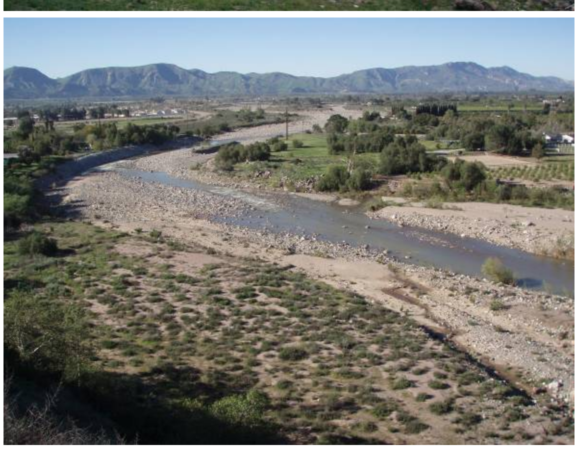


SESPE CREEK HYDROLOGY, HYDRAULICS, AND SEDIMENTATION ANALYSIS:

Watershed Assessment of Hillslope and River Geomorphic Processes

FINAL REPORT

April 2010

Prepared for
Ventura County Watershed Protection District
800 South Victoria Avenue
Ventura, CA 93009-1610

Prepared by
Stillwater Sciences
2855 Telegraph Avenue, Suite 400
Berkeley, CA 94705

Stillwater Sciences

Contact:

Peter Downs, Ph.D.
Senior Geomorphologist
Stillwater Sciences
2855 Telegraph Avenue, Ste 400
Berkeley, CA 94705
(510) 848-8098 x121
downs@stillwatersci.com
www.stillwatersci.com

John McCarthy, P.E.
Vice President
RBF Consulting
14725 Alton Parkway
Irvine, CA 92618
(949) 855-5759
jmccarthy@rbf.com
www.rbf.com

Yunsheng Su, Ph.D., P.E.
Engineer III
Ventura County Watershed Protection District
800 South Victoria Avenue
Ventura, CA 93009
(805) 654-2005
yunsheng.su@ventura.org

Cover photography (from top to bottom):

1. Eastward (downstream-facing) view of Sespe Creek with the Pine Mountains in background.
2. Burned hillslope surfaces in the upper Sespe watershed shortly after the 2006 Day Fire.
3. Middle subwatershed reach of Sespe Creek bordered by steep, barren bedrock units with the Topotopa Mountains in the left background.
4. Southward (downstream-facing) view of the lower reach of Sespe Creek near the City of Fillmore with the Sespe Creek Levee running along the left bank.

Acknowledgements of those not directly involved with the project:

We would like to thank individuals from a number of organizations who provided assistance during the course of this project: the U.S. Forest Service – Ojai Ranger District office granted us permission to access all areas of the Los Padres National Forest for our field surveys, the U.S. Forest Service – Los Padres National Forest provided geologic data and Day Fire spatial data, the City of Fillmore Engineering Department provided topographic data of lower Sespe Creek from 2004, the Ventura County Planning Division provided aggregate mining history information for lower Sespe Creek, Bruce Henderson of the U.S. Army Corps of Engineers provided aggregate mining activity information in lower Sespe Creek, Kevin Schmidt of the U.S. Geological Survey in Menlo Park provided useful post-fire sediment production information from their ongoing study in the Day Fire area, Bradley Monsma of California State University – Channel Islands and author of the book: The Sespe Wild provided useful historical and post-fire information from the watershed, Zeke Barlow and Jen Edney of the Ventura County Star newspaper shared photographs taken during the helicopter reconnaissance of the watershed in support of this project, and Peter Wohlgemuth of the U.S. Forest Service – Pacific Southwest Research Station who reviewed our draft report and shared useful comments related to post-fire erosion processes.

Suggested citation:

Stillwater Sciences. 2010. Sespe Creek hydrology, hydraulics, and sedimentation analysis: watershed assessment of hillslope and river geomorphic processes – final draft. Prepared by Stillwater Sciences, Berkeley, California for Ventura County Watershed Protection District, Ventura, California. April.

Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis: Watershed Assessment of Hillslope and River Geomorphic Processes

Executive Summary

Introduction

This report summarizes a fluvial morphology and sedimentation analysis performed by Stillwater Sciences in the Sespe Creek watershed—a major tributary to the Santa Clara River in Ventura County, California—for the purpose of aiding the Ventura County Watershed Protection District (VCWPD) with their assessment of post-fire sedimentation and flood protection levels in the lower reaches near the City of Fillmore. This geomorphology-based study is part of a larger project designed to evaluate the dynamics between hydrologic, hydraulic, and geomorphic processes and conditions in the watershed which, together, ultimately affect sedimentation in the lower reaches. The primary charge of this assessment has been to evaluate whether a post-fire sediment pulse following the 2006 Day Fire has reduced *or* will reduce the flood protection levels in the lower reach near the City of Fillmore, which is presently protected from flooding by the Sespe Creek Levee. Stillwater Sciences was tasked to conduct the watershed geomorphology (i.e., fluvial morphology and sedimentation) assessment from a historical (baseline) and contemporary (post-fire) perspective. Specific tasks conducted for this assessment that are summarized in this report include the following:

- Compilation and review of existing information relating to hillslope and channel geomorphic processes, in addition to information on fire effects on sediment production in southern California watersheds
- Characterization of hillslope geomorphic processes in the watershed and resulting sediment yields into the mainstem Sespe Creek
- Characterization of sediment transport and channel dynamics in the mainstem of Sespe Creek to understand how these processes affect channel morphology, specifically in the lower reach adjacent to the Sespe Creek Levee

Watershed Geomorphic Processes

The Sespe Creek watershed is one of the most pristine and geographically remote areas in southern California. Located in the tectonically-active Transverse Mountain ranges, the watershed has steep hillslopes mantled with shallow soils and shrub vegetation, and is drained by steep, coarse sediment-bearing tributaries. Sespe Creek is subject to large, flashy flood events that almost always coincide with El Niño years which, because of storm intensification over the last 40 years, have made large flood events more frequent in recent times (e.g., 1969, 1978, 1995, and 2005). Flood risk to the floodplain residents of Fillmore was addressed with the construction of a 3.3 km (2 mi) long, rock-revetted levee built in 1981, and now subject to management reassessment because of the concern with the potential for post-fire sedimentation following a series of recent wildfires in the upper watershed, specifically the 2006 Day Fire which burned a third of the watershed.

Sediment production in the watershed derives from two primary sources: (1) large volumes of fine sediment (i.e., silts and clays) are produced from highly erodible siltstones and mudstones throughout the watershed, and (2) relatively lower volumes of coarse sediment (i.e., sands and larger) are delivered primarily by rockfall from much harder sandstones and granitic rocks in the upper watershed. The fine sediments are easily transported downstream and out of the watershed once delivered to the drainage network. The presence of coarse sediment throughout the lower Sespe Creek channel downstream of the steep, confined gorge suggest that the gorge reach is capable of transporting coarse sediment from the upper watershed.

Sediment production rates throughout the watershed were assessed initially by classifying the watershed into three field-assigned rates of sediment production (low, medium, and high) based on combinations of three primary landscape characteristics: geology, vegetation, and hillslope gradient. The results of this geomorphic landscape unit (GLU) analysis indicate that the majority of the watershed has "medium" rates of sediment production, which suggests relatively homogeneous rates of production throughout the watershed. Numerical values of sediment production rates associated with the three classifications were determined from measured rates of sediment delivery to five nearby debris basins; the results of which provide an average annual sediment yield from Sespe Creek of 1,150,000 tonnes per year ($t\ a^{-1}$), or a yield per unit area estimate of 1,760 $t\ km^{-2}\ a^{-1}$. This sediment yield value implies an average annual rate of denudation in the watershed of 0.6 mm, which is consistent with the notion that rates of regional uplift (3–5 $mm\ a^{-1}$) must be significantly higher than the rate of lowering to explain the high elevations and relict uplifted landforms of the upper watershed. The predicted watershed sediment yield also agrees well with the sediment yield estimated from analysis of gauging records at the USGS stream gauge in the lower reach, which amounts to 1,523 $t\ km^{-2}\ a^{-1}$.

Sediment production rates have the potential to increase significantly within 5–10 years following a wildfire as a direct result of altered vegetation and rainfall-runoff relationships, soil structure, and rock weathering processes. A comparison of three post-fire sediment production methods indicates a range, and likely uncertainty, of predicted impacts from the recent Day Fire on sediment production and delivery into the mainstem channel. The U.S. Forest Service – Burned Area Emergency Response method, based on debris basin information compiled in 1949, indicates a 6-fold increase in total sediment yield from the watershed, primarily as a function of up to a 20-fold increase in sediment production in the burned areas. Using our earlier GLU methodology for calculating sediment production, but including a loss of vegetation cover as a consequence of wildfire, predicts a 10-fold increase in sediment production across burned areas, resulting in an overall 4-fold increase in sediment yield from the watershed as a whole. In contrast to these predicted order-of-magnitude increases in local sediment production, a previously published regression equation of Scott and Williams (1978) would predict only a maximum 3-fold sediment-yield increase across burned areas. The actual downstream impact of this predicted 3- to 20-fold increase in sediment production in the burned areas of the watershed depends upon antecedent rainfall and sediment-storage conditions, the magnitude of the first post-fire rainfall event and, critically, the routing of the sediment through lower Sespe Creek. As of summer 2008, field observations throughout the burned areas noted accumulations of poorly-sorted, clay to fine-gravel sized sediment at tributary mouths, delivered as debris flows that were supplied by increased hillslope rilling, gullying, and sheetwash. Farther downstream in the gorge, there is frequent evidence of the infilling of pools by sandy sediments, locally as deep as 5 m, which likely occurred during the moderate high flows in early 2008. It did not appear that coarse sediment delivery rates have increased in response to the wildfire, which is a significant finding when considering that coarse-grained sediments have greater influence on channel morphology, especially in the lower reaches where channel capacity, and thus flood protection levels, can be adversely affected by excessive accumulation of coarse sediment.

Sediment Transport and Morphological Change in Lower Sespe Creek

Sediment delivery to the lower reaches of Sespe Creek is sporadic, occurring during short-duration, high-intensity storm events. Using daily flow data between 1928–2009 and sediment sampling measurements taken between 1966–1978 by the USGS at the Sespe Creek gauge near Fillmore, annual sediment transport loads have varied between 250 tonnes transported in water year (WY) 1951 to 16 million tonnes transported in WY 2005, which contains the flood of record. The average annual yield predicted using the gauge data is 990,000 t a^{-1}, or a sediment yield per unit area of 1,520 t km^{-2} a^{-1} over this time period. Four high-flow years with large floods (WY 1969, 1978, 1995, and 2005) account for over half the total sediment yield, indicating the dominant discharge is the largest flow event on record (2005) and, therefore, distinguishing Sespe Creek from humid-region rivers that typically have a dominant discharge equivalent to an intermediate flood event (i.e., bankfull flow).

The hydrologic, hydraulic, and sediment production characteristics of the watershed together make Sespe Creek a highly dynamic river environment. A detailed evaluation of historical data that characterize the morphology of lower Sespe Creek between the gorge and the Santa Clara River reveals several significant findings, namely that lower Sespe Creek has occupied a largely similar, yet active stream course through its alluvial fan. In response to flood events and antecedent conditions, the active channel area, thalweg(s) location(s), and bed elevation have adjusted locally with some cumulative changes in the channel morphology. Since the 1970s, the cross-sectional area of the channel has generally decreased, as driven by aggradation, channel narrowing, or both, and occasionally has been related to lateral migration of the channel near the upstream end of the Sespe Creek Levee. These historical data specifically reveal that the 2005 floods acted as a depositional event, likely mobilizing a relatively large volume of stored sediments in the upper watershed and delivering this load—estimated at 16 million tonnes—to lower Sespe Creek; however, this amount only represents 5% of the annual total load estimated at the nearby (and slightly upstream) stream gauge indicating that the vast majority of sediment transported in that water year was delivered to the Santa Clara River rather than deposited in the lower reach of Sespe Creek. Bed lowering subsequent to the 2005 flood season has not been confirmed throughout the lower reach, but is inferred from rating curve adjustments at the stream gauge, which indicate that the channel bed locally rose and fell approximately 1.7 m (5.5 ft) from 2003 to 2005 to 2008. Another significant development in the channel's evolution is that the majority of flow is now conveyed by the east fork (overflow) channel rather than the west fork (mainstem) channel, which may have been driven by a combination of natural and man-made factors, including aggregate mining in the east fork channel during this recent period.

Synthesis

Sespe Creek is a relatively pristine watershed as there are few developments in the upper watershed that alter rainfall-runoff relationships; there are no large dams or diversion structures to enact significant flow regulation; urban development occupies only the extreme downstream end of the watershed, limiting its overall effect on watershed runoff; and, until recently, floodplain development was minimal. Further, apart from road and rail crossings, direct channel management of lower Sespe Creek was also limited until recently. Since the early 1980s, the Sespe Creek Levee (along with the concrete bank revetment immediately upstream) and short-term aggregate mining operations in the east fork channel have posed the only major direct interventions in channel processes, which may have resulted in the east fork channel becoming the dominant channel during this period.

The effects of the 2006 Day Fire, in addition to several other recent wildfires, include a short-term (5 – 10 years) increase in fine sediment-production from burned hillslopes and subsequent delivery to the mainstem channel. Because these materials are easily transported by Sespe Creek downstream and out of the watershed within a relatively short period of time and because coarse sediment production did not appear to increase following the wildfire event, it is unlikely that significant post-fire sedimentation throughout the lower reaches will occur. However, continued monitoring of the channel's flow capacity, as evaluated at cross-sections analyzed in this study, is recommended to identify local variations.

Due to the climatic and tectonic setting of Sespe Creek, the lower reach is thus a naturally highly dynamic environment subject to "re-setting" by very large floods rather than progressive alteration by intermediate flood events. This re-setting may involve significant bed aggradation during single floods (e.g., 2005), accompanied by abrupt changes in the creek's course. It should therefore be recognized that the entire alluvial fan extent of Sespe Creek is potentially part of the active channel bed, and that modifying fluvial processes by "training" the creek, either through channelization, dredging, bridge construction, or levees, is likely to result in understandable but largely unpredictable responses by the stream morphology during large flood events. While it is not possible to deterministically predict such possible changes, modeling the potential fluctuation in bed levels resulting from our predicted range of baseline and post-fire sediment yields delivered from the upper watershed should help quantify the possible risk to those residing on the adjacent floodplain areas.

Table of Contents

List of Tables

List of Figures

List of Appendices

1 INTRODUCTION

1.1 Project and Report Overview

The Sespe Creek watershed is one of the most pristine and geographically remote areas in all of southern California. It is also one of the few remaining watersheds in the region that lacks any flow regulation or diversion structures. Located in the semi-arid and tectonically active Transverse Mountain Ranges of Ventura County, the watershed has steep hillslopes mantled with shallow soils and covered by shrub vegetation, and is drained by steep, coarse sediment-bearing tributaries. Sespe Creek travels 97 km (60 mi) from its headwaters, following a sinuous course to the east through a relatively broad valley bottom, turning south through a bedrock-confined gorge, and out onto a widening alluvial fan past the City of Fillmore and into the Santa Clara River.

Due to a combination of high-elevation mountains and proximity to the Pacific Ocean, the watershed is frequently subjected to high-intensity winter storms that result in sudden flooding through the upper reaches and down towards the City of Fillmore. The most damaging flood events occurred during 1938, 1969, and 1978. These three years had measured peak flows of 1,586 $m^3 s^{-1}$ (56,000 cfs), 1,699 $m^3 s^{-1}$ (60,000 cfs), and 2,067 $m^3 s^{-1}$ (73,000 cfs) (USGS 11113000). In response to the risk of future such events, the U. S. Army Corps of Engineers (USACE) constructed a 3.2 km (2 mi) rock revetted levee between Sespe Creek and the City of Fillmore to contain flood waters within the channel. The capacity of flood protection originally afforded by the levee was for a very large flood peak of 3,426 $m^3 s^{-1}$ (121,000 cfs).

Since the levee's completion in 1981, the largest peak discharge has been 2,415 $m^3 s^{-1}$ (85,300 cfs in 2005). However, aggradation of sediment in the channel bed over time could effectively raise the elevation of Sespe Creek, resulting in the reduction of the levee's flood protection capacity for a given discharge. Sediment deposition in the lower reach of Sespe Creek may be indicative of increased sediment yields in the upstream reaches, driven by either earthquake-triggered landslides, a change in hydrologic conditions, or removal of soil-holding vegetation on the hillslopes. A major fire in the watershed would satisfy both of the last two potential causes. Since the levee was constructed, four major fires have burned the majority of the watershed. The Day Fire—the most recent and severe fire—occurred in September 2006, burning a third of the watershed and denuding the vegetation cover. Concerns of increased hillslope erosion, leading to increased deposition of sediment in the lower reach near the Sespe Creek Levee, has motivated the need for a comprehensive assessment of channel response to the Day Fire event.

In an effort to guide future management decisions on flood protection in the City of Fillmore with respect to the Sespe Creek Levee, the Ventura County Watershed Protection District (VCWPD) seeks to understand the dynamics between hydrologic, hydraulic, and geomorphic processes and conditions in the watershed which, together, ultimately affect sedimentation in the lower reach. The project was conducted by RBF Consulting Inc., Stillwater Sciences, and Aqua Terra. To assess the geomorphic conditions in the watershed from a historical (baseline) and contemporary (post-Day Fire) perspective, Stillwater Sciences was tasked to conduct a fluvial morphology and sedimentation analysis that entails the following:

- Compile and review existing information relating to hillslope and channel geomorphic processes, in addition to information on fire effects on sediment production in southern California watersheds

- Characterize hillslope geomorphic processes in the watershed and resulting sediment yields into the mainstem Sespe Creek

- Characterize sediment transport and channel dynamics in the mainstem of Sespe Creek to understand how these processes affect channel morphology, specifically in the lower reach adjacent to the Sespe Creek Levee

This report examines geomorphic processes across the Sespe Creek watershed at both the hillslope and mainstem channel scale. At the hillslope scale, field observations combined with literature values were utilized in a GIS-based analysis to construct estimates of average annual hillslope sediment production and delivery to the channel network, based on land cover, geology, and topographic relief. Within the mainstem channel, contemporary conditions were assessed using field-collected data, including sediment sizes and observed sediment delivery from tributaries. The sediment-size measurements were subsequently used in sediment-transport calculations and modeling performed by RBF Consulting. Evolution of the channel in the lower reach over the past 80 years was assessed using historic and current aerial photography and topography. The results from both hillslope and in-channel analyses have then been combined to develop a conceptual model of geomorphic processes in the watershed, with a focus on sedimentation processes in the lower reach for the purposes of informing appropriate future management decisions with respect to the level of flood protection provided by the Sespe Creek Levee.

1.2 Watershed Characteristics

Sespe Creek drains 674 km^2 (260 mi^2) of the Western Transverse Mountain Ranges—a semiarid and tectonically active region—in southern California (Figure 1-1). In total, Sespe Creek flows 97 km (60 mi) from its headwaters at the western edge of Ventura County downstream to its confluence with Santa Clara River near the City of Fillmore. The creek is fed by thirty named stream tributaries as it flows generally eastward in the upper reaches—within a wide alluvial and bedrock valley bounded by the Pine Mountains to the north and the Topatopa Mountains to the south—before eventually turning southward through the narrow, bedrock confined Sespe Creek gorge and then out onto a broad, alluvial fan towards the City of Fillmore and the Santa Clara River. Various geologic rock units are present, including shales, sandstones, and granites, which together have been uplifted by the relatively active tectonic processes associated with the Transverse Mountain Ranges (see Section 1.2.1) The topographic relief in this mountainous watershed varies from steep upland areas with rugged ridges to a broad, low-gradient valley bottom bordering much of the mainstem creek. Overall, elevations range from approximately 105 to 2,290 meters (350 to 7,500 ft) above sea level. At 674 km^2, Sespe Creek is the second largest sub-watershed in the Santa Clara River watershed, accounting for approximately 16% of the total area. Though frequently proposed as a site for a large dam since European-American arrival in the watershed (Freeman 1968), Sespe Creek and its tributaries have remained unregulated by water storage or water diversion infrastructure to the present day. A large portion of the watershed was designated as a Wild and Scenic River in 1992, affirming Sespe Creek's status as one of the most pristine watersheds in all of southern California: the majority of the watershed remains roadless and accessible only to recreational hikers.

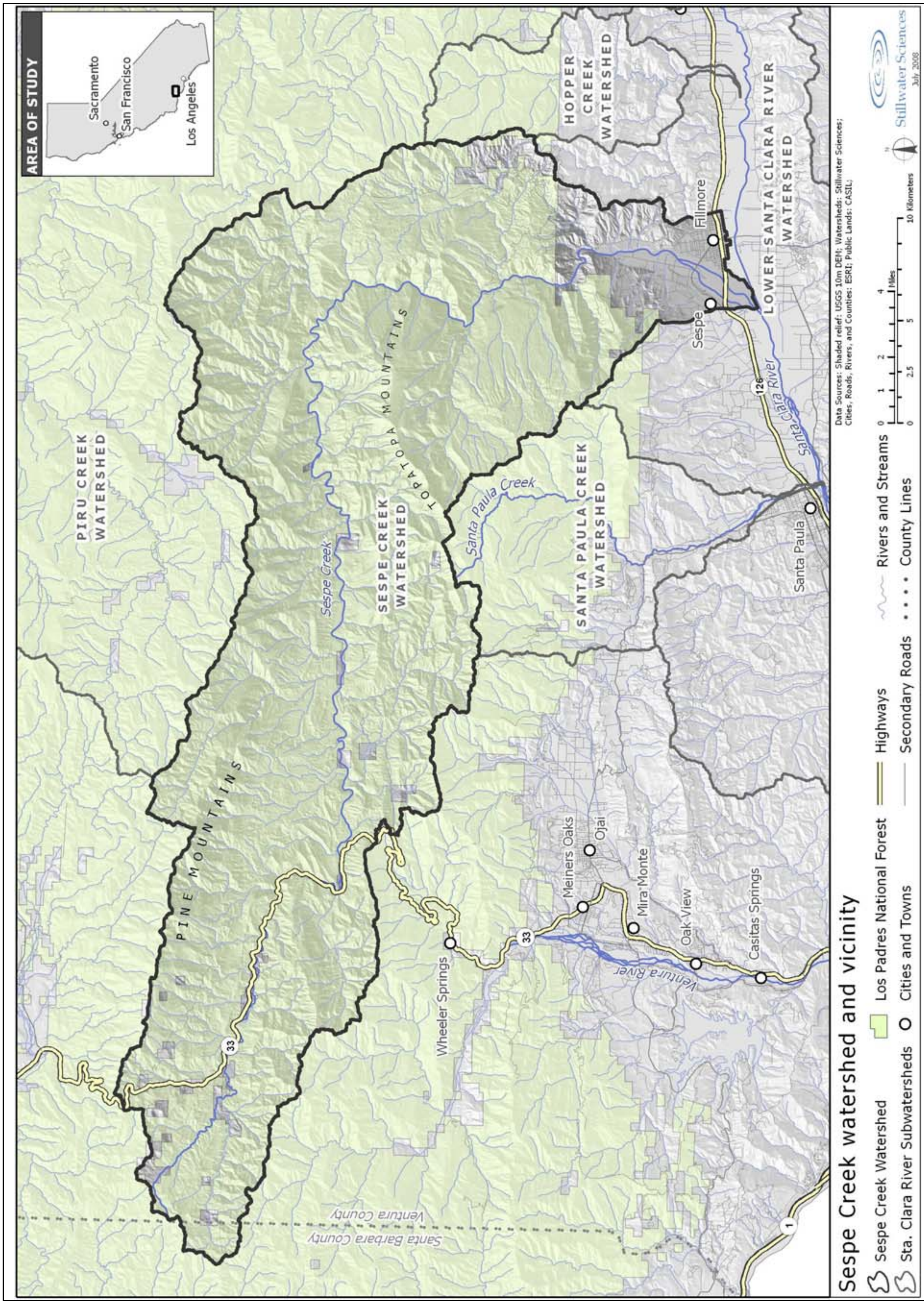


Figure 1-1. Sespe Creek watershed and vicinity.

For this report, the Sespe Creek watershed is divided into four morphologically similar areas (Table 1-1; Figure 1-2). The geomorphic subwatersheds are distinguished by unique features, such as valley width and inclusion within the Day Fire area. The subwatersheds are further organized upstream to downstream by the downstream terminus of select tributaries with the mainstem Sespe Creek. The *Upper* subwatershed includes all areas of the upper watershed draining to the Sespe Creek downstream to a point immediately below the confluence with Piedra Blanca Creek. This wide valley reach encompasses more than 40% of the total Sespe Creek watershed area and was not burned by either the 2006 Day Fire or 2003 Piru Fire, but it was partially burned most recently by the 2002 Wolf Fire (see fire history summary in Section 2.4.1). The *Middle* subwatershed continues downstream from the Upper subwatershed to a point immediately below the confluence with Alder Creek at the upstream end of the Sespe Creek gorge. The majority of this reach was burned by the Day Fire and is morphologically similar to the Upper subwatershed. The *Gorge* subwatershed constitutes the south-trending, very coarse-bedded gorge and continues downstream of Devil's Gate to a point immediately below Little Sespe Creek. The upper half of this reach was burned by the Day Fire and the eastern half was burned by the 2003 Piru Fire, with a small portion on the south-eastern divide most recently burned by the 2007 Ranch Fire. The *Lower* subwatershed continues downstream to the confluence with Santa Clara River and includes the Sespe Creek Levee and the City of Fillmore. This area was not burned by the Day Fire. Hillslope geomorphic processes, sediment yield estimates, and channel morphology characteristics and processes for each reach within these subwatersheds are discussed in Section 2 onward.

Table 1-1. Geomorphic subwatersheds designated for the Sespe Creek watershed.

Subwatershed	Geographic limits	Drainage Area (km^2)
Upper	Upper half of watershed to downstream of Piedra Blanca Creek	284
Middle	Downstream of Piedra Blanca Creek to downstream of Alder Creek	190
Gorge	Downstream of Alder Creek to downstream of Little Sespe Creek	176
Lower	Downstream of Little Sespe Creek to confluence with Santa Clara River	24
Total Sespe Creek watershed		**674**

1.2.1 Geology

The Sespe Creek watershed lies in the middle of a distinctive geologic province of California known as the Transverse Ranges. Unlike the Coast Ranges to the north and the Peninsular Ranges to the south, both of whose major ridges and intervening valleys trend generally NW–SE, the Transverse Ranges are oriented almost exactly east–west and form a marked disruption to the overall grain of California topography (Figure 1-3). Sespe Creek flows between two of these east–west ridges, the Topatopa Mountains on the south and Pine Mountain–San Rafael Peak on the north.

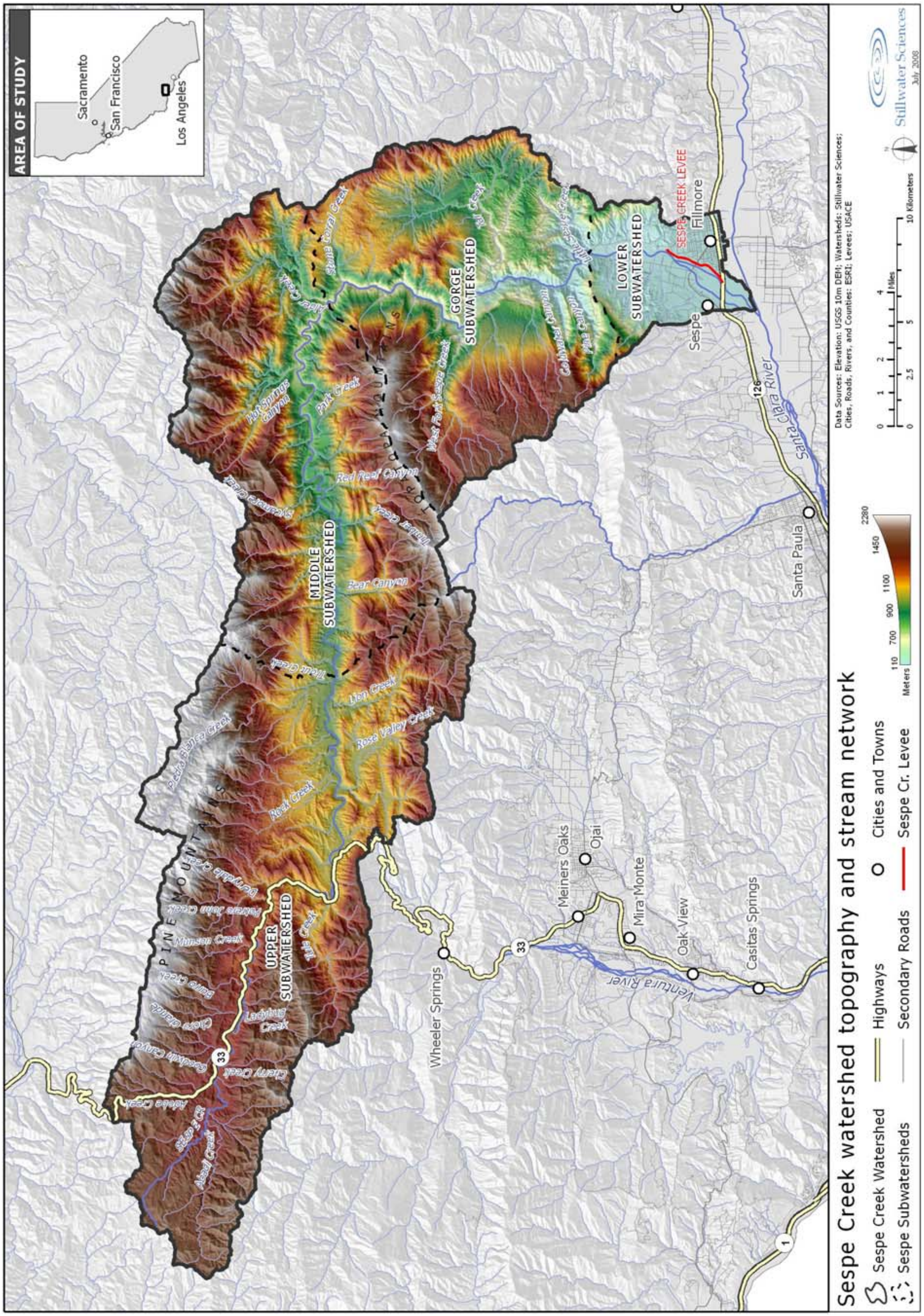


Figure 1-2. Sespe Creek watershed topography and stream network.

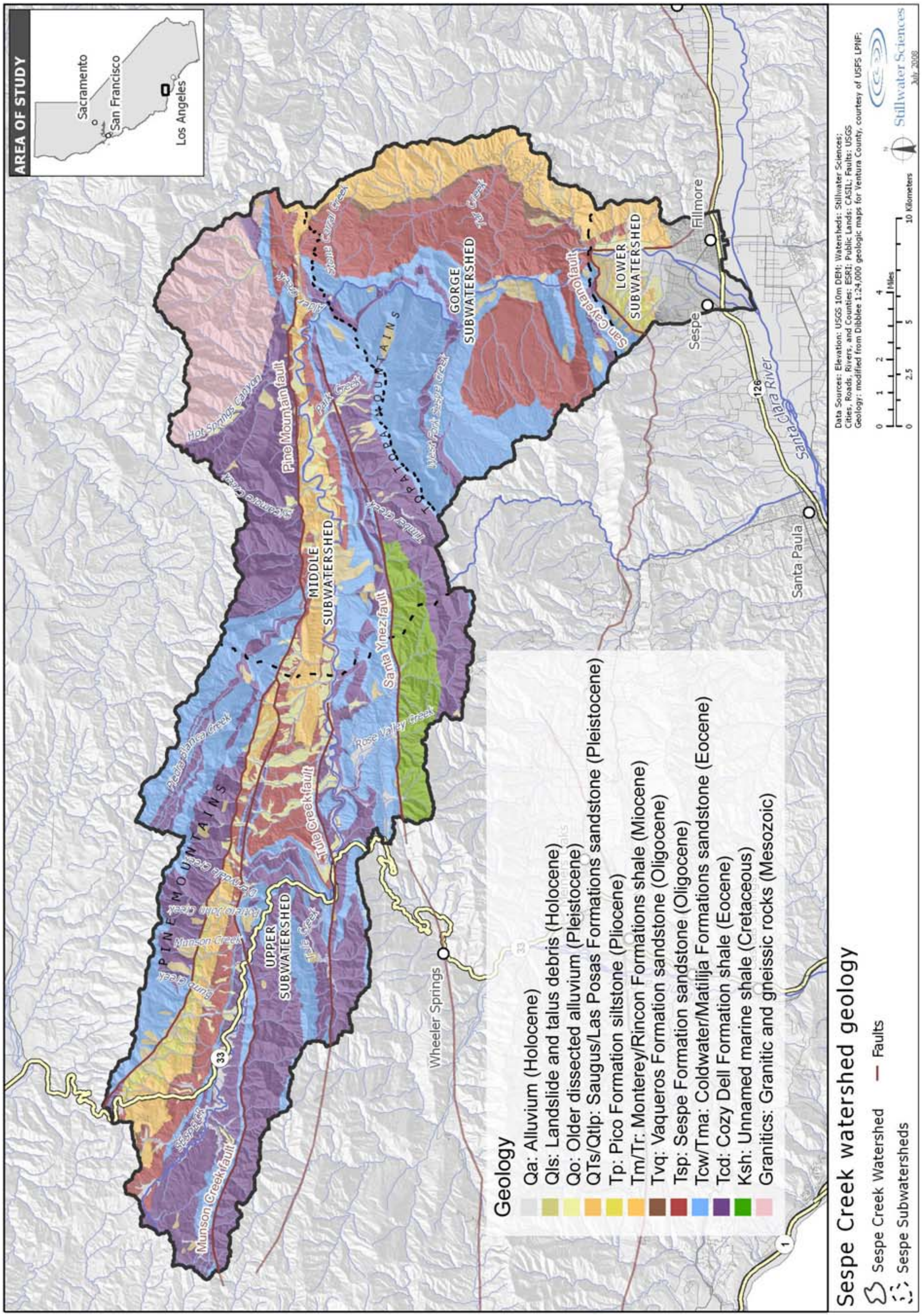


Figure 1-3. Generalized geologic map of the Sespe Creek watershed.

The regional tectonic activity of California over the last 6 million years has created this unusual topographic and geologic setting. Both north and south of this area, the 1,000-km-long (600-mile-long) San Andreas Fault (SAF) separates the northwest-moving Pacific plate from the (relatively) stationary North American plate. Where the SAF is straight, these plates slide past each other as a "transform plate boundary," with either continuous motion (at rates of a few centimeters per year) or stick–slip motion where movement is episodic (and expressed as earthquakes when it occurs). The SAF is deflected from its straight trend, however, at its intersection with a NE–SW trending cross-cutting fault, the Garlock Fault, about 50 km south of Bakersfield. Where the SAF is bent, the Pacific and North American plates cannot simply slip past each other. Because the underlying plate motion continues, the north-migrating rocks of the Pacific plate (which include those of the Sespe Creek watershed) "pile up" in the region south of the San Andreas Fault's bend. The crustal shortening that results from this underlying plate movement provides an ideal setting for rapid rates of landscape uplift. Additional explanation of tectonic activity and uplift rates are presented in Section 2.2.

North of the Santa Clara River, one fault expresses this north–south compression most prominently, the San Cayetano fault, which cuts west-to-east to the south of the Topatopa Mountains. It is a north-dipping thrust fault, where the upper block (north of the fault plane) has slid up the fault plane relative to the rocks of the lower block (south of the fault plane). Although the fault is exposed in the Sespe Creek watershed only near Fillmore, the entire watershed is part of the upper block. The rocks that constitute this upper block, and that underlie nearly the whole of the Sespe Creek watershed, are a mixture of mainly marine-deposited sandstone and shale, with minor amounts of pebbly conglomerate and area of older, intrusive igneous rocks in the northeast corner of the watershed (Figure 1-3). The sedimentary sequence of rocks here spans the last 50 million years of earth history.

1.2.2 Climate and hydrology

Coastal watersheds of southern California function according to a semi-arid, two-season Mediterranean-type climate, with wet cool winters and dry warm-to-hot summers. Rainfall and air moisture both tend to decrease with increasing distance from the coast. Within the Sespe Creek watershed, proximity to the Pacific Ocean moderates both seasonal and diurnal temperatures. Most precipitation occurs between November and March, with precipitation varying significantly throughout the watershed due to complex topographic features (Figure 1-4). For example, average annual precipitation is more than 100 cm (39 in) along the Pine Mountains, while it is less than 69 cm (27 in) in the headwaters of Hot Springs Canyon. Overall, wetter regions are generally located in the headwaters of Sespe Creek with the driest regions at the lowest elevations near Fillmore. At higher elevations, some winter precipitation falls as snow.

Periodicity in the pattern of the wet/dry years in southern California is correlated to the El Niño–Southern Oscillation (ENSO) climatic phenomenon. ENSO is characterized by warming and cooling cycles (oscillations) in the waters of the eastern equatorial Pacific Ocean. ENSO cycles have a 1–1.5 year duration and a 3–8 year recurrence interval. In southern California, ENSO years are characterized by relatively high rainfall intensities, with rivers and streams exhibiting higher annual peak flow magnitudes than they do in non-ENSO years (Cayan et al. 1999, Andrews et al. 2004). ENSO-induced climate change occurs on a multi-decadal time scale that is consistent with the recent shift from a relatively dry climate (averaged over the period 1944–1968) to a relatively wet climate (averaged over the period 1969–1995) in North America's Pacific region (Inman and Jenkins 1999). The recent wet period of the ENSO cycle, which likely still continues, is marked by strong El Niño years every 3–7 years. The most recent El Niño event (although weak) occurred in water year 2007.

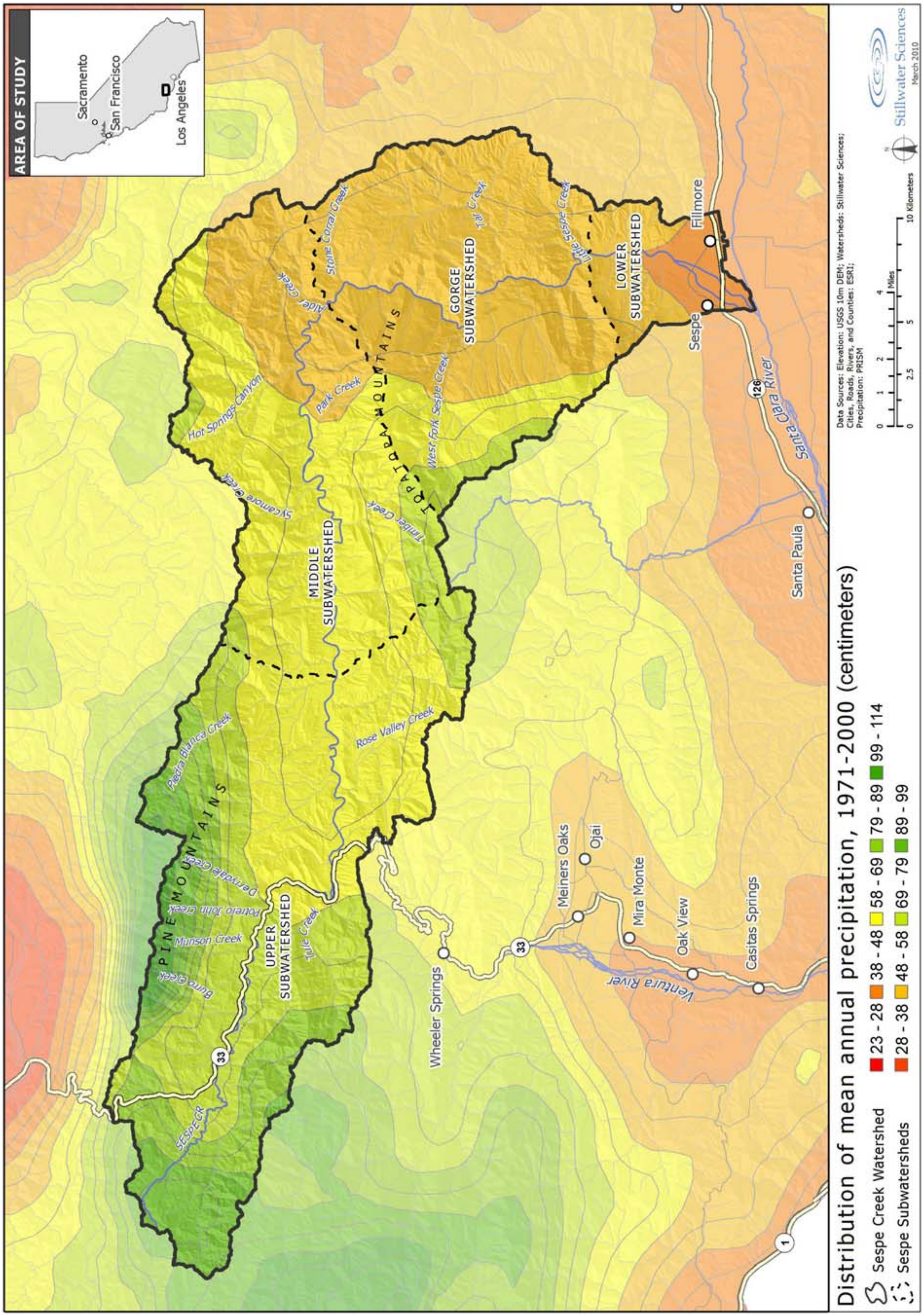


Figure 1-4. Distribution of mean annual precipitation based on data from the period 1971-2000.

The climatic and hydrologic characteristics of the watershed produce a perennial flow regime along the majority of the mainstem, while most tributaries and the mainstem throughout the Upper subwatershed experience intermittent flows. Similar to other streams in the region, the watershed experiences highly variable annual rainfall and peak flows. Typical of semi-arid to arid watersheds, flood flows in Sespe Creek typically increase, peak, and subside rapidly in response to high intensity rainfall (Figure 1-5). This hydrologic attribute is characteristic of a "flashy" hydrograph characterized by a rapid increase in discharge over short time period with a quickly developed peak discharge in relation to normal baseflow (Ward 1978). The three largest floods on record measured at the USGS stream gauging station downstream of the gorge and north of the City of Fillmore were in 1969 (824 m^3s^{-1} [29,100 cfs]), 1995 (816 m^3s^{-1} [28,800 cfs]), and 2005 (1,124 m^3s^{-1} [39,700 cfs]), which all occurred during ENSO years (USGS 11113000). In the summer and fall seasons, the lower half of Sespe Creek generally exhibits continuous baseflow to its confluence with the Santa Clara River.

1.2.3 Land Use / Land Cover

The Sespe Creek watershed remains one of the least developed regions of all of southern California (Figure 1-6). Approximately 90% of the watershed is enclosed within the Los Padres National Forest (Figure 1-1). Land development is generally concentrated in the Lower subwatershed near the City of Fillmore and consists chiefly of agriculture-related activities situated along much of the alluvial fan areas north and west of the city. Residential, commercial, and light industrial (typically in connection with agriculture processing) developments are present east of the Sespe Creek Levee in Fillmore. North of Fillmore, in the upland areas east of the Sespe Creek gorge and south of Tar Creek, lies the Sespe Oil Field, an active oil production area consisting of a network of oil pumps and pipelines. Crude oil and natural gas have been extracted from the Sespe Oil Field area since 1887 (USFS 2005).

Elsewhere in the watershed, developments are sparse and limited to scattered privately-held and municipal properties along Highway 33 and Rose Valley Road (Forest Road 6N31). The Sespe Wilderness, a protected and roadless area within Los Padres National Forest, encloses the majority of the watershed between Highway 33 and Devil's Gate at the mouth of the Sespe Creek gorge, thus limiting access to these areas to hiking, kayaking, and horseback riding only. Designated as a Wild and Scenic River in 1992, Sespe Creek is protected from future developments along a 51-km (31.5-mi) reach starting from Rose Valley/Howard and Rock creeks downstream through the Sespe Creek gorge (USFS 2003).

Land cover in the upland areas of the Sespe Creek watershed and along the floodplain, terraces, and valley bottom in the upper reaches are dominated by scrub/shrub (chaparral) vegetation; grasslands and mixed, deciduous, and evergreen woodlands constitute the remainder of the upland and floodplain land cover. Higher density vegetation cover and larger trees generally concentrate on north-facing slopes, higher elevations, or adjacent to perennial water sources. Scrub/shrub vegetation covers the majority of the upper watershed and consists of varies species including ceanothus (*Ceanothus cuneatus*), chamise (*Adenostoma fasciculatum*), and California scrub oak (*Quercus dumosa*). Despite the semi-arid climate, the vegetation cover in the Sespe Creek watershed effectively hinders erosion of land surfaces by providing: 1) a continuous surface cover that intercepts rainfall and prevents rainsplash erosion, and 2) roughness to the landscape surface that divide and slow sheetflow upon the land surface (see Section 2.3.3).

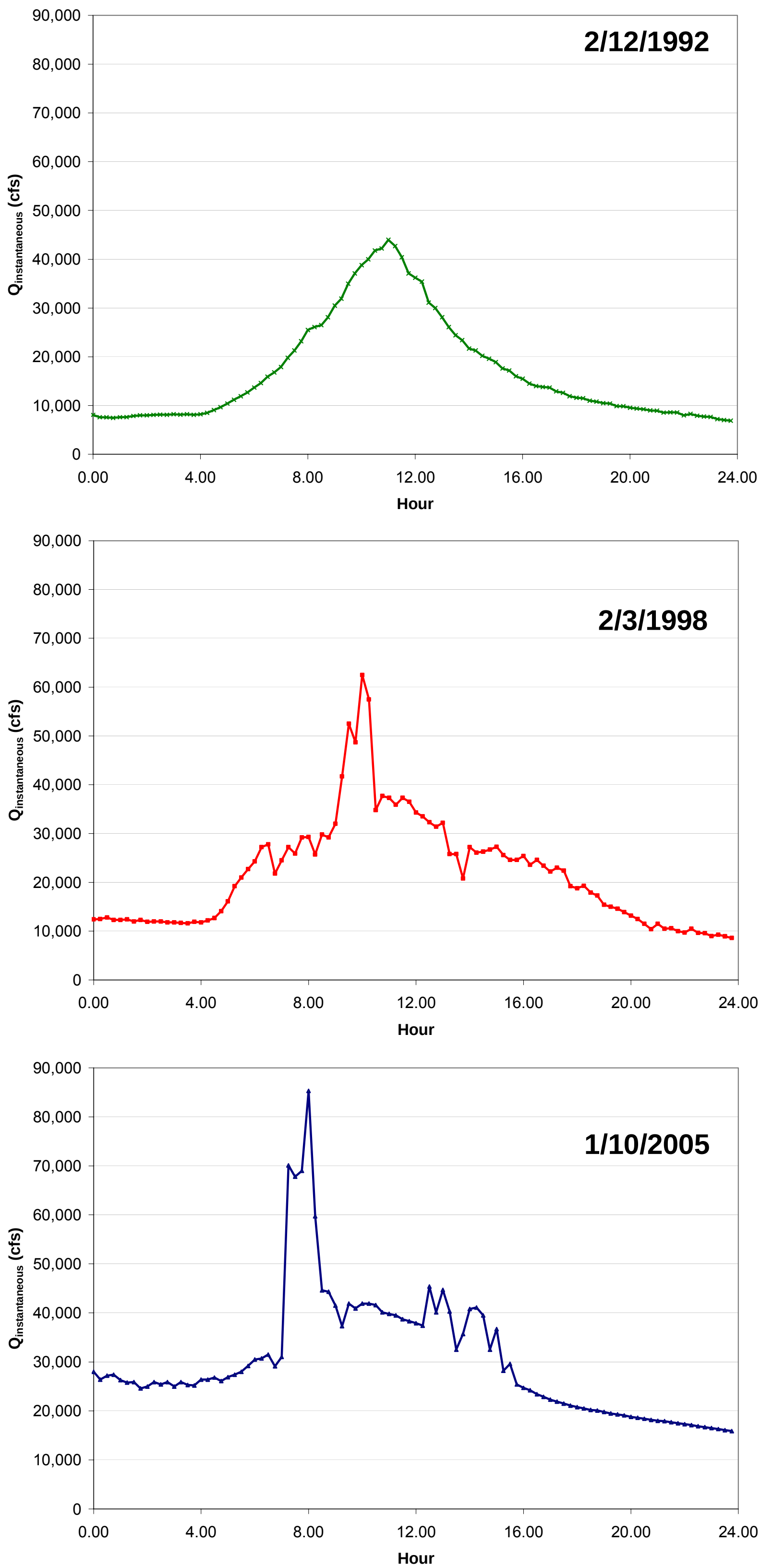


Figure 1-5. Storm hydrographs for Sespe Creek at Fillmore, CA (USGS 11113000).

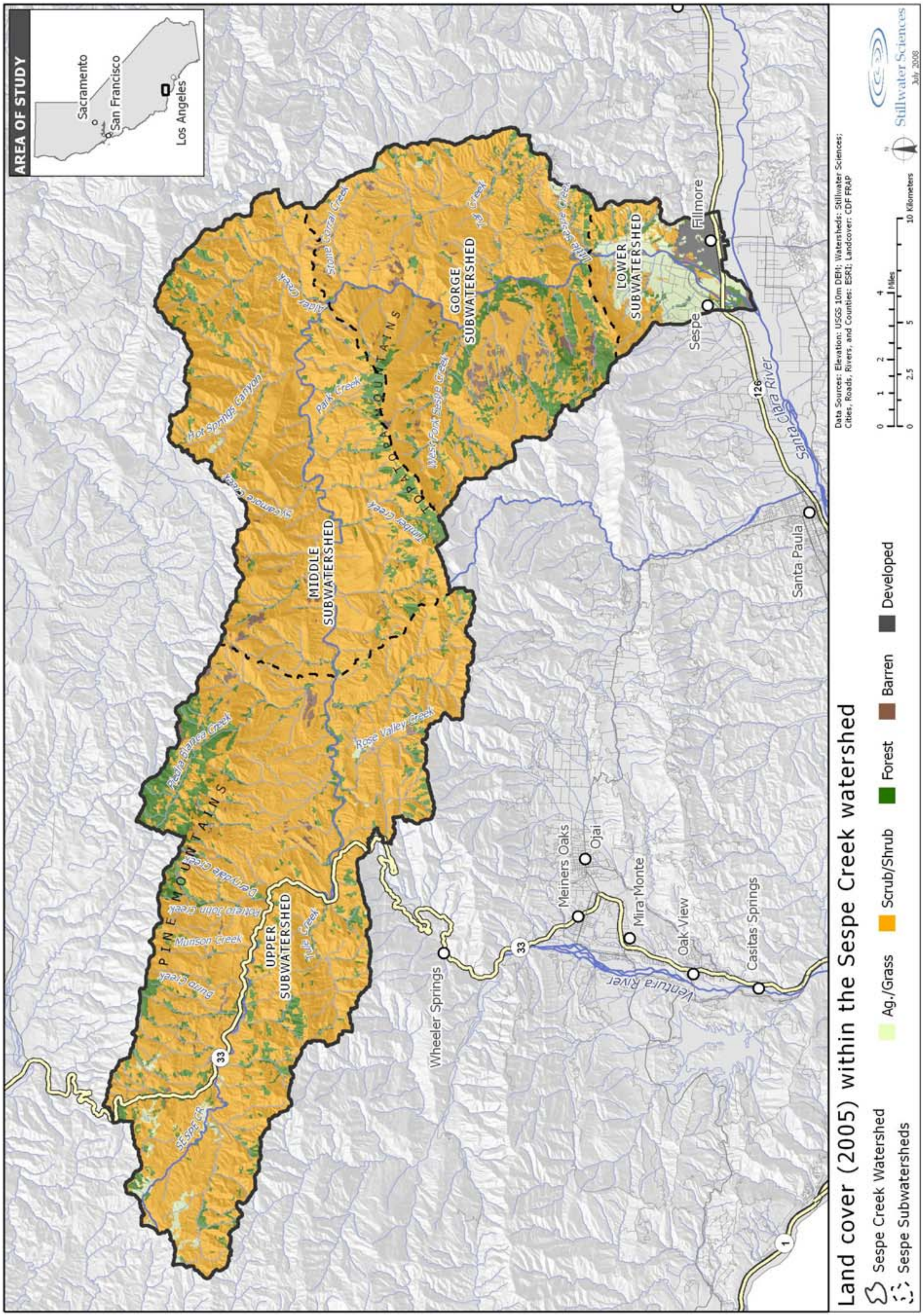


Figure 1-6. Land cover (2005) within the Sespe Creek watershed.

1.2.4 The City of Fillmore and the Sespe Creek Levee

Founded in 1888 and incorporated as a city in 1914, the City of Fillmore has progressively expanded, both in area and population (Freeman 1968; U.S. Census Bureau 2000). Until the latter half of the 20th century, the majority of residential developments were concentrated upon a raised terrace area, approximately 1 km to the east of Sespe Creek. This terrace feature, which can be viewed in aerial photos and topographic maps (Figure 1-7), is composed of late Pleistocene (~0.01 – 1 Ma) gravelly sediment and rises approximately 6 m (20 ft) above the present day floodplain elevation (Dibblee 1990a [Fillmore quadrangle]). The terrace elevation represents a former floodplain elevation and its western margin, or terrace face, indicates the eastern-most extent of the creek's left margin (see channel morphologic evolution discussed in Section 3.3).

Floodplain areas of Fillmore to the west and south of the terrace are naturally subject to frequent flooding from a combination of Sespe Creek and the Santa Clara River. Prior to floodplain residential development, damage resulting from Sespe Creek floods (e.g., in 1938) generally was limited to orchard lands and to road and rail crossings that connect Fillmore with settlements to the west. However, progressive residential development in the floodplain (initially the Los Seranos tract) resulted in significant property damage in the 1969 and 1978 floods, including one death in 1978 (USACE 1980). To protect existing floodplain residences, and mindful of the likelihood of future floodplain residential development, the U.S. Army Corps of Engineers selected and implemented a flood control alternative involving construction of a 3.3 km (2 mi) rock-revetted levee along the east side of Sespe Creek, running upstream from the Highway 126 bridge (Figure 1-7). The levee was designed to provide protection from the "Standard Project Flood" of 3,426 m^3s^{-1} (121,000 cfs; USACE 1980). Since the levee was completed in 1981, the largest flood to pass through occurred on January 10, 2005 and reached a peak flow of 2,415 m^3s^{-1} (85,300 cfs)—the largest flood peak on record (USGS 11113000).

Residential development has occurred to the west and north of the Los Seranos tract area since 1981, such that a significant proportion of Fillmore's population is now protected from flooding by the Sespe Creek Levee. Immediately upstream of the levee near the area locally referred as "Lookout Point" lies another flood-protection structure on the left bank, which consists of a 300-m (985-ft) long concrete and rock revetment. The function of this structure has been to halt bank erosion into several private properties located adjacent to the channel. Built in 1979, the structure was damaged in 1983, 1998, and 2005, which is likely a result of the local hydraulics driven by the channel geometry and course direction.

1.2.5 Wildfire and Potential Flood Impacts

Wildfire is important to the ecology of chaparral environments, such as those characterizing large parts of the Sespe Creek watershed. Fire also affects hydrology, soil properties, and slope and channel stability, causing an increase in the rate of sediment production and yield from burned watersheds (Florsheim et al. 1991). Within southern California chaparral-dominated watersheds, fires cause accelerated erosion during subsequent winter storms in what is termed the 'fire-flood' sequence (USDA Forest Service 1954). Large wildfires associated with the fire-flood sequence that have the potential to drastically impact watershed-scale sediment dynamics occur in southern California, on average, every 10 to 20 years (Hanes 1977, Conard and Weise 1998). The impact of these events on watershed geomorphic processes varies from months (Florsheim et al. 1991) to years (Lave and Burbank 2004) and depends primarily on watershed characteristics, fire characteristics, and local climatic conditions.

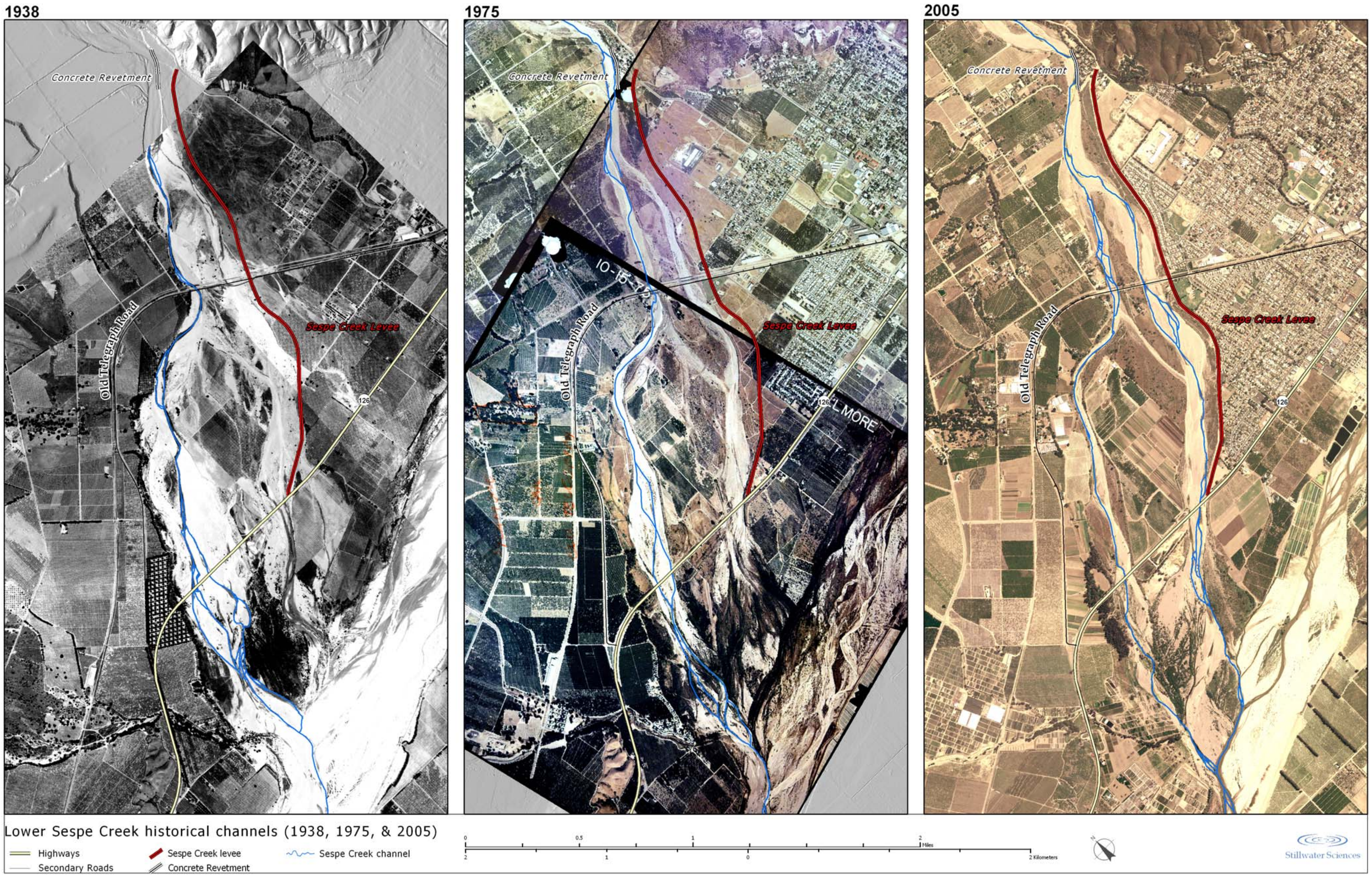


Figure 1-7. City of Fillmore and lower Sespe Creek in 1938, 1975, and 2005 showing the Sespe Creek Levee (constructed 1981), concrete revetment at Lookout Point, and terraces.

Of particular interest in September 2006, the Day Fire swept through the Los Padres National Forest, including large portions of Piru and Sespe Creek watersheds (Figure 1-8). The fire, the seventh largest on record in California (CDF 2007), burned a total area of approximately 655 km^2 (162,000 acres) (USFS 2006). Approximately 224 km^2 (55,250 acres) or one-third of the Sespe Creek watershed burned, making this fire the second largest on record in the watershed. The burn was situated in the northeast portion of the watershed, completely encompassing both sides of the valley between Timber Creek to the west, over to Alder Creek in the northeast, and down through the gorge to West Fork Sespe Creek at the southern extent. Terrain types impacted by the fires included steep, mountainous uplands and flat lowland terraces predominately capped by thin soils and vegetated by scrub/shrub (chaparral) species. The Day Fire, occurring shortly after significant fires in 2002 and 2003, raised concerns over fire effects on short-term and long-term sediment delivery dynamics and bed elevation change near the City of Fillmore. Bed elevation change involving aggradation could potentially reduce the level of flood protection afforded to Fillmore by the existing Sespe Creek Levee on the left bank, and so raise the prospect that levee modification may be required to retain specified levels of flood protection.

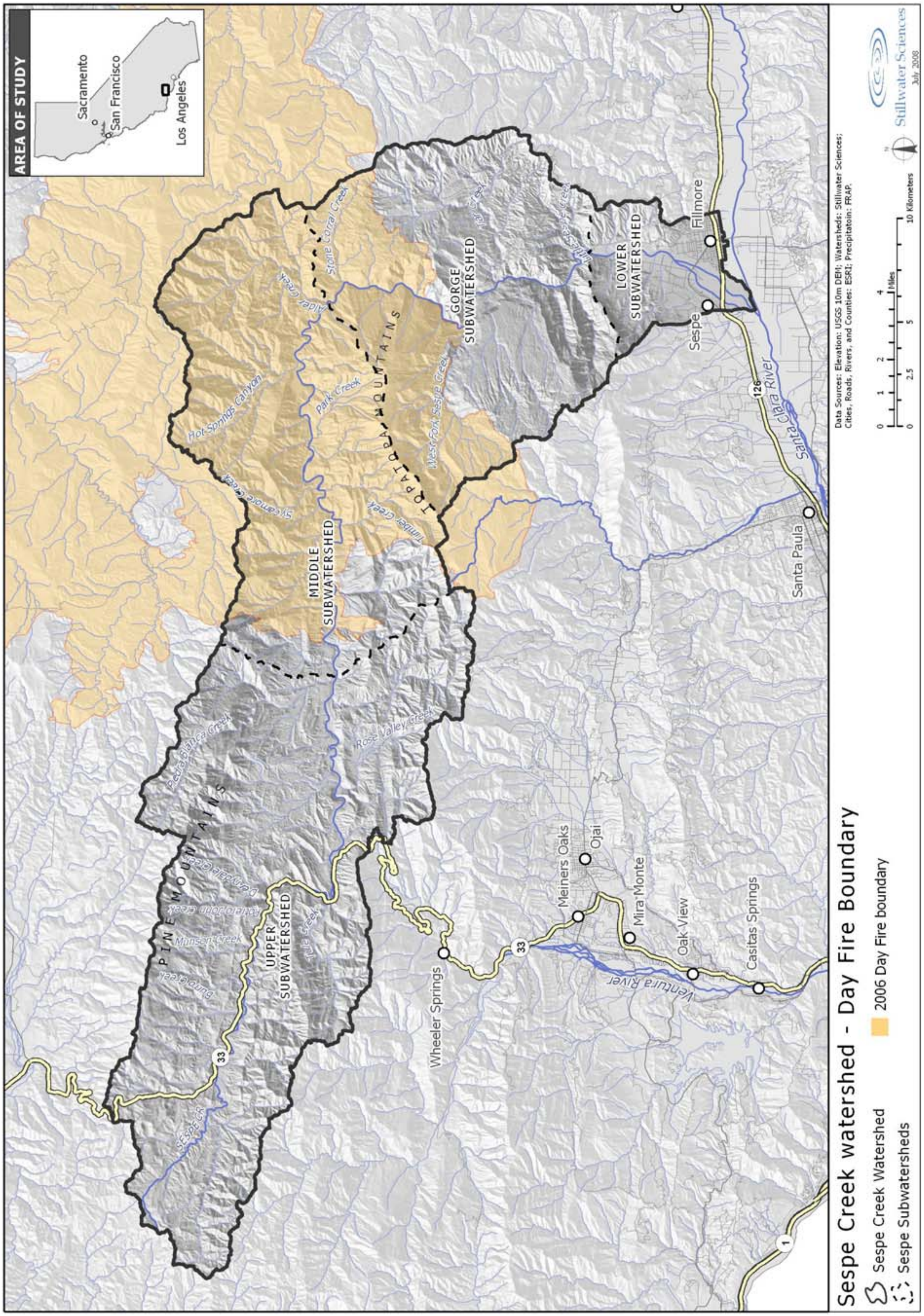


Figure 1-7. Day Fire (September 2006) extent in the Sespe Creek watershed.

2 WATERSHED GEOMORPHIC PROCESSES

2.1 Overview

Soil production and hillslope sediment transport are difficult to quantify, because they are driven by the episodic and commonly transient effects of rainstorms, windstorms, fires, earthquakes, and human and other disturbances (Benda and Dunne 1997, Gabet and Dunne 2003). The inherently episodic nature of erosional processes results in substantial year-to-year variability and makes any assessment of sediment-transport rates sensitive to the timescales over which they are averaged (Kirchner et al. 2001). For example, if the basin-wide erosion rate is averaged over a relatively dry 10-year period, it might be considerably lower than if it were averaged over a 10-year period that included several wet years. Although long-term averages cannot predict the sediment load for any given year, they nevertheless can be useful in assessing the long-term consequences of alternative management actions.

As the first step in understanding and quantifying the magnitude of sediment flux down the channel of Sespe Creek, this section evaluates the production of hillslope sediment across the watershed, and the delivery of that sediment into the channel network. The rates of sediment production and delivery have been estimated using a variety of techniques, over a variety of temporal and spatial scales, because different scales of analysis can provide more robust and reliable estimates than any single method alone. Over long timescales, best represented by the geologic record of the past several million years, an upper bound on the likely rate of sediment production can be approximated from the rate of overall landscape uplift. This provides a coarse indication of the likely range of average sediment-delivery rates across the watershed as a whole, and one that is completely independent of other methods. Over shorter, more human timescales, rates of sediment production can be assessed using a "geomorphic landscape unit" approach, in which different parts of the watershed are assumed to erode at different rates due to differences in their physical characteristics. The degree to which these two estimates agree with each other, and with additional data that assess rates of in-channel sediment transport directly, provides a measure of the reliability of these results.

2.2 Rates of Sediment Production Inferred from Geologic Evidence

Watershed topography reflects the interplay between uplift (if any) due to tectonic processes, and the sculpting and wearing away of slopes by erosion. In general, high steep mountains occur in areas that have been subjected to sustained rapid uplift, whereas gently sloping terrain is found where uplift is slow or has been followed by long periods of denudation. The linkages between uplift, slope steepness, and erosion imply that slopes should tend to contribute sediment in proportion to their uplift rates over the long term (Burbank et al. 1996)—rapid uplift rates usually result in high rates of sediment production. Uplift rates, in turn, are directly related to the tectonic setting and deformation history of the landscape.

2.2.1 Tectonic setting

The distribution of rocks in the Sespe Creek watershed has been strongly affected by movement along the major geologic structure of the region, the San Cayetano fault, over the last several million years (Figure 1-3). Just south of the Sespe Creek watershed boundary, this fault separates a sequence of hard sandstone and shale (mainly, the Matilija and Coldwater sandstones and the

Cozy Dell shale), all of Eocene age (i.e., about 50 million years old) that has been thrust over the much younger Pico, Santa Barbara, Las Posas, and Saugus formations, all shales and claystones less than 6 million years old. Rockwell (1988) estimates as much as 9 km (5.6 mi) of net vertical offset along this fault. These relationships are well-displayed northwest of Fillmore, where the erosion-resistant Eocene rocks (here, sandstone of the Matilija Formation), bounded at their base by the San Cayetano fault, overlook the gentle slopes of the younger Pico Formation (Figure 2-1).

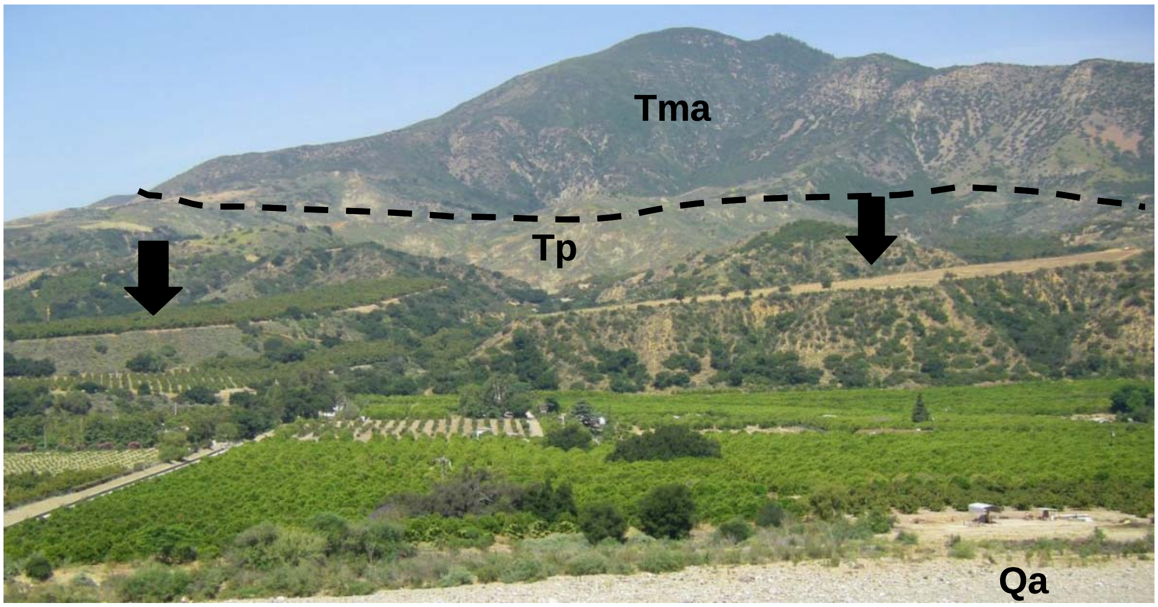


Figure 2-1. Matilija Sandstone (unit Tma; ~50 Ma old) above the much younger Pico Formation (Tp; ~2 Ma old). Approximate trace of the San Cayetano fault (dashed line) from Dibblee (1990a [Fillmore quad]). Note the uplifted terraces (arrows) sloping several degrees to the south in the middle distance. Modern Sespe Creek alluvium (Qa) visible along the lower edge of the photo.

North of the San Cayatano fault in the Sespe Creek watershed, three other east-west trending faults cut the rocks of the upper thrust block—the Santa Ynez fault and the Tule Creek fault lie south of Sespe Creek, and the Big Pine fault lies north of Sespe Creek (e.g., Dibblee, 1987 [Lion Canyon quadrangle]). Between each fault, a 40-million-year sequence of sedimentary rocks is repeated, with the youngest rocks of the Sespe, Monterey, and Rincon formations exposed at the lowest elevations. Sespe Creek flows in the valley underlain by these younger rocks; the older strata underlie the steep ridgetops that form the watershed boundary (Figure 1-3).

The general east-west grain of the geologic structure changes to fairly uniform north-south striking bedding in the vicinity of Topatopa Peak (elevation 1,893 m [6,210 ft]), overlooking the City of Fillmore. The east-to-west trend of Sespe Creek also turns by 90 degrees, leaving the upper valley of the watershed, wrapping around the east side of Topatopa Peak, and crossing the hard sandstones that constitute the Sespe Creek gorge. The rocks flanking the gorge display the uniform eastern dip of the bedding and expose nearly the entire 50-million-year-old sequence of sedimentary rocks in the watershed (Figure 2-2).

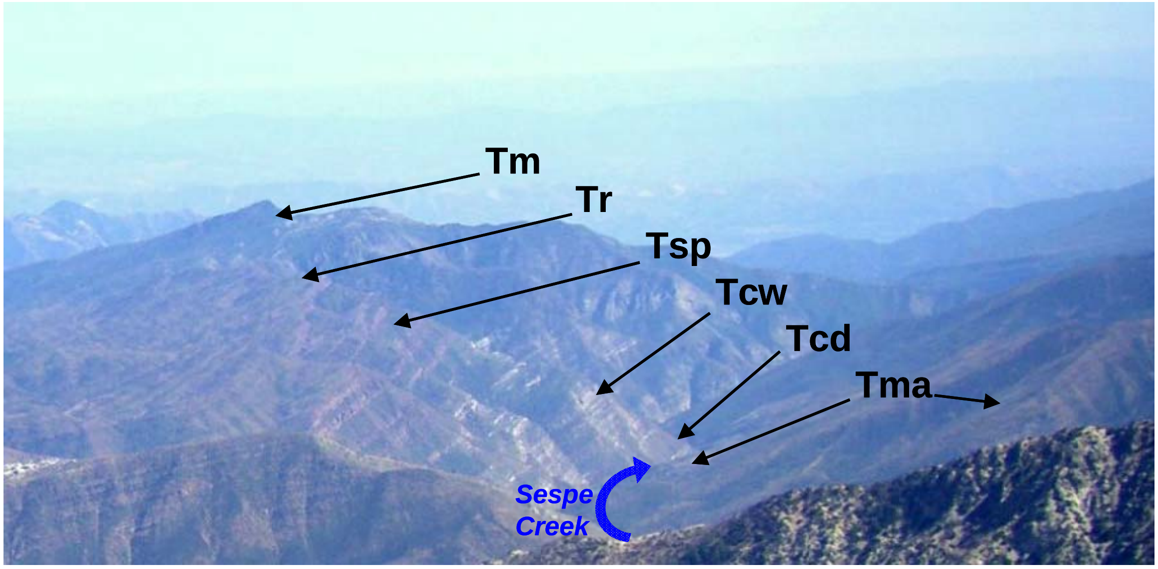


Figure 2-2. View south down the Sespe Creek gorge, displaying nearly the entire sequence of Tertiary sedimentary rocks as near-uniform east-dipping strata (Tma = Matilija Sandstone; Tcd = Cozy Dell Shale; Tcw = Coldwater Sandstone; Tsp = Sespe Sandstone; Tr = Rincon Shale; Tm = Monterey Shale). The Santa Clara River valley is in the middle distance.

Movement on the San Cayetano fault has resulted in substantial uplift of the ridges and valleys constituting the topography of the watershed. A reconstruction of the landscape uplift rate can provide an indirect but independent constraint on watershed erosion rates and ultimately sediment delivery rates to Sespe Creek. We therefore explore below the available sources of uplift data, and their interpretation, in some detail. These data sources include:

(1) Slip rates across faults, which are generally measured in the direction of movement but can also be translated into vertical (i.e., uplift) rates;
(2) Geomorphic features of known age and distinctive environments of formation (such as dated marine terraces that were originally created at sea level), which can provide a direct measure of uplift since their formation; and
(3) Direct geodetic measurements using precisely located benchmarks, which can provide year-to-year determination of movement, both lateral and vertical, of the earth's surface.

Each of these methods has application in the vicinity of the Sespe Creek watershed, and they all contribute to a broadly consistent picture of uplift rates.

2.2.2 Rates of fault slip

Reported rates of fault slip in and around the Sespe Creek watershed vary from place to place but they are everywhere rapid. A synthesis of existing literature relevant to the Santa Paula watershed, immediately south and west of Sespe Creek, suggested a representative recent uplift rate of 1–2 m per 1000 years (Stillwater Sciences 2007a), resulting primarily from movement on the San Cayatano fault. Just east of Fillmore, Rockwell (1988) argued that this fault displayed at least 7.5 km of motion in the last 1 Ma (million years) on the basis of stratigraphic offset. With a reconstructed dip of 30–40 degrees on the main fault plane, this amount of movement along the sloping surface translates into an equivalent vertical (i.e., uplift) rate of ≥4 m/1000 yr (or ≥4 mm a^{-1}).

Çemen (1989) also evaluated uplift rates on the San Cayetano fault, focusing on the area between the towns of Fillmore and Piru. His results closely match those of Rockwell (1988), with an estimated 7,300 m of fault offset over the ~1 Ma of the fault's existence. He also noted that the magnitude of offset over such a geologically brief time period suggests that the fault is potentially active and capable of damaging earthquakes.

Yeats (1988) evaluated evidence for long-term uplift rates on the Oak Ridge fault, which runs roughly parallel to the San Cayetano fault but on the south side of the Santa Clara valley, about 10 km distant. Both faults have formed under the same north–south compressional regime, and Yeats argues that they should have slip rates of the same general magnitude. Offset bedrock contacts across the Oak Ridge fault, with an (uncertain) age range of 200,000–400,000 yr, indicate vertical uplift of 6–12 mm a^{-1} over this time period, somewhat higher than the reconstructed rates for the San Cayetano fault. Molnar (1991, as cited in Petersen and Wesnousky 1994) reinterpreted some of Yeats' and Rockwell's cross-sections for the Oak Ridge fault and inferred slightly slower maximum slip rates (7 mm a^{-1}; equivalent to an uplift rate of about 4 mm a^{-1} along a fault surfaces dipping 35^o).

Huftile and Yeats (1995) evaluated overall shortening across the Transverse Ranges just west of the Sespe Creek watereshed, relying on some of the same stratigraphic markers as earlier studies. In this region, they concluded that the magnitude of shortening across the region was most likely about 5 km in the last 500,000 years, of which about 1/3 was taken up across the San Cayetano fault. This yields a horizontal shortening rate across the fault of 3–4 mm a^{-1}; because their reconstructed fault angle is about 45^o here, the resulting uplift rate would be of equivalent magnitude.

