

DRAFT

Development and Implementation of Hydromodification Control Methodology

Watershed Characterization Part 1: Precipitation and Landscape

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1. Introduction

Watershed Characterization can take many forms. For this effort, the Watershed Characterization focuses on those watershed processes that are related to stormwater management (e.g., infiltration, sediment delivery, runoff). The goal of the Central Coast Joint Effort is to protect or restore key watershed processes that would otherwise be adversely affected by new development and redevelopment occurring in the region. While the Joint Effort is focused on the development of hydromodification criteria for new and redevelopment, the results of the Watershed Characterization provides a foundation for broader natural resource objectives. The balance of natural watershed processes in any area is dictated by the combination of weather patterns and natural landscape attributes. Developing a stormwater management framework to protect those processes first requires a description of the physical landscape attributes and weather patterns present throughout the region, coupled with a scientific understanding of what role they play in determining the dominant watershed processes in an area. Ultimately, the type(s) and locations of key watershed processes can be reasonably predicted on the basis of landscape and weather combinations, and, thus, locally appropriate hydromodification management approaches can be developed.

This document, which represents the deliverable for Task 2 of Phase I of the Joint Effort, characterizes the physical landscape attributes and precipitation patterns that are anticipated to influence watershed processes throughout the Central Coast Region. A companion document, or Part II of the watershed characterization, will be developed during Task 3 and will field validate many of the findings in this report and add information about receiving waterbodies to complete the overall characterization of the watershed. As shown in Figure 1-1, the type(s) and location of watershed processes are influenced by

Precipitation—Essentially all watershed processes begin with rainfall. The spatial variation of rainfall patterns in the Central Coast can influence differences in local watershed responses.

Natural Landscape—The physical attributes of the landscape of any region determine the natural response to rainfall and, therefore, dictates the natural balance of watershed processes in the region.

Developed Landscape—Modification or disturbance of the natural landscape of any region can alter the natural balance of watershed processes in the region. For the purposes of this study, that includes both urban (e.g., imperviousness) and non-urban (e.g., agriculture, grazing) disturbances.

Over the very long-term geologic time scale, natural watershed processes of undisturbed areas will likely remain the same. However, anthropogenic alteration of the physical landscape can be manifest as changes to watershed processes, which in turn can result in altered receiving water conditions. To support subsequent tasks that will identify the type and distribution of natural watershed processes and evaluate the potential hydromodification impacts of development, it is important to characterize each of the three above primary influences on watershed processes on the basis of the best available data at the appropriate spatial scale(s).

Stratification of landscape and precipitation data sets into discrete categories, which are intended to represent homogeneous influences on watershed processes, is a foundational principal of large-scale watershed characterization studies. It reduces the seemingly infinite complexity of landscape and precipitation data sets into tractable groupings and allows an analysis to focus on the most important influences on watershed processes. For the purposes of this study, the term *watershed characterization* entails the full stratification and grouping of precipitation and landscape data (natural and developed) into discrete categories that are understood to most heavily influence local watershed processes. By employing such a stratification approach for this study, the deliverables of this task characterize the dominant precipitation trends, landscape features, and development patterns that are commonly understood to affect key watershed processes and group those characteristics at the appropriate geospatial scale for further analysis.

Section 2 of this report describes the spatial and time series data processing methods employed, while Section 3 describes the watershed characterization (i.e., stratification). Section 4 outlines the efforts expected to take place in subsequent tasks that will build on the characterization work presented in this document. While this document presents the results of the stratification analysis, subsequent work in Part II of the watershed characterization (Task 3 of this project) will complete the watershed characterization process by investigating receiving water attributes and validating landscape attributes in the field. Ultimately, the watershed characterization process will support the identification of watershed process zones, which could lend themselves to specifically tailored stormwater management practices.

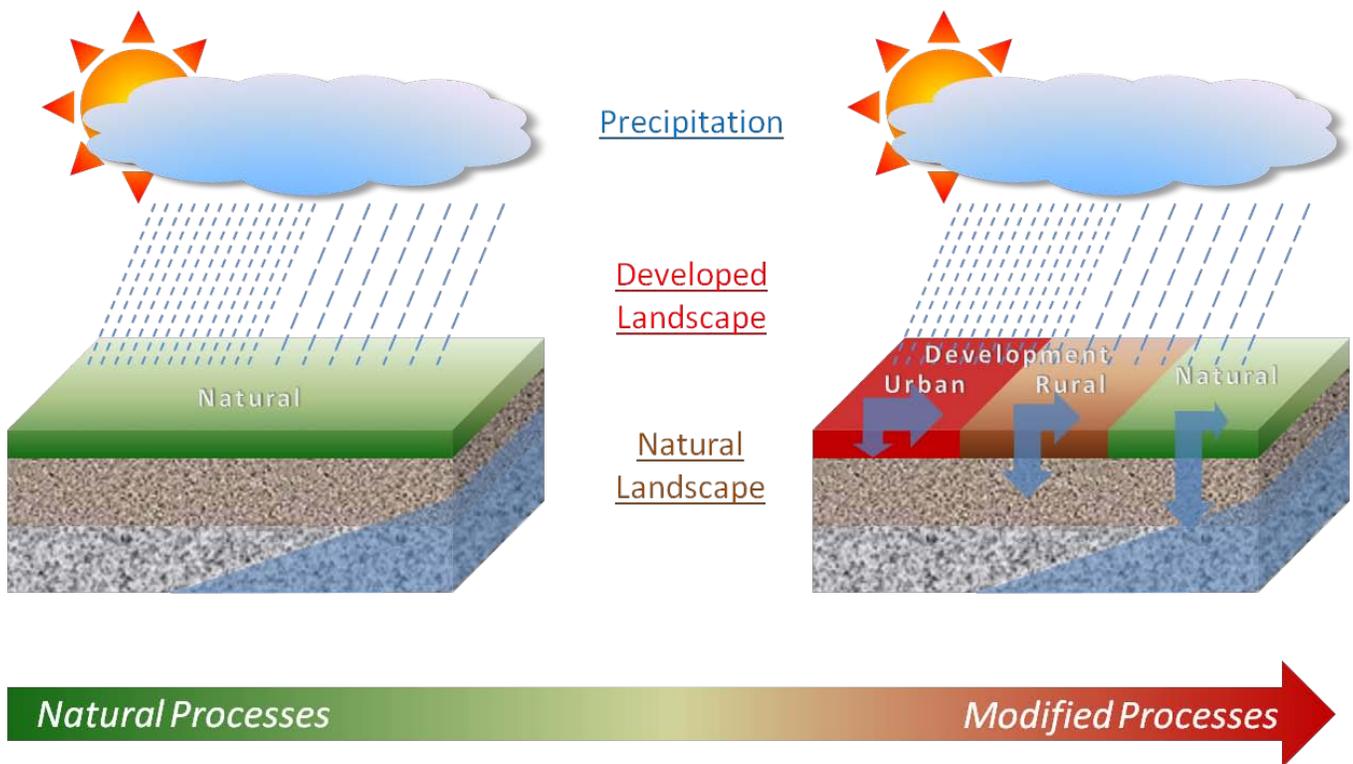


Figure 1-1. Three primary influences on watershed processes.

2. Methods

To understand how precipitation, natural landscape, and developed landscape influence watershed processes, it is helpful to understand the mechanics of the individual physical attributes (Table 2-1). Because each of the attributes contributes a different influence on watershed processes, it is important to prepare a sound, coherent data set with the appropriate spatial or temporal (or both) coverage to inform the characterization analyses (Section 3). Although many data sets were introduced in the Literature and Data Review, this section describes the methods employed to combine specific data into usable data sets to support the characterization process. Those same or additional data might be used at subsequent steps of the Joint Effort.

Table 2-1. Summary of attribute data sets needed for characterization

Watershed process influence	Attribute	Characterization purpose/ influence on watershed processes
Precipitation	Volume	<ul style="list-style-type: none"> Indicator of how “wet” a region is Runoff volume and frequency increases with greater volume
	Intensity	<ul style="list-style-type: none"> Indicator of storm “power” in a region Runoff velocity increases with greater intensity
Natural Landscape	Slope	<ul style="list-style-type: none"> Indicator of how steep a region is Runoff volume, velocity, and frequency increase with higher slope
	Geology	<ul style="list-style-type: none"> Indicator of landscape type Characteristics inform runoff and sediment yield processes
	Soil Types	<ul style="list-style-type: none"> Indicator of hydrologic response Characteristics quantify runoff and sediment yield response
Developed Landscape	Land Use	<ul style="list-style-type: none"> Indicator of land practices Characteristics inform changes in runoff and sediment yield response
	Land Cover	<ul style="list-style-type: none"> Indicator of imperviousness Greater imperviousness causes higher runoff volume, velocity, and frequency

2.1. Precipitation Data

Precipitation patterns play a significant role in determining watershed processes. Both precipitation volume and intensity can be used to examine the potential for surface runoff and erosion in a watershed. While volume is an indicator of relative total water availability, intensity is important for characterizing the potential energy available for surface erosion. In general, high rainfall volume areas with high-intensity rainfall will exhibit a stronger runoff response than low rainfall volume areas with low-intensity rainfall; however, low rainfall volume areas with more intense rainfall events could also exhibit a stronger runoff response than high rainfall volume areas with less intense rainfall.

For this study, recorded precipitation (both volume and intensity) data were compiled for the longest period available to provide a basis for characterizing the temporal and spatial rainfall patterns. The data sets were also quality controlled (i.e., generating *synthetic* data for gaps in existing records using data from nearby gauges) to provide a basis for consistent and reliable spatial and temporal comparison. The output from this effort was a long-term, continuous, rainfall data set with an hourly time step interpolated across the spatial extents of the

region. It is expected that the duration of high-intensity storms and the times of concentration relevant to this spatial scale of the drainage areas in this effort are likely best measured on an hourly time scale. Therefore, long-term, continuous data with an hourly time step are needed region-wide to accurately characterize precipitation intensity, which is measured in units of volume per time. That data set is used in Section 3 to develop maps of the spatial variation of volume and intensity and will be used in subsequent tasks to support any quantitative analyses needed to evaluate surface runoff changes due to hydromodification. The following paragraphs provide an overview of the data processing performed to support the characterization.

Weather data were obtained from three sources—the National Climatic Data Center (NCDC), the Parameter-elevation Regressions on Independent Slopes Model (PRISM) research group, and the California Irrigation Management Information System (CIMIS). The NCDC data were from the Summary of the Day (SOD) and the Hourly Precipitation Distribution (HPD) archives, from which precipitation totals and distributions, respectively, were retrieved and processed. A total of 44 NCDC SOD stations, 98 NCDC HPD stations, and 23 CIMIS stations were analyzed and processed for interpretation. The 44 SOD stations represent relatively current rainfall gages with relatively long periods of record that also capture a good spatial and temporal daily rainfall distribution for disaggregation. The HPD stations were used only for disaggregation of the SOD stations to an hourly time step. For this analysis, 61 years of rainfall data (10/01/1949–9/30/2010) were retrieved and processed. In general, the SOD network has a higher spatial density of rainfall gages than HPD.

The PRISM Climate Group at Oregon State University maintains a meteorological data set that incorporates observed point data, a digital elevation model (DEM), and expert knowledge of complex climatic extremes (including rain shadows, coastal effects, and temperature inversions). PRISM data are recognized worldwide as the highest-quality spatial climate data sets available. Because PRISM takes into account elevation in the spatial interpolation process, the data set is able to better quantify orographic influences in ungaged areas. However, PRISM as a data source provides only monthly precipitation volumes. It does not provide any information about intensity variation throughout the study area. Thus, additional sub-daily rainfall data were collected and assembled from as many local sources as practicable. Because of logistical and funding limitations, hourly data from NCDC were used to develop the spatially distributed time series.

The PRISM data set is quality controlled by its developers; therefore, no further quality control was required. Five spatially distributed NCDC stations were validated against their coincident PRISM grid data and were found to show good agreement. The NCDC precipitation data were recorded with quality flagging information, which was carried through during the processing. Where the data sets contained intervals of missing data, the missing intervals were estimated using weather data at nearby stations with unimpaired data. The method employed to patch that data involved a combination of weighting data from nearby stations and interpolating on the basis of orographic effects as indicated by the PRISM data set.

The amount of patching required at the various stations varied. The next three figures illustrate the variation in precipitation data quality and patching required from the San Francisco Airport gage with one of the highest quality data sets (Figure 2-1), to the Santa Barbara gage (Figure 2-2) which is typical of the quality control performed at most gages, to the Skyline Ridge Preserve gage (Figure 2-3) which became operational in 1995.

The results of this precipitation data processing effort provide complete coverage of hourly precipitation estimates for the entire Central Coast Region using the best available data in the resources of this project. By combining real data with the PRISM weighting methodology, that approach provides the foundation for developing average volume and intensity maps presented in Section 3 and for supporting quantitative analyses in subsequent tasks.

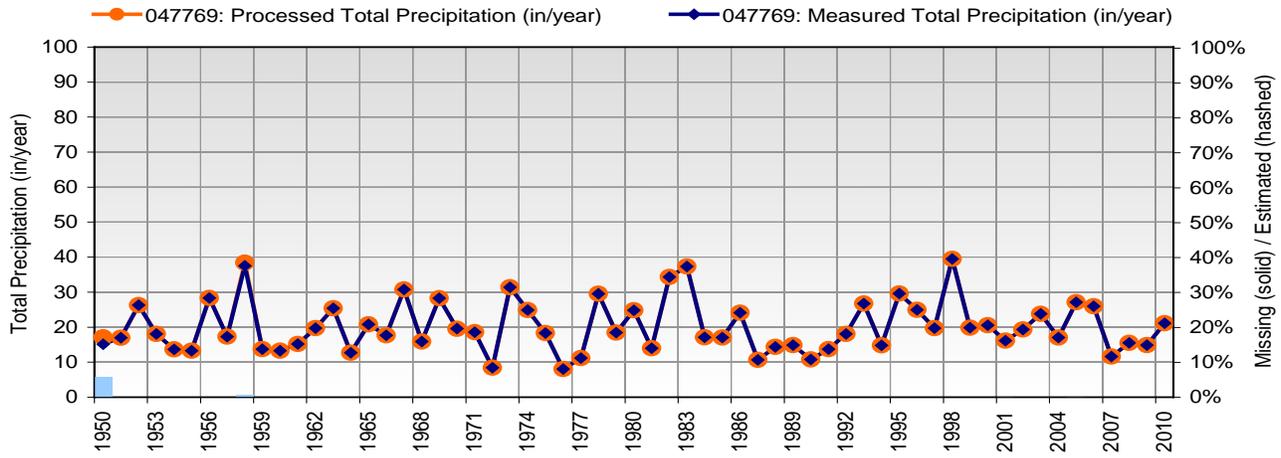


Figure 2-1. Total precipitation at SAN FRANCISCO WSO AP (047769), 1950-2010.

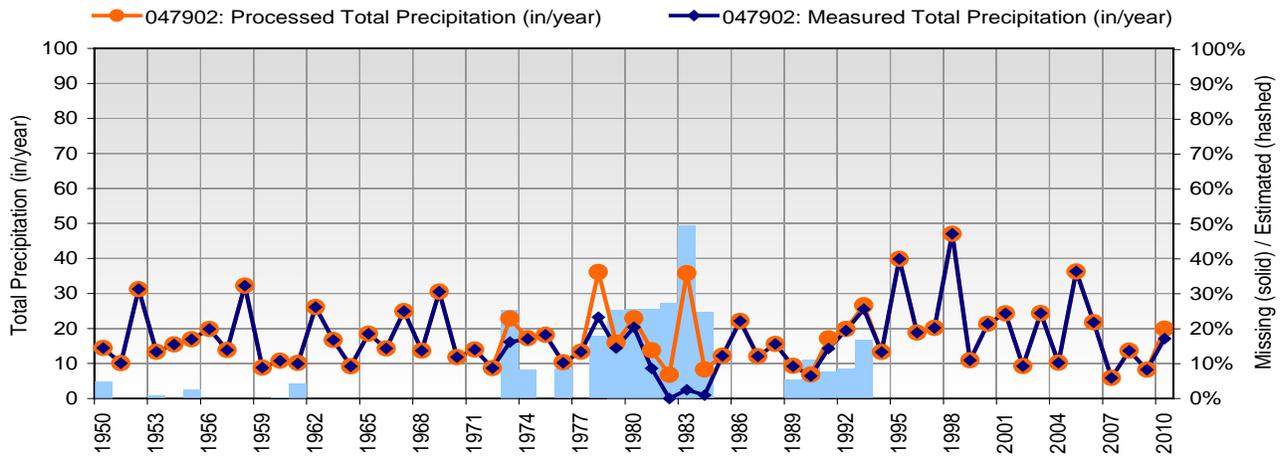


Figure 2-2. Total precipitation at SANTA BARBARA (047902), 1950-2010.

