of the upper watershed. Even in the flat grassland areas, synonymous with row crops, grazing, or development throughout the rest of the region, the landscape has been well preserved in its native condition because of minimal human influence, though a low-density road network does exist. There is one long-term USGS gage in the watershed, just upstream of Lake San Antonio. There are no BMI monitoring stations, but WQ monitoring stations do exist along its course.

**Nacimiento River** originates in the Santa Lucia Mountains and is intercepted by Lake Nacimiento before reaching its confluence with the Salinas River. The San Antonio River lies just to the northeast and flows nearly parallel to the Nacimiento River. Nearly the entire watershed is composed of extensively folded and faulted Tertiary sedimentary rocks and Mesozoic metasedimentary rocks, with some outcrops of Franciscan mélange throughout. No BMI monitoring stations have been established in the watershed, but a USGS gaging station just upstream of Lake Nacimiento has been operational since 1971. Little human influence exists in the watershed, especially in the upper watershed, and the most widespread land use is cattle grazing. Two adjacent CRAM assessments near-average conditions in the channel downstream of the lake, with significant inferred alterations in hydrology balanced by excellent buffer conditions.

**Upper Cuyama River** flows through a broad valley of deposited alluvial sediment, eroded from the Tertiary sandstones that compose most of the surrounding hillsides and steep mountains. The hydrology of the Cuyama River in the upper watershed is very episodic, flowing during spring runoff and during large rain events. The river is wide and shallow when it is flowing, and carries a very large sediment load, with few larger substrates in the channel and little riparian vegetation, even in the relatively undisturbed portion of the upper watershed. The upper watershed of the Cuyama has a single gage that has been in operation since 1945. Two BMI monitoring stations are located in the upper watershed—one lies upstream of most human impacts and represents relatively undisturbed watershed conditions. Downstream approximately 40 miles is another BMI monitoring station; here, the river has since crossed a landscape with farming, ranching and some small-scale residential development. From sampling in 2007 and 2008 at the uppermost station, BMI results reported % EPT 19–60 and total taxa richness of 10–18. The lowermost site, from a year-2000 sampling, did not report these metrics but found 31% tolerant taxa and 0.0 % intolerant taxa.

### 4.5.2 Summary of conditions in receiving waters of the Central Coast

These findings emphasize "streams" because they are found everywhere throughout the Region and these receiving waters express obvious visible responses to many types of disturbance (hydrologic, chemical, physical, etc.). Streams also provide a conduit by which altered conditions of water quality and biological health are passed downstream. We therefore expect these findings can provide valuable insight into the known or inferred condition of those other types of receiving waters that cannot be as directly measured or observed.

#### 4.5.2.1 This study

Of the many thousands of streams, rivers, lakes, and wetlands in the Central Coast Region, our review of the compiled data from less than thirty streams can only provide anecdotal evidence for receiving-water conditions as reflections of intrinsic watershed properties and landscape disturbance. Nonetheless, certain trends are so apparent that they emerge even from this limited subsample.

- Streams draining relatively undisturbed parts of the Region, notably the mid- to upper-elevation watersheds primarily in National Forest lands, typically exhibit stable morphology, episodically mobile sand-and-cobble beds, and varied populations of macroinvertebrates. Channels lower in the drainage network but still with a preponderance of undisturbed or only lightly disturbed watershed area tend towards wide, shallow channels with sandy beds and more active patterns of migration and local bank erosion, particularly in the drier eastern parts of the Region where these conditions of minimal watershed disturbance are more widespread. These channel attributes are typical of semiarid regions with episodically high sediment loads; they do not represent a pervasively "degraded" channel morphology, despite their divergence from an idealized single-thread meandering river common to more humid regions.
- In contrast, streams draining across the central valleys and coastal terraces of the Region, where grazing and/or more intensive agriculture or urban development are almost ubiquitous, display abundant evidence of physical and biological degradation. As reported in most other parts of the world, urbanization appears to impose the most severe impacts of any land use on stream channels where it occurs; however, its effects are spatially restricted relative to the Central Coast Region as a whole. The effects of grazing, in particular, show a strong dependency on watershed attributes, with steep slopes underlain by weak rocks showing the greatest response to trampling, flow concentration, and replacement of woody vegetation by grass.
- Streams in particular watershed settings display characteristic attributes. Across the flat valleys filled with Quaternary sediment (and generally corresponding to identified groundwater basins), channel density is low. Drainage courses that do exist are most commonly associated with the agricultural or roadway drainage and are distributed relatively sparsely across the plain. They typically are subjected to both physical alteration (e.g., ditching, cleaning, etc.) and the effects of pollutant-rich, hydrologically altered runoff; they display clear indicators of high nutrient loads.
- Another common watershed setting in the Region, steep mountain and foothill streams that emerge onto a populated coastal plain, exhibit marked downstream changes in channel attributes that reflect the combined influence of geology, topography, and land use. Channels of the South Coast (Atascadero, Mission, and Carpinteria) transition rapidly from cobble- and boulder-cascade morphologies with clean water and healthy benthic