2.2.3 Rates of uplift from geologic inference

Independent of the fault-slip studies discussed above, uplift rates in the Sespe Creek watershed have not been directly assessed. At least three other studies, however, provide direct evidence of uplift rates from regions to the southeast and west of the watershed. In the San Gabriel Mountains, about 50 km SE of Fillmore, Blythe et al. (2000) looked at the cooling history of mineral grains, which can indicate the age at which rocks now at the surface were buried at least several kilometers deep in the crust. The younger that age, the more rapid has been the exhumation of the overlying material. Based on such data, Blythe et al. determined likely uplift rates averaging as high as about 1 mm a^{-1} in the eastern San Gabriel Mountains, with less well-determined but significantly lower rates in the western San Gabriel Mountains.

To the west and south of the Sespe Creek watershed, uplifted marine terraces along the Pacific Ocean coastline from Santa Barbara south past Ventura and Malibu provide additional constraints. On the well-developed flight of Mesa Hills terraces in the city of Santa Barbara, Trecker et al. (1998) determined an overall uplift rate of 0.55 ± 0.05 mm a^{-1}. In the Ventura area, Lajoie et al. (1991) determined uplift rates of between 1 and 10 mm a^{-1} for terraces between 1800 and 80,000 years in age. Orme (1998) interpreted these data to show a four-fold decline in uplift rates over the last 200,000 years, ranging from 20 mm a^{-1} at the beginning of this period to 5 mm a^{-1} for the most recent 30,000 years. He also noted that rates decline substantially to the south, with estimates of only about 0.3 mm a^{-1} on terraces flanking the Santa Monica Mountains, about 50 km to the south-southeast.

2.2.4 Recent geodetic uplift measurements

Geologic evidence of uplift must average the inferred rates over periods determined by the age of the rocks or landforms being assessed, which range from a minimum of several thousand years to a maximum of more than a million years. In contrast, Global Positioning System (GPS) networks can make direct measurements of crustal movement over a period of just a few years. Although there are no assurances that short-term rates should equal long-term rates, they can provide independent verification of the general magnitude of each method. Donnellan et al. (1993) conducted one such GPS campaign over a 4.6-year period across the Ventura basin to obtain modern rates of north–south convergence. Across their network, spanning a region from about 25 km south of the Santa Clara River valley to just north of the San Cayetano fault, the convergence rates measured by Donnellan et al. (1993) were 7–10 mm a^{-1}. Two of their stations straddled the San Cayetano fault directly; they suggest a convergence across that structure of about 2 mm a^{-1} (although uncertainties in the measurements are of the same magnitude as the measurements themselves). As with the analysis of Huftile and Yeats (1995), horizontal convergence rates on a 45^{o}-dipping fault result in an equal magnitude of uplift.

A second 4-year GPS campaign (Argus et al. 1999), focused more to the southeast in the Los Angeles basin but including stations across the Ventura basin, came to very similar conclusions. The Ventura basin displays north–south shortening at rates of about 6 mm a^{-1}, with measured displacements taken up primarily by the Oak Ridge and San Cayetano faults. Although instrument locations were inadequate to separate the relative degrees of motion across these two structures, Yeats (1988) had previously argued that their respective offsets should be approximately equivalent and thus in the range of 3 mm a^{-1}.

2.2.5 Watershed uplift rates and implications for sediment production rates

In summary, published rates of crustal uplift in and surrounding the Sespe Creek watershed range from about 0.5 mm per year to more than ten times this value. Over the last 1 million years, estimates of rates range between 3 and 6 mm a^{-1}, with possibly reduced uplift rates over the last several thousand to tens of thousands of years. Uplift is certainly continuing into modern time, and the magnitude of vertical change is probably 3–5 meters per thousand years.

"Uplift rates," however, do not directly correlate with erosion rates or sediment production rates, and the geomorphic evidence from the Sespe Creek watershed indicates that these uplift rates almost certainly exceed the actual rate of hillslope erosion here. This evidence is primarily in the form of preserved, uplifted landforms, because faster degradation rates would presumably have consumed these features (Burbank et al. 1996). Multiple terraces on the upthrown (northern) block of the San Cayetano fault are prominent, both adjacent to the fault trace itself near Fillmore (Figure 2-1) and throughout the upper watershed (Figure 2-3). Any direct coupling of uplift and erosion rates is also thwarted by the likely location of much of that differential uplift, near the mouth of the creek where it crosses the San Cayetano fault. This intersection lies downstream of the Sespe Creek gorge, and so the rates at which the watershed adjusts to uplift can only proceed as rapidly as erosion can occur through the gorge. Based on the confined character of the creek through this reach (see Section 2.5.3), we conclude that this rate is significantly (but indeterminately) slower than the tectonic uplift that is ultimately driving the incision.

Based on these considerations, the long-term sediment production rate averaged across the watershed is almost certainly less (and possibly much less) than a few millimeters per year. To move beyond this broad constraint on predicted sediment production using evidence from tectonic uplift, however, requires a more refined assessment.

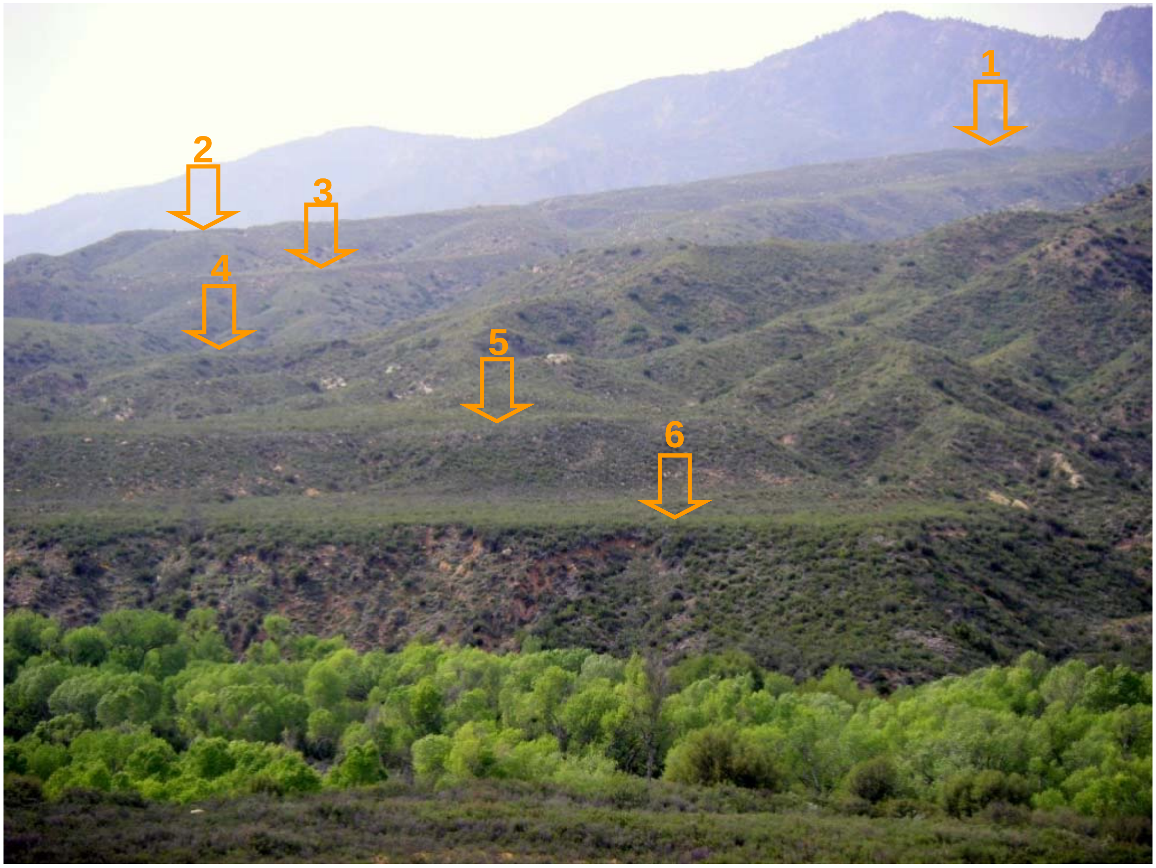


Figure 2-3. A flight of at least six uplifted terraces on the south side of Sespe Creek upstream of Piedra Blanca Creek. The lowest, youngest terrace (#6) is 40 m above the modern channel; the oldest (#1) is about 400 m above the channel and thus may be approximately 100,000 years old.

2.3 Coarse and Fine Sediment Production and Delivery

2.3.1 Lithology, erosion, and channel sediment

With rapid landscape uplift to drive hillslope processes and large areas of young, poorly consolidated sediments now hundreds of meters above the valley bottoms, the Sespe Creek watershed has geologic characteristics commonly associated with high rates of erosion. The eroded sediment is derived from two distinctly different sources (Figure 2-4):

1. Easily eroded siltstone and mudstone, found throughout the Sespe Creek watershed but with particularly extensive exposures throughout the E–W trending slopes of the Middle and Upper subwatersheds, upstream of the Sespe Creek gorge and along the southeastern edge of the watershed; and

2. Highly durable sandstone and granite, which form the northeast corner of the watershed and flank much of the lower creek where it passes through the Sespe Creek gorge, and are interbedded with the siltstones of the Middle and Upper subwatersheds.

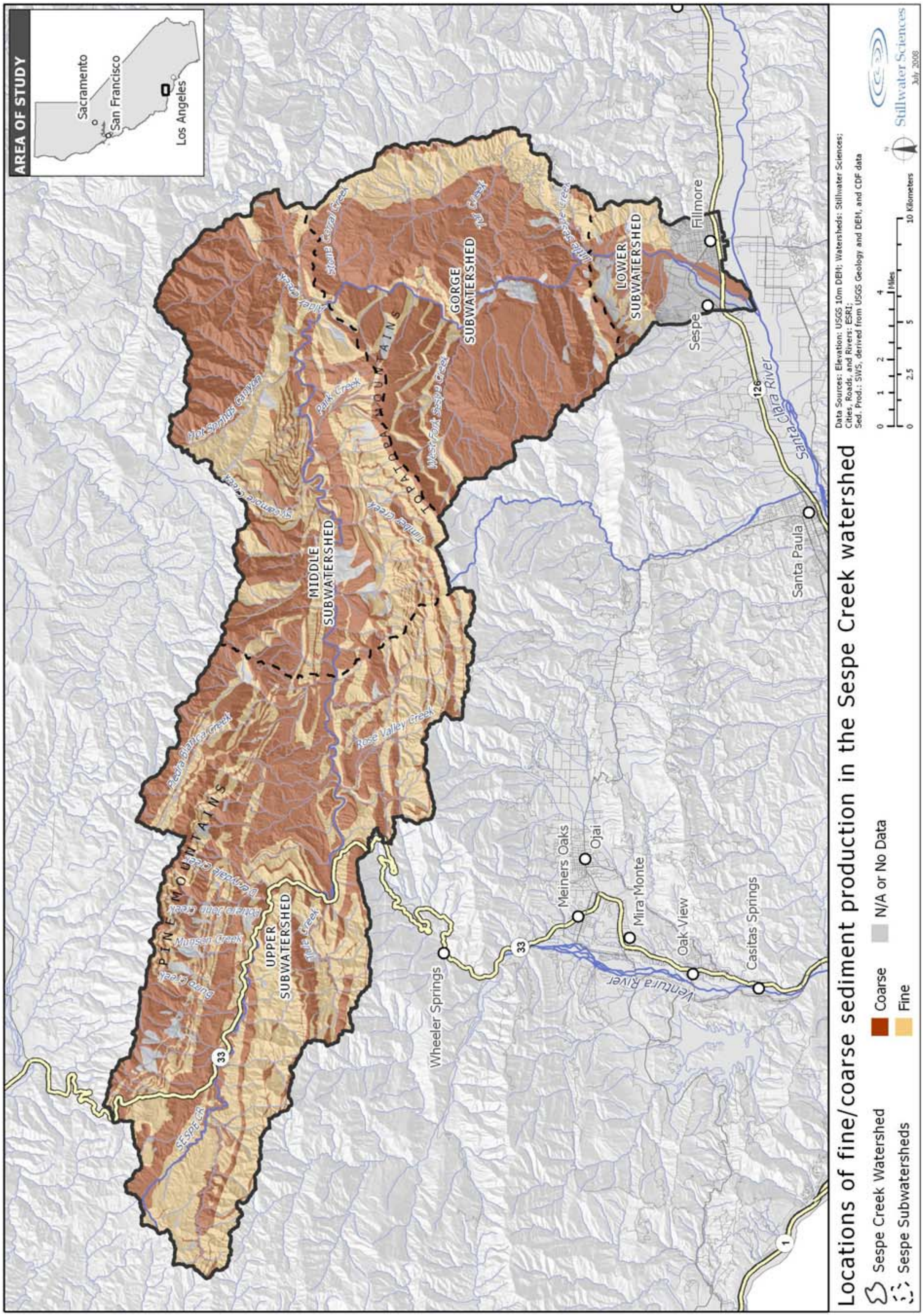


Figure 2-4. Generalized distribution of coarse-grained and fine-grained rocks across the Sespe Creek watershed.

This two-part division into fine-grained (i.e., siltstone) and coarse-grained (sandstone and granite) bedrock components is central to understanding the present behavior, and predicting the future behavior, of the stream channels throughout the Transverse Ranges, including Sespe Creek. By analogy to other rivers world-wide, the fine-grained load (<0.0625 mm) represents the majority of sediment that is delivered by hillslopes into the channel, and that is subsequently transported by the channel down to the trunk valley of the Santa Clara River. Field observations indicate that areas displaying rapid hillslope erosion are uniformly underlain by siltstone and mudstone.

Delivery of sandstone, however, from hillslopes to channels is also important. The sandstone clasts are resistant to mechanical breakdown during fluvial transport—although they become rounded within a short distance of their initial entry into the stream channel network, they persist throughout their passage down the network, which in many cases requires many tens of kilometers of transport. Duvall et al. (2004) found more than a five-fold difference in rock strength between two of the main rock types in the Sespe Creek watershed (Matilija Sandstone and Pico Siltstone). Based on observations along the channel of both Sespe Creek and Santa Paula Creek, this probably underestimates their relative durability to fluvial transport. Because of the persistence and dominance of sandstone-derived gravel and boulders in the coarse fraction of bedload sediment, channel morphology is largely determined by the delivery, transport, and floodplain deposition of these clasts. The presence or absence of this sediment in the channel also determines whether any given reach will be alluvial, flowing over loose bed sediment, or non-alluvial, with a scoured channel bottom that exposes the underlying bedrock.

Consequently, the processes and rates by which sediment is eroded off of hillslopes, and subsequently delivered to the channel network, vary substantially across the watershed. Given the profound differences in mechanical properties of the shale and sandstone bedrock, the processes affecting each must be considered distinctly.

2.3.2 Processes of sediment production and delivery

2.3.2.1 Fine sediment

The most highly erosive rocks in this region, those of the Pleistocene–Pliocene Saugus, Las Posas, and Pico formations (about 1–5 million years old), lie almost entirely to the south of the Sespe Creek watershed and constitute less than 2% of the watershed area, entirely near the mouth of the channel. To the west in the Santa Paula Creek watershed, these rocks are widely exposed and are major sources of fine sediment (<0.0625 mm) to the channel network; here, their contribution is nearly absent and results in significantly lower relative total sediment loads than in Santa Paula Creek (see below).

Instead, the largest contributors of fine sediment in the Sespe Creek watershed comprise thin-bedded shaley rocks, particularly in the Juncal, Cozy Dell, and Rincon formations, which cover slightly more than one-third of the watershed area (Figure 2-5). Elsewhere in the watershed, the Eocene-age Cozy Dell Shale (about 42 million years old [Prothero 2001]) and slightly older fine-grained facies of the Matilija and Juncal formations crop out from elevations of about 330 m (1,100 ft) up to more than 1,800 m (6,000 ft). Although many millions of years older than the Saugus and Pico formations and originally deposited in deep marine waters, these rocks now lie atop these younger rocks due to thrusting along the San Cayetano fault (and its subsidiaries). These rocks have been warped into a broad east–west syncline (i.e., a trough), whose north and south limbs form the broad boundaries of the Upper and Middle subwatersheds. Although clearly incised by the drainage network, the intensity of hillslope erosion on these older and typically better vegetated fine-grained units is significantly less than for the younger shales of the Saugus and Pico formations.

Figure 2-5. Typical exposure of thin-bedded shale of the Cozy Dell Formation.

Near the east end of the watershed, the San Cayatano fault bends to the south around the City of Fillmore, and its trace is covered by valley-bottom alluvium of the Santa Clara River. On the upthrown (i.e., north and east) side of the fault, a large belt of shale of the Miocene (5–10 million years ago) Monterey and Rincon formations has been uplifted to form the eastern boundary of the watershed. These rocks are generally very susceptible to erosion, particularly in the absence of vegetation; in total, they underlie almost 10 percent of the watershed area. This terrain includes much of the area burned by the Piru and Day fires, and so the presence of these rocks is particularly significant for fire-induced increases in soil erosion (see below).

By analogy to other studies, rates of fine sediment delivery from these fine-grained rocks should vary most directly with hillslope gradient and vegetation cover (Reid and Dunne 1996). Observations throughout the Sespe Creek and Santa Paula Creek watersheds (Stillwater Sciences 2007a) affirm this principle, recognizing that vegetation cover is both a cause and an effect of relative hillslope stability. Lack of vegetation cover enhances the rate of sediment delivery; but where the ground is unstable or eroding rapidly, vegetation does not grow well. Gradients are generally low to moderate in areas underlain by these rocks, because they are not strong enough to stand steeply without rapidly degrading (Schmidt and Montgomery 1995).

2.3.2.2 Coarse sediment

Well-indurated (i.e., well-cemented and very hard) sandstone, primarily associated with the Oligocene- and Eocene-age rocks of the Sespe Creek watershed (Sespe, Coldwater, and Matilija formations; Figure 2-6) but also locally present as interbeds in the shale-dominated deposits, are widespread throughout the watershed and underlie nearly one-half of its total area. Additional sources of coarse, durable rock include the granitic and gneissic rocks (6% of the watershed area), exposed in the northeast corner of the watershed, and both modern and old fluvial terraces largely composed of sandstone and granite cobbles and boulders (7% of the watershed area, of which about half is the modern river alluvium).

Figure 2-6. Sandstone bedding-plane surface of the Sespe Formation, east of the Sespe Creek gorge near the Dough Flat trailhead.

Areas underlain by these lithologies display characteristic modes of hillslope erosion and channel delivery that are very different from those of the fine-grained deposits. These rocks are quite resistant to surface erosion; unconsolidated soils are generally thin, and so downslope transport by rainsplash, rills, or shallow landsliding is volumetrically limited. In contrast, the rock itself is well-bedded and locally fractured by cross-cutting joints, and so steep bluffs are prone to rockfalls. Accumulations of talus at the base of these slopes are susceptible to mass transport or to gullying; the alluvial fan deposits at the base of such channels are commonly choked with coarse, subangular blocks.

Over much of the watershed, these rocks are only lightly deformed in broad, open folds. As a result, many extensive hillslopes express the near-planar geometry of these hard, gently-dipping sandstone strata. Where those rocks have been incised by river erosion, however, they display a steep face where the primary bedding has been crosscut (Figure 2-7). These areas are primary sources of coarse sediment into the channel network, and they are distributed widely throughout the watershed—notably in the Sespe Creek gorge, but also along the north and south valley walls of the Middle and Upper subwatersheds. Delivery of coarse sediment into steep gullies, and ultimately into Sespe Creek, is also active off of the granitic ridges of the northeastern watershed.

Figure 2-7. Example of the delivery of coarse sediment blocks into the channel network from the weathering of a single sandstone interbed.

2.3.3 Quantifying sediment delivery locations and rates

No matter how complete the description of processes that move sediment from hillslopes to river channels, a complete reconstruction of sediment-delivery rates over time and space is infeasible. As discussed above, delivery is controlled by such conditions as vegetation cover, rainfall, and the physical properties and topography of the hillslope deposit itself. These conditions, however, can be relatively steady through time, or they can be unpredictable. As a result, some delivery processes have fairly constant rates (such as soil creep), but many are unpredictably episodic (such as debris flows or rockfalls).

Although the conditions and events that deliver sediment from hillslopes to river channels vary greatly over time, different parts of the landscape can be readily identified as to their relative sediment-delivery potential. Given the fortuitous availability of sediment-accumulation data in this region (see below), we can also estimate time-averaged rates for these zones of relative sediment production with an opportunity to corroborate these predictions. These quantitative predictions do not characterize the specific influence of individual external events, which in this part of California are most commonly intense rainstorms, vegetation-destroying fires, and earthquakes (see Stillwater Sciences 2007b). However, they can provide several other benefits: 1) the relative contribution of different tributaries and subwatersheds can be identified more precisely; 2) the potential influence of vegetation-removing fire can be estimated in a spatial context; and 3) a calculated magnitude of sediment flux can be used in the context of future management options for in-channel management actions or structures.

Our approach for Sespe Creek followed that previously developed for Santa Paula Creek (Stillwater Sciences 2007a). We identified watershed factors judged critical to determining the sediment-production potential of the landscape, and we divided them into discrete categories to define "geomorphic landscape units" (GLUs) across the watershed (these were called "process domains" in Stillwater Sciences 2007a). We assigned relative, qualitative rates of sediment production to each of these GLUs ("High", "Medium", and "Low", commonly abbreviated H, M, and L throughout this report). Finally, we then determined numeric values of sediment delivery for each category of GLU on an annual unit-area basis, displaying their spatial distribution on maps and integrated their contributions into a single value of average annual sediment yield across the watershed. These steps are described in greater detail in the following sections.

2.3.3.1 Relative rates of sediment production

Although many factors can determine sediment-production rates from hillslopes, this study focused on three that were judged to impose the greatest range of variability over the watershed: rock type, hillslope gradient, and vegetation cover. Data sources for each were compiled in a GIS environment over the entire watershed at a resolution determined by the coarsest dataset (30 m).

Rock types were based on the 1:24,000-scale geologic maps of Dibblee (various; Figure 1-3). Following our approach for Santa Paula Creek, mapped units were grouped into categories of fine (shale) and coarse (sandstone and granite) (Figure 2-4), reflecting their likelihood of producing coarse sandstone blocks. Unconsolidated Quaternary deposits, exclusively modern river gravels (3.8% of the watershed area) and uplifted fluvial terraces (e.g., Figure 2-3; 3.6% by area), were considered "coarse" for purposes of this division, reflecting the observed abundance of cobbles and boulders in them. Qualitatively, the Miocene and Pliocene shaley rocks of the Pico, Caliente, Santa Margarita, Monterey, and Rincon Formations displayed greater erosivity than the older shales of the Cozy Dell and Juncal Formations, particularly on very steep slopes, but this distinction was not made across the watershed because the younger shales occupy only a few percent of the watershed as a whole.

Hillslope gradients were generated directly from the digital elevation model, which in turn was based on a USGS 10-m Digital Elevation Model (Figure 2-8). Based on observed ranges of relative erosion and slope instability, the continuous range of hillslope gradients was categorized into three groups: 0–20%, 20–60%, and steeper than 60%. These categories differed from those used in the Santa Paula Creek analysis (0–10%, 10–20%, >20%), because marked differences in erosion were not expressed on slopes as flat as 10%, and because over 84% of the Sespe Creek watershed is steeper than 20% and thus would provide little slope-based discrimination of sediment-production rates. The consequences of this change are very modest, as noted below.

Lastly, land cover was based on a classified Landsat image at 30-m resolution (National Land Cover Dataset of 2001 [Homer et al. 2004]), previously developed for the entire Santa Clara River watershed (Figure 1-6). By an automated classification system, five grouped categories were identified; they largely correspond to vegetation covers of forest, scrub, and agriculture and/or grassland; developed land; and barren/miscellaneous (which included bare rock and water of the river channel itself, where wide enough to register at this scale).

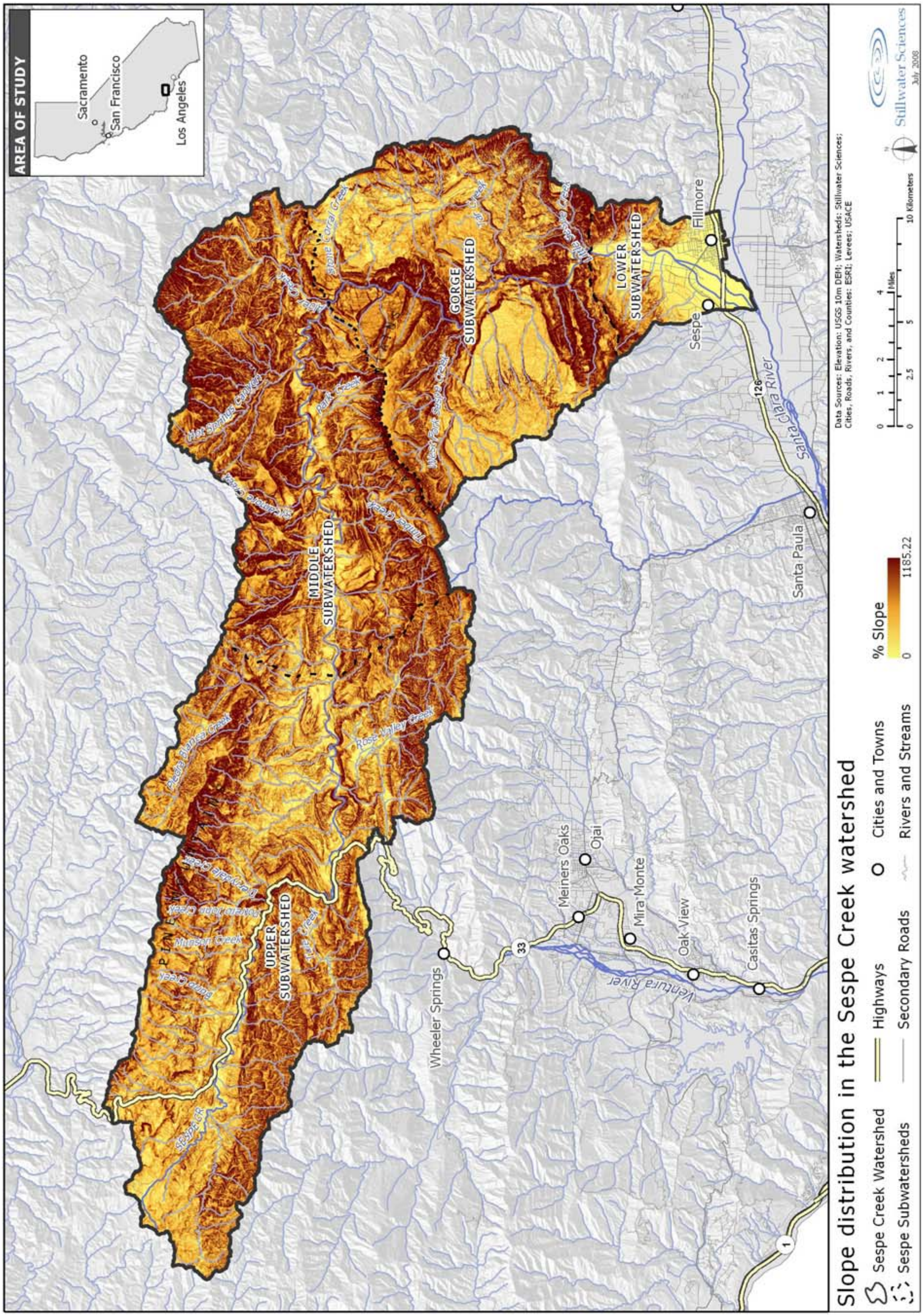


Figure 2-8. Hillslope gradient distribution in the Sespe Creek watershed.

These three factors (geology, slope, and land cover) could theoretically overlap into 30 possible geomorphic landscape units—that is, areas that each has a unique combination of these factors, judged to be the major determinants of hillslope sediment production and, ultimately, sediment yield from the watershed as a whole. In fact, nearly every combination of these factors was represented in the watershed (28 of 30), but nearly two-thirds of the watershed is included in just three types: Sandstone Scrub 20–60%, Shale Scrub 20–60%, and Sandstone Scrub >60%. Only 12 of the possible combinations cover more than one percent of the total watershed area (Table 2-1), and account for nearly 97% of the watershed area (Table 2-1).

Table 2-1. Geomorphic landscape units (GLUs) over percent as a percent of total watershed area (representation = 96.9% of the watershed).

Geomorphic landscape units	% of watershed
Sandstone Scrub 20-60%	27.5%
Shale Scrub 20-60%	18.6%
Sandstone Scrub >60%	15.9%
Shale Scrub >60%	11.0%
Sandstone Scrub 0–20%	7.9%
Sandstone Forest 20-60%	3.9%
Sandstone Forest >60%	2.8%
Shale Scrub 0–20%	2.8%
Shale Forest 20-60%	2.1%
Shale Forest >60%	1.9%
Sandstone Forest 0–20%	1.5%
Sandstone Ag/grass/bare 0–20%	1.0%

For the Santa Paula Creek study (Stillwater Sciences 2007a), representative areas in each of the major categories were visited in the field and categorized into a limited number of relative sediment-delivery rates, based on observed indications of erosion and mass-wasting processes. This effort was continued in Sespe Creek but emphasized only those geologic terrains that are not present in Santa Paula Creek (notably, the areas of granitic rock in the northeast corner of the Sespe Creek watershed and the pre-Tertiary rocks along its southern boarder). Relative differences between many of the different GLUs were dramatic, lending confidence to a coarse, three-fold division of relative rates. Figure 2-9 illustrates some of these differences in relative sediment-production processes. The assignments of relative sediment yield by type of geomorphic landscape unit are listed in Table 2-2.

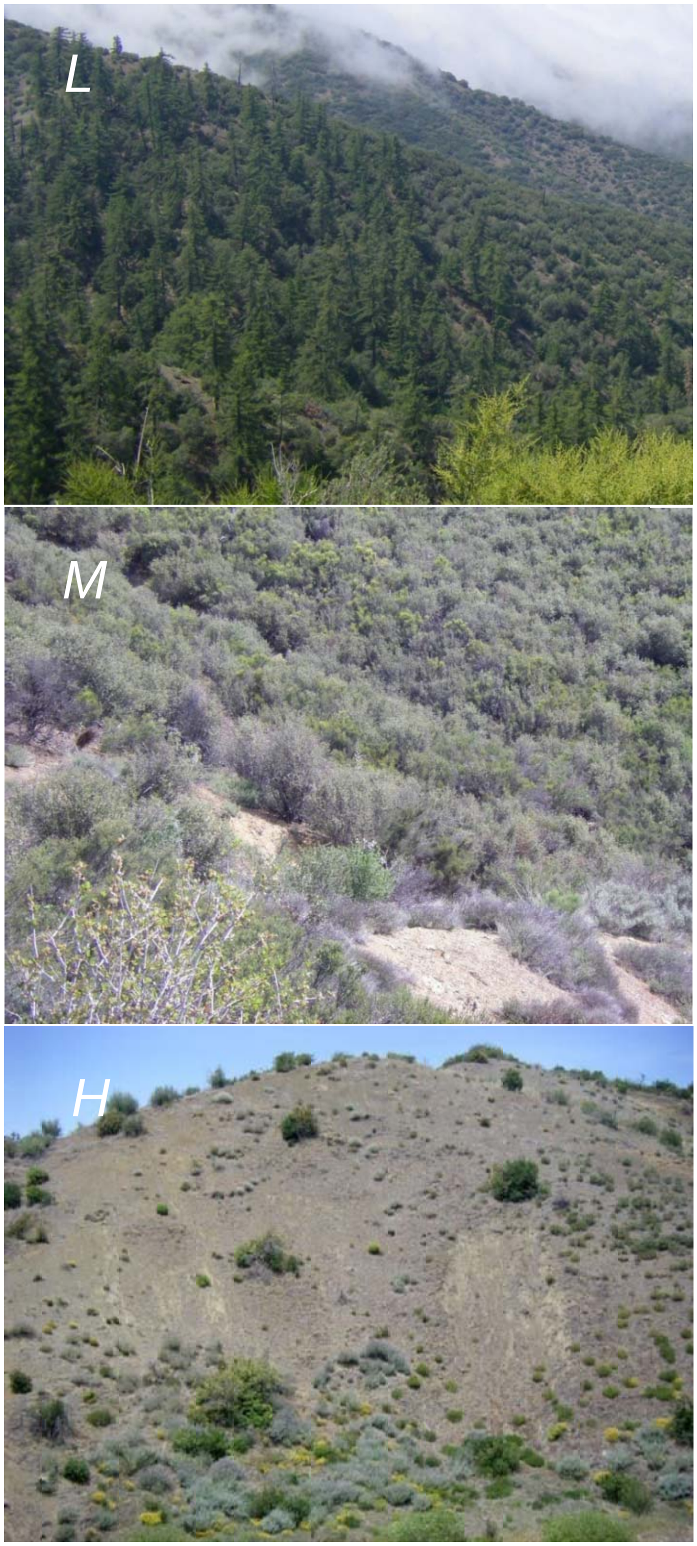


Figure 2-9. Examples of different geomorphic landscape units (GLUs) and their relative levels of sediment production. Top, sandstone forest 20–60%; middle, shale scrub 20–60%; bottom, shale ag/grass/bare >60%.

Table 2-2. Relative sediment production by geomorphic landscape unit (GLU).

Geomorphic landscape unit	Relative sediment production
Shale Forest 0–20%	Low
Shale Forest 20–60%	Low
Shale Forest >60%	Low
Sandstone Forest 0–20%	Low
Sandstone Forest 20–60%	Low
Sandstone Forest >60%	Low
Shale Ag/grass/bare 0–20%	Medium
Shale Misc. 0–20%	Medium
Shale Misc. 20–60%	Medium
Shale Misc. >60%	Medium
Shale Developed 0–20%	Medium
Shale Developed 20–60%	Medium
Shale Scrub 0–20%	Medium
Shale Scrub 20–60%	Medium
Shale Scrub >60%	Medium
Sandstone Ag/grass/bare 0–20%	Medium
Sandstone Ag/grass/bare 20–60%	Medium
Sandstone Misc. 0–20%	Medium
Sandstone Misc. 20–60%	Medium
Sandstone Misc. >60%	Medium
Sandstone Developed 0–20%	Medium
Sandstone Developed 20–60%	Medium
Sandstone Developed >60%	Medium
Sandstone Scrub 0–20%	Medium
Sandstone Scrub 20–60%	Medium
Sandstone Scrub >60%	Medium
Shale Ag/grass/bare 20–60%	High
Shale Ag/grass/bare >60%	High
Sandstone Ag/grass/bare >60%	High

A map showing the distribution of the 28 GLU categories across the entire watershed is displayed in Figure 2-10; their distribution by relative sediment-delivery category from Table 2-2 is shown in Figure 2-11.

This map shown in Figure 2-11 effectively represents a prediction of the relative production of sediment from every part of the watershed. The most striking attribute of this map is the relative spatial uniformity of sediment generation across the watershed. This reflects the underlying combination of geology, slope, and land cover that place over three-quarters of the watershed area into our assigned sediment-delivery category of "Medium". Less than 1% registers "High," with these areas predominantly on steep bare or grass-covered hillsides at the extreme west end and lowermost parts of the watershed.

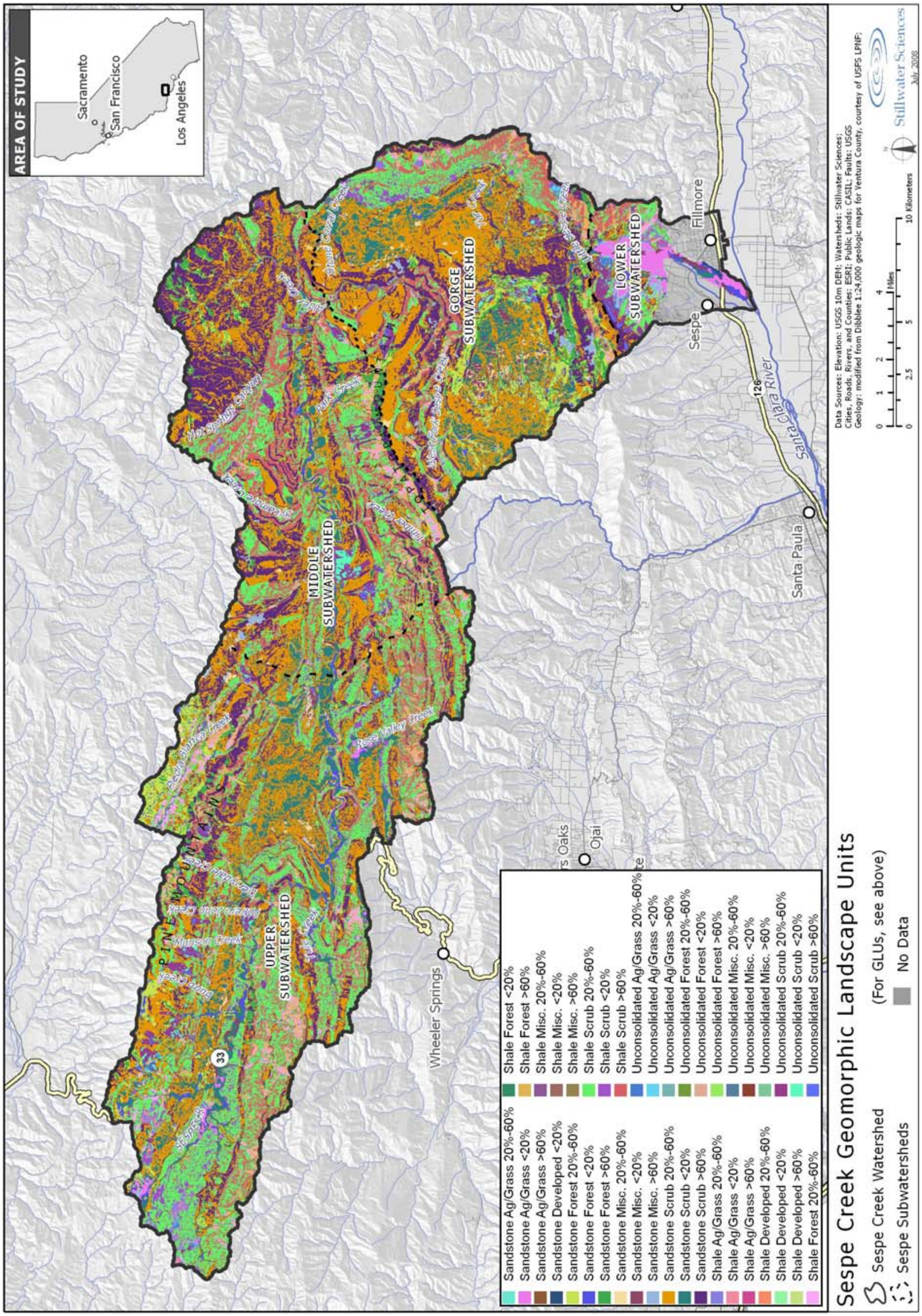


Figure 2-10. Geomorphic landscape units (GLUs) in the Sespe Creek watershed.

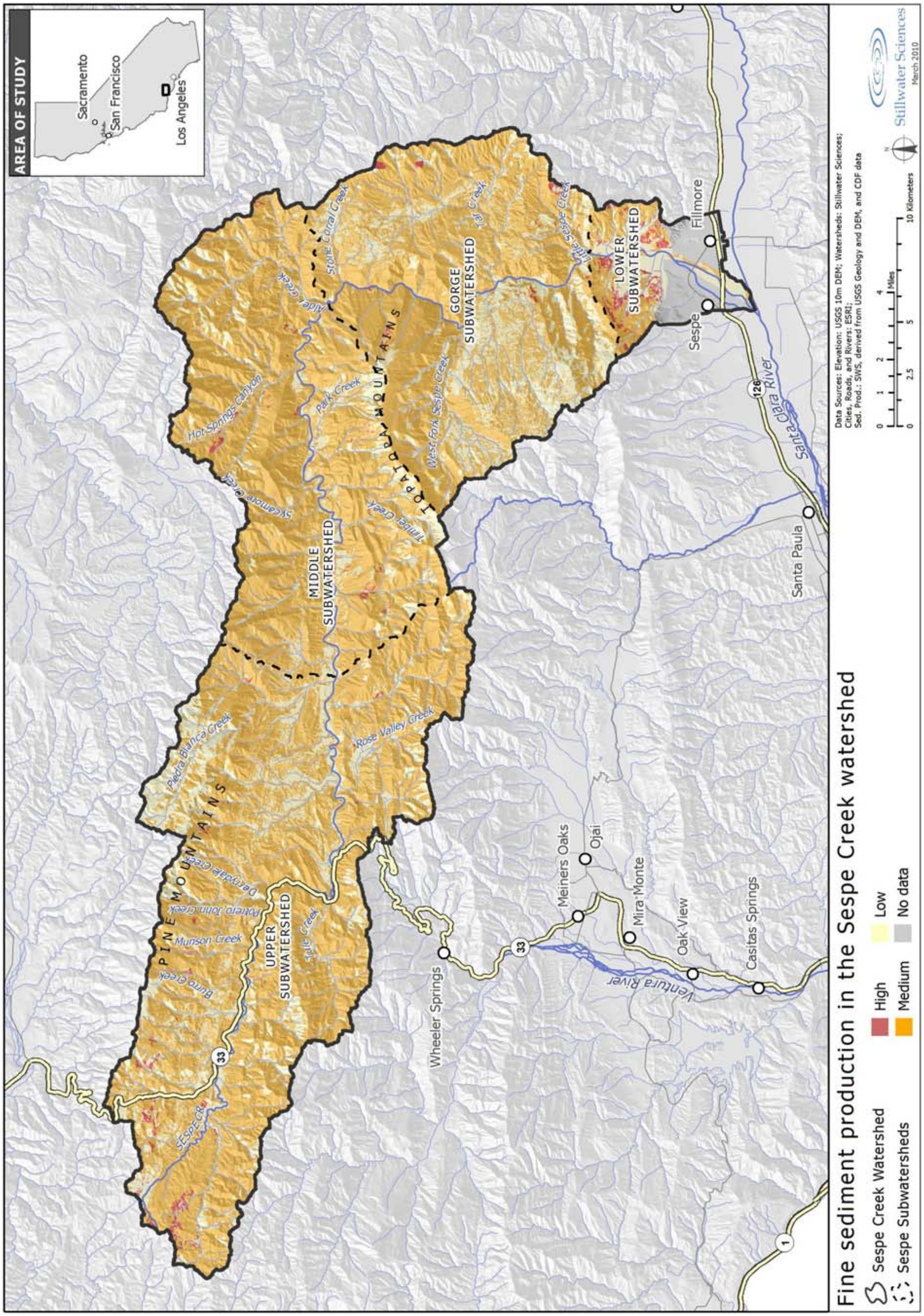


Figure 2-11. Predicted fine-sediment production in the Sespe Creek watershed.

This spatial prediction is lacking in two significant respects, however. The first is that it does not account for any routing or storage of sediment within the channel network. Available sources of sediment data for Sespe Creek are available to test, at least indirectly, the severity of this shortcoming and are discussed in the next section. The second inadequacy of this analysis is that it is based on the vegetative cover of the Landsat imagery, which predates and so does not include any influence of the Piru and Day fires. The analysis does, however, provide a basis for assessing the influence of these fires on the sediment yield of the Sespe Creek watershed; this is explored later in the document.

2.3.3.2 Quantified rates of total sediment delivery

Although a qualitative characterization of sediment-production zones is useful for understanding how the watershed behaves, numeric values for the rates of production and, ultimately, downstream sediment delivery are particularly valuable for applied studies. They can be used to assess the magnitude of downstream sediment loads and the potential consequences of vegetation changes (particularly by fire), and they can also inform the locations where greatest management attention should be invested.

Efforts to quantify the rates of sediment production from this landscape benefits from lengthy records maintained by the Ventura County Watershed Protection District (VCWPD 2005) on the volumes of sediment excavated from their debris basins. A subset of these data was compiled for the Santa Clara River Geomorphology Report (Stillwater Sciences 2007b) from basins in that watershed, spanning basins with average sediment yields from a few hundred to almost 20,000 tonnes per square kilometer per year (t km^{-2} a^{-1}). To assess potential sediment yields for Sespe Creek, this population was further restricted to those debris basins closest to the Sespe Creek watershed (including one, Jepson Wash, that drains to Sespe Creek itself) (Table 2-3). We tallied only those years of accumulation following the first recorded excavation of the basin (so the beginning and ending times were under equivalent, empty conditions).

Table 2-3. Debris basin data from Ventura County used to quantify rates of sediment delivery in the Sespe Creek watershed.

Name	Contrib. area (km^2, from GIS)	Annual average sediment yield (yd^3 a^{-1})*	Sediment yield per unit area (t km^{-2} a^{-1})	Years evaluated*	Location
Real Wash	0.6	7,423	18,929	1969–2005	12 km east of Sespe Creek
Warring Canyon Debris Basin	2.8	12,039	6,578	1969–1998	0.4 km east of Real Wash
Jepson Wash Debris Basin	3.5	9,174	4,010	1969–2005	Southwest edge, Sespe Creek watershed
Fagan Canyon	7.5	12,500	2,550	1994–2005	2 km west of Santa Paula Creek
Adams Barranca Debris Basin	21.8	27,362	1,920	1998–2005	2 km west of Fagan Canyon

*Source: VCWPD (2005)

Not surprisingly, the overall magnitude of annual unit-area sediment accumulation rates is inversely related to drainage area. This is a common outcome of sediment-yield studies, reflecting the "dilution" of high-yield areas with a broader spectrum of GLUs and the greater opportunity for storage of sediment (e.g., longer hillslopes, broader floodplains) in larger river systems, which results in lower rates of downstream delivery for a given rate of hillslope production. This pattern is confounded, however, because the largest contributing watersheds (Fagan and Adams Barranca) also have the shortest records. They are also farthest from the mouth of Sespe Creek.

The greatest limitation, however, is the attempt to characterize sediment yield from a 674-km^2 watershed with data from those one to two orders of magnitude smaller. Not only are the dominant processes of sediment transport and storage likely to be different, but also the geology, vegetation cover, and climate may not be analogous. Given the close proximity of the debris basins to Sespe Creek, the geographic factors are largely addressed; but the physiography of the Transverse Ranges and that direction of approaching storms impose a significant west-to-east gradient in rainfall, evidenced by isohytal maps of the region (Figure 1-4) and quantified by the long-term stream gauge data for Santa Paula Creek (which drains only the front, south-facing slope of the ridge) and Sespe Creek (whose watershed area is primarily interior to the range). These physiographic factors result in a specific annual runoff (i.e., discharge per year per unit area of watershed) for Sespe Creek that is only about three-quarters that of Santa Paula Creek, because although Sespe Creek is 6.5 times the area of Santa Paula Creek, its mean annual discharge averages only five times greater (Figure 2-12). This is undoubtedly a factor in determining the relative rates of sediment production from these two watersheds, albeit difficult to quantify precisely.

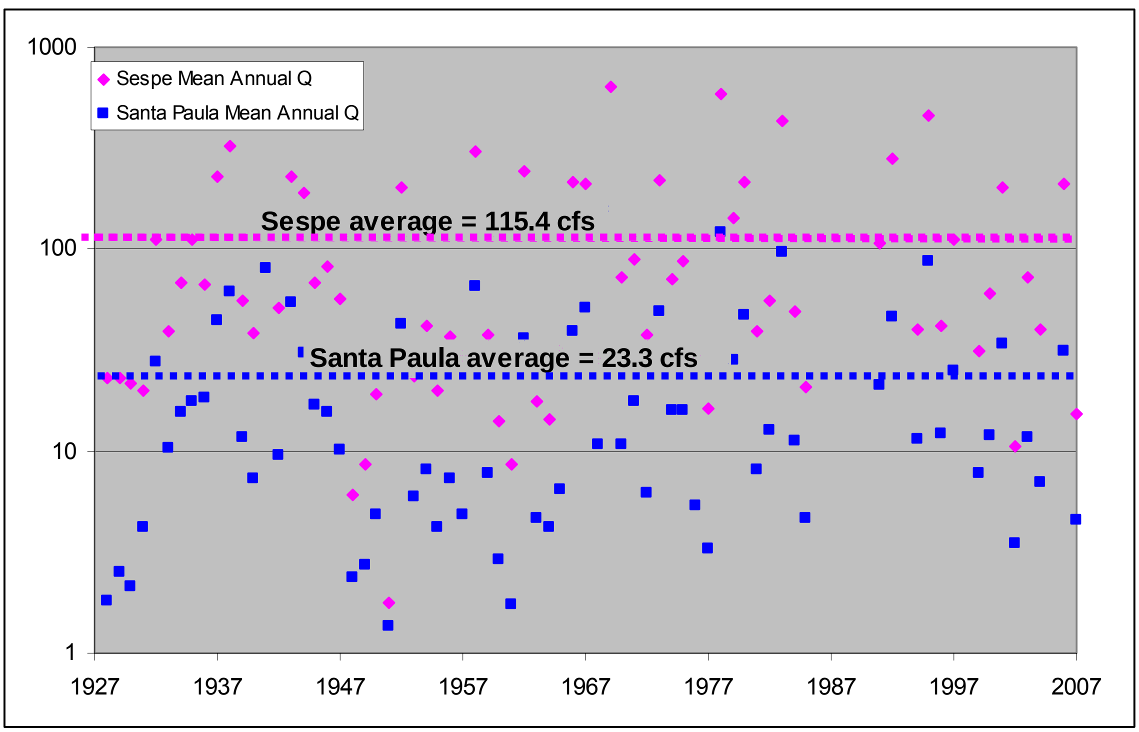


Figure 2-12. Mean average discharges for all years of coincident record at the USGS gages for Sespe Creek (11113000) and Santa Paula Creek (11113500). Although Sepse Creek drains 6.5 times the area of Santa Paula Creek, its discharge is only five times greater.

Following our approach for Santa Paula Creek (Stillwater Sciences 2007a) we first defined GLUs across each of the watersheds contributing to the five selected debris basins (note that this was already accomplished for Jepson Wash, being part of the Sespe Creek watershed). They were categorized into areas of H, M, and L sediment yield, using the criteria developed for the Sespe Creek watershed as a whole (Table 2-2), with the exception that the observed conditions of very high delivery corresponding to steep, shrub-covered Miocene and Pliocene rocks were assigned a value of "H" (Figure 2-13). The results are displayed in Figure 2-14.

Figure 2-13. View of Real Wash debris basin located to the southeast of Hopper Creek watershed. This basin receives sediment from a steep, shrub-covered Miocene and Pliocene rock (GLU) terrain with an assigned sediment yield value of "High".

We then assigned specific numeric values to the relative categories of "high," "medium," and "low" sediment delivery by geomorphic landscape unit, recognizing that these values will not be particularly well constrained. The values applied for Santa Paula Creek (Stillwater Sciences 2007a) were 22,000, 2,400, and 300 t km^{-2} a^{-1} for the GLUs identified as "high," "medium," and "low,", respectively, based on a broader set of debris-basin data and watershed-scale sediment-delivery rates calculated by Warrick (2002). These values are probably somewhat high, however, when applied to the Sespe Creek watershed as a whole by virtue of modestly lower precipitation.

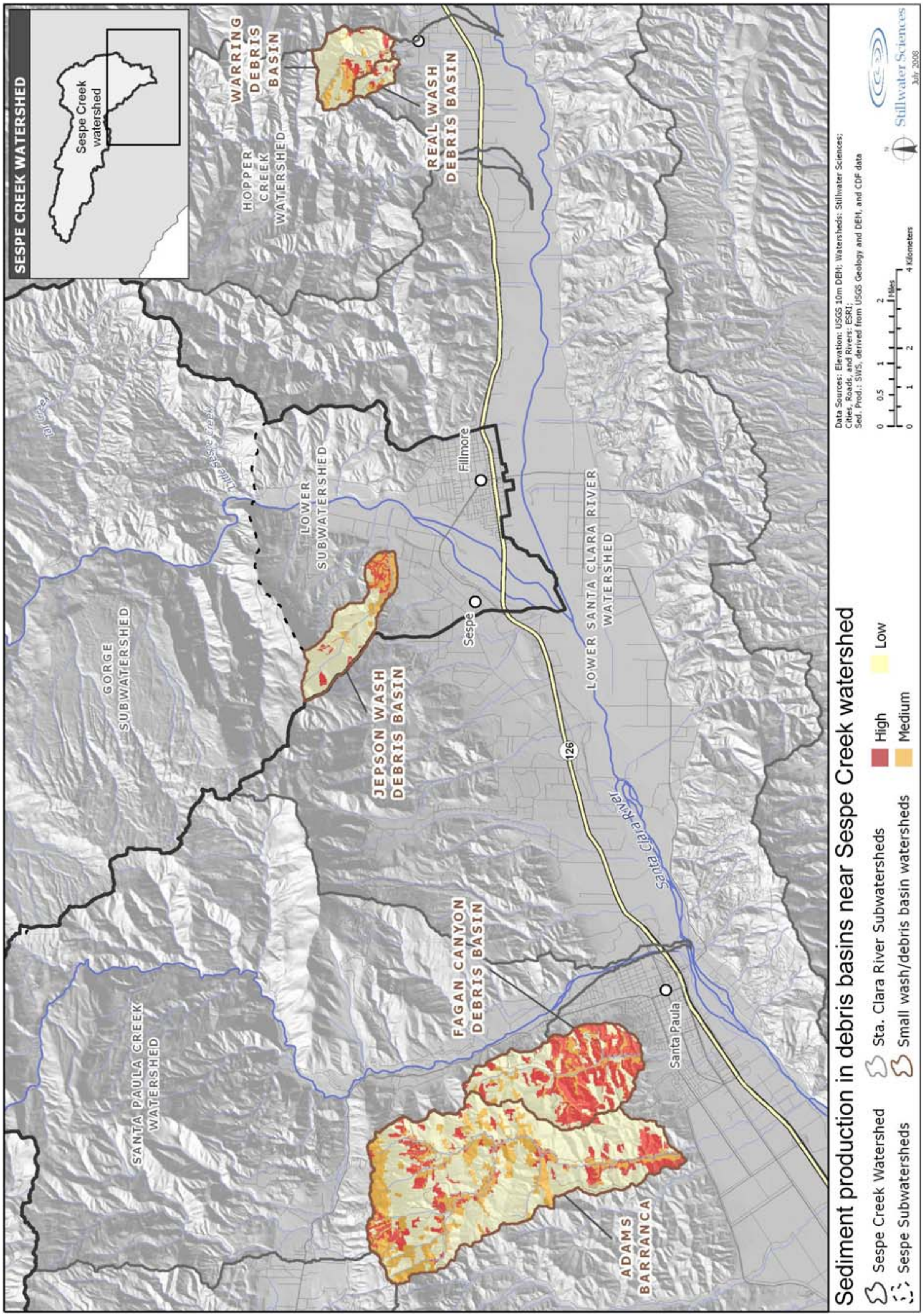


Figure 2-14. Geomorphic landscape units (GLUs), with assigned levels of sediment production, across the five nearby watersheds draining into debris basins with records of sediment removal.

To improve the confidence of sediment-yield estimates, we compared the measured rates of sediment production for the five debris basins of Table 2-3 with predicted rates using our GLUs and a range of unit-area sediment-production factors. The five basins were visited in the field to insure that the contributing watersheds were generally representative of the Sespe Creek-area landscape. Our pre-established categories of geology, land cover, and slope were applied to generate categories and total areas of H, M, and L sediment production. Several different combinations of sediment-delivery factors were applied in order to evaluate a range of alternatives; Figure 2-15 presents those results using the factors from Santa Paula Creek ("SPC factors") and a modestly lower set using only single-precision values ("Reduced factors", where H = 20,000, M = 2,000, and L = 300 t km^{-2} a^{-1}). In total, this results in a predicted annual sediment yield of 1,150,000 t a^{-1} (1,760 t km^{-2} a^{-1}). This is equivalent to a watershed-averaged landscape lowering rate of 0.6 mm a^{-1}.

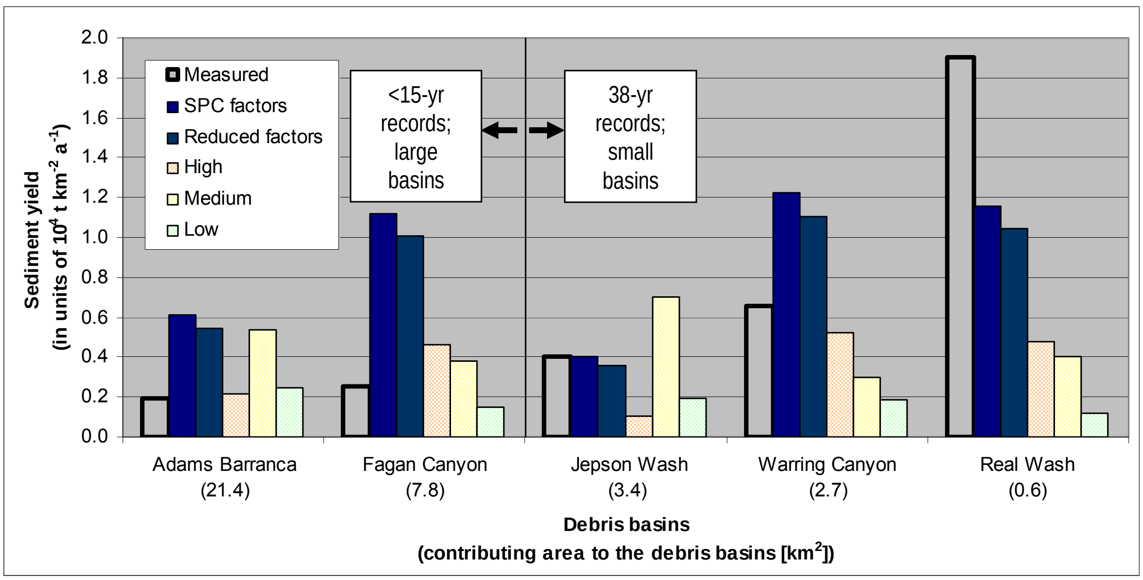


Figure 2-15. Measured and predicted debris basin sediment yields. "Measured" values are calculated from VCWPD (2005); predicted values were calculated using the unit-area sediment-delivery factors from Santa Paula Creek (Stillwater Sciences 2007a) and a set of factors reduced 0–20% from these values. The bars "High", "Medium", and "Low" show the proportional area in each category identified in the contributing watershed.

These results emphasize both the value and the limitations of such an analysis. Predictions, particularly for the smaller watersheds closer to Sespe Creek, correspond relatively "well" (and in the case of Jepson Wash, remarkably so), although factor-of-two errors are likely. Predicted values do not differ systematically from measured values, except that the largest basins are both over-predicted. The identification of "High" sediment-production areas is the critical driver for the predicted yields in all but Jepson Wash, because the relative areas are significant and the factor is one or more orders of magnitude larger than for the other areas. In contrast, the value assigned to "Medium" areas exerts the greatest influence on the Jepson results, because this category represents 70% of the total watershed area. This dominance is the case in the Sespe Creek watershed as a whole and, perhaps fortuitously, the correspondence between measured and predicted values is closest for this debris basin as well.

Although by convention these rates are all expressed on a "per year" basis, both geomorphic theory and common sense acknowledge that actual sediment production is highly episodic, with many years of relatively little production punctuated by erratic pulses of very high delivery associated with large storms. These values are averaged over the period of debris-basin records, namely a few decades, and so they have significant uncertainty—truly extreme rainfall (or rain following fire) events are not included, nor are multi-decadal droughts. Year-to-year variability may be of the same order, or more, as the predicted "annual" values themselves.

The overall reliability of these calculations is best evaluated in the context of other, independent data. In tectonically active regions, the rate of landscape lowering through hillslope erosion and fluvial transport is strongly influenced by the rate of landscape uplift. Over long periods of geologic time, these two rates must crudely balance (e.g., Willett and Brandon 2002)—if they did not, either mountains would grow without bounds or topographic relief would be obliterated altogether. The previous discussion of uplift rates, as determined by a variety of fault studies and geodetic measurements, suggests that the Sespe Creek watershed is being raised tectonically at several times this predicted rate of sediment yield. This was also the case in Santa Paula Creek (Stillwater Sciences 2007a), but the disparity between uplift and calculated erosion is even greater here, a combination of increased activity to the east along the San Cayetano Fault; and reduced rainfall, a greater proportion of durable rock, and thus overall lower erosion rates in Sespe Creek.

A testable consequence of this predicted imbalance between uplift and erosion should be the widespread preservation of relict landscape features, particularly river terraces that stand above the level of the modern fluvial system. These are in fact abundant, mapped by Dibblee (various dates) throughout the watershed that represents multiple stages in the region's uplift history, and that now stand many hundreds of meters above the modern Sespe Creek and readily visible in the modern landscape (Figure 2-3). These give qualitative confirmation to a calculated erosion rate that is significantly lower to the uplift rate, although it provides no additional constraints.

More quantitative corroboration of the predicted sediment yield derives from direct measurements of sediment discharge. The U.S. Geological Survey stream gauge for Sespe Creek, just downstream of the Little Sespe Creek confluence (USGS 11113000), was the site of sediment discharge measurements between 1966 and 1978. When combined with the 80-year discharge record at the gauge (see Section 3.2), these data indicate a total average annual sediment yield of 1,523 t km^2 a^{-1}. This extrapolated measurement is likely the most reliable estimate of long-term average sediment yields from the watershed, and it differs from our GLU-based approach of 1,760 t km^{-2} a^{-1} by nearly 10%. This remarkable degree of correspondence is surely fortuitous, but it lends some confidence to the expectation that our predictions are reasonable and can provide a basis to explore the spatial distribution of sediment sources in the watershed, and the potential effects of vegetation removal due to fire or human activity.

2.3.3.3 Delivery of coarse sediment

Analogous to the procedure for fine sediment, geomorphic landscape units across the Sespe Creek watershed were evaluated for their relative contribution of coarse sediment (i.e., sandstone and granitics) into the channel. This component of the sediment load is highlighted because of the overriding influence of this resistant lithology on the bedload and morphology of the river. For this analysis, areas mapped as having sandstone- or granite/gneiss-dominated lithologies were included, together with modern and older fluvial deposits (which have a high proportion of cobbles and boulders). This probably results in a modest under-representation of actual cobble- and boulder-contributing areas, because even the shaley units include interbeds of sandstone that were observed to constitute as much as about 10 percent of the deposit.

The assignments of geomorphic landscape units into coarse sediment-delivery categories are listed in Table 2-4, based on our prior analysis for Santa Paula Creek with a few local modifications based on the changes in slope categories (i.e., using 20–60% as the intermediate slope category here instead of 10–20%). Their spatial distribution across the watershed is displayed in Figure 2-16. In contrast to our analysis of total sediment delivery (Section 2.3.3.2), however, we have found no measured data to provide numeric values to the relative categories of "High," "Medium," and "Low" coarse sediment production (or to their spatial integration across the watershed as a whole). We therefore have not quantified the absolute rate of coarse sediment delivery into Sespe Creek, on the spatial distribution of relative coarse-sediment production areas. The coarse-fraction (>0.0625 mm) of the total long-term average sediment yield was estimated using the USGS sediment discharge records and is presented below in Section 3.2.

Table 2-4. Coarse-sediment delivery by geomorphic landscape unit (GLU).

Geomorphic landscape unit	Coarse sediment production
Sandstone Ag/grass/bare 0–20%	Low
Sandstone Misc. 0–20%	Low
Sandstone Developed 0–20%	Low
Sandstone Forest 0–20%	Low
Sandstone Forest 20–60%	Low
Sandstone Forest >60%	Low
Sandstone Scrub 0–20%	Low
Sandstone Misc. 20–60%	Medium
Sandstone Developed 20–60%	Medium
Sandstone Developed >60%	Medium
Sandstone Scrub 20–60%	Medium
Sandstone Scrub >60%	High
Sandstone Ag/grass/bare 20–60%	High
Sandstone Ag/grass/bare >60%	High
Sandstone Misc. >60%	High

Inspection of this map emphasizes several features of the predicted sources of coarse sediment. First, sources of coarse sediment are widely distributed across the watershed, and so the channel likely has ready access to coarse sediment throughout its length. Second, about 15 percent of the total map area is predicted to be zones of "high" delivery. These zones are primarily steep and nominally shrub-covered slopes, based on the GIS-based land-cover classifications. Field inspection revealed that many of these high-delivery areas have a very sparse vegetative cover that does not significantly impede the processes that deliver coarse blocks to the channel network (Figure 2-17).

Unlike the movement of fine sediment, which tends to correspond closely to the flow of water down the channel network, coarse bedload sediment moves only episodically and is subject to the vagaries of local flow competency, long-term floodplain storage, and hydraulic constrictions. Thus the "coarse sediment connectivity" (Hooke 2003) of a channel network can influence the downstream flux of bedload material as significantly as the initial hillslope supply itself.

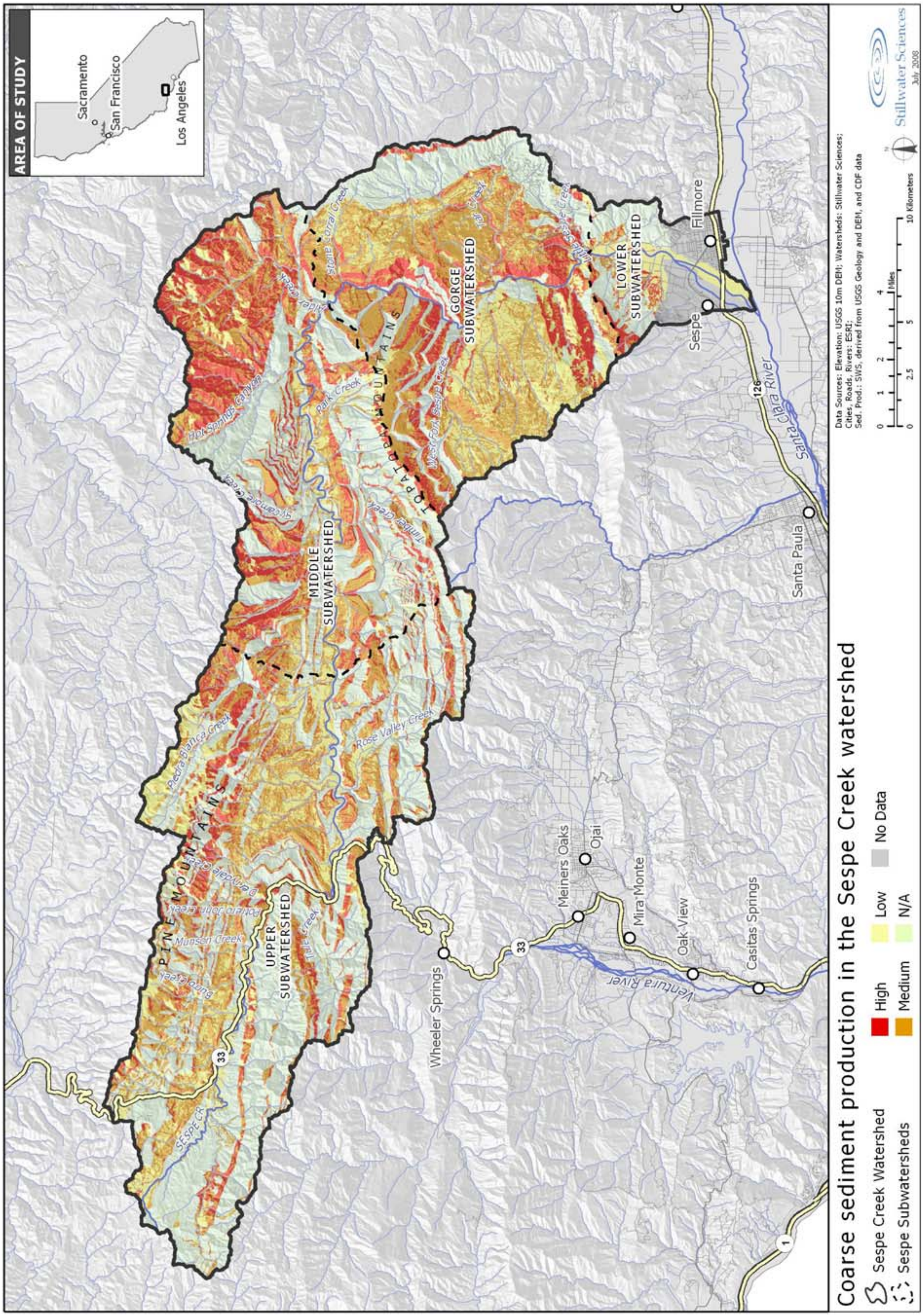
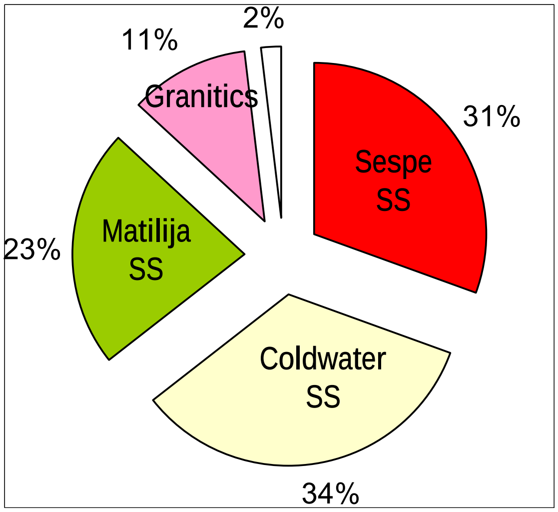


Figure 2-16. Predicted coarse-sediment production in the Sespe Creek watershed.

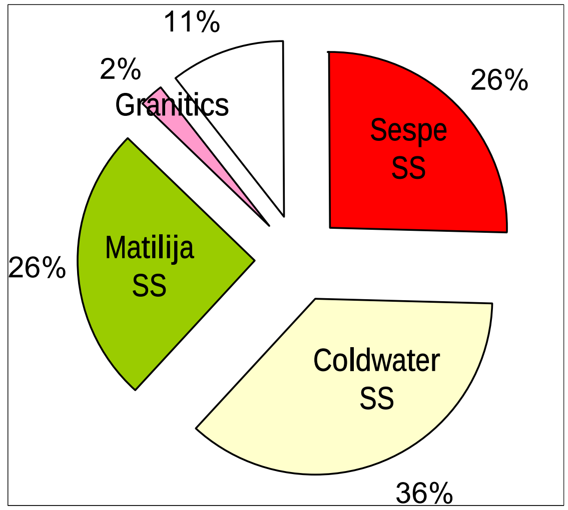
Figure 2-17. Relatively rapid delivery of Sespe Sandstone boulders from steep, nominally shrub-covered hillslopes of the Gorge subwatershed.

The only potentially significant constriction along the mainstem channel of Sespe Creek is the entrance to the Sespe Creek gorge. Upstream, the river has a meandering alluvial pattern with abundant sediment stored on active point bars and in the near-channel floodplain (see Section 2.5.2). Once in the gorge, however, the channel is highly confined and expresses little sediment storage. Downstream of the gorge, sediment deposition is again voluminous, suggesting that the gorge is primarily a transport zone (see Section 3) but one that may not significantly impede the downstream delivery of material.

The role of the gorge in blocking (as opposed to just rapidly transporting) sediment from upstream was evaluated semi-quantitatively, owing to the fortuitous distribution of distinguishable rock types in the watershed. Downstream of the gorge, on the alluvial floodplain adjacent to the rock-and-concrete revetment (3810158 N, 323047 E; see sample location at PC-6 on Tile 5 of 9 in Appendix A), a tally of lithologic types in the coarsest-grained fraction (>400 mm intermediate diameter) was made in a randomly selected 10 x 10 m area of the floodplain occupied by very coarse sediment. We compared the relative proportion of clasts types with the gross area of exposed lithologies across the watershed as a whole (Figure 2-18); the correspondence between the two sets of data are remarkably close for the sandstone units but significantly different for the granitic rocks, which outcrop only upstream of the Sespe Creek gorge. These results suggest that input of coarse sediment from the walls of the gorge itself, primarily Sespe Sandstone with lesser contributions of Coldwater Sandstone (and even less of Matilija Sandastone) do not overwhelm the contribution from upstream; but they also indicate that the downslope and/or downstream transport of granitics is probably impeded. This is judged more likely a consequence of long hillslope-delivery distances from granitic outcrop sources high on the northeast slopes than from any blockage at the mouth of the gorge. Overall, Sespe Creek benefits greatly from lacking any significant anthropogenic influences on coarse sediment connectivity. This relatively good degree of sediment connectivity stands in direct contrast with neighboring Santa Paula Creek, where a highway road crossing and a diversion structure are well-correlated with severe downstream scour from insufficient sediment transport (Stillwater Sciences 2007a).



Fraction of coarse-grained lithologies, watershed-wide (from GIS)



Fraction of coarse-grained lithologies on Fillmore reach floodplain (from GIS)

Figure 2-18. Comparative fractions of coarse-grained lithologies on a watershed-wide basis (left panel) and from point-counting of boulders ($D_{50} \geq 400$ mm; n = 47) on the Lower subwatershed floodplain, below the Gorge subwatershed (right panel). Except for the relative paucity of granitic rocks below the gorge, rocks are relatively uniformly represented by total outcrop area. The relative absence of granitics, coupled with the lack of any enhanced prevalence of Sespe Formation sandstone (which makes up most of the wall rock of the gorge) suggests that impeded movement of granitic boulders down from their high-elevation outcrops in the northeast part of the watershed, rather than blockage of the coarse sediment load at the upstream end of the gorge, is responsible for the pattern. The open slice in both graphs represents other, less common lithologies; of note, only one shale boulder was found, emphasizing the lack of durability of this rock type.

2.4 Effects of Wildfire on Sediment Production and Delivery

2.4.1 Fire History in the Sespe Creek watershed

Wildfires have always been a significant component of the environmental disturbance pattern in the Sespe Creek watershed. The watershed is dominated by large areas of contiguous chaparral vegetation, which is fire-dependent for germination and regeneration and thus has a proclivity to burn (Keeley et al. 1981, Keeley 1987). In addition to the type of vegetation, climate, soil type, and fire history patterns all play a primary role in controlling fuel conditions for fires within the watershed (USFS 1997). For example, areas of chaparral vegetation within the watershed that have not been burned in over 50 years have heavy fuel volumes and have the highest potential for catastrophic wildfire (USFS 1997). Currently, most of the Sespe Creek watershed (70% by area) is designated as Wilderness, divided between the Sespe Wilderness and the Sespe Condor Sanctuary, both of which are within the Los Padres National Forest (Figure 1-1). As these wilderness areas are undeveloped with nominal fuel control efforts and large stands of older chaparral vegetation, wildfires continue to control vegetation generation as well as affect hydrologic and geomorphic dynamics within the watershed at varying spatial and temporal scales.

Over the past century, the majority of the Sespe Creek watershed has been burned by wildfire (Figure 2-19). Most of the watershed (73%) has been burned at least twice in the last century, with 4% having no fire history and 2% having burned more than four times. The estimated return interval of fires within chaparral-dominated areas of the watershed is approximately 40–50 years (USFS 1997), which is driven primarily by vegetation type in addition to local climate, hillslope aspect, hillslope gradient, elevation, fuel accumulation, and ignition sources (USFS 1997). In total, there have been 19 major wildfires within the watershed from 1915 to 2007, ranging in characteristics such as burn duration, burn footprint, and time since the last burn, and thus having varying impacts on watershed disturbance (Table 2-5). Of these fires, seven can be considered the most significant as they burned over 40 km^2 (10,000 acres) of the watershed (approximately 6% of the watershed area) (Figure 2-20). In particular, the Matilija Fire (1932), Wheeler #2 Fire (1985), Piru Fire (2003), and Day Fire (2006) were fires that burned the most sizable portions of the watershed (>80 km^2 [>20,000 acres]) and are known to have had significant impacts in the Sespe Creek and adjacent watersheds.

Table 2-5. Major documented fires in the Sespe Creek watershed (1915-2007).