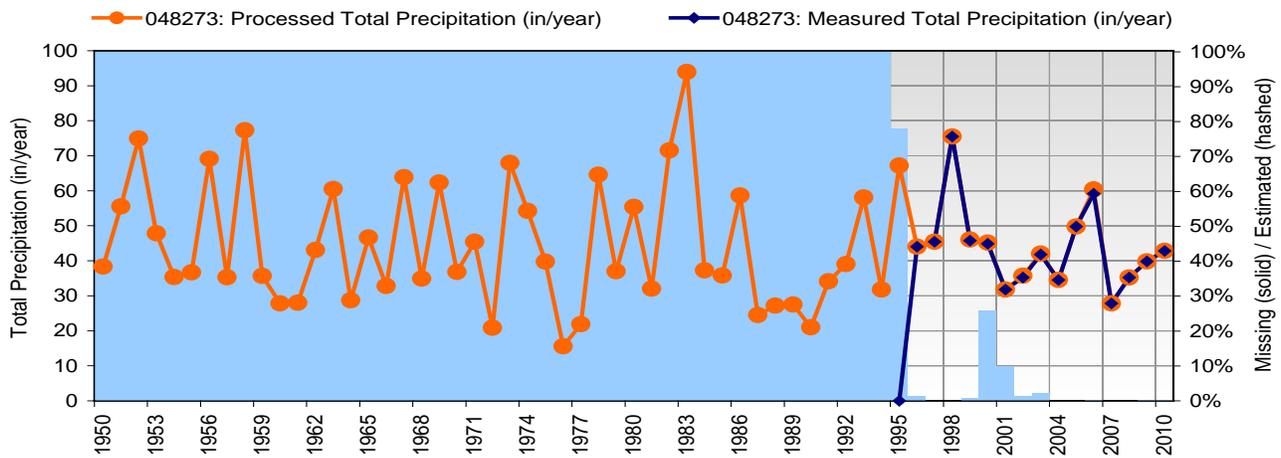


Figure 2-3. Total precipitation at SKYLINE RIDGE PRESERVE (048273), 1950-2010.

2.2. Natural Landscape Data

Landscape characteristics play a key role in determining how any section of land responds to precipitation, natural or human disturbances, or just the long passage of geologic time. It is expected that the natural landscape data sets combined with the precipitation data sets can adequately characterize the natural balance of key watershed processes at the scale of the entire Central Coast Region. Important landscape data sets that were introduced in the Literature and Data Review are processed in this section to ensure that each is in a format to support the watershed characterization task of Section 3.

2.2.1. Slope

Slope and topography are basic watershed characteristics that are needed in any consideration of watershed processes or in developing standards and practices to prevent the adverse effects of hydromodification. Hillside gradient plays a large role in the runoff and erosion potential of an area. In general, areas with greater slopes are more likely to display surface runoff and to have greater volumes and velocities of that runoff and so more likely to experience erosion.

Hillslope gradients were generated from the National Elevation Dataset (USGS 2009), a product of the USGS (U.S. Geological Survey), with 10-meter data resolution. On the basis of the distribution of slopes and observed ranges of relative erosion and slope instability, the continuous range of hillslope gradients was categorized into three groups: 0–10 percent, 10–40 percent, and steeper than 40 percent (Table 2-2 and Figure 2-4). The categorical gradient groups were based on a previous project completed by Stillwater Sciences in a watershed in the Central Coast Region (Santa Rosa watershed, northern San Luis Obispo County; Stillwater Sciences 2010).

Table 2-2. Hillslope gradient categories and proportional area for the Central Coast Region

Slope range	Percent of watershed area
0–10%	26%
10–40%	42%
> 40%	32%

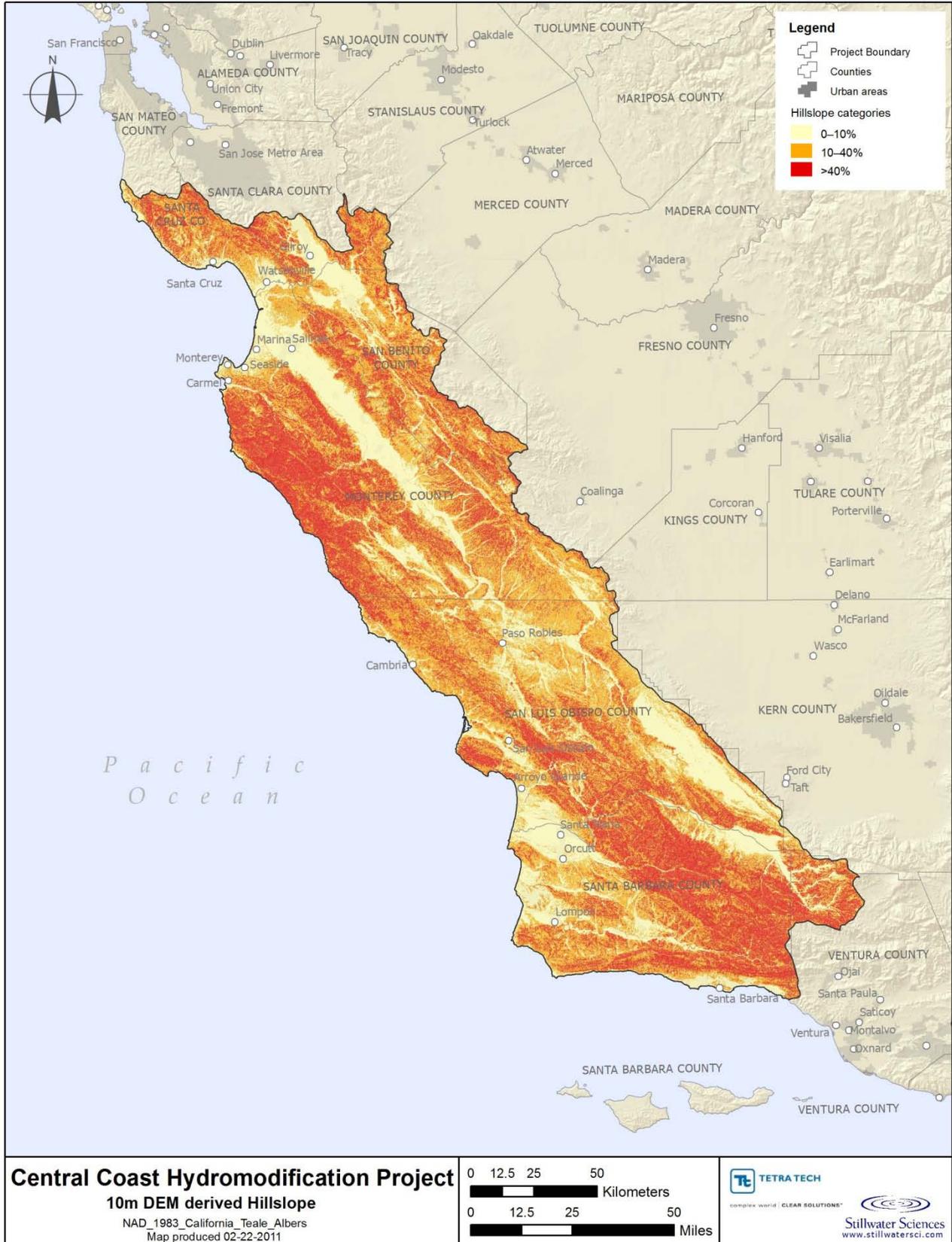


Figure 2-4. 10-m DEM derived hillslope map of the Central Coast Region.

2.2.2. Geology

The Geologic Map of California, digitized from Jennings et al. (1977) is a geologic categorization covering all of California and was used as an initial delineator of the geologic terrains of the Central Coast Region. The resolution is at a coarse scale of 1:750,000. It is anticipated that any subsequent, more detailed investigation of selected areas may make use of a geologic layer of larger scale to delineate important geologic features with greater precision.

The Jennings map identifies nearly 1,000 unique rock units across California. Of those, 56 were grouped by Jennings according to region and age, and 34 of those occur in the Central Coast Region. Of those 34 regional stratigraphic units, those of similar age or depositional environment were further grouped by the project team into generalized geologic categories for use in characterizing the natural landscape (Table 2-3; Figure 2-5).

Because the sedimentary units constitute a large portion of the region and vary quite drastically in their structural integrity, a detailed evaluation was made to subdivide those materials with similar erodibility (i.e., competent versus weak) and degree of consolidation (i.e., poorly versus moderately versus well). The most competent formations (e.g., granite/metamorphic), however, were not subdivided. The specific considerations are outlined below.

- The Quaternary deposits were not separated because they are all young and fairly weak. Their boundaries also form the basis of specific *groundwater basins* (CDWR 2004) identified by the Central Coast Region and collected during Task 1 of the Joint Effort.
- Tertiary sediments were subdivided according to the relative composition of shale versus sandstone, which has an overriding influence on the types of sediment produced during weathering. The project team has elsewhere observed that the moderately competent sandstone units are more prone to gully and rilling, relative to the easily eroded shale, which tend to be very conducive to both landsliding and gully (Stillwater Sciences 2010). However, because of the coarse scale of the original information provided by the Jennings data, the sedimentary units will remain separated only by age of formation at this step. A geographic information system (GIS) platform was used to identify the proportion of area that each geologic unit composes throughout the Central Coast Region. The value of further subdivision will be considered on the subwatershed scale during Task 2.4, because this one category accounts for such a significant component of the region (37 percent by area) (Table 2-3).
- A similar approach was considered with the Mesozoic metasedimentary units. Those formations are expected to be more competent than the younger Tertiary sedimentary formations, but the parent material could still dictate the dominant type of weathering experienced. After assessing the proportional amount of area that each unit constitutes, however, it was determined that those rocks do not need to be divided, because the sandstone units compose most of the area of the two combined.
- Paleozoic and Pre-Paleozoic formations were grouped with the metasedimentary rocks because of their competence.
- The granitic rocks, Tertiary and Quaternary volcanic rocks, and the Mesozoic and Paleozoic metamorphic rocks (including metavolcanic and metasedimentary) were grouped because of their relative resistance to erosion and anticipated similarity of geology-determined watershed processes.
- Serpentine was grouped with the more competent metamorphic rocks because it has undergone high-grade metamorphism and tends to be fairly competent. More consideration might be warranted though, because of the thin soil profile that develops in such types of terrain.
- The mélangé group will remain separated. The unit is less competent than most other units in the region and has been shown to contribute large amounts of sediment proportional to the amount of area it covers.

Table 2-3. Generalized geologic categories for the Central Coast Region

Generalized geologic categories	Proportional area in the Central Coast Region (percentage)
Quaternary sedimentary deposits	30%
Tertiary sedimentary rocks	37%
Mesozoic metasedimentary rocks	12%
Tertiary volcanic rocks, granitic rocks, Mesozoic and Paleozoic metamorphic rocks	11%
Franciscan mélangé	11%

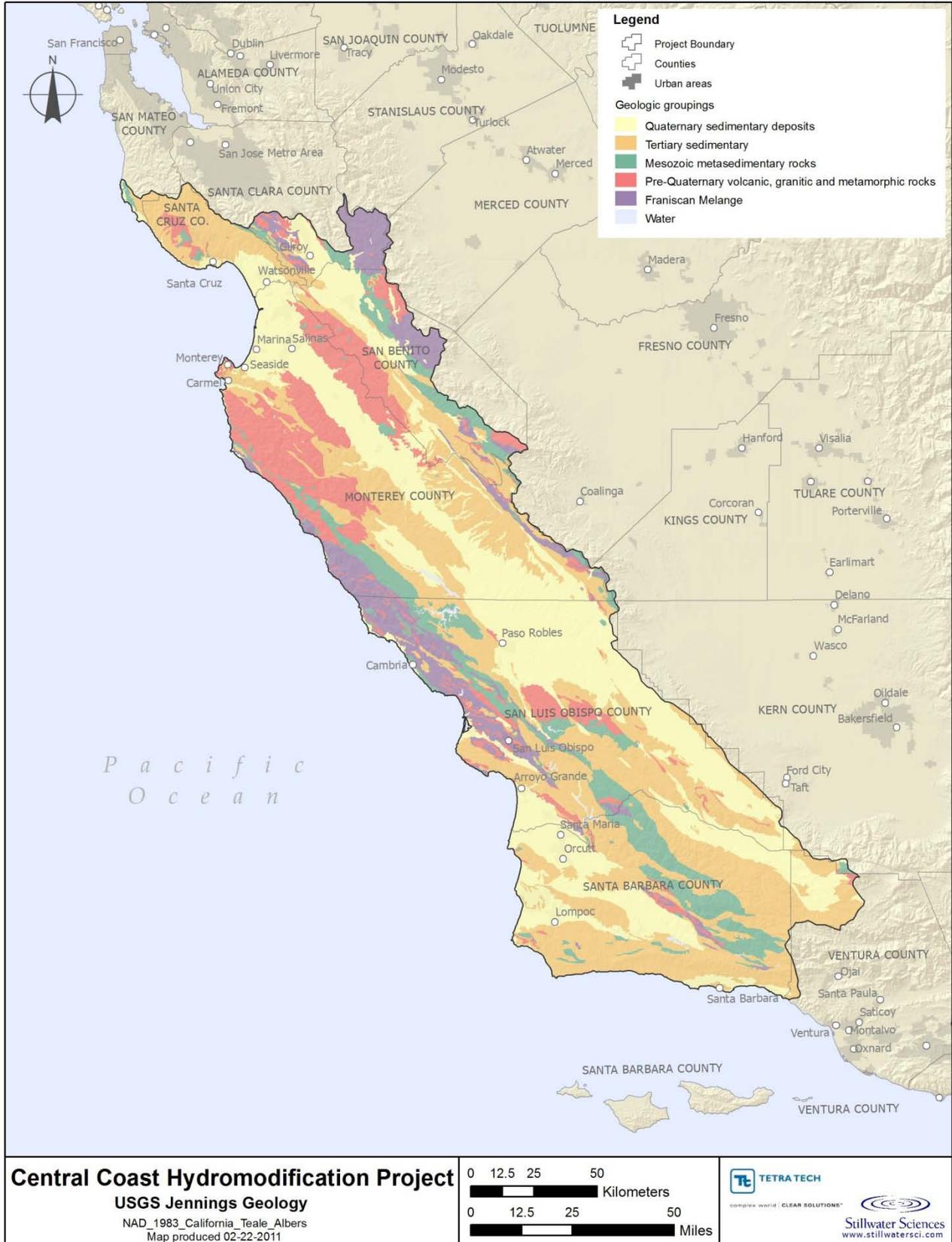


Figure 2-5. USGS Jennings geology map of the Central Coast Region.

2.2.3. Soils

The soils data provides spatial characterization of known soil conditions and will be used to identify limitations on infiltration rates and sediment contribution. That data set is used to evaluate the runoff or infiltration potential of areas of land, on the basis of the makeup of soils. The Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) Database was used to delineate soil types for the Central Coast Region (NRCS 1994). Mapping scales generally range from 1:12,000 to 1:63,360. SSURGO is the most detailed level of soil mapping done by the NRCS. Field mapping methods using national standards are used to construct the soil maps in the database; SSURGO digitizing duplicates the original soil survey maps.

Hydrologic soil groups are based on estimates of runoff potential and are assigned to four groups (A, B, C, and D) (Figure 2-6). The proportional amount of area within the Central Coast Region that each soil class covers is given in Table 2-4.

Table 2-4. Soil unit classification in the Central Coast Region

Soil type ^a	Description of soil type ^b	Proportional amount of area (percent)
A	Sand, loamy sand, or sandy loam. Soils having a high infiltration rate (low runoff potential) when thoroughly wet	4%
B	Silt loam or loam. Soils having a moderate infiltration rate when thoroughly wet	26%
C	Sandy clay loam. Soils having a slow infiltration rate when thoroughly wet	36%
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material	32%
n/a (water)	Water	3%

Notes:

a. The B/D soil group accounts for less than 0.01 percent of area and is not included in this table. The B/D grouping indicates moderate infiltration rates when dry and slow infiltration rates when saturated.

b Soil type descriptions provided by NRCS.