populations to lowland gullies (in some cases, concrete-encased) incised into their own debris fans with heavy macrophyte growth and poor biological diversity.

- Hydrologic analysis of the data local to the Central Coast, to date, has not revealed statistically significant trends. Findings from elsewhere in southern California, however, suggest that increased peak discharges, likely from subsurface flow converted to surface runoff, are almost certain to be associated with urban development here as well.
- Although most streams show clear indications of degradation as they pass through urban areas, not all do. Aptos and Soquel creeks, for example, display only modest declines in BMI indicators as the channel enter more urban areas; closer inspection of these and other examples, however uncommon, may offer some guidance for effective mitigation measures.
- Conversely, stream conditions are not always “pristine” upstream of urban areas; indeed, we have found abundant documentation of degraded in-channel conditions without any watershed urbanization at all. This provides a clear reminder that receiving-water degradation is not the sole purview of urbanization, or that degraded conditions in an urban channel can be wholly corrected by actions within the urban parts of the contributing watershed.

#### 4.5.2.2 Other studies—biological indicators

Results from here in the Central Coast Region echo those from the last several decades of scientific studies from around the world. More local studies, however, can provide additional insight into these relationships. Ode et al. (2005) defined a “Southern Coastal California Index of Biotic Integrity” (SCIBI), with about half of their data collected from the Central Coast Region. They selected seven minimally correlated metrics for the B-IBI: percent collector-gatherer + collector-filterer individuals (% collectors), percent non-insect taxa, percent tolerant taxa, Coleoptera richness, predator richness, percent intolerant individuals, and EPT richness. They found strong, statistically significant correlations between the SCIBI and “percent watershed unnatural” (i.e., the inverse of “natural land”), percent watershed in agriculture, and road density within a “local” zone (defined as 5 km from the measurement site). Channel alteration was also significantly (and inversely) correlated with SCIBI scores.

The data of Ode et al. (2005) were also the focus of a meta-analysis of B-IBI studies from the West Coast (Waite et al. 2010). Of the seven metrics used in Ode et al.’s original study, Waite et al. (2010) used only percent EPT taxa and total taxa richness; the predictor models linking these two response variables to environmental stressors were most strongly (by far) influenced by human population density in the contributing watershed.

Mazor et al. (2010) evaluated the utility of existing bioassessment protocols at 21 low-gradient California stream sites, including 6 within the Central Coast Region. They found a minimum detectable difference between scores using the Southern California IBI between 19 and 22, allowing discrimination of the 100-point index into at most five discrete categories. Their data also showed classic relationships between typical environmental stressor variables (urban and agricultural land cover in the contributing watershed) and biological health (Figure 4-10). As with other studies of urbanization’s effects (e.g., Booth et al. 2004), a low percentage of disturbed land does not guarantee high-quality biological conditions but, conversely, high percentages of disturbed land assure poor conditions regardless of other stream and watershed attributes.