Fire name	Start date	Duration (days)	Total burn area		Burn area within Sespe Creek watershed		% of Sespe Creek watershed burned
			km^2	acres	km^2	acres	
1915 Fire	Unknown	Unknown	0.6	156	0.6	156	0.1
Sespe/Piru	9/28/1917	Unknown	178	44,003	64	15,752	9
Matilija	9/7/1932	Unknown	890	219,967	491	121,388	73
Edwards	11/22/1939	Unknown	19	4,772	8.1	2,008	1.2
Wheeler Springs	9/12/1948	Unknown	91	22,496	8.5	2,104	1.3
Boulder Creek	8/22/1957	Unknown	15	3,734	11	2,697	1.6
Sespe	8/23/1964	Unknown	3.1	771	3.1	771	0.5
Poplar	8/2/1970	Unknown	5.8	1,421	5.1	1,249	0.8
Goodenough	11/5/1971	Unknown	9.1	2,255	6.8	1,679	1.0
Bear	8/22/1972	7	70	17,324	53	13,093	8
Wheeler #2	7/1/1985	14	496	122,670	94	23,229	14
Lion	10/20/1991	3	12	2,849	12	2,849	1.7
Grand	7/2/1996	Unknown	44	10,948	17	4,104	2.5
Piru Incident	10/18/1998	Unknown	51	12,611	6.8	1,678	1.0
Wolf	6/1/2002	13	88	21,638	85	21,099	13
Piru	10/23/2003	14	258	63,718	92	22,668	14
Day	9/4/2006	28	655	161,791	224	55,247	33
Zaca	7/4/2007	60	0.6	156	0.4	102	0.1
Ranch	10/20/2007	26	178	44,003	2.2	534	0.3

Sources: CDF 2004, CDF 2007, Dunn 1989, Cahill 2002, USFWS 2004, USFS 2006

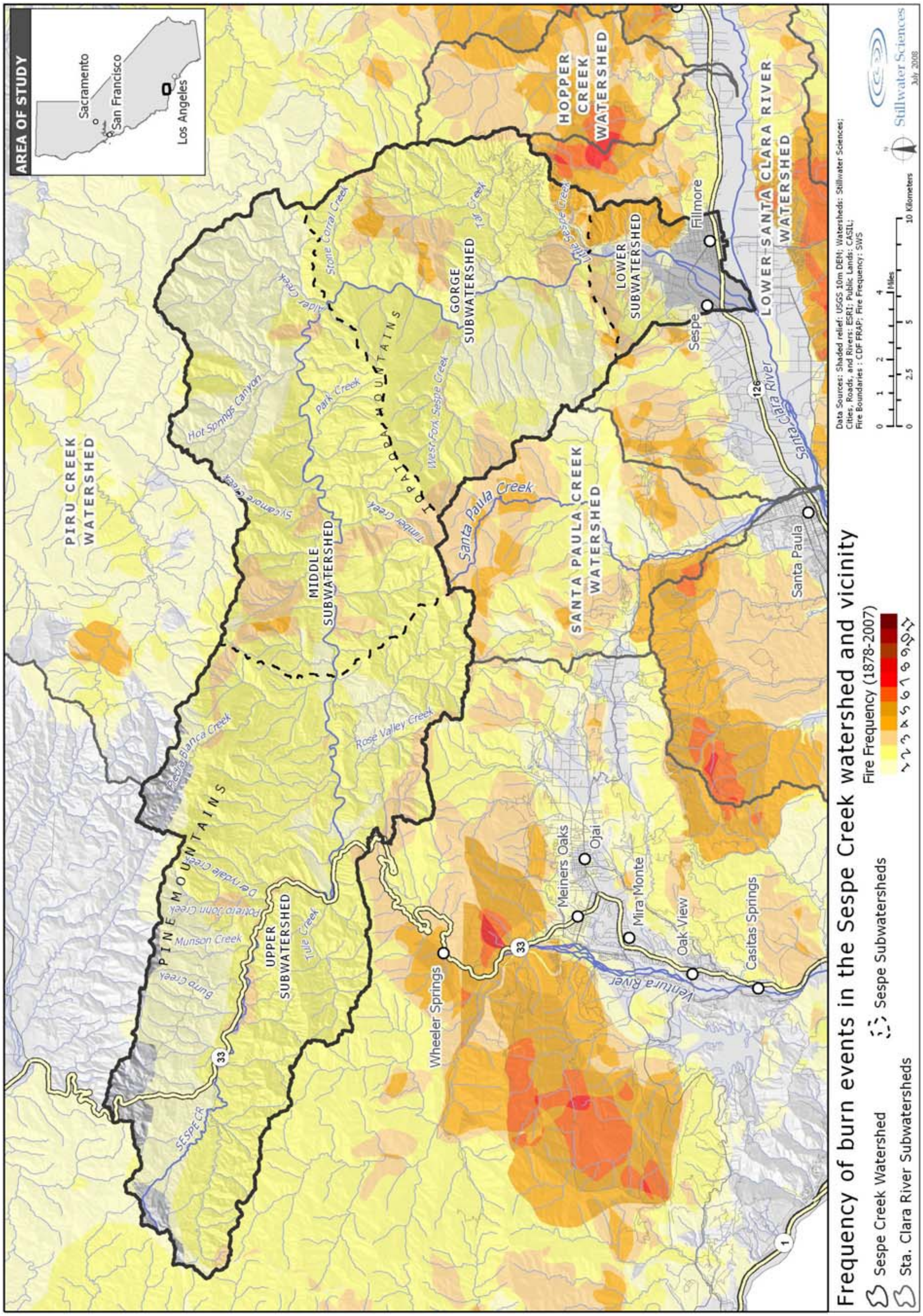


Figure 2-19. Frequency of burn events in the Sespe Creek watershed and vicinity (1878 - 2007).

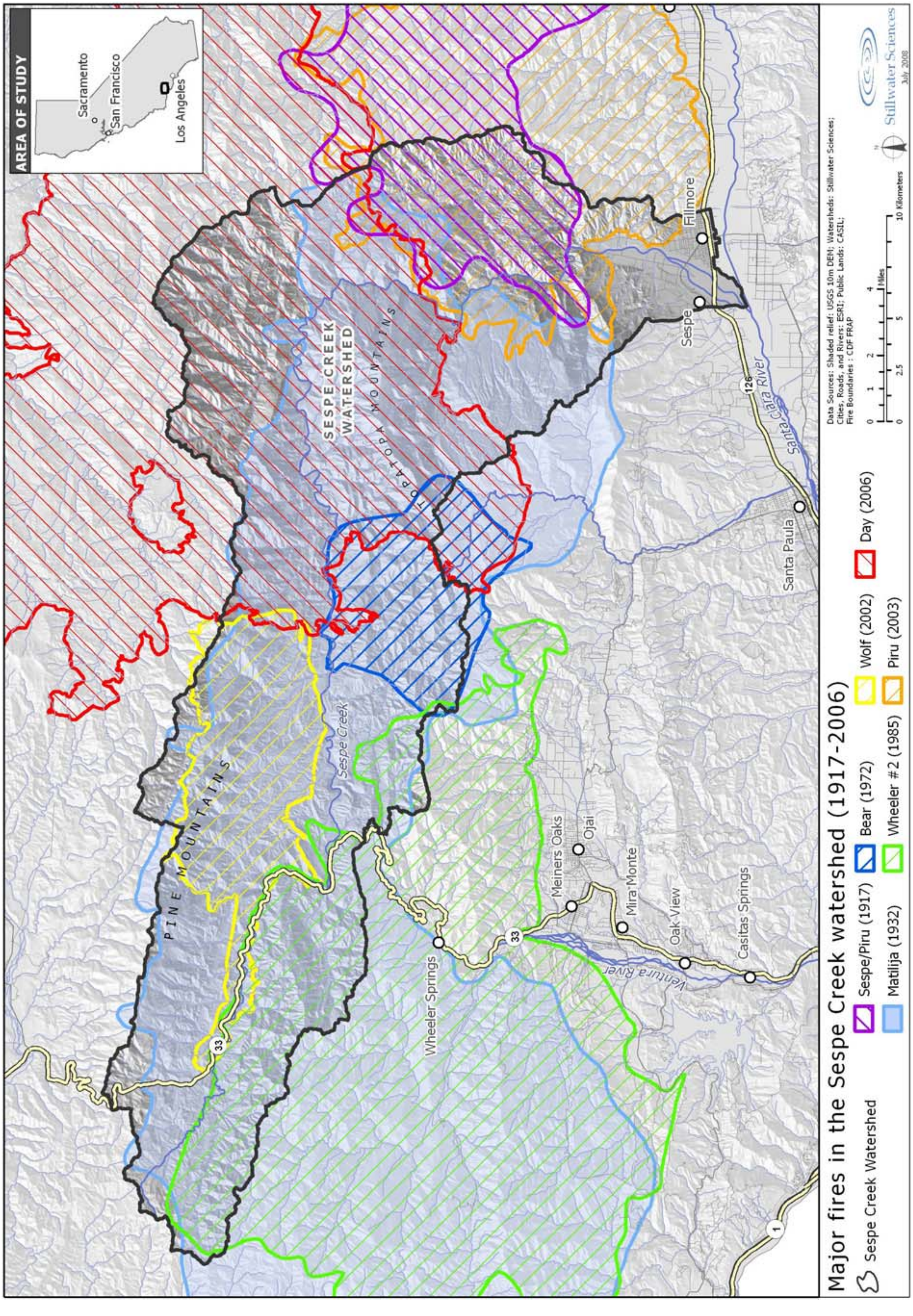


Figure 2-20. The seven largest fires in the Sespe Creek watershed (1915 - 2007).

The Matilija Fire (1932) is the largest fire recorded to date in the Sespe Creek watershed and the first major wildfire recorded in the watershed following large-scale watershed settlement by European-Americans. The Matilija Fire is the largest brushfire in Ventura County history and the third largest wildfire in California state history, causing no fatalities or structural loss but causing damages costing over $50 million (Levin 2002, CDF 2007). The fire burned approximately 220,000 acres in total throughout Santa Barbara and Ventura counties, encompassing most of the Los Padres National Forest and approximately 73% of the Sespe Creek watershed (Table 2-5 and Figure 2-20) (CDF 2004, CDF 2007, Levin 2002). Intense Santa Ana winds, higher than normal air temperatures, and very low humidity during the fire, in addition to regional drought conditions preceding the fire, were the key factors in promoting the severity and extent of the fire (Keeley and Zedler 2009). In the 23 months leading up to the Matilija Fire, the watershed was drier than the long-term average (as measured by the Palmer Drought Severity Index [PDSI]) (Keeley and Zedler 2009), resulting in very low soil moisture watershed-wide and large areas of desiccated, wilting, and dead vegetation. In the five years following the fire, daily mean flow at the City of Fillmore exceeded the instantaneous bankfull flow ($Q_{1.5\text{-year}}$ = 125 $m^3 s^{-1}$ [4,425 cfs] at USGS gauge 11113000) for a total of four days, suggesting that there were several post-fire storm events large enough to cause widespread erosion of burned surfaces and subsequent sediment transport to the mainstem channel.

The Wheeler #2 Fire (1985) was the next major fire in the Sespe Creek watershed after the Matilija Fire and the third largest Sespe Creek watershed fire recorded to date, burning approximately 14% of the total watershed area (Table 2-5 and Figure 2-20). The fire burned over 122,000 acres in total throughout Santa Barbara and Ventura counties in 14 days, with over 60% of the burn area characterized by high severity wildfires (Barro et al. 1988, Dunn 1989). In the end, the Wheeler # 2 Fire caused a loss of 26 structures and cost over $9 million to contain (Keeley and Zedler 2009, www.sb-outdoors.org/Interpretive/Wildfires/wheeler.php). Similar to the Matilija Fire, the severity and extent of the Wheeler #2 Fire was impacted by higher than normal air temperatures, very low humidity during the fire, and regional drought conditions preceding the fire (Keeley and Zedler 2009). Accelerated erosion rates and impacts to sediment yield dynamics associated with the Wheeler #2 Fire were documented in adjacent watersheds. For example, in a small upland catchment (~2 km^2) in the Matilija Creek watershed, Florsheim et al. (1991) showed that two post-fire storms that occurred seven months after the fire caused significant in-channel sediment deposition and aggradation (storm 1) followed by transport of the deposited sediment and a return to pre-burn channel elevation (storm 2).

The Piru Fire (2003) is the fourth largest fire in Sespe Creek to date, burning approximately 14% of the total watershed area (Table 2-5 and Figure 2-20). In total, the Piru Fire (2003) burned over 63,000 acres throughout the Piru, Hopper, and Sespe Creek watersheds, which included the Hopper Mountain Wildlife Refuge, Sespe Condor Sanctuary, and Sespe Wilderness (USFWS 2004, Cannon et al. 2008). The fire burned for 14 days, with approximately 30% of the area being characterized by high burn severity, and was responsible for the loss of 8 structures, costing over $6 million to contain (USFWS 2004). Higher than normal air temperatures, very low humidity, and the presence of Santa Ana winds caused the fire to grow in size over several days. Specifically, Santa Ana winds in the afternoon of the third day of the fire (10/25/03) fueled the fire significantly, causing it to spread west from the Piru Creek watershed to the Hopper Creek watershed (USFWS 2004).

Cannon et al. (2008) examined post-fire sediment delivery throughout the Piru Fire burn area during the winter following and developed a threshold for debris flow initiation as a function of rainfall intensity (I) and storm duration (D);

$I = 12.5D^{-0.4}$

where intensity is in mm/hour and duration is in hours. Above this threshold curve, post-fire debris flows were generated by the winter storms monitored. Conditions represented by the threshold line range from 4 mm over 10 minutes to 80 mm over 20 hours, which have recurrence intervals of less than one year and 2 years, respectively (Cannon et al. 2008, Bonnin et al. 2006).

After the Matilija Fire, the recent Day Fire (2006) is the next largest wildfire to date for both the Sespe Creek watershed and Ventura County, and it is the seventh largest wildfire on record for all of California (CDF 2007). The Day Fire burned 655 km^2 (161,791 acres) in total and 224 km^2 (55,247 acres) in the Sespe Creek watershed (33% of the watershed area), including large portions of the Sespe Wilderness and Sespe Condor Sanctuary (Table 2-5 and Figure 2-20). Included in this burned area was approximately 61 km^2 (15,000 acres) that had no previous fire history. Within the Sespe Creek watershed, fire severity for the Day Fire was primarily moderate (71% of burn area) and a small area (<1%) had a high fire severity (USFS 2006) (Figure 2-21). The Day Fire burned for 28 days, caused the loss of 11 structures, and cost over $70 million to contain (USFS 2006, CDF 2007). Similar to the Matilija and Wheeler #2 fires, intense Santa Ana winds, higher than normal air temperatures, and very low humidity during the fire, in addition to regional drought conditions preceding the fire, were the key factors in controlling the severity and extent of the fire (Keeley and Zedler 2009).

2.4.2 Impacts of Wildfire on Sediment Dynamics in Chaparral Environments

Wildfire can cause significant physical changes to watershed ground surfaces, thereby affecting geomorphic and hydrologic processes responsible for the production and delivery of sediment to adjacent channels. Impacts include both direct changes to the physical properties of rocks and soil, or changes to geomorphic and hydrologic process rates until pre-fire conditions are reestablished (Shakesby and Doerr 2006). These changes can reduce the infiltration rate by an order of magnitude, shift the dominant run-off process from subsurface storm flow to overland flow, and increase peak flows and sediment yield by more than 2 orders of magnitude (see Larsen and MacDonald 2007 and the citations therein). The primary changes to watershed ground surfaces induced by wildfires include removal of vegetation, alteration to soil physical and chemical structure, and changes to rates of bedrock and *in-situ* coarse sediment erosion. The specific geomorphic and hydrologic impacts associated with these wildfire-induced changes are described below.

Vegetation and Runoff

Removal of vegetation by wildfire increases overland flow and soil losses relative to undisturbed watersheds (see Shakesby and Doerr 2006 and the citations therein), and in general these changes tend to be directly related to fire severity, which is a function of fire duration and intensity (Prosser and Williams 1998). Vegetation removal can be important in post-fire hydrologic response as it temporarily reduces or stops transpiration, interception, and surface storage of precipitation, thereby increasing the relative percentage of post-fire precipitation that results in overland flow (Tiedemann et al. 1979, Loaiciga et al. 2001). Within chaparral environments, changes to vegetation cover from wildfire have been shown to increase the amount of post-fire overland flow by over 7 times the values on unburned hillslopes (Wells 1981), and vegetation re-growth 3 years after a wildfire has been shown to decrease overland flow by almost 80% of the value immediately after the fire (Cerda and Doerr 2005).

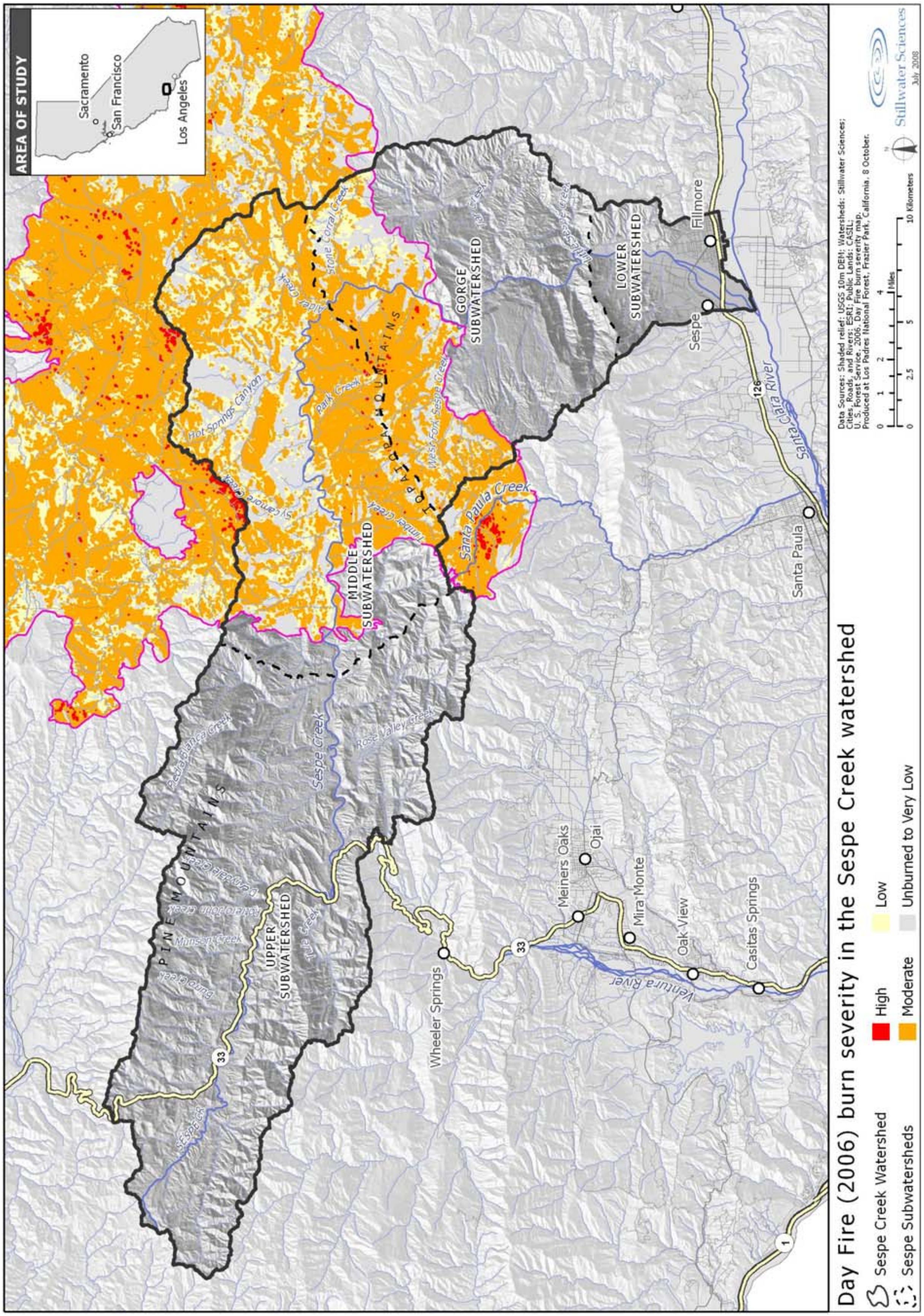


Figure 2-21. Day Fire burn severity based on the USFS (2006) Burned Area Emergency Response (BAER) report.

With respect to soil loss, fire-induced vegetation removal can cause both a loss of natural check dams of coarse organic material that act to store sediment on hillslopes, and an increase in the bare surface area available for erosion, thereby increasing the overall amount of post-fire sediment delivered to channels (Wells 1981). Fire-induced reduction in vegetation cover can also increase soil erosion by direct rainsplash, causing erosion by subsequent overland flow to occur more readily compared to pre-fire conditions (Shakesby and Doerr 2006). Terry and Shakesby (1993) have also shown that post-fire water repellent soils can remain non-cohesive during precipitation events, thereby making soil particles more easily detached by rainsplash. Many researchers consider the effects of rainsplash as the most important factor leading to increased post-fire soil erosion (Shakesby and Doerr 2006).

Soil Structure

Burning of soil during wildfires typically results in soil that is more friable, less cohesive, more water repellent, and more erodible (DeBano et al. 1998, Scott et al. 1998, Neary et al. 1999, Doerr et al. 2005). Fire-induced changes to the soil physical properties depend largely on soil type and the soil temperature reached during the fire (DeBano et al. 1998). Physical changes to the soil induced by wildfires include removal of the top organic litter layer and changes to the concentration of hydrophobic substances and to the particle size distribution (i.e., amount of sand, silt, and clay) of the soil. The differences in the amount of organic litter removed by fire can have a significant impact on the amount of precipitation that infiltrates. Copeland (1965) showed that for a litter cover of 60-75%, 98% of the simulated precipitation was infiltrated, whereas for a 10% litter cover, only 27% of precipitation was infiltrated. High temperatures also can cause hydrophobic organic substances in topsoil to become volatile and attach to soil particles in the soil subsurface, thereby making the subsurface soil more hydrophobic and causing the infiltration to decrease (Doerr et al. 2005). For example, fire-induced soil water repellency has been shown to increase overland flow by 1.5 to 3 times over values in un-burned areas (Prosser 1990). High temperatures associated with wildfires have also been shown to decrease the relative distribution of clay particles in a soil, thereby decreasing the soil cohesion and increasing the soil's erosion potential (Duriscoe and Wells 1981). Recent laboratory studies by Moody and Smith (2005) show that unburned cohesive forest soils can have critical shear stresses for erosion initiation that are over five times greater than those for the same soils rendered non-cohesive by wildfire. These studies have also shown a similarity in the temperature thresholds for changes to soil water repellency and the critical shear stress for soil erosion initiation, suggesting an inherent link between the two soil properties (Moody and Smith 2005).

Rock weathering

Fire effects on rock erosion rates are primarily a function of fire temperature and rock physical properties, which include lithology, surface area, and water content, and are manifested through two dominant processes: spalling (detachment of lensoid-shaped fragments up to 3 cm in length) and actual rock fracture. In general, fire temperature and rock properties act to decrease the rock strength, thereby making the rock more susceptible to subsequent erosion. A laboratory analysis by Goudie et al. (1992) showed that igneous rocks have a relatively larger decrease in rock strength associated with increasing temperature than sedimentary rocks, and at temperatures indicative of chaparral wildfires (685°C, as reported in Wright and Bailey 1982), the granite tested had an 80-90% decrease in rock strength, where as the sandstone tested had only a 20% decrease in rock strength. Specifically, spalling associated with wildfires can result in the erosion of several centimeters from a rock surface (Dorn 2003) and has been shown to be influenced strongly by lithologic characteristics. For instance, Ballais and Bose (1994) noted post-fire spalling on sedimentary rock (limestones and sandstones), but observed no post-fire spalling on metamorphics (gneisses and schists). Rock fracture of large boulders on hillslopes following wildfires has been shown to be an important agent in creating smaller, more mobile clasts. In those arid and semi-arid environments where chemical weathering of rock surfaces can be slow and depth-limited, it has been suggested to be a key mechanism for landscape evolution (Dragovich 1993, Dorn 2003).

2.4.3 Impacts on Rates of Sediment Production and Delivery

Dozens of studies have been made of the changes in runoff and sediment yield following fire, most recently compiled by Shakesby and Doerr (2006). Most of the work has been concentrated in semi-arid regions of the world with vegetative and climatic characteristics similar to southern California, and so many of the results have broad applicability to the Sespe Creek watershed. From local studies, De Koff et al. (2006) measured a 6.6-fold increase in sediment yield from a prescribed burn in chaparral-covered southern California; Wells (1981) documented up to ten- to hundred-fold increases in sediment transport rates in woodlands of the San Gabriel Mountains. Other short-term increases in erosion rates following wildfires in chaparral-dominated southern California watersheds include factors of as much as 18-fold (Wohlgemuth 2003) to 35-fold times (Rowe et al. 1954) over long-term pre-fire values. Most of these increases can be attributed to increases in dry raveling rates, both during and immediately after fires, and increases in sediment delivery along post-fire rills (Wells et al. 1987; Wells 1987).

Most reported studies, however, cannot calculate the proportional increase in sediment production because they have limited or no data on pre-fire sediment rates (but well-measured post-fire rates). The compilation of Shakesby and Doerr (2006, their Table 3) lists 25 separate first-year post-fire erosion measurements for watersheds ranging in size from <0.001 km^2 to >5 km^2. Erosion rates reported by Shakesby and Doerr (2006) range between 0 – 41,400 t km^{-2} and have a median value of about 6,000 t km^{-2}. The lone San Gabriel Mountain study reported in this compilation (from Krammes and Osborne 1969) measured 19,700 t km^{-2} for 3 plots having a combined area less than 10^{-4} km^2.

Reported rates tend to decline rapidly following the first year of post-fire rains, which leads to a so-called ‘window of disturbance’ (Prosser and Williams 1998) that begins immediately after a wildfire and can vary in length from several seconds to a decade, depending on fire and watershed characteristics (Figure 2-22). For instance, Doerr et al. (2000) showed that wildfire can affect soil infiltration characteristics and sediment production and delivery dynamics for periods ranging up to several months, depending on fire duration and intensity. Other research has shown that the overall cumulative impact of fire on sediment production and delivery dynamics can be on the order of years, with impact durations ranging from 2–4 years (Wohlgemuth et al. 1998) to up to 10 years after the fire (LACFCD 1959, USFS 1997). One study that specifically assessed coarse sediment production separately found elevated rates for at least five years following a burn (Reneau et al. 2007). The 5 years following a fire has been suggested to be the most critical for fire-induced sediment production (Lave and Burbank 2004). Because of very high rates immediately post-fire, however, wildfire still may account for 50 % (Davis et al. 1989) to 80% (Lave and Burbank 2004) of the total observed sediment production and subsequent delivery within chaparral-dominated southern California watersheds.

Fire changes the mechanisms and rates of both sediment production and sediment delivery, as well as the relative importance of the various factors that can influence the magnitude and duration of the effects of fire on sediment dynamics. Dominant post-fire sediment production processes within southern California chaparral watersheds include dry ravel (i.e., downslope movement of sediment by gravity), rilling (i.e., erosion of gullies that delivery water and sediment to larger channels), and debris flows. The post-fire sediment delivery process within these types of watersheds is dominated by debris flows at smaller scales and fluvial transport at larger scales. The primary factors affecting fire-induced increases to sediment production, in addition to inherent watershed characteristics, include wildfire burn intensity and severity. Factors affecting fire-induced increases to sediment delivery include an increased sediment production as well as post-fire precipitation dynamics. The fire-induced changes to the dominant mechanisms and rates of sediment production and delivery directly after a fire, and the primary factors affecting these changes, are detailed below.

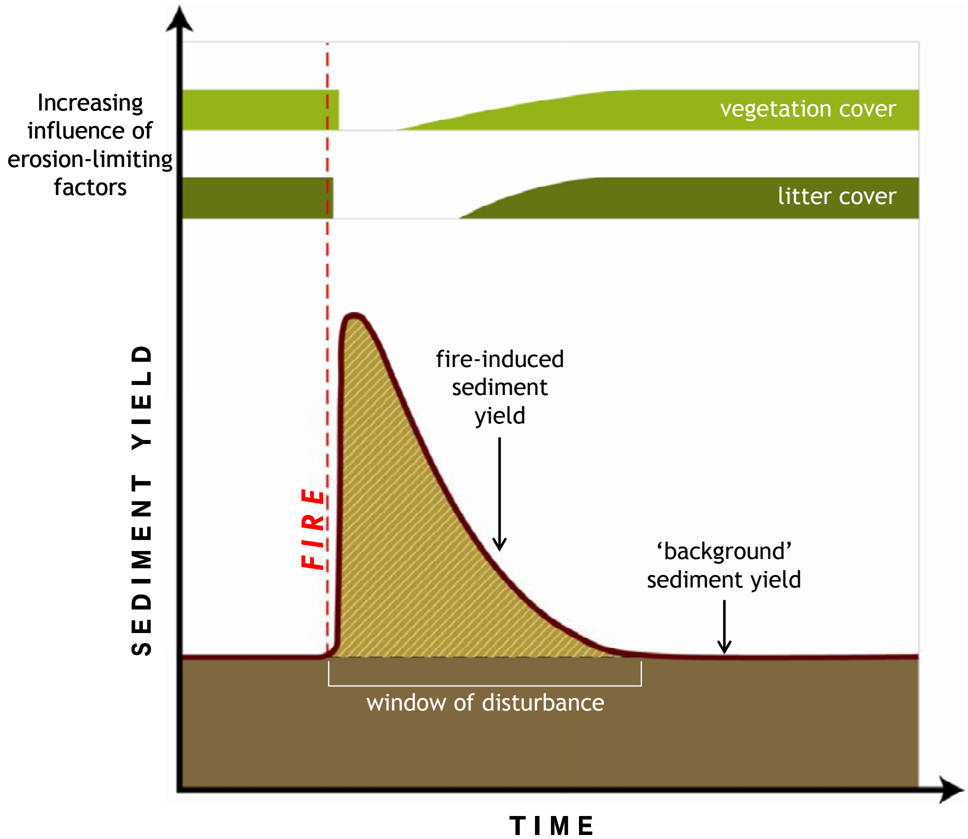


Figure 2-22. Conceptualization of sediment yield and associated vegetation and litter recovery during the fire-induced "window of disturbance" (based on Shakesby and Doerr 2006).

2.4.3.1 Mechanisms of post-fire sediment production and delivery

Within chaparral-dominated watersheds, wildfire can cause a shift in the relative importance of the few dominant sediment-production mechanisms that occur in this type of environment. In the absence of wildfire, the dominant erosion processes are dry ravel and shallow landsliding (Rice 1982, Florsheim et al. 1991). On steep, chaparral hillslopes, dry ravel can account for over half of the hillslope sediment production (Krammes 1965, Rice 1974, DeBano et al. 1979, Robichaud et al. 2000). During and directly following wildfires in chaparral watersheds, but before the first post-fire rainfall occurs, sediment production is dominated by a pulse of dry ravel as granular sediment stored behind organic barriers (e.g., stems, downed branches, organic litter) is liberated when these barriers are incinerated (Wohlgemuth, pers. comm. 2008). Precipitation falling upon the burned surfaces leads to increased occurrences of rill erosion induced by concentrated overland flow. Over time, shallow landsliding may occur several years after a fire with the decay of roots of fire-killed plants and the loss of cohesion and shear strength (Wohlgemuth, pers. comm. 2008). Dry ravel, which occurs more readily on steep, south-facing slopes with less vegetation, has been shown to constitute 90% of in-channel gravel deposited during the first post-fire storm (Florsheim et al. 1991). Dry ravel rates following wildfire have been shown to increase by 1 (Krammes 1960, Rice 1982) to 2 orders of magnitude (Wells 1987) over the pre-fire values in chaparral-dominated southern California watersheds. As an example, Davis et al. (1989) measured post-fire dry ravel to be approximately 35,000 $m^3\ km^{-2}\ a^{-1}$ (or 17,500 $t\ km^{-2}\ a^{-1}$ assuming a bulk density of 2,000 $kg\ m^{-3}$) in the Matilija Creek watershed (Ventura County), well over 300 times the background rate given by Rice (1982) for a similar chaparral watershed in the region. Increased overland flow due to changes in soil infiltration dynamics (i.e., increased water repellence) and changes in vegetation coverage can lead to flow concentration and rill development (Wells 1987). The development of post-fire rill networks is related to the scouring effect of small-scale debris flows during precipitation events (Wells 1981, Gabet 2003). The depth of post-fire rill networks is hypothesized to be self-limited, as un-burnt soils at depth should cause overland flow to infiltrate (Shakesby and Doerr 2006).

The changes to sediment production mechanisms following wildfires in chaparral watershed cause an associated change in the primary method of sediment delivery. At larger watershed scales (>>1 km^2), fluvial transport of hillslope-derived sediment is the primary mode of in-channel sediment delivery for pre- and post-fire conditions in chaparral-dominated, southern California watersheds (e.g., Davis et al. 1989, Florsheim et al. 1991). At smaller watershed scales, several studies have shown sediment delivery by debris flow to be the dominant post-fire sediment delivery process within chaparral environments (Wells 1987, Weirich 1989, Cannon et al. 2001, Cannon et al. 2008). Debris flows occur through a process called 'progressive sediment bulking,' where sediment entrainment begins with run-off generation at higher elevations, which then converges and concentrates in hollows and low-order channels (Meyer and Wells 1997). Once within channels, debris flows can begin to entrain and transport coarse sediment. Hillslope sediment input from increased post-fire dry ravel and rilling are important to the bulking process leading to debris flows (Parrett 1987, Meyer and Wells 1997). Post-fire debris flows occur primarily within areas underlain by sedimentary rocks, with debris flow occurrence having a positive correlation with relief ratio and a negative correlation with basin area (Wells et al. 1987)

2.4.3.2 Factors Affecting Fire-induced Impacts to Sediment Production and Delivery

Wildfire burn severity can have profound effects on the fire-induced impacts to sediment production and delivery dynamics. Wildfire burn severity is primarily a function of three elements: fuel conditions, weather conditions during the fire, and antecedent soil and vegetation moisture conditions. Wohlgemuth et al. (1999) observed that wildfire-induced erosion from areas previously unburned for decades were 10 times greater than erosion from areas that had been burned within the previous 5 years. These differences were attributed to high fuel availability in the unburned areas leading to greater fire severity, more site alteration (e.g., litter consumption, soil structure changes), and subsequent higher erosion rates. A similar study showed that lower fire severity associated with a controlled burn caused post-fire erosion rates for the same area to be 25% to 50% of the post-fire erosion rate associated with a high severity wildfire (Wohlgemuth 2003). In addition to precipitation and humidity effects, wind conditions, and in particular the regional Santa Ana winds, during wildfire can have significant effect on fueling wildfires and increasing fire intensity and severity. The Santa Ana winds typically blow south-southwesterly from inland deserts during the height of fire season in southern California (August through November) when highly flammable chaparral vegetation is at its driest. These winds are controlled by large-scale synoptic pressure patterns, yet their intensity can very localized due to topographic effects (Keeley and Fotheringham 2001), making prediction of their behavior very difficult. The combination of recent precipitation events prior to the start of a wildfire and relative humidity during a wildfire control background moisture conditions and therefore play a strong role in determining the fire's intensity and severity.

In conjunction with the impacts of wildfire to watershed physical characteristics, post-fire precipitation also plays a crucial role in determining the effect of wildfire on sediment delivery dynamics. For Sespe Creek, unit discharge (i.e., discharge per unit watershed area) one year after a fire has been suggested to increase by a factor of 4 for a 1-year storm event and by a factor of 2 for a 100-year storm event (USFS 1997). With regards to mechanisms of sediment delivery, post-fire sediment delivery by debris flows in chaparral-dominated watersheds occurs during relatively small post-fire storms, not necessarily requiring a long period of antecedent rainfall, and previous studies have shown that post-fire sediment delivery in this environment is more correlated with storm intensity than other precipitation variables (Wells 1987). A recent study of post-fire debris flows in southern California by Cannon et al. (2008) showed that post-fire debris flows were generated with as little as two hours, and up to 16 hours, of low-intensity rainfall (2-10 mm/hr). A study conducted by the Los Angeles County Flood Control District (LACFCD 1959) determined sediment delivery as a function of storm intensity, watershed relief index, and vegetation re-growth (no growth directly after the fire and almost complete re-growth a decade after the fire) (Figure 2-23). The results from the LACFCD (1959) study show that an increase in post-fire storm intensity by a factor of 2 results in an increase in post-fire sediment delivery by approximately 49 times the pre-fire rate directly after the fire, approximately 20 times the pre-fire rate 1 year after the fire, approximately 4.5 times the pre-fire rate 5 years after the fire, and approximately 3 times the pre-burn rate 10 years after the fire.

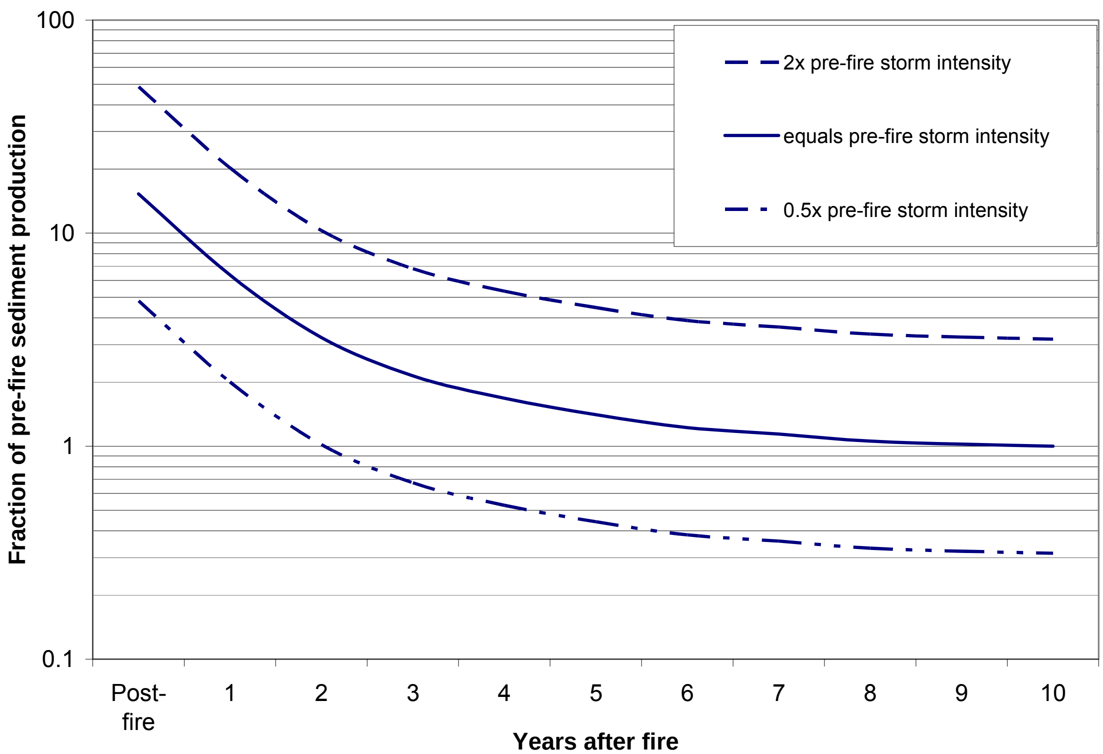


Figure 2-23. Fire effects on sediment production in Los Angeles County debris basins as a function of storm intensity and time since burn (LACFCD 1959, as given in Lave and Burbank 2003).

2.4.4 Estimates of fire-induced sediment delivery increases

The complexity of hillslope and vegetation changes as a result of fire, the stochastic interplay of burn areas and intense rainstorms in the several years immediately following of a fire, and the variety of field-measured factors raise cautionary notes for any attempts to predict quantitative increases in sediment production as a result of recent fires in the Sespe Creek watershed. These published results, however, in combination with our analysis of geomorphic landscape units across the watershed, offer order-of-magnitude constraints on the range of likely consequences to sediment yield in the watershed.

2.4.4.1 Analysis Using BAER Method

Sediment yield in the Sespe Creek watershed following the Day Fire was determined as part of the United States Forest Service Burned Area Emergency Response (BAER) assessment (USFS 2006). The Day Fire BAER assessment used the methodology detailed in Rowe et al. (1949) to predict the cumulative effect of Wolf Fire (2002), Piru Fire (2003), and Day Fire (2006) on annual erosion rates and sediment delivery for the period directly following the Day Fire. Rowe et al. (1949) used sedimentation records from debris basins in Los Angeles County to determine the relationship between peak flow and sediment delivery for the individual unburned debris basins for a wide variety of flow conditions. These data were then compared to a 10-year record of post-fire sediment delivery data for similar watersheds that had burned, and relationships between peak flow and sediment delivery were adjusted to account for the effect of fire. These relationships were then used in the BAER assessment to predict the pre-Wolf Fire and post-Day Fire normalized annual sediment yield (sediment volume per contributing watershed area) for Sespe Creek near the mouth at the City of Fillmore.

The BAER assessment concluded that the suite fires that occurred in the Sespe Creek watershed between 2002 and 2006 resulted in a 6-fold increase in annual watershed normalized sediment delivery, with most of post-fire sediment coming from two tributary watersheds burned in the Day Fire (USFS 2006). At the watershed-scale the BAER assessment calculated an increase in Sespe Creek watershed sediment delivery from 2,817 yd^3 mi^{-2} a^{-1} (1,663 t km^{-2} a^{-1}) to 17,257 yd^3 mi^{-2} a^{-1} (10,188 t km^{-2} a^{-1}) as a result of the Wolf, Piru, and Day fires. The analysis also showed that annual sediment yield from Hot Springs Canyon (63% burned in the Day Fire) increased by a factor of ~20, and annual sediment yield from West Fork Sespe Creek (90% burned in the Day Fire) increased by a factor of ~70 as a result of these fires. Approximately 98% of the total Day Fire footprint in the Sespe Creek watershed was in these two tributary watersheds (51% of the fire area in Hot Springs Canyon and 47% of the fire area in West Fork Sespe Creek), and the sediment yield calculated for these two tributaries alone accounts for approximately 85% of the total post-fire watershed sediment yield.

2.4.4.2 Analysis Using Geomorphic Landscape Units

A simplified approach that provides a snapshot of average annual increases, and that identifies those parts of the landscape that are the most likely contributors of increased sediment load, can be accomplished by changing our GIS representation of land cover across the watershed to bare ground. Changes in land cover, in turn, will change the unit-area contribution of sediment to the channel network. This can be simulated by changing each land-cover category in the GLU analysis to rating appropriate for a minimal level of vegetation cover (Table 2-6). The greatest increases in sediment delivery will occur in those GLUs shaded on the table the increase to "High," of which those in the "Scrub" are most common in the watershed.

Table 2.6. Categories of relative rates of sediment production assigned for the post-fire scenario.

Geomorphic landscape unit	Original sediment-production rating*	Fire scenario sediment-production rating
Sandstone Ag/grass/bare 0–20%	Low	Low
Sandstone Ag/grass/bare 20–60%	High	High
Sandstone Ag/grass/bare >60%	High	High
Sandstone Developed 0–20%	Medium	Medium
Sandstone Developed 20–60%	Medium	Medium
Sandstone Developed >60%	Medium	Medium
Sandstone Forest 0–20%	Low	Low
Sandstone Forest 20–60%	Low	High
Sandstone Forest >60%	Low	High
Sandstone Misc. 0–20%	Medium	Medium
Sandstone Misc. 20–60%	Medium	High
Sandstone Misc. >60%	Medium	High
Sandstone Scrub 0–20%	Low	Low
Sandstone Scrub 20–60%	Medium	High
Sandstone Scrub >60%	Medium	High
Shale Ag/grass/bare 0–20%	Low	Medium
Shale Ag/grass/bare 20–60%	High	High
Shale Ag/grass/bare >60%	High	High
Shale Developed 0–20%	Medium	Medium
Shale Developed 20–60%	Medium	High
Shale Forest 0–20%	Low	Medium
Shale Forest 20–60%	Low	High
Shale Forest >60%	Low	High
Shale Misc. 0–20%	Medium	Medium
Shale Misc. 20–60%	Medium	High
Shale Misc. >60%	Medium	High
Shale Scrub 0–20%	Medium	Medium
Shale Scrub 20–60%	Medium	High
Shale Scrub >60%	Medium	High

* Values reproduced from Table 2-2.
NOTE: Shaded categories are those altered between the two scenarios.

The order-of-magnitude increase in sediment production from the Day Fire can be readily inferred from the area of the watershed burned (33%) and the maximum rate of sediment delivery predicted by the GLU approach (i.e., 20,000 t km^{-2} a^{-1} if the entire area became a "high" sediment source area). Such a change would contribute an additional 6,000 t km^{-2} a^{-1} when averaged over the watershed area as a whole, suggesting as much as a five-fold increase in the total sediment yield relative to the unburned prediction.

Based on the analysis using the categories of Table 2-6, the actual predicted increase in sediment yield from the Day Fire is shown graphically in Figure 2-24 and summarized in Table 2-7.

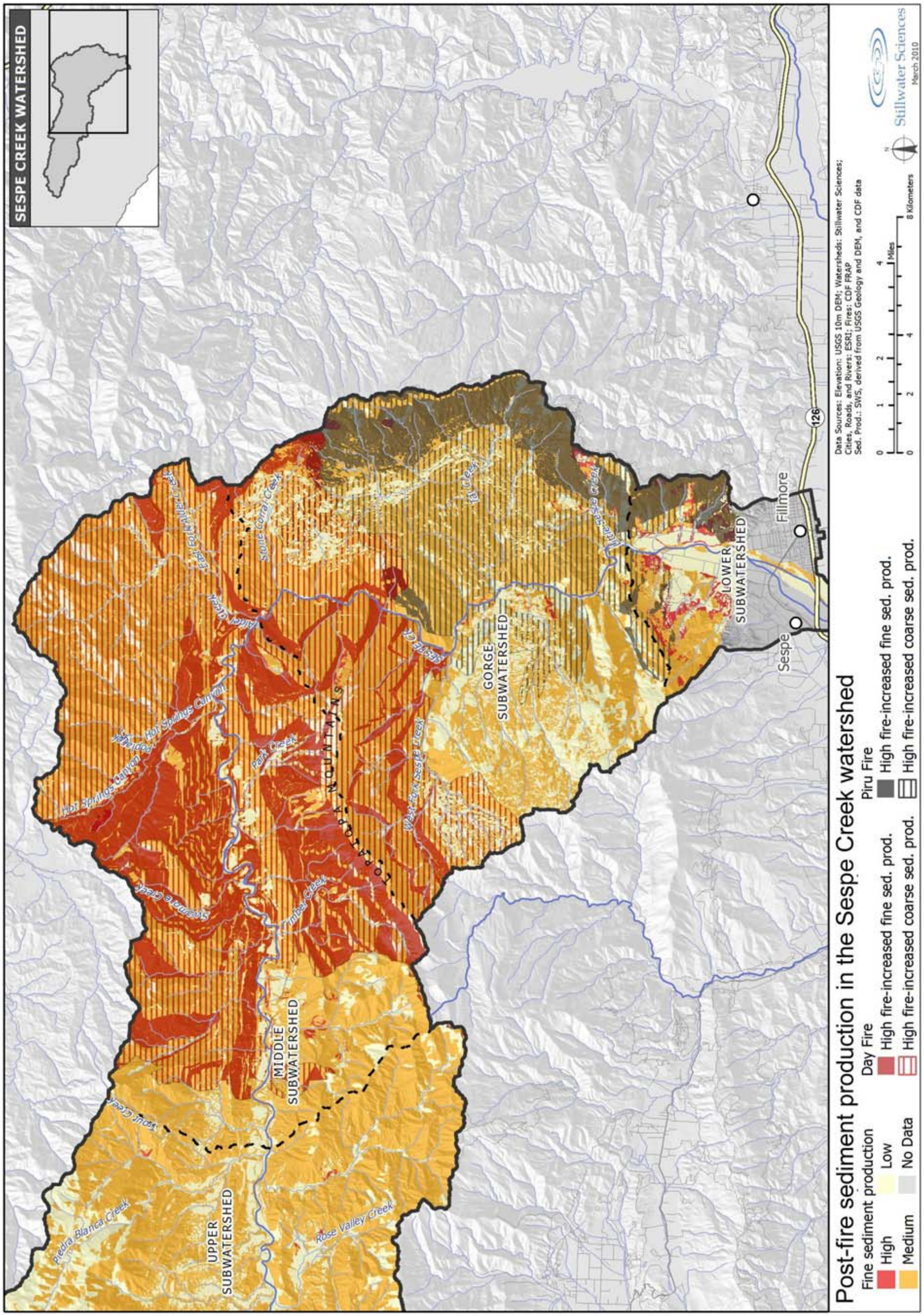


Figure 2-24. Predicted fine-sediment production for pre-fire and post-fire (Day and Piru fires) scenarios in the Sespe Creek watershed.

Table 2.7. Predicted increase in sediment yield from the Day Fire.

Scenario	"High" rating	"Medium" rating	"Low" rating	Totals
PRE-FIRE				
Area (km^2)	1	223	35	
Sediment production ($t\ a^{-1}$)	22,229	445,729	10,611	**478,569**
Total ($t\ km^2\ a^{-1}$):				**1,845**
POST-FIRE *				
Area (km^2)	238	5	16	
Sediment production ($t\ a^{-1}$)	4,765,791	10,702	4,711	**4,781,204**
Total ($t\ km^2\ a^{-1}$):				**18,436**

* See Figure 2-24.

This GLU analysis of Day Fire effects shows a 10-fold change between the pre- and post-fire scenarios over the Day Fire area based on a difference of about 4.3 million tonnes. This additional sediment contribution raises the overall sediment yield of the Sespe Creek watershed by an additional 5,500 t km^2 a^{-1} (from 1,760 to about 7,200 t km^2 a^{-1}, a four-fold increase), when averaged across the watershed area as a whole. The increase in post-fire annual watershed sediment delivery derived from this analysis is thus rather similar to the 6-fold increase in sediment yield predicted by the BAER assessment of the Day Fire impacts.

The GLU analysis, however, carries a cautionary note for any prediction of post-fire erosion. Published literature, and common sense, indicates that the stochastic interplay of summertime burns and subsequent rains will determine the actual consequence of a given fire on the sediment loads. After just a single year the magnitude of sediment-production increases should substantially decline; and after no more than a few years the effect may be nearly indiscernible from background levels. As vegetation regrows, rates would return to values more typical of the long-term averages predicted by the GLU analysis.

2.4.4.3 Impact of fire on storm sediment yields

Insofar as sediment delivery in the Sespe Creek watershed is event-driven (i.e., most sediment is delivered over short time periods by intense storms), the sediment yield during high-magnitude, infrequent storm events can be as important as assessing average annual sediment delivery for understanding sediment transport dynamics, geomorphic evolution, and the response of engineered structures. Following the 1969 flood events in southern California, Scott and Williams (1978) analyzed the storm-induced sediment yield for Transverse Range watersheds in Los Angeles and Ventura County (which included drainages in and adjacent to the Sespe Creek watershed). We revisited this analysis to assess the magnitude of sediment delivery that could be expected in the Sespe Creek watershed during such a significant storm event.

The equation devised by Scott and Williams (1978) for calculating sediment yield for the 1969 flood event (>50-yr return) was derived from multiple regression analysis of watershed characteristics, storm conditions, and measured sediment accumulation in debris basins with contributing watershed areas between 0.2 and 2.7 km^2 (i.e., very much smaller than the scale of fires that have occurred here). Their equation for predicting the sediment delivered in the 1969 storm event, calibrated on data from the region including the Sespe Creek watershed, is:

$$\log Sy = 1.244 + 0.828(\log A) + 1.382(\log ER) + 0.375(\log SF) + 0.251(\log FF) + 0.840(\log K)$$

where Sy = sediment yield (yd^3),
A = drainage area (mi^2),
ER = watershed elongation ratio (ratio of the diameter of a circle, having an area equal to the watershed area, to the maximum watershed length parallel to the channel),
SF = area of slope failures ($acres/mi^2$),
FF = a fire factor (product of the area of land not revegetated since the last major fire and the percent of the watershed burned), and
K = a storm factor (measure of antecedent soil moisture conditions and the peak intensity of the storm).

This equation invites an alternative approach to predicting the influence of fire, based on their calibration data set. The "FF" term influences the final result by approximately the one-quarter root of its value (i.e., $FF^{0.251}$). Thus, a 10,000-fold increase in this factor would increase the total predicted sediment yield ten-fold, which approximates the order-of-magnitude change in the sediment production reported from recently and fully burned watersheds (including those reported in Scott and Williams 1978). However, the FF term in this equation only varies between 1 and 100, permitting at most a 3-fold increase in rates as predicted by this equation. This highlights one of the serious shortcomings of regression equations—conditions of interest (e.g., a large watershed burn) that require extrapolation from the actual conditions used to calibrate the equation are likely to yield results that have little physical meaning or applicability.

2.4.4.4 Implications for sediment transport to the Lower subwatershed reaches of Sespe Creek

The preceding analyses suggest that the Day Fire has had a large effect on sediment production rates in the Middle subwatershed region of Sespe Creek. Rates of production may have increased by an order of magnitude, if not more, and overall rates of delivery are predicted to have increased in the range of 3- to 6- fold. However, the experimental research from which these estimates have been derived is limited to studies at the scale of hillslope plots or small watersheds (frequently debris basins), in which it is feasible to make an overall volumetric estimate of sediment delivery. Very rarely does the area of study extend beyond 10 km^2, and frequently they are at areas of 0.1 km^2 or less.

In comparison, the Sespe Creek watershed is 674 km^2, a size at which numerous opportunities exist for wildfire-derived sediment to be transferred into short-term storage rather than be delivered directly to the lower reaches of Sespe Creek between the gorge and the Santa Clara River. Even for the small watersheds that characterize the data set of Scott and Williams (1978) (no more than 2.7 km^2), their resulting regression equation indicates the dampening effect of increasing area—sediment yield increases with area, but at a rate less than unity (i.e., $A^{0.828}$). As such, sediment delivery becomes increasingly a function of fluvial sediment transport processes in progressively larger contributing areas, and so transport through the channel network will depend more on overall flood magnitude than on local storm intensity (or other factors that can dominate locally). Thus, not all the sediment eroded from hillslopes as a result of wildfire will be transported to the lower reaches of Sespe Creek, and fluvial sediment transport processes will act to meter out the delivery to some degree.

In addition, the dynamics of large pulses of sediment will be very different, depending on the size of the sediment (Lisle et al. 2001). Fine sediment pulses travel as an attenuating and translating wave (similar to a flood wave), whereas coarse sediment disperses *in situ*, progressively fanning out from its point of entry into the mainstem channel. The implication is for further buffering of the lower reaches of Sespe Creek from the full sediment impacts of the wildfire: a large fraction of very fine (<0.0625 mm) sediment will travel rapidly through the lower reaches into the Santa Clara River as washload or fine suspended load, while the coarse sediment load will have a longer-lasting but more subtle effect on bed elevations. The primary impact on bed elevations may relate strongly to the fraction of wildfire-derived sediment that is sand (i.e., fine enough to travel as a wave, but coarse enough to settle on the bed of the lower reaches). Field observations of both hillslope sediments and in-channel deposits suggest that this size fraction is quite abundant in the fire-derived sediments throughout the channel network (see Section 2.5.2).

It is possible to model the fluvial transport of a pulsed sediment supply (Cui and Parker 2005), including differentiating the transport characteristics of sand versus a mix of gravels and cobbles (Wilcock and Crowe 2003). These models were developed originally to simulate the impact of landslides into rivers (Cui et al. 2003 a, b) and were adapted for use in simulating dam removal effects on sediment transport (Cui et al. 2006a, b). Within the Sespe Creek watershed, this type of modeling approach could provide a very effective way of determining the temporal and spatial dynamics of bed elevation change in the Lower subwatershed reaches of Sespe Creek as the fire-induced sediment from the upper watersheds is delivered during storm events over the next several years.

2.5 Sespe Creek Morphology and Sediment Character

Throughout its course through the watershed, Sespe Creek generally follows a moderately sinuous route with a moderate gradient (1.5%) through various geomorphically-distinct reaches. The reach types range from unconfined, alluvial reaches composed of material previously transported by the channel and with some degree hydrological connectivity with their neighboring floodplain, to bedrock-confined gorges in which the bed and banks are composed of bedrock with at most a thin alluvial deposit. Sediment stored within a confined reach is wholly limited to the channel bed and at tributary confluences, where present.

To characterize and better understand current channel geomorphic conditions at the watershed scale, the following information and discussion is summarized for each distinct subwatershed, as previously identified in Section 1.2 and shown in Figure 1-2. The subwatersheds have been further differentiated into morphologically similar channel reaches to better characterize the channel conditions (Figure 2-25). Our analysis of contemporary channel morphology draws upon information assembled from a literature review, air photo analysis, GIS analysis, and field observations and collected data (spring 2008).

Summary information in Table 2-8 indicates that reaches of the subwatersheds to have variable, but consistently low to moderate channel gradients ranging from an average 0.8 % throughout the Lower subwatershed (i.e., alluvial fan and channel mouth) up to 2.4% in the confined Lower Gorge reach. A long-profile of the entire length of Sespe Creek is shown on Figure 2-26. Based on field observations and consistent with previous studies (Gutowski 1978, Dvorsky 2000), there are no significant slope breaks in the form of head-cuts or waterfalls present on Sespe Creek, but they are present along several tributaries (e.g., Lion Canyon and Alder creeks). The channel bed is generally organized into a plane-bed morphology throughout, with some pool-riffle structure present in the gorge reaches. Channel widths are a function of the degree of valley confinement, and the average values in the Upper, Middle, and Gorge subwatershed reaches range between 31 and 55 m. Once entering the Santa Clara River valley, the average channel width in reaches of the Lower subwatershed is considerably larger than the average channel widths of the upstream reaches (by up to a factor of seven). Channel bed substrate is dominated by coarse gravel deposits with exposed bedrock within confined channel areas. The channel bed in the Lower Gorge reach is significantly coarser than the other reaches and is dominated by coarse cobble deposits, with large boulders and exposed bedrock. Sediment stored at the mouths of tributaries is generally finer in the upstream reaches (e.g., Derrydale and Lion Canyon Creeks) and coarser in the downstream reaches (e.g., Alder and West Fork Sespe creeks).

Specific details pertaining to the geomorphic characteristics of each reach is provided below. The locations of the subwatersheds and stream reaches are shown in Figure 2-25. The longitudinal profile of Sespe Creek is shown in Figure 2-26.

Table 2-8. Sespe Creek channel characteristics by subwatershed reaches.

Sub-watershed	Type	Reaches	Length (km)	Channel gradient [A]	Average channel width (m) [B]	Facies distribution (% of reach channel area) [C]	Dominant facies type distribution (% of reach channel area) [C]
Upper	Alluvial/ Confined	Headwater Wash, Upper Gorge, Upper Terrace	42.7	1.7%	31	CG (>50%) CSG (<50%)	G (>50%)
Middle	Alluvial	Middle Terrace, Granitics	27.0	1.0%	55	CSG (33%) S (15%) GS (6%)	G (58%) S (27%) C (15%)
Gorge	Confined	Lower Gorge	19.1	2.4%	45	BGC (>50%) SGC (<50%)	C (>50%)
Lower	Alluvial	Valley, Fillmore	8.3	0.8%	224	CSG (>50%)	G (>50%)

[A] Slope from 10-meter resolution DEM. See Figure 2-26 for long-profile of Sespe Creek.
[B] Width measured every 1 km (2005 aerial photograph) for Upper, Middle, and Lower Gorge reaches. Width measured every 0.9 km at regularly spaced cross-sections for Lower reach (2005 aerial photograph, 2005 LiDAR).
[C] Facies data for Upper and Lower Gorge reaches compiled from rapid visual assessment and select facies mapping at tributary confluences. Facies data for Middle reach compiled from rapid visual assessment and longitudinal facies mapping throughout reach. Facies data for Lower reach compiled from channel facies mapping and particle size distribution data of bed substrate, including sediment size analysis data from LADPW (2008). CG = cobbly-gravel [gravel dominates], CSG = cobbly-sandy-gravel, S = sand, GS = gravelly-sand, BGC = boulder-gravelly-cobble, SGC = sandy-gravelly-cobble, G = gravel, C = cobble. See Buffington and Montgomery (1999) for more detail. See Appendix A for facies maps and sediment size distribution data.

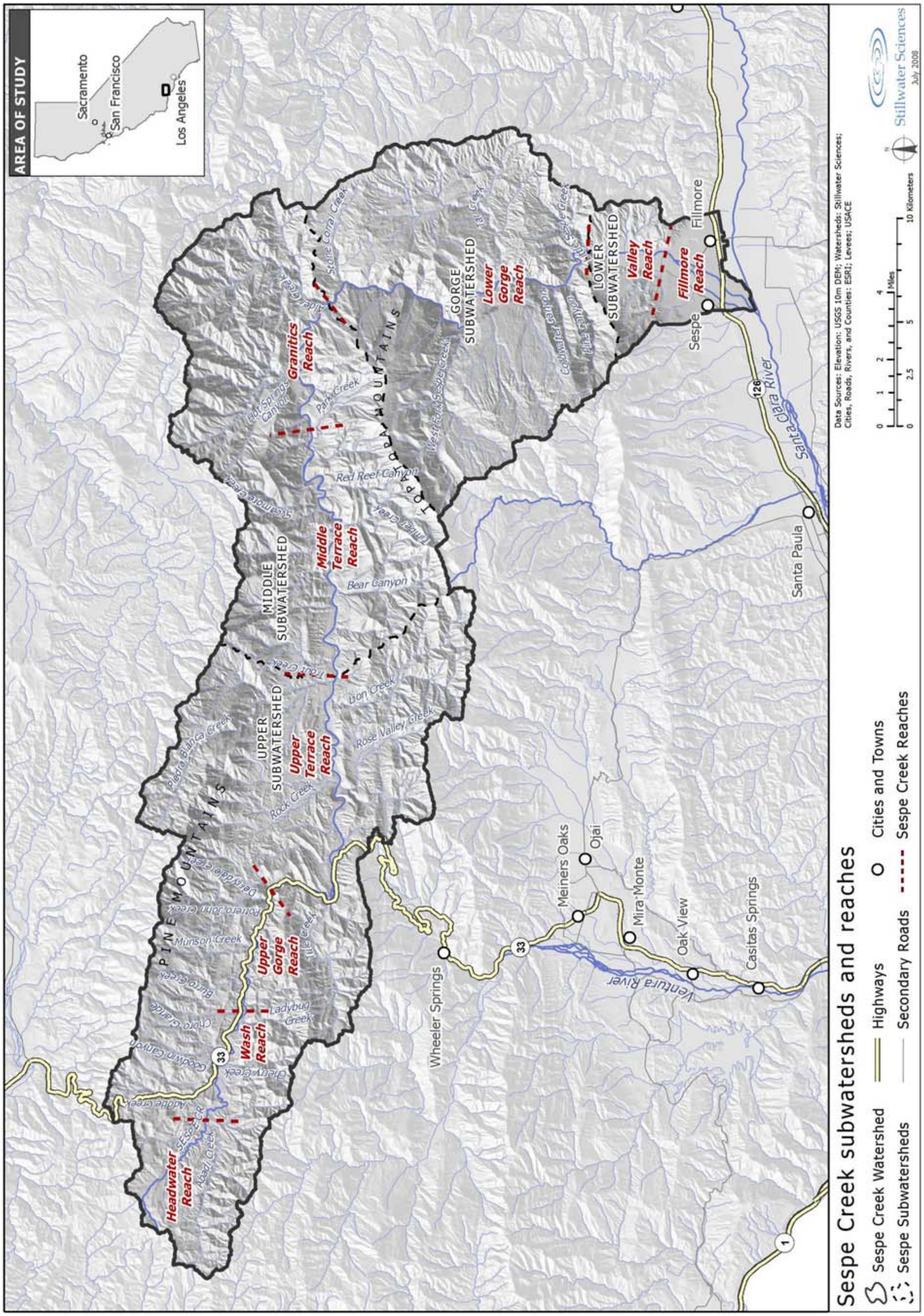


Figure 2-25. Sespe Creek subwatersheds and channel reaches.

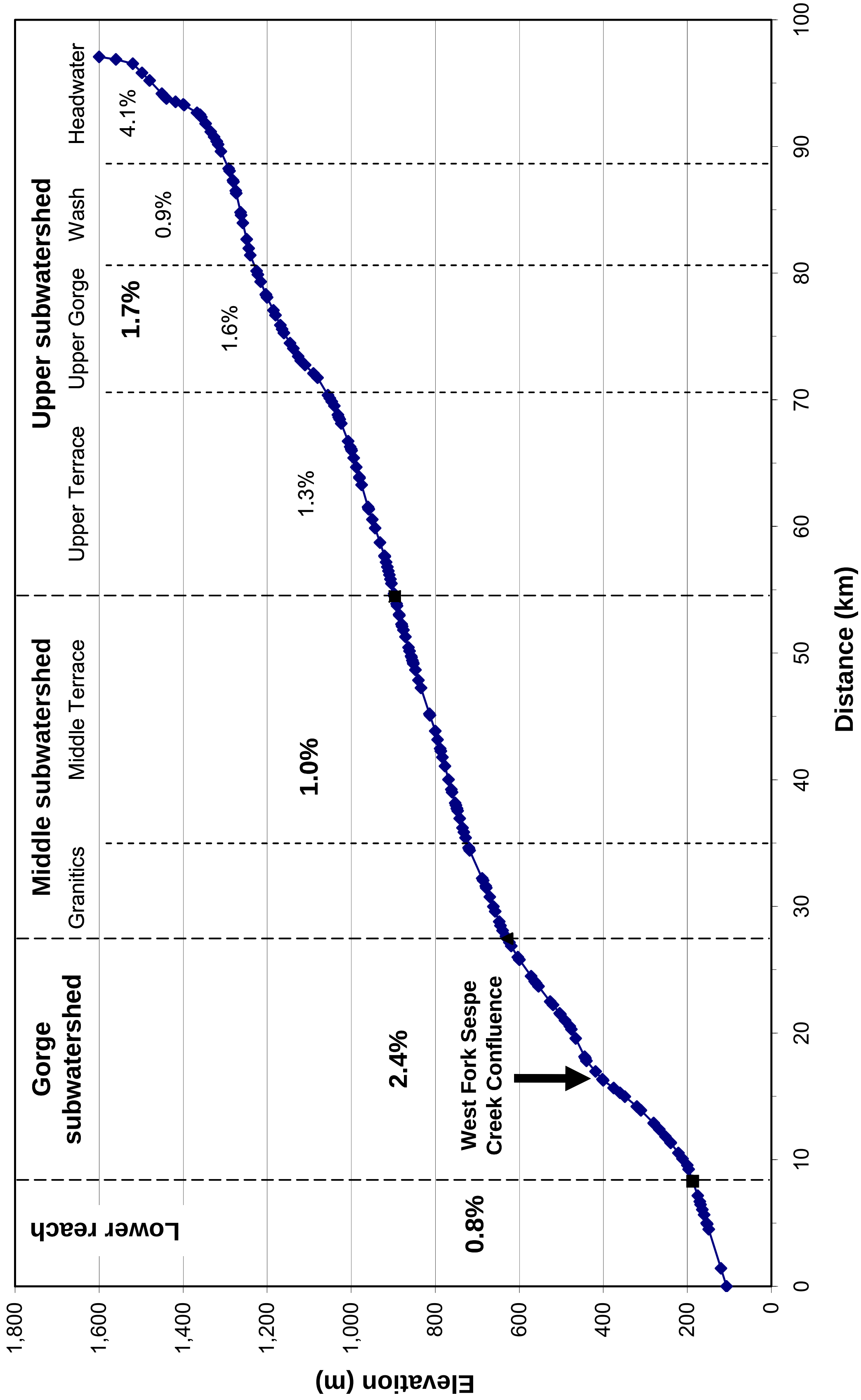


Figure 2-26. Longitudinal profile of Sespe Creek showing subwatersheds and channel reaches.

2.5.1 Reaches of the Upper Subwatershed

The Upper subwatershed encompasses over 40% of the Sespe Creek watershed by area, from the headwaters down to a point below the confluence with Piedra Blanca Creek (Figure 1-2). Most tributary streams in this portion of the watershed exhibit intermittent flow, while only the largest streams exhibit perennial flow (e.g., Tule, Rose Valley, and Piedra Blanca creeks). However, all streams, including Sespe Creek, have reportedly run dry between August and October during drought years (USGS 11111500), thereby exclusively limiting transport of sand-sized sediment and greater (>0.0625 mm) to the winter and spring seasons. Within this subwatershed, Sespe Creek drops in elevation by 700 m (2,300 ft) as it gradually flows through varied terrain types, beginning with the relatively steep headwaters and down through three other geomorphically distinctive reaches. The four reaches of the Upper subwatershed are referred to as below:

- Headwater (western watershed divide to Abadi Creek)
- Wash (Abadi Creek to Chorro Grande Creek)
- Upper Gorge (Chorro Grande Creek to 1.5 km downstream of Derrydale Creek)
- Upper Terrace (1.5 km downstream of Derry Dale Creek to Piedra Blanca Creek)

These four reaches each have unique geomorphic features, including stream gradient, valley width, and bed texture (Table 2-9). Sespe Creek flows east and parallel to the Pine Mountain fault to the north and the Munson Creek fault to the south in the upper two reaches, but then cuts south across the Munson Creek fault and various rock units through the Upper Gorge reach. The creek eventually flows eastward again in the Upper Terrace reach as it parallels the Pine Mountain fault to the north and the Santa Ynez fault to the south. The 2002 Wolf Fire burned much of the lower half of the Upper subwatershed, including the valley bottom of the Wash reach and eastern uplands that drain into the Upper Gorge reach (Figure 2-20). Burned vegetation with new growth was observed on the adjacent hillslopes in spring 2008.

Table 2-9. Reach characteristics for the Upper subwatershed.

Reach	Type	Length (km)	Channel gradient[A]	Average channel width (m) [B]	Facies distribution (% of reach channel area) [C]	Dominant facies type distribution (% of reach channel area) [C]
Headwater	Confined	10	4.1%	3.7	CG (>50%) CSG (<50%)	G (>50%)
Wash	Alluvial	9	0.9%	29		
Upper Gorge	Confined	9	1.7%	25		
Upper Terrace	Alluvial	15	1.3%	53		

[A] Slope from 10-meter resolution DEM. See Figure 2-26.
[B] Width measured every 1 km at regularly spaced cross-sections (2005 aerial photographs).
[C] Facies data compiled from channel facies mapping and particle size distribution data (SWS field data collection 2008) (CG = cobbly-gravel [gravel dominates], CSG = cobbly-sandy-gravel, G = gravel. See Buffington and Montgomery (1999) for more detail. See Appendix A for detailed facies maps and sediment size distribution data.

The Headwater reach has the steepest gradient (4.1%) in the entire watershed as it follows a sinuous course confined by moderately steep valley walls (Figure 2-26). This reach also has the narrowest average channel width (3.7 m) and depth (<1 m), which is a function of the small size of the contributing drainage area providing only intermittent flows to the creek and tributaries. At the confluence with Abadi Creek, the valley bottom broadens and Sespe Creek transitions to the Wash reach. This is characteristically a wider (29 m), lower gradient (0.9%), and mostly alluvial channel with occasional bedrock exposures (Figure 2-27). Because this reach is situated upstream of the constricted Upper Gorge reach, it effectively serves as an area of sediment storage with a bordering floodplain composed of alluvial materials (silts to coarse cobbles). The bed substrate is composed of fine gravel to medium cobble deposits (cobbly-gravel [CG]) (D_{50}=~20 mm, D_{84}=~80 mm) (see Appendix A for information on facies designation) overlying shale bedrock of the Cozy Dell Formation. The channel bed morphology is generally plane-bedded, but with occasional shallow pools and riffles. Sediment stored within the lower 100 m of Cherry, Godwin, and Chorro Grande creeks was characterized as cobbly-sandy-gravel, with relatively similar particle sizes (D_{50}=20 – 35 mm, D_{84} = 80 – 100 mm) (see Appendix B for observational data and photos of tributary confluences). These slightly steeper (1-2%), plane-bedded streams were bordered by a relatively wide floodplain or low terrace within approximately 200 m of their respective confluences with Sespe Creek.

Figure 2-27. View of Wash reach of the Upper subwatershed near Cherry Creek. The channel is bordered by a floodplain to the south and the bed substrate is cobbley-gravel (D_{50} = 10 mm, D_{84} = 50 mm as shown in photo) with some bedrock exposures (left bank).

The Upper Gorge reach begins below Chorro Grande Creek and extends 1.5 km downstream of Derrydale Creek, where the creek trends to the south rather than to the east (Figure 2-28). The creek crosses varied shale and sandstone rock units of the Cozy Dell, Matilija, and Juncal formations. The Upper Gorge reach is characterized by a steeper gradient (1.7%) relative to the Wash and Upper Terrace reaches upstream and downstream, and an average channel width of 25 m. Similar to the much larger gorge in the Gorge subwatershed, this upper gorge is confined by steep valley walls, with nearly vertical walls in sections (e.g., at the USGS gauging station [11111500]), and it lacks any adjacent floodplain areas. In addition to the steep valley walls, the creek is also impinged by Highway 33 throughout this area as the road runs along the creek in the canyon bottom. As a result of these constrictions, sediment storage is limited to the channel bed and at the mouths of tributaries.

Figure 2-28. View of Upper Gorge reach of the Upper subwatershed near Potrero John Creek. The channel is confined by steep valley walls with exposed bedrock. The channel bed substrate is bouldery-cobbly-gravel (D_{50} = 60 mm, D_{84} = 200 mm as shown in photo).

Despite the channel constrictions, the bed morphology is generally plane-bedded with no distinguishable breaks in slope (e.g., headcuts or waterfalls). Coarse boulder aggregations are rare and are typically present upstream of bedrock constrictions, such as near the confluence with Potrero John Creek. The bed substrate varies throughout, ranging between sandy gravel (SG) (D_{50}=~10 mm, D_{84}=~40 mm) to bouldery-cobbly-gravel (BCG) (D_{50}=~60 mm, D_{84}=~200 mm) (Appendix A). Several moderately steep tributaries enter this reach, including Burro, Munson, Potrero John, and Derrydale creeks, which all drain south-facing hillslopes entering the north side of Sespe Creek (Appendix B). Sediment sizes stored at the mouths of these intermittent streams range from sands to coarse cobbles, with few (<5%) boulders (cobbly-sandy-gravel to cobbly-gravel) (D_{50}=20–40 mm, D_{84}=60–130 mm). All streams were bordered by a floodplain or low terrace composed of materials similar to the bed substrate, with the exception of Potrero John Creek which cuts through a narrow bedrock gorge that limits sediment storage to the stream bed. The majority of Derrydale Creek watershed was burned during the 2002 Wolf Fire, yet the channel bed and floodplain surfaces did not contain any discrete patches of silt or sand-sized sediment (as was observed at several tributaries within the Day Fire area; see Section 2.5.2).

As Sespe Creek continues south towards Tule Creek, it transitions from the confined Upper Gorge reach into a relatively broad, unconfined, alluvial valley bottom (100-200 m wide) in the Upper Terrace reach (Figure 2-29). Sespe Creek eventually flows eastward along the Tule Creek fault trace (Dibblee 1987 [Lion Canyon quadrangle]) and parallel to the Pine Mountain and Santa Ynez faults to the north and south, respectively (Figure 1-3). Through this reach, the creek follows a slightly lower gradient (1.3%) as compared to the Upper Gorge reach. It has a sinuous course bordered by narrow floodplain areas which, in turn, are bounded by multi-stage terraces. The alluvium-capped terraces are characterized as broad, bench-like surfaces, typically situated on the southern slopes of the Pine Mountains and stepping down along the north side of Sespe Creek (Gutowski 1978). The channel has an average width of 53 m; with its adjacent floodplain, it achieves a maximum width of approximately 200 m between the terraces. Similar to the Wash reach farther upstream and the Lower Terrace immediately downstream, sediment is actively stored on the floodplain areas during high flow events. A mix of sediment sizes was observed on the floodplain and channel bars, ranging from sand (D_{50}=0.0625–2 mm) to coarse cobble (gravelly-bouldery-cobble) (D_{50}=200 mm) (Appendix A). The morphology of the channel bed is generally plane-bedded with some pool-riffle features, including cut banks and point bars, at a few of the tighter meander bends. The bed substrate varies between coarse sand to fine cobble (cobbly-gravelly-sand to cobbly-gravel) (D_{50}=1–50 mm, D_{84}=8–100 mm) (Appendix A). The few bedrock exposures, mainly on channel banks impinged against terrace slopes, include shales of the Coldwater and Rincon formations and sandstones of the Coldwater, Sespe, and Vaqueros formations. Sediment stored on the beds of the lower 100 m of Tule and Lion Canyon creeks were both composed of cobbly-gravel (D_{50} =~30 mm, D_{84} =~100 mm) (Appendix B). Sediment stored in Piedra Blanca Creek, one of the largest tributary basins in the Sespe Creek watershed, was considerably coarser (gravelly-cobble to bouldery-gravelly-cobble) (D_{50} = 60–90 mm, D_{84} = 200–300 mm). Similar to Derrydale Creek basin upstream, the Piedra Blanca Creek basin was almost entirely burned during the 2002 Wolf Fire. Again, no silt or sand-sized sediment patches were observed on the channel bed, floodplain, or low terrace surfaces (see Section 2.5.2). All tributaries, including Rock and Rose Valley creeks are plane-bedded and bordered by narrow floodplain areas composed of similar materials, with the exception of Lion Canyon Creek which emerges from a sinuous canyon with minimal storage capacity beyond the channel bed (Gutowski 1978).

Figure 2-29. View of Upper Terrace reach of the Upper subwatershed. Sespe Creek flows left to right in photo. Multi-stage terraces border the active channel to the north. Bedrock of the

Sespe Sandstone Formation and the Pine Mountains are in the background.

2.5.2 Reaches of the Middle Subwatershed

The mainstem channel in the Middle subwatershed of the Sespe Creek watershed extends approximately 27 km from just upstream of the Trout Creek confluence down to the confluence with Alder Creek (Figure 2-25). The Middle subwatershed is the most upstream portion of Sespe Creek watershed that was impacted by the 2006 Day Fire, with over 80% of the contributing subwatershed area burned in that fire. Within the Middle subwatershed, the mainstem channel gradient is relatively low (1.0%) and the average channel width is approximately 55 m. The channel flows through predominantly sedimentary rock units of the Sespe, Monterey, and Vaqueros sandstones and Rincon shales, and parallel to the Pine Mountain fault to the north and the Santa Ynez fault to the south. From Trout Creek to Alder Creek, there are several other relatively large (>4 km^2) tributary watersheds that drain into the mainstem in the Middle subwatershed from both the north-facing and south-facing slopes, including Bear Canyon, Timber Creek, Sycamore Creek, Red Reef Canyon, Park Creek, and Hot Springs Canyon. The main tributary channels are crossed by the Pine Mountain and Santa Ynez faults.

The Middle subwatershed consists of two mainstem reaches:

- Middle Terrace (upstream of Trout Creek to Park Creek)
- Granitics (Park Creek to Alder Creek)

These two reaches have unique geomorphic features, including stream gradient, valley width, tributary sediment contribution, and bed texture (Table 2-10).

Table 2-10. Reach characteristics for the Middle subwatershed.

Reach	Type	Length (km)	Channel gradient[A]	Average channel width (m) [B]	Facies distribution (% of reach channel area) [C]	Dominant facies type distribution (% of reach channel area) [C]
Middle Terrace	Alluvial	18.5	0.9%	60	CSG (23%) S (19%) BGC (8%)	G (45%) S (31%) C (23%) Br (<1%)
Granitics	Alluvial	8.0	1.3%	44	CSG (53%) SG (14%) GS (7%)	G (83%) S (17%)

[A] Slope from 10-meter resolution DEM. See Figure 2-26.
[B] Width measured every 1 km at regularly spaced cross-sections (2005 aerial photograph).
[C] Facies data compiled from channel facies mapping and particle size distribution data (SWS field data collection 2008) (CG = cobbly-gravel [gravel dominates], CSG = cobbly-sandy-gravel, G = gravel. See Buffington and Montgomery (1999) for more detail. See Appendix A for detailed facies maps and sediment size distribution data.