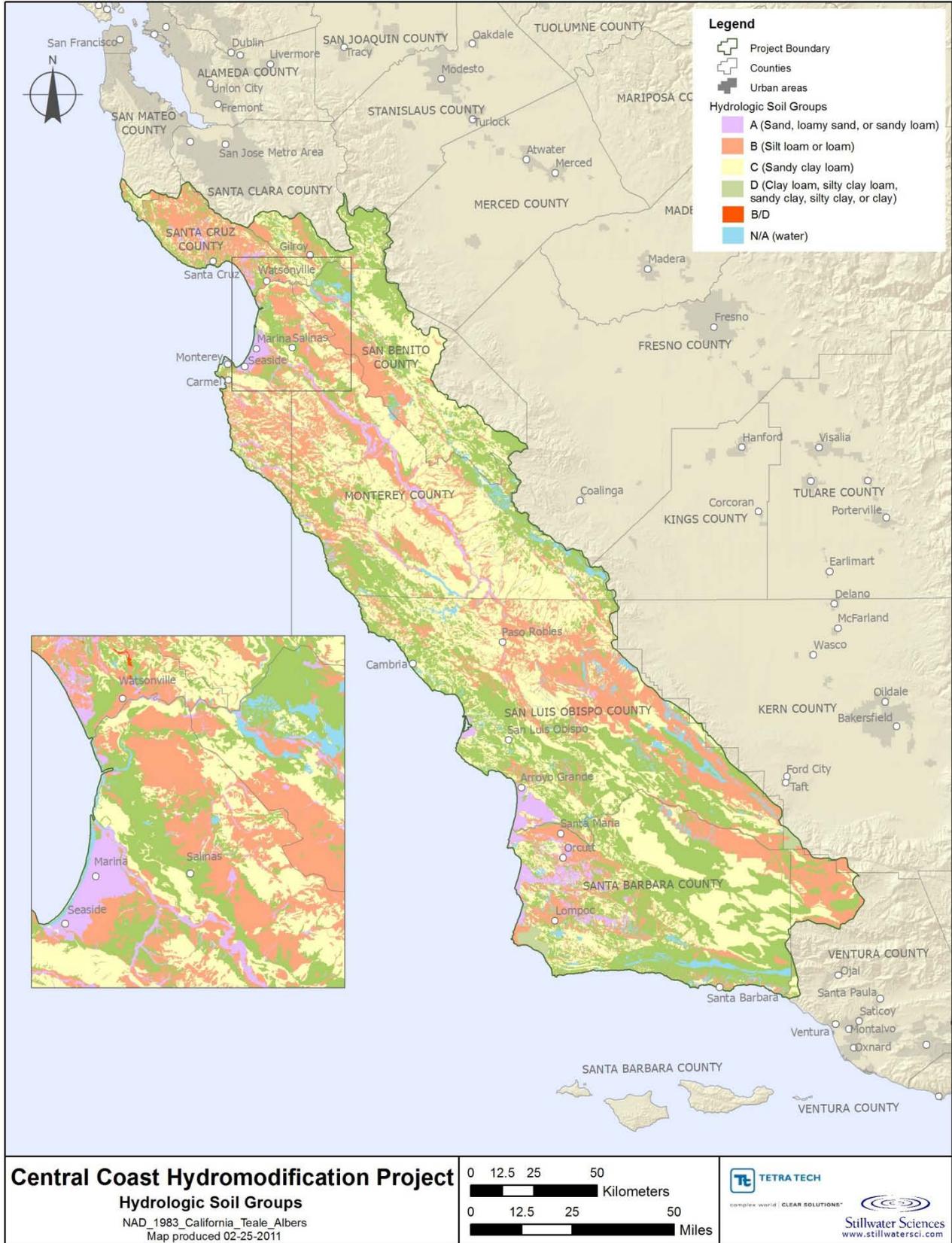


Figure 2-6. Hydrologic soil groups map of the Central Coast Region.

2.3. Developed Landscape Data

Accurately characterizing the developed landscape (e.g., urban imperviousness, agricultural land uses, grazing practices) in the Central Coast is foundational to understanding how the disturbance of the landscape affects watershed processes. Whereas the data in the previous two sections will be used to characterize the nature and distribution of key watershed processes, developed landscape data will be used to characterize existing conditions. That information will be used in subsequent tasks to help validate the zoning of watershed processes by comparing the predicted watershed processes with observed field conditions and data.

Developed landscape data can come in a variety of forms. For the purposes of characterizing the development in the Central Coast, it is most important to understand the landscape changes that have the greatest potential for altering the natural balance of watershed processes. Although various data sets were introduced in the Literature and Data Review, each plays an important role in characterizing the development in different areas of the region. This section provides an overview of the methods employed to assemble region-wide composite GIS layers to represent development. The data from different sources were compared for the scale/resolution and accuracy, and each was assessed for its suitability to represent important characteristics. The output from this section includes GIS layers of land use, land cover, and imperviousness to characterize development for the entire Central Coast Region.

2.3.1. Land Use, Land Cover, and Imperviousness

Land use information is an important data set for characterizing watershed conditions because it strongly correlates with imperviousness, pollutant loading rates, and changes in sediment yield of a natural landscape. That information can be culled from a variety of sources ranging from locally maintained tax assessor parcel databases to multispectral geospatial analysis of aerial imagery. The Literature and Data Review introduced the available land use data from several sources for the Central Coast Region that varied in quality, currency, resolution, and cost:

- 2005 Central Coast Watershed Studies (CCoWS) Land Use Map—30-meter resolution
- 2006 National Land Cover Dataset (NLCD)—30-meter resolution
- 2010/2011 County Parcel Data (from each of the counties in the region)—10-meter resolution
- 2010/2011 ParcelQuest Land Use Database—10-meter resolution

Each of the land use layers has limitations in terms of its use for the project ranging from differences in land use categories (County Parcel Data), currency and resolution (CCoWS and NLCD), to cost (ParcelQuest). Figure 2-7 shows a comparison of the four different sources of land use layers in the southern Santa Barbara County region and highlights the spatial differences between the layers. Although the remotely sensed information provides accurate and numerous classifications of non-urban land uses, it lacks sufficient resolution to discriminate between different urban land uses (e.g., commercial versus industrial). Alternatively, the tax assessor parcel database identifies distinct urban land uses and a more general classification for non-urban land uses. For the purposes of accurately characterizing developed land use conditions, the parcel information provides a better understanding of urban development, while the different categories included in the NLCD data provides the greatest level of detail for understanding the land use in the remaining non-urban areas.

In addition to the parcel land use information for urban areas, an advanced remote sensing spectral analysis was performed to more accurately account for the presence of impervious surfaces in most of the urban areas identified throughout the Central Coast. The transportation layers identified in the Literature and Data Review were also analyzed to estimate road widths for all roads throughout the Central Coast from a comparison to aerial imagery (USDA FSA APFO 2009). That higher degree of understanding of imperviousness information is anticipated to be useful in subsequent tasks to assist with validating hydromodification impacts in specific areas.

To create a composite land use layer of current conditions, several of the above mentioned data sets were combined to leverage each layer's strength, including the ParcelQuest parcel layer, the 2006 NLCD land use layer, and the 2010 U.S. Census Tiger Roads layer. Those layers were combined to create a composite land use layer using the detailed parcel data for urban areas and the more general NLCD data for rural areas. The creation of the composite layer also included a review of all land use layers and correcting errors in land use type that were found in the ParcelQuest data. Once the composite layer was complete, each of the attribute types (mixed forest, shopping centers, parking lots, and such) was assigned to one of 11 major land use categories (Table 2-5) on the basis of its land use subtype. The composite land use layer (Figure 2-8) is used in Section 3 to assess each area's change in potential for runoff and reduced infiltration due to development.

Table 2-5. Land use distribution in the Central Coast Region

Land use group	Area (acres)	Percent area
Agriculture	486,224	6.72%
Commercial	24,222	0.33%
High Density Residential	7,083	0.10%
Industrial	14,142	0.20%
Institutional	19,134	0.26%
Low Density Residential	435,756	6.03%
Medium Density Residential	75,750	1.05%
Transportation	103,166	1.43%
Vacant	394,803	5.46%
Vegetation	5,638,285	77.96%
Water	33,791	0.47%

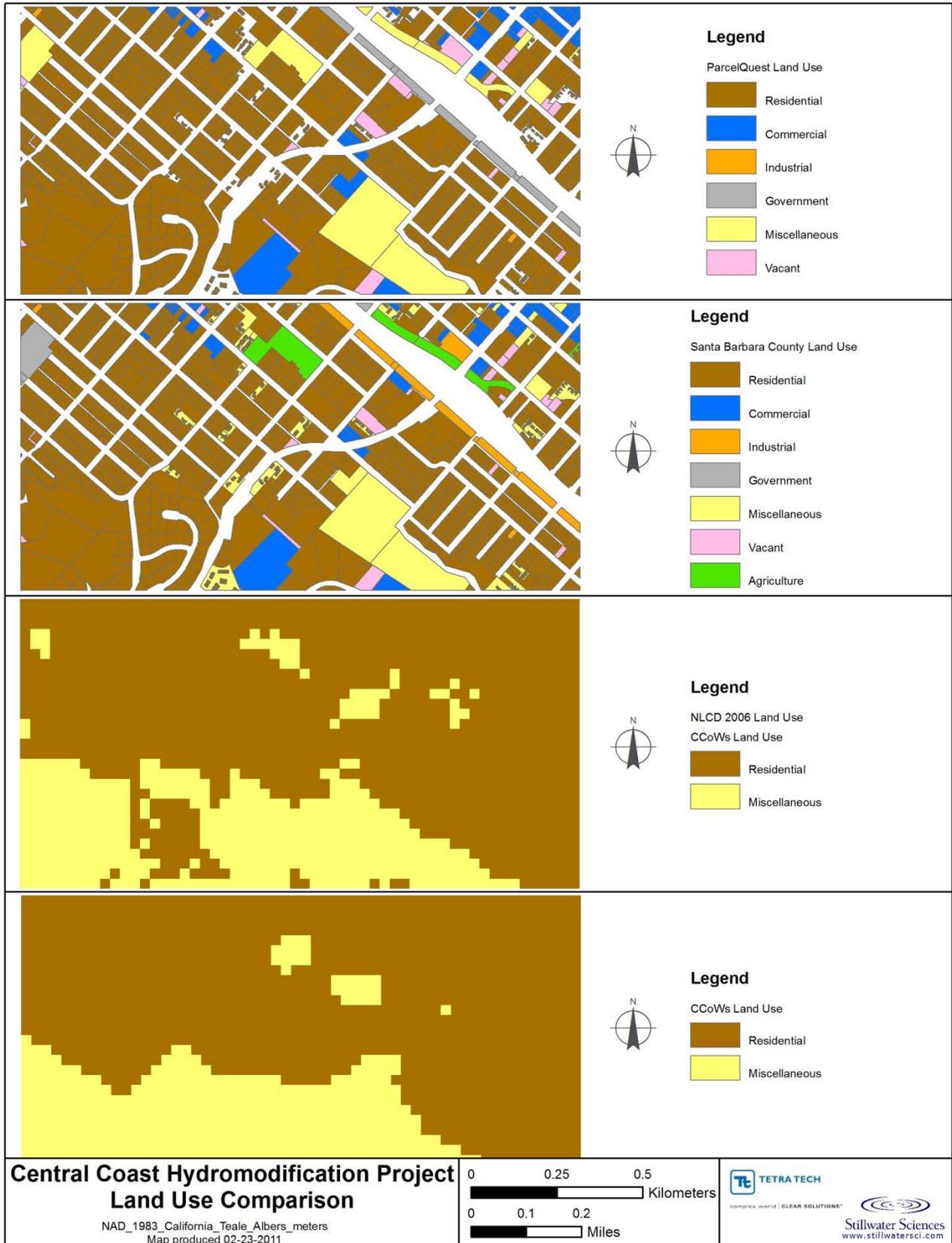


Figure 2-7. Comparison of land use data in the southern Santa Barbara Country region.

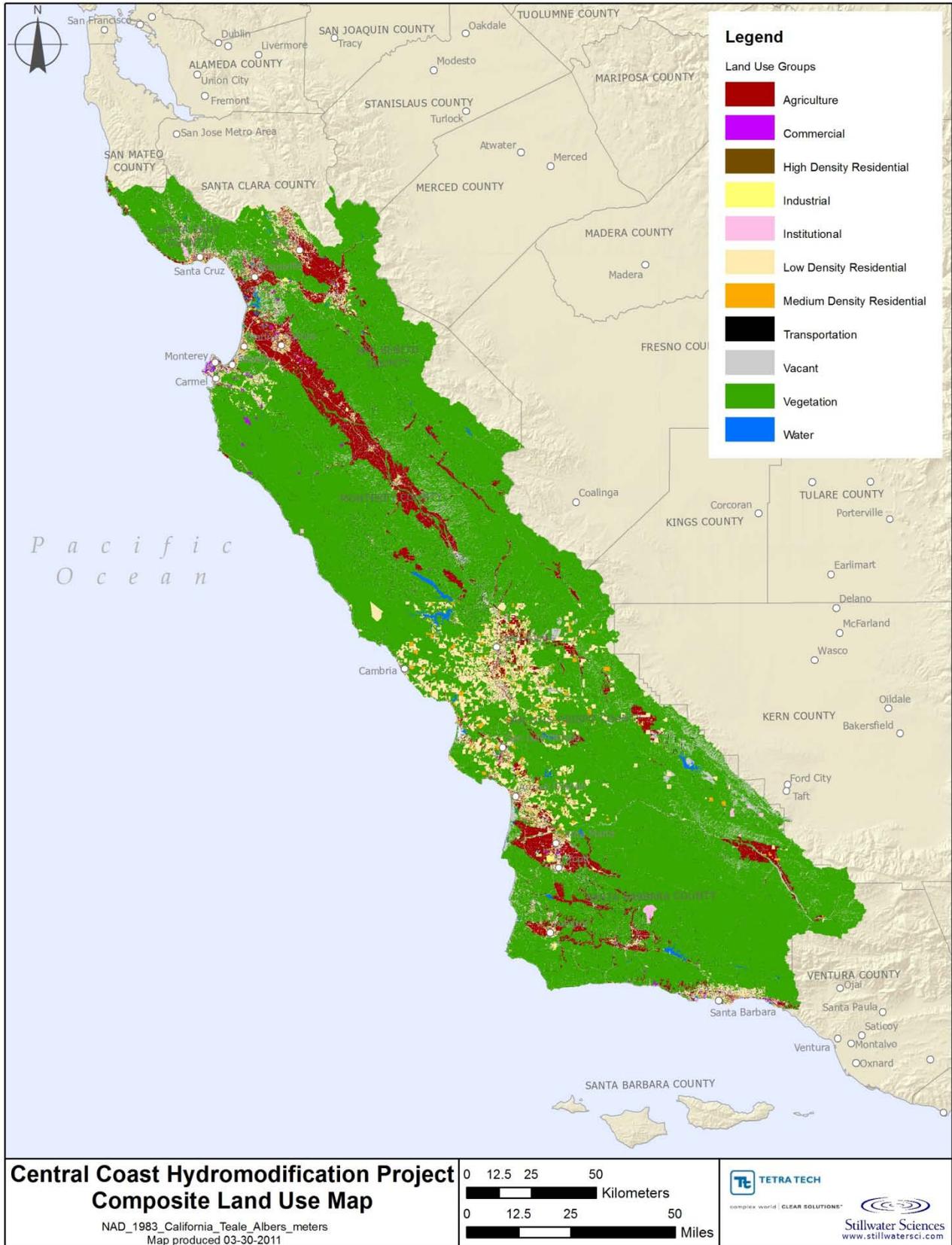


Figure 2-8. Composite land use map of the Central Coast Region.

2.3.2. Historical Conditions

One method for validating the expected impacts of development on an area is to perform a comparison of receiving water responses between current and historical conditions. That requires an understanding of both land use and receiving water response during two different periods. To facilitate that analysis, historical land use data for the year 1985 and 2001 were also downloaded from the NLCD website (USGS 2011 and MRLC 2011). Those layers are anticipated to be used in subsequent tasks to support validation analyses.

3. Watershed Characterization: Precipitation and Landscape

Part I of the watershed characterization effort focused on characterizing the precipitation, natural landscape, and developed landscape, which are considered the three factors that primarily contribute to defining spatial distribution of key watershed processes throughout the Central Coast Region. It involved synthesis of both spatial and temporal data. This section presents the effort in the logical sequence presented in Section 1 of this report.

When precipitation falls on undisturbed land, it first encounters elements associated with the natural landscape. The resulting watershed processes depend on the attributes of that landscape. Where urbanization is dominant, the same precipitation event will exhibit a watershed response that differs from that of a more natural landscape element (the term *hydromodification* is often used to describe the changes in the natural balance of watershed processes due to development). Where natural land cover prevails, the combined effects of hillslope gradient and geological material is the best indicator of the expected watershed response to precipitation.

The analysis has both spatial and temporal aspects, which will be discussed briefly in the following sections. This section presents the synthesis of the attribute data sets that characterize the precipitation, natural landscape, and developed landscape throughout the Central Coast Region. Each data set is analyzed to determine a logical grouping into discrete categories, which are intended to represent homogeneous influences on watershed processes. The resulting characterization reduces the seemingly infinite complexity of landscape and precipitation data sets into tractable groupings that provide insight to the most important influences on watershed processes.