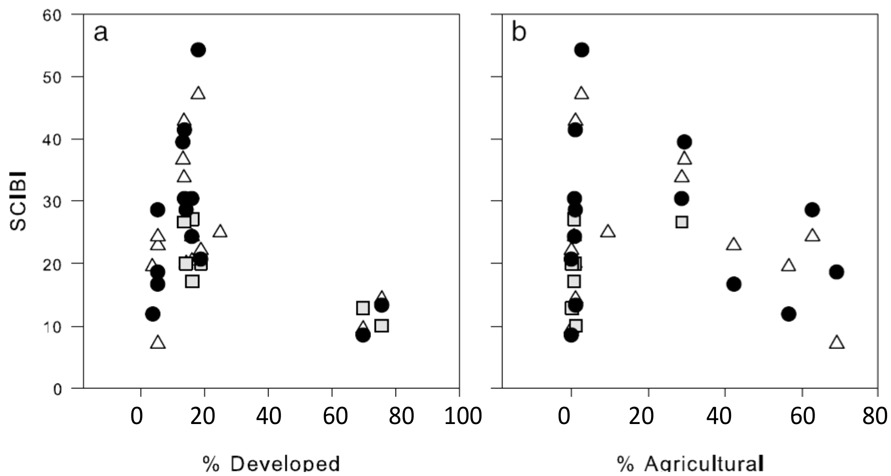


**Figure 4-10.** Southern California IBI scores versus land-cover metrics (each point represents the mean of all samples collected by each of three sampling protocols at each site). Note that the relationships do not suggest a classic linear regression but rather a factor-ceiling distribution (Thompson et al. 2007), wherein any result is possible below an upper threshold for a given level of land cover (reproduced from Figure 4 of Mazor et al. 2010).

#### 4.5.2.3 Other studies—chemical and toxicological indicators

A variety of statewide programs have collected, compiled, and analyzed chemical data from around the Region. The Surface Water Ambient Monitoring Program (SWAMP) has conducted or compiled the bulk of these, of which those relating to sediment and water toxicity are most useful for filling in gaps in our work for the Joint Effort.

SWAMP has compiled multiple data sources into a statewide review of sediment and water toxicity, primarily from rivers, streams and the marine nearshore (Hunt et al. 2010). Overall, they found about 80% of sites were non-toxic where the "local" land use (defined as land use within 1 km of the site; whole-watershed land use was not assessed) was less than 25% agriculture and less than 10% urban. For the sites with either or both of these land uses above their respective threshold, 47% (urban) and 58% (agricultural) of sites had results of at least "low" toxicity, with more than half of those rated "highly toxic" in the study. Sites from the Central Coast Region are illustrated in Figure 4-11.

