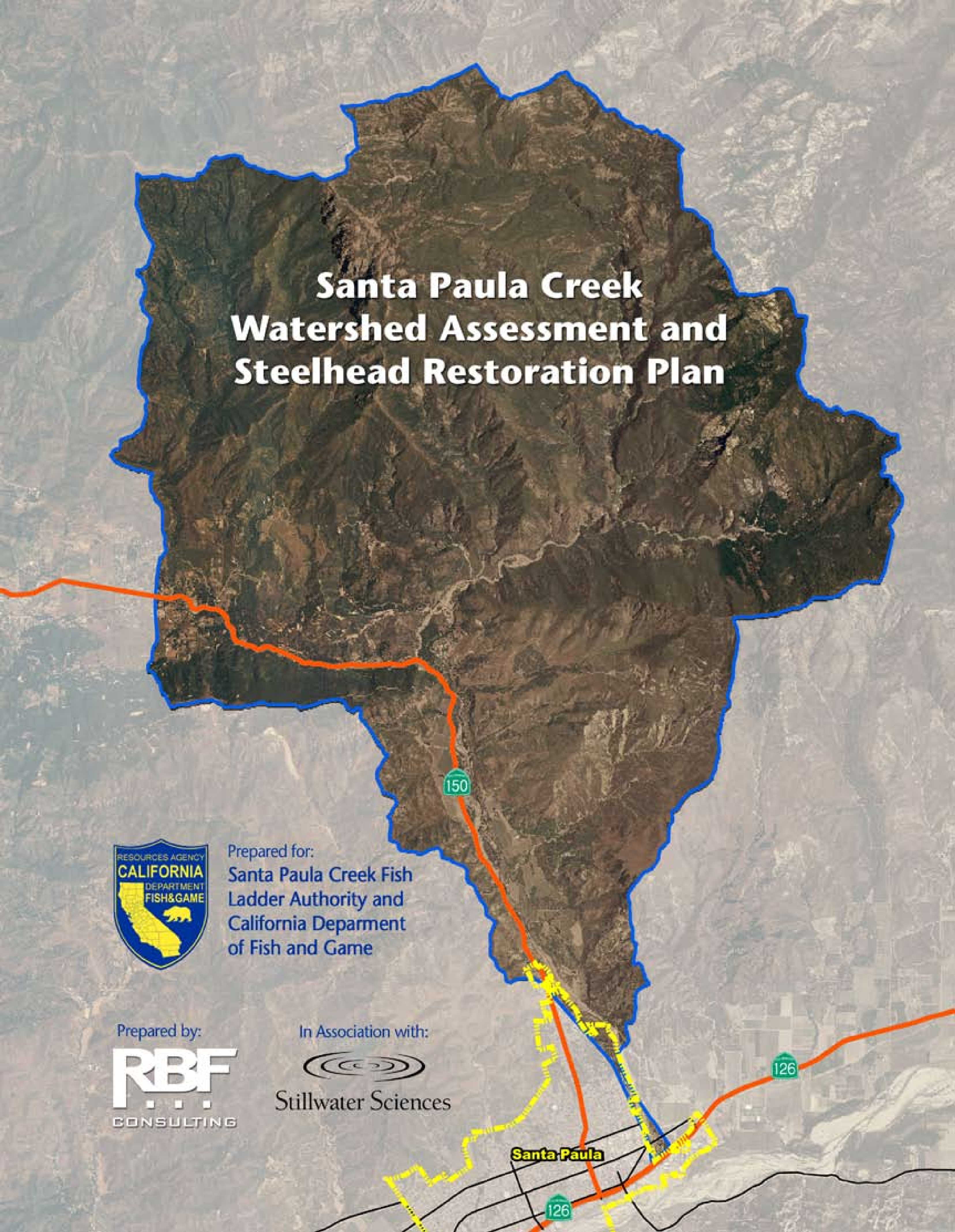
Santa Paula Creek Watershed Assessment and Steelhead Restoration Plan



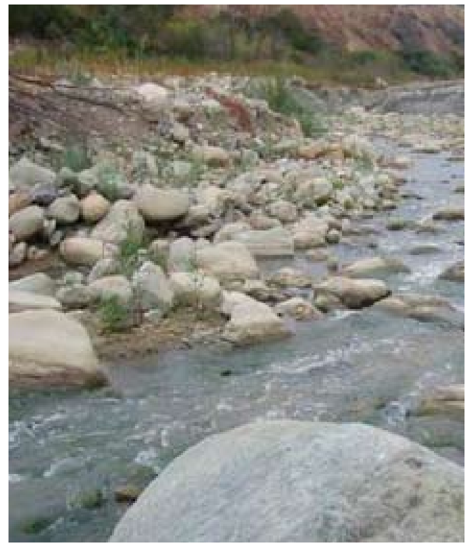
Prepared for:
Santa Paula Creek Fish Ladder Authority and California Deparment of Fish and Game