3.1. Subwatershed Delineation

An accurate delineation of watershed boundaries is important for assessing hydrology and hydromodification in any system, because of the expected flow paths of stormwater runoff to quantity and quality. Watershed boundaries can play multiple crucial roles in this project. First, watershed boundaries could act as the delineation boundary for any grouping of watershed characteristics that is performed in subsequent tasks. That could be advantageous in any system where precipitation patterns are the principle determiner of watershed processes, because the subcomponents in each drainage area are hydrologically connected. However, that approach might dampen some signals that would otherwise be important in systems where landscape characteristics drive the watershed processes by averaging them with others. Second, a system of watershed boundaries with correct connectivity information helps any further quantitative analysis needed in future tasks by facilitating the quick and easy assessment of determining the entire drainage area for any receiving water location on the Central Coast.

Subwatershed delineation refers to subdividing the entire Central Coast Region area into smaller, discrete subwatersheds. The subdivision was based on the National Hydrography Dataset Plus (NHDPlus) catchments (USEPA and USGS 2010). The NHDPlus provides high-resolution subwatershed delineations through the entire Central Coast Region at a resolution of 1:100,000. The NHDplus catchments layer divides the entire Central Coast Region into 15,026 subwatersheds. To better preserve the spatial segmentation of the regional watersheds, all 15,026 subwatersheds can be used for the future modeling or analysis efforts; but for this analysis, the subwatersheds were grouped at three levels on the basis of NRCS watershed boundaries at hydrologic unit code (HUC) 12, HUC 10, and HUC 8 levels (NRCS 2010). The subwatershed routing information was carefully scrutinized to ensure that flow routing was properly represented between 15,026 subwatersheds. The method for grouping the subwatersheds and assigning the flow routing information is summarized in the subsequent sections of this subtask. Figure 3-1 illustrates the watershed delineation map of the Central Coast Region.

To create the subwatershed layer, several geoprocessing functions were used to combine data from the different sources. The initial step in that process was to select the catchments from the NHDPlus regional drainage layer whose geometric center (centroid), was inside the project boundaries. To determine downstream flow direction, the selected catchments were joined to the NHDPlus-NHDFlow table. The two files were joined using the

COMID field from the catchments layer and the FROMCOMID field from NHDFlow table. Once the tables were joined, the TOCOMID field was used as the downstream COMID for each catchment.

After reviewing the catchments and the assigned flow direction, some errors were noticed with the NHDFlow data. The NHDFlow data incorrectly had each catchment that bordered the Pacific Ocean coastline flowing to the next catchment to the south instead of flowing to the ocean. Using aerial imagery, topography, and the NHDFlow Line layer, the attributes for each catchment were manually updated to the correct TOCOMID value.

To create a subwatershed catchments layer with the most diversity in terms of drainage size, three levels of HUCs and their corresponding downstream HUCs were also calculated for each NHDPlus catchment. To accomplish that, NRCS HUC data were joined to the catchments layer using a Spatial Join function, and each catchment was assigned to a HUC 12, HUC 10, and HUC 8 drainage area. Table 3-1 summarizes the number of units in the entire Central Coast Region at HUC8, HUC10, HUC12, and NHDplus catchment levels; they are displayed on Figure 3-1. The NRCS attribute data also contained downstream flow values for the HUC 12 and HUC 10 boundaries, which were subsequently assigned to each catchment. The HUC 8 downstream data were not included in the NRCS layer and, therefore, were calculated manually using topography information and the NHDPlus Flow Line layer.

Table 3-1. Subwatershed delineation for the Central Coast Region

Delineation category	Number of units within Central Coast Region
NHDplus catchments	15,026
HUC12 subwatersheds	353
HUC10 watersheds	67
HUC8 subbasins	14

Because of the NHDplus catchments layer and the NRCS HUC layer being from different sources, some edge matching issues led to some catchments not being assigned the necessary HUC. The catchments that did not have their HUC assigned automatically, because of catchment centroids not aligning with HUC boundaries, were then visually inspected and manually assigned the appropriate HUC values again.

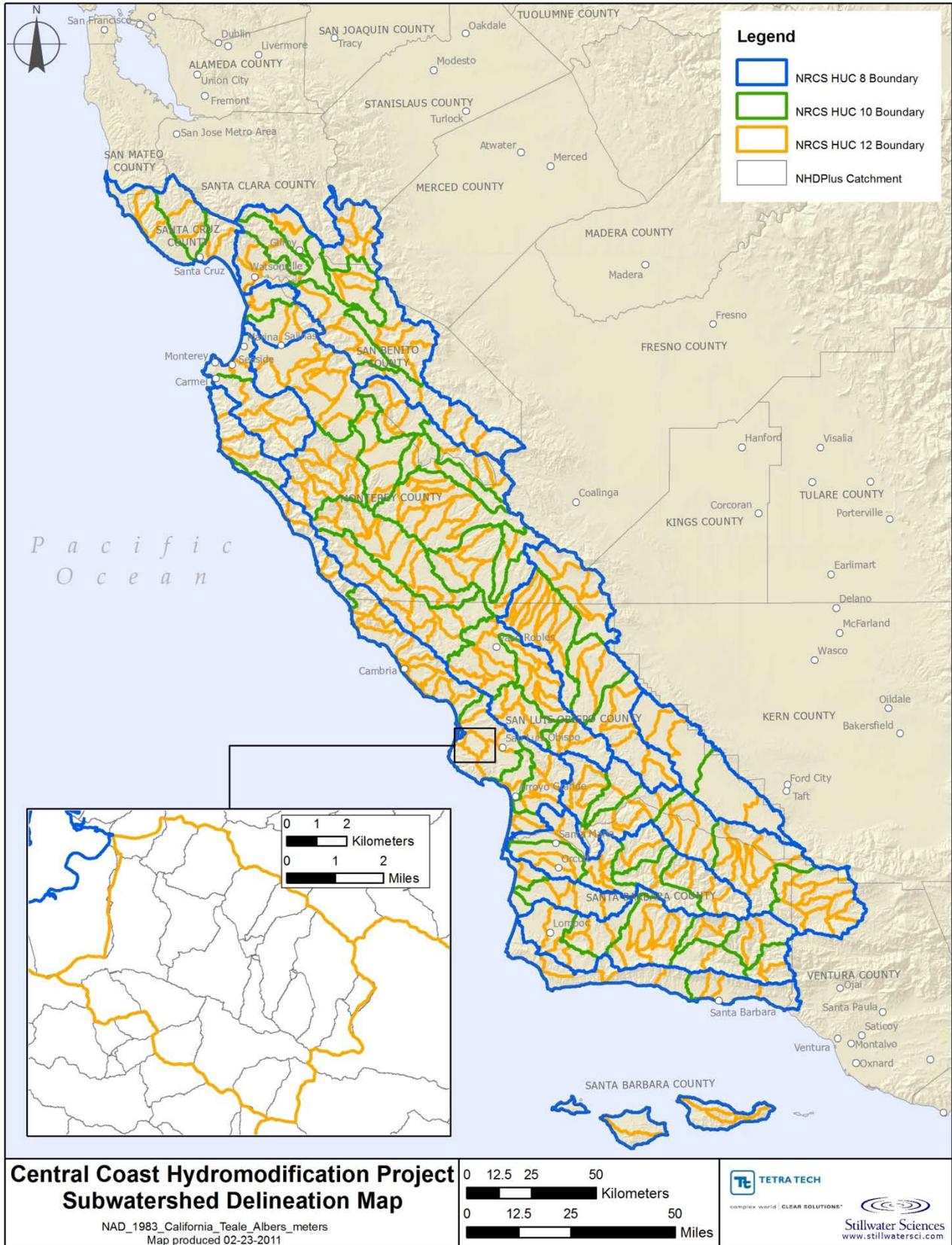


Figure 3-1. Watershed delineation map of the Central Coast Region.

3.2. Precipitation Characterization

Characterizing precipitation volume and intensity is an important step in determining the potential for surface runoff and erosion in a watershed. While volume is an indicator of relative total water available to stimulate watershed processes, intensity is important for estimating the potential energy available for surface erosion. This section describes the process for using the interpolated, quality-controlled, time-series precipitation data sets that were developed in Section 2, to produce two precipitation zone maps for average volume and intensity. In subsequent tasks, the results of the precipitation characterization can be combined with the results of the landscape characterizations presented in the following sections to help identify the spatial distribution of key watershed processes present throughout the Central Coast Region.

3.2.1. Estimating Spatial Variability of Rainfall Volume

Both the original recorded and the quality-controlled data series were summarized as annual averages for the respective 61- and 17-year analytical periods of record, 10/01/1949 to 09/30/2010 for precipitation (Figure 3-2). The average annual values were sorted by gage elevation to see if there were any discernable trends present as a function of elevation. The individual stations are listed on the x-axis, elevation as the line/area series read on the primary y-axis, and the respective average annual quantities are stacked bar graphs read on the secondary y-axis. In each of those figures, the darker portion of the stacked bar graph represents the original recorded data over the period of record, while the lighter portion represents the estimated quantity. Because those totals are annualized over the respective periods of record, the stacked bar graphs also represent the percent coverage at each location. In smaller, homogeneous watersheds, precipitation generally increases with elevation. In this study area, precipitation varies more notably, suggesting that elevation alone is not a good predictor of expected precipitation. To assess appropriate spatial predictors, a contour map was generated for the average annual precipitation data set. Figure 3-3 is an isohyetal map of the NCDC SOD station 61-year data summary.

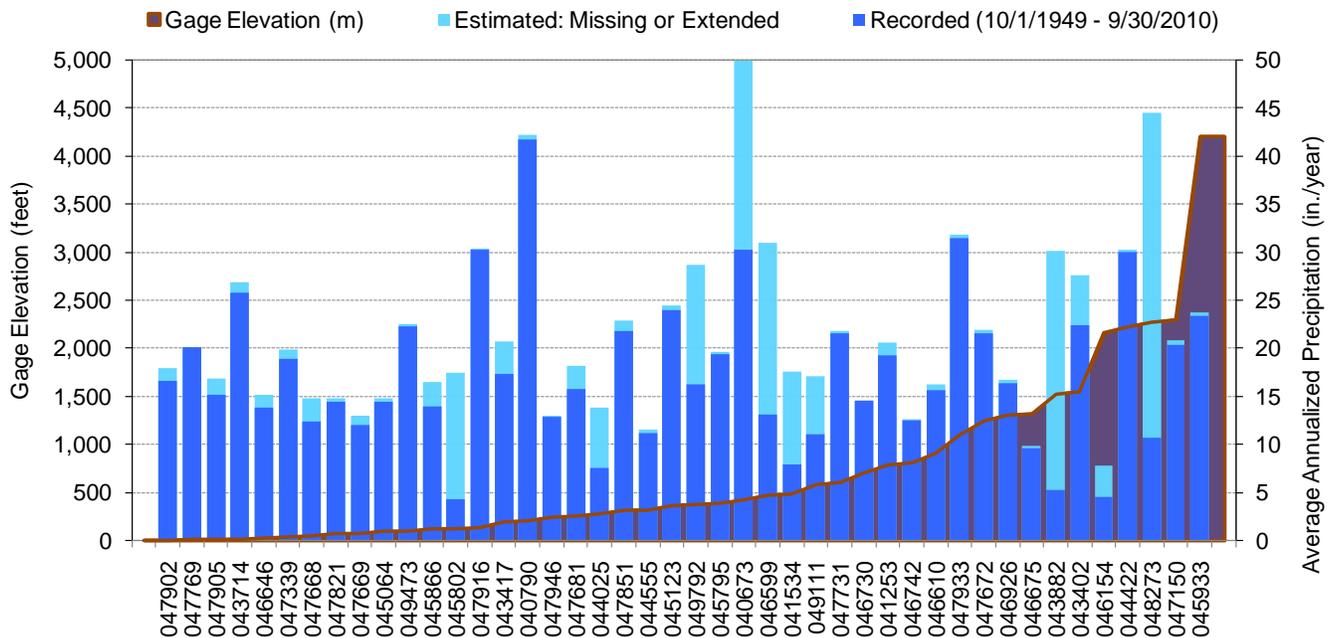


Figure 3-2. Average annual precipitation totals by NCDC SOD station and gage elevation.

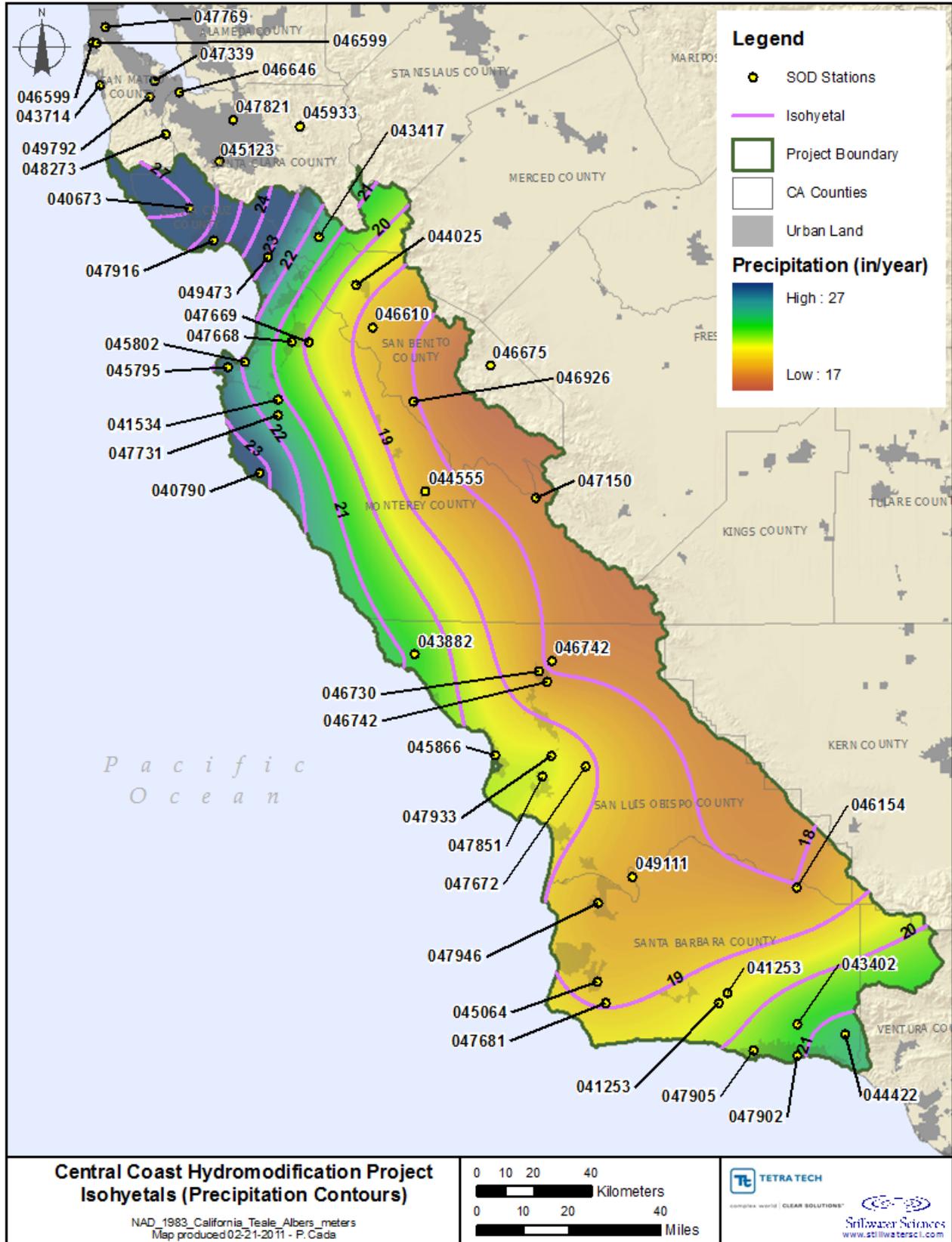


Figure 3-3. Average annual precipitation isohyetal map for NCDC SOD stations (10/1/1949–9/30/2010).

3.2.2. PRISM Data Set

The PRISM Climate Group at Oregon State University maintains a meteorological data set that incorporates observed point data, a DEM, and expert knowledge of complex climatic extremes (including rain shadows, coastal effects, and temperature inversions). PRISM data set is recognized worldwide as the highest-quality spatial climate data sets available. The data are provided at a 4-square-kilometer resolution for the entire contiguous United States and are summarized as monthly precipitation totals. Figure 3-3 presents a precipitation summary for 10/1/1949 through 9/30/2010 for the Central Coast study area. Although Figure 3-3 and Figure 3-4 both show similar spatial trends in terms of rainfall volume distribution, differences between Figure 3-3 and Figure 3-4 mainly occur wherever (1) observed NCDC gage data are sparse and (2) orographic influences prevail. Because the PRISM group takes into account elevation in the spatial interpolation process, the data set is able to better quantify orographic influences in ungaged areas. Because of that, it is recommended that the PRISM data be used for the purposes of evaluating annual rainfall volume patterns. However, it is important to note that PRISM as a data source provides only monthly precipitation volumes. It does not provide any information about intensity variation throughout the study area. A separate analysis is provided below to develop the map.