The Middle Terrace reach is similar in geomorphic characteristics to the Upper Terrace reach in the Upper subwatershed. Within the Middle Terrace reach, the creek has a relatively low gradient

(0.9 %), a sinuous course over the 18.5 km of channel, and bordering floodplain areas that in turn are bounded by the multi-stage terraces present in the Upper Terrace reach (Figure 2-30). In general, the terraces throughout this reach are laterally close to the channel bed. The channel has an alluvial form (meander bends, cut banks, depositional bars), with an average channel width of approximately 60 m (though much wider at bend-induced depositional zones) and a maximum floodplain width of approximately 200 m between the terraces. Several large-scale bank failures are present at the outside of meander bends. The bed morphology is generally plane-bedded with some pool-riffle features, and the bed substrate, including materials stored on the adjacent bars, transition from coarser deposits at the upstream end (e.g., gravelly-bouldery-cobble, D_{50}=160 mm, D_{84}=300 mm) to finer deposits at the downstream end of the reach (e.g., cobbly-sandy-gravel, D_{50}=20 mm, D_{84}=150 mm) (Appendix A). Bedrock has a significant influence on channel morphology at many locations within this reach: bedrock terraces confine the channel and control meander dynamics, exposed bedrock on the bed of Sespe Creek acts as grade control and defines local channel slope, and vertically-oriented sedimentary units at tributary mouths act as natural weirs that affect sediment deposition and channel slope at the tributary mouth. Bedrock exposures represented in this reach includes shales of the Rincon formations and sandstones of the Coldwater, Monterey, Sespe, and Vaqueros formations.

Figure 2-30. View of the Middle Terrace reach of the Middle subwatershed. The view is looking downstream and is located 1.5 km downstream of Trout Creek. A floodplain is present to the left side of the channel and a low terrace is immediately to the right. The bed substrate in this segment is a bouldery-sandy-cobble (D_{50} =~80 mm).

Sediment delivered from tributaries within the Middle Terrace reach becomes somewhat finer downstream as a function of both lithology and fire impacts. Sediment stored on the beds of the lower 100 m of Trout Creek, Bear Canyon, Timber Creek, and Red Reef Canyon are composed of coarse gravel to coarse cobble with sand and boulders present (D_{50} =50–150 mm, D_{84} =200–300 mm) (Appendix B). Sediment stored farther downstream at the mouths of Sycamore and Park creeks is considerably finer that the sediment in upstream tributaries, with the tributary beds composed of sandy-gravel (D_{50}=20–60 mm, D_{84}=50–200 mm). The Trout Creek and Bear Canyon basins were not burned in the Day Fire; however, the Trout Creek basin was burned during the 2002 Wolf Fire and appears to have revegetated and thus largely recovered from that fire as of our field work in spring 2008.

Effects of the Day Fire in the impacted area include burned vegetation on the hillslopes, large finer-grained (silt to fine-gravel) sediment deposits stored at the mouths of the tributaries that buried existing mature vegetation (composed predominantly of finer sediment), and rilling and gullying on hillslopes (Figure 2-31). The sediment deposits were evident at the mouths of larger tributaries, as well as at the mouth of many smaller, unnamed tributaries draining south-facing slopes. Based on ground- and air-based field observations, the source of these deposits was from widespread rilling, shallow gullying, and sheetwash on the burned hillslopes throughout the Middle subwatershed. These deposits are presumed to be the result of debris flows where mixed-sized sediment was delivered by the eroding hillslopes into the channel, thereby concentrating within the channel and "bulking" the flow, encouraging further entrainment of sediment particles (Cannon et al. 2008). The entrained sediment dropped out at the mouth of the tributary where bed slopes decrease and channel widths increase (i.e., lower shear stresses). Observed tributary debris deposits were poorly sorted, indicating rapid delivery, and ranged in size from silt to gravel, with the majority of the observed deposits to have a median grain size of approximately 2–4 mm. No evidence of infiltration-dominated hillslope failures, such as large-scale, post-fire landslide scars, was observed within the contributing tributary watersheds.

Figure 2-31. Sediment delivery directly to Sespe Creek from large-scale rilling on hillslopes burned during the Day Fire (2006) in the Middle Terrace reach.

The Granitics reach defines the transition from the upstream alluvial channel morphology to a bedrock gorge downstream of the reach. Within this reach, the creek has a relatively higher gradient (1.3%) and a sinuous course over its 8.0 km of travel, and it remains bordered by multi-stage terraces; however, the terraces are higher above the channel than in the Middle Terrace reach (Figure 2-32). Similar to the Middle Terrace reach, however, the channel has an alluvial form with several large-scale bank failures at the outside of meander bends. The average channel width is smaller (approximately 44 m, though much wider at bend-induced depositional zones). The bed morphology is generally plane-bedded and the bed substrate, including materials stored on the adjacent bars, is predominantly gravel throughout the reach (sandy-gravel to gravel, D_{50}=10–30 mm, D_{84}=80–200 mm) (Appendix A). A unique feature of this reach is the delivery of granitic and gneissic clasts to the mainstem channel from Hot Springs Canyon and Alder Creek, which both drain the intrusive plutonic unit in the northeast portion of the watershed (Figure 1-3).

Figure 2-32. View of the Granitics reach of the Middle subwatershed. The view is looking upstream towards the west and is located above the VCWPD rain gage between Park Creek and Hot Springs Canyon. Available floodplain areas are considerably less in this portion of the Middle subwatershed as compared to the Middle Terrace reach upstream. The adjacent hillslope are mostly without vegetation due to the Day Fire.

Overall, sediment contributed from tributaries within the Granitics reach is finer than sediment delivered from tributaries in the Middle Terrace reach. Sediment stored on the beds of the lower 100 m of Hot Springs Canyon and Alder Creek is composed of cobbly-sandy-gravel with boulders present (D_{50} =30–50 mm, D_{84} =150–250 mm) (Appendix B). In particular, Alder Creek has large boulders (> 1,000 mm) in the channel upstream of its confluence with Sespe Creek that affect sediment storage and sediment delivery dynamics (i.e., rate and particle size) to Sespe Creek downstream.

Effects of the Day Fire within this portion of the Sespe Creek watershed are ubiquitous. Large areas of burned vegetation on north- and south-facing hillslopes are present. Large debris deposits at the mouths of the major tributaries and numerous unnamed tributaries, composed predominantly of finer-grained sediments (D_{50}=2–4 mm), are also present (Figure 2-33). Burned hillslopes and debris deposits also have rill- and gully-networks that continue to deliver sediment to Sespe Creek during storm events. Similar to the Middle Terrace reach, debris deposits were evident at the mouths of larger tributaries, as well as at the mouths of many smaller, unnamed tributaries draining the south-facing slopes.

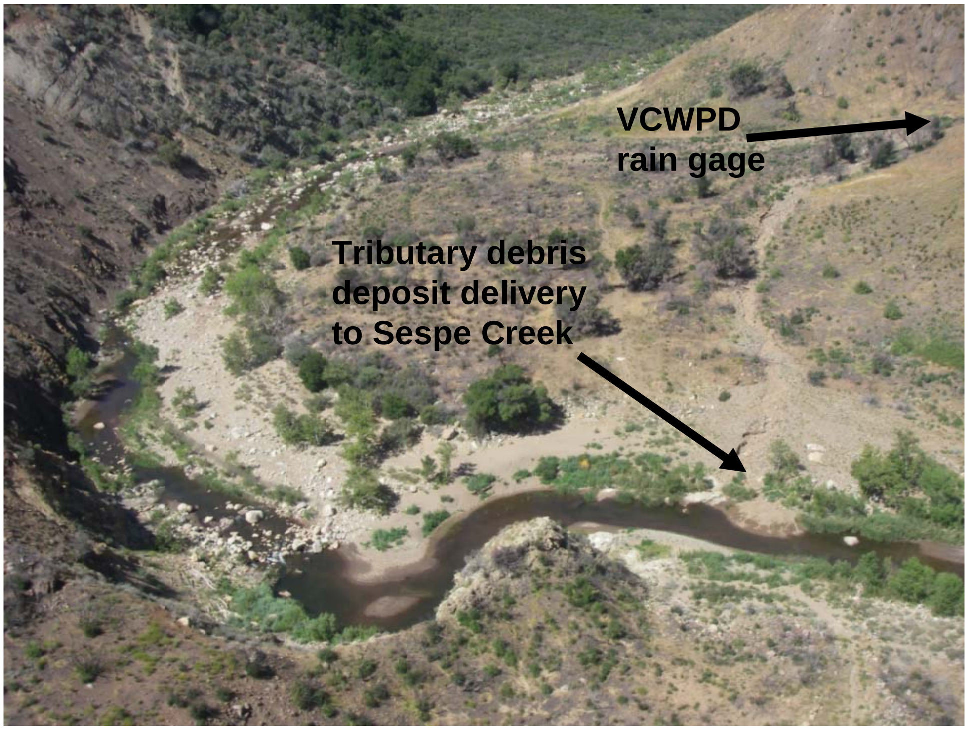


Figure 2-33. View of a post-Day Fire tributary debris fan in the Granitics reach located 1 km downstream of Park Creek. A fine-grained sandy-gravel (D50 = 20 mm, D84 = 60 mm) fan deposit enters a sand-bedded segment of Sespe Creek. The debris deposit buried vegetation with recent burn damage indicating that the tributary-derived sediment deposited after the 2006 Day Fire. The VCWPD rain gage is located where the tributary exits its confined valley.

2.5.3 The Lower Gorge Reach

Only one reach is defined in the Gorge subwatershed, namely the Lower Gorge reach (to distinguish it from the Upper Gorge reach along Highway 33 in the Upper subwatershed). It extends between the tributary confluences of Alder Creek to the north and Little Sespe Creek to the south. Similar to the Upper Gorge reach, the Lower Gorge reach winds southward through a narrow, bedrock-confined, V-shaped canyon (Figure 2-34). The channel gradient is moderately steep (2.4%), but it remains clear of any localized steeper grades associated with either high bedrock drops or massive boulder jams such as those present in Alder Creek (which displays a 10% grade over the lower 1 km) and other major tributaries in this reach (e.g., Stone Corral, West Fork Sespe, Coldwater Canyon, and Pine Canyon creeks). In comparison to the broader Middle reach upstream, the channel width is narrower on average (45 m), and no floodplain areas exist here due to the constriction imposed on the channel by the steep canyon walls.

Figure 2-34. View of Lower Gorge reach. View is looking downstream and is located upstream of West Fork Sespe Creek. Bed substrate is a coarse cobble with some post-Day Fire sand deposition. Bedrock of the Cozy Dell Shale Formation (Tcd) is exposed on both sides of the gorge in this segment.

Due to the relatively narrow width and steep gradient of the channel, sediment storage in this reach is limited to the channel bed and at the mouths of tributaries. The bed is composed of poorly sorted deposits, ranging from coarse sand (~1 mm) to very coarse boulders (>4,000 mm), overlying shallow and exposed sandstone and shale bedrock. The bed substrate transitions from a very coarse cobble deposit (bouldery-gravelly-cobble [BGC]) (D_{50}=~200 mm, D_{84}=~1,000 mm) at the upstream end to a fine cobble deposit at the downstream end (sandy-gravelly-cobble [SGC]) (D_{50} =~100 mm, D_{84} =~200 mm) (Appendix A). The bed morphology is poorly organized, having neither a definitive plane-bed or step-pool morphology typical of steeper canyon reaches (Montgomery and Buffington 1997). In general, the bed morphology most resembles a very coarse-grained, plane-bedded stream between non-regularly spaced large boulder bars and scour pools. The coarse, angular boulders are essentially large rock blocks locally derived from infrequent rock falls. These materials are too large to be transported by high magnitude flows and so, over time, they are mechanically worn down *in situ*, either by abrasion or disintegration (Gutowski 1978). The presence of bedrock exposures on the channel bed in places indicates that there is not a trend of reach-wide aggradation of coarse materials, and that Sespe Creek is presently capable of transporting the majority of coarser-grained sediment through the gorge that is delivered by fluvial transport from upstream and delivery from the adjacent hillslopes. Conversely, the lack of a continuously exposed bedrock channel bed with minimal to no alluvial cover indicates that there is not a trend of reach-wide sediment evacuation or incision. Therefore, a near-steady sediment supply from the Lower Gorge reach to the lower watershed can be inferred.

Sediment sources to the Lower Gorge reach include the major tributaries and adjacent canyon walls where both silty-sandy soils and very coarse cobble and boulder rock materials are delivered directly to the stream bed. Similar to the upstream reaches, finer-grained sediment delivery processes observed on the hillslopes and canyon walls observed in this reach included dry ravel, rilling, and shallow gullying, especially in areas of burned or otherwise low-density vegetation cover. Coarser-grained sediment delivery processes included alluvial transport from the major tributaries and rockfall from massive bedrock exposures along the canyon walls. A general characterization of tributary sediment storage at the mouths of the West Fork Sespe and Little Sespe creeks revealed the former to be composed of very coarse bouldery-cobble (D_{50}=~250 mm, D_{84}=~1,000 mm), while the latter contained coarse cobbly-sandy-gravel (D_{50}=~30 mm, D_{84}=~60 mm) (Appendix B).

Following the 2006 Day Fire, finer-grained sediment accumulation has been prevalent throughout the Lower Gorge reach. Observations made in spring 2008 by VCWPD and Stillwater staff noted that many of the pools in the upper half of the gorge between Alder and West Fork Sespe creeks have been filled with sand-sized materials (D_{50}=0.0625 – 2 mm) (Figure 2-35). According to field hydrographers from VCWPD that semi-annually monitor rain and stream gauges throughout the watershed, the pools, which had previously reached depths up to approximately 5 m, have been filled in by approximately 90% of their volume (H. Weishaar, pers. comm. 2008). Review of aerial photos taken prior to the Day Fire (NAIP 2005) reveals that many pools visible in the photos confirm that they were previously clear of sand. VCWPD hydrographers also noted that the sand accumulated in the gorge pools following the winter storms of 2008 (H. Weishaar, pers. comm. 2008). This sand is almost surely derived from shallow hillslope erosion exacerbated by the Day Fire, as evidenced by the numerous tributary debris fans that were observed to be post-2006 in age within the Middle subwatershed.

Figure 2-35. View of post-Day Fire aggraded fine sediment on the channel bed and in pools along the Lower Gorge reach. View is looking downstream and is located upstream of West Fork Sespe Creek. Bedrock of the Matilija Sandstone (Tma) is exposed on the right side.

2.5.4 Reaches of the Lower Subwatershed

In this lowermost subwatershed, Sespe Creek emerges from the confined Sespe Creek gorge below Little Sespe Creek and broadens out to form a low-gradient alluvial fan. Alluvial fans represent the depositional end to a sediment transport corridor that is typically fed by rock debris eroded in an arid or semi-arid, mountainous basin. Fan morphology is generally characterized by a broad, nearly symmetrical plan view, decreasing stream gradient in the downstream direction, and corresponding downstream fining of bed substrate. The fan morphology of the Lower subwatershed can be categorized as a Type II alluvial fan based on the classification scheme developed by Blair and McPherson (1994). The salient characteristics of this typology, which adequately defines the fan characteristics of the Lower subwatershed, include: 1) small to large contributing drainage-basin size; 2) quartz-rich sandstone bedrock lithology underlying the drainage basin; 3) rare occurrence of clay in the drainage basin; 4) distally decreasing downfan slope style; 5) poorly sorted sandy and pebble gravel to boulder cobble bed substrate that fines in the downstream direction; and 6) common presence of granular or sandy interbeds and distal sand-skirt facies (Blair and McPherson 1994). This form of an alluvial fan may not necessarily exhibit net aggradation over time provided that stream flow in the primary channel(s) can adequately maintain near-equilibrium between imported and exported sediment, which appears to be the case in the lower Sespe Creek.

Typical of alluvial fan morphology, the number of stream channels increases downstream as Sespe Creek transitions from a predominately single-thread stream during the majority of the year (i.e., late spring to late fall low flows) to a multi-thread stream during seasonal high flow conditions (i.e., winter and early spring flows). Within the lower half of Sespe Creek in the Lower subwatershed—termed henceforth as the Fillmore reach—the creek bifurcates into two dominate channels, the west fork (mainstem) and the east fork (overflow), that continue down to the Santa Clara River. No perennial and few intermittent tributary streams enter the creek in this reach. The closest coarse sediment-providing tributary to this reach is Little Sespe Creek in the Gorge subwatershed (see Section 2.5.3). Other seasonal flows arrive via culverts and irrigation ditches draining the adjacent crop fields on the plains and foothills. As a result, the majority of water supplied to this reach year-round is delivered from upstream.

Although adjacent hillslopes in this subwatershed have a “high” sediment yield rating based on the GLU analysis (see Section 2.3), the efficiency of sediment delivery (particularly the coarse fraction: >0.0625 mm) is limited by roads, agricultural fields, and drainage routing structures, including storm drains and culverts. Together, these land-use features act to effectively limit sediment delivery to this channel reach. In addition, the majority of rock units represented as the coarser sediment clasts (i.e., gravel, cobble, boulder) on the channel bed are derived from lithologies present upstream (e.g., sandstones of Sespe, Coldwater, and Matilija formations and granite/gneissic rocks), rather than from those present locally in this subwatershed (e.g., Monterey sandstones and Quaternary-age alluvial units) (Figures 1-3 and 2-18). The reaches of this subwatershed therefore function as a corridor of silt to sand sediment transport and gravel to boulder sediment deposition and abrasion into smaller clasts. This inference is supported by the downstream fining of sediment along the length of the stream bed.

This subwatershed contains two geomorphically distinctive reaches (Figure 2-25):

- Valley (Little Sespe Creek to the Sespe Creek Levee and left bank revetment)
- Fillmore (Sespe Creek Levee to the Santa Clara River)

In the Valley reach, the stream behaves as a mostly straight, single-thread channel (during low flows) bounded on either side by a floodplain or terrace (Figure 2-36). Floodplain materials on the west (right bank) side are mapped as geologically young stream deposits (Qa unit in Dibblee 1990a), while the floodplain and terrace materials on the east (left bank) side are mapped as being older alluvium with some occurrences of Monterey Formation shale bedrock along the stream bank (Qoa and Tm units in Dibblee 1990a) (see Figure 1-3). Bedrock exposures are also found along the channel banks at the upstream end of the reach near the USGS stream gauging station. The majority of flows are generally well contained within the channel banks, but evidence of occasional floodplain inundation is provided by a comparison of measured gauge heights at the local stream gauging station (USGS 11113000) and channel depths measured from the floodplain surface at five regularly spaced cross-sections (see cross-section analysis in Section 3.3 and Appendix C). The elevation differences between channel bed and the adjacent floodplain and/or terrace areas ranged between 4.0 and 15.2 m, with an average of 10.2 m (Table 2-11) while several peak flow events have reached heights above the channel bed in excess of 6 m (20 ft). Due to the infrequency of overbank flows in this reach, storage of sediment is limited to the channel bed and bars, or active channel area. The morphology of the active channel bed is generally plane-bedded, with a pool-riffle structure at several channel bends.

Figure 2-36. View of the Valley reach of the Lower subwatershed. View is looking downstream and is located downstream of Little Sespe Creek as the valley broadens towards the Santa Clara River. Bed substrate is sandy-gravelly-cobble (D_{50} = 70 mm, D_{84} = 158 mm [LADPW 2008]).

The Valley reach is also characterized by having a stream gradient of 0.9% and an average width of 170.2 m, which, together, promote the deposition of sand-sized (>0.0625 mm) sediment and greater as shear stresses are diminished relative to those within the steeper and narrower Lower Gorge reach upstream. Facies mapping and pebble count analyses conducted in select points along this reach, in addition to two sediment samples collected in 2005 by the Los Angeles

County Department of Public Works (LADPW 2008), reveal that the bed substrate is composed of poorly sorted, coarse-grained deposits (sandy-gravelly cobble [SGC])(D_{50}=70 mm, D_{84}=158 mm). Although boulders are distributed throughout, they account for less than 5% of the total bed substrate present. The dominant facies type and sediment size measurement locations along the channel bed and results in the Lower subwatershed reaches are shown on Figure 2-37 (see Appendix A for detailed facies maps). As previously stated above, the lithology of coarse substrate in this reach chiefly includes sandstones of the Sespe, Matilija, and Coldwater formations, with granitic and gneissic rocks and few mudstones (Figure 2-18).

Table 2-11. Reach characteristics for the Lower subwatershed.

Reach	Type	Length (km)	Channel gradient [A]	Average channel width (m) [B]	Average channel depth (from floodplain or terrace) (m) [C]	Facies distribution (% of reach channel area) [D]	Dominant facies type distribution (% of reach channel area) [D]
Valley	Alluvial	3.8	0.9%	170.2	10.2	SGC (>50%) CSG (<50%)	C (>50%) G (<50%)
Fillmore	Alluvial	4.5	0.7%	278.1	3.9	S (20%) CSG (19%) CGS (14%)	G (46%) S (36%) C (19%)
Total	Alluvial	8.3	0.8%	224.2	7.1	CSG (>50%)	G (>50%)

[A] Slope from 10-meter resolution DEM. See Figure 2-26.
[B] Width measured every 0.9 km at regularly spaced cross-sections (2005 aerial photograph, 2005 LiDAR). See Figure 2-37 for cross-section locations. See Appendix C for cross-section figures.
[C] Depth measured every 0.9 km along thalweg trace at regularly spaced cross-sections (2005 LiDAR).
[D] Facies data compiled from channel facies mapping and particle size distribution data (LADPW 2008, SWS field data collection 2008). Valley reach determined from LADPW (2008) pebble count data and Stillwater rapid visual assessment of bed substrate. Fillmore reach determined from Stillwater 2008 facies mapping and pebble count data (SGC = sandy-gravelly-cobble [cobble dominates], CSG = cobbly-sandy-gravel, S = sandy, CGS = cobbly-gravelly-sand). See Buffington and Montgomery (1999) for more detail. See Appendix A for detailed facies maps and sediment size distribution data.

Evidence of active migration of the channel, is provided by nearly vertical cut-banks present along the outer side of meander bends in the stream course. Complemented by opposing point bars on the inner side of the bends, together these features viewed in cross-section show an asymmetrical form typical of meandering streams (see Section 3.3 and Appendix C for cross-section analysis results). Bank erosion is prevented along the left side (east) of a channel bend upstream of the levee where the bank has been revetted with concrete and rock to protect several residential properties (Figures 2-38). This is an area of focused energy during high flows due to: 1) a high angle of attack of flow towards the bank, and 2) relatively narrow channel width compared with wider channel widths immediately upstream. Within 250 m upstream of the bend apex, the active channel boundary constricts abruptly from 142 m to 104 m (see cross-sections [XS] 10B and XS 10A in Figures C-14 and C-13, respectively, in Appendix C), a difference of 38 m (125 ft). The revetted bank was damaged most recently during the 2005 flood event and was subsequently repaired. Bed scour and undermining of the revetment was observed in spring 2008 (Figure 2-39).

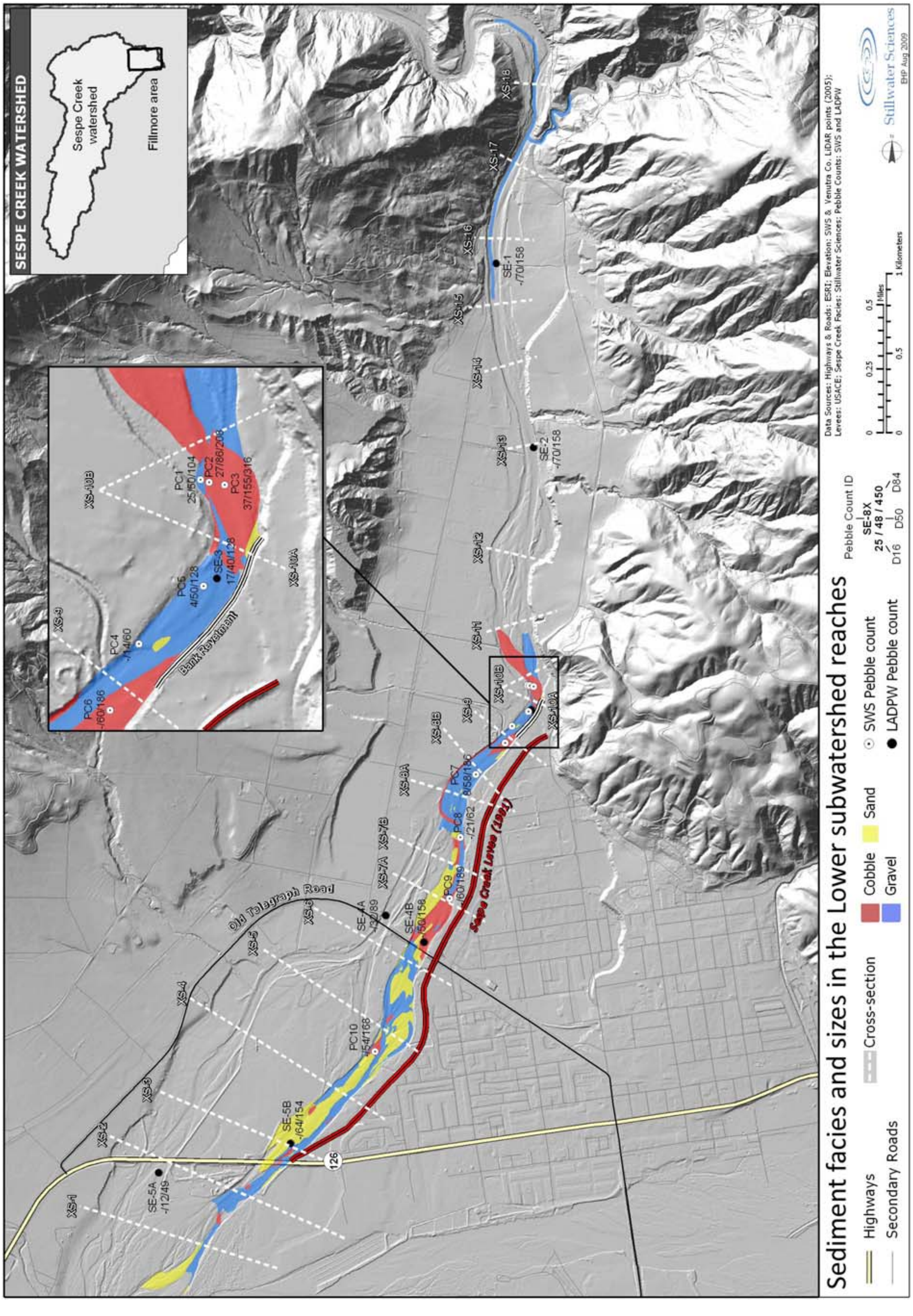


Figure 2-37. Dominant facies type and sediment size measurement locations and results in the Lower subwateshed reaches.

Figure 2-38. View of the concrete-rock bank revetment structure located along the left bank upstream of the Sespe Creek Levee in the Fillmore reach. View is looking downstream.

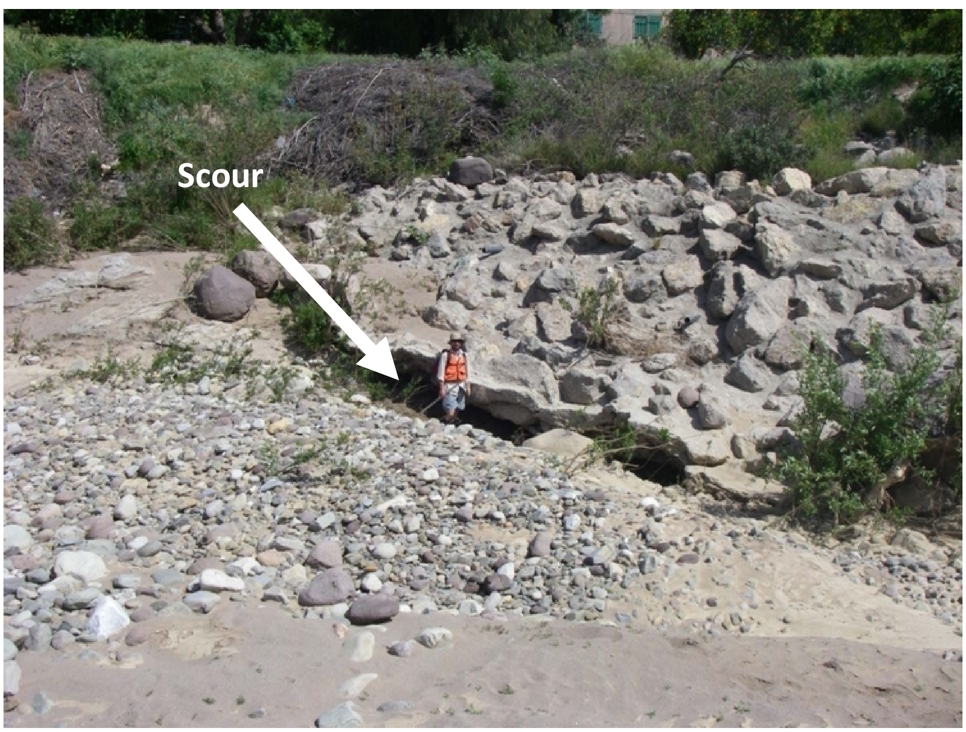


Figure 2-39. View of scour at the upstream end of the bank revetment structure located along the left bank upstream of the Sespe Creek Levee.

The Fillmore reach is bordered to the east by the Sespe Creek Levee (Figures 1-7 and 2-37), which sits back from the left (eastern) stream bank allowing a narrow (~60-m width) floodplain composed of geologically young alluvium (Qa unit in Dibblee 1990a) to remain. Sespe Creek bifurcates into two separate channels approximately 750 m upstream of the Old Telegraph Road and Southern Pacific Railroad bridges. The western course is considered as the mainstem Sespe Creek, while the course to the east is designated as the Sespe Creek Overflow channel (USACE 1980). Presently, the latter conveys most of the average annual flow, based on observations of 2005 aerial photographs of the reach and field observations made in spring 2008.

Compared to the Valley reach upstream, the channel gradient and depths in the Fillmore reach decrease (0.7% and 3.9 m) while channel widths increase substantially (278.1 m) as the number of braid channels increases towards the mouth (filled during moderate to high flows in winter and spring). This reach is depositional with active channel widening (i.e., bank erosion) and reworking of ephemeral bed features (e.g., mid-channel bars). Evidence of recent bank erosion was observed along the right bank, opposite the upstream end of the Sespe Creek Levee and about 1.4 km upstream of Old Telegraph Road bridge, where irrigation pipes and fruit trees were projecting out from the top of the bank (Figure 2-40). Scour and aggradation of the channel bed was observed adjacent to the pilings of the road and railway bridges (Figure 2-41). The channel bed exhibits a quasi pool-riffle morphology as the main thalweg traverses back and forth between the boundaries of the outer channel banks. At the head of the east fork (overflow) channel, a relatively steep (1-5%) riffle, or knickpoint, is present. The bed elevation downstream of the riffle is approximately 2.5 m (8 ft) lower than the riffle head and the bed elevation of the west fork channel, which has directed the majority of the stream flow over the riffle and into the east fork channel.

Figure 2-40. View of exposed irrigation piping and fruit tree roots at actively eroding right bank opposite the upstream end of the Sespe Creek Levee in the Fillmore reach.

Figure 2-41. View of scour and deposition on either side of a bridge support for the Southern Pacific Railway bridge immediately upstream of the Old Telegraph Road Bridge on the east fork (overflow) of Sespe Creek in the Fillmore reach.

A comprehensive identification of substrate facies and particle sizes in the Fillmore reach during spring 2008 revealed that the bed substrate transitions from very poorly sorted, coarse gravel-cobble, cobble-gravel deposits (D_{50}=50–155 mm, D_{84}=104–316 mm) at the upstream end of the Sespe Creek Levee to moderately sorted, fine sand-gravel deposits (D_{50}=12–64 mm, D_{84}=49–154 mm) at the confluence with the Santa Clara River (Figure 2-37; see facies map tiles in Appendix A). The heterogeneity in bed texture is clearly expressed by the numerous facies types identified here. The bed morphology is indicative of a semi-arid system having abrupt, or flashy, hydrographs whereby the recessional limb time period is insufficient to provide for differential sorting and deposition of discrete particle sizes on the channel bed (Blair and McPherson 1994, Hassan et al. 2006).

Classification of the channel pattern into a distinct typology for both reaches of the Lower subwatershed provides an important step in understanding the morphodynamic behavior of river systems. In the reaches of the Lower subwatershed of Sespe Creek, the channel pattern is clearly stage-dependent and cannot be easily classified as either a straight, meandering, or braided channel. Based on relationships between slope and discharge for braided versus meandering channels, the channel would be classified as "braided" rather than "meandering," because the average slope (0.8%) of the two reaches and a bankfull discharge (R.I.≈2 yrs) in excess of 2.8 m^3 s^{-1} (100 cfs) plot above the threshold line (Leopold and Wolman 1957, Lane 1957, Ackers and Charleton 1971 as cited in Schumm and Kahn 1972). Alternatively, using pattern classifications developed for dryland rivers with highly variable flows (Graf 1983, 1988a, 1988b) or implied in regions with extended drought- and flood-dominated flow regimes (e.g., Warner 1987, 1994; Erskine and Warner 1988), the Lower subwatershed reaches can be classified as a "compound" channel. Graf describes compound channels as having two modes of operation, with a single meandering channel at low flow and a braided channel at higher flows (1988b, p. 202). Overall, both reaches fit well within this classification as the multiple braid channels re-activate during high flows, while a mainstem channel (one in each of the east and west forks) dominates during low flow conditions throughout the majority of the year.

3 SEDIMENT TRANSPORT AND MORPHOLOGICAL CHANGE IN LOWER SESPE CREEK

3.1 Overview

Geomorphic evolution of river channels is driven by characteristics of hillslope and fluvial sediment production, delivery and transport, integrated with the dynamic properties of the channel perimeter. These dynamics are influenced by factors that include geologic and topographic controls, climatic conditions, vegetation cover and land use, and channel alteration. For southern California watersheds in their undisturbed condition, their high rates of tectonic uplift, a semi-arid environment, and an active fire regime result in extremely high sediment production rates during frequent high-intensity, short duration storm events (see Section 2). These factors are likely to contribute to naturally high rates of sediment transport, watershed sediment yield, and channel morphologic change in lower Sespe Creek. Further, channel modifications (e.g., in-channel sediment removal, bank armoring, flood routing structures) can significantly impact sediment transport and morphologic dynamics, causing channel destabilization and accelerated rates of channel incision, aggradation, and bank erosion, as established already for other channels in the Santa Clara River watershed (e.g., Santa Paula Creek and the lower Santa Clara River [Stillwater Sciences 2007a, 2007b]).

To understand the channel geomorphic evolution in the Lower subwatershed of Sespe Creek, an assessment of current and historic fluvial geomorphic characteristics was conducted in the context of geologic controls, hydrologic regime, and flood protection structures. Sediment transport dynamics for current watershed conditions were analyzed to: 1) determine the magnitude of annual sediment delivery from the watershed; and 2) define the frequency at which significant channel geomorphic change occurs. Channel geomorphic changes over the past 70 years is reconstructed to the extent permitted from a variety of archive data sources analyzed to identify the key controls on historic morphologic evolution and postulate the projected trajectory of future channel morphology. These results will be crucial in guiding the development of management solutions for flooding, sedimentation, and erosion issues related to sustaining flood protection capacities with the Sespe Creek Levee in the City of Fillmore.

3.2 Sediment Transport Dynamics

The dynamics of sediment transport in the channel reaches of the Lower subwatershed are influenced initially by local and regional controls on sediment supply and caliber upstream (e.g., human activities, fires, and large storm events), as previously investigated (see Section 2.5). Thereafter, the potential for channel morphologic change is defined primarily by the relationship between flow and sediment discharge during storm events, and the associated magnitude and frequency of sediment-transporting events. In particular, the transport of sediment including and exceeding the sand-size fraction (i.e., greater than 0.0625 mm) is critical in determining in-channel geomorphic processes and change. In this context, analyses were undertaken using data from the USGS stream gauging site near the City of Fillmore over the past 80 years to determine both the impact of individual short-term storm events in sediment transport, and the long-term (cumulative over time) watershed sediment yield. The latter provides an average value of sediment exported from the Sespe Creek watershed for comparison with sediment production and delivery characteristics identified in Section 2. Results from this analysis are presented below and are discussed in the context of management challenges in Section 4.2.

3.2.1 Sediment discharge

We explored the dynamics of sediment discharge in Sespe Creek using the daily mean flow record for Sespe Creek and a watershed sediment-rating curve. By combining the watershed sediment-rating curve with the distribution of daily mean flows (i.e., the frequency at which a particular flow is equaled or exceeded in the gauge record), we can determine the magnitude and frequency of daily sediment transporting flows within the watershed. This can indicate the "dominant discharge" for Sespe Creek (namely, the flow or range of flows that transports the most sediment over time) and thus the role of individual flood events in prompting geomorphic change.

This analysis drew on flow and sediment discharge data recorded near the mouth of Sespe Creek. Daily mean flow data was compiled from the Sespe Creek stream gauging site downstream of the Little Sespe Creek confluence (USGS 11113000) for WY 1928 through July 2008. The frequency of daily mean flows was determined by dividing the daily mean flow in its original units of cfs into log-based categories (i.e., defined by increasing the exponent by 0.1), spanning discharge increments from 10^{-2} cfs (0.01 $m^3 s^{-1}$) to 10^3 cfs (1,000 $m^3 s^{-1}$) and fitting a regression through the relationship (see also Stillwater Sciences 2007b, Appendix C). The sediment discharge rating curve was calculated using a combination of the suspended sediment load (total and coarse [>0.0625 mm]) and bedload estimates. The sediment rating curve for suspended sediment was derived using instantaneous suspended sediment discharge data measured by the USGS between 1966 and 1978 regressed against the associated instantaneous flow data from the USGS 11113000 gauging station. The rating curve for bedload discharge at this Sespe Creek gauge was calculated as 10% of the total load, as suggested by Williams (1979) for southern California rivers. The suspended and bedload rating curves were combined to give both a total and coarse (>0.0625 mm) sediment rating curve for Sespe Creek near the confluence with the Santa Clara River and the City of Fillmore (Figure 3-1).

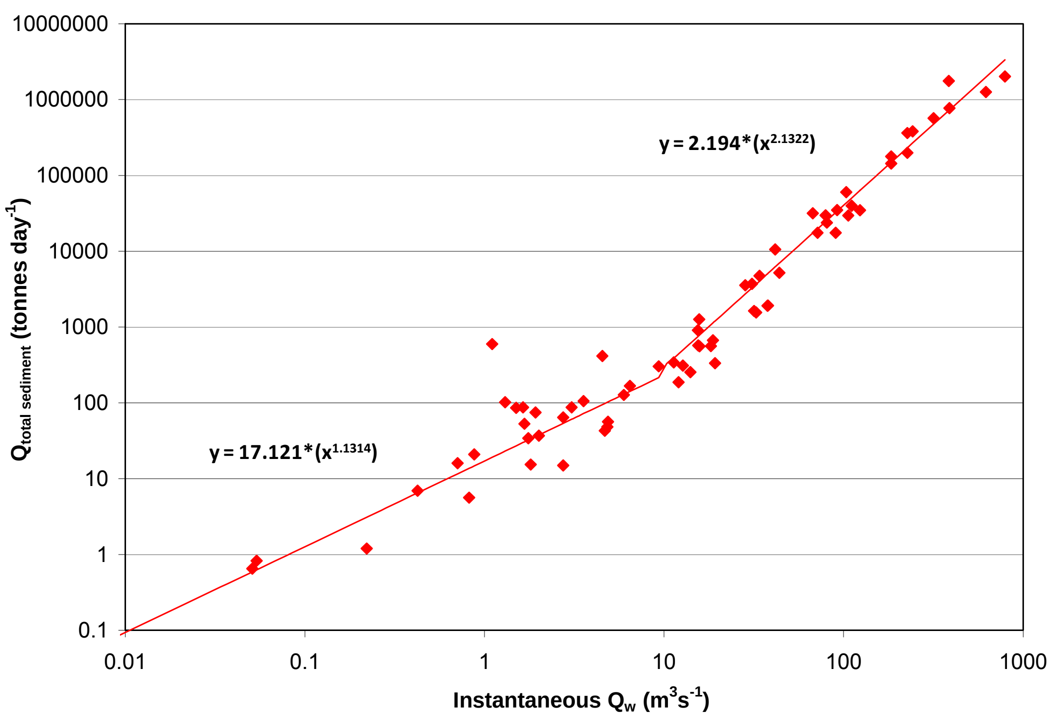


Figure 3-1. Sediment rating curve (suspended load + bedload) for Sespe Creek at Fillmore [USGS gage 11113000].

The annual total sediment yield estimate for WY 1928 to 2009 for Sespe Creek near the Santa Clara River confluence is 990,028 tonnes a^{-1}, or a yield per unit area of 1,523 tonnes km^{-2} a^{-1} (Figure 3-2). Over the past 80 years, annual sediment discharge is estimated to have ranged from a low of approximately 250 tonnes (WY 1951) to in excess of 16 million tonnes during WY 2005, which contains the flood of record. Four water years (1969, 1978, 1995, and 2005) account for over half of the total sediment yield. Consideration of only the coarse fraction (>0.0625 mm) of the total average annual sediment yield reveals an estimated value of 234,534 tonnes a^{-1}, or a per unit area contribution of 361 tonnes km^{-2} a^{-1}. Coarse sediment sizes included suspended sediment and bedload greater than 0.0625 mm, which excludes silt and clay sized particles as they will transport as suspended or dissolved load even in low flow conditions and are therefore frequently carried through lower Sespe Creek and into the Santa Clara River and beyond (Simons and Li 1983). As such, these particles have little influence on the channel morphology and the dynamics of morphological change.

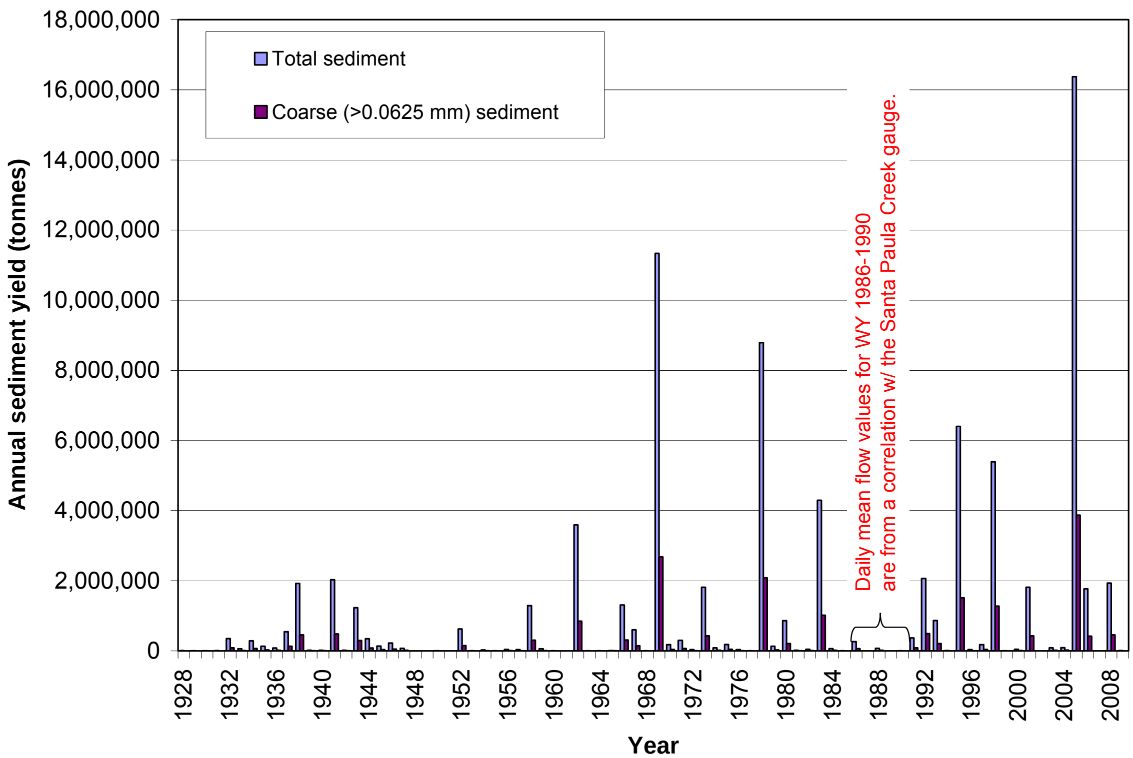


Figure 3-2. Calculated total sediment yield (suspended load + bedload) and coarse (>0.0625 mm) sediment load for Sespe Creek at Fillmore (USGS gage 11113000). Note: the daily mean flow values for WY 1986-1990 were absent for this gauge, but were derived here based on a correlation (R^2=86%) with the Santa Paula Creek gauge (USGS 11113500).

Examination of the sediment yield from Sespe Creek within the context of the regional ENSO signal for southern California rivers shows that more than three-quarters of the total sediment delivered over the period of record (WY 1928-2009) occurred during sixteen ENSO years. Furthermore, the data show that average annual sediment yield has been over five times higher in the recent wetter period (post-1960) as compared to the average annual yield prior to 1960.

The magnitude-frequency analysis of coarse (>0.0625 mm) sediment transport (using daily mean discharge) is shown in Figure 3-3. These data show that the majority of sediment transport in Sespe Creek occurs during very brief intervals, a characteristic shared by other basins in the Santa Clara River watershed (Stillwater Sciences 2007a, 2007b). These data also show that the "dominant discharge" (the single discharge that performs the most work in terms of sediment transport over the long term) is in fact the highest flow on record (2005), meaning that the daily mean discharge that has delivered the most sediment over the entire period of record is the single day with the highest daily mean discharge. This trend is similar for results from other Santa Clara River watershed locations, and is representative of conditions postulated for semi-arid and arid environments (e.g. Wolman and Gerson 1978). This is in contrast to humid environments, where a more intermediate flow generally dominates, and corresponds closely with the bankfull discharge (R.I.≈1.5-2 years) (Wolman and Miller 1960, Emmett and Wolman 2001).

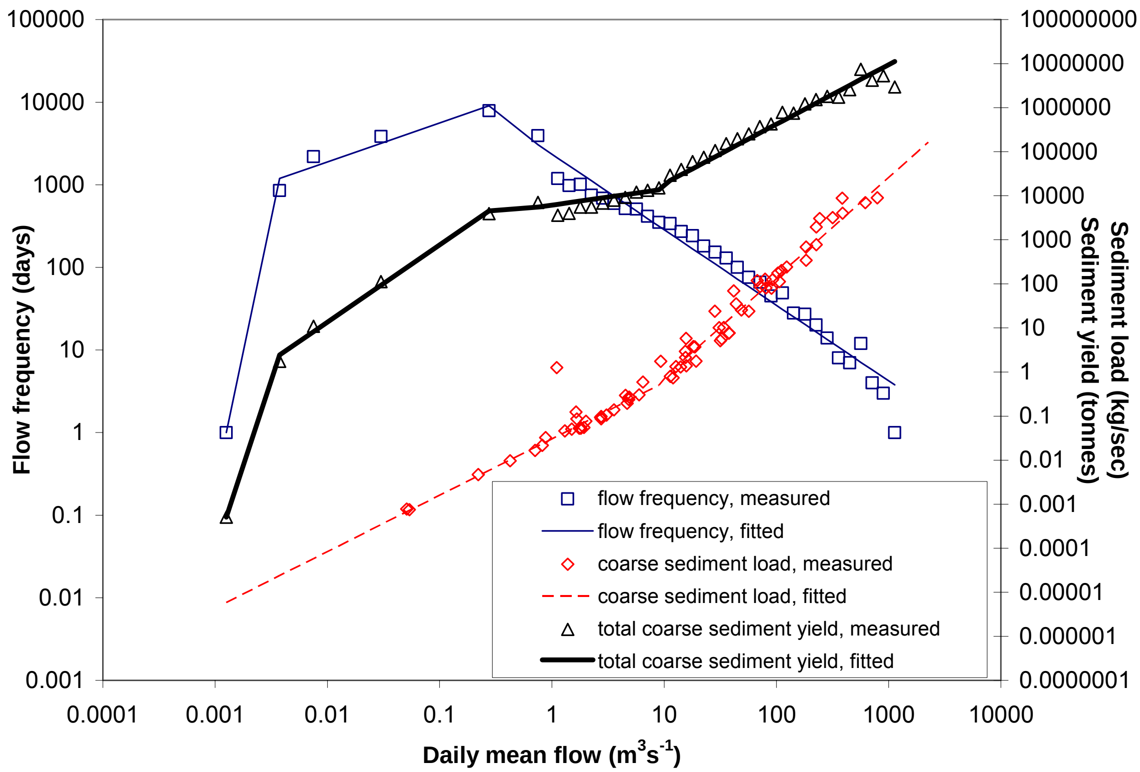


Figure 3-3. Flow frequency and coarse (>0.0625 mm) sediment load for long-term daily mean flow record for Sespe Creek at Fillmore [USGS gage 11113000]. Note: the daily mean flow values for WY 1986-1990 were absent for this gauge, but were derived here based on a correlation (R^2=86%) with the Santa Paula Creek gauge (USGS 11113500).

The consequences of this geomorphic condition are significant for riverine management. In southern California river systems such as Sespe Creek, where the dominant discharge corresponds to the largest flow on record, the dynamics of river morphology may not exhibit equilibrium tendencies, with small, year-to-year fluctuations around a long-term average condition. Instead, the Sespe Creek channel and floodplain are prone to abrupt changes during episodically high flows that can cause considerable change in the bed and banks of the channel. These changes, expressed as rapid bank erosion or significant fluctuations in local channel bed elevation (see below) may have significant impacts for floodplain settlement beside the channel.

3.3 Channel Morphology Change (1938-2008)

Sespe Creek is unique among most California streams of this size by remaining relatively undeveloped and, most importantly, unregulated by dams or diversions. In consequence, the sediment production, delivery, and transport processes at work today may be similar to those operating prior to European-American settlement in the region. In the upper watershed, the role of cattle grazing in reducing vegetation cover (and subsequently allowing enhanced rates of soil erosion) following European-American settlement until the late Nineteenth century drought is unclear (see Stillwater Sciences 2007b, p 19-24); however, Cleland (1940) reports that Rancho Sespe—the 36 km^2 (8,880-acre) Mexican land grant established in 1833 that encompassed the Lower subwatershed—once supported up to over 10,000 head of livestock that freely roamed across the landscape of the Lower subwatershed and perhaps northward into the Upper subwatershed. If true, grazing may have caused significant changes to rainfall-runoff relationships and vegetation patterns. In the Lower subwatershed, cattle grazing and extensive efforts to clear riparian woodland for agriculture during the late-Nineteenth century (Gordan 1996 as cited in Boughton et al. 2006) is likely to have reduced bank resistance to erosion, allowing the channel to widen and change course more easily. According to historical accounts (e.g., in Freeman 1968), many large, mature trees were lost during the large flood of 1884 (possibly in response to dry conditions for much of the preceding 40-year period). If true, it is possible that the morphology of the contemporary Sepse Creek channel may have evolved from around this time. Understanding these processes and their controls on channel morphology is vital in predicting future conditions, specifically the long-term trajectory of channel behavior near Fillmore and the Sespe Creek Levee (particularly with respect to bed aggradation and bank erosion).

To characterize how Sespe Creek responds to natural perturbations in the watershed, such as large flood events, we analyzed channel morphology for the Lower subwatershed reaches over the past 70 years. Channel features assessed were channel thalweg(s) location(s), channel depth, and channel width. Data sources included aerial photography dating from 1938 through 2005, orthorectified topographic maps from the 1970s and 2004, high-resolution elevation data (LiDAR) from 2005, and field observations and collected data from spring 2008 (Table 3-1). The active channel areas—defined as the area of the channel bed showing evidence of recent sediment scour or deposition—in the Fillmore reach in the years of 1938, 1970, and 2005 were also assessed. Cross-sections of channel topography in the 1970's, 2004 (Fillmore reach only), and in 2005 are presented in Appendix C (see Figure 3-4 for cross-section locations). Changes in channel morphology and factors affecting the geomorphic change are presented below.

Table 3-1. Data sources utilized in channel morphologic evolution analysis.

Data Source	Date	Coverage extent in Lower subwatershed reaches [A]	Channel features	Q_w (daily average discharge in cfs) [B]	Max Q_w preceding date in same water year [B]
Aerial Photograph	5/10/38	Fillmore	Channel thalweg(s) location(s) and floodplain boundaries	117	14,800 (Mar 2)
	1/4/66	Fillmore		544	11,900 (Dec 29, 1965)
	2/26/69	Fillmore		8,460	29,100 (Jan 25); 22,600 (Feb 25)
	1/31/70	Fillmore and Valley		26	110 (Jan 10)
	10/15/75	Fillmore and Valley		0.46	5,110 (Mar 8)

Data Source	Date	Coverage extent in Lower subwatershed reaches [A]	Channel features	Q_w (daily average discharge in cfs) [B]	Max Q_w preceding date in same water year [B]
	3/6/78	Fillmore and Valley		4,200	28,000 (Feb 9)
	2/26/80	Fillmore and Valley		640	9,320 (Feb 16)
	3/4/83	Fillmore		2,800	25,500 (Mar 1)
	3/25/92	Fillmore and Valley		1,330	17,000 (Feb 12)
	1/16/95	Fillmore and Valley		557	28,800 (Jan 10)
	2/11/98	Fillmore and Valley		1,240	21,700 (Feb 3)
	2005	Fillmore and Valley		NA	39,700 (Jan 9)
Topographic Map (2-ft elev. contours) [C]	4/23/68 (SCR to Hwy 126) 7/24/71 (Hwy 126 to Old Telegraph Road) 11/17/77 (Old Telegraph Road to Little Sespe Creek)	Fillmore and Valley	Channel thalweg(s) location(s), gradient, width, and depth	21 2.4 0.31	530 (Mar 8) 1,200 (Dec 21, 1970) 753 (May 9)
Topographic Map (2-ft elev. contours) [D]	7/26/04	Fillmore		2.2	4,370 (Feb 26)
LiDAR	2/24/05	Fillmore and Valley		4,890	39,700 (Jan 9)
Field Observation	4/1/08	Fillmore and Valley	Channel thalweg location, bed morphology, and bed substrate	101	22,500 (Jan 27)

[A] Extent of Sespe Creek coverage in data source determined from measured distance along stream course up from the confluence with the Santa Clara River.
[B] Data from USGS stream gauging station at upstream end of Lower subwatershed (USGS 11113000).
[C] Topographic maps prepared by Ventura County Department of Public Works using orthorectified aerial photographic sets from 1968-1977.
[D] Topographic maps in AutoCAD format prepared by the City of Fillmore Engineering Department using orthorectified aerial photographs from 2004.

Sespe Creek emerges from the Lower Gorge reach into a valley that broadens consistently towards its confluence with the Santa Clara River (see Section 2.5.4). Although subtle in form, the valley morphology is generally indicative of an alluvial fan landscape in which Sespe Creek would have discharged into the Santa Clara River at different locations over time. Multiple terrace surfaces running parallel to and on either side of Sespe Creek are evident and especially visible on the LiDAR data (Figure 3-4), some of which are recorded in geological mapping as uplifted marine terraces on the adjacent hillslopes (Figure 2-1). The lowest terraces on the alluvial fan have been recorded as an alluvial feature by Dibblee (1990a [Fillmore quadrangle]), indicating that Sespe Creek has likely incised into its valley following base level changes in the lower Santa Clara River. The eastern exposure of the lowest terrace shows clearly as a pronounced terrace bluff running through the City of Fillmore along A Street, while the western terrace bluff runs along Cliff Avenue, approximately 1.7 km distant. The scallop-shaped patterning along the terrace is clear evidence that, at some time past, Sespe Creek ran along the toe of the terrace. Similar-shaped features have been produced by recent storm events and are evident at the downstream end of the Valley reach. There is no empirical evidence that the lower Santa Clara River has incised adjacent to Sespe Creek in the last 80 years (Stillwater Sciences 2007b), and so the terrace, although "recent" in geological terms, probably pre-dated European-American settlement of the region. Indeed, the City of Fillmore originally extended only to the terrace edge (Figure 1-7), suggesting that the terrace provided a clear demarcation of a flood-free zone to early settlers.

Since 1938, Sespe Creek has followed a course between the gorge and the Santa Clara River generally similar to that which is still active today. Both the west (mainstem) and east (overflow) forks of the Fillmore reach downstream of the Old Telegraph Road bridge have been continuously active during that period. Specific historical changes in lower Sespe Creek are presented below.

Channel thalweg and active channel area changes

In the Valley and Fillmore reaches, data presented in Figure 3-4 illustrates that the channel thalweg position has moved between each aerial photograph, indicating that the thalweg is re-set after each flood event. This is consistent with the notion of a highly changeable fluvial system according to the dynamics of individual storm events. The number of stream paths (i.e., multiple thalwegs) increase with downstream distance as the stream transitions to a broad, multi-thread (i.e., braided) stream closer to the confluence with the Santa Clara River. The quantity of stream paths appears to have varied little for a given season over the past 70 years.

In the Fillmore reach, evidence from aerial photographs indicates that the total area of the active channel bed bounded between the right and left banks has reduced progressively since 1938 (Figure 3-5) although, locally, the channel has eroded into the historic floodplain. The historic data reveal that there are a few areas showing widening due to bank erosion or narrowing due to accretion (e.g., bar growth or bed aggradation). For instance, the scallop-shaped expansion of the active channel bed area between photographs taken in 1938 and 1970 (near the upstream end of the 1938 photo coverage, see Figure 3-5) is most likely evidence for erosion of the right bank during the 1969 flood event. The photographs show similar, but more recent lateral adjustment by bank erosion has occurred along the right bank cross-sections XS-10B and XS-11 between the 1970s and 2005 (Figure 3-5, and Figures C-14 and C-15). Since 1977, the right bank has migrated 51 m (167 ft) at XS 10B and 83 m (273 ft) at XS 11. Active erosion along the right bank continues downstream towards the head of the west and east fork channels near XS 8B based on recent field observations and on the aerial photographic evidence (Figure 2-40), which has amounted to approximately 21 m (70 ft) between the 1970s and 2005 (Figure C-11 of XS-8B). Channel widening has also occurred along the head of the east fork (overflow) channel, which has increased in width by 143 m (469 ft) at XS 7A and 155 m (510 ft) at XS 7B.

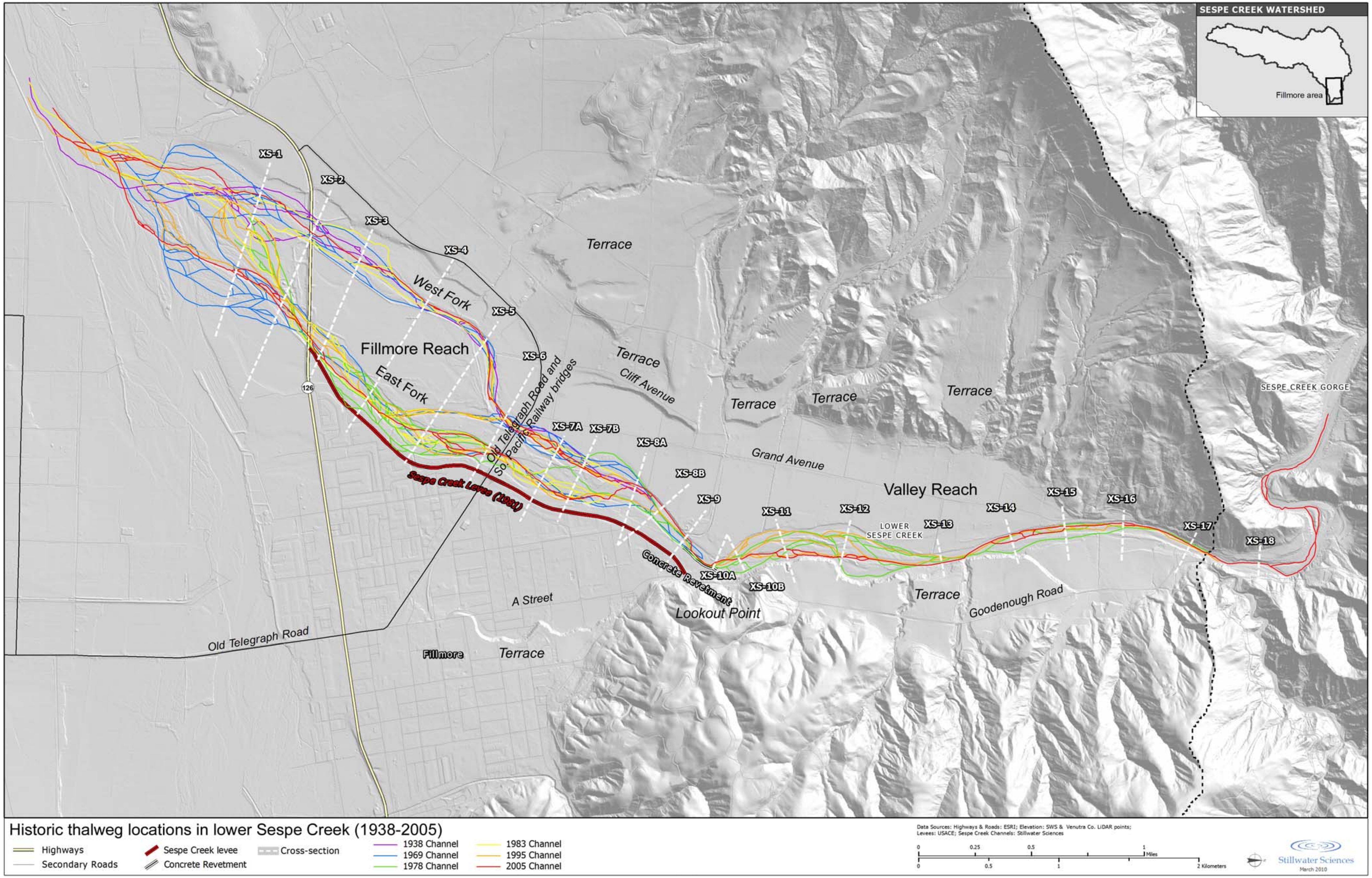


Figure 3-4. Thalweg locations during 1938, 1969, 1978, 1983, 1995, and 2005 in the Valley and Fillmore reaches of the Lower subwatershed. Multi-stage terraces are also shown.

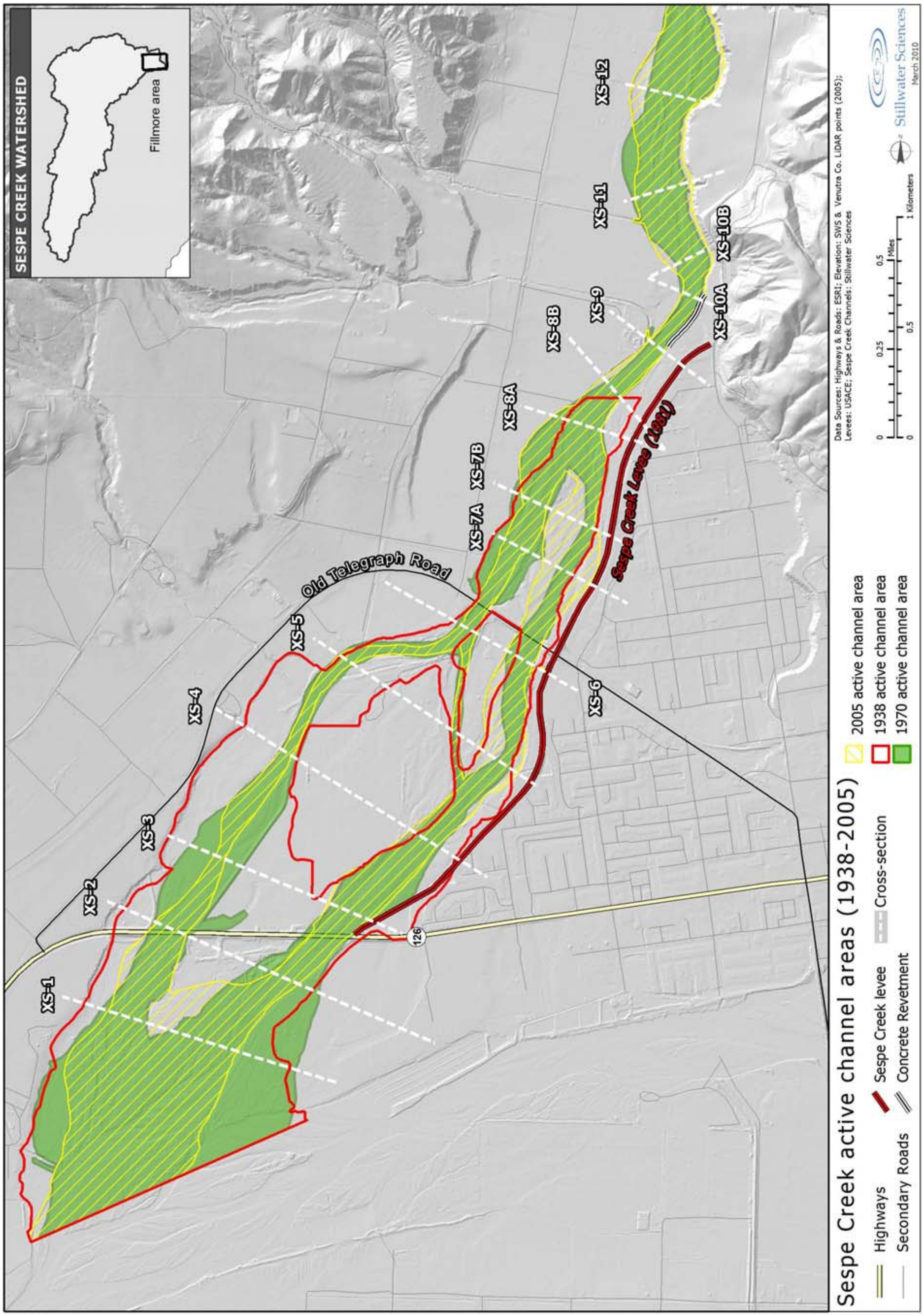


Figure 3-5. Active channel areas in 1938, 1970, and 2005 in the Fillmore reach of Sespe Creek.

Bed elevation changes

In addition to changes in the channel width, the lower Sespe Creek channel bed elevation has fluctuated over time in response to flood events, as shown in a comparison of the channel cross-sections (Appendix C). Using relatively high-precision elevation data (2-ft contour spacing) collected in the 1970s, 2004, and 2005, a general trend of net channel area capacity reduction is revealed at the majority of evaluated cross-sections (Table 3-2). This channel area reduction has been caused by bed aggradation, channel narrowing, or both. Bed lowering has occurred along some portions of the channel, but more so along the east fork (overflow) channel and particularly between the 1970s and 2004 (see discussions on post-1969 channel modifications and aggregate mining below). The comparison of 2004 and 2005 cross-sections in the Fillmore reach shows a more pronounced degree of channel area reduction due to sedimentation induced during the 2005 flood event (Note: the 2004 elevation data does not extend upstream of Lookout Point near XS-9). Figure 3-6 shows the differences in the 2004 and 2005 surface elevations of the lower Sespe Creek channel in the Fillmore reach. Areas of aggradation, as shown in red, are more extensive than areas of incision, as shown in blue. Maximum aggradation and incision that occurred as a direct result of the 2005 flood event amounted to about 10 ft (3 m) in some locations. In total, about 800,000 tonnes is estimated to have accumulated in the channel between 2004 and 2005 (Table 3-3). In comparison to the estimated sediment yield in the corresponding water year of 2005 using stream gauge data, this accumulated mass only equates to 5% of the annual total load and perhaps up to 21% of the annual coarse load; the remainder of the total sediment load was delivered to the Santa Clara River.

Table 3-2. Change in channel cross-sectional area along lower Sespe Creek. [A]

Cross-section	Change in cross-section area (ft^2) [B]				Description of channel change related to change in cross-section area	
	(1970s -2004)	2004-2005	Total (1970s-2005)		East Fork	West Fork
XS-1	-1,420	-4,920	-6,340	Reduction	1970s – 2005: aggradation	1970s – 2004: aggradation; 2004 – 2005: incision and migration
XS-2	-5,900	-2,630	-8,530	Reduction	1970s – 2005: incision and narrowing	1970s – 2005: aggradation
Highway 126 bridge crossing						
XS-3	-3,840	-1,870	-5,710	Reduction	1970s – 2004: incision 2004 – 2005: aggradation	1970s – 2005: aggradation
XS-4	670	-830	-160	Reduction	1970s – 2004: incision 2004 – 2005: aggradation	1970s – 2005: aggradataion
XS-5	670	-1,010	-340	Reduction	1970s – 2004: incision and migration; 2004 – 2005: aggradation	1970s – 2005: aggradation
Old Telegraph Road and Railway bridges crossing						
XS-6	800	-1,130	-330	Reduction	1970s – 2005: widening	1970s – 2005: aggradation
XS-7A	4,380	-1,290	3,090	Enlargement	1970s – 2004: incision and widening 2004 – 2005: aggradation	1970s – 2004: incision 2004 – 2005: aggradation

Cross-section	Change in cross-section area (ft^2) [B]				Description of channel change related to change in cross-section area	
	(1970s -2004)	2004-2005	Total (1970s-2005)		East Fork	West Fork
XS-7B	90	-620	-530	Reduction	1970s – 2005: incision and migration	1970s – 2005: aggradation
					Mainstem (upstream of east and west forks)	
XS-8A	-260	-1,350	-1,610	Reduction	1970s – 2004: incision and migration 2004 – 2005: aggradation	
XS-8B	770	-1,130	-360	Reduction	1970s – 2004: migration and widening 2004 – 2005: aggradation and widening	
XS-9	-170	-1,240	-1,410	Reduction	1970s – 2004: incision and narrowing 2004 – 2005: aggradation	
XS-10A	2004 topographic data do not extend this far upstream		-1,670	Reduction	1970s – 2005: aggradation	
XS-10B			30	Enlargement	1970s – 2005: migration	
XS-11			-5,150	Reduction	1970s – 2005: aggradation	
XS-12			2,220	Enlargement	1970s – 2005: migration	
XS-13			-1,460	Reduction	1970s – 2005: aggradation	
XS-14			-710	Reduction	1970s – 2005: aggradation	
XS-15			-420	Reduction	1970s – 2005: aggradation	
XS-16			210	Enlargement	1970s – 2005: incision and migration	
XS-17			-220	Reduction	1970s – 2005: channel incision and aggradation	
XS-18			760	Enlargement	1970s – 2005: incision	

[A] See cross-section figures in Appendix C.
[B] Values are indicated as either positive or negative and are reported in the units provided in the source data (i.e., 2-ft contour topographic maps). Positive values indicate an enlargement in the cross-sectional area (e.g., incision, widening), while negative values indicate a reduction in the cross-sectional area (e.g., aggradation, narrowing).

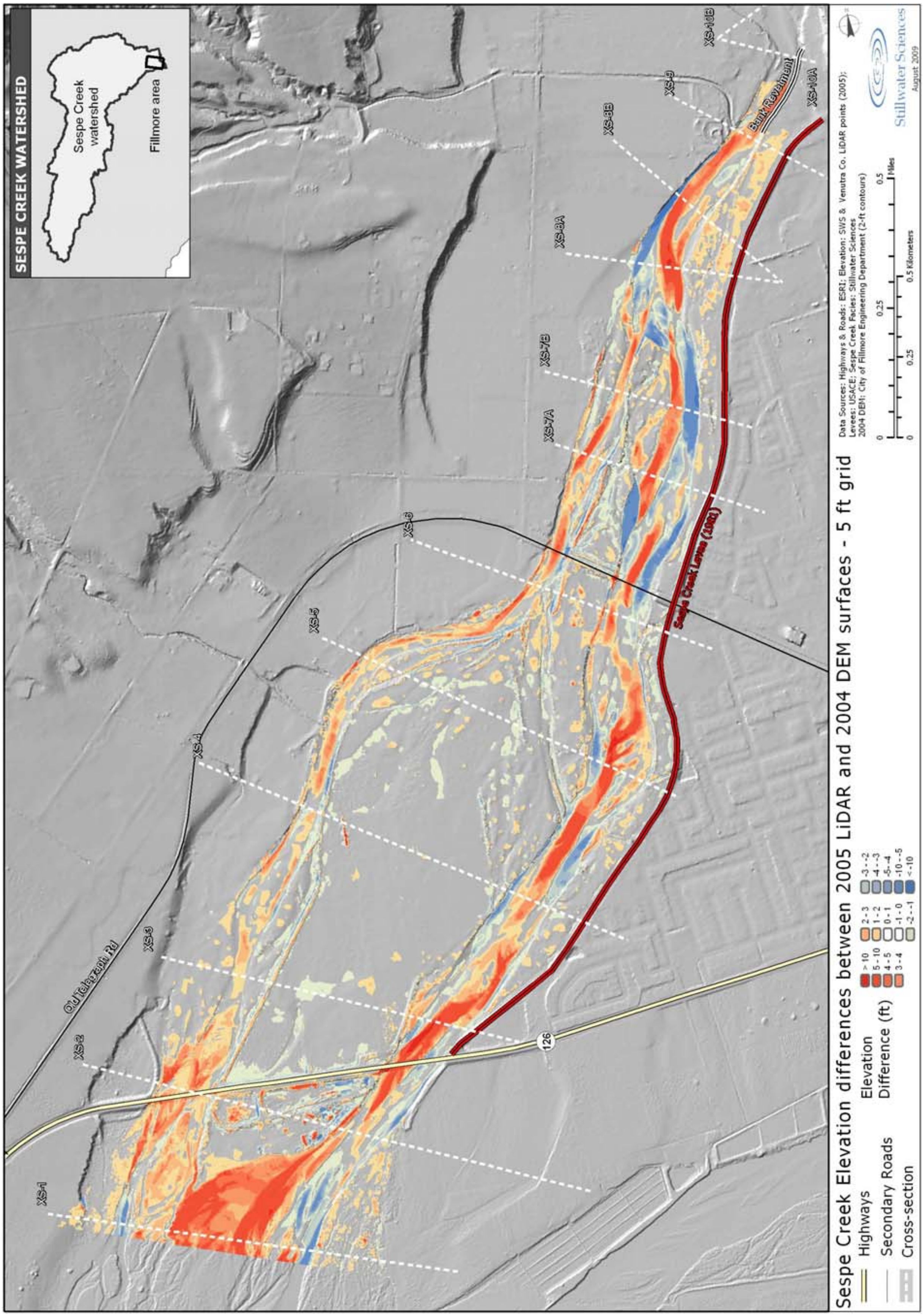


Figure 3-6. Channel surface elevation differences between 2004 and 2005 in the Fillmore reach of Sespe Creek.

Table 3-3. Change in the amount of stored sediment in the Fillmore reach of lower Sespe Creek between 2004 and 2005.

Total change [A]			Estimated watershed sediment yield in corresponding water year of 2005		% of estimated annual watershed sediment load deposited in reach	
			Total load	Coarse load	Total load	Coarse load
(yd^3)	(m^3)	(tonnes)[B]	(tonnes)	(tonnes)	(%)	(%)
522,900	399,800	799,600	16,377,000	3,872,000	5	21

[A] Values are indicated as either positive or negative and are reported in the units provided in the source data (i.e., 2-ft contour topographic maps).
[B] Assumed bulk density of 2.0 tonnes per cubic meter.
[C] Water year of 2005: 9/30/04 – 9/30/05.

Bed elevation changes along lower Sespe Creek following the 2005 flood event (i.e, after the 2005 LiDAR data were collected) are not known, but evidence at the nearby stream gauge indicates the channel bed returning to its original elevation following the passage of sediments in the 2005 flood event. A comparison of inferred bed elevations for a given discharge, before and after the 2005 flood event at the USGS stream gauging station downstream of Little Sespe Creek, reveals temporary aggradation and subsequent re-incision of the channel bed.

Table 3-4. Change in stream gauge height before and after the 2005 flood event (USGS 11113000).

Date	Daily discharge		Gauge height		Gauge height change		Aggradation / incision
	($m^3 s^{-1}$)	(cfs)	(m)	(ft)	(m)	(ft)	
7 May 2003	6.8	240	1.57	5.16			
11 April 2005	6.6	233	3.26	10.7	1.69	5.54	Aggradation
5 March 2008	6.6	232	1.59	5.23	-1.67	-5.47	Incision

Shifts between the east and west forks

Between the years of 1938 and 1975, the dominant fork of Sespe Creek was the west fork (mainstem), although the widths of the two forks were comparable and both conveyed flood waters (e.g., 1969) (see Figure 3-5 showing active channel areas). Following the floods of 1969, the west fork was channelized as shown on aerial photos taken in 1970 (Figure 3-7). The straight, trapezoidal channel form extended 1 km from where the fork begins down to and slightly beyond the Old Telegraph Road bridge, and is relatively narrow as compared to the active bed width of either of the west or east fork channels. Aerial photos taken during the 1969 floods clearly show that this segment was previously braided and un-channelized. The dredging and channelization of the west fork was likely intended to promote flow into the west fork while repairs were made to the east span of the Southern Pacific Railway bridge that was destroyed during the floods of 1969. The east fork channel may have also been re-configured, and possibly backfilled, based on evidence of tractor marks and the diversion of all flow to the west fork. The straight channel form of the west fork appears to have been reworked naturally by the creek as of 1980.