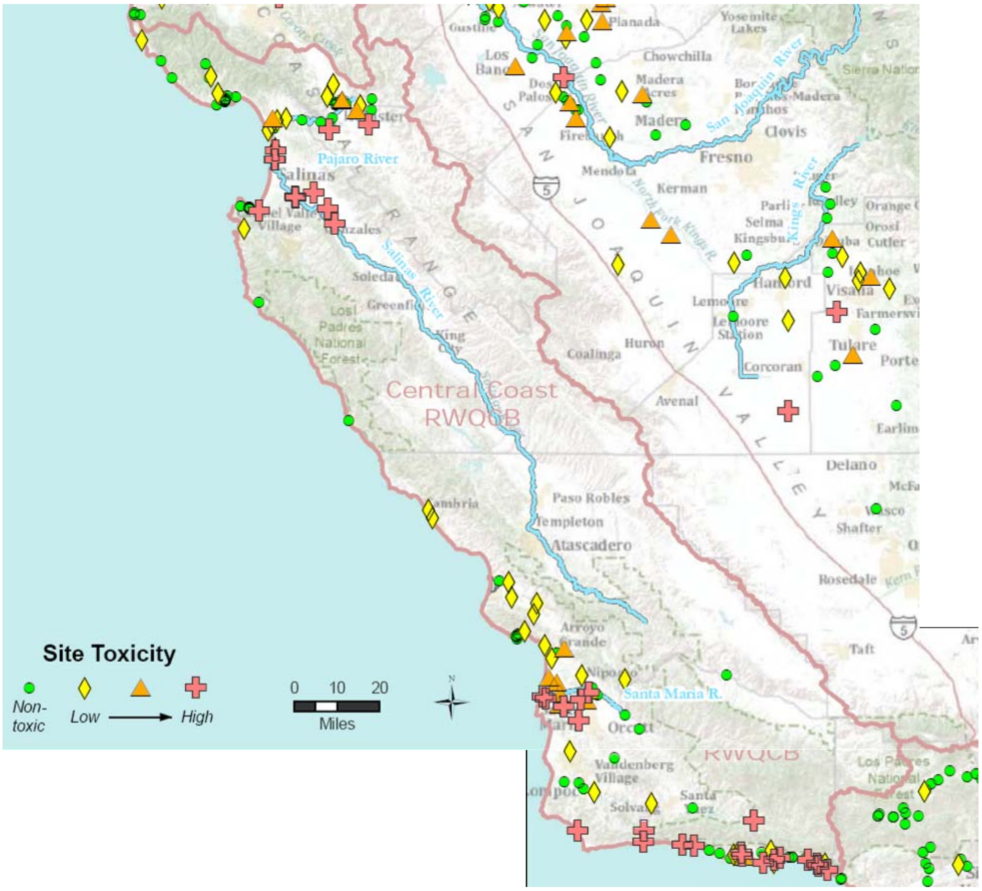


**Figure 4-11.** Magnitude of toxicity at sites in the Central Coast Region, based on the most sensitive species in either water or sediment samples at each site (reproduced from Hunt et al. 2010, their Figure 5). Areas with multiple sites showing severe toxicity are (north-to-south) the Pajero River, the lower Salinas River, the Santa Maria valley, and multiple points along the Santa Barbara coast.

SWAMP also compiled data on contaminants in fish from over 200 lakes across California (Davis et al. 2010), of which 12 are in the Central Coast Region (from north to south, they are Chesbro Reservoir, Loch Lomond Reservoir, Uvas Reservoir, Pinto Lake, Hernandez Reservoir, Lake San Antonio, Lake Nacimiento, Santo Margarita Lake, Lopez Lake, Little Oso Flaco Lake, Lake Cachuma, and Jameson Lake). Of the contaminants likely associated with human land-use activities, the following lakes were identified as having the high category of contaminant concentration(s):

- Little Oso Flaco Lake (downstream of Arroyo Grande and Nipomo, and the agricultural fields north of the Santa Maria River): PCBs (all tested species), Dieldrin, DDT; and
- Chesbro Reservoir (just west of Morgan Hill in the northern-most part of Region, with limited drainage from adjacent residential land uses): PCBs (catfish and carp).
- Pinto Lake (just north of Watsonville, in a mixed agricultural/residential watershed), had lower but still significant concentrations of Dieldrin and DDT.

The lake with the greatest number of detected contaminants (Little Oso Flaco Lake) receives contributions from both urban and agricultural landscapes, as does the less severely impacted Pinto Lake (and to an even lesser extent, Chesbro Reservoir). A cursory review of the other lakes in the Central Coast Region covered by this study indicates that nearly all of the others have very limited amounts of urban or agricultural land uses, again suggesting a good (and not surprising) correspondence between contaminants and upstream human activity.

#### 4.5.2.4 Summary of findings

In summary, the relationships between watershed disturbance and stream-channel condition that we have observed in the Central Coast Region are clearly reflected in other, more focused and systematically analyzed data sets. Virtually all of these other studies, however, have approached these conditions from a purely statistical perspective—they provide no insight into causality, except as it can be inferred from the scientific literature or common knowledge. Task 4 of the Joint Effort will seek the causal linkages between watershed disturbance, altered watershed processes, and receiving-water conditions. This analysis, in turn, should provide a more reasoned basis for tailoring management strategies, including (but not limited to) hydromodification control plans, to the actual conditions responsible for degradation of receiving waters.

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