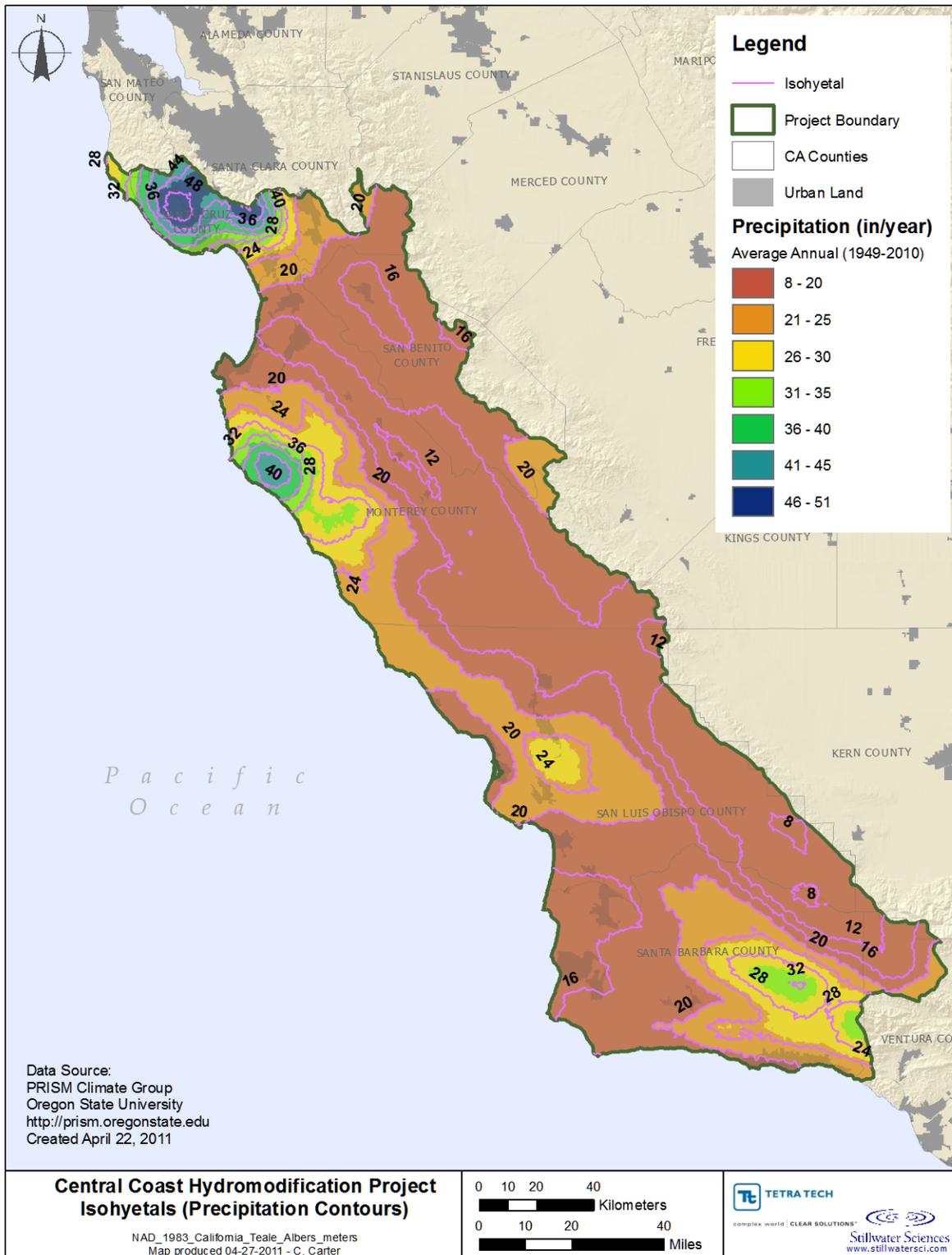


Figure 3-4. Average annual precipitation isohyetal map for PRISM rainfall volumes (10/1/1949–9/30/2010).

3.2.3. Estimating Spatial Variability of Rainfall Intensity

Rainfall intensity distributions were estimated for the study area by downscaling monthly PRISM rainfall totals to hourly using nearby hourly rainfall totals. The process was performed at the HUC12 scale instead of the 4-square-kilometer scale to improve data management. About 1,800 PRISM 4-square-kilometer grid cells cover the Central Coast Region; however, 334 HUC12 watersheds are in the Central Coast Region.

An accepted practice in other regional municipalities nearby to the Central Coast Region study area involves using the 85th percentile rainfall depth as a design target for post-construction structural or treatment control BMPs (LACDPW 2002; WEF & ASCE 1998). The 85th percentile rainfall depth represents the typical design stormwater capture volume for urban areas. The 85th percentile storm event was used as a threshold for characterizing rainfall intensity. For the 61-year period and for each disaggregated HUC12 PRISM-derived data location (334 unique locations in all), the average of peak intensities for all storms greater than or equal to the 85th percentile rainfall depth was computed for relative spatial comparison. The purpose of that exercise was to determine if any apparent zones have more or less intense rainfall occurs relative to other zones.

3.2.4. Stratification of Results

To simplify future analyses to assess the importance of the variation of rainfall patterns, it is helpful to stratify the information into groups or ranges of data that represent similar characteristics (e.g., high, medium, low). Natural breaks for three categories of intensity distribution were identified using spatial analysis GIS utilities. The breaks in the data were plotted alongside their associated area distribution as shown in Figure 3-5 to show the percentage of the study area in each category. Figure 3-6 shows this analysis repeated for total annual rainfall volume previously shown in Figure 3-4. The corresponding maps for intensity and volume distribution categories are shown in Figure 3-7 and Figure 3-8, respectively. Figure 3-9 shows precipitation zones of similar overlapping volume and intensity.

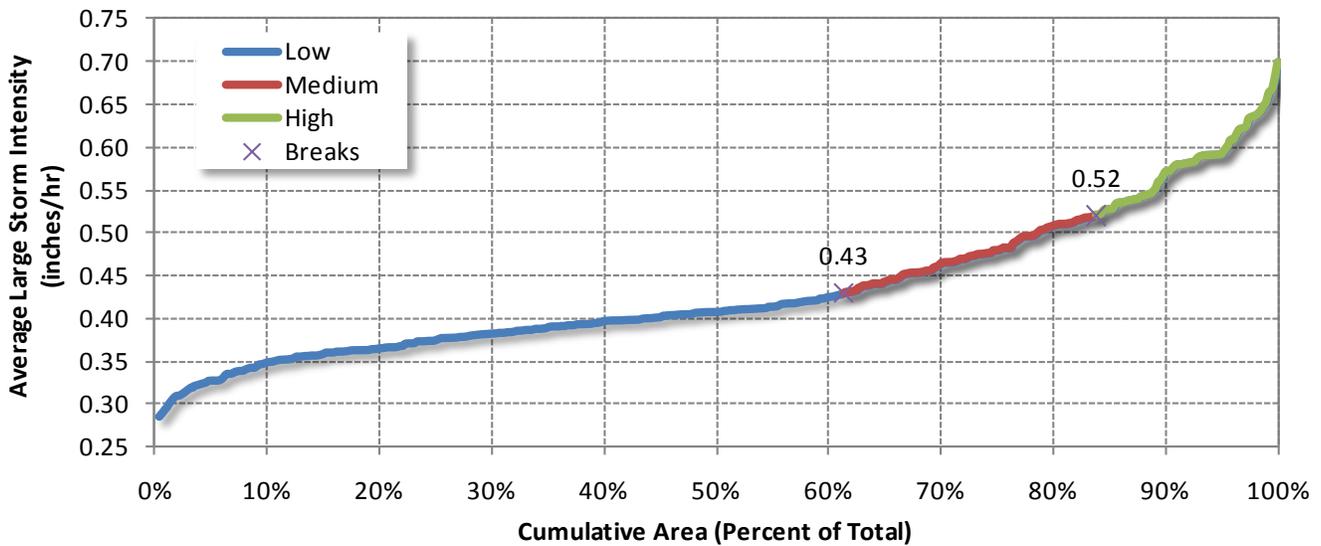


Figure 3-5. Large-storm intensity distribution categories for the Central Coast study area.

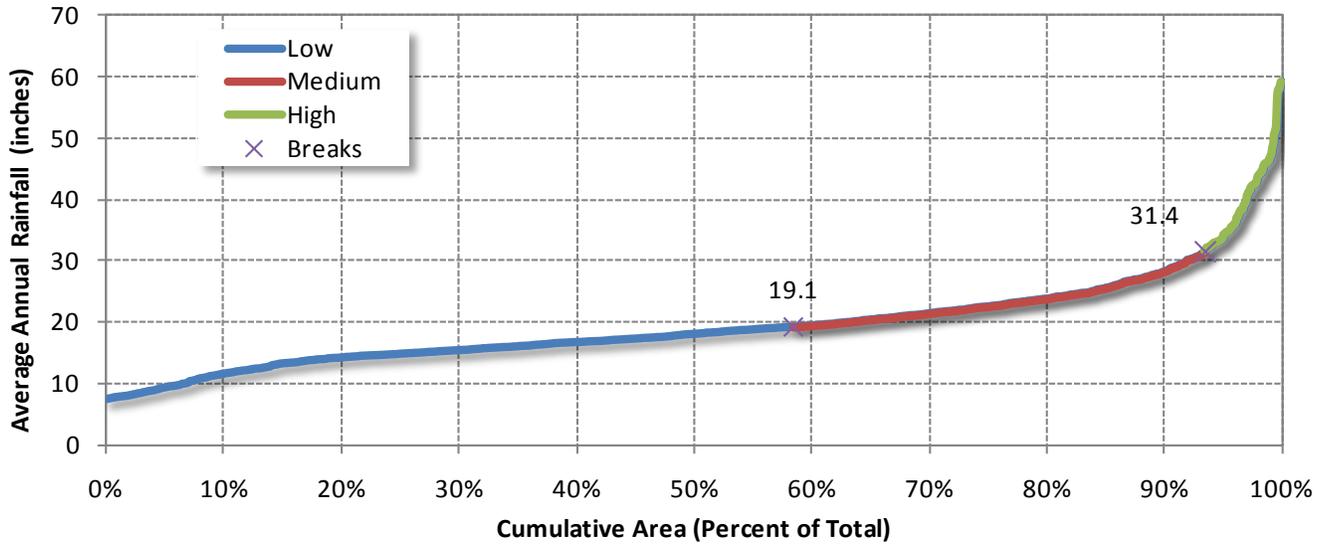


Figure 3-6. Average annual volume distribution categories for the Central Coast study area.

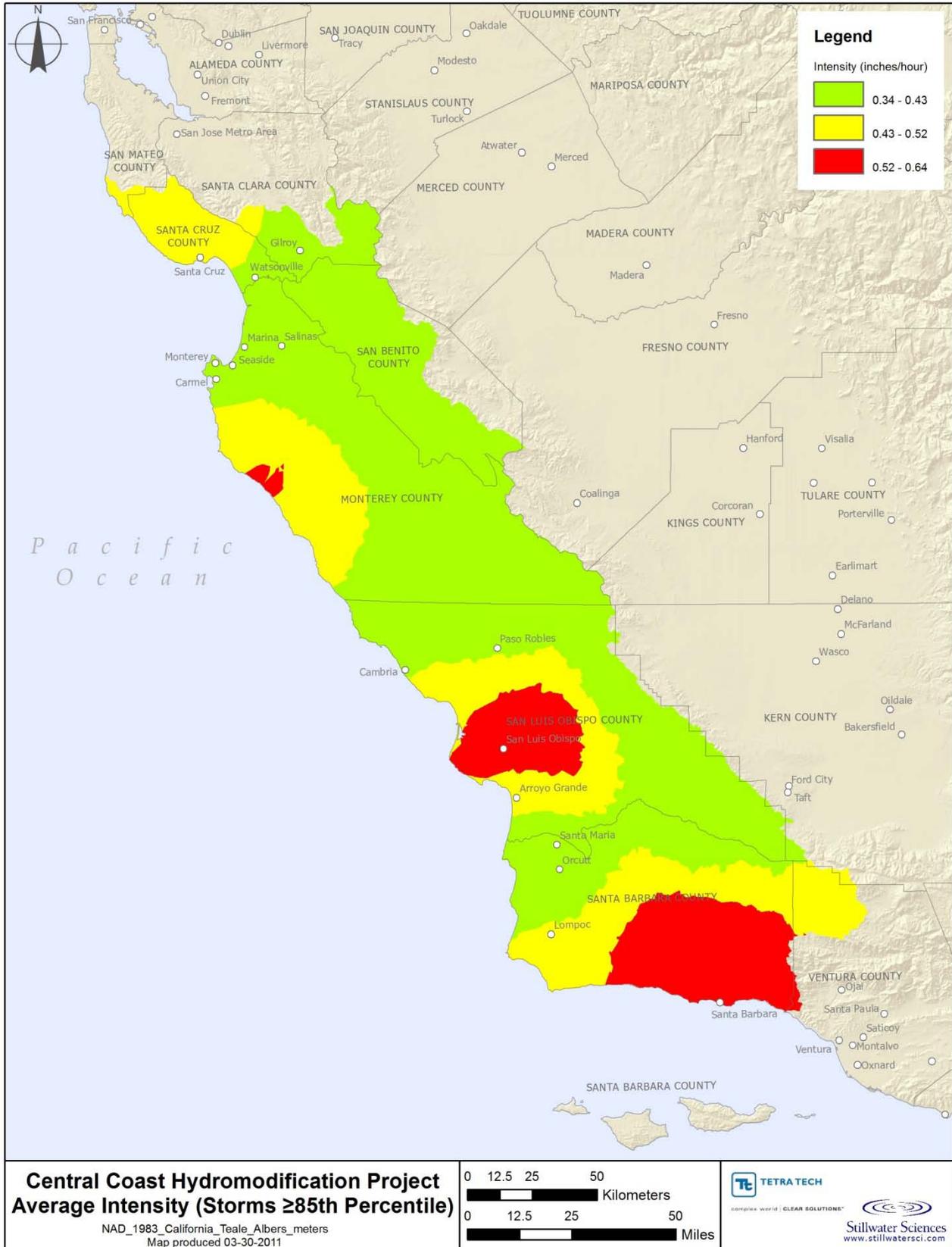


Figure 3-7. Map of large-storm intensity distribution categories for the Central Coast study area.

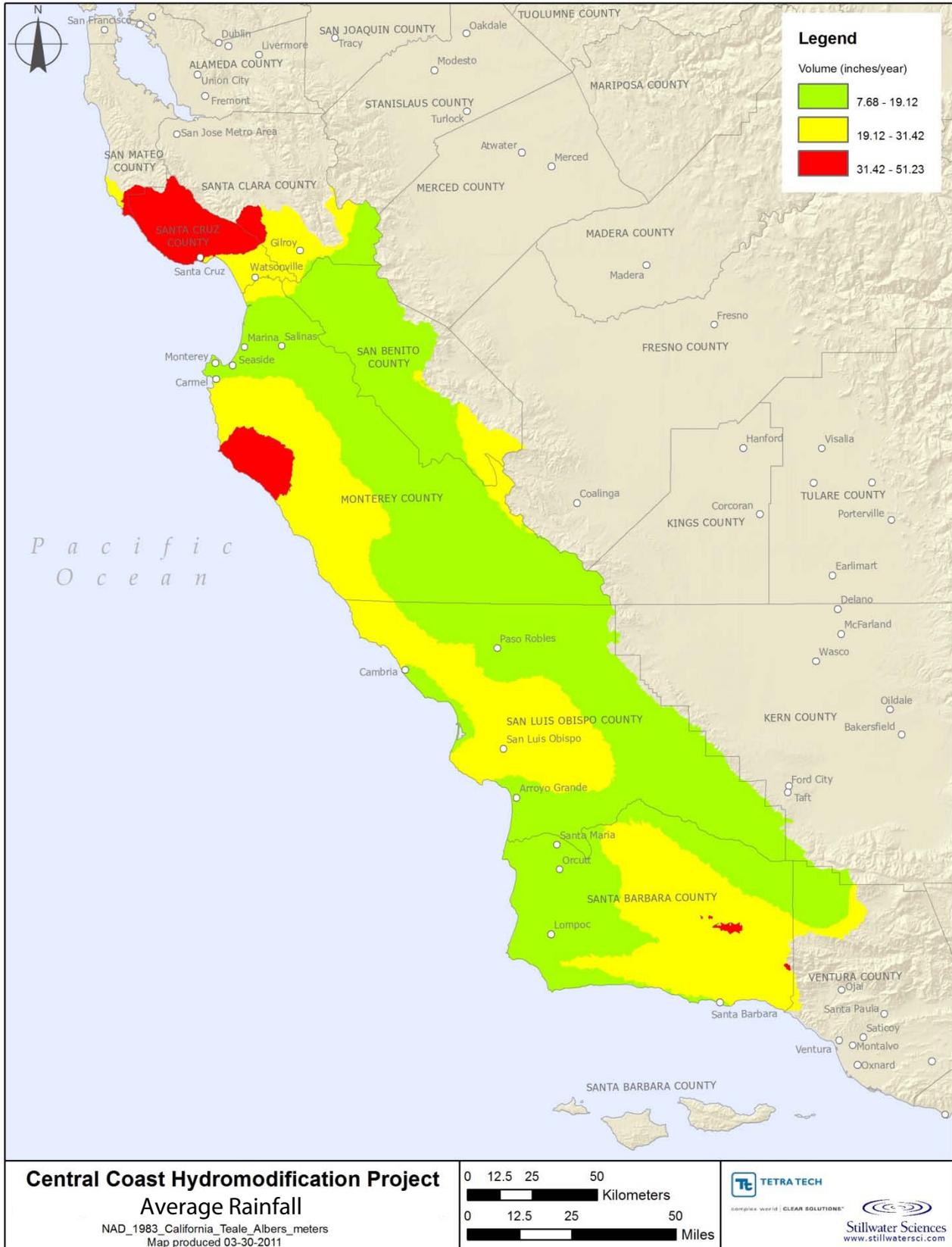


Figure 3-8. Map of average annual volume distribution categories for the Central Coast study area.