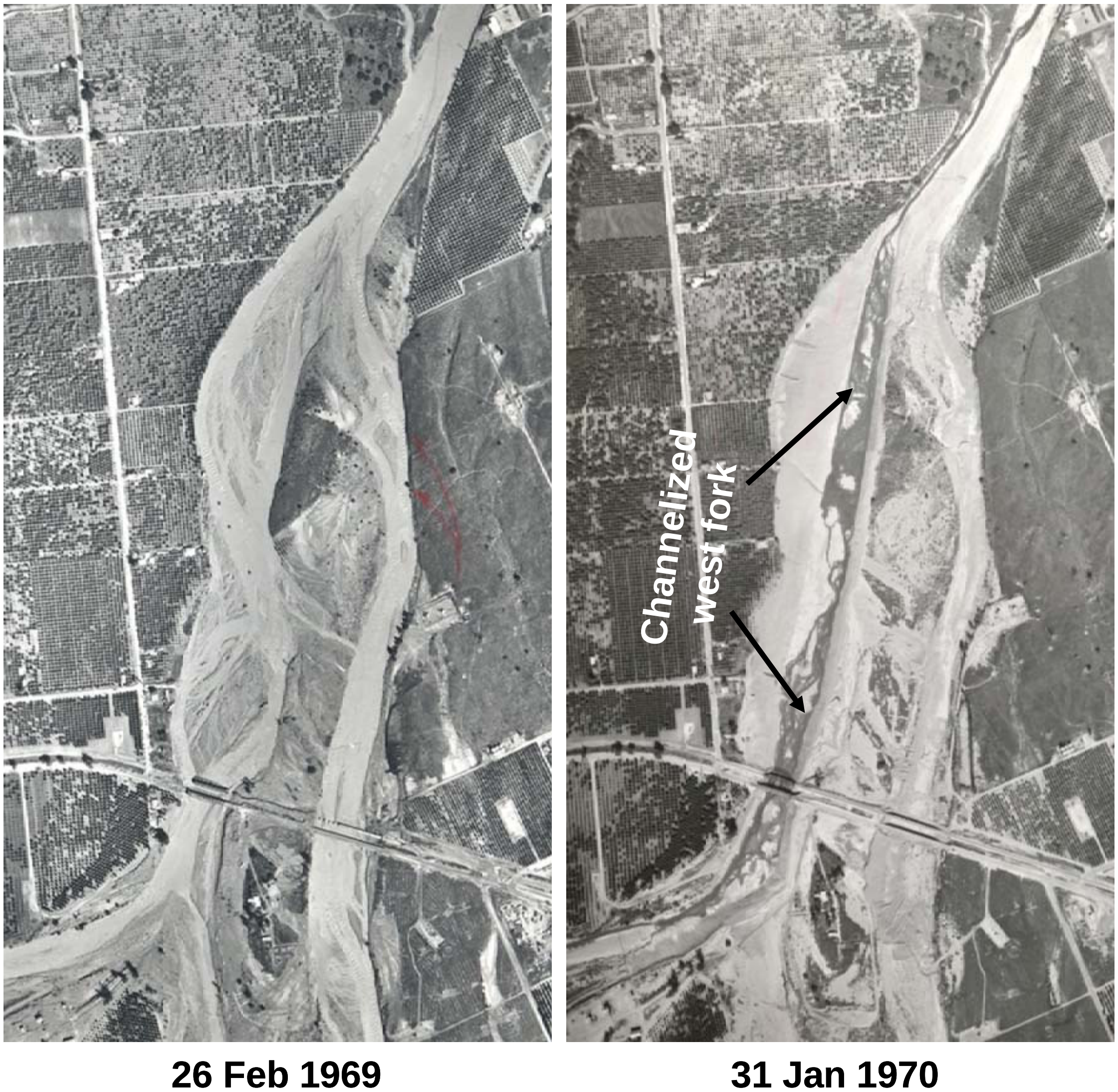


Figure 3-7. Aerial images taken in 1969 (left) and 1970 (right) of the Fillmore reach of lower Sespe Creek showing a channelized form of west fork (mainstem) channel upstream and downstream of the Old Telegraph Road bridge in 1970. The east spans of the road and railway bridges were damaged during the 1969 floods and were repaired before 1970.

Since 1978, the dominant channel has generally been the east fork. With the construction of the Sespe Creek Levee in the early 1980s, the east fork channel was partially modified to accommodate the levee and its associated groins that are buried beneath the adjacent floodplain area between the active channel and the levee (USACE 1980). Since its construction, the dominant channel has been the east fork, either as intended by the levee's overall design or as a consequence to its presence in the Fillmore reach. Aggregate mining in the east fork channel during this period may have also influenced this change (see below).

Aggregate mining effects

Potential impacts of in-channel aggregate mining operations are briefly evaluated here based on information provided through Ventura County and U. S. Army Corps permit records. Since 1985, a single aggregate mining company has held a 30-year Conditional Use Permit (CUP #4185) to extract sand and gravel materials from the lower Sespe Creek channel between the Old Telegraph Road bridge and 610 m (2,000 feet) downstream of the Highway 126 bridge (West Coast 2006, Ventura County 2008). The permit area size is 239.3 acres; however, the excavation area size indicated on the permit is only 98.8 areas in the east fork channel only. Excavation of the west fork channel was allowable only under special circumstances (e.g., mitigation measure of the action and/or related to the Flood Control District's construction of a diversion channel in the west fork channel). The Interim Management Plan application submitted in November 2006 summarized past mining activities (West Coast 2006):

- Excavation activities occurred between 1986 and 1992. (Note: excavation activities may resume in summer/fall 2010 [see below].)
- Mining was restricted to dry gravel bars and extended vertically down to the "prescribed mining depth", or approximately 5-feet above the groundwater level (as indicated in the field by the water surface elevation in the low flow channel).
- Approximately 700,000 tonnes (780,000 tons) of aggregate materials were excavated from the east fork of Sespe Creek between 1986 and 1992, with amounts diminishing over this period (Table 3-5).

The amount of sediment excavated from the creek during mining operations represents about 25% of the total sediment yield estimated for the watershed during that period (see Figure 3-2), but represents over 100% of the estimated coarse sediment yield during that period (Table 3-5). The latter result indicates, simply, that more coarse sediment was removed from the channel during this period than could have been replaced by coarse sediment delivered from upstream. As such, the result of the mining activity is likely to have been to lower bed elevations in the east fork channel, an interpretation corroborated by channel bed lowering depicted in the cross-sections between Highway 126 and Old Telegraph Road bridges (i.e., XS-3, XS-4, and XS-5) (see Figures C-4, C-5, and C-6 in Appendix C). Related to this change, lower bed elevations in the east fork will create an imbalance between flood flows carried by the west and east forks of Sespe Creek that encourage the east fork channel to become the dominant channel.

Aggregate mining has not occurred since 1992 but, in 2006, the mining operators were granted permits from various state and federal agencies (e.g., USACE) to resume mining of upper bar surfaces and river terrace banks within the permit area until their CUP expires in 2015. The permitted extraction amount is approximately 91,200 yds^3, equivalent to about 140,000 tonnes, during this period (USACE 2007). Aggregate mining activities are expected to resume in summer or fall of 2010 (B. Henderson, pers. comm., 2010). Assuming the permitted extraction amount of 140,000 tonnes is distributed evenly across the next 6 years (2010 – 2015), the average annual extraction amount would be approximately 23,300 t a^{-1}, or approximately 10% of our predicted annual coarse sediment load from the watershed (235,000 t a^{-1}). However, extraction activities that serve to lower bed elevations in the east fork relative to the west fork will serve to promote scouring flood flows in the east fork (especially where excavation occurs prior to a large flood event) and potentially encourage the formation of a knickpoint that could propagate upstream, furthering the enlargement of the east fork channel and continuing the diversion of the majority of flow into that channel.

Table 3-5. Reported amount of aggregate materials excavated from lower Sespe Creek with comparisons against the estimated annual sediment yields from the watershed.

Year	Total amount excavated [A, B]		Estimated total sediment yield from the watershed in corresponding water year [C]	Estimated coarse sediment yield from the watershed in corresponding water year [C]	% of excavated amount from the estimated annual total sediment yield	% of excavated amount from the estimated annual coarse sediment yield
	(tonnes)	(tons)	(tonnes)	(tonnes)		
1986	308,801	340,395	268,214	63,847	115	484
1987	0	0	1,712	355	0	0
1988	0	0	73,903	17,548	0	0
1989	190,519	210,011	1,642	319	11,603	59,724
1990	90,145	99,367	2,903	645	3,105	13,976
1991	83,946	92,534	371,518	88,485	23	95
1992	33,360	36,773	2,065,752	490,461	2	7
Total [D]	**706,771**	**779,080**	**2,785,645**	**661,660**	**25**	**107**

[A] Source: Blue Star Materials interim management plan application (West Coast 2006).
[B] Source document describes this amount as the "total amount delivered", which is assumed here to equal the total amount excavated from the channel.
[C] Estimated by Stillwater Sciences using the sediment rating curve established at the USGS stream gauge in Fillmore (see Figures 3-1 and 3-2). Note: the daily mean flow values for WY 1986-1990 were absent for this gauge, but were derived here based on a correlation (R^2=86%) with the nearby Santa Paula Creek gauge (USGS 11113500).
[D] The total excavated amount reported here may under-estimate the actual amount excavated during this period because some annual amounts were not reported in the source document. The total estimated sediment yields span the entire period of 1986 to 1992.

Bridge effects

Besides the Sespe Creek Levee and the concrete bank revetment in the Lookout Point area, the other major infrastructure elements directly in contact with lower Sespe Creek are the bridges of Highway 126, Old Telegraph Road, and Southern Pacific Railway (see Figure 3-4). These bridges each span the entire width of the creek channel and include bridge pilings to support them above the channel. The bridge abutments on either side of the channel act to fix the channel width, preventing any natural bank erosion from occurring, while the pilings create turbulent flow conditions when flows are high in the channel. The differential flows passing by the pilings result in variable occurrences of scour (where flows concentrate) and deposition (where flows slow down). This sort of variable scour and deposition is clearly seen in the photograph of the Southern Pacific Railway bridge where scouring flows exposed piling foundations and sediment deposition buried adjacent piling foundations (Figure 2-41). These structures, therefore, clearly have an influence on sediment transport through lower Sespe Creek by altering flow patterns and promoting locally variable bed erosion and deposition.

4 DISCUSSION

4.1 Summary: understanding of current conditions

The Sespe Creek watershed is a steep, remote mountainous river basin of the Western Transverse Ranges. Rates of tectonic uplift are rapid and on the order of 3–5 mm per year. Sediment supplied from the upper watershed is delivered through the Sespe Creek gorge onto the alluvial fan of the Lower subwatershed of Sespe Creek. Seventy percent of the watershed is federally designated as wilderness and a large portion of Sespe Creek was granted Wild and Scenic status in 1992. Population in the watershed is sparse and concentrated at the City of Fillmore, which occupies a terrace and the adjacent floodplain to the east of Sespe Creek and north of the confluence with the Santa Clara River. The original settlement occupied the eastern terrace above the present-day elevation of Sespe Creek. Riparian clearing first opened the area for grazing and then orchard-based agriculture on the floodplain, but urban development in Fillmore over the last 40 years has replaced orchards on the floodplain areas east of the creek.

The semi-arid climate of the region makes Sespe Creek subject to large, flashy flood events that almost always coincide with El Niño years, and which have a recurrence interval of 3–8 years. Intensification of El Niño storms over the last 40 years has made large flood events far more frequent in recent times; examples include the very large floods in 1969, 1978, 1995, and 2005 (the largest flood of record). Flood risk to the floodplain residents of Fillmore was addressed with the construction of a 3.3 km (2 mi) long, rock-revetted levee built in 1981, and now subject to management reassessment.

In the upper watershed, the semi-arid climate supports chaparral vegetation which is naturally vulnerable to periodic wildfires. The Day Fire, the second largest fire recorded in the watershed, burned one-third of the watershed in September 2006 and effectively denuded the vegetation from the steep hillslopes throughout the burned areas. This event has raised concerns for the potential impact of increased sediment yields leading to sedimentation and the rise of bed elevations in the lower reaches of Sespe Creek, which might increase flood risk to the City of Fillmore.

Long-term sediment production in the watershed can be subdivided into two primary components. Large volumes of fine sediment (i.e., silts and clays) are derived from highly erodible siltstones and mudstones throughout the watershed, whereas coarse sediment is derived primarily by rockfall from much harder sandstones and granitic rocks in the Middle and Gorge subwatersheds. Rates of coarse sediment production are much lower than those of fine sediment; however, coarser-grained sediments such as gravel, cobbles and boulders have great importance to the structure of the fluvial system. Field measurements of coarse sediment in the Lower subwatershed suggest that the gorge is capable of delivering and transporting coarse sediment from the upper watershed, unlike some bedrock constrictions in the adjacent Santa Paula Creek watershed. Not surprisingly, field observations in the Sespe Creek watershed suggest higher rates of sediment production in areas underlain by erodible, shaley bedrock, sparse vegetation, and steep hillslopes (>60%).

Classifying the watershed into three field-assigned rates of sediment production (low, medium and high) based on combinations of geology, vegetation, and hillslope gradient indicates that the majority of the watershed has "medium" rates of sediment production, which suggests relatively homogeneous rates of sediment production throughout the watershed. Quantifying the rate of sediment production used a methodology previously developed for the neighboring Santa Paula Creek watershed. Numerical values of sediment production rates associated with the three classifications were determined from county-reported rates of debris basins. The rates used in this study were derived from measured rates of sediment delivery to five nearby debris basins, with reasonably good success, particularly given the confounding effects of basin size, slope aspect, and relative precipitation. The resulting predicted average annual rate of sediment yield from Sespe Creek is 1,760 t km^{-2} a^{-1}. By comparison, the long-term average annual rate of sediment production for all particle sizes (i.e., total yield) from analysis of gauging records at the USGS stream gauge at the upstream end of the Valley reach is 1,523 t km^{-2} a^{-1}, a surprising level of agreement for studies of this kind. The rate of sediment yield implies an annual average rate of denundation in Sespe Creek of 0.6 mm, which is consistent with the notion that rates of uplift (3–5 mm a^{-1}) must be significantly higher than the rate of lowering to explain the high elevations and relict uplifted landforms of the upper watershed.

The potential for wildfire in the Sespe Creek watershed upstream of the Sespe Creek gorge is high, in part because of the dominance of chaparral vegetation. Overall, 73% of the area has burned at least twice in the last century, with 19 major fires in the period of 1915-2007. Seven of these fires burned over 40 km^2 (6% of the watershed). The largest fire on record was the 1932 Matilija Fire, but three recent fires round out the largest four events, including the Day Fire (2006) as the second largest recorded event, the Wheeler #2 fire (1985) as the third, and the Piru Fire (2003) as the fourth. Each burned more than 80 km^2 (12%) of the watershed.

Wildfire affects the processes and mechanisms of sediment production and delivery and has the potential to dramatically increase hillslope sediment yield. Changes to vegetation and rainfall-runoff relationships, soil structure, and rock weathering are important processes, resulting in greater sediment production through dry ravel, rilling, and debris flows. The impact of an individual precipitation event on post-fire erosion depends on the wildfire extent and severity, the time since the fire, and the intensity of the first post-fire precipitation event. Wildfire impacts on sediment production wane after about 5–10 years as vegetation recovers. At larger spatial scales, the impact of wildfire becomes masked by sediment storage opportunities and the requirement for large fluvial events to transport fire-derived sediment through the channel network.

Comparison of three methods indicates the range, and likely uncertainty, of predicted impacts from the recent Day Fire in Sespe Creek on sediment production and delivery into the mainstem channel. The USFS BAER method, based on debris basin information compiled in 1949, indicates a 6-fold increase in total sediment yield from the watershed, primarily as a function of up to a 20-fold increase in sediment production locally in the highly burned Hot Springs Canyon and West Fork Sespe Creek tributaries. Using our earlier methodology for calculating sediment production, but including a loss of vegetation cover as a consequence of wildfire, predicts a 10-fold increase in sediment production across burned areas, resulting in an overall 4-fold increase in sediment yield from the Sespe Creek watershed as a whole. In contrast to these predicted order-of-magnitude increases in local sediment production, a previously published regression equation of Scott and Williams (1978) would predict only a maximum 3-fold sediment-yield increase across burned areas. The actual downstream impact of this predicted 3- to 20-fold increase in sediment production in the burned areas of the watershed depends upon antecedent rainfall and sediment-storage conditions, the magnitude of the first post-fire rainfall event and, critically, the routing of the sediment through lower Sespe Creek.

According to field observations in spring 2008, the impact of wildfire events throughout the channel network is variable. In the Upper subwatershed, most recently burned by the 2002 Wolf Fire, new vegetation growth is evident and few sediment accumulations along the channel network remain. Conversely, in the Middle subwatershed (80% burned by the Day Fire in 2006), accumulations of poorly-sorted sediment are common at tributary mouths. Upslope evidence of hillslope rilling, gullying, sheetwash, and debris accumulations is abundant and little vegetation recovery is evident. Farther downstream in the confined and steeper Lower Gorge reach, there is frequent evidence of the infilling of pools by sandy sediments, locally as deep as 5 m. Observations by local Ventura County agency staff suggest that pool infilling occurred during moderate high flows in 2008. This is consistent with the notion of the progressive downstream transport of sediment derived from the 2006 fire event. Because the Day Fire occurred close to the gorge, where locations for fluvial sediment storage are relatively limited, the additional sediment load is probably best understood as a pulse of sediment that is delivered with little or no attenuation to the reaches of the Lower subwatershed from the gorge.

Sespe Creek exits the Lower Gorge reach and forms a large, low-gradient alluvial fan that extends to the confluence with the Santa Clara River. The channel is at first incised and single-threaded before giving way to multiple channel "braids" in the vicinity of Fillmore and the Sespe Creek Levee. The creek bed is composed largely of poorly-sorted cobble-gravel deposits, indicative of its nature as a highly dynamic creek during high flow events. Sporadic evidence for lateral migration and bank erosion is evident and occurs during flood events, when the thalweg of this otherwise largely straight channel becomes directed at the channel banks. The channel becomes bifurcated downstream alongside the levee in two forks, known as Sespe Creek (west fork) and Sespe Creek Overflow (east fork). These two forks have existed for many years; currently, the majority of flow is conveyed by the east fork (overflow) channel that is closest to the levee and the City of Fillmore.

Sediment delivery to the lower reaches of Sespe Creek is sporadic, occurring during short-duration, high-intensity storm events. Using daily flow data between 1928–2009 and sediment sampling measurements taken by the USGS at the Sespe Creek gauge (1966–1978), annual sediment transport loads have varied between 250 tonnes transported in WY 1951 to 16 million tonnes transport in WY 2005, which contains the flood of record. As previously noted, the average annual yield is 1,523 t km^{-2} a^{-1} over this time period. Four high-flow years with large floods (WY 1969, 1978, 1995, and 2005) account for over half the total sediment yield. Because large floods occur almost always in El Niño years, and strong El Niño events have occurred with greater frequency in the last 40 years, that average of annual sediment yields is five times higher in the 'wetter" period since 1960 than in the preceding period of record. The "dominant discharge" (i.e., the single discharge of given frequency that performs the most work in terms of sediment transport over the long term) is the largest flow event on record (2005), because of the very high rates of sediment transport and the wide range of high flow events. In contrast, humid-region rivers typically have a dominant discharge that is an intermediate flood event (the bankfull flow) with a return period in the range of 1.5 to 2 years. This difference speaks to Sespe Creek as a highly dynamic river environment.

Historical evidence for the morphology of the Lower subwatershed reaches of Sespe Creek from air photos, LiDAR, and cross-sections indicates that the creek flows over an alluvial fan whose floodplain is bounded on each bank by an alluvial terrace that is recent in geological time, but pre-dates European-American settlement of the region. Since 1938, aerial photographs indicate that Sespe Creek has occupied a largely similar course through its alluvial fan, although the overall active channel area closer to the mouth seems to have reduced, suggesting a narrower channel. Near the upstream end of the levee, sporadic bank erosion during large floods has added to the active channel bed area. The location of the channel thalweg (or thalwegs, where braided) has re-set after each flood event. Since the 1970s, the cross-sectional capacity of the channel has generally decreased, as driven by aggradation, channel narrowing, or both, and occasionally has been related to lateral migration of the channel (e.g., near the Lookout Point area). Comparison of 2004 and 2005 elevation data reveals that the 2005 floods acted as a depositional event, likely mobilizing a relatively large volume and particle size distribution of stored sediments in upstream areas and delivering this load—estimated at 16 M tonnes—to lower Sespe Creek; however, this amount only represents 5% of the annual total load estimated at the nearby stream gauge. Although not confirmed in the field at the analyzed cross-section locations, evidence of bed lowering since the 2005 depositional event is provided by measurements taken at the stream gauge: the bed rose and fell approximately 1.7 m from 2003 to 2005 to 2008.

Aerial photographic evidence indicates that the west fork of Sespe Creek carried more discharge than the east fork (overflow) from some period before 1938 to after 1975. In 1970, the west fork was channelized to divert further flow from the east fork to permit repairs to the railroad crossing damaged in the 1969 flood. By about 1978, flow was instead focused in the east fork and has remained so until the current day. This condition may have been exacerbated by the construction and/or presence of the Sespe Creek Levee or by aggregate mining activities that operated in the east fork channel and reportedly removed 700,000 tonnes of sediment in a seven year period, thereby lowering the channel bed elevation and promoting the capture of a greater proportion of the flow in Sespe Creek. The other significant effect to the lower Sespe Creek morphology is the crossing of three bridges that have locally altered flow patterns and promoted variable patterns of bed scout and deposition.

4.2 Change in Sespe Creek and Implications for Management

The evolutionary trajectory for Sespe creek is far less clear than for neighboring Santa Paula Creek (Stillwater Sciences 2007a), or the lower Santa Clara River (Stillwater Sciences 2007b). This occurs in part because there is a relative paucity of historical information, preventing a detailed reconstruction of past channel conditions. However, it also reflects a relative smaller impact from human actions in the watershed: Sespe Creek is a relatively pristine watershed in many respects. Human influences have occurred since European-American settlement of the region, but apart from changes possibly brought about by grazing during the latter half of the Nineteenth century, other human impacts have been relatively mild. For instance, citrus agriculture in the Lower subwatershed may have led to changes in runoff but the overall impact in the watershed is small; there are few roads in the watershed, reducing probable road-related impacts; there are no large dams or diversion structures to enact significant flow regulation; urban development occupies only the extreme downstream end of the watershed, limiting its overall impact on watershed runoff; and, until recently, floodplain development was minimal. Further, apart from road and rail crossings, direct channel management of Sespe Creek was also limited until recently—Sespe Creek has not been subject to large-scale straightening (although pilot channels have been occasionally excavated to direct low flows after large floods), and the Sespe Creek Levee was not built right to the channel edge and instead follows the natural swing of the river, leaving the revetted portion of the left bank upstream of the levee and the short-term aggregate mining operations in the Fillmore reach as the only major direct interventions in channel processes.

Sespe Creek is potentially vulnerable to changes to its downstream base level caused by human impacts on bed elevations in the Santa Clara River, but there is little evidence of any influence, based on a 70-year reconstruction of bed elevations in the Santa Clara River (Stillwater Sciences 2007b). Incision, however, may have occurred earlier in the history of European-American occupation. The other major potential human influence on fluvial processes in Sespe Creek is the potential for altered rates of sediment delivery as a result of changes in the frequency of wildfire (caused by accidental or deliberate fire starts). The extent of this influence is undetermined, but it is apparent that the Sespe Creek watershed is naturally susceptible to wildfire simply as a consequence of climate and vegetation type.

The effects of the 2006 Day Fire, in addition to several other recent wildfires, include a short-term (5 – 10 years) increase in fine sediment-production from burned hillslopes and subsequent delivery to the mainstem channel. Because these materials are easily transported by Sespe Creek downstream and out of the watershed within a relatively short period of time and because coarse sediment production did not appear to increase following the wildfire event, it is unlikely that significant post-fire sedimentation throughout the lower reaches will occur. However, continued monitoring of the channel's flow capacity at the cross-sections analyzed in this study is recommended to identify local variations in channel width and depth.

Given the relatively mild human impact, and because Sespe Creek is extremely flashy and capable naturally of transporting a very wide size distribution of sediment, it is probable that geomorphic functions in the Lower subwatershed reaches are largely those imposed by progressive environmental fluctuation rather than human influence. Shorter-term morphological changes in Sespe Creek likely occur as a function of climate oscillations and change that influence vegetation cover, the natural frequency of wildfires, and the frequency of large flood events, all of which influence sediment production, delivery, and transport through the watershed. By this perspective, the morphology of the Lower subwatershed reaches also should oscillate, with stochastic variations in bed level and planform position over time (unless subject to the influence of accelerated climate changes). Channel position will shift and bed elevations will rise and fall according to the primary controls on sediment delivery to the creek, namely the influence of sediment pulses caused by wildfire (sediment production and delivery to the channel network) and flood events (sediment transport through the channel network).

In terms of flood management, it is logical that hydraulic calculations are set against the extent of likely fluctuations in bed elevation caused by the transmission of a sediment fan or pulse emanating from the mouth of Sespe Creek gorge. For flood risk assessment, flood routing would utilize a period of maximum likely bed elevation as the starting condition, to provide a worst-case scenario. Using our GIS-based analyses, one worse-case scenario would involve pulsing a sediment accumulation of "excess" sediment equating to 4.3 million tonnes (the additional sediment load derived from the extent of the Day Fire burn area [see Table 2.7]) of known sediment size distribution through Sespe Creek using a variety of different flow scenarios, including larger and smaller high flow events.

The Fillmore reach of Sespe Creek is thus a naturally highly dynamic environment subject to "re-setting" by very large floods rather than progressive alteration by intermediate flood events. Re-setting may involve significant bed aggradation during single floods (e.g., 2005), accompanied by abrupt changes in the creek's course. As such, the utility of historical knowledge in making precise future predictions is limited only to guidance. Instead, it should be recognized that the entire alluvial fan extent of Sespe Creek is potentially part of the active channel bed, and that modifying fluvial processes by "training" the creek, either through channelization, dredging, bridge constriction, or levees, is likely to result in understandable but largely unpredictable responses by the stream morphology during large flood events. While it is not possible to deterministically predict such possible changes, modeling the potential fluctuation in bed levels resulting from our predicted range of sediment yields delivered from the upper watershed should help quantify the possible risk to those residing on the adjacent floodplain areas.

5 REFERENCES

5.1 Printed Sources

Ackers, P. and F. G. Charlton. 1971. The slope and resistance of small meandering channels. Institute of Civil Engineers Proceeding Supplement XV, Paper 73625.

Andrews, E., R. Antweiler, P. Neiman, and F. Ralph. 2004. Influence of ENSO on flood frequency along the California Coast. Journal of Climate 17: 337-348.

Argus, D. F., M. B. Heflin, A. Donnellan, F. H. Webb, D. Dong, K. J. Hurst, D. C. Jefferson, G. A. Lyzenga, M. M. Watkins, and J. F. Zumberge. 1999. Shortening and thickening of metropolitan Los Angeles measured and inferred by using geodesy. Geology 27: 703-706.

Ballais, J.-L., and M.-C. Bosc. 1994. The ignifracts of the Sainte-Victoire Mountain (Lower Provence, France). Pages 217-227 *in* M. Sala and J. L. Rubio, editors. Soil erosion and degradation as a consequence of forest fires. Geoforma Ediciones, Logroño, Spain.

Barro S. C., P. M. Wohlgemuth, and A. G. Campbell. 1988. Post-fire interactions between riparian vegetation and channel morphology and the implications for stream channel rehabilitation choices.

Benda, L., and T. Dunne. 1997. Stochastic forcing of sediment supply to channel networks from landsliding and debris flow. Water Resources Research 33: 2849-2863.

Blair, T., and J. McPherson. 1994. Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages. Journal of Sedimentary Research 64: 450-489.

Blythe, A. E., D. W. Burbank, K. A. Farley, and E. J. Fielding. 2000. Structural and topographic evolution of the central Transverse Ranges, California, from apatite fissiontrack, (U/Th)/He and digital elevation model analyses. Basin Research 12: 97-114.

Bonnin, G. M., D. Martin, B. Lin, T. Parzybok, M. Yekta, and D. Riley. 2006. Precipitation-frequency atlas of the United States. NOAA Atlas 14, Volume 1, Version 4. NOAA, National Weather Service, Silver Spring, Maryland.

Boughton, D. A., P. B. Adams, E. Anderson, C. Fusaro, E. Keller, E. Kelley, L. Lentsch, J. Nielsen, K. Perry, H. Regan, J. Smith, C. Swift, L. Thompson, and F. Watson. 2006. Steelhead of the southcentral/southern California coast: population characterization for recovery planning. NOAA Technical Memorandum NMFS. October 2006.

Buffington, J. M., and D. R. Montgomery. 1999. A procedure for classifying textural facies in gravel-bed rivers. Water Resources Research 35: 1903-1914.

Burbank, D. W., J. Leland, E. Fielding, R. S. Anderson, N. Brozovic, R. Reid-Mary, and C. Duncan. 1996. Bedrock incision, rock uplift and threshold hillslopes in the northwestern Himalayas. Nature 379: 505-510.

Cahill, F.. 2002. The 2002 fire prediction for the Los Padres Forest. 6 June. http://www.wildlandfire.com/docs/2003_n_before/fritzrept02.htm

Cannon, S. H., Kirkham, R. M., Parise, M., 2001. Wildfire-related debris flow initiation processes, Storm King Mountain, Colorado. Geomorphology 39: 171-188.

Cannon, S. H., J. E. Gartner, R. C. Wilson, J. C. Bowers, and J. L. Laber. 2008. Storm rainfall conditions for floods and debris flows from recently burned areas in southwestern Colorado and southern California. Geomorphology 96: 250-269.

Cayan, D., K. Redmond, and L. Riddle. 1999. ENSO and hydrologic extremes in the western United States. Journal of Climate 12: 2881-2893.

CDF (California Department of Forestry and Fire Protection). 2004. Fire perimeter GIS data. CDF, Fire and Resource Enhancement Program, Sacramento.

CDF. 2007. 20 largest California wildland fires by acreage burned. http://www.fire.ca.gov/communications/downloads/ fact_sheets/20LACRES.pdf

Çemen, I. 1989. Near-surface expression of the eastern part of the San Cayetano fault: a potentially active thrust fault in the California transverse ranges. Journal of Geophysical Research 94: 9665-9677.

Cerdà, A., and S. H. Doerr. 2005. Long-term soil erosion changes under simulated rainfall for different vegetation types following a wildfire in eastern Spain. Journal of Wildland Fire 14: 423-437.

Cleland, R. 1940. The place called Sespe. Privately printed.

Conard, S., and D. Weise. 1998. Management of fire regime, fuels, and fire effects in southern California chaparral: lessons from the past and thoughts for the future. Pages 342-350 *in* T. L. Pruden and L. A. Brennan, editors. Proceedings of the conference on fire in ecosystem management: shifting the paradigm from suppression to prescription. Tall Timbers Research Station, Tallahassee, Florida.

Copeland, O. L. 1965. Land use and ecological factors in relation to sediment yields. Pages 72-84 *in* Proceedings of the federal interagency sedimentation conference, 1963. Miscellaneous Publication 970. U. S. Department of Agriculture, Washington, D. C.

Cui, Y., G. Parker, T. E. Lisle, J. Gott, M. E. Hansler-Ball, J. E. Pizzuto, N. E. Allmendinger, and J. M. Reed. 2003a. Sediment pulses in mountain rivers: 1. Experiments. Water Resources Research 39: 1239, doi: 10.1029/2002WR001803.

Cui, Y., G. Parker, J. Pizzuto, T. E. and Lisle. 2003b. Sediment pulses in mountain rivers: 2. Comparison between experiments and numerical predictions. Water Resources Research 39: 1240, doi: 10.1029/2002WR001805.

Cui, Y. and G. Parker. 2005. Numerical model of sediment pulses and sediment supply disturbances in mountain rivers. Journal of Hydraulic Engineering 131: 646-656.

Cui, Y., G. Parker, C. Braudrick, W. E. Dietrich, and B. Cluer. 2006a. Dam Removal Express Assessment Models (DREAM). Part 1: Model development and validation. Journal of Hydraulic Research 44: 291-307.

Cui, Y., C. Braudrick, W. E. Dietrich, B. Cluer, and G. Parker. 2006b. Dam Removal Express Assessment Models (DREAM). Part 2: Sensitivity tests/sample runs. Journal of Hydraulic Research 44: 308-323.

Davis, F., Keller, E., Parikh, A., and Florsheim, J., 1989. Recovery of the chaparral riparian zone after wildfire. General Technical Report PSW-110, p. 194-203. USDA Forest Service, Pacific Southwest Research Station, Albany, California.

DeBano, L. F., R. M. Rice, and C. E. Conrad. 1979. Soil heating in chaparral fires: effects on soil properties, plant nutrients, erosion, and runoff. Research Paper PSW-RP-145. USDA Forest Service, Pacific Southwest Forest and Range Experimental Station, Berkeley, California.

DeBano, L. F., D. G. Neary, and P. F. Ffolliott. 1998. Fire's effects on ecosystems. Wiley, New York.

De Koff, J. P., Graham, R. C., Hubbert, K. R., P. M. Wohlgemuth. 2006. Prefire and postfire erosion of soil nutrients within a chaparral watershed. Soil Science 171: 915-928.

Dibblee, T. 1985a. Geologic map of the Old Man Mountain quadrangle, Ventura County, California. Scale 1:24,000. Dibblee Geological Foundation, Santa Barbara, California.

Dibblee, T. 1985b. Geologic map of the Wheeler Springs quadrangle, Ventura County, California. Scale 1:24,000. Dibblee Geological Foundation, Santa Barbara, California.

Dibblee, T. 1987. Geologic map of the Lion Canyon quadrangle, Ventura County, California. Scale 1:24,000. Dibblee Geological Foundation, Santa Barbara, California.

Dibblee, T. 1990a. Geologic map of the Fillmore quadrangle, Ventura County, California. Scale 1:24,000. Dibblee Geological Foundation, Santa Barbara, California.

Dibblee, T. 1990b. Geologic map of the Santa Paula Peak quadrangle, Ventura County, California. Scale 1:24,000. Dibblee Geological Foundation, Santa Barbara, California.

Dibblee, T. 1992. Geologic map of the Santa Paula quadrangle, Ventura County, California. Scale 1:24,000. Dibblee Geological Foundation, Santa Barbara, California.

Dibblee, T. 1996a. Geologic map of the Devils Heart Peak quadrangle, Ventura County, California. Scale 1:24,000. Dibblee Geological Foundation, Santa Barbara, California.

Dibblee, T. 1996b. Geologic map of the Topatopa quadrangle, Ventura County, California. Scale 1:24,000. Dibblee Geological Foundation, Santa Barbara, California.

Doerr, S. H., R. A. Shakesby, and R. P. D. Walsh. 2000. Soil water repellency, its characteristics, causes and hydro-geomorphological consequences. Earth-Science Reviews 51: 33-65.

Doerr, S. H., P. Douglas, R. Evans, C. P. Morley, N. Mullinger, R. Bryant, and R. A. Shakesby. 2005. Effects of heating and postheating equilibration times on soil water repellency. Australian Journal of Soil Research 43: 261-267.

Donnellan, A., B. H. Hager, and R. W. King. 1993. Discrepancy between geological and geodetic deformation rates in the Ventura basin. Nature 366: 333-336.

Dorn, R.I.. 2003. Boulder weathering and erosion associated with a wildfire, Sierra Ancha Mountains, Arizona. Geomorphology 55: 155-171.

Dragovich, D. 1993. Fire-accelerated weathering in the Pilbara, Western Australia. Zeitschrift fur Geomorphologie 37: 295-307.

Dunn, A. 1989. The effects of prescribed burning on fire hazard in the chaparral: toward a new conceptual synthesis. Pages 23-29 in N. H. Berg, editor. Proceedings of the symposium on fire and watershed management. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station.

Duriscoe, D. M., and W. G. Wells, II. 1982. Effects of fire on certain physical properties of selected chaparral soils. Pages 594-595 *in* C. E. Conrad and W. C. Oechel, Technical Coordinators. Proceedings of the symposium on dynamics and management of Mediterranean-type ecosystems. General Technical Report PSW-58. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

Duvall, A., E. Kirby, and D. Burbank. 2004. Tectonic and lithologic controls on bedrock channel profiles and process in coastal California. Journal of Geophysical Research 109: 1-18.

Dvorsky, J. R. 2000. The influence of valley morphology and coarse sediment distribution on rainbow trout populations in Sespe Creek, California at the landscape scale. Master's thesis, University of California, Santa Barbara.

Emmett, W. W. and G. M. Wolman. 2001. Effective discharge and gravel-bed rivers. Earth Surface Processes and Landforms 26: 1269-1380.

Erskine, W. and R.F. Warner. 1988. Further assessment of flood- and drought-dominated regimes in south eastern Australia. Australian Geographer 29: 257-261.

Florsheim, J., E. Keller, and D. Best. 1991. Fluvial sediment transport in response to moderate storm flows following chaparral wildfire, Ventura County, southern California. Geological Society of America Bulletin 103: 504-511.

Freeman, V. M. 1968. People□land□water: Santa Clara Valley and Oxnard Plain, Ventura County, California. Lorrin L. Morrison, Los Angeles.

Gabet, E. J. 2003. Post-fire thin debris flows: sediment transport and numerical modelling. Earth Surface Processes and Landforms 28: 1341-1348.

Gabet, E. J., and T. Dunne. 2003. A stochastic sediment delivery model for a steep Mediterranean landscape. Water Resources Research 39: 1237.

Gordon, B. L. 1996. Monterey Bay Area: Natural history and cultural imprints [3rd ed.]. Boxwood Press, Pacific Grove.

Goudie, A. S., R. J. Allison, and S. J. McLaren. 1992. The relations between modulus of elasticity and temperature in the context of the experimental simulation of rock weathering by fire. Earth Surface Processes and Landforms 17: 605-615.

Graf, W.L. 1983. Flood-related change in an arid region river. Earth Surface Processes and Landforms 8: 125-39.

Graf, W.L. 1988a. Fluvial processes in dryland rivers. Springer - Verlag, Berlin.

Graf, W.L. 1988b. Applications of catastrophe theory in fluvial geomorphology. In Anderson, M. G. ed., Modeling geomorphological systems. J. Wiley and Sons, Chichester, 33-47.

Gutowski, V. P. 1978. Stream terraces along Sespe Creek, Ventura County, California. Pages 60-72 *in* A. E. Fritsche, editor. Depositional environments of Tertiary rocks along Sespe Creek, Ventura County, California. Pacific Coast Paleogeography 3. Society of Economic Paleontologists and Mineralogists.

Hanes, T. 1977. Chaparral. Pages 417-470 *in* M. G. Barbour and J. Major, editors. Terrestrial vegetation of California. John Wiley & Sons, New York.

Hassan, M. A., R. Egozi, and G. Parker. 2006. Experiments on the effect of hydrograph characteristics on vertical grain sorting in gravel bed rivers. Water Resources Research 42: W09408, doi:10.1029/2005WR004707.

Homer, C., C. Huang, L. Yang, B. Wylie, and M. Coan. 2004. Development of a 2001 National Landcover Database for the United States. Photogrammetric Engineering and Remote Sensing 70: 829-840. http://www.mrlc.gov/.

Hooke, J. 2003. Coarse sediment connectivity in river channel systems: a conceptual framework and methodology. Geomorphology 56: 79-94.

Huftile, G. J., and R. S. Yeats. 1995. Convergence rates across a displacement transfer zone in the western Transverse Ranges, Ventura basin, California. Journal of Geophysical Research 100: 2043-2068.

Inman, D., and S. Jenkins. 1999. Climate change and the episodicity of sediment flux of small California rivers. Journal of Geology 107: 251-270.

Keeley, S. C., J. E. Keeley, S. M. Hutchinson, and A. W. Johnson. 1981. Postfire succession of the herbaceous flora in southern California chaparral. Ecology 62: 1608-1621.

Keeley, J. E. 1987. Role of fire in seed germination of woody taxa in California chaparral. Ecology 68: 434-443.

Keeley, J. E., and C. J. Fotheringham. 2001. Historic fire regime in southern California shrublands. Conservation Biology 15: 1536-1548.

Keeley, J., and P. Zedler. 2009. Large, high intensity fire events in southern California shrublands: debunking the fine-grain age patch model. Ecological Applications 19: 69-94.

Kirchner, J. W., R. C. Finkel, C. S. Riebe, D. E. Granger, J. L. Clayton, J. G. King, and W. F. Megahan. 2001. Mountain erosion over 10 yr, 10 k.y., and 10 m.y. time scales. Geology 29: 591-594.

Krammes, J. S. 1960. Erosion from mountain side slopes after fire in southern California. Research Note PSW-171. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

Krammes, J. S. 1965. Seasonal debris movement from steep mountainside slopes in southern California. Pages 85-88 *in* Proceedings of the federal interagency sedimentation conference, 1963. Miscellaneous Publication 970. U. S. Department of Agriculture, Washington, D. C.

Krammes, J. S., and J. F. Osborne. 1969. Water repellent soils and wetting agents as factors influencing erosion. Pages 177-186 in L. F. DeBano and J. Letey, editors. Proceedings of the symposium on water-repellent soils. Riverside, California.

LACFCD (Los Angeles County Flood Control District). 1959. Report on debris reduction studies for mountain watersheds of Los Angeles County. Los Angeles, California.

LADPW. 2008. Santa Clara River Fluvial Study: field investigation report, volume 2: Ventura County. November.

Lajoie, K. R., D. J. Ponti, C. L. Powell II, S. A. Mathieson, and A. M. Sarna-Wojcicki. 1991. Emergent marine strandlines and associated sediments, coastal California; a record of Quaternary sea-level fluctuations, vertical tectonic movement, climatic changes, and coastal processes. Pages 190-203 *in* R. B. Morrison, editor. The geology of North America. Volume K-2. Quaternary non-glacial geology: coterminous United States. The Geological Society of America, Boulder, Colorado.

Lane, E. W. 1957. A study of the shape of channels formed by natural streams in erodible material. M.R.D. Sediments Series no. 9, U.S. Army Corps of Engineers, Engineering Division, Missouri River, Omaha, Nebraska.

Larsen, I. J., and L. H. MacDonald. 2007. Predicting postfire sediment yields at the hillslope scale: testing RUSLE and Disturbed WEPP. Water Resources Research 43: W11412, doi:10.1029/2006WR005560.

Lavé, J., and D. Burbank. 2004. Denudation processes and rates in the Transverse Ranges, southern California: erosional response of a transitional landscape to external and anthropogenic forcing. Journal of Geophysical Research 109: F01006, doi:10.1029/2003JF000023.

Leopold, L. B. and M. G. Wolman. 1957. River channel patterns; braided, meandering, and straight. U. S. Geological Survey Professional Paper 282-B.

Levin, C. 2002. Wolf Fire. Ventura Star, 3 June 2002.

Lisle, T. E., Y. Cui, G. Parker, J. E. Pizzuto, and A. M. Dodd. 2001. The dominance of dispersion in the evolution of bed material waves in gravel-bed rivers. Earth Surface Processes and Landforms 26: 1409-1420.

Loaiciga, H. A., D. Pedreros, and D. Roberts. 2001. Wildfire–streamflow interactions in a chaparral watershed. Advances in Environmental Research 5: 295-305.

Meyer, G. A., and S. G. Wells. 1997. Fire-related sedimentation events on alluvial fans, Yellowstone National Park, USA. Journal of Sedimentary Research 67: 776-791.

Molnar, P. 1991. Final report to the Southern California Earthquake Center for work performed during the period from September through December, 1991. Southern California Earthquake Center Report. 126 pp.

Montgomery, D. R., and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109: 596-611.

Moody, J. A., and J. D. Smith. 2005. Critical shear stress for erosion of cohesive soils subjected to temperatures typical of wildfires. Journal of Geophysical Research 110: F01004, doi:10.1029/2004JF000141.

Neary, D. G., C. C. Klopatek, L. F. DeBano, P. F. Ffolliott. 1999. Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management 122: 51-71.

Orme, A. R. 1998. Late Quaternary tectonism along the Pacific coast of the California: a contrast in style. Geological Society of London Special Publications 146: 179-197.

Parrett, C. 1987. Fire-related debris flows in the Beaver Creek drainage, Lewis and Clark County, Montana. Pages 57-67 *in* Water-Supply Paper 2330. U. S. Geological Survey.

Peterson, M. D., and S. G. Wesnousky. 1994. Fault slip rates and earthquake histories for active faults in southern California. Bulletin of Seismological Society of America 84: 1608-1649.

Prosser, I. P. 1990. Fire, humans and denudation at Wangrah Creek, Southern Tablelands, N.S.W.. Australian Geographical Studies 28: 77-95.

Prosser, I. P., and L. Williams. 1998. The effect of wildfire on runoff and erosion in native Eucalyptus forest. Hydrological Processes 12: 251-265.

Prothero, D. R. 2001. Magnetostratigraphic tests of sequence strategraphic correlations from the southern California Paleogene. Journal of Sedimentary Research 71: 526-536.

Reid, L. M., and T. Dunne. 1996. Rapid construction of sediment budgets for drainage basins. Catena-Verlag, Cremlingen, Germany.

Reneau, S. L., D. Katzman, G. A. Kuyumjian, A. Lavine, and D. V. Malmon. 2007. Sediment delivery after a wildfire. Geology 35: 151-154.

Rice, R. M. 1974. The hydrology of chaparral watersheds. Pages 27-34 *in* M. Rosenthal, editor. Symposium on living with the chaparral. Special Publication. Sierra Club, San Francisco, California.

Rice, R. M. 1982. Sedimentation in the chaparral: how do you handle unusual events? Pages 39-49 *in* F. J. Swanson, R. J. Janda, T. Dunne and D. N. Swanston, editors. Workshop on sediment budgets and routing in forested drainage basins: proceedings. General Technical Report PNW-141. U. S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Robichaud, P. R., J. L. Beyers, and D. G. Neary. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. General Technical Report RMRS-GTR-63. USDA Forest Service Rocky Mountain Research Station.

Rockwell, T. 1988. Neotectonics of the San Cayetano fault, Transverse Ranges, California. Geological Society of America Bulletin 100: 510-513.

Rowe, P. B., C. M. Countryman, and H. C. Storey. 1949. Probable peak discharges and erosion rates from Southern California watersheds as influenced by fire. U. S. Forest Service.

Rowe, P. B., C. M. Countryman, and H. C. Storey. 1954. Hydrological analysis used to determine effects of fire on peak discharge and erosion rates in southern California watersheds. U. S. Forest Service, Forest and Range Experiment Station, Berkeley, California.

Schmidt, K. M., and D. R. Montgomery. 1995. Limits to relief. Science 270: 617-620.

Schumm, S. A., and H. R. Khan. 1972. Experimental study of channel patterns. Geological Society of America Bulletin 83: 1755-1770.

Scott, K. M., and R. P. Williams. 1978. Erosion and sediment yields in the Transverse Ranges, southern California. Professional Paper No. 1030. U. S. Geological Survey, Washington, D. C.

Scott, D. F., D. B. Versfeld, and W. Lesch. 1998. Erosion and sediment yield in relation to afforestation and fire in the mountains of the Western Cape Province, South Africa. South African Geographical Journal 80: 52-59.

Simons, Li & Associates. 1983. Hydraulic, erosion and sedimentation study of the Santa Clara River Ventura County, California. Prepared for Ventura County Flood Control District, Ventura, California.

Shakesby, R. A., and S. H. Doerr. 2006. Wildfire as a hydrological and geomorphological agent. Earth-Science Reviews 74: 269-307.

Stillwater Sciences. 2007a. Santa Paula Creek watershed planning project: geomorphology and channel stability assessment. Prepared by Stillwater Sciences, Berkeley, California for California Department of Fish and Game, Santa Paula Creek Fish Ladder Joint Power Authority. November.

Stillwater Sciences. 2007b. Santa Clara River Parkway floodplain restoration feasibility study: assessment of geomorphic processes for the Santa Clara River watershed, Ventura and Los Angeles counties, California. Prepared by Stillwater Sciences, Berkeley, for California Coastal Conservancy, Oakland. August.

Terry, J. P., and R. A. Shakesby. 1993. Soil water repellency effects on rainsplash: simulated rainfall and photographic evidence. Earth Surface Processes and Landforms 18: 519-525.

Tiedemann, A. R., C. E. Conrad, J. H. Dieterich, J. W. Hornbeck, W. F. Megahan, L. A. Viereck, and D. D. Wade. 1979. Effects of fire on water: a state-of-knowledge review. Proceedings of the national fire effects workshop. General Technical Report WO-10. USDA Forest Service.

Trecker, M. A., L. D. Gurrola, and E. A. Keller. 1998. Oxygen-isotope correlation of marine terraces and uplift of the Mesa Hills, Santa Barbara, California, USA. Geological Society of London Special Publication 146: 57-69.

USACE (U.S. Army Corps of Engineers). 1980. Detailed project report for flood control and environmental assessment for Sespe Creek at Fillmore, Ventura County, California. U.S. Army Corps of Engineers, Los Angeles District, California.

USACE. 2007. Environmental assessment, 404(b)(1) evaluation public interest review. Permit file number: 200601205-BAH. Prepared by the U.S. Army Corps of Engineers, North Coast Branch, Ventura, California.

United States Census Bureau. 2000. Fact finder: Fillmore city, California. http://factfinder.census.gov/home/saff/main.html [Accessed July 10, 2008].

USFS (USDA Forest Service). 1954. Fire-flood sequences on the San Dimas Experimental Forest. USDA Forest Service, California Forest and Range Experiment Station 6.

USFS. 1997. Sespe Watershed Analysis: Ojai Ranger District, Los Padres National Forest.

USFS. 2003. Comprehensive river management plan – Sespe Creek, Los Padres National Forest. Prepared by USDA Forest Service, Pacific Southwest Region, California.

USFS. 2005. Los Padres National Forest oil and gas leasing analysis Final Environmental Impact Statement, Kern, Los Angeles, Monterey, Santa Barbara, Ventura, and San Luis Obispo Counties, California. Prepared by USDA Forest Service, Los Padres National Forest, Goleta, California.

USFS. 2006. 2006 Day Fire Burned Area Emergency Response (BAER) Assessment. 2006 Day Fire Los Padres Portion Initial 2500-8, version 11-15-06.

USFWS (U. S. Fish and Wildlife Service). 2004. Piru Fire Burned Area Emergency Response Plan.

Ventura County. 2008. Ventura County General Plan, Goals, Policies, and Programs. Prepared by Ventura County, California and last amended by the Ventura County Board of Supervisors on 16 December 2008.

VCWPD (Ventura County Watershed Protection District). 2005. Debris and detention basins. Ventura, California.

Ward, R. 1978. Floods: a geographical perspective. Macmillan, New York.

Warner, R. F. 1987. Spatial adjustments to temporal variations in flood regime in some Australian rivers. In Richards, K. S. ed., River channels: environment and process. Blackwell, Oxford, 14-40.

Warner, R.F. 1994. A theory of channel and floodplain responses to alternating regimes and its application to actual adjustments in the Hawkesbury River, Australia. In Kirkby, M. J. ed., Process models and theoretical geomorphology. J. Wiley and Sons, Chichester, 173 - 200.

Warrick, J. 2002. Short-term (1997–2000) and long-term (1928–2000) observations of river water and sediment discharge to the Santa Barbara channel, California. Doctoral dissertation. University of California, Santa Barbara.

Weirich, F. H. 1989. The generation of turbidity currents by subaerial debris flows, California. Geological Society of America Bulletin 101: 278-291.

Wells, W. G., II. 1981. Some effects of brushfires on erosion processes in coastal Southern California. Pages 305-342 *in* T. R. H. Davies and A. J. Pearse, editors. Erosion and sediment transport in Pacific Rim Steeplands Symposium. Association of Hydrological Sciences, Christchurch, New Zealand.

Wells, W. G., II. 1987. The effects of fire on the generation of debris flows in southern California. Geological Society of America, Reviews in Engineering Geology 7: 105-114.

Wells, W. G., II., P. M. Wohlgemuth, and A. G. Campbell. 1987. Postfire sediment movement by debris flows in the Santa Ynez Mountains, California. Pages 275-276 *in* R. L. Beschta, T. Blinn, G. E. Grant, G. G. Ice, and F. J. Swanson, editors. Erosion and sedimentation in the Pacific Rim. International Association of Hydrological Sciences, Corvallis, Oregon.

West Coast (West Coast Environmental and Engineering). 2006. Blue Star Materials interim management plan application, California Mine ID No. 91-56-0013. Submitted to Ventura County. 17 November.

Wilcock, P. R. and J. C. Crowe. 2003. A surface-based transport model for sand and gravel. Journal of Hydraulic Engineering 129: 120-128.

Willett, S. D., and M. T. Brandon. 2002. On steady states in mountain belts. Geology 30: 175-178.

Williams, R. 1979. Sediment discharge in the Santa Clara River basin, Ventura and Los Angeles Counties, California. U. S. Geological Survey, Menlo Park, California.

Wohlgemuth, P., J. Beyers, C. Wakeman, and S. Conard. 1998. Effects of fire on grass seedling and soil erosion in southern California chaparral. 19th Forest Vegetation Management Conference.

Wohlgemuth, P., J. Beyers, and S. Conard. 1999. Postfire hillslope erosion in southern California chaparral: a case study of prescribed fire as a sediment management tool. Pages 269-276 *in* General Technical Report PSW-GTR-173. USDA Forest Service, Pacific Southwest Research Station.

Wohlgemuth, P. M. 2003. Hillslope erosion following the Williams fire on the San Dimas experimental forest, southern California. Second international wildland fire ecology and fire management congress. American Meteorological Society.

Wolman, M. G. and R. Gerson. 1978. Relative scales of time and effectiveness of climate in watershed geomorphology. Earth Surface Processes and Landforms 3: 189-208.

Wolman, M., and J. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology 68: 54-74.

Wright, H., and A. Bailey. 1982. Fire ecology: United States and southern Canada. Wiley, New York.

Yeats, R. S. 1988. Late Quaternary slip rates on the Oak Ridge fault, Transverse Ranges, California: implications for seismic risk. Journal of Geophysical Research 93: 137-149.

5.2 Personal Communications

Henderson, B. 2010. Senior Project Manager, U.S. Army Corps of Engineers, Regulatory Division, North Coast Branch. Phone conversation with G. Leverich, Stillwater Sciences, providing aggregate mining information.

Weishaar, H. 2008. Hydrographer, Ventura County Watershed Protection District. In person conversation with G. Leverich, Stillwater Sciences, providing post-fire sedimentation information.

Wohlgemuth, P. M. 2008. Researcher, U.S. Forest Service, Pacific Southwest Research Station, Riverside Forest Fire Laboratory. Written correspondence with S. Dusterhoff, Stillwater Sciences, providing fire-related erosion and sedimentation impact information.

APPENDICES

Appendix A

Facies Mapping and Sediment Size Analysis

FACIES MAPPING AND SEDIMENT SIZE ANALYSIS

Mapping of sedimentary facies throughout the Sespe Creek subwatersheds involved delineating distinct units of surface sediment mixtures. In the Upper, Middle, and Gorge subwatersheds, and the Valley reach of the Lower subwatershed, facies were mapped longitudinally along the channel bed. A nearly continuous facies map was produced for the Middle subwatershed, while facies mapped in the Upper and Gorge subwatersheds and Valley reach of the Lower reach were focused, primarily, at the confluences with major tributaries (see Appendix B). In the Fillmore reach of the Lower subwatershed, facies were mapped both longitudinally and laterally along the entire width of the channel bed, following the east fork channel downstream towards the Santa Clara River. The east fork was mapped because it has effectively become the dominant channel within the last 30 years, and therefore conveys the majority of water and sediment during flow events responsible for morphologic changes to the channel. This fork is also closest to the Sespe Creek Levee, which is sensitive to changes in the active channel (e.g., flood protection capacity relationship with bed elevation and roughness). In combination with the mapped sediment facies, sediment size measurements were also taken in this reach, as well as rapid size estimates of facies in the longitudinal facies throughout the upstream reaches, to be used in sediment transport modeling conducted by RBF Consulting, Inc. as part of this project.

The facies mapping method used for this study was based on the methodology devised by Buffington and Montgomery (1999) for mapping short reaches (20–50 m). To be applicable to a larger scale appropriate for the stream length surveyed along Sespe Creek, the Buffington and Montgomery (1999) methodology was modified to capture a more simplified classification of sedimentary facies. Within the facies classification, the surface was classified according to the proportional occurrence of the five most prevalent substrate types (sand [S], gravel [G], cobble [C], boulder [B], and bedrock [Br]) (see Table A-1). The qualifying criteria for a substrate type to be included in a facies classification were that an individual substrate type comprised ≥5% of the surface facies, or that the two sub-ordinate classes together comprised ≥10%. Where the qualifying criteria were not met, the surface was classified according to the one or two most frequent substrate types, with the dominant substrate type being listed last (e.g., cobble [C] if cobble comprised more than 95% of the material or gravelly cobble [GC] if gravel comprised at least 5% of the bed material and cobble comprised the remaining bed material and no other substrate type represented more than 5% of the surface area).

Table A-1. Particle size classes used for facies mapping and pebble count measurements.

Size class	Grain size (mm)
Boulder	
very coarse	2,048–4,096
coarse	1,024–2,048
medium	512–1,024
fine	256–512
Cobble	
coarse	128–256
fine	64–128
Gravel	
very coarse	32–64
coarse	16–32
medium	8–16
fine	4–8
very fine	2–4
Sand	0.0625–2

Wolman (1954) pebble counts were conducted to assist in field determination of sediment facies and to chronicle the actual grain size distributions of individual facies within the reach. Collection and analysis of bulk samples were not feasible due to the coarse size of particles which would require too great a sample volume. For the standard McNeil sampling method for gravel- and cobble-bed rivers, the total bed material samples should be large enough so that the mass of the largest particle in each sample is less than about five percent of the total sample mass (Bunte and Abt 2001). For the pebble count sampling, the intermediate (b) axis of 100 surface bed particles was measured at 10 locations within the Fillmore reach. The relative proportion of each grain class was determined in the field to then guide the classification of facies units with the same visual characteristics. The pebble count data for each location were compiled into particle size distributions so that representative grain size fractions could be extracted. After filtering the field data, facies and particle size distribution information were entered into a database and transferred to a GIS format.

The pebble count data for the Fillmore reach are presented graphically in Figures A-1 through A-10. Aerial photography mapping tiles of the Lower subwatershed showing the mapped sediment facies and pebble count locations and their size distribution (i.e., D_{16}, D_{50}, D_{84}) are presented in Tiles 1 of 9 through 9 of 9. Also presented on these tiles are sediment sample locations and results from the 2005 Los Angeles County Department of Public Works sampling effort on the channel bed of both the Valley and Fillmore reaches of Sespe Creek (LADPW 2008). These data were included to support our findings (e.g, SE-3, SE-4B), to provide data in areas that were not included in our mapping effort (e.g., SE-1, SE-2, SE-4A), and to highlight changes in the channel bed substrate since 2005 (e.g., SE-5B). Map tiles showing mapped facies with estimated sediment size distributions (i.e., D_{50} and D_{84}) in the Upper, Middle, and Gorge subwatersheds are presented in Tiles 1 of 20 through 20 of 20.

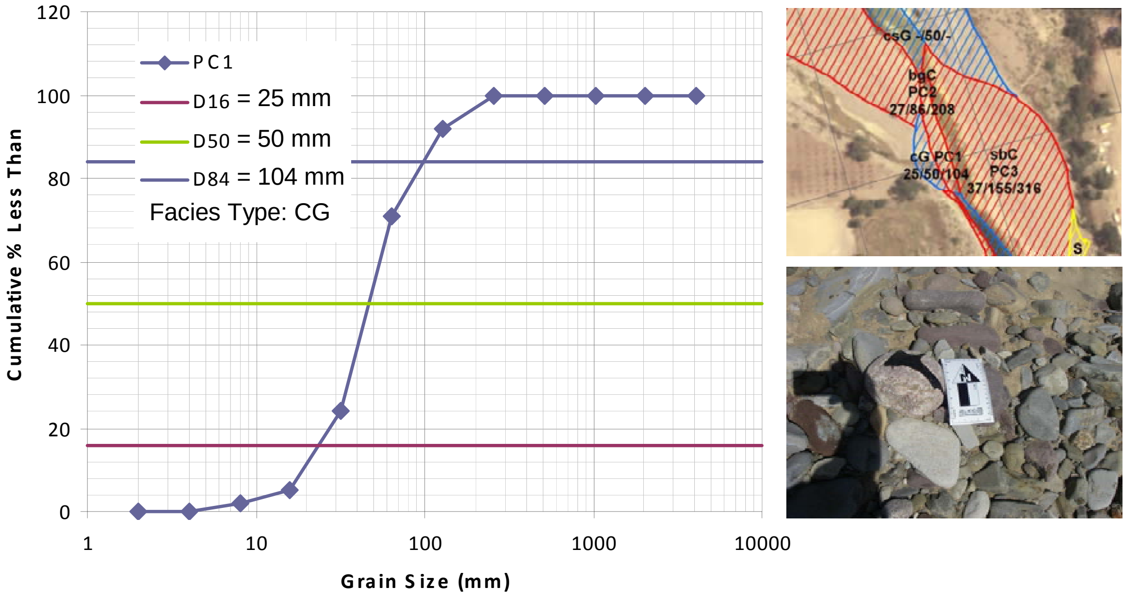


Figure A-1. Particle size distributions derived from pebble count 1 (PC 1) data.

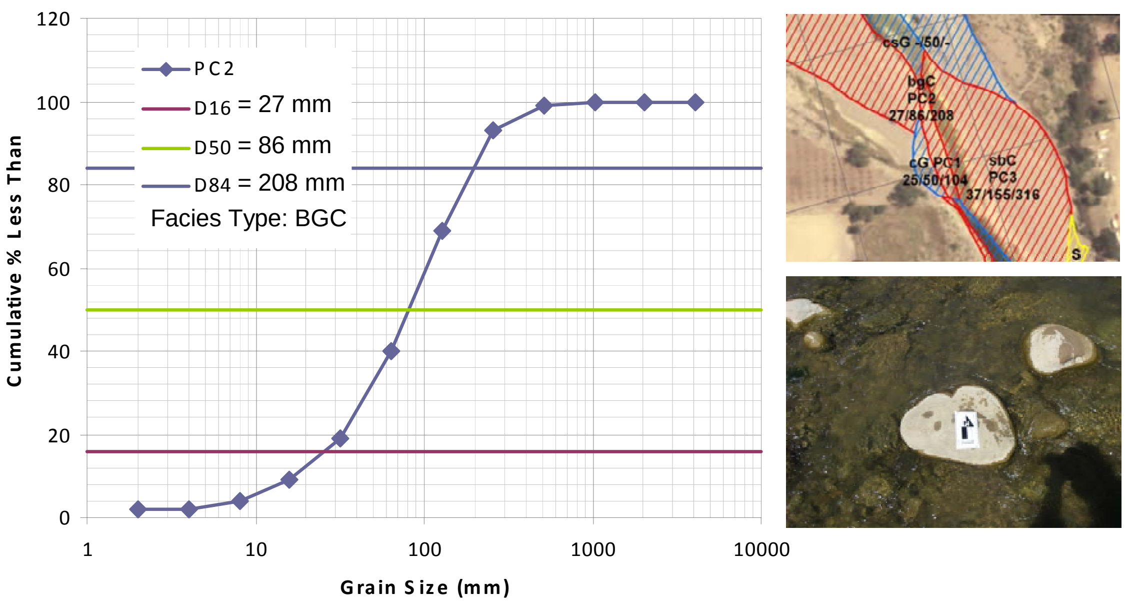


Figure A-2. Particle size distributions derived from pebble count 2 (PC 2) data.

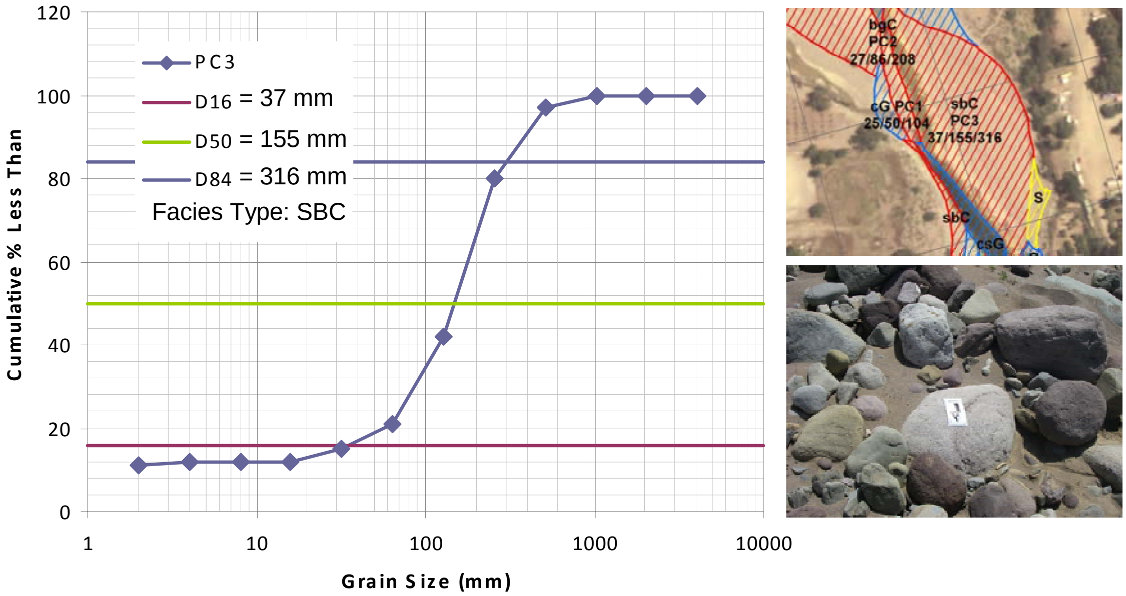


Figure A-3. Particle size distributions derived from pebble count 3 (PC 3) data.

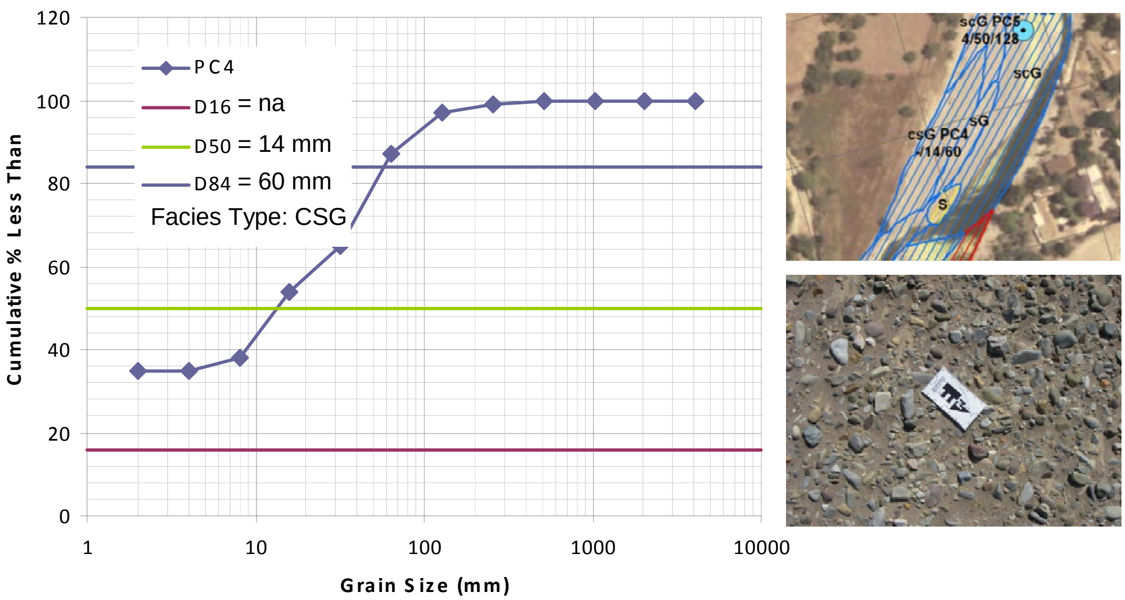


Figure A-4. Particle size distributions derived from pebble count 4 (PC 4) data.

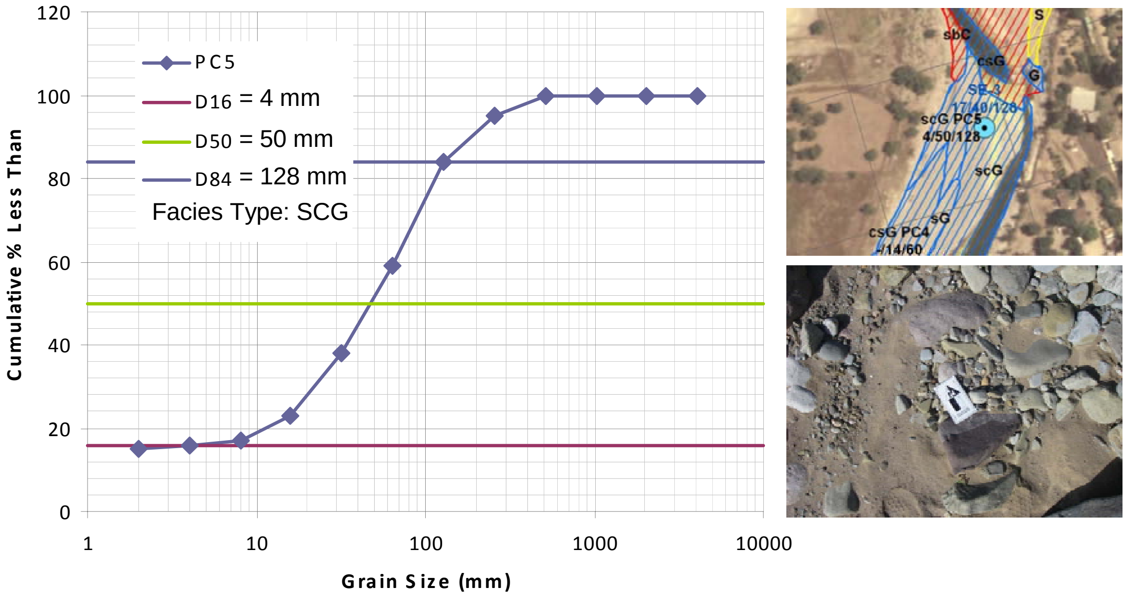


Figure A-5. Particle size distributions derived from pebble count 5 (PC 5) data.

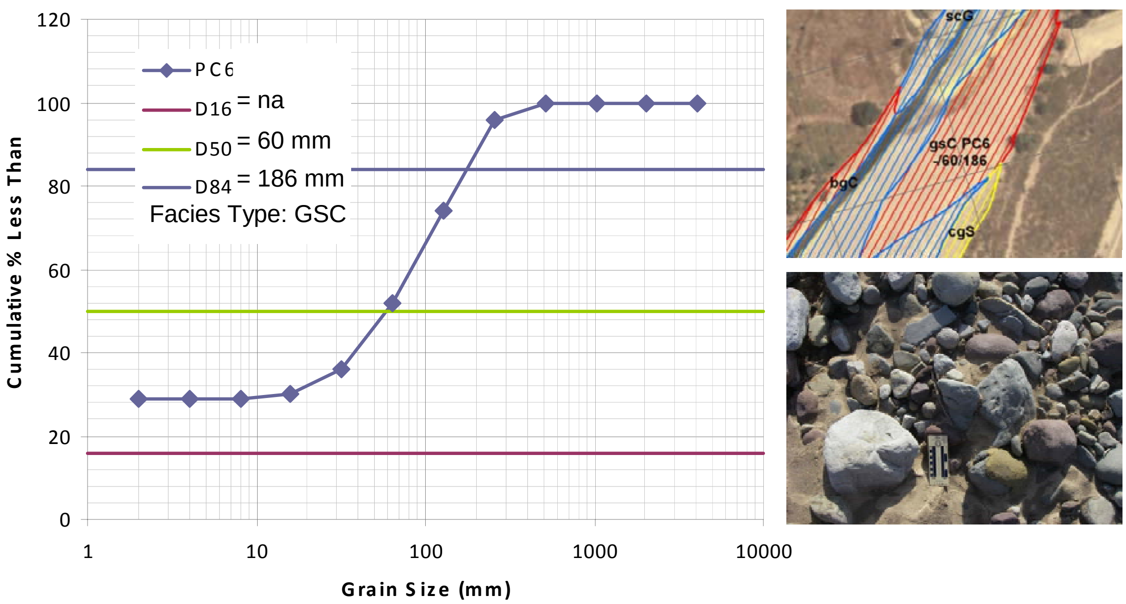


Figure A-6. Particle size distributions derived from pebble count 6 (PC 6) data.

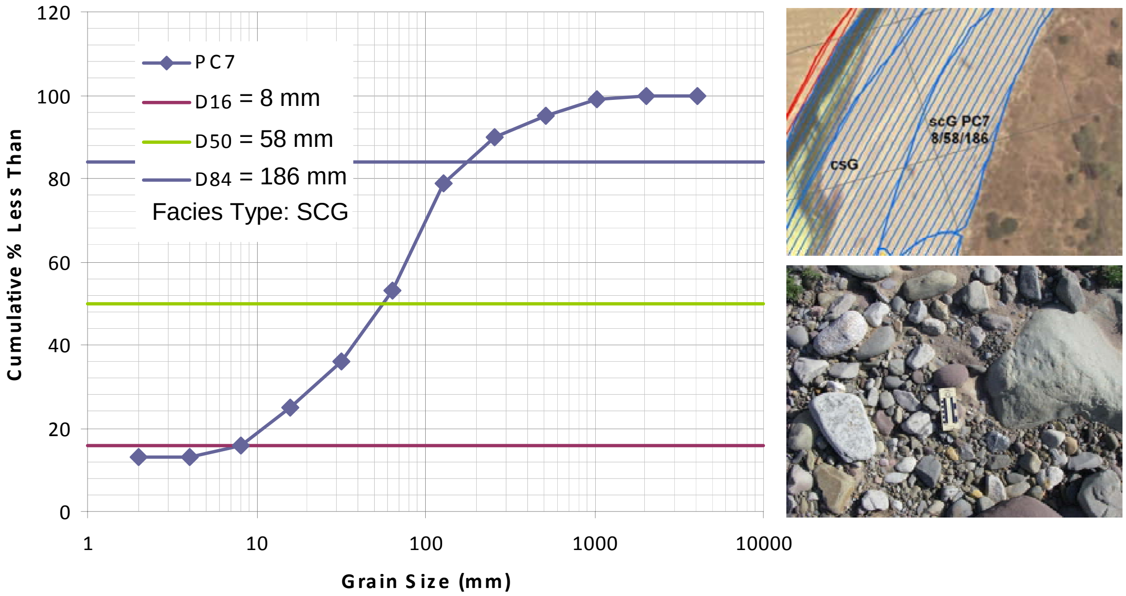


Figure A-7. Particle size distributions derived from pebble count 7 (PC 7) data.

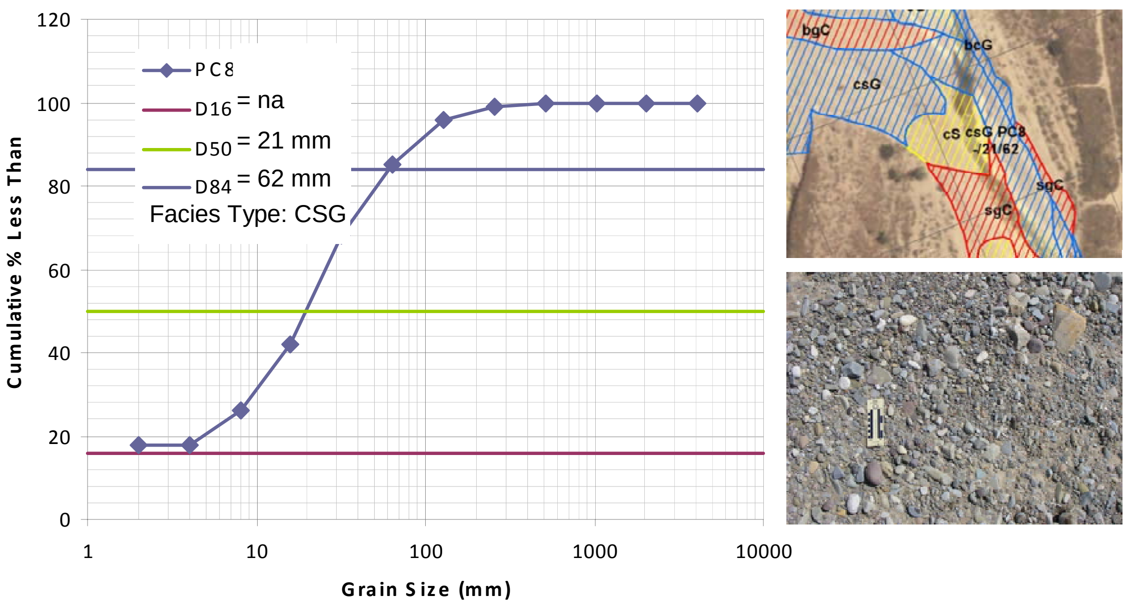


Figure A-8. Particle size distributions derived from pebble count 8 (PC 8) data.

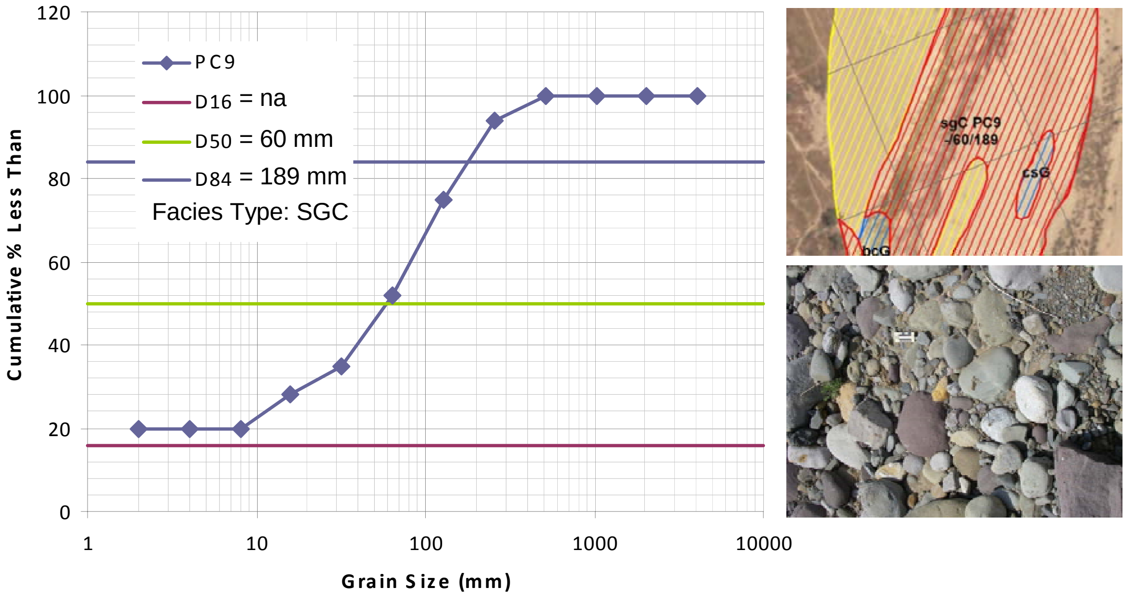


Figure A-9. Particle size distributions derived from pebble count 9 (PC 9) data.

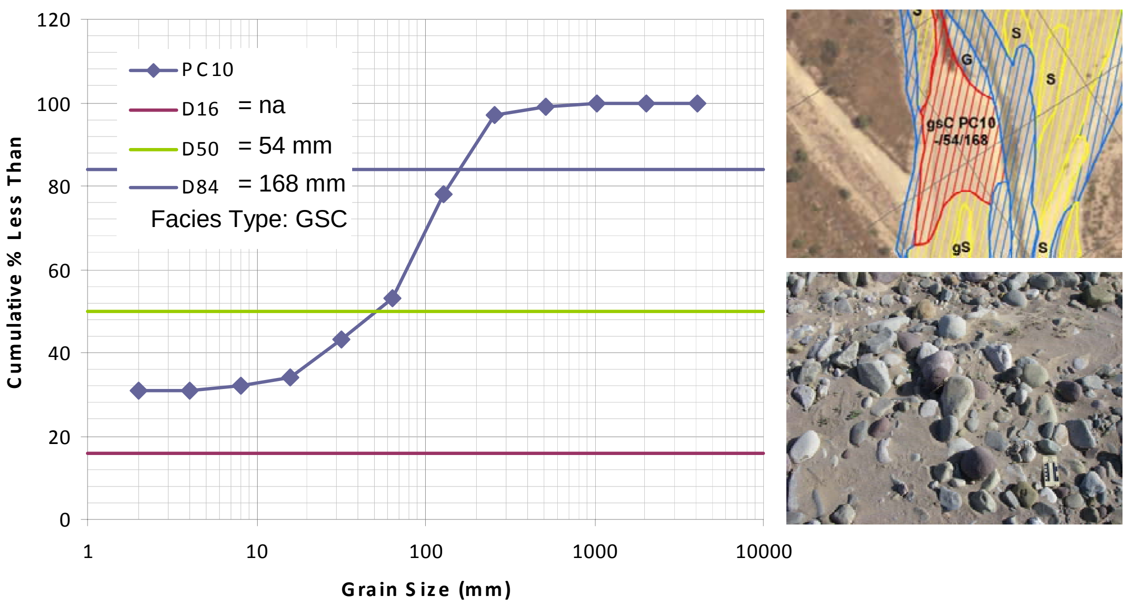


Figure A-10. Particle size distributions derived from pebble count 10 (PC 10) data.

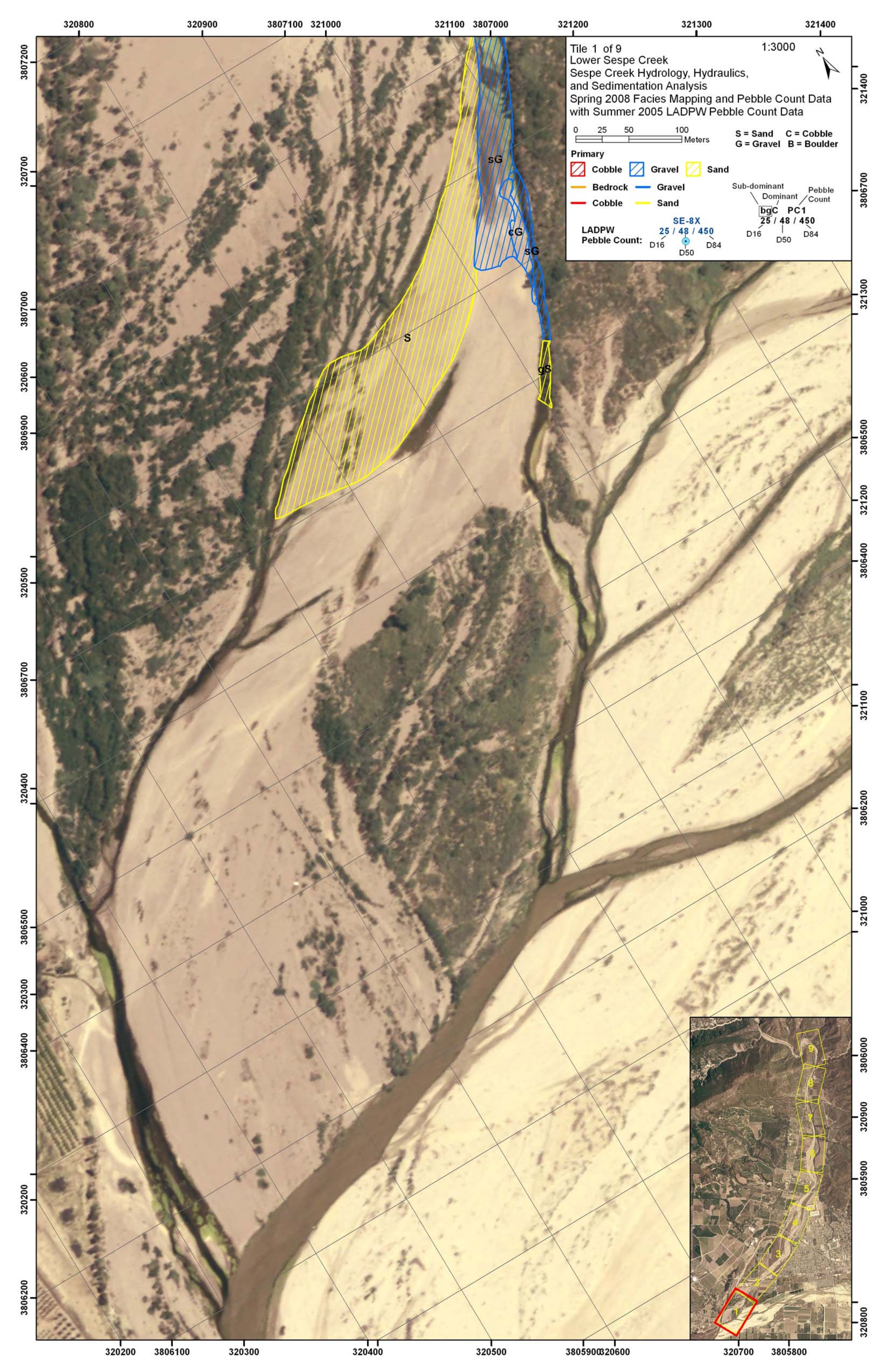
REFERENCES

Buffington, J. M., and D. R. Montgomery. 1999. A procedure for classifying textural facies in gravel-bed rivers. Water Resources Research 35: 1903-1914.

Bunte, K. and S. R. Abt. 2001. Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. Gen. Tech. Rep. RMRS-GTR-74. Fort Collins,CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 428 p.

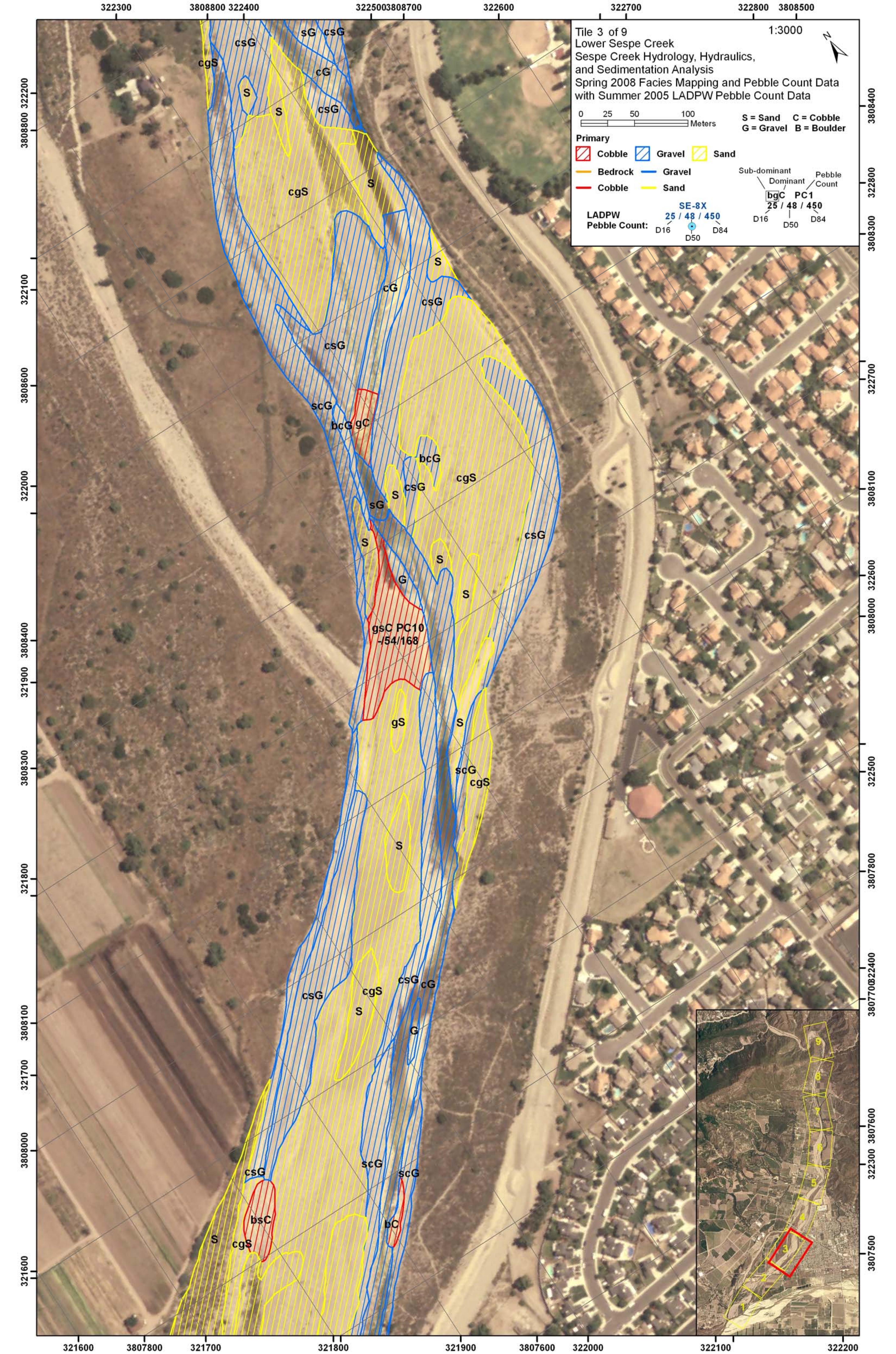
LADPW. 2008. Santa Clara River Fluvial Study: field investigation report, volume 1: Los Angeles County. November.

Wolman, G.M. 1954. A method of sampling coarse river-bed material. Transactions of the American Geophysical Union 35: 951-956.

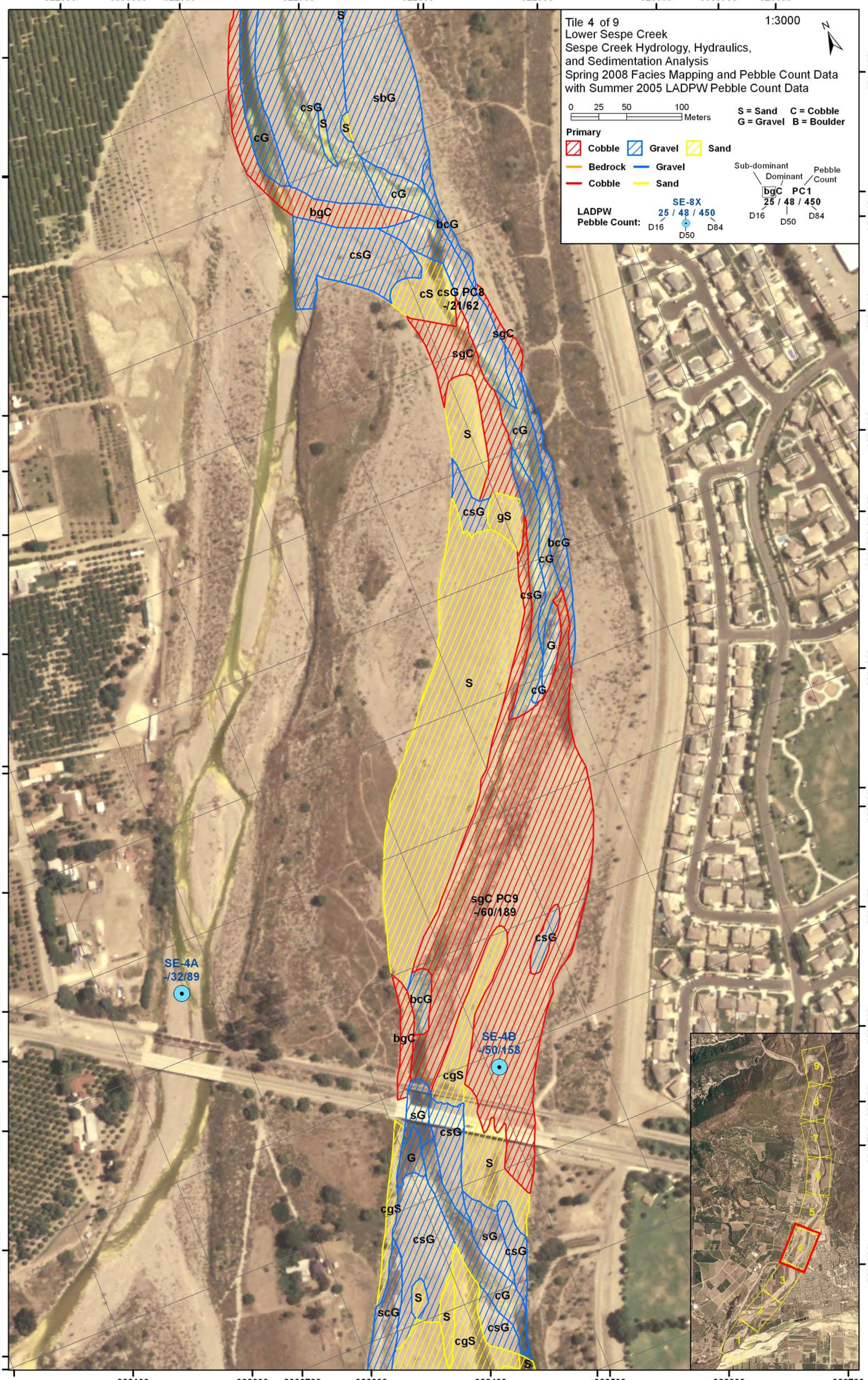


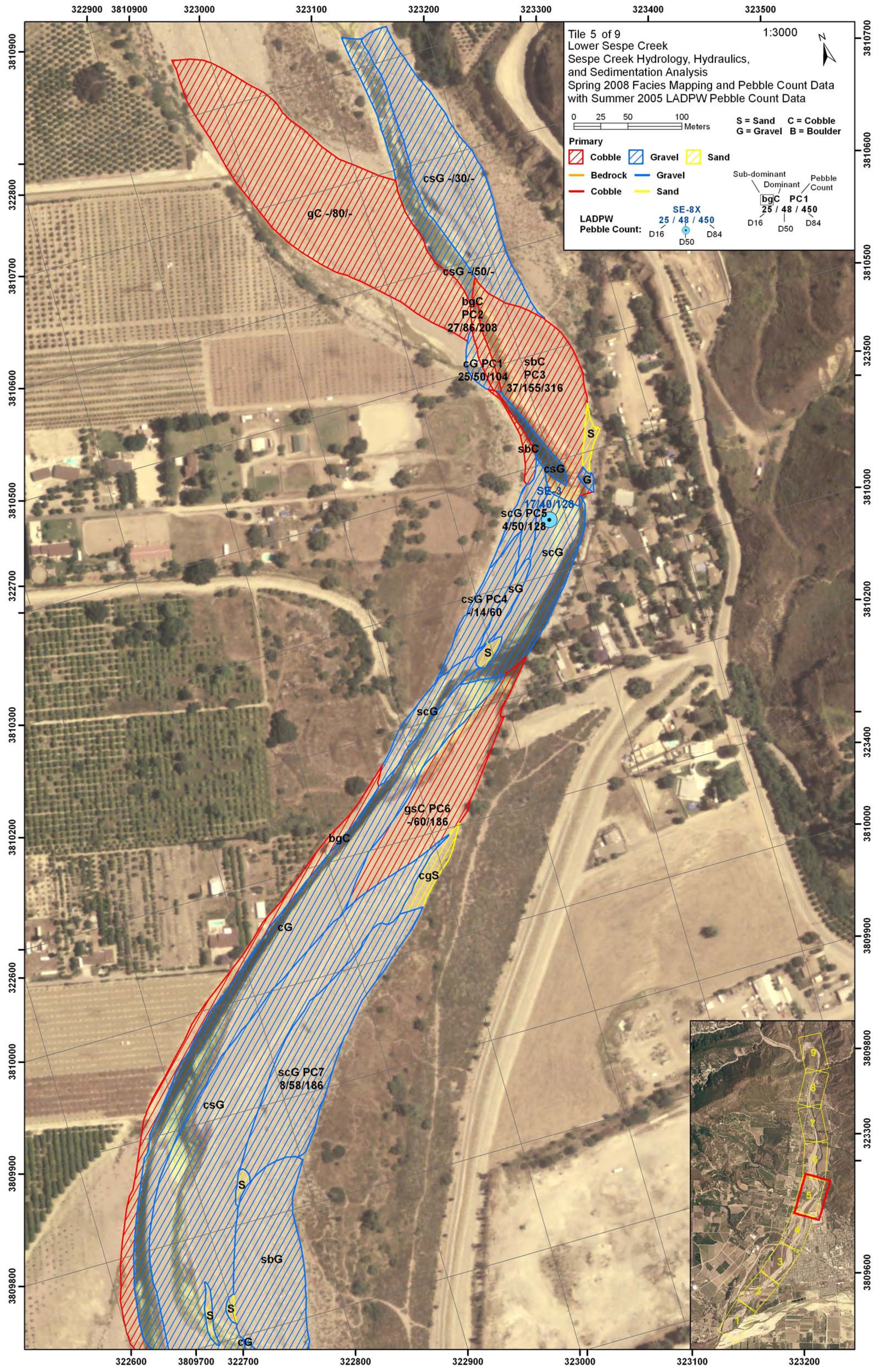
Tile 1 of 9
1:3000
Lower Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping and Pebble Count Data with Summer 2005 LADPW Pebble Count Data
0 25 50 100 Meters
S = Sand C = Cobble
G = Gravel B = Boulder
Primary
Cobble
Gravel
Sand
Bedrock
Gravel
Cobble
Sand
Sub-dominant
Dominant
Pebble Count
bgC PC1
25 / 48 / 450
D16 D50 D84
LADPW Pebble Count:
SE-8X
25 / 48 / 450
D16 D50 D84
sG
cG
sG
S
gS
320800
320900
3807100
321000
321100
3807000
321200
321300
321400
320200
3806100
320300
320400
320500
3805900
320600
320700
3805800

Tile 2 of 9
1:3000
Lower Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping and Pebble Count Data with Summer 2005 LADPW Pebble Count Data
0 25 50 100 Meters
S = Sand C = Cobble
G = Gravel B = Boulder
Primary
Cobble Gravel Sand
Bedrock Gravel
Cobble Sand
Sub-dominant
Dominant
Pebble Count
bgC PC1
25 / 48 / 450
D16 D50 D84
LADPW Pebble Count:
SE-8X
25 / 48 / 450
D16 D50 D84
SE-5B
-/64/154
bsC
cgS
bC
scG
S
G
scG
cG
bgC
gsC
csG
cG
gC
sG
cG
G
sG
cG
321600
3808000
321700
3807900
321800
3807800
321900
322000
322100
320900
321000
3806900
321100
3806800
321200
3806700
321300



Tile 3 of 9
1:3000
Lower Sespe Creek
Sespe Creek Hydrology, Hydraulics,
and Sedimentation Analysis
Spring 2008 Facies Mapping and Pebble Count Data
with Summer 2005 LADPW Pebble Count Data
0 25 50 100 Meters
S = Sand C = Cobble
G = Gravel B = Boulder
Primary
Cobble Gravel Sand
Bedrock Gravel
Cobble Sand
Sub-dominant
Dominant
Pebble Count
bgC PC1
25 / 48 / 450
D16 D50 D84
LADPW Pebble Count:
SE-8X
25 / 48 / 450
D16 D50 D84
gsC PC10
-/54/168


Tile 4 of 9
1:3000
Lower Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping and Pebble Count Data with Summer 2005 LADPW Pebble Count Data
0 25 50 100 Meters
S = Sand C = Cobble
G = Gravel B = Boulder
Primary
Cobble Gravel Sand
Bedrock Gravel
Cobble Sand
Sub-dominant Dominant Pebble Count
bgC PC1
25 / 48 / 450
D16 D50 D84
LADPW Pebble Count:
SE-8X
25 / 48 / 450
D16 D50 D84
sgC PC9
-/60/189
csG PC8
-/21/62
SE-4A
-/32/89
SE-4B
-/50/158

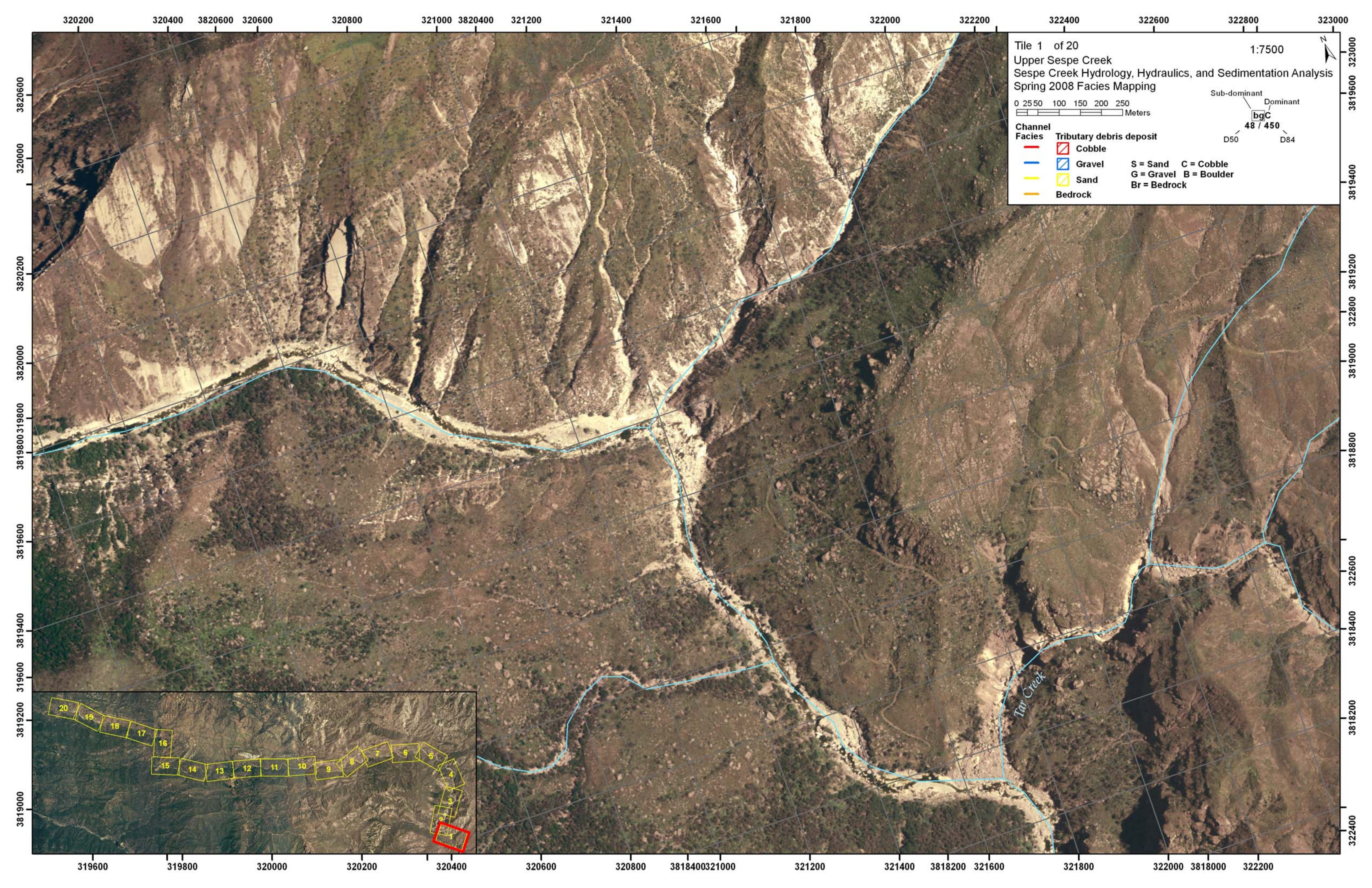

Tile 5 of 9
1:3000
Lower Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping and Pebble Count Data
with Summer 2005 LADPW Pebble Count Data
0 25 50 100 Meters
S = Sand C = Cobble
G = Gravel B = Boulder
Primary
Cobble Gravel Sand
Bedrock Gravel
Cobble Sand
Sub-dominant
Dominant
Pebble Count
bgC PC1
25 / 48 / 450
D16 D50 D84
LADPW Pebble Count:
SE-8X
25 / 48 / 450
D16 D50 D84
gC -/80/-
csG -/30/-
csG -/50/-
bgC PC2 27/86/208
cG PC1 25/50/104
sbC PC3 37/155/316
S
sbC
csG
G
SE-3 17/40/128
scG PC5 4/50/128
scG
sG
csG PC4 -/14/60
S
scG
gsC PC6 -/60/186
bgC
cgS
cG
scG PC7 8/58/186
csG
S
sbG
S
S
cG
322900 3810900 323000 323100 323200 323300 323400 323500
322600 3809700 322700 322800 322900 323000 323100 323200
3810900 322800 3810700 3810600 3810500 322700 3810300 3810200 322600 3810000 3809900 3809800
3810700 3810600 3810500 323500 3810300 3810200 323400 3810000 3809900 3809800 323300 3809600
1 2 3 4 5 6 7 8 9

Tile 6 of 9
1:3000
N
Lower Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping and Pebble Count Data with Summer 2005 LADPW Pebble Count Data
0 25 50 100 Meters
S = Sand C = Cobble
G = Gravel B = Boulder
Primary
Cobble Gravel Sand
Bedrock Gravel
Cobble Sand
Sub-dominant
Dominant
Pebble Count
bgC PC1
25 / 48 / 450
D16 D50 D84
LADPW Pebble Count:
SE-8X
25 / 48 / 450
D16 D50 D84
gC -/80/-
csG -/50/-
csG -/30/-
1
2
3
4
5
6
7
8
9

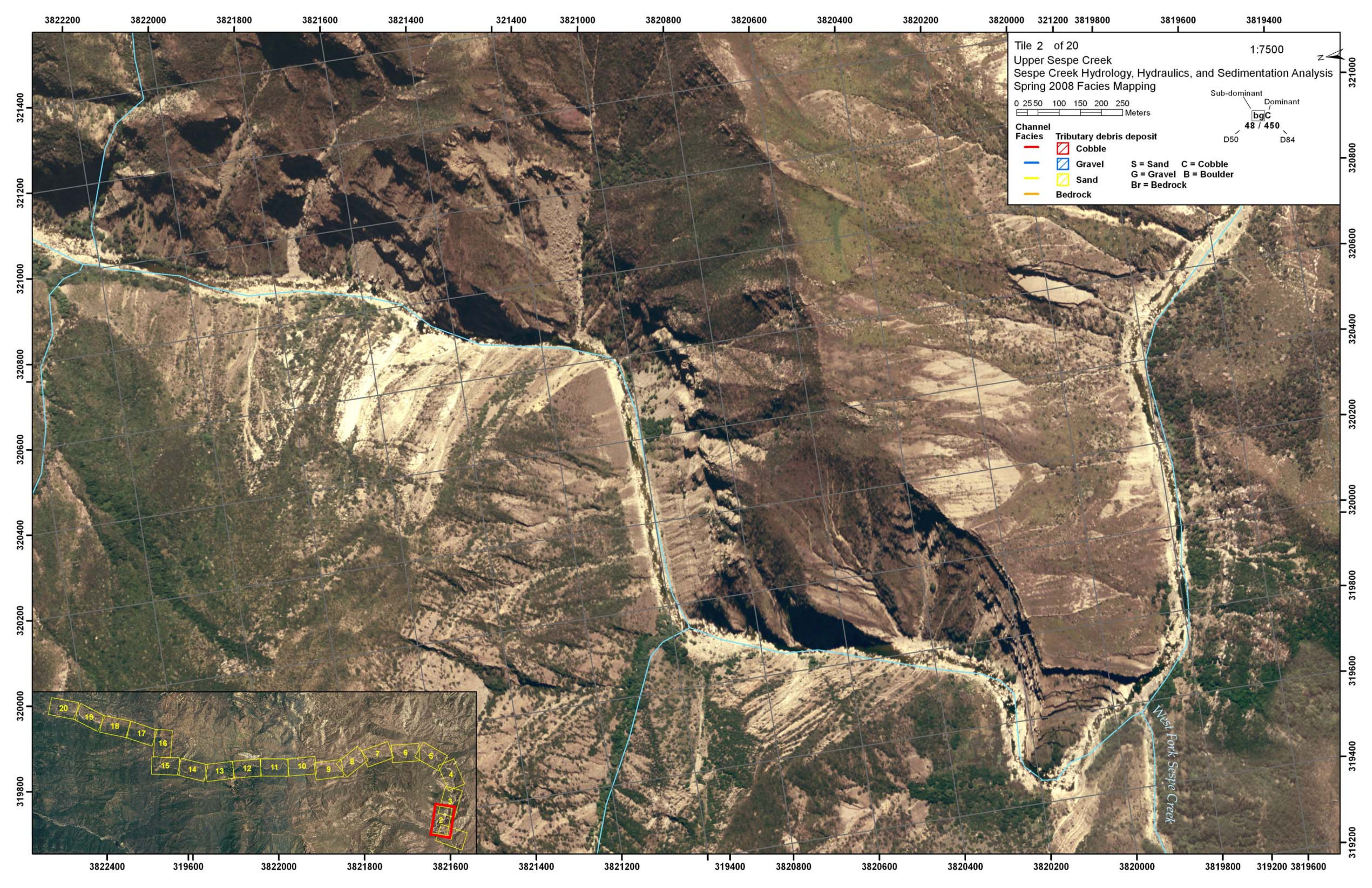
Tile 7 of 9
1:3000
N
Lower Sespe Creek
Sespe Creek Hydrology, Hydraulics,
and Sedimentation Analysis
Spring 2008 Facies Mapping and Pebble Count Data
with Summer 2005 LADPW Pebble Count Data
0 25 50 100 Meters
S = Sand C = Cobble
G = Gravel B = Boulder
Primary
Cobble
Gravel
Sand
Bedrock
Gravel
Cobble
Sand
Sub-dominant
Dominant
Pebble Count
bgC PC1
25 / 48 / 450
D16
D50
D84
LADPW Pebble Count:
SE-8X
25 / 48 / 450
D16
D50
D84
csG
D50 40
SE-7
-/70/188
322700
322800
322900
323000
323100
323200
323300
3813100
323400
322900
323000
323100
323200
323300
323400
323500
323600
1
2
3
4
5
6
7
8
9

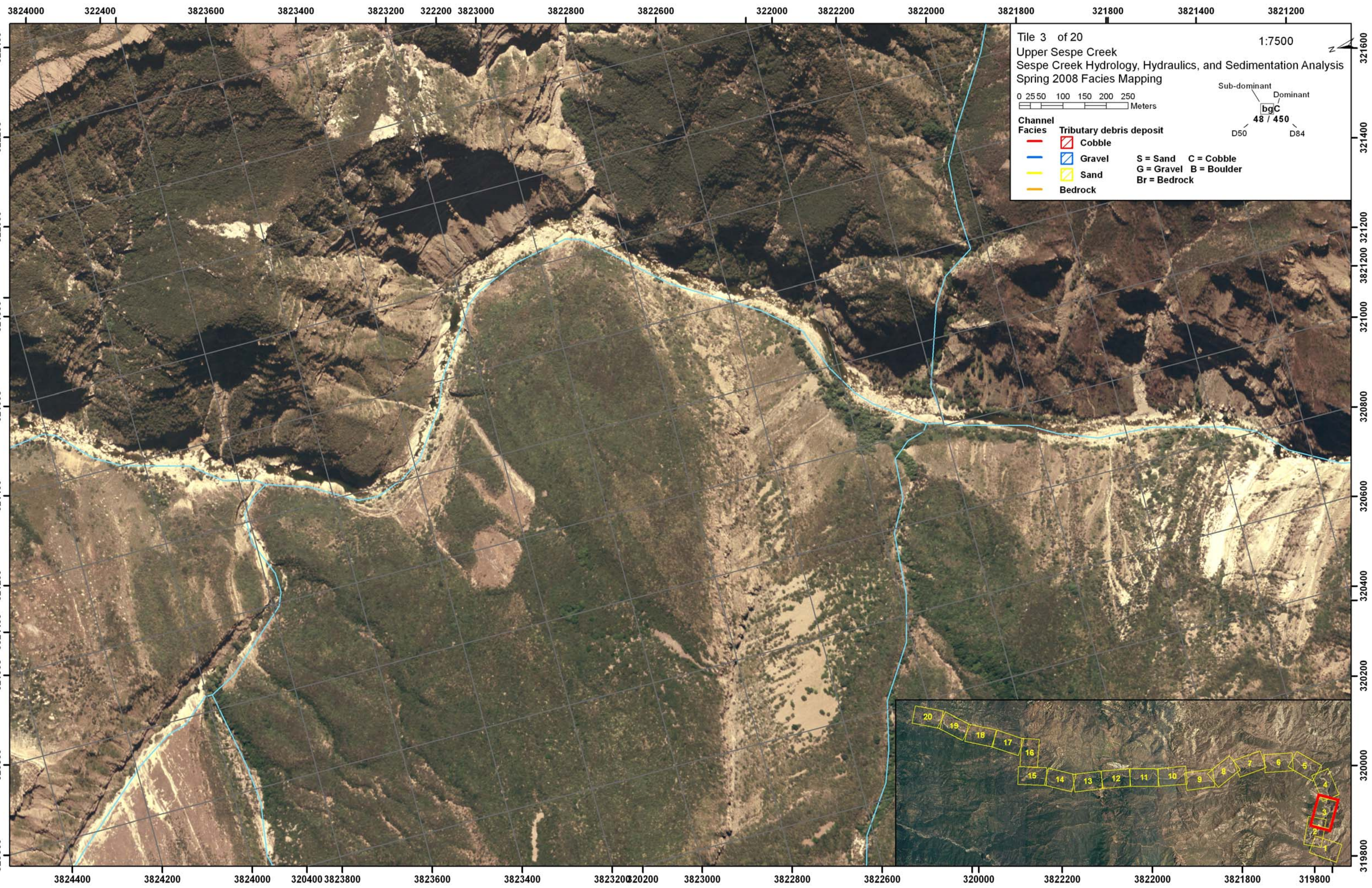
Tile 8 of 9
1:3000
Lower Sespe Creek
Sespe Creek Hydrology, Hydraulics,
and Sedimentation Analysis
Spring 2008 Facies Mapping and Pebble Count Data
with Summer 2005 LADPW Pebble Count Data
0 25 50 100 Meters
S = Sand C = Cobble
G = Gravel B = Boulder
Primary
Cobble Gravel Sand
Bedrock Gravel
Cobble Sand
Sub-dominant Dominant Pebble Count
bgC PC1
25 / 48 / 450
D16 D50 D84
LADPW Pebble Count:
SE-8X
25 / 48 / 450
D16 D50 D84
csG
D50 30
csG
D50 40
SE-1
-/70/158
323000 323100 3814100 323200 323300 323400 323500 323600 323700
3814100 3814000 3813900 3813800 322900 3813700 3813600 3813500 3813400 322800 3813300 3813200 3813100 3813000
3813900 3813700 323700 3813600 3813500 3813400 323600 3813300 3813200 3813100 3813000 323500 322900 3812900 3812800
322800 322900 323000 323100 323200 323300 323400
9 8 7 6 5 4 3 2 1

Tile 9 of 9
1:3000
Lower Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping and Pebble Count Data
with Summer 2005 LADPW Pebble Count Data
N
0 25 50 100 Meters
S = Sand C = Cobble
G = Gravel B = Boulder
Primary
Cobble Gravel Sand
Bedrock Gravel
Cobble Sand
Sub-dominant Dominant Pebble Count
bgC PC1
25 / 48 / 450
D16 D50 D84
LADPW Pebble Count:
SE-8X
25 / 48 / 450
D16 D50 D84
csG
D50 50
csG
D50 30
csG
D50 40
322700 322800 322900 323000 323100 323200 323300
323000 323100 323200 323300 323400 323500 323600
3815100 3815000 3814900 3814800 3814700 3814600 3814500 3814300 3814200 3814100 3814000 322900
3815200 3815100 3815000 3814900 3814700 3814600 3814500 3814400 3814200 3814100
322700 322800
323400 323500 323600



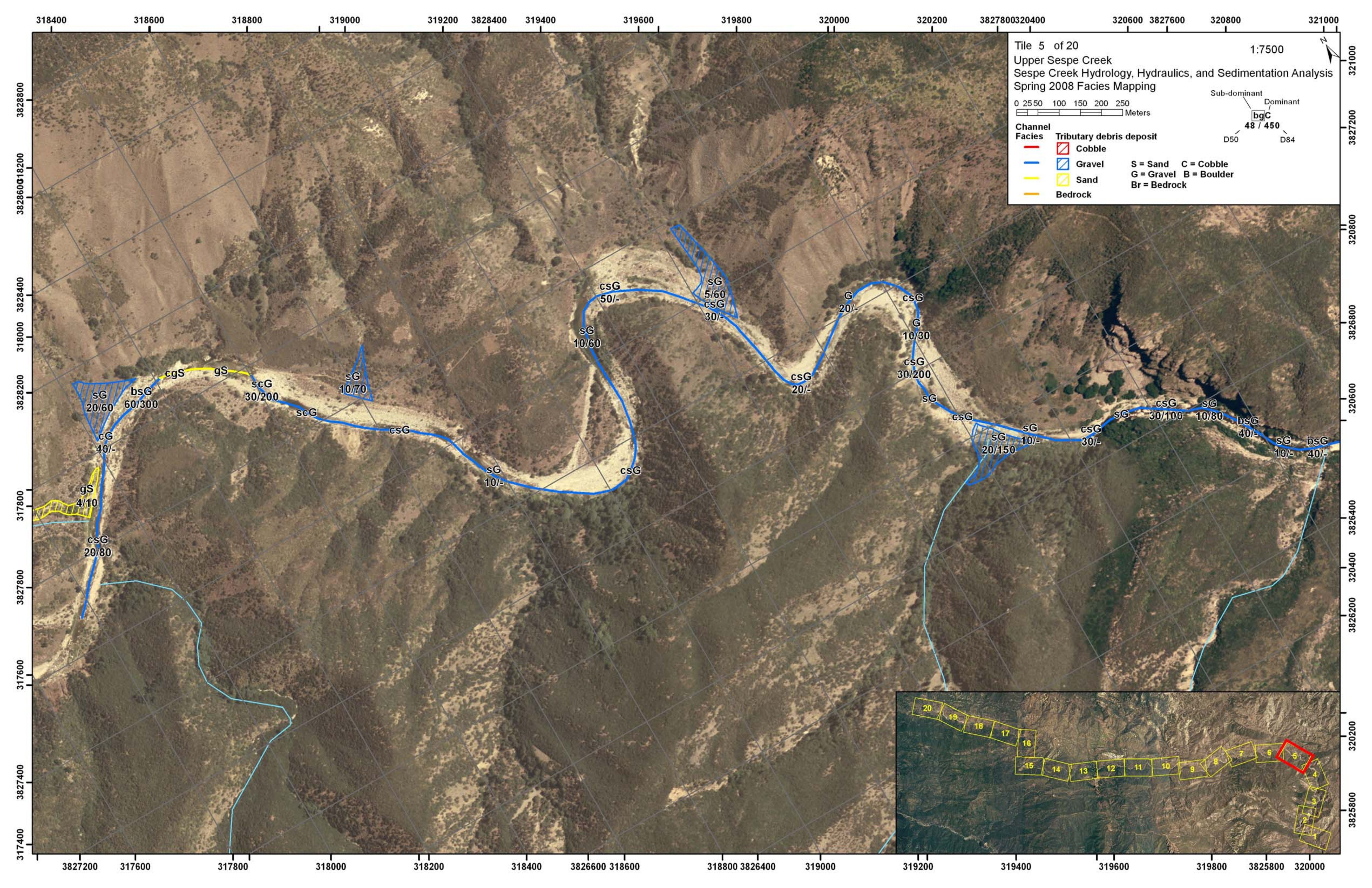
Tile 1 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand
C = Cobble
G = Gravel
B = Boulder
Br = Bedrock
Tar Creek


Tile 2 of 20
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
1:7500
0 25 50 100 150 200 250 Meters
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
West Fork Sespe Creek

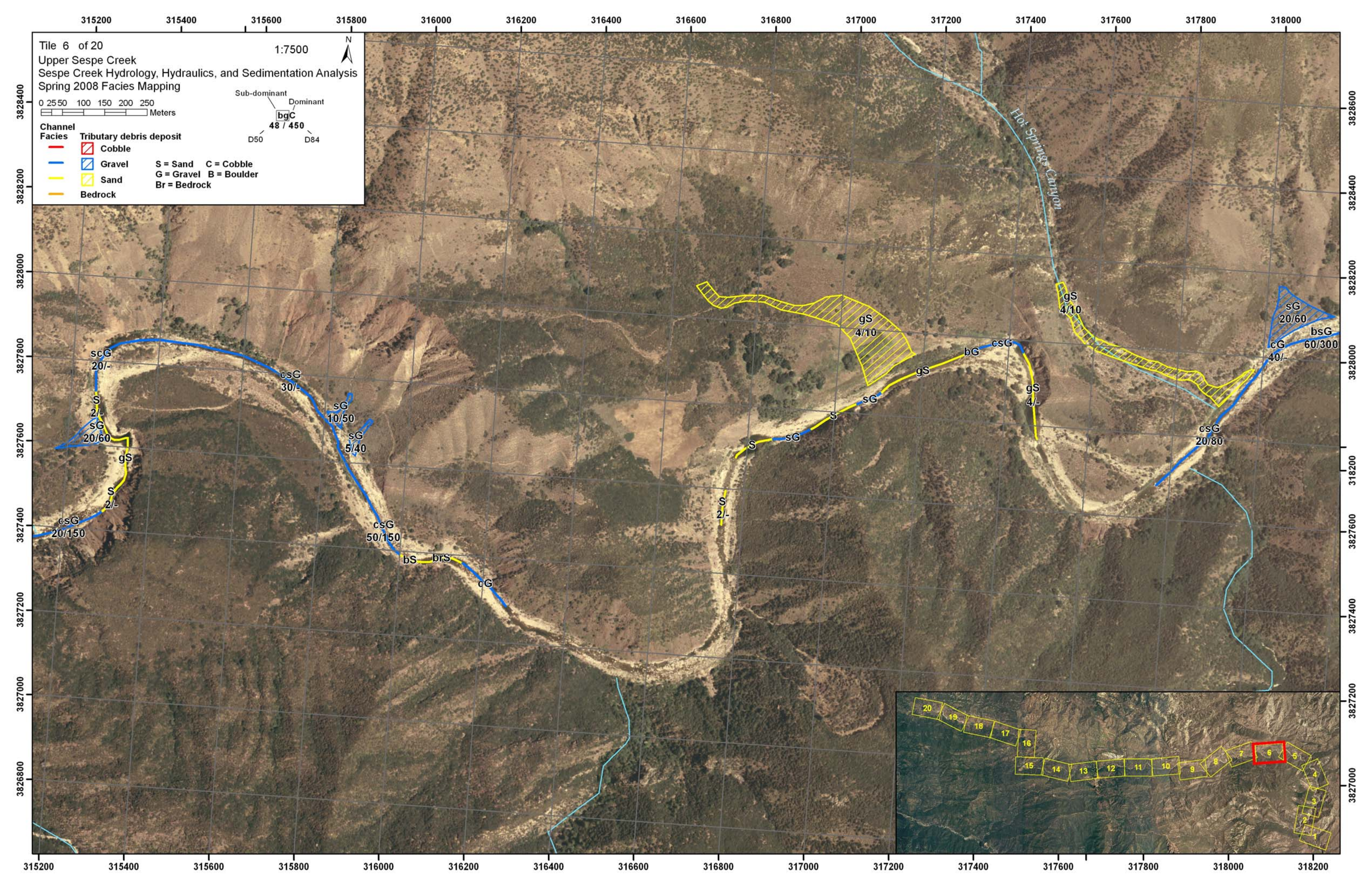


Tile 3 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

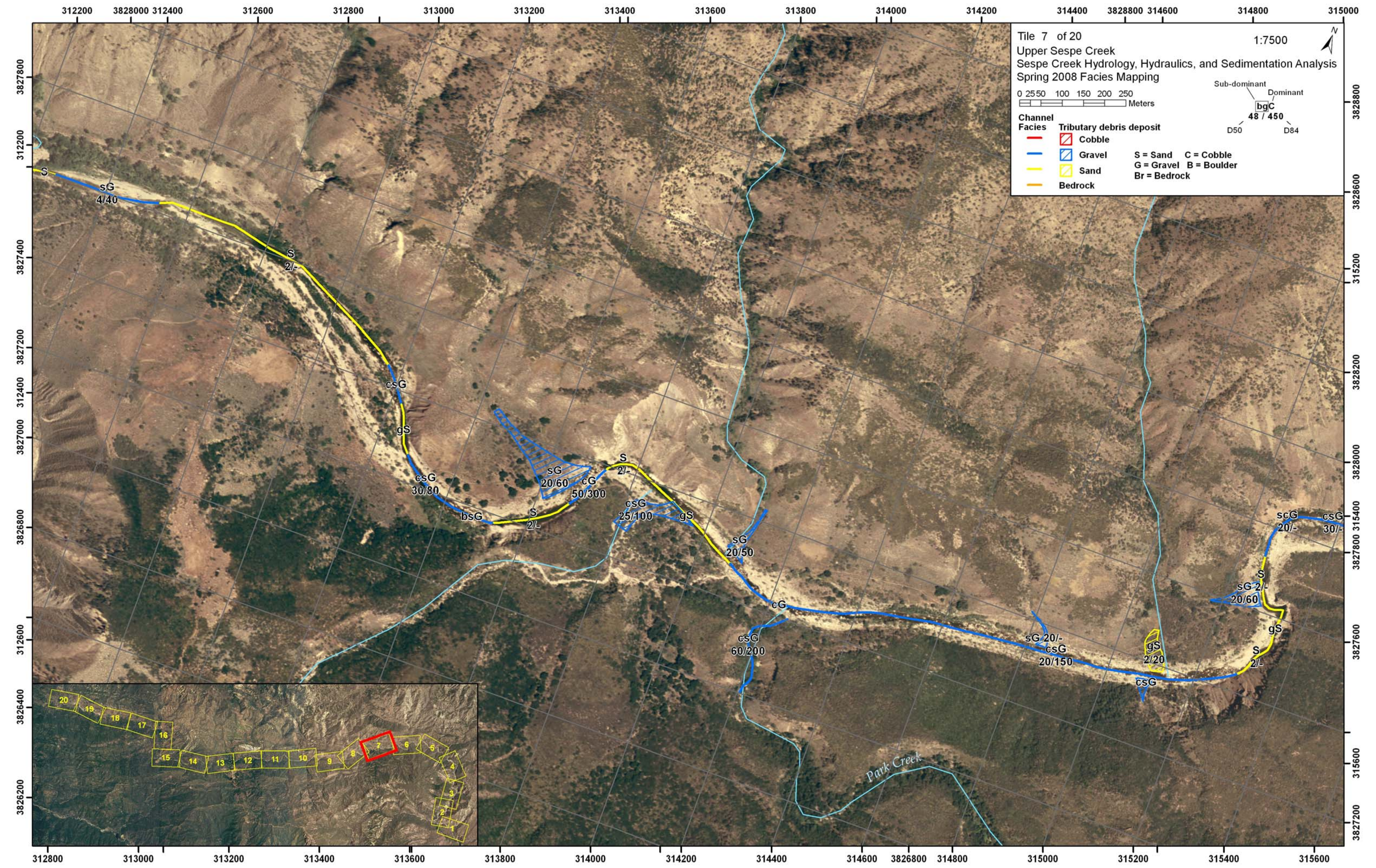
Tile 4 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
Stone Corral Creek
Alder Creek
bsG
50/400
csG
30/250
brG
50/200
csG
20/-
bsG
40/-
sG
10/80
bsG
40/-
sG
10/-
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1



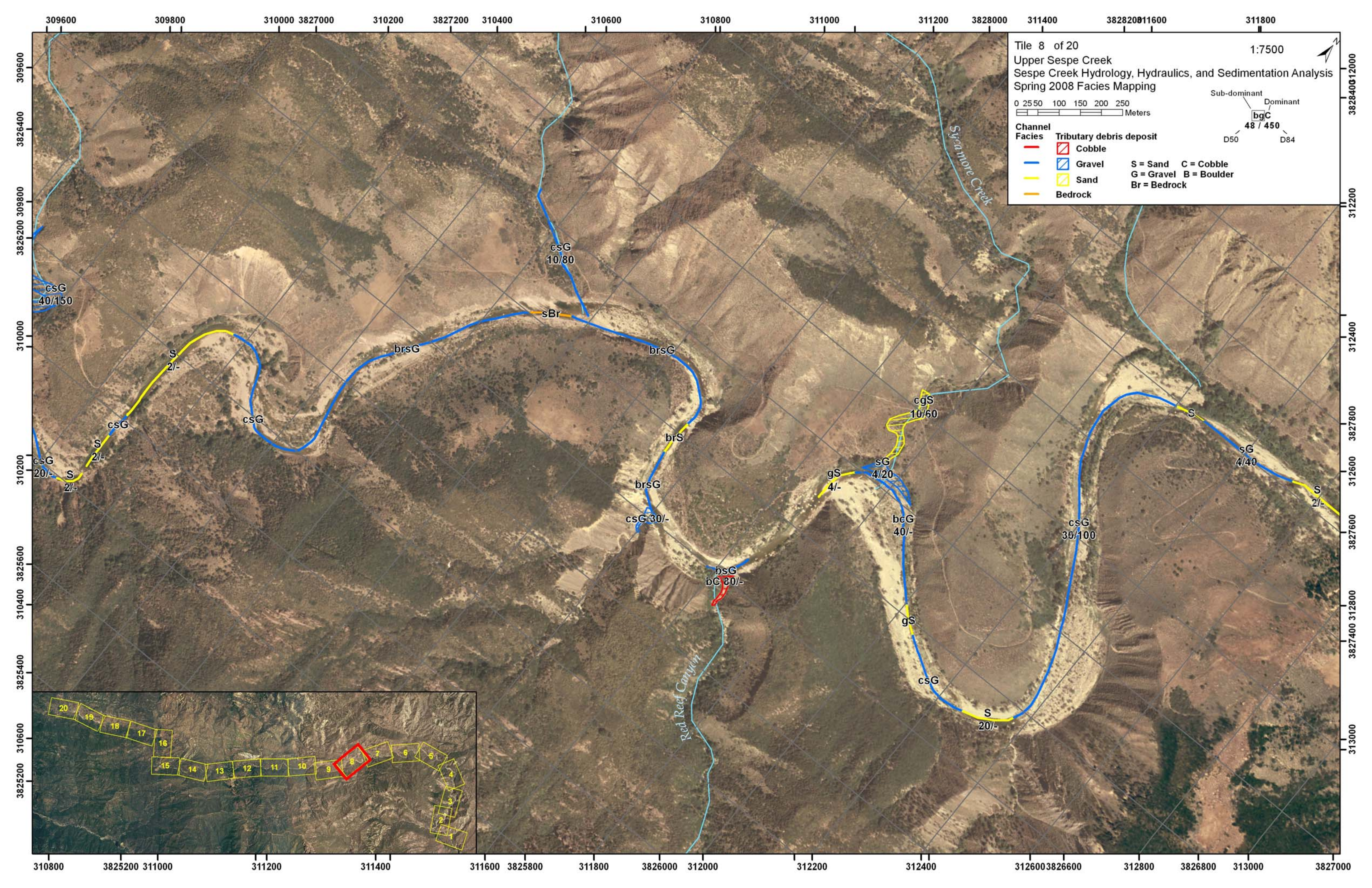
Tile 5 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
csG 50/-
sG 10/60
sG 5/60
csG 30/-
G 20/-
csG
G 10/30
csG 30/200
csG 20/-
sG
csG
sG 20/150
sG 10/-
csG 30/-
csG 30/100
sG 10/80
bsG 40/-
sG 10/-
bsG 40/-
cgS
gS
scG 30/200
sG 10/70
sG 20/60
bsG 60/300
scG
csG
cG 40/-
sG 10/-
csG
gS 4/10
csG 20/80

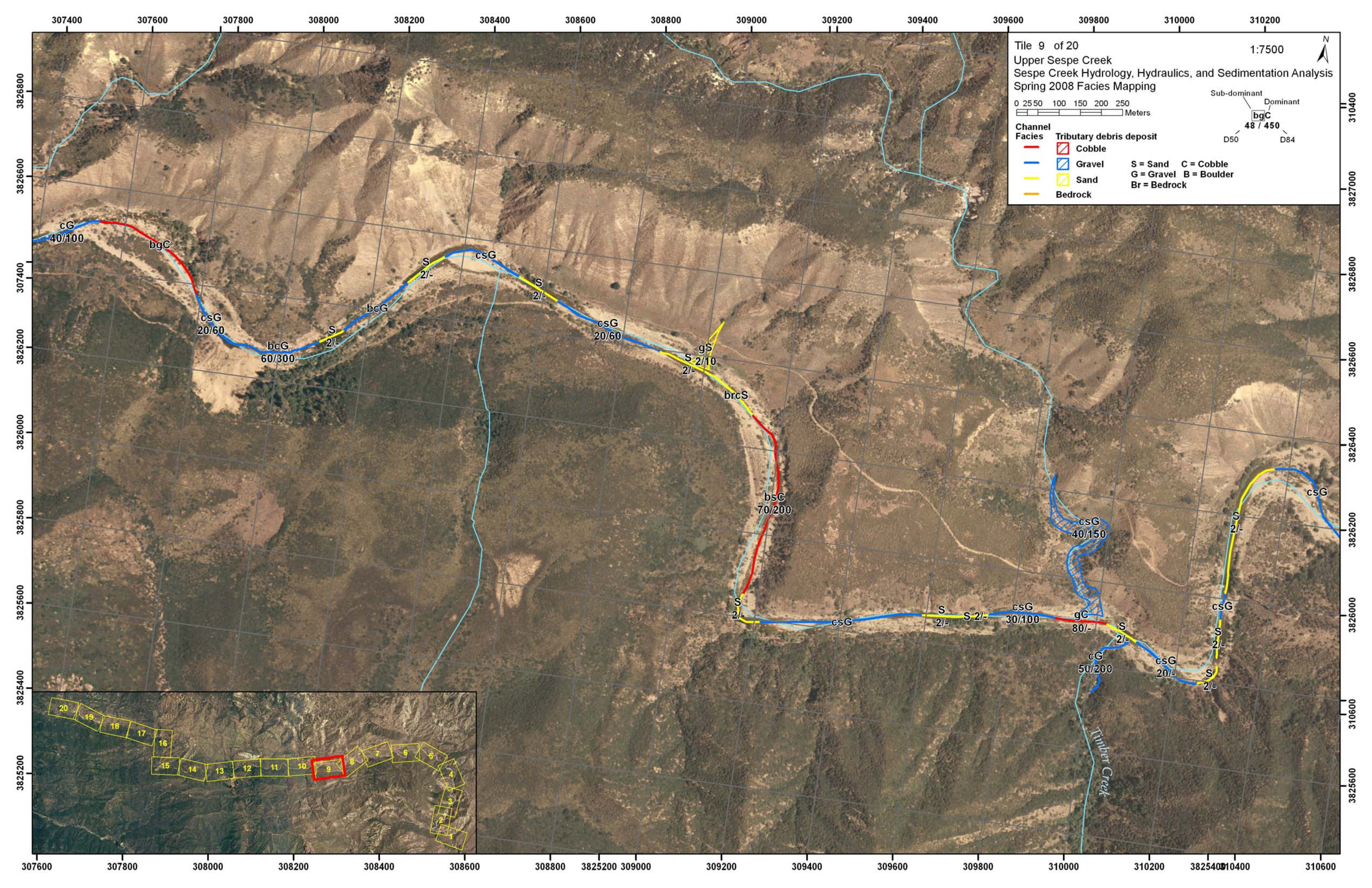


Tile 6 of 20
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
1:7500
N
0 25 50 100 150 200 250 Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
Hot Springs Canyon
scG 20/-
csG 30/-
sG 10/50
sG 5/40
S 2/-
sG 20/60
gS
S 2/-
csG 20/150
csG 50/150
bS
brS
cG
S 2/-
S
sG
S
sG
gS
gS 4/10
bG
csG
gS 4/-
gS 4/10
csG 20/80
cG 40/-
sG 20/60
bsG 60/300

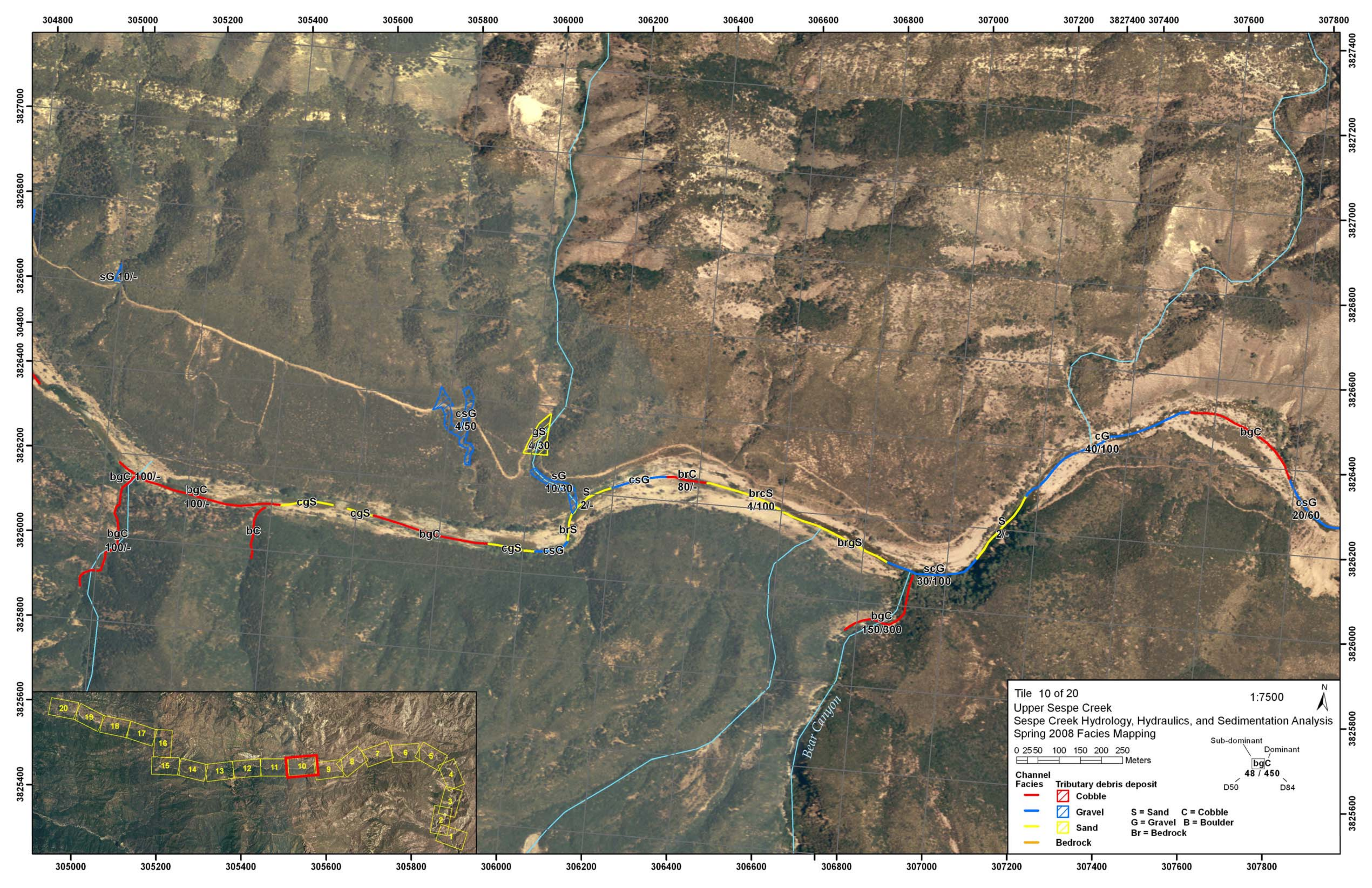


Tile 7 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand
C = Cobble
G = Gravel
B = Boulder
Br = Bedrock
S
sG 4/40
S 2/-
csG
gS
csG 30/80
bsG
S 2/-
sG 20/60
cG 50/300
S 2/-
csG 25/100
gS
sG 20/50
cG
csG 60/200
sG 20/-
csG 20/150
gS 2/20
csG
S 2/-
gS
sG 20/60
S 2/-
scG 20/-
csG 30/-
Park Creek
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

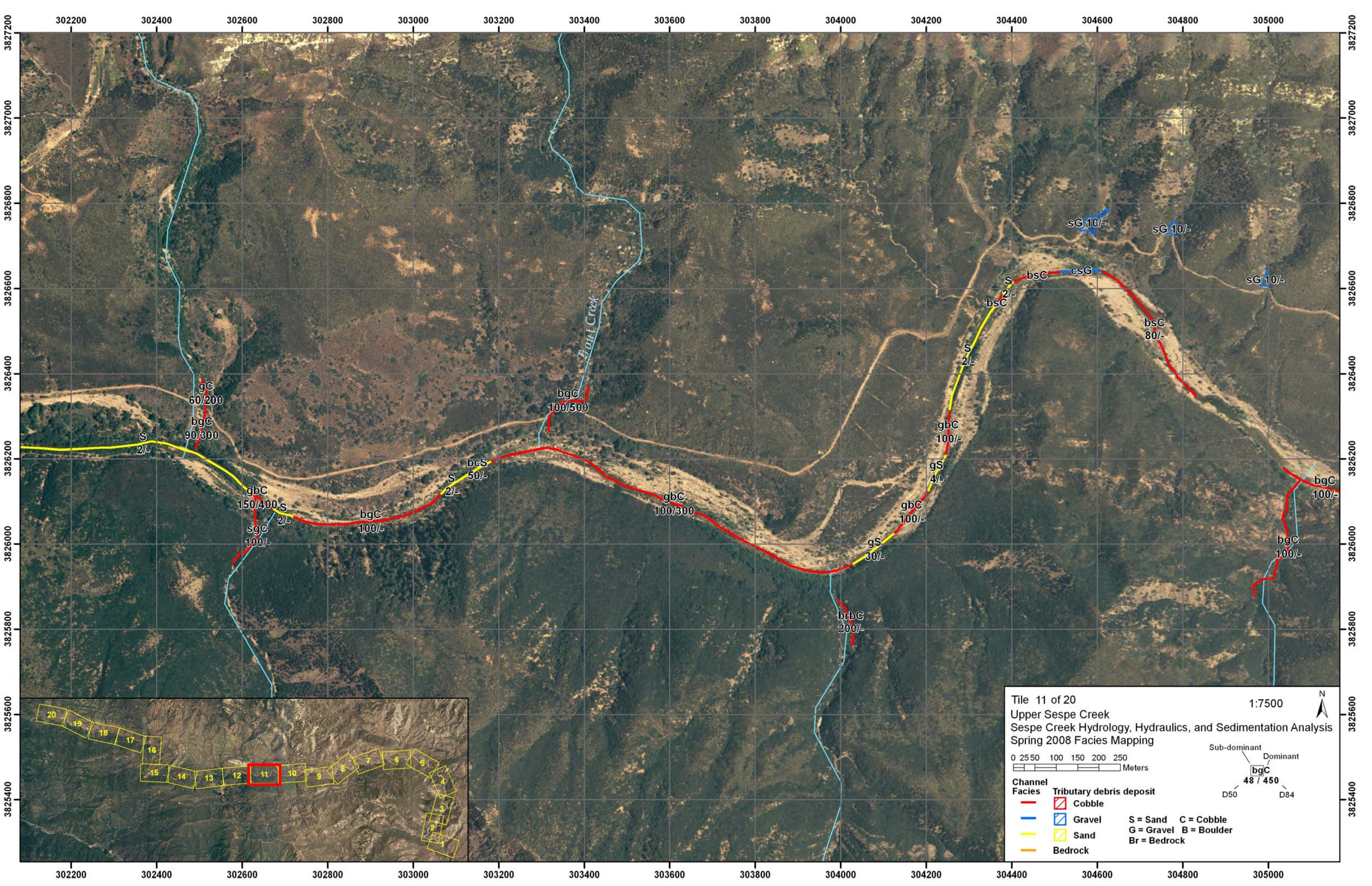

Tile 8 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
Sycamore Creek
Red Reef Canyon
csG 40/150
csG 10/80
sBr
brsG
S 2/-
csG
S 2/-
csG 20/-
S 2/-
brS
brsG
csG 30/-
bsG
bC 80/-
cgS 10/60
gS 4/-
sG 4/20
bcG 40/-
gS
csG
S 20/-
csG 30/100
S
sG 4/40
S 2/-



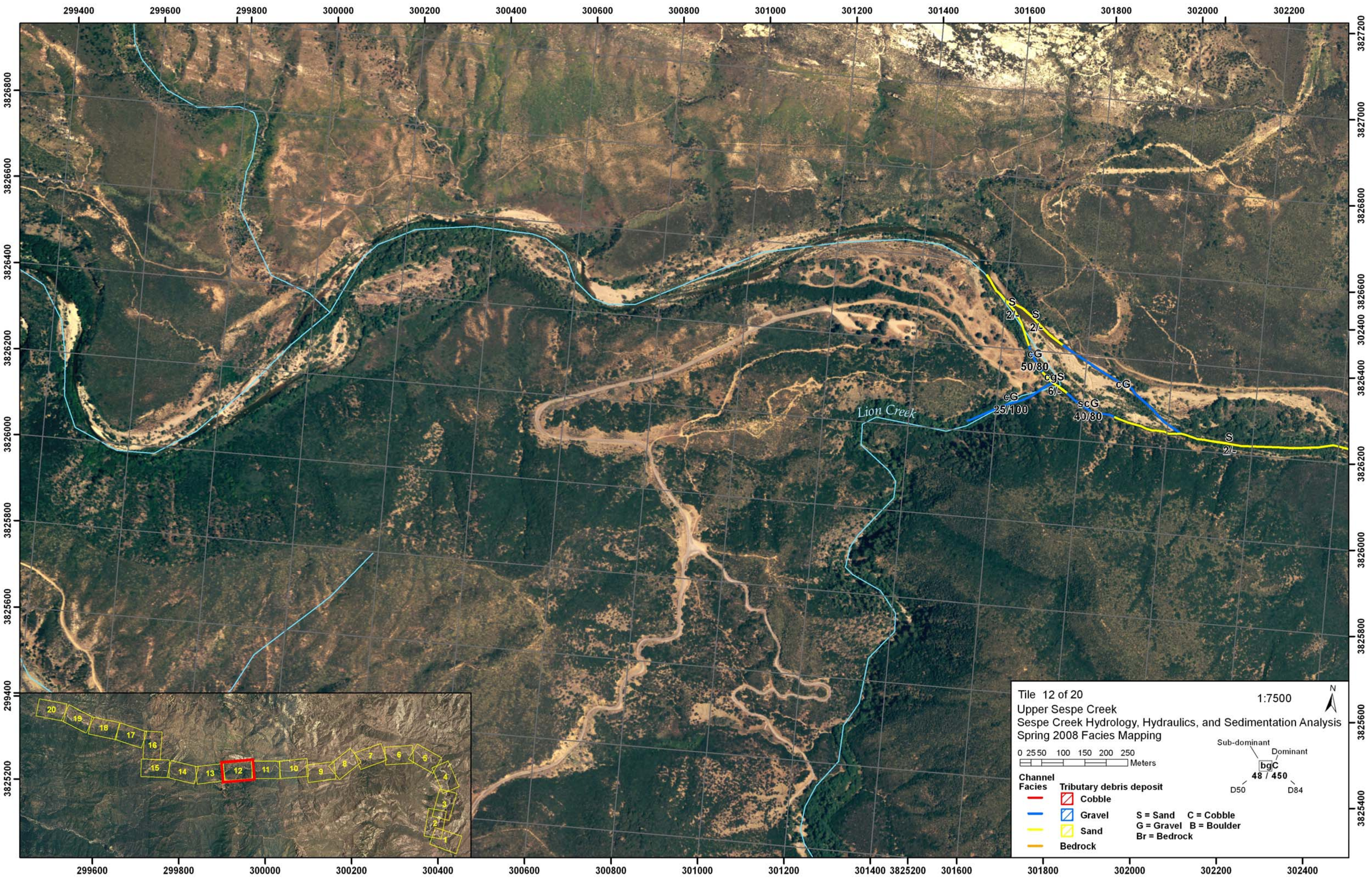
Tile 9 of 20
1:7500
N
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250 Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
cG 40/100
bgC
csG 20/60
bcG 60/300
S 2/-
bcG
S 2/-
csG
S 2/-
csG 20/60
gS 2/10
S 2/-
brcS
bsC 70/200
S 2/-
csG
S 2/-
S 2/-
csG 30/100
gC 80/-
S 2/-
cG 50/200
csG 40/150
csG 20/-
S 2/-
S 2/-
csG
S 2/-
csG
Timber Creek
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

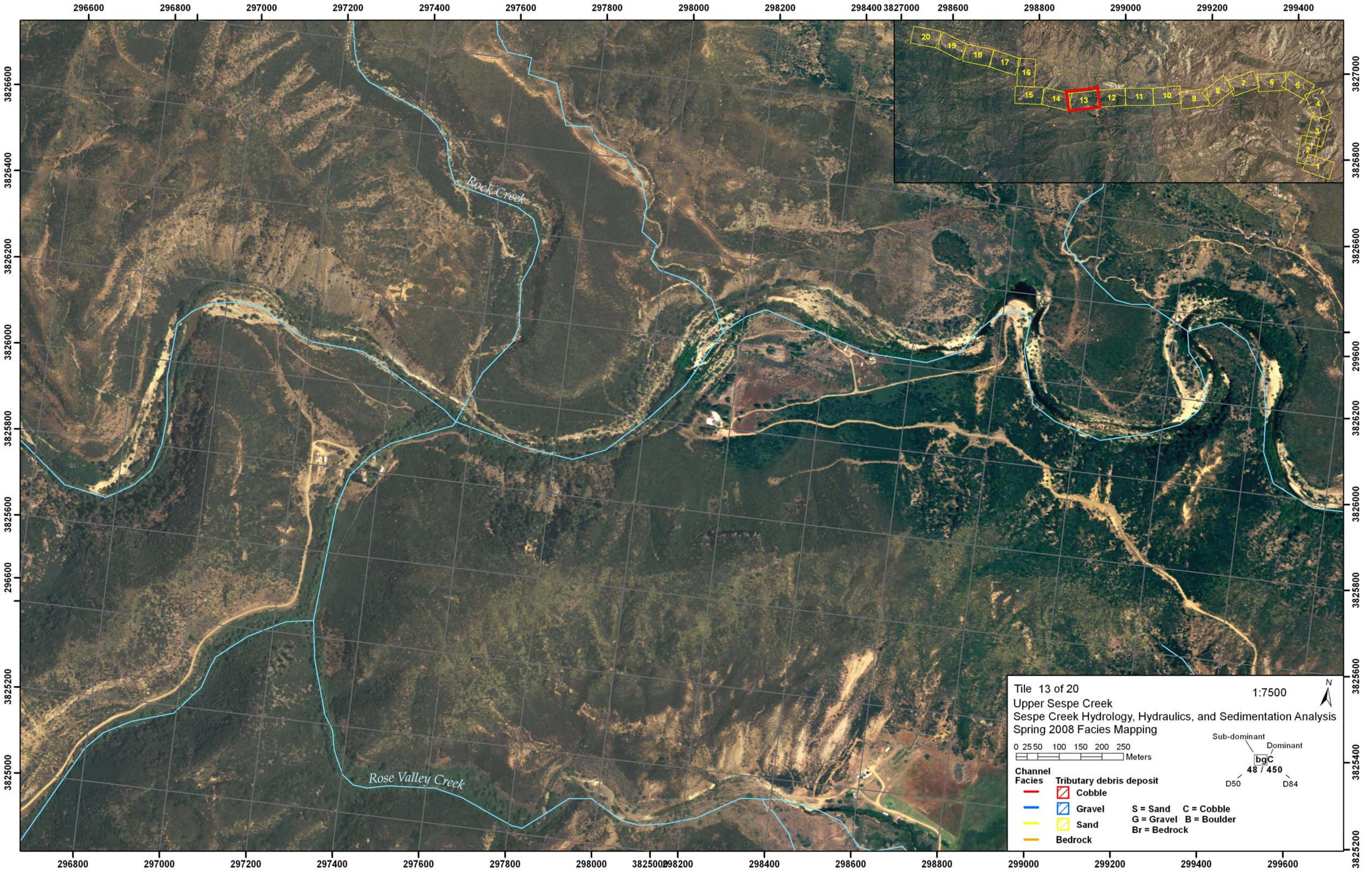


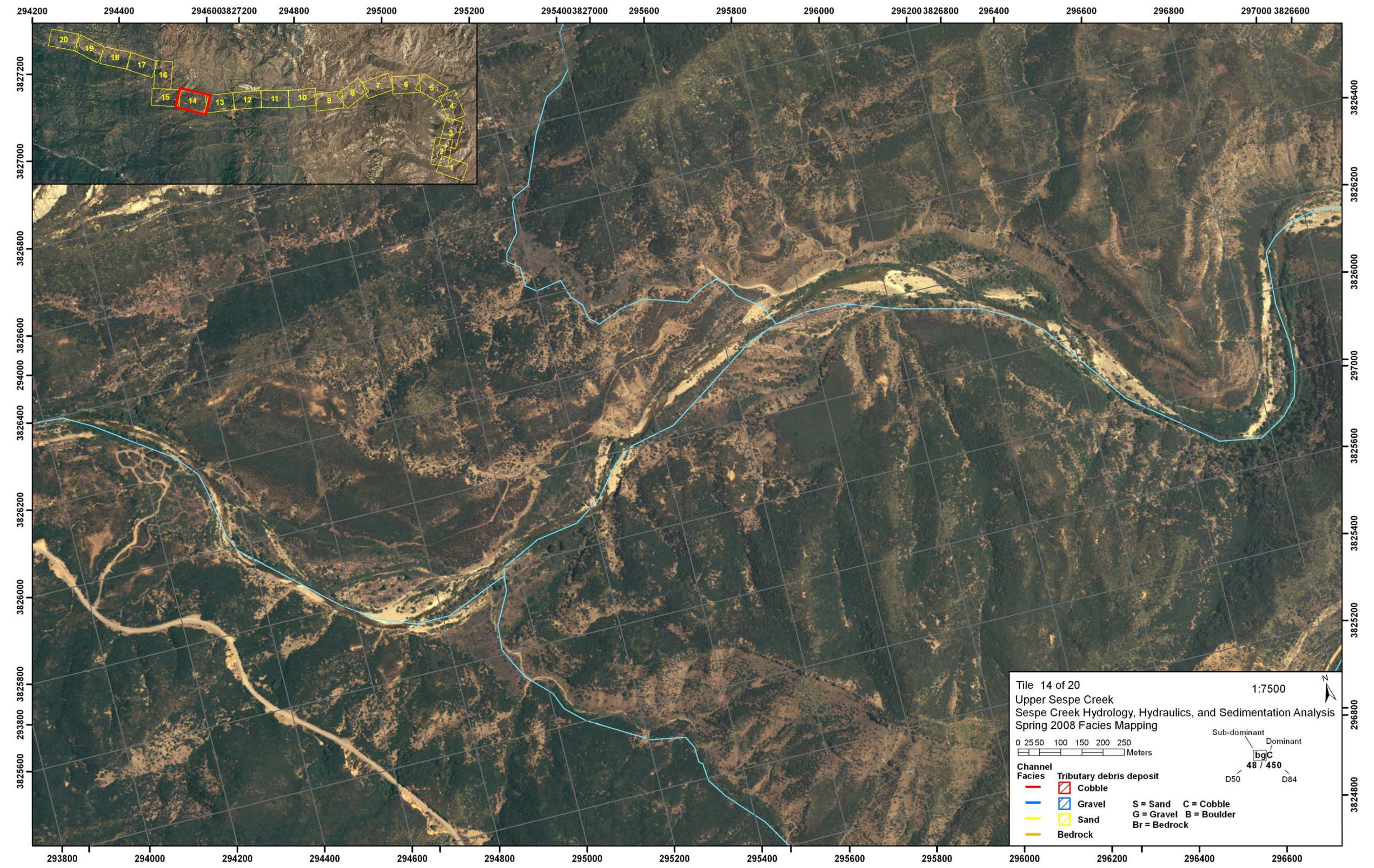
Tile 10 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
N
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
Bear Canyon
sG 10/-
csG 4/50
gS 4/30
bgC 100/-
bgC 100/-
bC
bgC 100/-
cgS
cgS
bgC
cgS
csG
sG 10/30
S 2/-
brS
csG
brC 80/-
brcS 4/100
brgS
scG 30/100
bgC 150/300
S 2/-
cG 40/100
bgC
csG 20/60
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
304800
305000
305200
305400
305600
305800
306000
306200
306400
306600
306800
307000
307200
307400
307600
307800
3827400
3827200
3827000
3826800
3826600
3826400
3826200
3826000
3825800
3825600
3825400