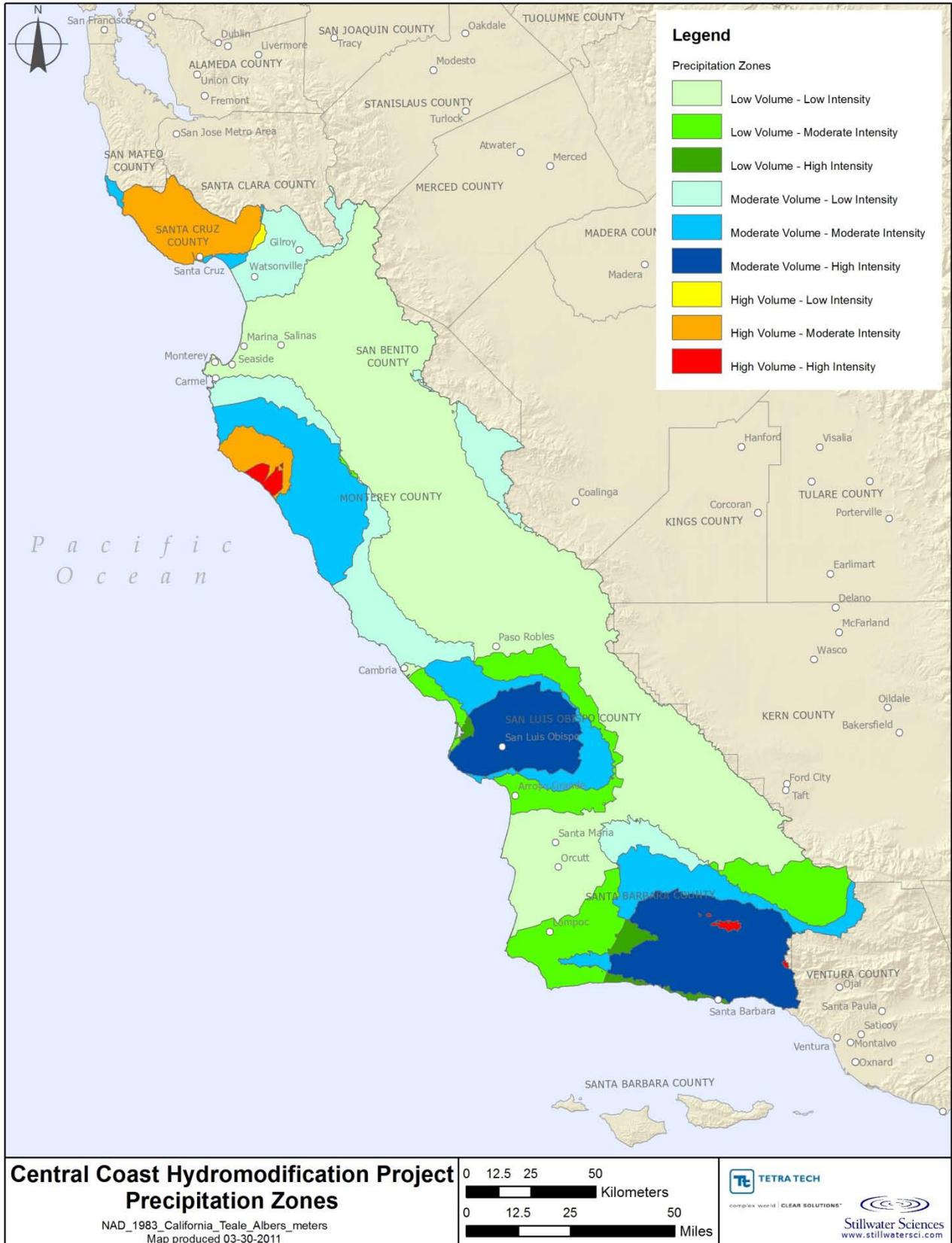


Figure 3-9. Map of precipitation zones of similar intensity and volume.

3.2.5. Observations and Potential Implications

The following paragraphs provide a brief discussion of possible ways in which the characterization of the precipitation might be used to support the analysis work included in subsequent tasks.

Precipitation is influenced by certain geological features such as elevation throughout various parts of the Central Coast Region. The network of mountain ridges and valleys result in weather lifting that causes higher precipitation along the western coastal areas and drier, more arid climates for the inland areas of the region. Use of the PRISM data enhanced the resolution of precipitation because it accounts for orographic influences during spatial interpolation. As noted, the general trend was more precipitation toward the coast, particularly the northern coast of the study area and less rainfall inland toward the eastern boundary of the study area. Because the objective of this study is to characterize hydromodification, which is largely driven by anthropogenic changes, precipitation resolution in urban areas will likely be more important than non-urban areas. Nonetheless, understanding how topography affects weather will help to gage the variation of potential impacts of future development and the resulting associated potential hydromodification throughout the study area.

It is expected that the primary indicator for gauging impacts of hydromodification, especially in urban areas is rainfall intensity. Intensity is correlated with erosion potential, sediment loading, and flood frequency in urban settings. As noted, the PRISM data were disaggregated to hourly to estimate intensity distribution throughout the study area. That effort was limited by the spatial distribution of available hourly NCDC rainfall gages. It was originally recommended that additional subdaily gages be compiled and used for the effort, especially those in and around existing or planned urban areas; however, the resulting estimates from the current HPD data set provide a good snapshot of relative intensity variation throughout the study area. A secondary benefit of this effort is that the resulting high-resolution precipitation data can be readily adapted for future data analysis or modeling efforts.

3.3. Natural Landscape Characterization

As previously discussed, under natural conditions, watershed processes (e.g., surface runoff, infiltration, sediment production and delivery) are primarily controlled by the physical attributes of the natural landscape (e.g., vegetation, soil, geology) and rainfall. Those processes can be relatively steady through time, or they can be highly variable. For example, some sediment delivery processes have fairly constant rates (such as soil creep), but can be unpredictably episodic (such as debris flows or rockfalls). Such complexities cannot be fully addressed in a GIS environment across an 11,000 mi² region, but they nonetheless produce recognizable signatures on the landscape.

Although the conditions that affect the delivery of water, chemical constituents, or sediment (or all three) to the receiving water vary greatly over time, different parts of the landscape can be readily identified as to their *relative* production and delivery potential, and the dominant process(es) by which that happens. (Note: For the purposes of this study, the fate and transport of natural chemical constituents is assumed to be approximated by the fate and transport of sediments and is not explicitly included in any analyses). On the basis of available landscape data, we can identify similar combinations of landscape attributes throughout the Central Coast Region that are expected to correlate directly with key watershed processes (a correlation to be completed in Task 4 of the Joint Effort). To accomplish that first step, we divided critical landscape attributes into discrete categories across the watershed that, in combination, influence multiple watershed processes (Reid and Dunne 1996; Montgomery 1999).

Acknowledging that many factors can determine the presence and dominance of particular watershed processes, this study focused on three that were judged to be most important throughout the Central Coast Region: geology type, hillslope gradient, and land cover. Data sources for each landscape category were compiled in a GIS format for the entire watershed at a resolution determined by the coarsest data set (i.e., 30 m). The following describes the methods used in this task.

Rock types were derived from the geologic map of California, produced by Jennings et al. (1977), and re-mapped to a 1:750,000 scale. Mapped units were grouped into seven categories on the basis of anecdotal information and previous studies in the region, largely by competency and degree of consolidation. The relative proportions of the geology categories are summarized in Table 3-2.

Table 3-2. Geology categories, generalized from Jennings et al. (1977) and as applied across the Central Coast Region

Geology category	% of area
Quaternary sedimentary deposits	30%
Tertiary sedimentary rocks	37%
Mesozoic metasedimentary rocks	12%
Tertiary volcanic rocks	11%
Granitic rocks	
Mesozoic and Paleozoic metamorphic rocks	
Franciscan mélange	11%

Land cover was based on NLCD 2006 data at 30-m resolution; the categories and their relative proportions are reported in Section 2.3.1. Several of the *urban* land-cover classifications were combined into a single *Intense Urban* category, because they were not well-represented as an area percentage across the entire region, and because the primary application of this characterization is to recognize watershed processes from undisturbed parts of the landscape. Several of the non-urban categories were similarly combined into one *Vegetated* category, again because many of the categories were quite rare across the entire region and offered little additional discriminating power.

Hillslope gradients were generated directly from the DEM, which in turn was based on a USGS 10-m DEM. On the basis of the distribution of slopes and on observed ranges of relative erosion and slope instability seen in previous studies in and adjacent to the region (e.g., Stillwater Sciences 2010), the continuous range of hillslope gradients was categorized into three groups: 0–10 percent, 10–40 percent, and steeper than 40 percent.

The discrete categories defined for those three factors (geology, land cover, and slope) could theoretically overlap into 84 possible combinations—that is, areas that each has a unique combination of the factors that are judged to be the major determinants of watershed processes. Many of the combinations, however, represented less than 1 percent of the total area of the region—those were combined into other categories that were judged to be qualitatively similar and appeared more commonly. In contrast, just five of the original categories account for more than half of the region (with the two most common being moderately steep [10 to 40 percent] vegetated Tertiary sedimentary rocks, and moderately steep vegetated Quaternary deposits).

After grouping and combining the original, initial categories into a tractable number of groups, the following final list was generated (Table 3-3) and used for the next stage of analysis.

Table 3-3. Natural landscape categories as a percent of total watershed area

Natural landscape categories	% of watershed area
Franciscan Melange; Vegetated; 0–40%	1%
Franciscan Melange; Vegetated; > 40%	4%
Mesozoic Metasediments; Vegetated; 0–40%	2%
Mesozoic Metasediments; Vegetated; > 40%	4%
Pre-Quaternary Non-Sedimentary; Vegetated; 0–40%	5%
Pre-Quaternary Non-Sedimentary; Vegetated; > 40%	5%
Quaternary Sedimentary; Vegetated; 0–10%	7%
Quaternary Sedimentary; Vegetated; 10–40%	15%
Quaternary Sedimentary; Vegetated; > 40%	10%
Tertiary Sedimentary; Vegetated; 0–10%	2%
Tertiary Sedimentary; Vegetated; 10–40%	4%
Tertiary Sedimentary; Vegetated; > 40%	15%
All; Low-Mid Residential; 0–10%	2%
All; Low-Mid Residential; 10–40%	3%
All; Low-Mid Residential; > 40%	3%
Intense Urban; Intense Urban; All	2%
Water	15%

3.3.1. Initial Natural Landscape Areas

The above analysis represents the initial characterization of the natural landscape and each discrete combination of attributes listed in Table 3-2 is expected to have a specific influence on watershed processes. However, for the purposes of simplifying this analysis to support subsequent tasks, it is helpful to perform an initial grouping of the natural landscape categories on the basis of known and understood boundaries. Therefore, the region was subdivided to simplify the characterization based primarily on the HUC 12 subwatersheds, resulting in 354 subwatersheds. A number of those were larger than 50 square miles, and they were further subdivided to yield a final list of 406 discrete *landscape areas*. The 406 landscape areas were each categorized with a distribution of the amount of area composed of the 17 natural landscape categories (Table 3-3). Because the landscape area boundaries were drawn on drainage divides but typically included both *flat* and *steep* areas, great variability in natural landscape category percentages for the various landscape areas was displayed within the data set. That required a statistical analysis to identify credible correlations between the natural landscape category distributions in the landscape areas. Two general approaches were used in the search for patterns in the data: cluster analysis and principal components analysis (PCA). All the analyses were carried out using the open-source “R” programming language.

The goal of cluster analysis is to identify groups of landscape areas with similar distributions of natural landscape categories. We selected two of the many algorithms in common use to achieve this task, called DIANA and AGNES in the literature. DIANA (DIvisive ANALysis) is a divisive hierarchical method: it begins by assigning all records to a single cluster and proceeds by breaking clusters into two smaller clusters until each record is in its own cluster. That process is repeated as often as desired on each daughter cluster until a desired number of clusters are reached (or until every cluster has only one member). In contrast, AGNES (AGglomerative NESTing) is an agglomerative hierarchical method that works in the opposite direction: it begins by assigning each record to a separate cluster and proceeds by merging clusters, until the requisite number is reached or all records are in one cluster. All clustering methods require some concept of *distance* between pairs of records; we used the basic euclidean distance between vectors to define distance, and we explored both divisive and agglomerative approaches.

After inspection of results from both AGNES and DIANA on various numbers of clusters between 4 and 16, we found that a tractable number of groups with broadly even representation between groups were achieved by grouping the 406 landscape areas into 12 DIANA categories (Table 3-4; Figure 3-10). We emphasize that nothing is intrinsically *better* or *worse* about this grouping, relative to any other version that the analyses supplied. It simply met four key objectives better than others that we investigated: (1) statistically unbiased as to the choice of groups (true of all alternatives); (2) a tractable number of groups (a precondition of every analysis, with the value of 12 selected on the basis of considerations of the overall project’s scope, schedule, and purpose); (3) reasonable representation of all groups in the landscape (a 12-group scheme with one group having < 1 percent total area would be, functionally, only an 11-group scheme); and (4) providing a spatially coherent zonation of the region (because geology and topography extend across multiple landscape areas, any classification scheme should show a similar *grain* of spatial commonality and coherence).