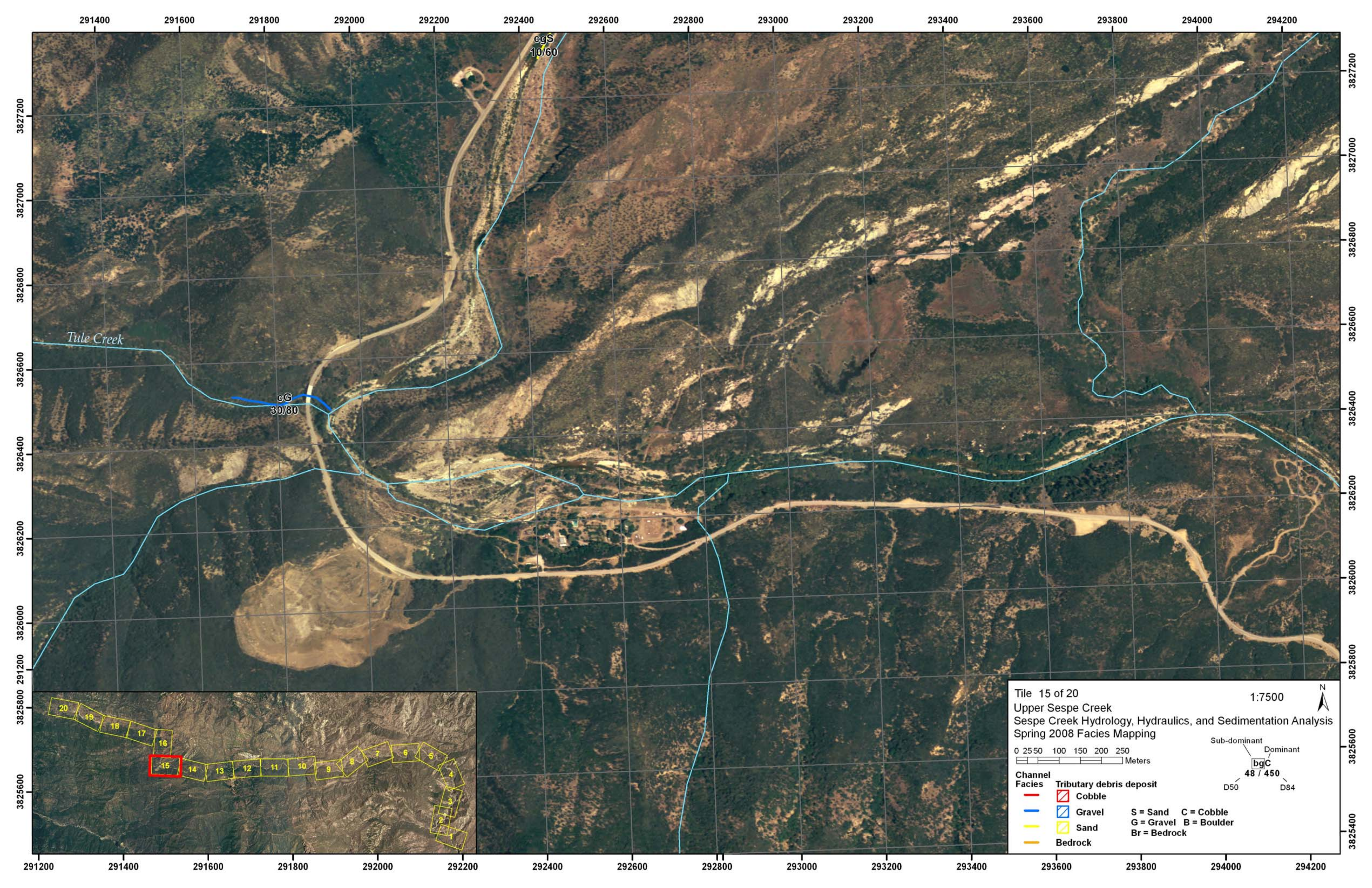
Tile 11 of 20
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
1:7500
N
0 25 50 100 150 200 250 Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
Trout Creek
gC 60/200
bgC 90/300
S 2/-
gbC 150/400
S 2/-
sgC 100/-
bgC 100/-
S 2/-
bcS 50/-
bgC 100/500
gbC 100/300
brbC 200/-
gS 30/-
gbC 100/-
gS 4/-
gbC 100/-
S 2/-
bsC
S 2/-
bsC
csG
bsC 80/-
sG 10/-
sG 10/-
sG 10/-
bgC 100/-
bgC 100/-


Tile 12 of 20
1:7500
N
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
Lion Creek
S
2/-
cG
50/80
cgS
6/-
cG
25/100
scG
40/80
299400
299600
299800
300000
300200
300400
300600
300800
301000
301200
301400
301600
301800
302000
302200
302400
3826800
3826600
3826400
3826200
3826000
3825800
3825600
3825400
3825200
3827200
3827000
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

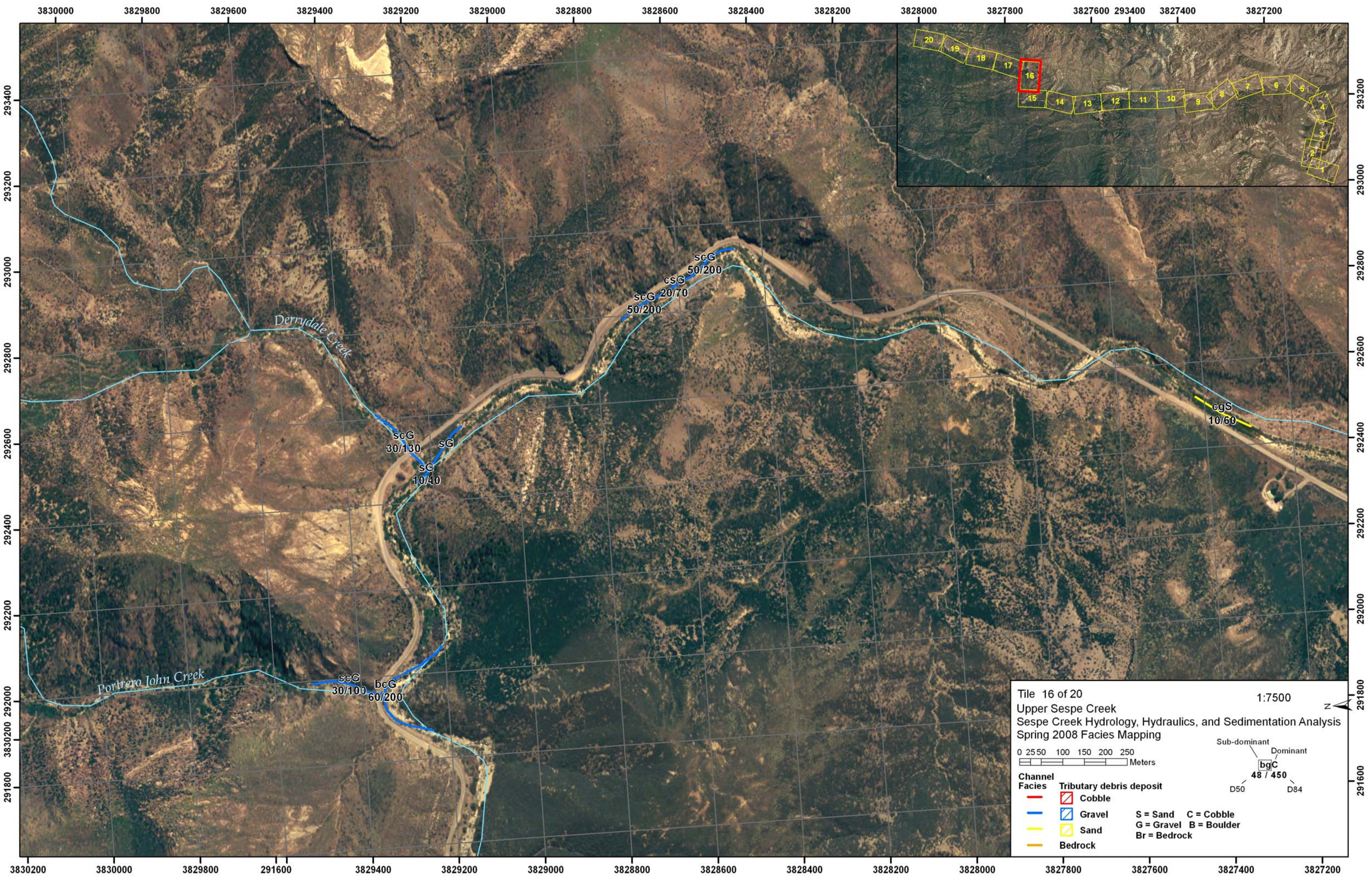

Rock Creek
Rose Valley Creek
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
Tile 13 of 20
1:7500
N
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250 Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
296600 296800 297000 297200 297400 297600 297800 298000 298200 298400 3827000 298600 298800 299000 299200 299400
296800 297000 297200 297400 297600 297800 298000 3825000 298200 298400 298600 298800 299000 299200 299400 299600
3826600 3826400 3826200 3826000 3825800 3825600 296600 3825400 3825200 3825000
3827000 3826800 3826600 299600 3826200 3826000 3825800 3825600 3825400 3825200



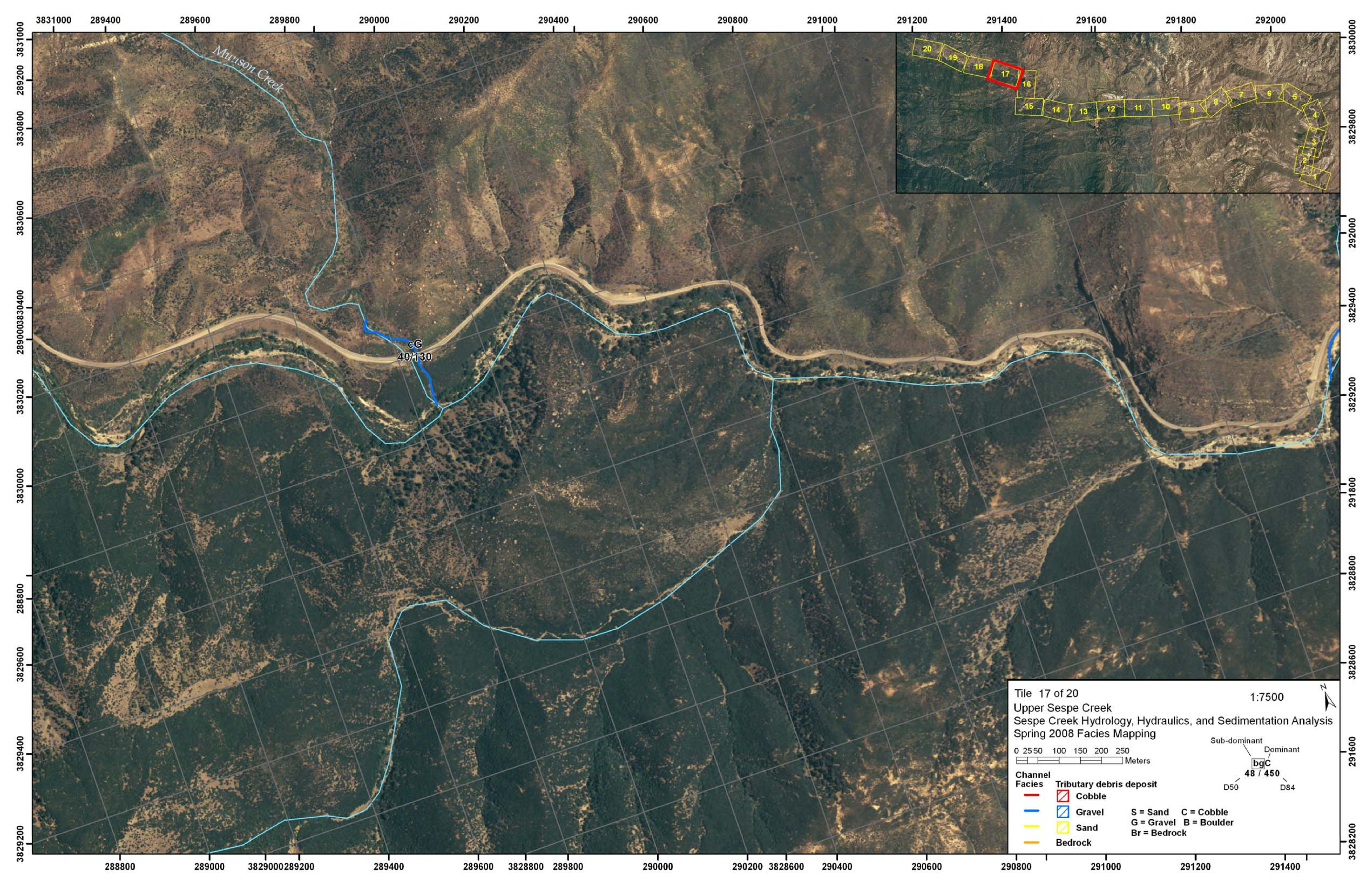
Tile 14 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250 Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand
C = Cobble
G = Gravel
B = Boulder
Br = Bedrock
N

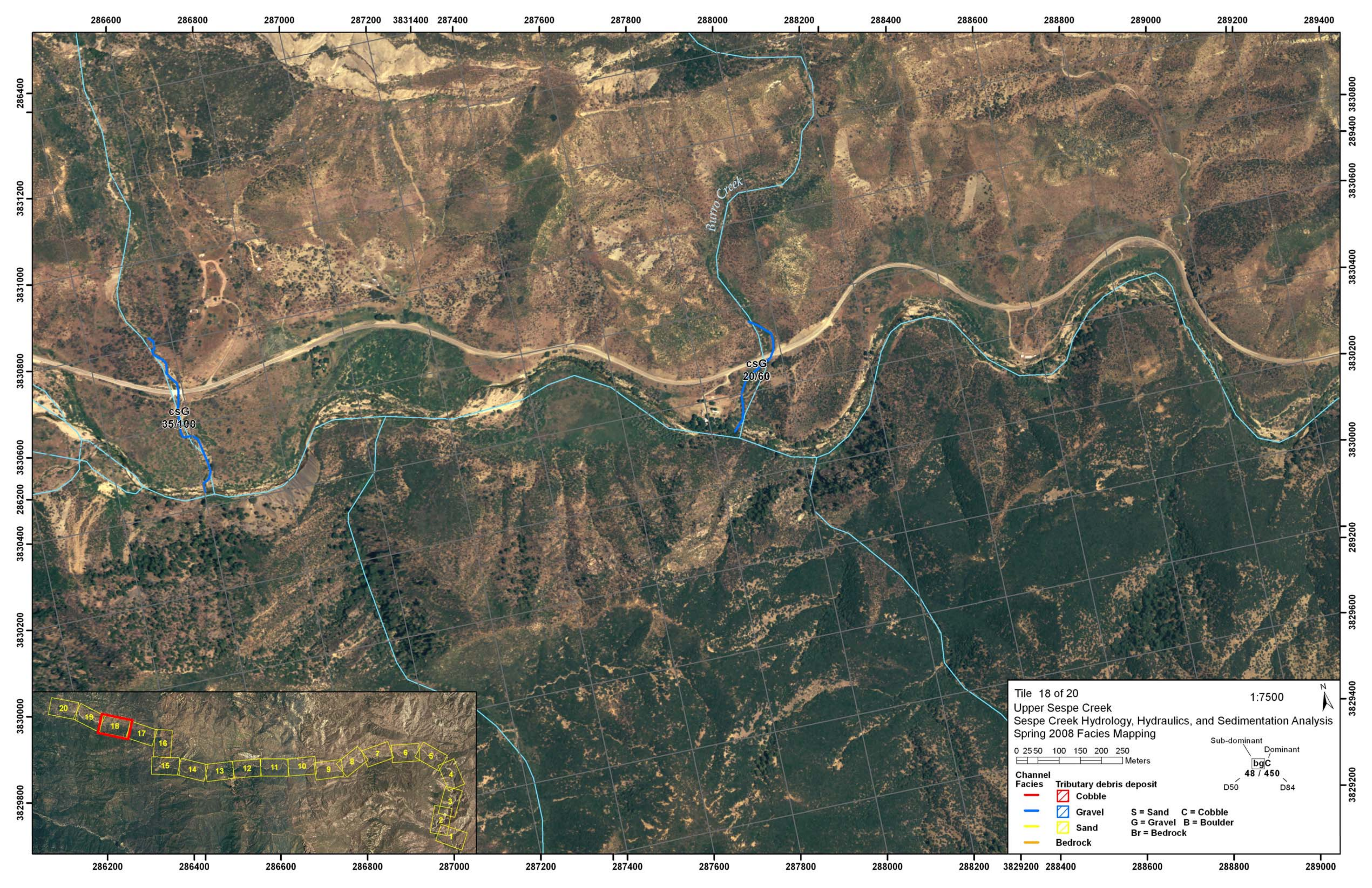


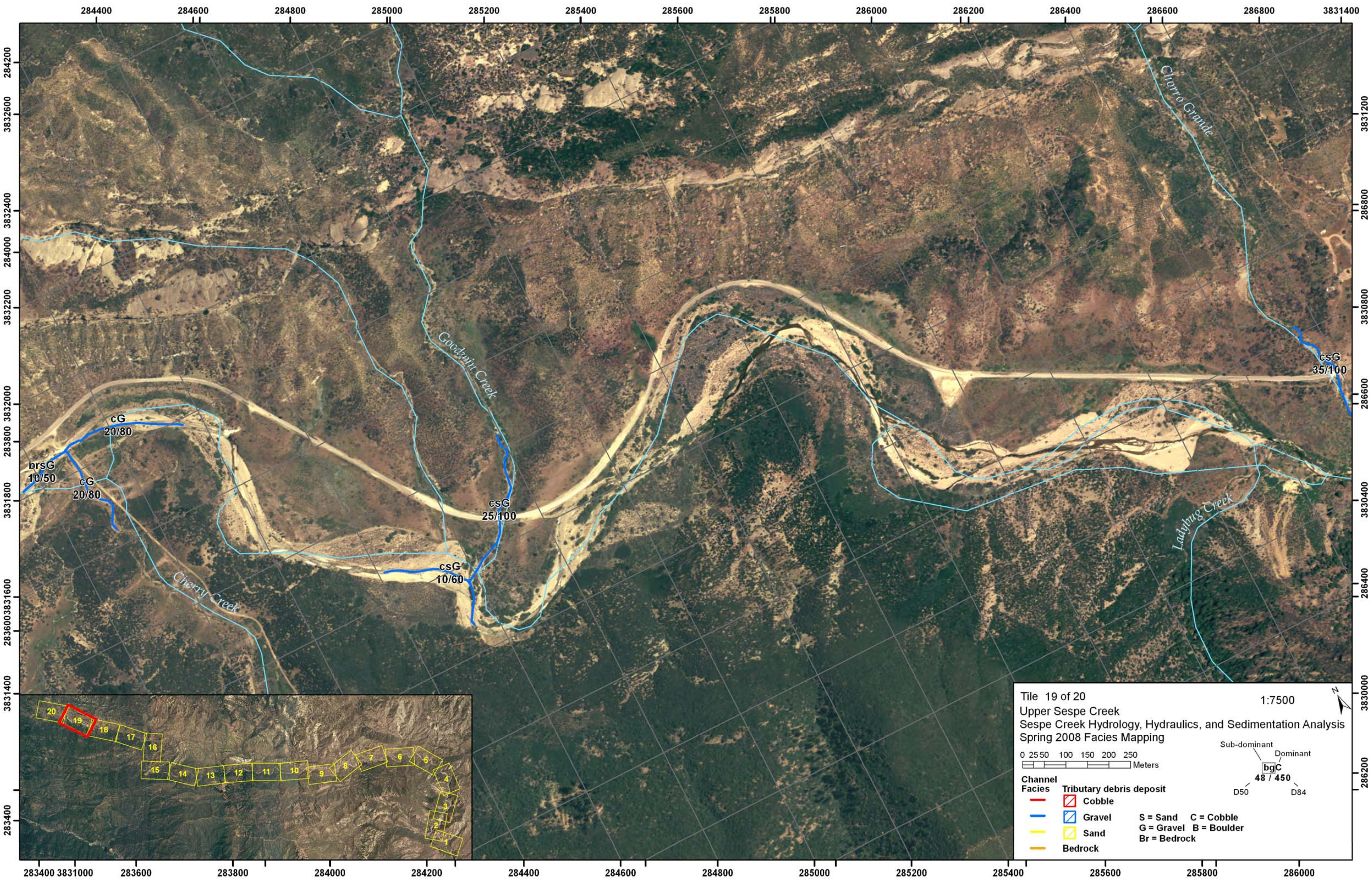
291400
291600
291800
292000
292200
292400
292600
292800
293000
293200
293400
293600
293800
294000
294200
291200
3827200
3827000
3826800
3826600
3826400
3826200
3826000
3825800
3825600
3825400
Tule Creek
cgS
10/60
cG
30/80
Tile 15 of 20
1:7500
N
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1



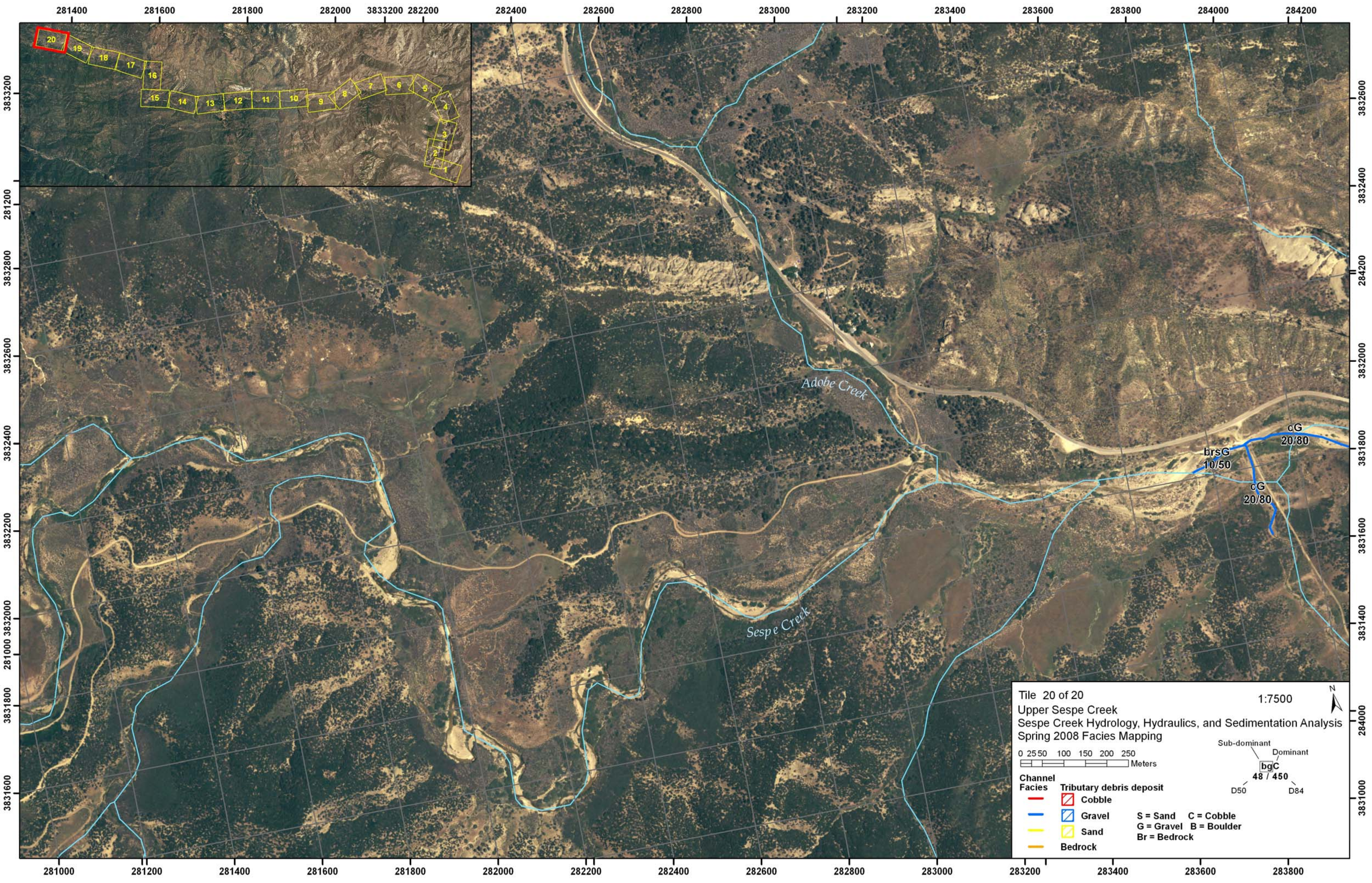
Derrydale Creek
Portrero John Creek
scG 50/200
csG 20/70
scG 50/200
scG 30/130
sG
sG 10/40
cgS 10/60
scG 30/100
bcG 60/200
Tile 16 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250 Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock


3831000 289400 289600 289800 290000 290200 290400 290600 290800 291000 291200 291400 291600 291800 292000
Munson Creek
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
cG
40/130
288800 289000 3829000 289200 289400 289600 3828800 289800 290000 290200 3828600 290400 290600 290800 291000 291200 291400
3831000 3830800 3830600 3830400 3830200 3830000 3829800 3829600 3829400 3829200
3830000 3829800 3829600 3829400 3829200 3829000 3828800 3828600 3828400 3828200
Tile 17 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock


Burro Creek
csG
35/100
csG
20/60
Tile 18 of 20
1:7500
N
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock



Tile 19 of 20
1:7500
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
0 25 50 100 150 200 250
Meters
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
Sub-dominant
Dominant
bgC
48 / 450
D50
D84
N
Chorro Grande
Goodwin Creek
Cherry Creek
Ladybug Creek
csG
35/100
cG
20/80
brsG
10/50
cG
20/80
csG
25/100
csG
10/60
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
284400
284600
284800
285000
285200
285400
285600
285800
286000
286200
286400
286600
286800
3831400
283400
3831000
283600
283800
284000
284200
284400
284600
284800
285000
285200
285400
285600
285800
286000


Adobe Creek
Sespe Creek
brsG
10/50
cG
20/80
cG
20/80
Tile 20 of 20
Upper Sespe Creek
Sespe Creek Hydrology, Hydraulics, and Sedimentation Analysis
Spring 2008 Facies Mapping
1:7500
0 25 50 100 150 200 250 Meters
Channel Facies
Tributary debris deposit
Cobble
Gravel
Sand
Bedrock
S = Sand C = Cobble
G = Gravel B = Boulder
Br = Bedrock
Sub-dominant
Dominant
bgC
48 / 450
D50
D84

Appendix B

Tributary Confluence Assessment

Tributary Confluence Data Checklist

Tributary Name: **LITTLE SESPE CREEK**	Map Tile# **8 of 9 (LOWER SUBWATERSHED)**
Field Crew: **GTL SRD** Form completed by **GTL**	Date **6 APRIL 08** Time ______ AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): **10-20 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE**
- Incision (entrenchment): **CHANNEL INCISED/CONFINED BELOW ADJACENT FLOODPLAIN/TERRACE**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES, >3m ABOVE CHANNEL BED**
- Gradient:
  - at mouth (0m u/s): **1-2%**
  - at 25m u/s: **2-3%**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **SCRUB/SHRUB WITH RIPARIAN TREES (WILLOWS)**
- LWD presence: **NONE**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE TO STEEP**
- Hillslope / valley description: **STEEP CANYON/GORGE**
- Geology in valley: **SANDSTONE/SHALE**
- Debris flows: **OBSERVED SOME SLIDE ACTIVITY >1 KM U/S IN WATERSHED ALONG DOUGH FLAT ACCESS ROAD (SESPE OIL FIELDS)**
- Rockfalls: **SAME**
- Vegetation cover on hillslopes: **SCRUB/SHRUB WITH TREES (OAKS, ALDERS)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **30 mm**
- D84: **150 mm**
- Size Distribution: **SILT TO BOULDERS**
- Facies Present (and mapped on tiles): **CSG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, sands ? Percent?): **HIGH (~40-50%)**
- Turbidity relative to Sespe Creek: **CLEARER**
- Storage: **STORAGE OF FINE AND COARSE MATERIALS LIMITED TO ACTIVE CHANNEL AREA**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **PIRU**
- Evidence of fire in tributary watershed: **BURNED TREES ON UPPER HILLSLOPES (WITH REGROWTH)**
- General fire related effects on tributary watershed: **INCREASED SEDIMENT LOADING**
- Ash presence in channel sediment? **NO**
- Debris flows? **YES, BUT FARTHER UPSTREAM ON HILLSLOPES (LANDSLIDES NEAR ROAD CROSSINGS)**
- Excess sedimentation of fines, ravel, boulders, etc. **FINE (SILT TO FINE GRAVEL) DEPOSITS ALONG LOWER 1 KM OF STREAM BED**

Tributary Confluence Data Checklist

Tributary Name: **W. FORK SESPE CREEK (ASSESSED FROM THE AIR)**	Map Tile# **2 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **GTL**	Date **6 JUNE 08** Time **12:00** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): **UNKNOWN**

Tributary Morphology:
- Single or multi-thread channel: **SINGLE**
- Incision (entrenchment): **NO**
- Headcuts on tributary (within 100m of Sespe): **YES, NEAR MOUTH**
- Terraces present: YES
- Gradient:
  - at mouth (0m u/s): **VERY STEEP AT MOUTH (~10%)**
  - at 25m u/s: **SAME**
  - at 50m u/s: **SAME**
  - at 100m u/s: **STEP-POOL (5-10%)**
- Vegetation cover along tributary: **SCRUB/SHRUB WITH RIPARIAN (COTTONWOODS, WILLOW)**
- LWD presence: **NONE**

Hillslope / Valley Morphology
- Hillslope gradient: **MODERATE TO STEEP CANYON/VALLEY**
- Hillslope / valley description: **DEEP CANYON/VALLEY ENTERING SESPE GORGE**
- Geology in valley: **SANDSTONE/SHALE**
- Debris flows: **NONE VISIBLE**
- Rockfalls: **YES, FROM CANYON WALLS**
- Vegetation cover on hillslopes: **SCRUB/SHRUB WITH TREES (OAK)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):
- D50: **250 mm** D84: **1,000 mm**
- Size Distribution: **GRAVEL TO LARGE BOULDERS (BEDROCK BLOCKS)**
- Facies Present (and mapped on tiles): **BC**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, sands ? Percent?): **LOW (<5%)**
- Turbidity relative to Sespe Creek: **UNKNOWN**
- Storage: **STORAGE OF COARSE SEDIMENT LIMITED TO CHANNEL BED**

Fire Effects:
- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **DAY (ON SOUTH-FACING VALLEY WALL)**
- Evidence of fire in tributary watershed: **BURNED VEGETATION ON HILLSLOPES**
- General fire related effects on tributary watershed: **NONE OBVIOUS**
- Ash presence in channel sediment? **NO**
- Debris flows? **NONE VISIBLE, AND NO POST-FIRE DEBRIS DEPOSITS OBSERVED AT MOUTH**
- Excess sedimentation of fines, ravel, boulders, etc.: **POSSIBLE**

Tributary Confluence Data Checklist

Tributary Name: **ALDER CREEK**	Map Tile# **4 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **5 APRIL 08** Time **10:15** **AM** PM

Flow? Yes / **YES** Approx. Discharge (cfs): **10-20 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE**
- Incision (entrenchment): **MODERATE TO NONE**
- Headcuts on tributary (within 100m of Sespe): **BOULDER STEPS AND HEAD CUTS U/S IN GRAVEL BED**
- Terraces present: **YES (CURRENT AND ABANDONED ~10 M HIGHER AT D/S SECTION)**
- Gradient:
  - at mouth (0m u/s): **STEEP (>5%)**
  - at 25m u/s: **2-3% (STEP-POOL)**
  - at 50m u/s: **SAME**
  - at 100m u/s: **BECOMES CONTROLLED BY LARGE BOULDER/BEDROCK**
- Vegetation cover along tributary: **RIPARIAN (COTTONWOOD, ALDER, HERBACEOUS, SCRUB WILLOW)**
- LWD presence: **NONE**

Hillslope / Valley Morphology

- Hillslope gradient: **STEEP**
- Hillslope / valley description: **E AND W-FACING SLOPES: MASS WASTING/ROCKFALL; GORGE U/S OF >100 M OF MOUTH**
- Geology in valley: **SANDSTONE BEDROCK WITH GRANITICS/GNEISSICS BED SUBSTRATE**
- Debris flows: **VISIBLE ON RB**
- Rockfalls: **YES, R AND L SIDES**
- Vegetation cover on hillslopes: **CHAPPARAL (BURNED WITH REGROWTH)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **20-30 mm** D84: **250 mm**
- Size Distribution: **SAND TO BOULDER**
- Facies Present (and mapped on tiles): **CSG (BSG U/S OF MOUTH)**
- Rock type (SS, Sh, Gr, etc.): **SS, G, Sh, GNEISSIC**
- Fines Content (clays, silts, fine sands? Percent?): **30-40%**
- Turbidity relative to Sespe Creek: **CLEARER**
- Storage: **STORAGE OF COARSE AND FINE SEDIMENT IN CHANNEL (LOTS OF SILTS AND SANDS)**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **DAY**
- Evidence of fire in tributary watershed: **BURNED TREES AND SHRUBS ON FLOODPLAIN AND HILLSLOPES; PARTIALLY BURIED BURNED VEGETATION (POST-FIRE DEPOSIT)**
- General fire related effects on tributary watershed: **EXCESS OF FINE SILTS-GRAVELS**
- Ash presence in channel sediment? **NO**
- Debris flows? **NO SLIDES OBSERVED; DEBRIS DEPOSITS U/S OF ALDER CREEK GORGE (~600 M U/S OF MOUTH)**

Tributary Confluence Data Checklist

Tributary Name: **HOT SPRINGS CANYON**	Map Tile# **6 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **4 APRIL 08** Time **15:00** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): **10-20 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE (AT LOW FLOW)**
- Incision (entrenchment): **MODERATE INCISION THROUGH SED DEPOSIT**
- Headcuts on tributary (within 100m of Sespe): **NO (BOULDER STABILIZE GRADE)**
- Terraces present: **YES (ACTIVE)**
- Gradient:
  - at mouth (0m u/s): **BOULDER –FORCED STEP-POOL (2-3%)**
  - at 25m u/s: **2-3% SAME**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **RIPARIAN (OAK, COTTONWOOD, SCRUB WILLOW)**
- LWD presence: **SOME**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE TO STEEP**
- Hillslope / valley description: **SE FACING, SESPE SANDSTONE VISIBLE**
- Geology in valley: **GRANITICS AND GNEISSIC ROCKS**
- Debris flows: **POST-FIRE DEBRIS DEPOSITS AT MOUTH (SILT TO FINE GRAVEL)**
- Rockfalls: **YES, ROCKFALL VISIBLE ON LB AND RB SLOPES**
- Vegetation cover on hillslopes: **SPARSE HERBACEOUS/SCRUB (BURNED WITH REGROWTH)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **40-50 mm**
- Size Distribution: **SILT TO BOULDER**
- Facies Present (and mapped on tiles): **CSG (WITH <5% BOULDERS)**
- Rock type (SS, Sh, Gr, etc.): **SS, GRANITE, Sh, GNEISS**
- Fines Content (clays, silts, fine sands? Percent?): **30-40% SAND**
- Turbidity relative to Sespe Creek: **SAME**
- Storage: **STORAGE OF COARSE AND FINE SEDIMENT IN CHANNEL (LOTS OF SILTS AND SANDS), CHANNEL IS INCISING THROUGH CURRENT DEPOSIT**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **DAY**
- Evidence of fire in tributary watershed: **BURNED TREES AND SHRUBS ON FLOODPLAIN AND HILLSLOPES; PARTIALLY BURIED BURNED VEGETATION (POST-FIRE DEPOSIT)**
- General fire related effects on tributary watershed: **INCREASED SEDIMENT LOADING**
- Ash presence in channel sediment? **NO**
- Debris flows? **NO SLIDES OBSERVED; DEBRIS DEPOSITS THROUGHOUT MOUTH**
- Excess sedimentation of fines, ravel, boulders, etc.

Tributary Confluence Data Checklist

Tributary Name: **PARK CREEK**	Map Tile# **7 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **4 APRIL 08** Time **11:00** **AM** PM

Flow? Yes / **YES** Approx. Discharge (cfs): **10 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE (AT LOW FLOW)**
- Incision (entrenchment): **NONE**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES (ACTIVE), CHANNEL SLIGHTLY INSET**
- Gradient:
  - at mouth (0m u/s): **STEP-POOL (2-3%)**
  - at 25m u/s: **SAME**
  - at 50m u/s: **1-2% BETWEEN BOULDER STEPS**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **SCRUB/SHRUB AND RIPARIAN (OAK, COTTONWOOD, SCRUB WILLOW)**
- LWD presence: **NONE**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE TO STEEP**
- Hillslope / valley description: **NORTH FACING, VEGETATED HILLSLOPES**
- Geology in valley: **SANDSTONES AND CONGLOMERATES**
- Debris flows: **NONE VISIBLE**
- Rockfalls: **NONE VISIBLE**
- Vegetation cover on hillslopes: **HERBACEOUS/SCRUB/TREES (MOSTLY BURNED WITH REGROWTH)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **60 mm** D84: **200 mm**
- Size Distribution: **SILT TO BOULDER**
- Facies Present (and mapped on tiles): **CSG (WITH ~5% BOULDERS)**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh, (CONGLOMERATE BOULDERS)**
- Fines Content (clays, silts, fine sands? Percent?): **20-30% SAND**
- Turbidity relative to Sespe Creek: **SAME**
- Storage: **LOTS OF STORAGE IN CHANNEL (LARGE BOULDERS TRAP FINER MATERIAL)**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **DAY**
- Evidence of fire in tributary watershed: **BURNED TREES AND SHRUBS ON FLOODPLAIN AND HILLSLOPES**
- General fire related effects on tributary watershed: **INCREASED FINE SEDIMENT LOADING POSSIBLE**
- Ash presence in channel sediment? **NO**
- Debris flows? **NO SLIDES OBSERVED; DEBRIS DEPOSITS THROUGHOUT MOUTH**
- Excess sedimentation of fines, ravel, boulders, etc. **POSSIBLE**

Tributary Confluence Data Checklist

Tributary Name: **SYCAMORE CREEK**	Map Tile# **8 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **3 APRIL 08** Time **15:00** AM **PM**

Flow? Yes / **<u>YES</u>** Approx. Discharge (cfs): <**10 CFS**

Tributary Morphology:
- Single or multi-thread channel: **SINGLE (AT LOW FLOW)**
- Incision (entrenchment): **YES, INCISION THROUGH SAND-GRAVEL DEPOSIT**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES, CURRENT AND HIGHER ABANDONED, ~1-1.5 m HIGHER**
- Gradient:
  - at mouth (0m u/s): **MEANDERING LOW FLOW CHANNEL (<1 – 1%)**
  - at 25m u/s: **SAME**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **LOW: SCRUB/SHRUB AND FEW TREES**
- LWD presence: **NONE**

Hillslope / Valley Morphology
- Hillslope gradient: **MODERATE TO STEEP**
- Hillslope / valley description: **SOUTH FACING, SPARSE AND BURNED VEGETATION, BEDROCK EXPOSURES**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **ONE POSSIBLE DEBRIS FLOW/LANDSLIDE SCAR PRESENT ON SOUTH-FACING SLOPE ~200-300 M U/S OF MOUTH**
- Rockfalls: **SOME**
- Vegetation cover on hillslopes: **HERBACEOUS (MOSTLY BURNED, WITH REGROWTH)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):
- D50: **4 mm (<50 m U/S), 10 mm** (**50-200 m U/S)**
- D84: **20 mm (<50 m U/S), 50 mm (50-200 m U/S)**
- Size Distribution: **SAND TO BOULDER**
- Facies Present (and mapped on tiles): **SG (<50 m U/S), CGS (50-200 m U/S)**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **HIGH ~50% SAND**
- Turbidity relative to Sespe Creek: **SAME**
- Storage: **LARGE AMOUNT OF STORAGE OF FINE SANDY MATERIAL (ALSO COARSER MATERIALS BEING TRANSPORTED)**

Fire Effects:
- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **DAY**
- Evidence of fire in tributary watershed: **BURNED SHRUBS ON FLOODPLAIN AND HILLSLOPES; PARTIALLY BURIED BURNED VEGETATION (POST-FIRE DEPOSIT)**
- General fire related effects on tributary watershed: **INCREASED FINE SEDIMENT LOADING**
- Ash presence in channel sediment? **NO**
- Debris flows? **NO SLIDES OBSERVED; DEBRIS DEPOSITS THROUGHOUT MOUTH**
- Excess sedimentation of fines, ravel, boulders, etc. **YES, LOTS OF POST-FIRE FINES**

Tributary Confluence Data Checklist

Tributary Name: **TIMBER CREEK**	Map Tile# **9 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **3 APRIL 08** Time **14:00** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): **20-30 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE**
- Incision (entrenchment):**NONE**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES, CURRENT AND HIGHER ABANDONED, ~3 m HIGHER**
- Gradient:
  - at mouth (0m u/s): **STEP-POOL MORPHOLOGY (2-5%)**
  - at 25m u/s: **SAME**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **SCRUB/SHRUB AND RIPARIAN TREES (OAK, COTTONWOOD)**
- LWD presence: **VERY FEW PIECES (BURNED TREES)**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE TO STEEP**
- Hillslope / valley description: **NORTH FACING, WELL-VEGETATED (PRE-BURN)**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NONE VISIBLE**
- Rockfalls: **MINOR SLIDE ON LB VALLEY WALL**
- Vegetation cover on hillslopes: **SCRUB/SHRUB (MOSTLY BURNED, WITH REGROWTH)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **50 mm**
- D84: **200 mm**
- Size Distribution: **SAND TO BOULDER**
- Facies Present (and mapped on tiles): **CG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **HIGH 30-40% SAND**
- Turbidity relative to Sespe Creek: **SAME**
- Storage: **STORAGE OF GRAVEL BEHIND BOULDER IN WETTED CHANNEL (BOULDERS IN CHANNEL AND ON FLOODPLAIN), STORAGE OF FINE SEDIMENT ON FLOODPLAIN**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **DAY**
- Evidence of fire in tributary watershed: **BURNED SHRUBS ON FLOODPLAIN AND HILLSLOPES**
- General fire related effects on tributary watershed: **VEGETATION LOSS**
- Ash presence in channel sediment? **NO**
- Debris flows? **NONE VISIBLE**
- Excess sedimentation of fines, ravel, boulders, etc. **YES, LARGE AMOUNT OF FINE SEDIMENT IN CHANNEL AND ON FLOODPLAIN**

Tributary Confluence Data Checklist

Tributary Name: **BEAR CANYON**	Map Tile# **10 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **3 APRIL 08** Time **10:30** **AM** PM

Flow? Yes / **YES** Approx. Discharge (cfs): **30-40 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE**
- Incision (entrenchment):**NONE**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES**
- Gradient:
  - at mouth (0m u/s): **STEEP/CASCADE(>5%)**
  - at 25m u/s: **STEEP (2-3%)**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **RIPARIAN TREES (COTTONWOOD, ALDER, WILLOW)**
- LWD presence: **VERY FEW PIECES**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE TO STEEP**
- Hillslope / valley description: **NORTH FACING, WELL-VEGETATED**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NONE VISIBLE**
- Rockfalls: **NONE VISIBLE**
- Vegetation cover on hillslopes: **SCRUB/SHRUB (CHAPPARAL)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **150 mm**
- D84: **300 mm**
- Size Distribution: **FINE GRAVEL TO BOULDER**
- Facies Present (and mapped on tiles): **BGC**
- Rock type (SS, Sh, Gr, etc.): **SS**
- Fines Content (clays, silts, fine sands? Percent?): **LOW <10%**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **STORAGE OF LARGE MATERIAL**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **DAY (EDGE OF BURN PERIMETER AT MOUTH, UPLANDS OUTSIDE OF BURNED AREA)**
- Evidence of fire in tributary watershed: **NO**
- General fire related effects on tributary watershed: **NONE**
- Ash presence in channel sediment? **NO**
- Debris flows? **NONE VISIBLE**
- Excess sedimentation of fines, ravel, boulders, etc. **NO**

Tributary Confluence Data Checklist

Tributary Name: **TROUT CREEK**	Map Tile# **11 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **2 APRIL 08** Time ______ AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): **~10 CFS**

Tributary Morphology:
- Single or multi-thread channel: **SINGLE**
- Incision (entrenchment):**NONE**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES**
- Gradient:
  - at mouth (0m u/s): **2-3%**
  - at 25m u/s: **1-2%**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **SCRUB OAK/CHAPPARAL/SOME COTTONWOOD**
- LWD presence: **NONE**

Hillslope / Valley Morphology
- Hillslope gradient: **MODERATE**
- Hillslope / valley description: **SOUTH FACING, WELL-VEGETATED**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NONE VISIBLE**
- Rockfalls: **NONE VISIBLE**
- Vegetation cover on hillslopes: **SCRUB/SHRUB (CHAPPARAL)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):
- D50: **100 mm**
- D84: **500 mm**
- Size Distribution: **FINE GRAVEL TO BOULDER**
- Facies Present (and mapped on tiles): **BGC (WETTED CHANNEL), BCG (BANKS AND FLOODPLAIN)**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **20-30%**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **STORAGE OF FINER MATERIAL, LOW STORAGE CAPACITY FOR LARGER MATERIALS**

Fire Effects:
- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **WOLF**
- Evidence of fire in tributary watershed: **NO**
- General fire related effects on tributary watershed: **NONE**
- Ash presence in channel sediment? **NO**
- Debris flows? **NONE VISIBLE**
- Excess sedimentation of fines, ravel, boulders, etc. **NO**

Tributary Confluence Data Checklist

Tributary Name: **PIEDRA BLANCA CREEK**	Map Tile# **11 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **2 APRIL 08** Time ______ AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): **20-30 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE**
- Incision (entrenchment):**MODERATE TO NONE**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES (ACTIVE ~10 YR FLOW LEVEL)**
- Gradient:
  - at mouth (0m u/s): **STEEP/COARSE WITH FINES AT MOUTH IN SESPE CK (2-5%)**
  - at 25m u/s: **STEEP (2-5%)**
  - at 50m u/s: **~2%**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **SCRUB OAK/CHAPPARAL/SOME COTTONWOOD AT MOUTH**
- LWD presence: **FEW PIECES IN CHANNEL**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE TO STEEP**
- Hillslope / valley description: **SOUTH FACING, BEDROCK-CONFINED VALLEY UP TO HIGH ELEVATIONS (PINE MTNS), WELL-VEGETATED**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NONE VISIBLE**
- Rockfalls: **SOME VISIBLE AT HIGHER ELEVATIONS**
- Vegetation cover on hillslopes: **SCRUB/SHRUB (CHAPPARAL), BARE BEDROCK**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **60 mm (<100 m U/S), 90 mm (100-200 m U/S)**
- D84: **200 mm (<100 m U/S), 300 mm (100-200 m U/S)**
- Size Distribution: **FINE GRAVEL TO BOULDER**
- Facies Present (and mapped on tiles): **BCG (<100 m U/S), GC/CG (100-200 m U/S)**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **LOW (<10%) IN WETTED CHANNEL**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **IN-CHANNEL STORAGE (FINES IN BANKFULL CHANNEL, COARSER MATERIAL IN WETTED CHANNEL)**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **WOLF**
- Evidence of fire in tributary watershed: **NO**
- General fire related effects on tributary watershed: **NONE**
- Ash presence in channel sediment? **NO**
- Debris flows? **NONE VISIBLE**
- Excess sedimentation of fines, ravel, boulders, etc. **LARGE DEPOSIT OF FINE SEDIMENT AT MOUTH INTO SESPE CREEK, POSSIBLE POST-WOLF FIRE EFFECT**

Tributary Confluence Data Checklist

Tributary Name: **LION CANYON**	Map Tile# **12 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **2 APRIL 08** Time **13:00** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): ~**20 CFS**

Tributary Morphology:
- Single or multi-thread channel: **SINGLE**
- Incision (entrenchment):**MODERATE TO NONE**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES (ACTIVE ~10 YR FLOW LEVEL)**
- Gradient:
  - at mouth (0m u/s): **1%**
  - at 25m u/s: **STEEP RIFFLE SECTION (2-3%)**
  - at 50m u/s: **POOL SECTION <1%**
  - at 100m u/s: **IN ACCESSIBLE**
- Vegetation cover along tributary: **RIPARIAN (COTTONWOOD/WILLOWS)**
- LWD presence: **FEW PIECES IN CHANNEL**

Hillslope / Valley Morphology
- Hillslope gradient: **MODERATE TO STEEP**
- Hillslope / valley description: **NORTH FACING, GORGE OPENING TO SESPE CREEK VALLEY**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NONE VISIBLE**
- Rockfalls: **NONE VISIBLE**
- Vegetation cover on hillslopes: **SCRUB/SHRUB (CHAPPARAL), CONIFER-MIXED HARDWOOD**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):
- D50: **25 mm**
- D84: **100 mm**
- Size Distribution: **FINE GRAVEL TO COBBLE**
- Facies Present (and mapped on tiles): **CG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **LOW (<10%) IN WETTED CHANNEL**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **BARS AND IN WETTED CHANNEL, WITH FINER MATERIAL (COARSE SAND TO COARSE GRAVEL)**

Fire Effects:
- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: Yes / **No**:
- Evidence of fire in tributary watershed: **NO**
- General fire related effects on tributary watershed: **NONE**
- Ash presence in channel sediment? **NO**
- Debris flows? **NONE VISIBLE**
- Excess sedimentation of fines, ravel, boulders, etc. **NONE**

Tributary Confluence Data Checklist

Tributary Name: **TULE CREEK**	Map Tile# **15 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **7 APRIL 08** Time **12:00** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): ~**10 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE, CROSSES UNDER HWY 33**
- Incision (entrenchment): **NONE**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **NONE**
- Gradient:
  - at mouth (0m u/s): **2-3%**
  - at 25m u/s: **SAME**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **RIPARIAN (COTTONWOOD/WILLOWS) WITHIN AND ALONG CHANNEL**
- LWD presence: **FEW PIECES IN CHANNEL**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE TO STEEP**
- Hillslope / valley description: **EAST FACING**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NONE VISIBLE**
- Rockfalls: **NONE VISIBLE**
- Vegetation cover on hillslopes: **WELL VEGETATED ON HILLSLOPES: SCRUB/SHRUB (CHAPPARAL) WITH SOME TREES**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **30 mm**
- D84: **80 mm**
- Size Distribution: **FINE GRAVEL TO COBBLE (FINES ON BED UPSTREAM OF BRIDGE: SOURCE OF FINES=RB, SOURCE OF COARSE MATERIALS=LB)**
- Facies Present (and mapped on tiles): **CG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **20-30% IN WETTED CHANNEL**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **IN WETTED CHANNEL AND ADJACENT FLOODPLAIN, CONGESTED AT MOUTH DUE TO DENSE RIPARIAN VEGETATION (D/S OF HIGHWAY BRIDGE)**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: Yes / **No**:
- Evidence of fire in tributary watershed: **NO**
- General fire related effects on tributary watershed: **NONE**
- Ash presence in channel sediment? **NO**
- Debris flows? **NONE VISIBLE**
- Excess sedimentation of fines, ravel, boulders, etc. **NONE**

Tributary Confluence Data Checklist

Tributary Name: **DERRY DALE CREEK**	Map Tile# **16 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **7 APRIL 08** Time **13:00** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): <**10 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE, CROSSES UNDER HWY 33**
- Incision (entrenchment): **NONE**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES (ACTIVE ALONG EITHER SIDE)**
- Gradient:
  - at mouth (0m u/s): **STEEPER (>10%)**
  - at 25m u/s: **PLANE-BED/STEP-POOL (1%)**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **SCRUB/SHRUB (CHAPPARAL) (SOME BURNED U/S OF HIGHWAY BRIDGE), RIPARIAN (WILLOWS) AT MOUTH**
- LWD presence: **NONE**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE TO STEEP**
- Hillslope / valley description: **WEST FACING, SPARSE VEGETATION**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NONE VISIBLE**
- Rockfalls: **SMALL ROCK FALLS VISIBLE ON RB VALLEY SIDE (RB=COARSE CONTRIBUTOR, LB=FINER CONTRIBUTOR)**
- Vegetation cover on hillslopes: **SCRUB/SHRUB**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **30 mm**
- D84: **130 mm**
- Size Distribution: **SILT TO BOULDERS**
- Facies Present (and mapped on tiles): **SCG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **20-30%**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **STORAGE POTENTIAL OF FINE AND COARSE SEDIMENT ON LOWER/HIGHER BARS/TERRACE U/S OF HIGHWAY BRIDGE**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **WOLF**
- Evidence of fire in tributary watershed: **BURNED VEGETATION ON FLOODPLAIN AND HILLSLOPES (VEGETATION REGROWTH)**
- General fire related effects on tributary watershed: **NONE OBVIOUS**
- Ash presence in channel sediment? **NO**
- Debris flows? **NO DEBRIS DEPOSIT EVIDENCE**
- Excess sedimentation of fines, ravel, boulders, etc. **NONE**

Tributary Confluence Data Checklist

Tributary Name: **POTRERO JOHN CREEK**	Map Tile# **16 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **7 APRIL 08** Time **13:30** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): ~**10 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE, CROSSES UNDER HWY 33**
- Incision (entrenchment): **CANYON REACH CUTTING THROUGH OLDER ALLUVIAL DEPOSIT IN PLACES**
- Headcuts on tributary (within 100m of Sespe): **NONE, BUT STEPS ARE PRESENT**
- Terraces present: **YES**
- Gradient:
  - at mouth (0m u/s): **1-2%**
  - at 25m u/s: **SAME**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **RIPARIAN (WILLOW, COTTONWOOD), SCRUB/SHRUB (SOME BURNED)**
- LWD presence: **NONE**

Hillslope / Valley Morphology

- Hillslope gradient: **STEEP CANYON**
- Hillslope / valley description: **SOUTH FACING, SPARSE VEGETATION, EXPOSED BEDROCK ON BOTH SIDES OF CANYON**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NONE VISIBLE**
- Rockfalls: **YES**
- Vegetation cover on hillslopes: **SCRUB/SHRUB WITH FEW CONIFERS**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **30 mm**
- D84: **100 mm**
- Size Distribution: **SILT TO BOULDERS**
- Facies Present (and mapped on tiles): **SCG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **10-20%**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **STORAGE OF FINER MATERIALS BEHIND LARGE CLASTS IN WETTED CHANNEL**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **WOLF**
- Evidence of fire in tributary watershed: **BURNED HILLSLOPES (VEGETATION REGROWTH)**
- General fire related effects on tributary watershed: **NONE OBVIOUS**
- Ash presence in channel sediment? **NO**
- Debris flows? **NO DEBRIS DEPOSIT EVIDENCE**
- Excess sedimentation of fines, ravel, boulders, etc. **NONE**

Tributary Confluence Data Checklist

Tributary Name: **MUNSON CREEK**	Map Tile# **17 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **7 APRIL 08** Time **13:45** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): <**10 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE, CROSSES UNDER HWY 33**
- Incision (entrenchment): **NO**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES**
- Gradient:
  - at mouth (0m u/s): **PLANE BED (~1%)**
  - at 25m u/s: **SAME**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **RIPARIAN (WILLOW), SCRUB/SHRUB**
- LWD presence: **NONE**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE**
- Hillslope / valley description: **SOUTH FACING**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **YES, OLDER (PRE-FIRE) LANDSLIDE ON WEST-FACING HILLSIDE**
- Rockfalls: **YES, SMALLER ROCKFALL ON WEST-FACING HILLSIDE**
- Vegetation cover on hillslopes: **SCRUB/SHRUB**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **40 mm**
- D84: **130 mm**
- Size Distribution: **SILT TO BOULDERS**
- Facies Present (and mapped on tiles): **CG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **<10%**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **STORAGE OF FINE AND COARSE MATERIALS ON FLOODPLAIN**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **WOLF**
- Evidence of fire in tributary watershed: **BURNED HILLSLOPES (VEGETATION REGROWTH)**
- General fire related effects on tributary watershed: **NONE OBVIOUS**
- Ash presence in channel sediment? **NO**
- Debris flows? **NO DEBRIS DEPOSIT EVIDENCE**
- Excess sedimentation of fines, ravel, boulders, etc. **NONE**

Tributary Confluence Data Checklist

Tributary Name: **BURRO CREEK**	Map Tile# **18 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **7 APRIL 08** Time **15:00** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): <**10 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE, CROSSES UNDER HWY 33**
- Incision (entrenchment): **NO**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **NO, FLOODPLAIN CHANNEL**
- Gradient:
  - at mouth (0m u/s): **PLANE BED (~1%)**
  - at 25m u/s: **SAME**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **RIPARIAN (WILLOW), SCRUB/SHRUB**
- LWD presence: **NONE**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE**
- Hillslope / valley description: **SOUTH FACING**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NO**
- Rockfalls: **YES, SESPE SS FALLING INTO FLOODPLAIN FROM RIDGE**
- Vegetation cover on hillslopes: **SCRUB/SHRUB (SOME BURNED)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **20 mm**
- D84: **60 mm**
- Size Distribution: **SILT TO COBBLE**
- Facies Present (and mapped on tiles): **CSG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **20-30%**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **RELATIVELY LARGE STORAGE AREA OF FINE AND COARSE SEDIMENT ON FLOODPLAIN AND COARSE SEDIMENT IN CHANNEL**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **WOLF**
- Evidence of fire in tributary watershed: **BURNED HILLSLOPES (VEGETATION REGROWTH)**
- General fire related effects on tributary watershed: **NONE OBVIOUS**
- Ash presence in channel sediment? **NO**
- Debris flows? **NO DEBRIS DEPOSIT EVIDENCE**
- Excess sedimentation of fines, ravel, boulders, etc. **NONE**

Tributary Confluence Data Checklist

Tributary Name: **CHORRO GRANDE CREEK**	Map Tile# **18 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **7 APRIL 08** Time **14:15** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): <**10 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE, CROSSES UNDER HWY 33**
- Incision (entrenchment): **NO**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **NO, FLOODPLAIN CHANNEL**
- Gradient:
  - at mouth (0m u/s): **PLANE BED (1-2%)**
  - at 25m u/s: **SAME**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **SCRUB/SHRUB (SOME BURNED)**
- LWD presence: **NONE**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE**
- Hillslope / valley description: **SOUTH FACING**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NO**
- Rockfalls: **NO**
- Vegetation cover on hillslopes: **SCRUB/SHRUB (SOME BURNED)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **35 mm**
- D84: **100 mm**
- Size Distribution: **SILT TO BOULDER**
- Facies Present (and mapped on tiles): **CSG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **20-30%**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **STORAGE OF FINE AND COARSE SEDIMENT ON FLOODPLAIN AND COARSE SEDIMENT IN CHANNEL**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **WOLF**
- Evidence of fire in tributary watershed: **BURNED VEGETATION ON FLOODPLAIN (VEGETATION REGROWTH)**
- General fire related effects on tributary watershed: **NONE OBVIOUS**
- Ash presence in channel sediment? **NO**
- Debris flows? **NO DEBRIS DEPOSIT EVIDENCE**
- Excess sedimentation of fines, ravel, boulders, etc. **NONE**

Tributary Confluence Data Checklist

Tributary Name: **GODWIN CREEK**	Map Tile# **19 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **7 APRIL 08** Time **14:30** AM **PM**

Flow? Yes / **YES** Approx. Discharge (cfs): <**10 CFS**

Tributary Morphology:

- Single or multi-thread channel: **SINGLE, CROSSES UNDER HWY 33**
- Incision (entrenchment): **NO**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES, WITH FLOODPLAIN**
- Gradient:
    - at mouth (0m u/s): **PLANE BED (1-2%)**
    - at 25m u/s: **SAME**
    - at 50m u/s: **SAME**
    - at 100m u/s: **SAME**
- Vegetation cover along tributary: **SCRUB/SHRUB (SOME BURNED)**
- LWD presence: **NONE**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE**
- Hillslope / valley description: **SOUTH FACING**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **NO**
- Rockfalls: **SMALL ROCKFALLS VISIBLE**
- Vegetation cover on hillslopes: **SPARSE SCRUB/SHRUB (SOME BURNED)**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **25 mm**
- D84: **100 mm**
- Size Distribution: **SILT TO BOULDER**
- Facies Present (and mapped on tiles): **CSG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **30%**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **STORAGE OF FINE AND COARSE SEDIMENT ON FLOODPLAIN AND COARSE SEDIMENT IN CHANNEL**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: **Yes** / No: **WOLF**
- Evidence of fire in tributary watershed: **BURNED VEGETATION ON FLOODPLAIN (VEGETATION REGROWTH)**
- General fire related effects on tributary watershed: **NONE OBVIOUS**
- Ash presence in channel sediment? **NO**
- Debris flows? **NO DEBRIS DEPOSIT EVIDENCE**
- Excess sedimentation of fines, ravel, boulders, etc. **NONE**

Tributary Confluence Data Checklist

Tributary Name: **CHERRY CREEK**	Map Tile# **20 OF 20 (UPPER SUBWATERSHEDS)**
Field Crew: **GTL SRD** Form completed by **SRD**	Date **7 APRIL 08** Time **14:45** AM **PM**

Flow? Yes / **NO** Approx. Discharge (cfs):

Tributary Morphology:

- Single or multi-thread channel: **SINGLE**
- Incision (entrenchment): **MODERATE THROUGH FAN/FLOODPLAIN**
- Headcuts on tributary (within 100m of Sespe): **NONE**
- Terraces present: **YES, WITH FLOODPLAIN (SHARED WITH SESPE CREEK)**
- Gradient:
  - at mouth (0m u/s): **PLANE BED (1-2%)**
  - at 25m u/s: **SAME**
  - at 50m u/s: **SAME**
  - at 100m u/s: **SAME**
- Vegetation cover along tributary: **SCRUB/SHRUB**
- LWD presence: **NONE**

Hillslope / Valley Morphology

- Hillslope gradient: **MODERATE**
- Hillslope / valley description: **NORTH FACING, VERY WELL VEGETATED**
- Geology in valley: **SANDSTONES AND SHALES**
- Debris flows: **FEW SMALL-SCALE SLIDES VISIBLE ON EAST-FACING SLOPES**
- Rockfalls: **NONE**
- Vegetation cover on hillslopes: **SCRUB/SHRUB (FLOODPLAIN), CONIFERS ON HILLSLOPES**

Sediment Delivered by Tributary at Mouth
(*What is being delivered to Sespe Creek by the tributary?*):

- D50: **20 mm**
- D84: **80 mm**
- Size Distribution: **SAND TO BOULDER**
- Facies Present (and mapped on tiles): **CG**
- Rock type (SS, Sh, Gr, etc.): **SS, Sh**
- Fines Content (clays, silts, fine sands? Percent?): **<10%**
- Turbidity relative to Sespe Creek: **CLEAR (SAME AS SESPE)**
- Storage: **LOW STORAGE IN WETTED CHANNEL, STORAGE OF FINE MATERIALS ON FLOODPLAIN**

Fire Effects:

- Tributary within Day, Piru, or Wolf fire boundaries based on mapping: Yes / **No**:
- Evidence of fire in tributary watershed: **NONE**
- General fire related effects on tributary watershed: **NONE**
- Ash presence in channel sediment? **NO**
- Debris flows? **NONE**
- Excess sedimentation of fines, ravel, boulders, etc. **NONE**

Figure B-1. View of sediment stored at the downstream end of Little Sespe Creek upstream of the Lower subwatershed of Sespe Creek. (Little Sespe Creek enters Sespe Creek under the private road bridge on the left side of the photo.)

Figure B-2. View of sediment stored at the downstream end of West Fork Sespe Creek in the Lower Gorge reach of Sespe Creek. (View looking upstream.)

Figure B-3. View of sediment stored at the downstream end of Alder Creek in the Granitics reach of Sespe Creek. (View looking upstream.)

Figure B-4. View of sediment stored at the downstream end of Hot Springs Canyon in the Granitics reach of Sespe Creek. (View looking upstream.)

Figure B-5. View of sediment stored at the downstream end of Park Creek in the Middle Terrace reach of Sespe Creek. (View looking upstream.)

Figure B-6. View of sediment stored at the downstream end of Sycamore Creek in the Middle Terrace reach of Sespe Creek. (View looking upstream.)

Figure B-7. View of sediment stored at the downstream end of Timber Creek in the Middle Terrace reach of Sespe Creek. (View looking upstream.)

Figure B-8. View of sediment stored at the downstream end of Bear Canyon in the Middle Terrace reach of Sespe Creek. (View looking upstream.)

Figure B-9. View of sediment stored at the downstream end of Trout Creek in the Middle Terrace reach of Sespe Creek. (View looking upstream.)

Figure B-10. View of sediment stored at the downstream end of Piedra Blanca Creek in the Upper Terrace reach of Sespe Creek. (View looking upstream.)

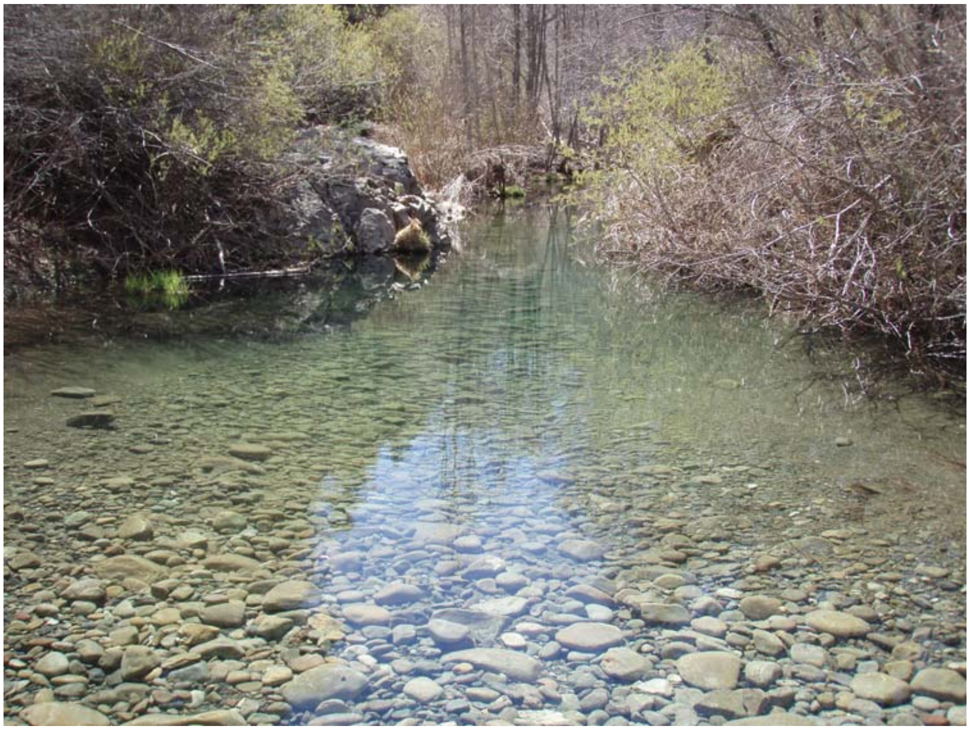


Figure B-11. View of sediment stored at the downstream end of Lion Canyon Creek in the Upper Terrace reach of Sespe Creek. (View looking upstream.)

Figure B-12. View of sediment stored at the downstream end of Tule Creek in the Upper Terrace reach of Sespe Creek. (View looking upstream.)

Figure B-13. View of sediment stored at the downstream end of Derry Dale Creek in the Upper Gorge reach of Sespe Creek. (View looking upstream with new vegetation growth on hillslopes burned by the 2002 Wolf Fire.)

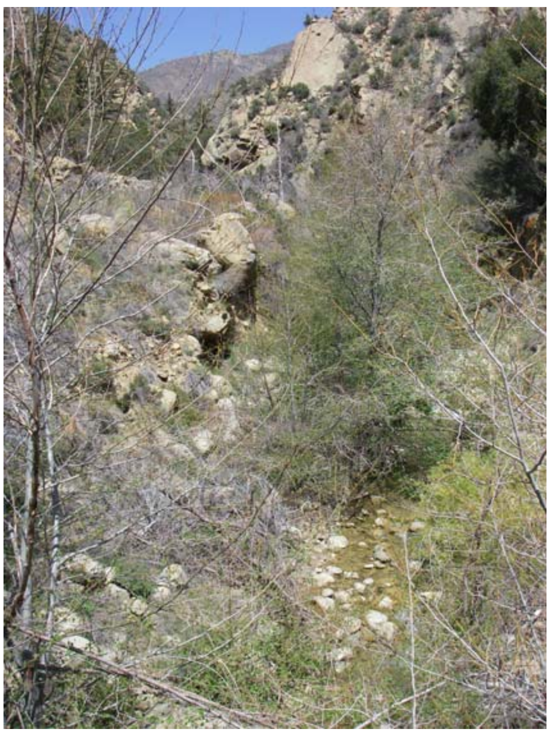


Figure B-14. View of sediment stored at the downstream end of Potrero John Creek in the Upper Gorge reach of Sespe Creek. (View looking upstream.)

Figure B-15. View of sediment stored at the downstream end of Munson Creek in the Upper Gorge reach of Sespe Creek. (View looking upstream.)

Figure B-16. View of sediment stored at the downstream end of Burro Creek in the Upper Gorge reach of Sespe Creek. (View looking downstream.)

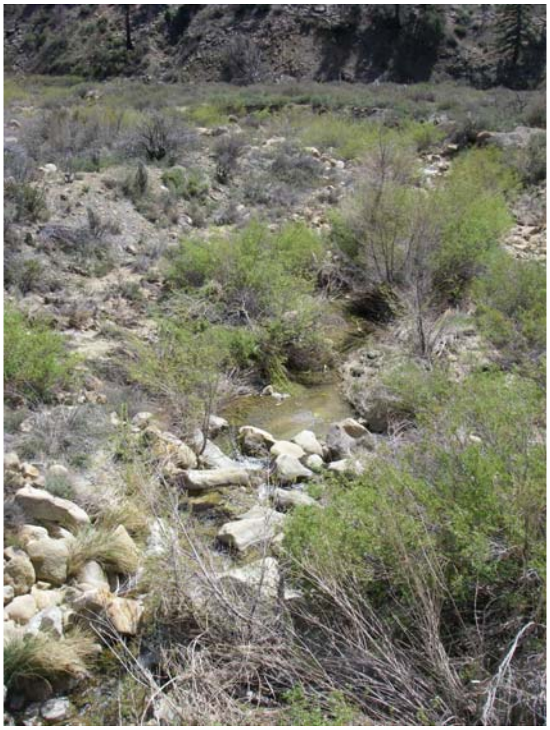


Figure B-17. View of sediment stored at the downstream end of Chorro Grande Creek in the Wash reach of Sespe Creek. (View looking downstream.)

Figure B-18. View of sediment stored at the downstream end of Godwin Creek in the Wash reach of Sespe Creek. (View looking upstream.)

Figure B-19. View of sediment stored at the downstream end of Cherry Creek in the Wash reach of Sespe Creek. (View looking upstream.)

Appendix C

Cross-sections of Lower Sespe Creek

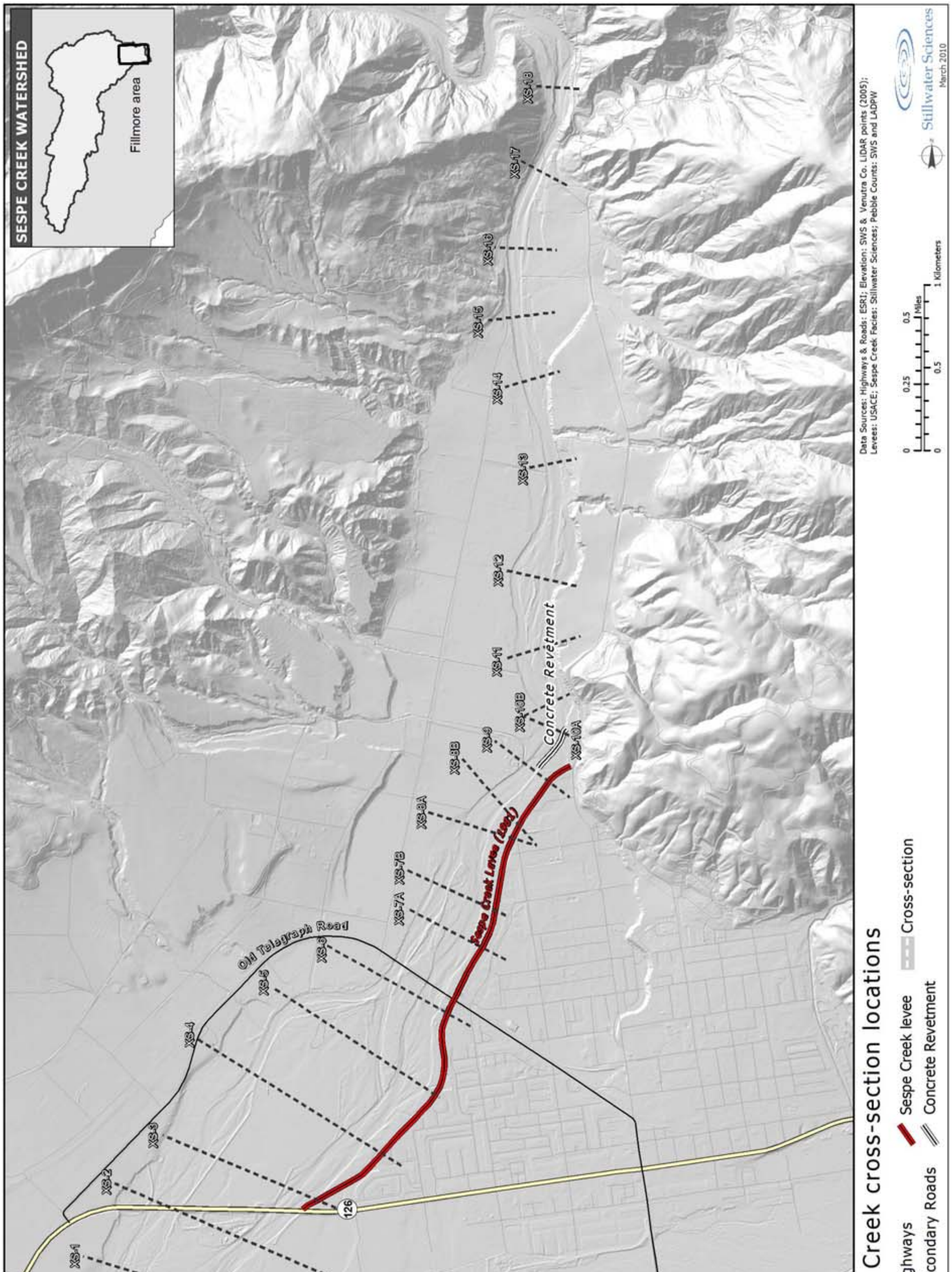


Figure C-1. Locations of cross-sections along lower Sespe Creek.