Table 3-4. Distribution of groups as determined by the DIANA-12 technique for the 406 landscape areas of the Central Coast Region

Group number	% of watershed area
1	16%
2	4%
3	7%
4	9%
5	5%
6	11%
7	11%
8	7%
9	3%
10	2%
11	20%
12	4%

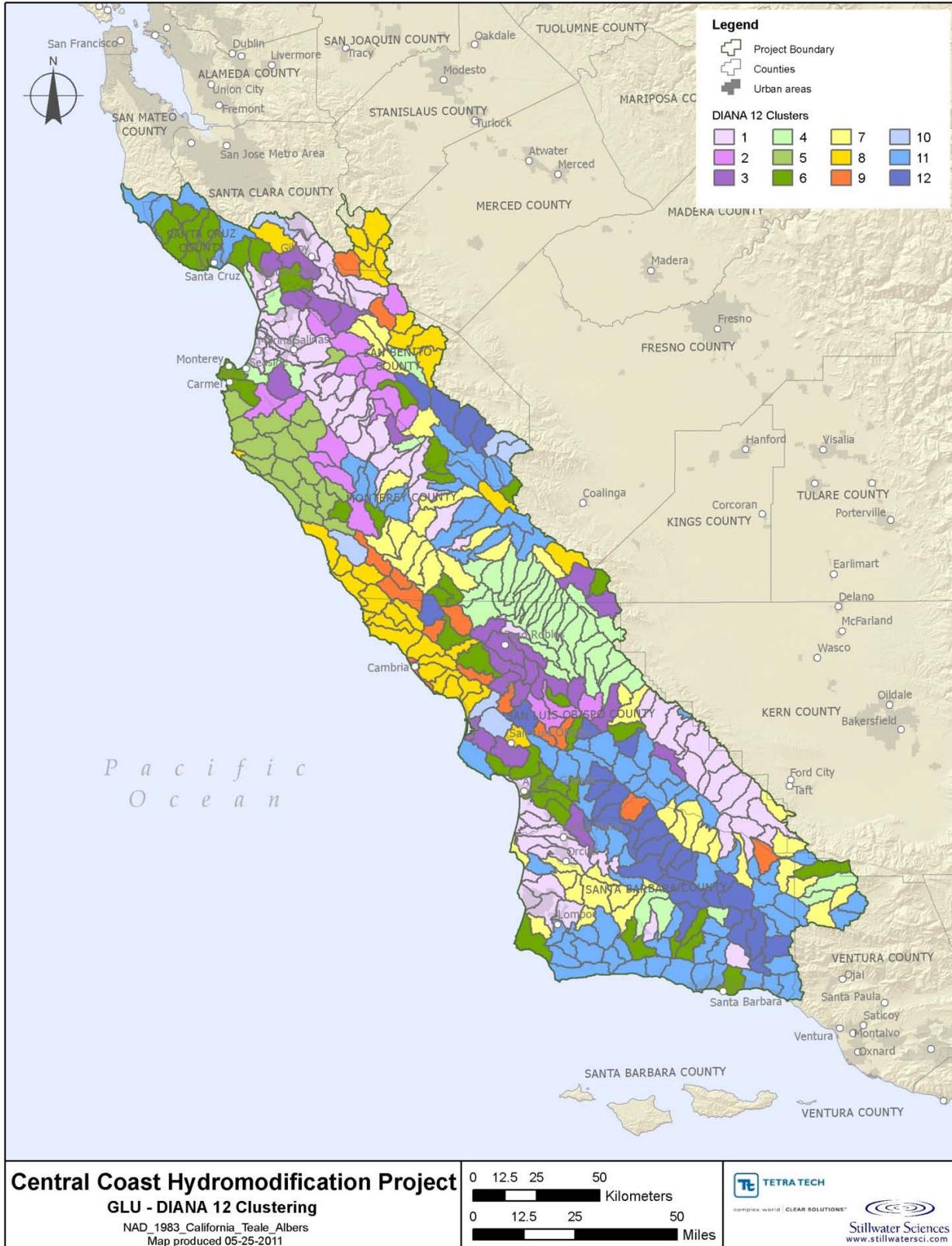


Figure 3-10. Distribution of groups as determined by the DIANA-12 technique for the 406 landscape areas of the Central Coast Region.

3.3.2. Identification of Representative Natural Landscape Areas

As originally conceived in the scope for the Joint Effort, one or more *representative* landscape areas identified from the initial set of analyses would be identified for Task 3 field validation of the likely suite of key watershed processes responsible for the production and movement of water and sediment, and (2) the qualitative condition of any associated receiving waters. The nature of the region (and the data developed to represent it), however, rendered that approach unnecessarily restrictive for the upcoming application (that of characterizing watershed processes) for several reasons. First, the vast majority of the region is only lightly developed—entire landscape areas with less than 0.5 percent imperviousness are widely distributed, providing ample opportunity to evaluate and verify conditions across a wide geographical range. Second, at the scale of whole landscape areas, the landscape expression of different major processes—for example, surface runoff versus deep infiltration, or surface erosion versus mass failures—are quite evident without detailed inspection, and so field inspections need not be overly limited in range.

Note that the scope for Part I of the watershed characterization also included the identification of representative receiving water groups. For the evaluation of receiving waterbodies, however, observational data (along with any additional chemical or biological data that might exist from local or regional jurisdictions) requires more time than could possibly be invested across the entire population of rivers, streams, lakes, wetlands, and nearshore areas in the Central Coast Region. Although the original scope of work envisioned the identification of those representative receiving water areas in Part I of the watershed characterization, the ability to identify such *representative* sites in the context Part II is more appropriate.

3.4. Developed Landscape Characterization

To support the development of credible hydromodification management criteria, it is important to understand the nature of development and the resulting impacts on watershed processes in the Central Coast Region. Because increased connected imperviousness results in greater volumes and velocities of runoff, often the most obvious impacts are those visibly observed in receiving waters and associated monitoring data (e.g., flow data). However, development impacts on subsurface receiving waters are difficult to observe and monitoring data are scarce. Therefore, the characterization of development in the Central Coast is accomplished in the context of its impacts on surface runoff hydrology. The characterization of the developed landscape in the Central Coast Region presented in this section will provide the foundational information to support the analyses of future tasks, such as

- Validating the natural landscape categories with regards to predicting surface runoff and sediment delivery processes
- Helping to evaluate the relative importance of the spatially varied precipitation component
- Validating the predicted impact of development in terms of surface runoff

To accurately characterize the developed landscape in the context of how the development might affect surface hydrology, it is important to consider three GIS layers, Land Use (Section 2.3.1), Soil Hydrologic Groups (Section 2.2.3), and Slope (Section 2.2.1). In the following subsections, the strategy for generally grouping the properties of the data sets is described. Each of the more general groups qualitatively rated from 1 to 3 to represent the relative influence on the potential for surface runoff (i.e., 1: low, 2: moderate, 3: high). The unique combinations of properties from the three data sets should determine the nature of the change in runoff patterns. In subsequent tasks, that determination will be compared to the types of changes that are observed in the natural landscape or receiving waters.

3.4.1. Land Use Influence on Runoff Potential

The composite land use data set developed and described in Section 2 of this report was used as the basis for this part of the analysis. Because the composite data set contained over 50 different attribute types (e.g., mixed forest, shopping centers, parking lots), each was assigned to one of 11 major land use categories on the basis of their expected hydrologic response to simplify the analysis. Those major categories were then assigned an integer land

use influence on runoff potential value ranging from 1 to 3 on the basis of assumed level of imperviousness. The results of that analysis (Table 3-5 and Figure 3-11) provide a characterization of the nature of the development and an assessment of its likely impact on surface runoff potential. The same procedure was also performed to create similar maps for the land use layer from 1985, not presented in this report.

Table 3-5. Land use influence on runoff potential (current)

Land use group	Area (acres)	Percent area	Land use influence (value)
Agriculture	486,224	6.72%	Low (1)
Commercial	24,222	0.33%	High (3)
High Density Residential	7,083	0.10%	High (3)
Industrial	14,142	0.20%	High (3)
Institutional	19,134	0.26%	High (3)
Low Density Residential	435,756	6.03%	Moderate (2)
Medium Density Residential	75,750	1.05%	High (3)
Transportation	103,166	1.43%	High (3)
Vacant	394,803	5.46%	Moderate (2)
Vegetation	5,638,285	77.96%	Low (1)
Water	33,791	0.47%	Low (1)

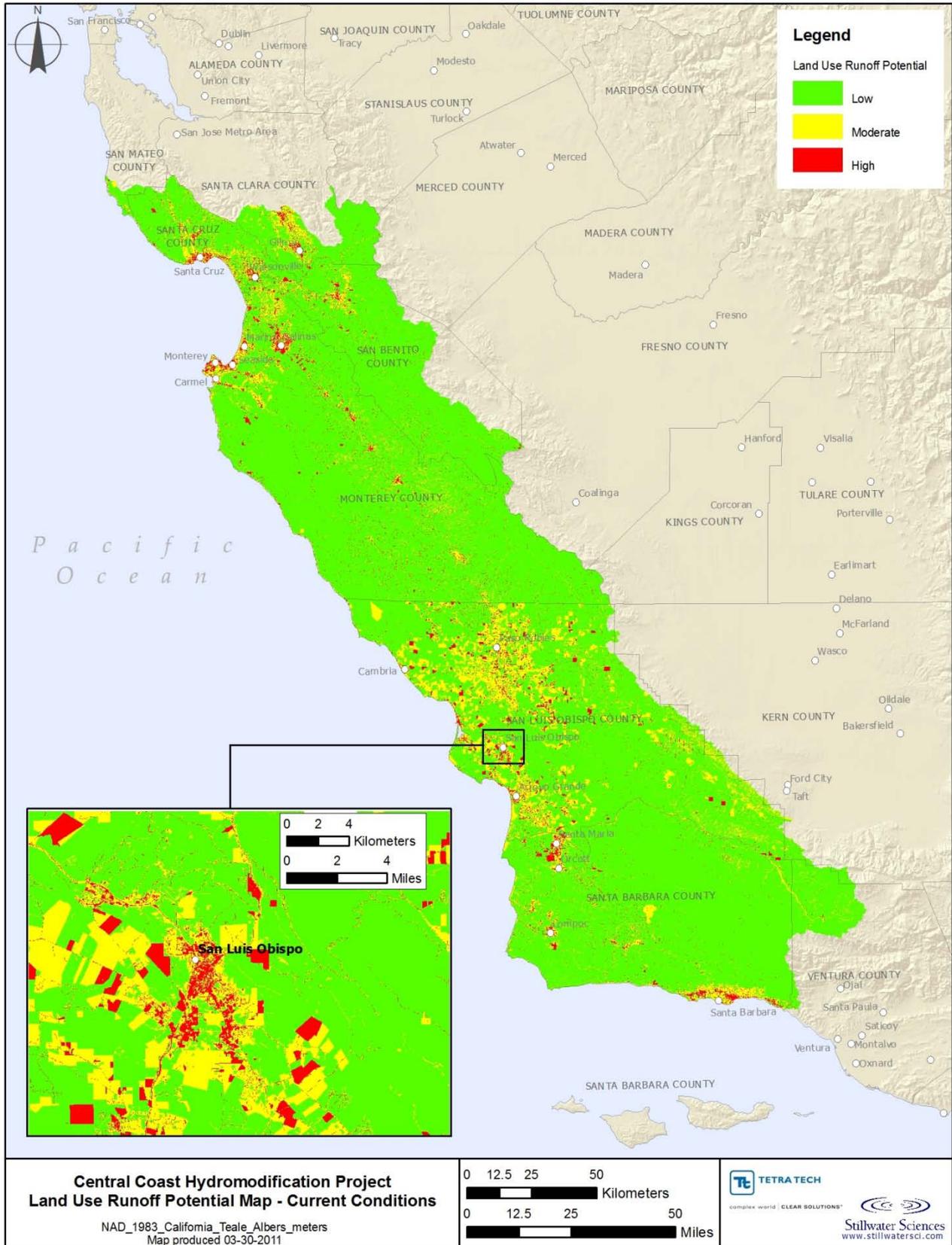


Figure 3-11. Map of land use influence on runoff potential.

3.4.2. Soil Influence on Runoff Potential

Using the soil group data defined in Section 2.2.3, each of the soil hydrologic groups was assigned an integer influence value ranging from 1 to 3 on the basis of their potential for generating surface runoff. Soils with high impermeability were rated highest; soils with high infiltration capacity were rated lowest. The results of that analysis (Table 3-6; Figure 3-12) provide a characterization of the influence of soil type on runoff potential. Because that is not expected to change with time, the same map can be used with current and historical land use characterizations.

Table 3-6. Soil influence on runoff potential

Soil type	Description of soil type	Soil influence (value)	Area (acres)	Percent area
A	Sand, loamy sand, or sandy loam. Soils having a high infiltration rate (low runoff potential) when thoroughly wet	Low (1)	282,628	3.91%
B	Silt loam or loam. Soils having a moderate infiltration rate when thoroughly wet	Low (1)	1,846,527	25.53%
C	Sandy clay loam. Soils having a slow infiltration rate when thoroughly wet	Moderate (2)	2,591,406	35.83%
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material	High (3)	2,298,007	31.77%
n/a (water)	Water	Low (1)	213,788	2.96%

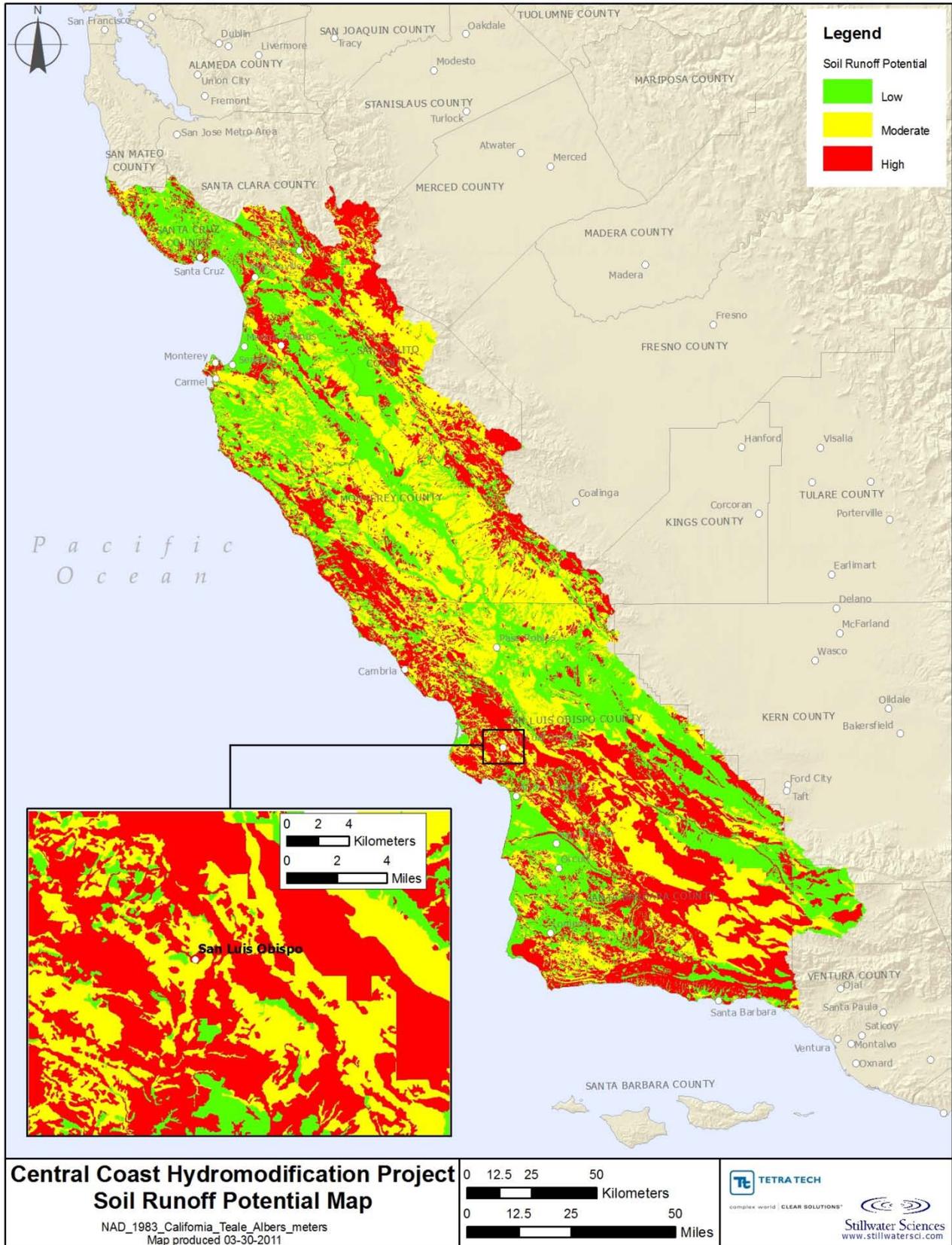


Figure 3-12. Map of soil influence on runoff potential.

3.4.3. Slope Influence on Runoff Potential

Using the slope data defined in Section 2.2.1, the data were broken down into three categories of low, moderate, and high slopes, and each group was assigned an integer influence value ranging from 1 to 3 on the basis of its potential for generating runoff. High sloping areas were rated highest; shallowly sloped areas were rated lowest. The results of this analysis (Table 3-7; Figure 3-13) provide a characterization of the influence of slope on runoff potential. Because that is not expected to change with time, the same map can be used with current and historical land use characterizations.