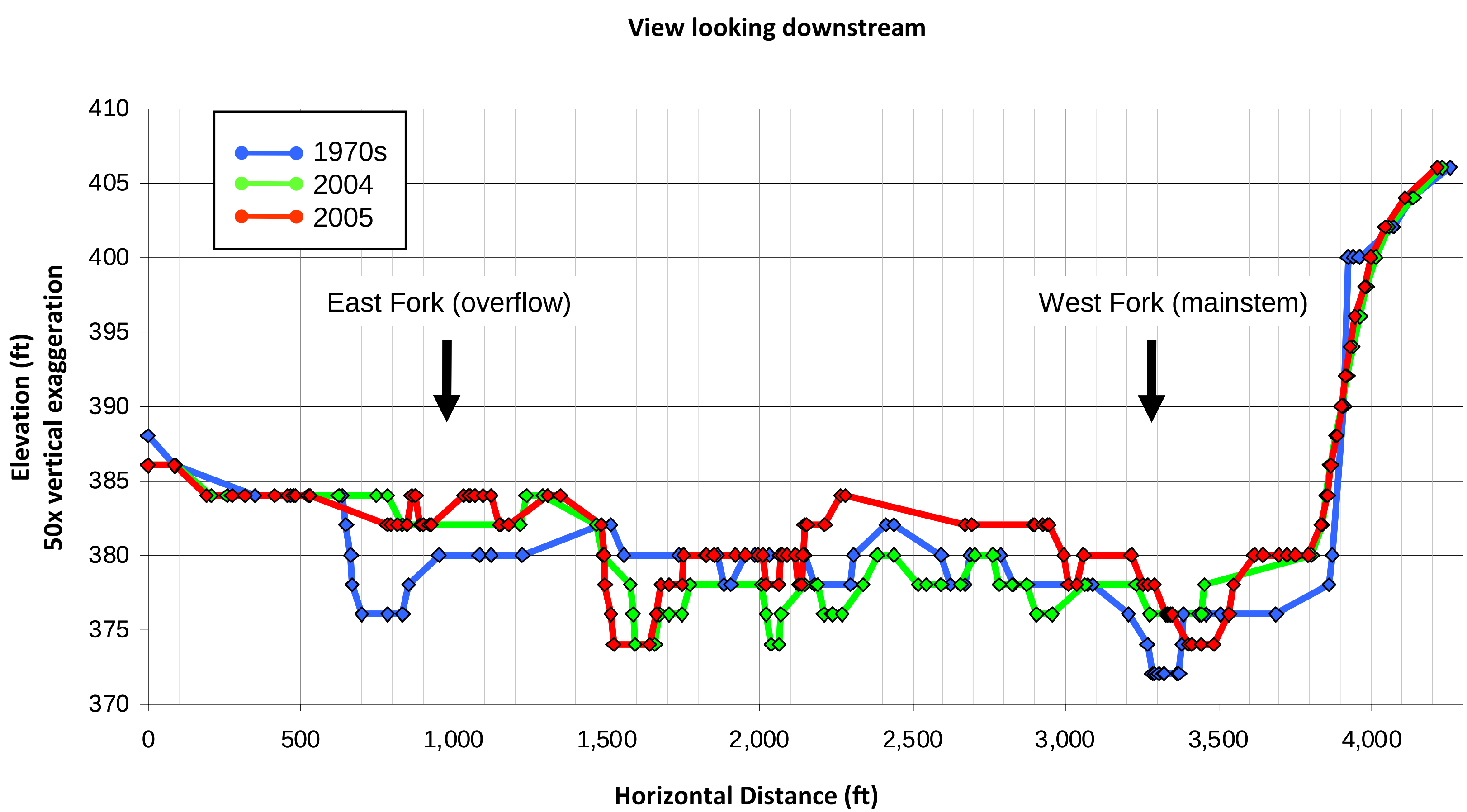


Figure C-2. Cross-section 1 (XS-1) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68 and 7/24/71), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

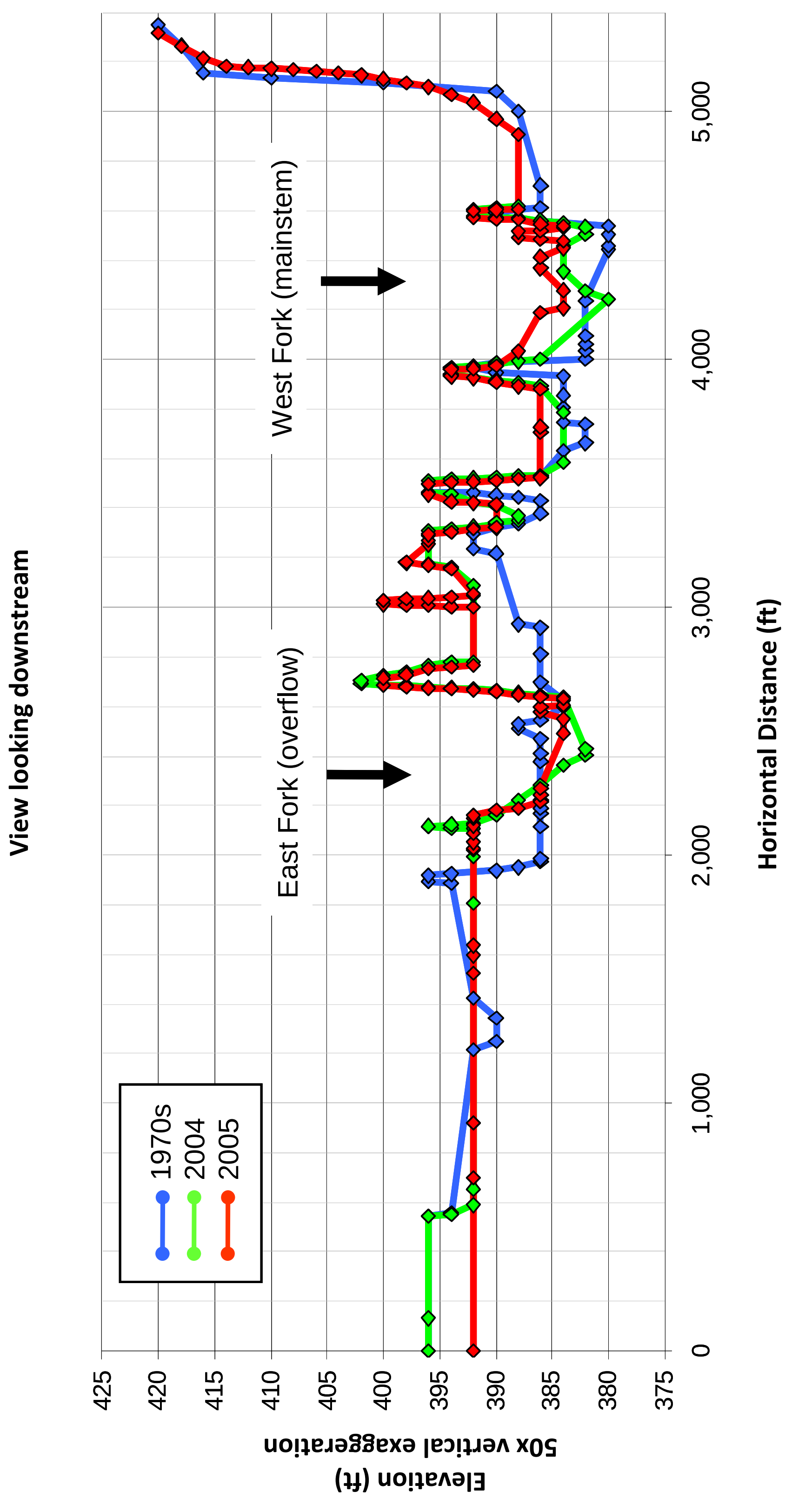


Figure C-3. Cross-section 2 (XS-2) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68 and 7/24/71), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

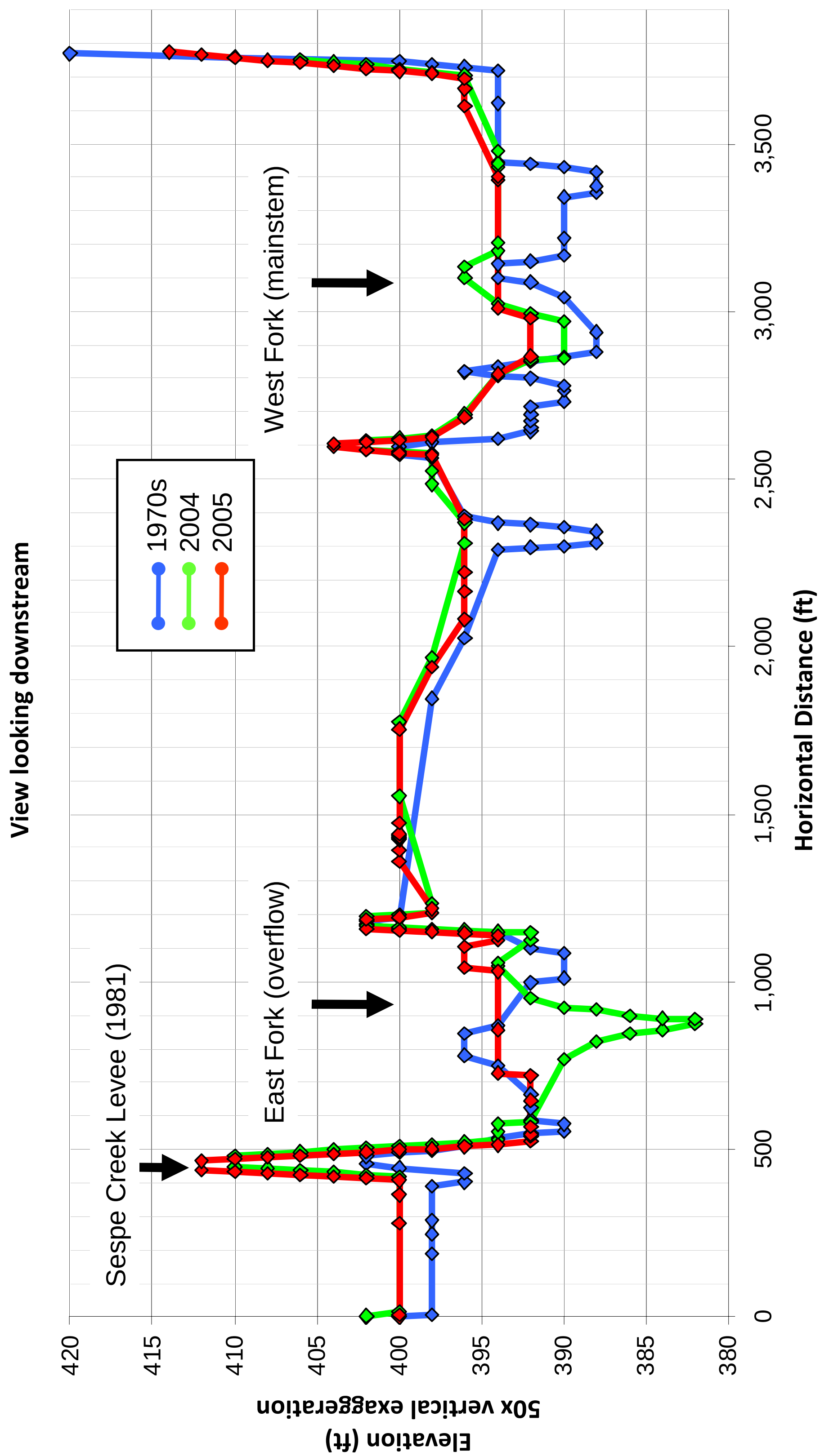


Figure C-4. Cross-section 3 (XS-3) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68, 7/24/71, and 11/17/77), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

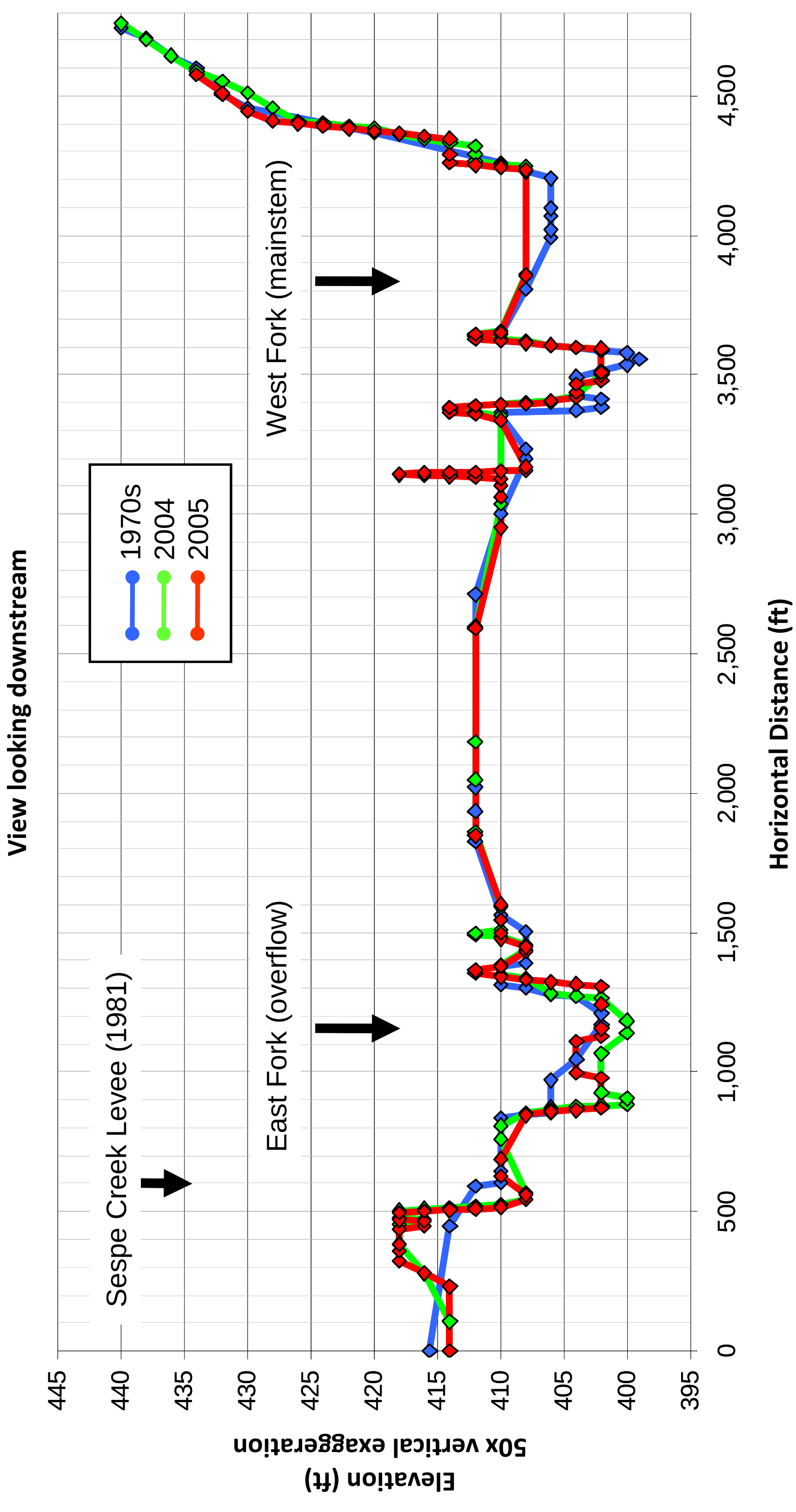


Figure C-5. Cross-section 4 (XS-4) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68 and 11/17/77), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

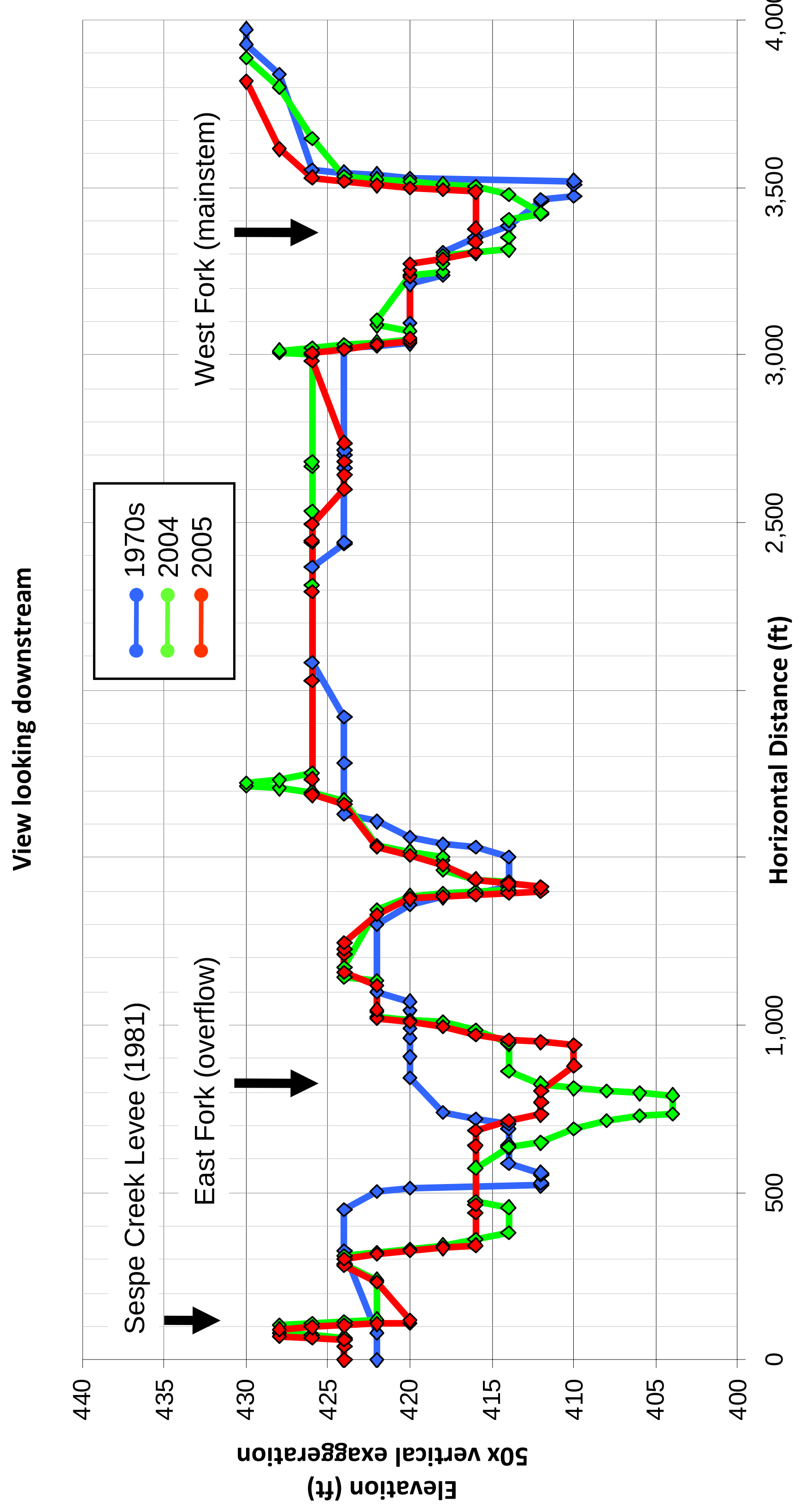


Figure C-6. Cross-section 5 (XS-5) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68 and 11/17/77), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

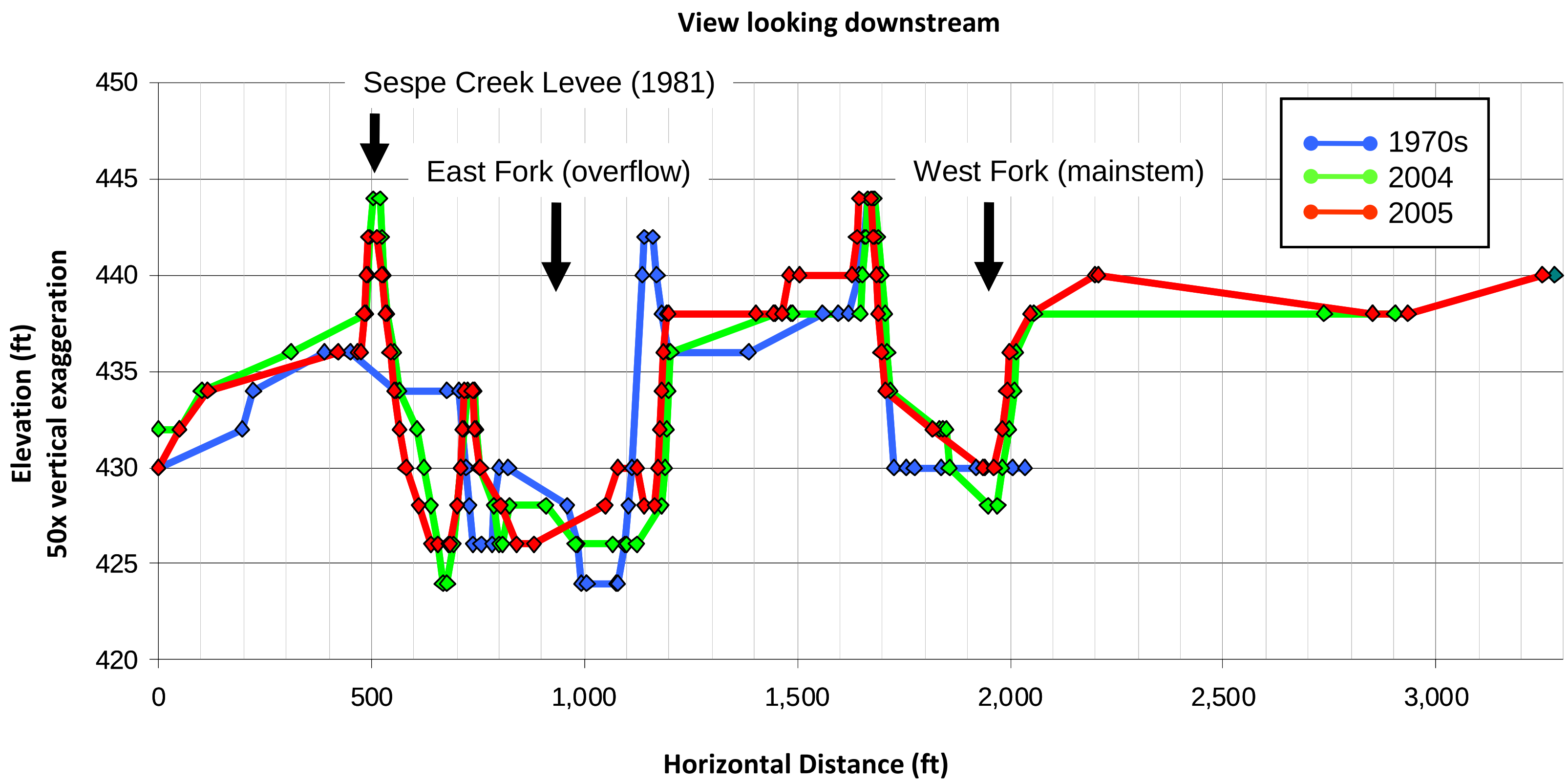


Figure C-7. Cross-section 6 (XS-6) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68 and 11/17/77), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

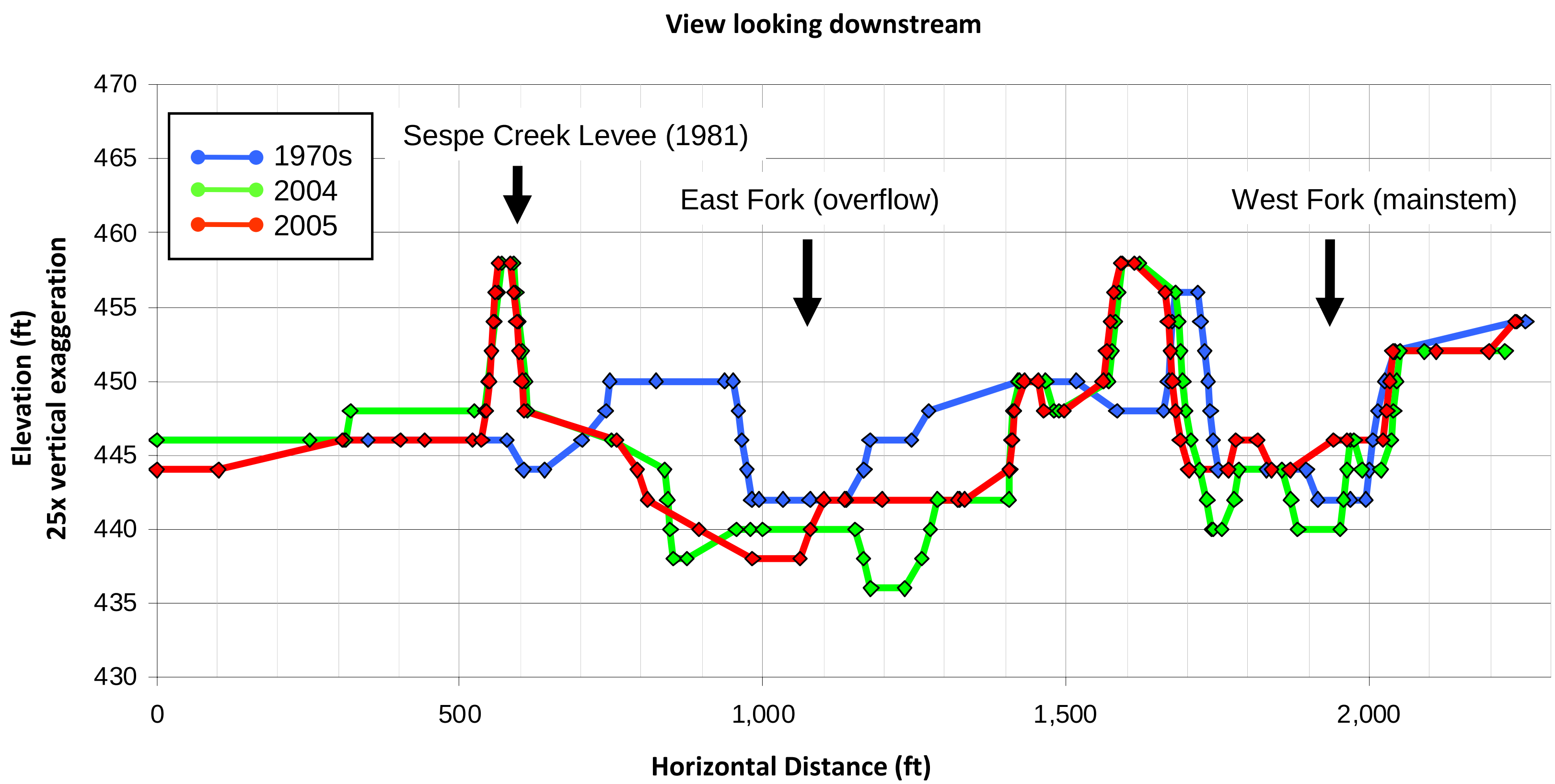


Figure C-8. Cross-section 7A (XS-7A) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68 and 11/17/77), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

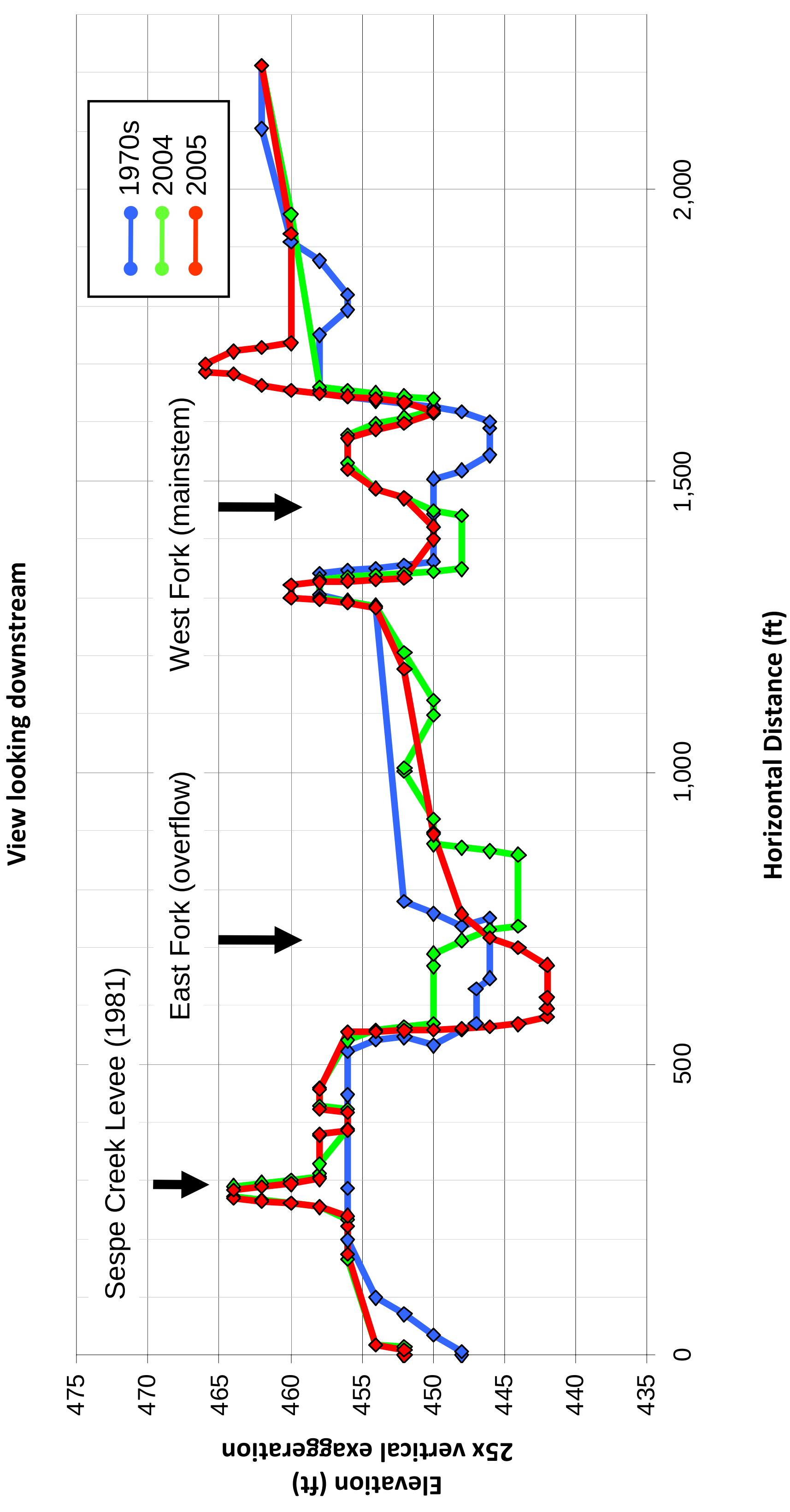


Figure C-9. Cross-section 7B (XS-7B) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68 and 11/17/77), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

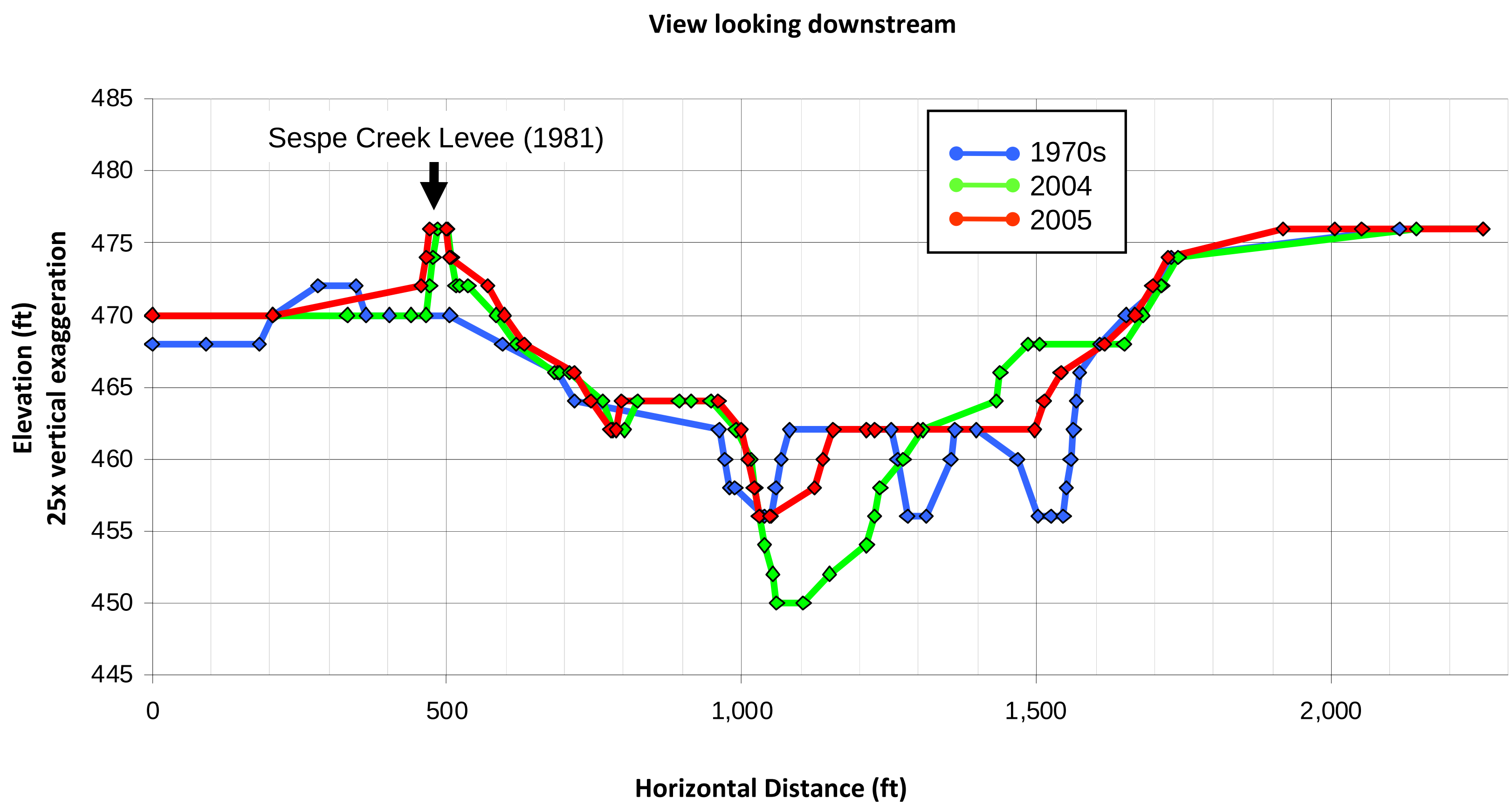


Figure C-10. Cross-section 8A (XS-8A) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68 and 11/17/77), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

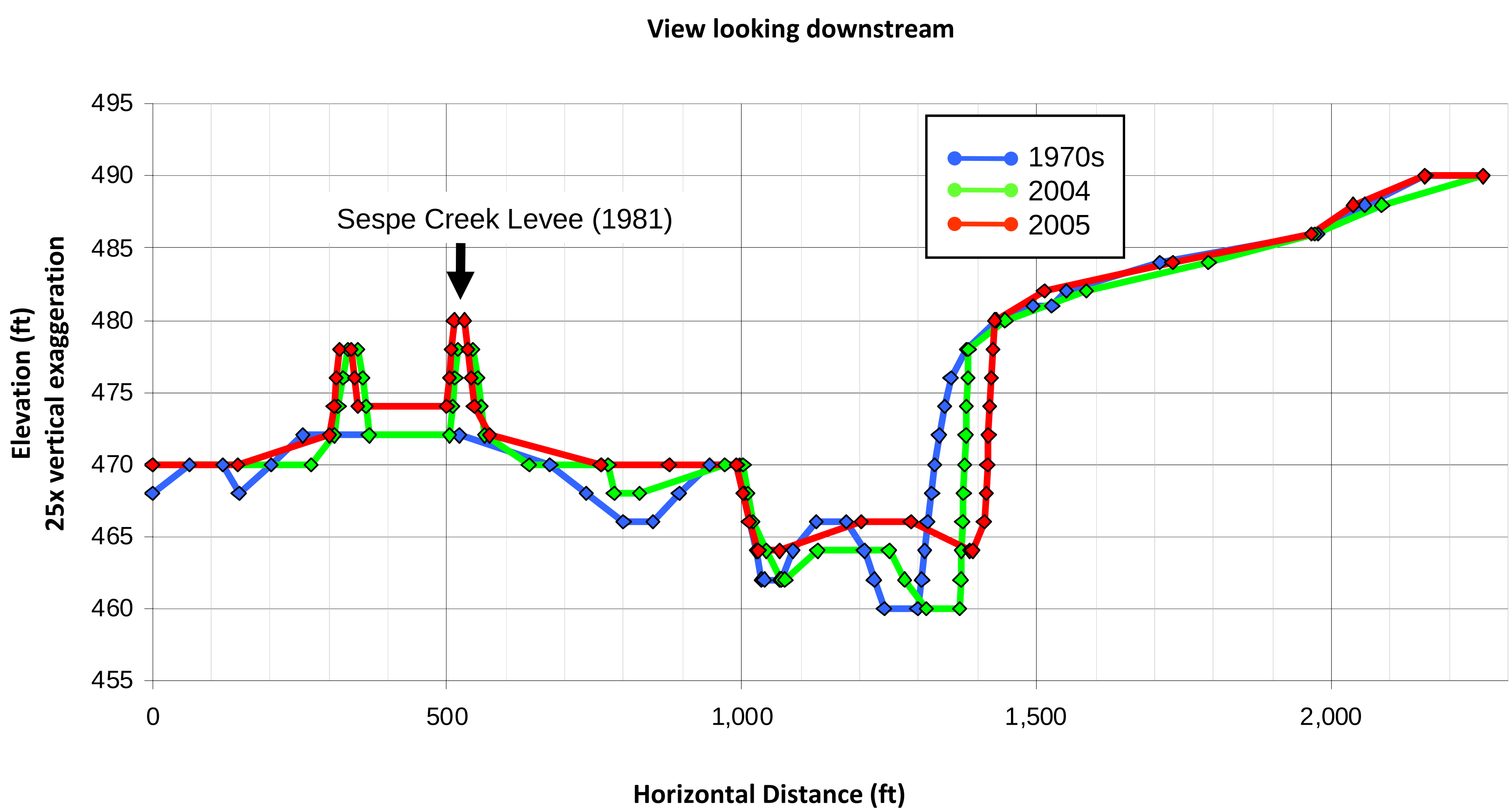


Figure C-11. Cross-section 8B (XS-8B) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68 and 11/17/77), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

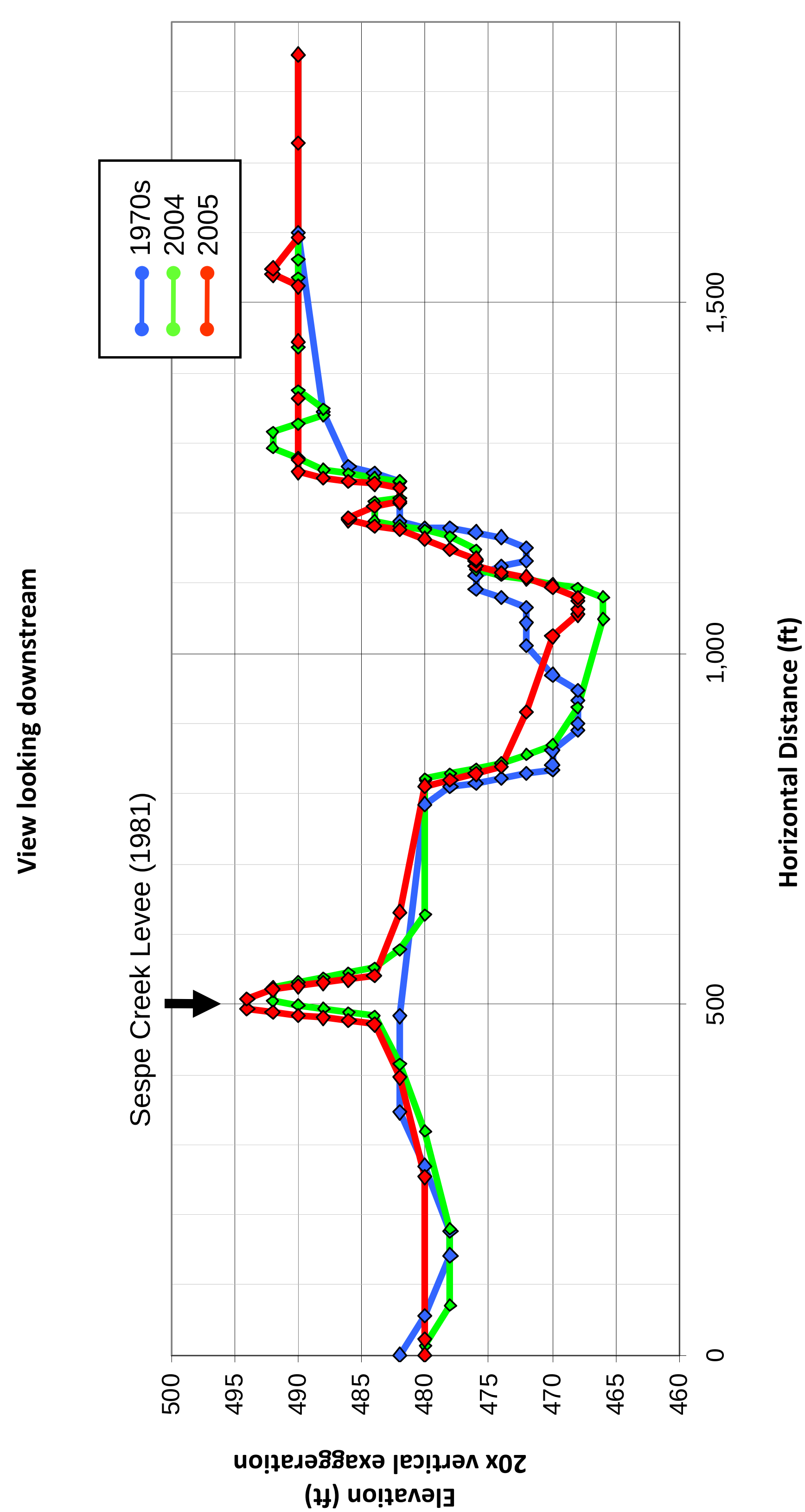


Figure C-12. Cross-section 9 (XS-9) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 4/23/68 and 11/17/77), 2004 (from 2-ft contour CADD compiled by City of Fillmore Engineering Department by photogrammetric methods from photography dated 7/26/04) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

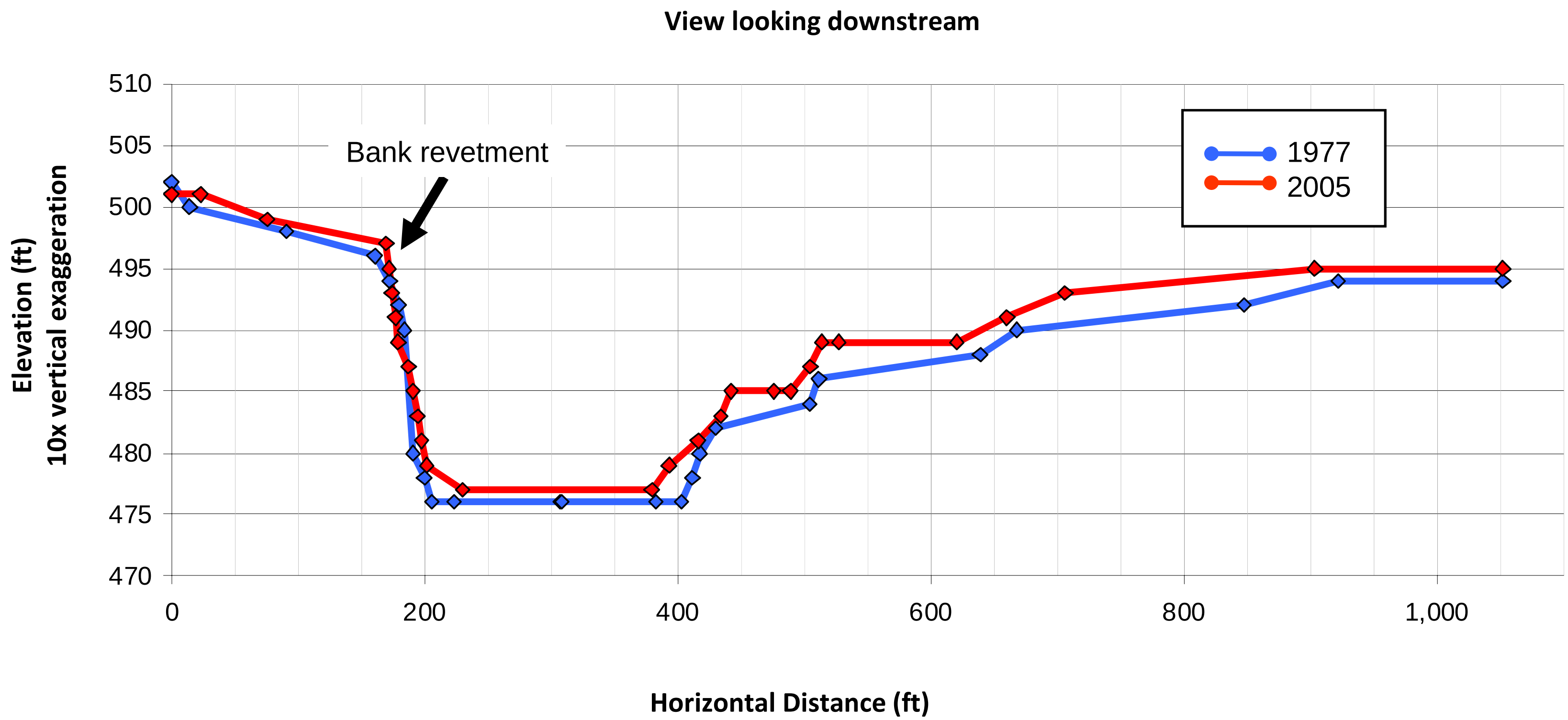


Figure C-13. Cross-section 10A (XS-10A) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 11/17/77) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

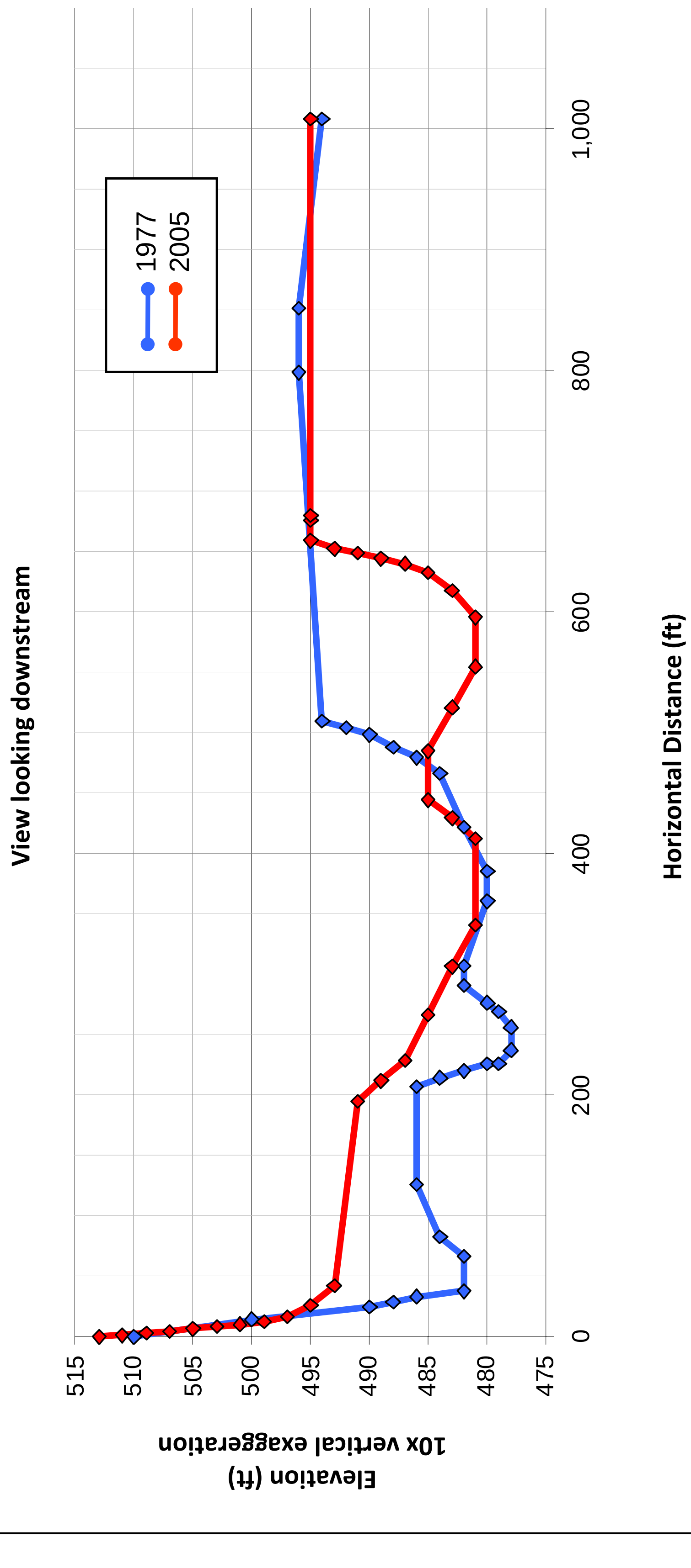


Figure C-14. Cross-section 10B (XS-10B) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 11/17/77) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

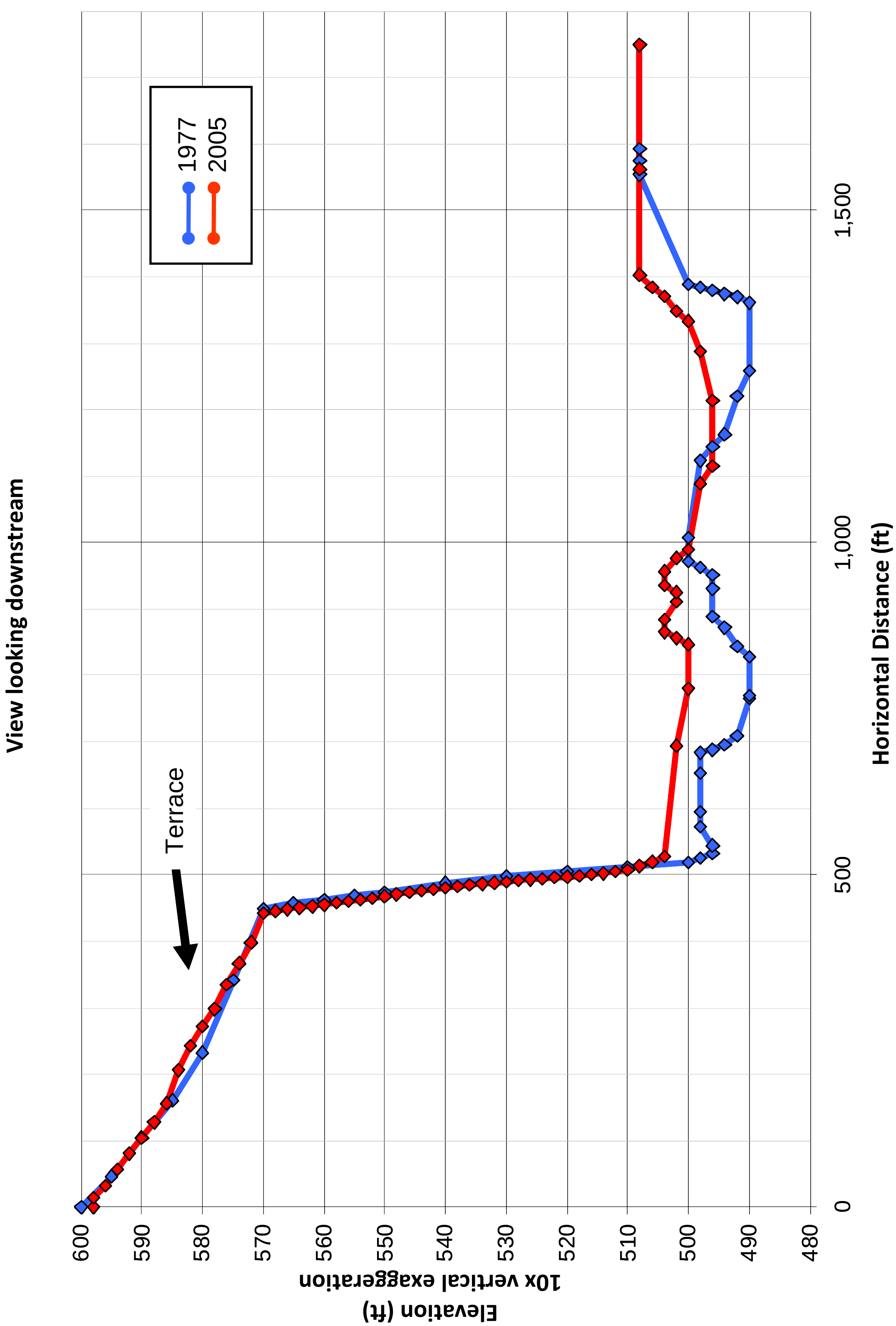


Figure C-15. Cross-section 11 (XS-11) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 11/17/77) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

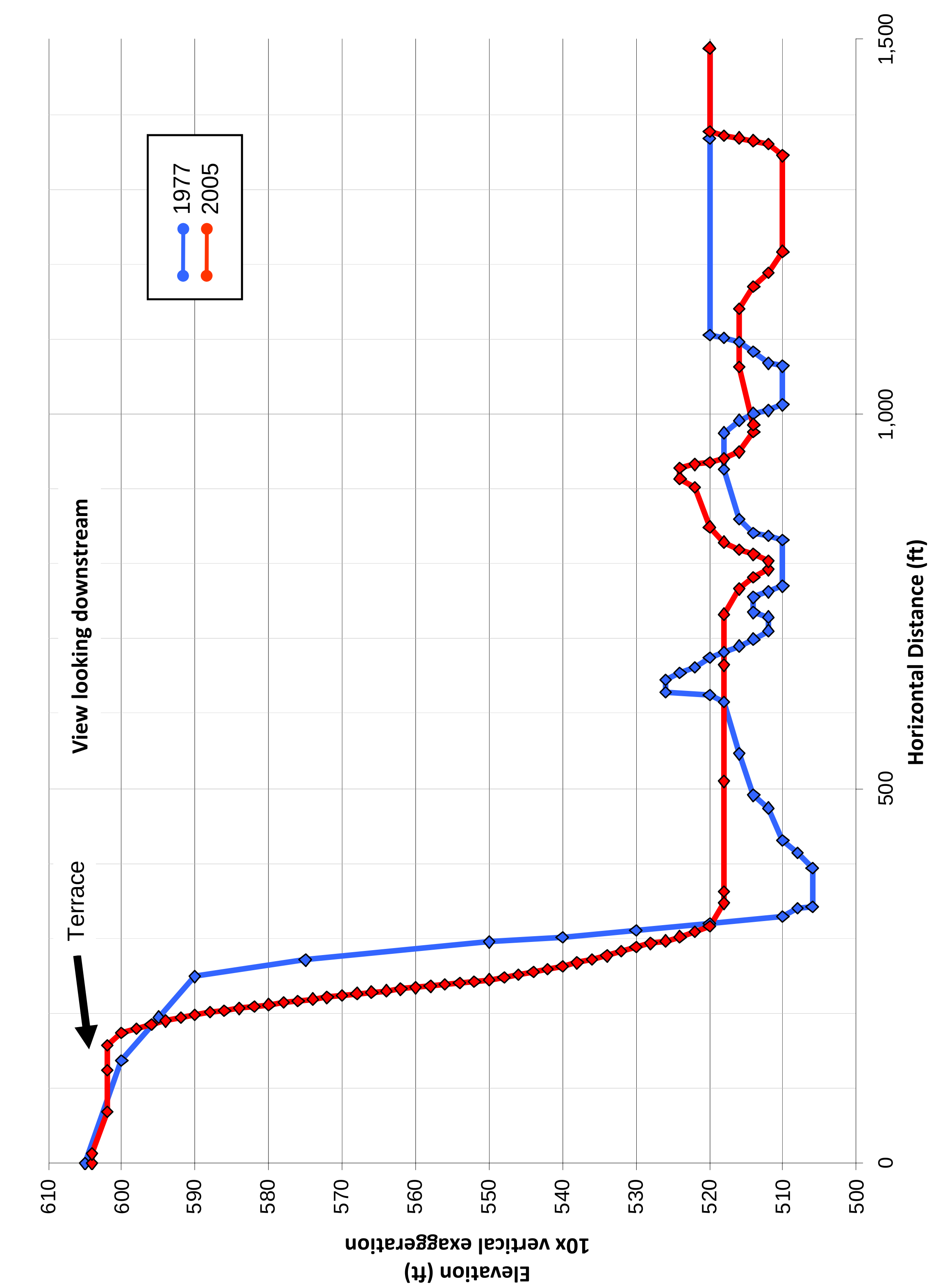


Figure C-16. Cross-section 12 (XS-12) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 11/17/77) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

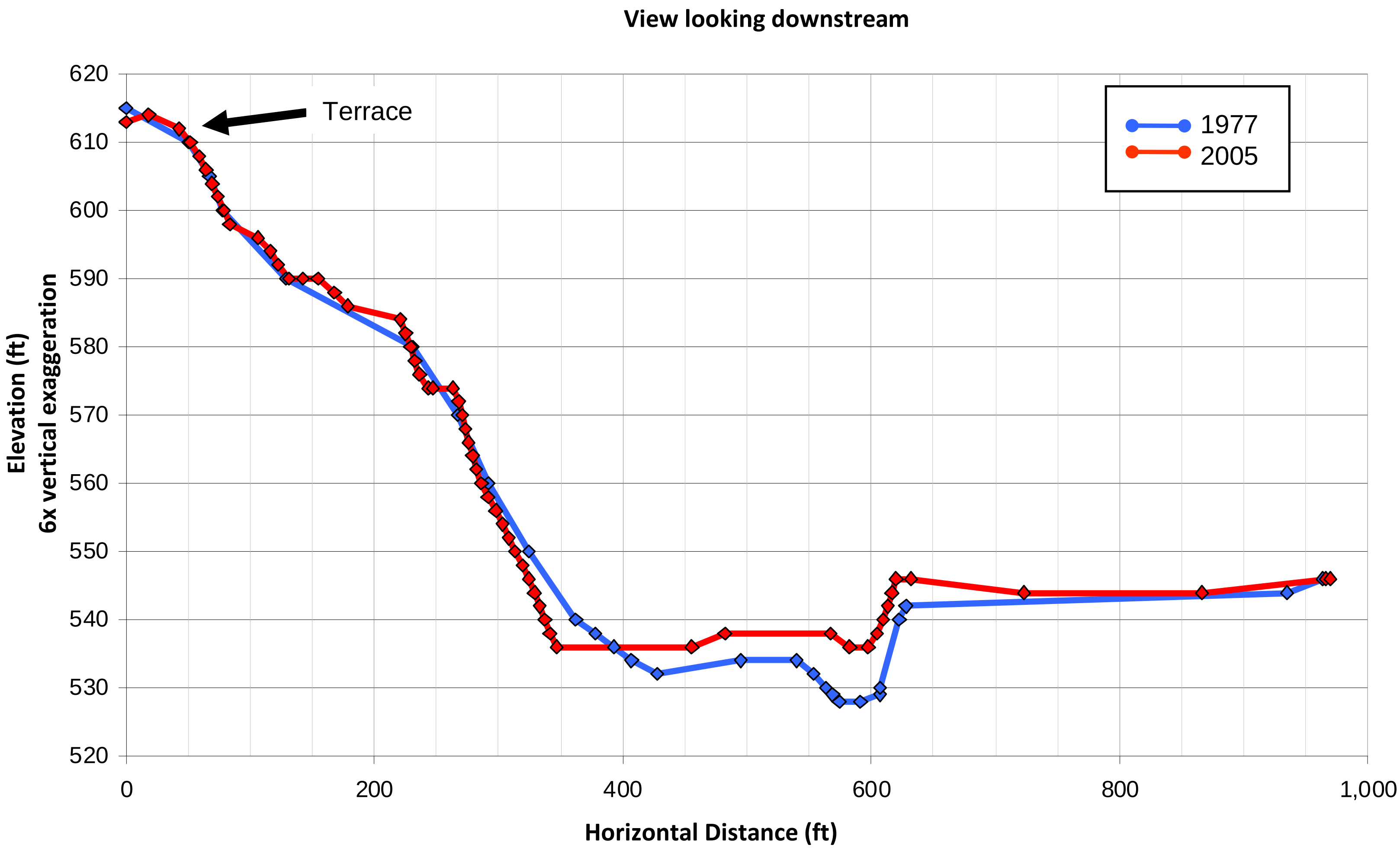


Figure C-17. Cross-section 13 (XS-13) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 11/17/77) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

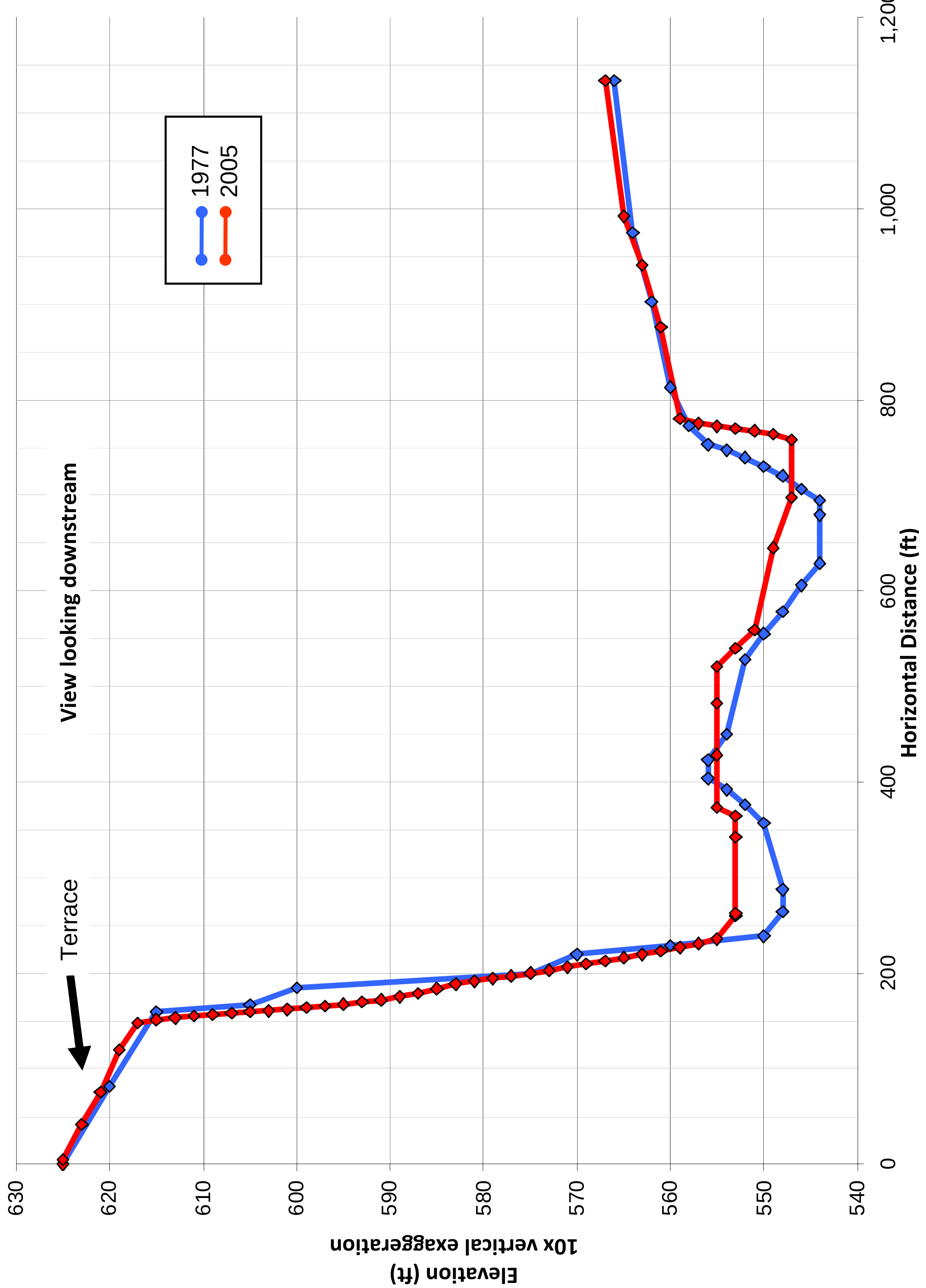


Figure C-18. Cross-section 14 (XS-14) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 11/17/77) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

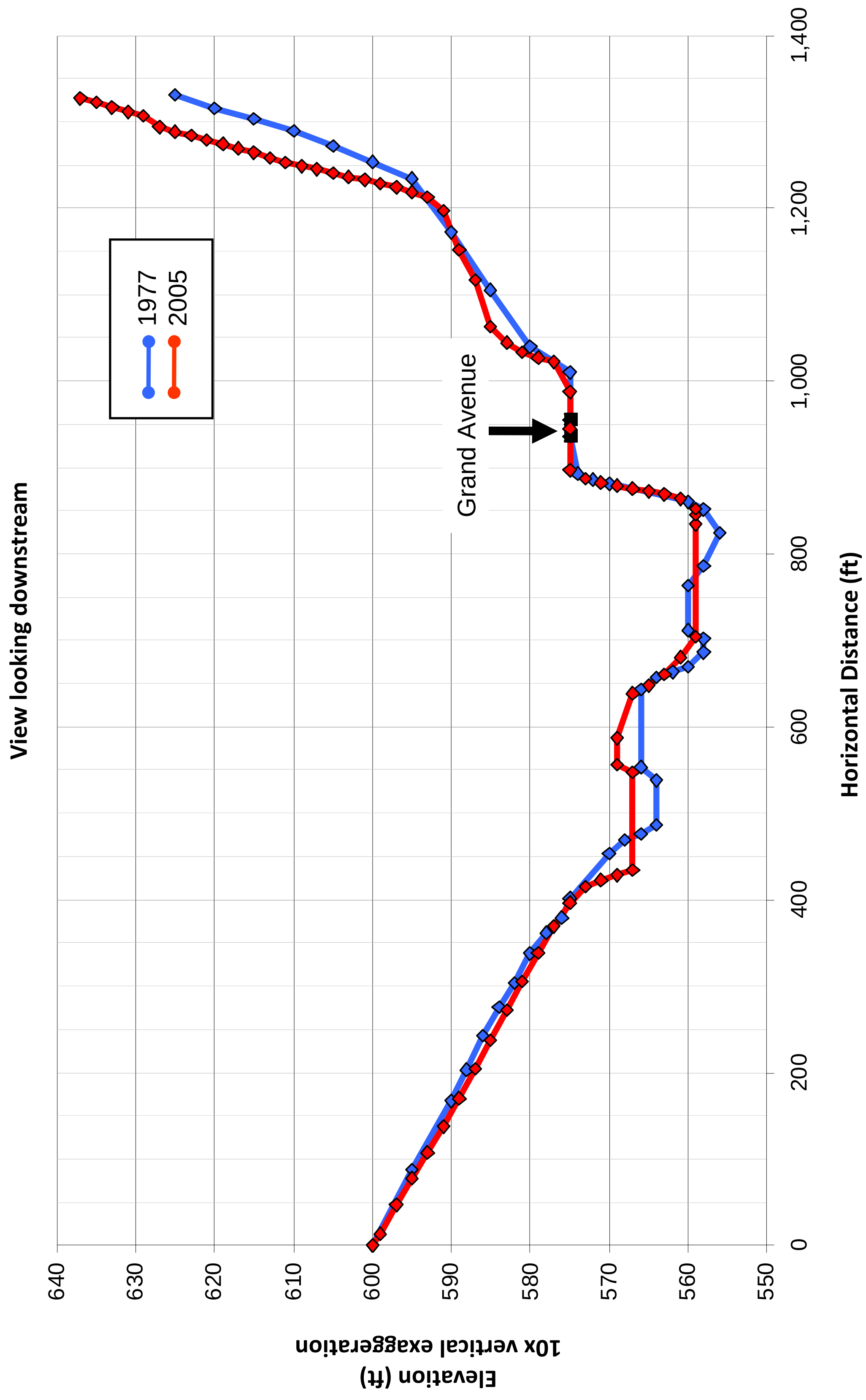


Figure C-19. Cross-section 15 (XS-15) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 11/17/77) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

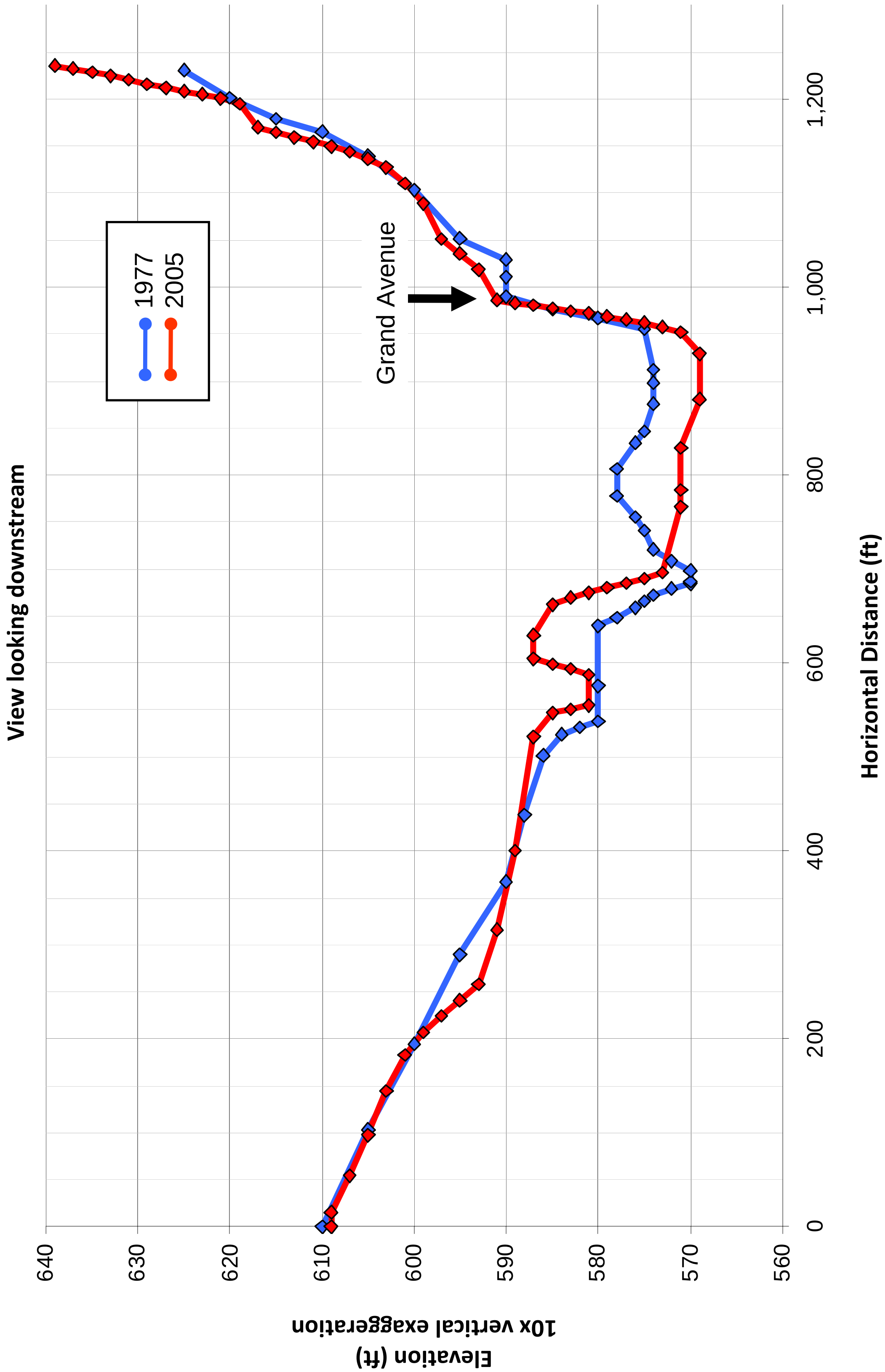


Figure C-20. Cross-section 16 (XS-16) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 11/17/77) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

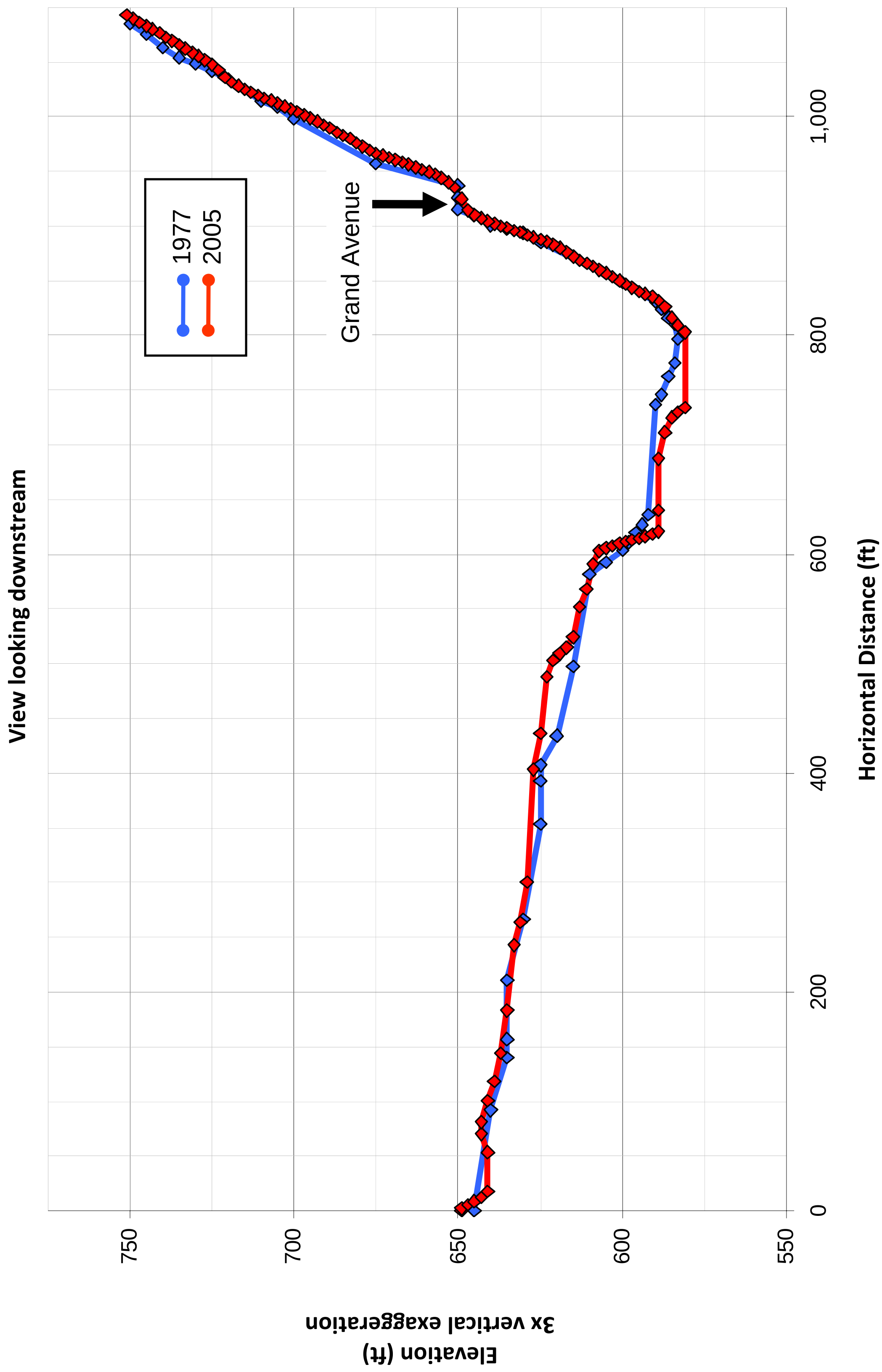


Figure C-21. Cross-section 17 (XS-17) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 11/17/77) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).

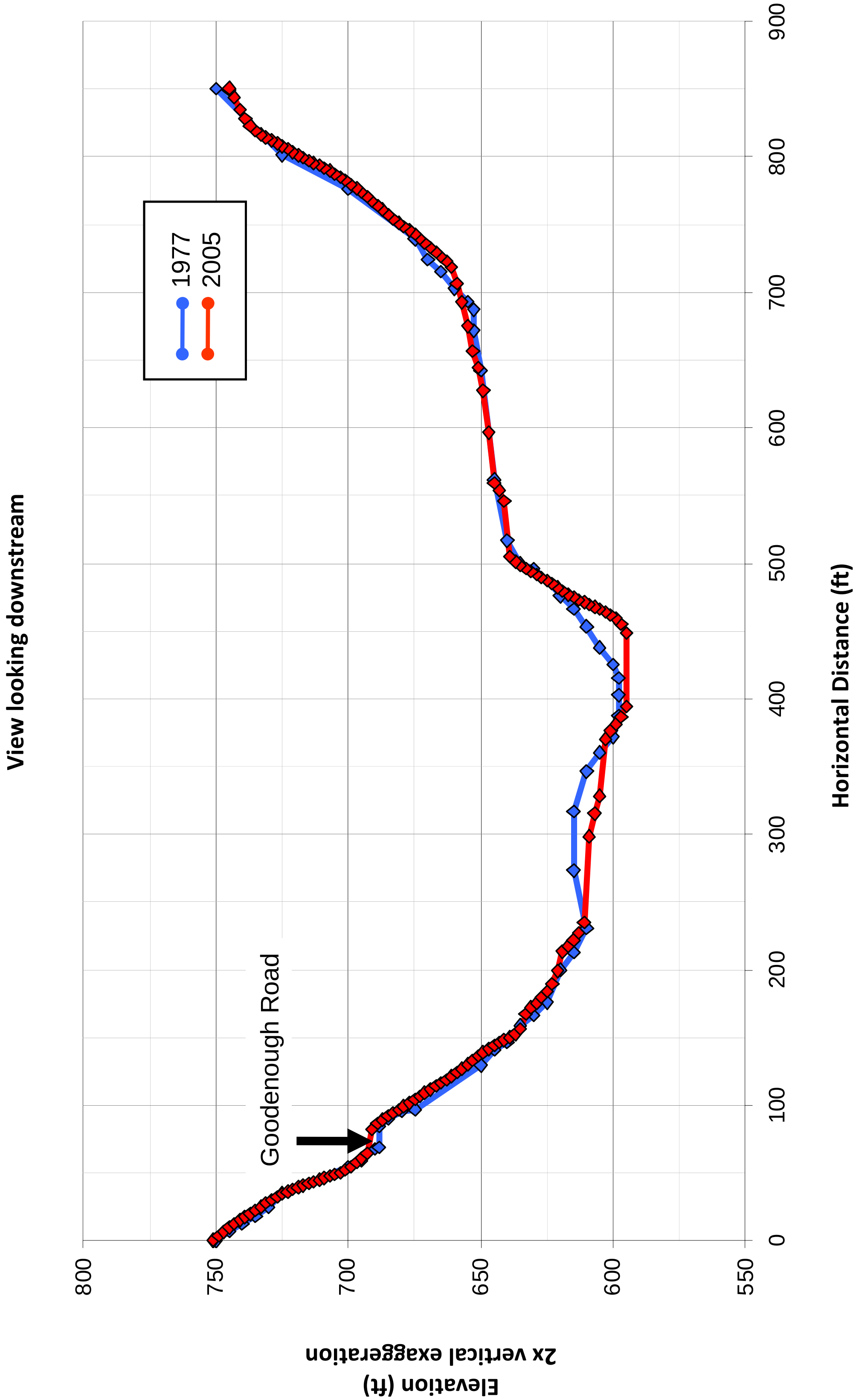


Figure C-22. Cross-section 18 (XS-18) showing channel topography in the 1970s (from 2-ft contour maps compiled by VCDPW by photogrammetric methods from photography dated 11/17/77) and 2005 (from 2-ft contours generated from LiDAR dated 2/24/05).