Table 3-7. Slope influence on runoff potential

Slope category	Slope influence (Value)	Area (acres)	Percent area
0–10%	Low (1)	1,865,730	25.80%
10–40%	Moderate (2)	3,035,440	41.97%
> 40%	High (3)	2,331,186	32.23%

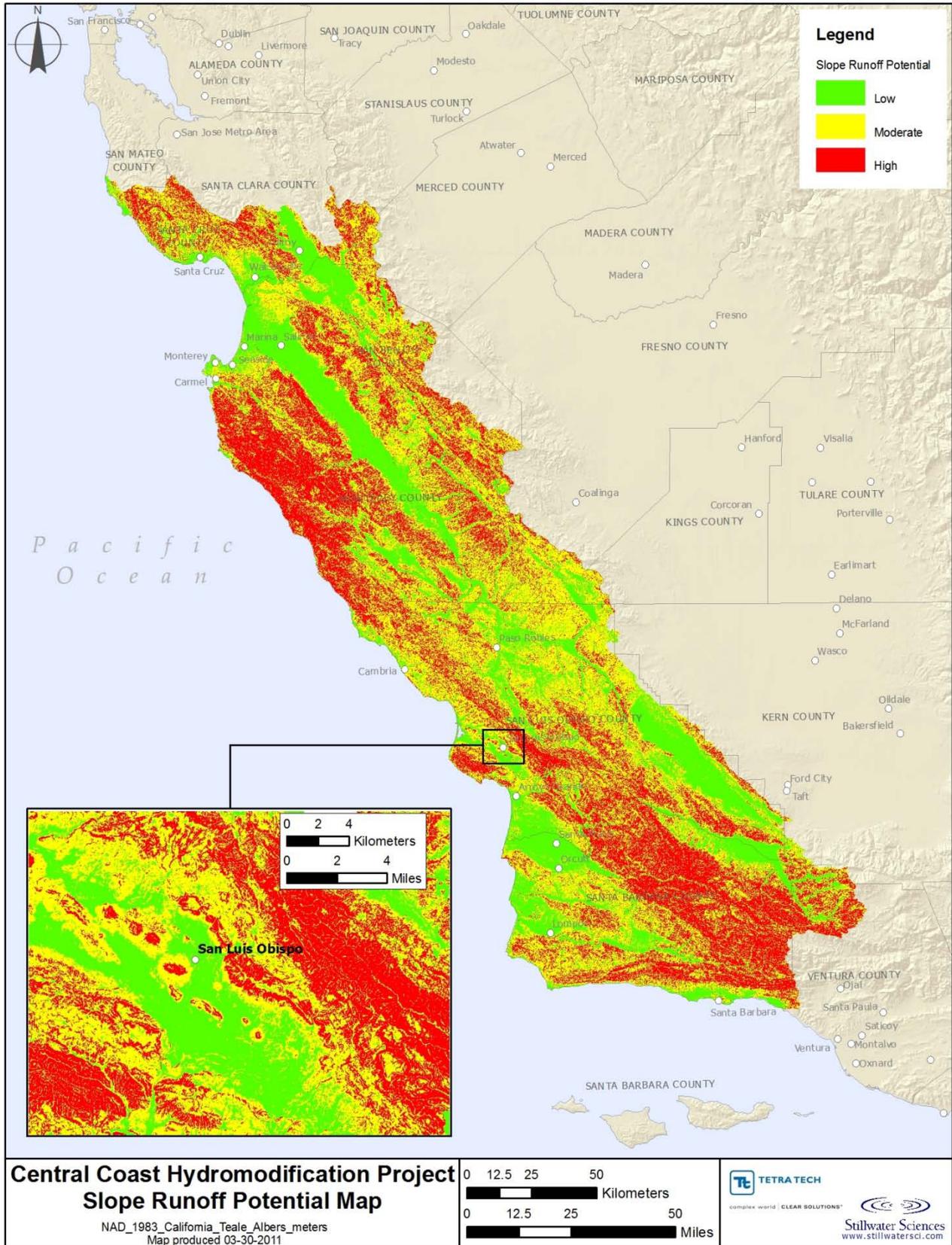


Figure 3-13. Map of slope influence on runoff potential.

3.4.4. Characterization of the Developed Landscape

The characterization of the developed landscape (in the context of its influence on surface runoff) is accomplished by combining the results from the characterization of the three individual components (current land use, soil, and slope). The components were overlaid to create a new GIS layer with 27 possible combinations and 7 possible *influence values*, ranging from 3 to 9 (Table 3-8). The influence values are then grouped into low (3 and 4), moderate (5–7), and high (8 and 9) to represent the overall runoff response for each combination (Figure 3-14). That map characterizes the combined influences of land use, soil type, and slope on the potential to generate runoff. Areas receiving low scores are expected to exhibit similar low potential for surface runoff, whereas areas receiving high scores are expected to exhibit similar high potential for runoff. A similar map was also created for the historic condition, which differs only in the distribution of land use changes between those two periods (not included in this report).

The benefit of that approach is that it provides the ability to evaluate and visualize the range of influences that development in different areas will have on local surface runoff processes. For instance, surface runoff processes from an area with naturally high runoff potential are likely to be less severely influenced by new development than an area with naturally low potential for surface runoff. That ability to predict such influences will be helpful when evaluating the linkage between the developed conditions of the landscape with receiving water conditions and will provide a validation of the natural landscape characterization described in the previous section.

Table 3-8. Developed landscape influence on runoff potential

Land use influence	Soil influence	Slope influence	Relative influence on runoff processes	Area (acres)	Percent area
Low (1)	Low (1)	Low (1)	3	764,839	10.58
Low (1)	Low (1)	Moderate (2)	4	670,271	9.27
Low (1)	Low (1)	High (3)	5	441,275	6.10
Low (1)	Moderate (2)	Low (1)	4	292,647	4.05
Low (1)	Moderate (2)	Moderate (2)	5	1,116,369	15.44
Low (1)	Moderate (2)	High (3)	6	873,088	12.07
Low (1)	High (3)	Low (1)	5	294,275	4.07
Low (1)	High (3)	Moderate (2)	6	831,113	11.49
Low (1)	High (3)	High (3)	7	874,423	12.09
Moderate (2)	Low (1)	Low (1)	4	222,319	3.07
Moderate (2)	Low (1)	Moderate (2)	5	113,003	1.56
Moderate (2)	Low (1)	High (3)	6	24,366	0.34
Moderate (2)	Moderate (2)	Low (1)	5	67,316	0.93
Moderate (2)	Moderate (2)	Moderate (2)	6	131,747	1.82
Moderate (2)	Moderate (2)	High (3)	7	50,405	0.70
Moderate (2)	High (3)	Low (1)	6	90,752	1.25
Moderate (2)	High (3)	Moderate (2)	7	99,442	1.37
Moderate (2)	High (3)	High (3)	8	50,343	0.70
High (3)	Low (1)	Low (1)	5	77,460	1.07
High (3)	Low (1)	Moderate (2)	6	25,085	0.35
High (3)	Low (1)	High (3)	7	4,324	0.06
High (3)	Moderate (2)	Low (1)	6	23,440	0.32
High (3)	Moderate (2)	Moderate (2)	7	28,968	0.40
High (3)	Moderate (2)	High (3)	8	7,426	0.10
High (3)	High (3)	Low (1)	7	32,681	0.45
High (3)	High (3)	Moderate (2)	8	19,442	0.27
High (3)	High (3)	High (3)	9	5,535	0.08

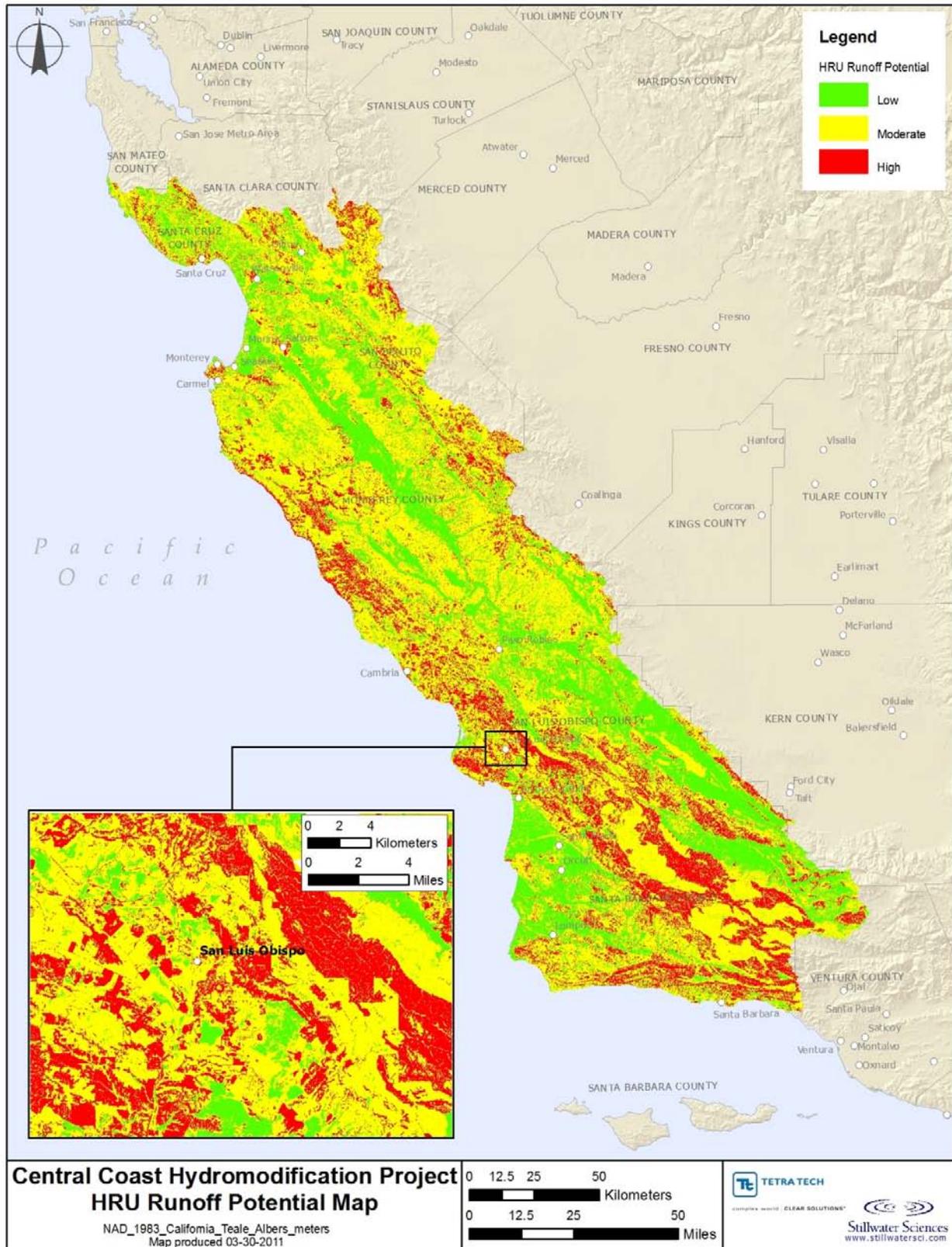


Figure 3-14. HRU impact map (current conditions).

3.4.5. Observations and Potential Implications

The above characterization of the developed landscape provides the framework for evaluating the impacts of development on runoff potential. The following paragraphs provide a brief discussion of possible ways in which the characterization of the developed landscape might be used to support the analysis work included in subsequent tasks. The relative scoring approach allows for a quick and simplistic visualization of the potential for generating surface runoff, highlighting heavily contributing areas in red. The approach facilitates the validation of several assumptions made as part of this project.

First, although the natural landscape categories are excellent tools for evaluating a broad suite of watershed processes on the spatial scale of interest to this project, soil types inform the more common analytical approach for quantifying runoff. Thus, the characterization of soil types and slope (minus land use) in the context of runoff potential provides a good opportunity to independently validate the natural landscape characterization approach. Several large areas could be evaluated for runoff potential using both approaches and compared for both their map-based prediction and their expression in the field. Such assessments will be made during Part II of the watershed characterization process.

Second (and related to the first), this ability to quickly and accurately assess runoff potential provides the opportunity to assess the relative importance of precipitation. Simple analyses can be conducted on undeveloped areas with similar landscape characteristics (on the basis of natural landscape and developed landscape characterization results) but different rainfall patterns. That could include a simple assessment of USGS gauge data to investigate runoff per unit area and compare results from the two areas; it is also amenable to direct observation in different parts of the region with strongly differing rainfall patterns. That will also occur during Part II of the watershed characterization.

Third, the temporal component of the development characterization provides the opportunity to test the predictions of developmental impacts on specific watershed types. By assessing the differences in the current and historical developed landscape characterizations, areas can be identified where there has been a large increase in runoff potential. The hydromodification criteria development process must attempt to predict watershed responses to development to determine the appropriate management strategies. To the extent that these predictions include increased runoff and possible erosive stream degradation, the predictions can be tested and validated through the temporal analysis by combining field observations with historical stream gage analysis and comparing the results.

4. Next Steps

The basic premise of the Joint Effort is that if receiving water conditions can be linked to specific combinations of precipitation and landscape conditions, then, on the basis of both scientific understanding of watershed processes and empirical data, we can establish a sound basis for establishing appropriate management for hydromodification control.

Task 2 of the Joint Effort, described in this report, has used GIS data layers to define a credible initial set of precipitation and landscape zones on the basis of weather patterns and physical attributes of the region that are likely to determine the relative importance of watershed processes. Task 3, Part II of the watershed characterization, will field-evaluate that initial set of landscape zones, refining their boundaries or choice of primary data sets (or both) to improve the criteria, attributes, and locations for a *final* set of landscape zones. It will also collect observational data, and compile existing quantitative data, for a range of receiving waters that can be used to evaluate the downstream consequences of altered key watershed processes.

Task 4 will synthesize the analyses and deliverables from Tasks 1-3. Its first objective is to identify and characterize multiple watershed process *zones*, reflecting areas with similar combinations of precipitation and natural landscape attributes with similar watershed processes and that respond similarly to disturbance. The task will also evaluate the degree to which those initial zones can truly be generalized across the region. Natural landscape areas with the same conditions and inferred key watershed process are likely to have similar opportunities and constraints for the selection and application of stormwater management strategies. Products from this task will thus set the framework for development of the methodology for establishing numeric performance criteria in Task 5.

The central objective of Task 4, however, is to summarize the relationships (linkages) between physical attributes, watershed processes, and receiving waters. Those linkages will provide the rationale for applying alternative approaches to restoring disturbed watershed processes across the diverse landscape of the Region. Finally, Task 5 will finalize the analytics of the project and document the methodology needed to complete the development of the hydromodification management strategy, namely the development of numeric criteria.

5. References

- CDWR (California Department of Water Resources). 2004. Groundwater basin map. <http://www.water.ca.gov/groundwater/bulletin118/gwbasin_maps_descriptions.cfm>. Accessed September 15, 2006.
- Jennings, C.W., R.G. Strand, and T.H. Rogers. 1977. Geologic map of California. Scale 1:750,000. California Division of Mines and Geology, CA.
- LACDPW (Los Angeles County Department of Public Works). 2002. Development Planning for Storm Water Management: A Manual for the Standard Urban Storm Water Mitigation Plan (SUSMP). Los Angeles County Department of Public Works, Los Angeles, CA.
- Montgomery, D.R. 1999. *Process domains and the River Continuum*. Journal of the American Water Resources Association, 35 (2), pp. 397-410.
- MRLC (Multi-Resolution Land Characteristics Consortium). 2011. Access Data: NLCD 2001. <<http://www.mrlc.gov/>>. Accessed February 28, 2011.
- NRCS (Natural Resources Conservation Service). 1994. U.S. General Soil Map (SSURGO). <<http://soils.usda.gov/survey/geography/statsgo/description.html>>. Accessed November 19, 2010.
- NRCS (Natural Resources Conservation Service). 2010. NRCS HUC boundaries. <<http://www.nrcs.usda.gov/>>. Accessed October 20, 2010.
- Reid, Leslie M. and Thomas Dunne, 1996. Rapid Evaluation of Sediment Budgets. Reiskirchen: Germany, Catena Verlag (GeoEcology paperback), 164 p.
- Stillwater Sciences. 2010. *Santa Rosa Creek Watershed Management Plan: Watershed Geomorphology Assessment*. Final Technical Report. Prepared by Stillwater Sciences, Berkeley, CA, for Greenspace—The Cambria Land Trust, Cambria, CA.
- USDA FSA APFO (U.S. Department of Agriculture, Farm Service Agency, Aerial Photography Field Office) 2009. National Agricultural Imagery Program. <<http://www.atlas.ca.gov/download.html>>. Accessed January 31, 2011.
- USEPA (U.S. Environmental Protection Agency) and USGS (U.S. Geological Survey). 2010. NHDPlus Catchments. <<http://www.horizon-systems.com/nhdplus/>>. Accessed October 25, 2010.
- USGS (U.S. Geological Survey). 2009. National Elevation Dataset. <<http://ned.usgs.gov/>>. Accessed October 20, 2010.
- USGS (U.S. Geological Survey). 2011. Enhanced Historical Land-Use & Land-Cover Data Sets of the USGS (1985). <<http://water.usgs.gov/GIS/dsdl/ds240/index.html/>>. Accessed February 28, 2011.
- WEF (Water Environment Federation) and ASCE (American Society of Civil Engineers). 1998. *Urban Runoff Quality Management*, Water Environment Federation (WEF) Manual of Practice No. 23, American Society of Civil Engineers (ASCE) Manual and Report on Engineering Practice No. 87. Water Environment Federation, Alexandria, VA, and American Society of Civil Engineers, Reston, VA.