Prepared by:
RBF CONSULTING

In Association with:
Stillwater Sciences

Santa Paula Creek Watershed Assessment and Steelhead Restoration

January 2009



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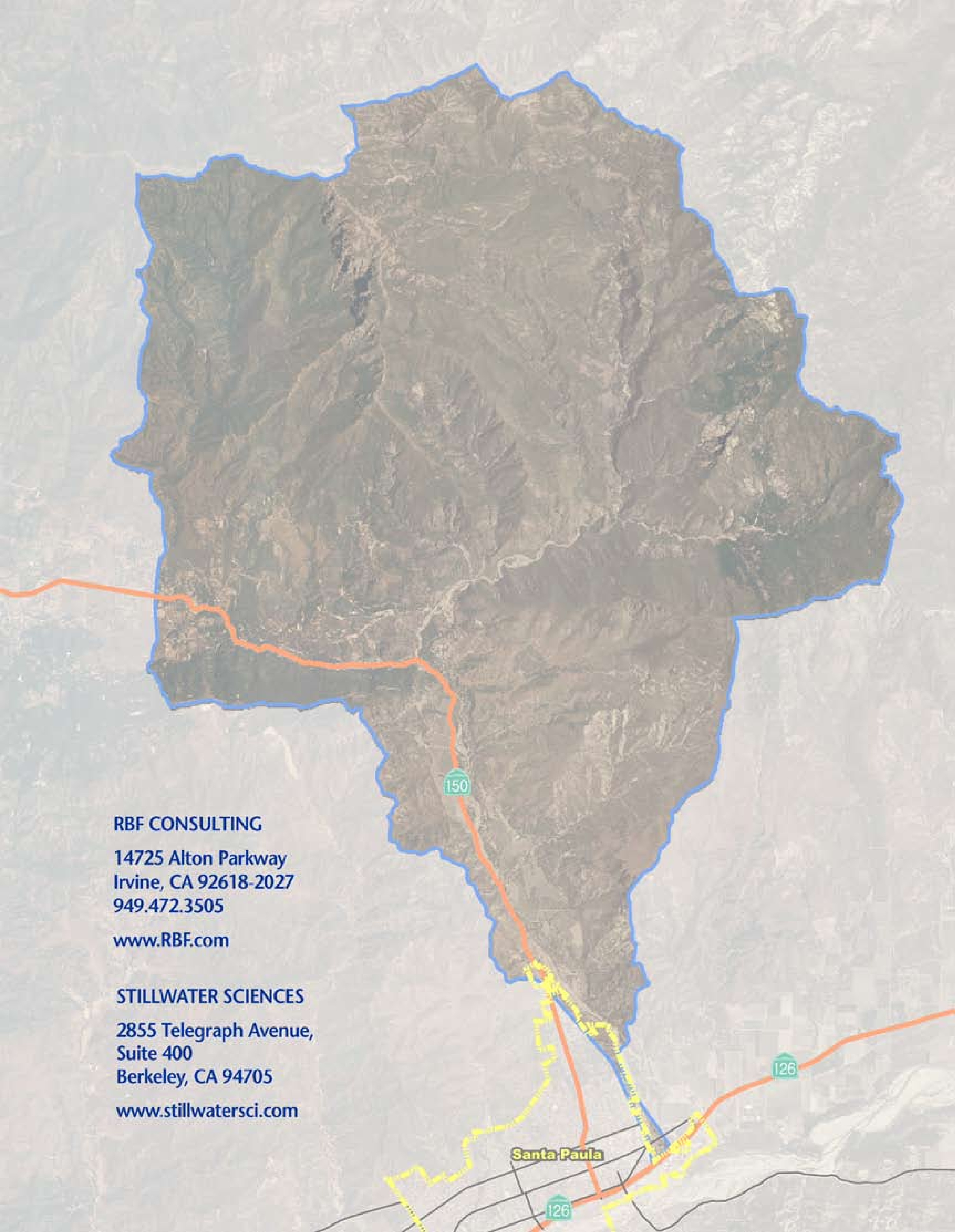

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Table of Contents

List of Figures

List of Tables

Appendices

Technical Studies

Santa Paula Creek Watershed Planning Project: Geomorphology and Channel Stability Assessment. Stillwater Sciences. November 2007.

Santa Paula Creek Watershed Planning Project: Hydrology and Hydraulic Watershed Assessment. RBF Consulting. May 2007.

Santa Paula Creek Watershed Planning Project: Steelhead Habitat and Population Assessment. Stillwater Sciences. December 2007.

1 INTRODUCTION

1.1 Description of the Watershed

Santa Paula Creek, in southwest Ventura County, California, is one of three main historical spawning tributaries for the endangered southern steelhead (*Oncorhynchus mykiss*). The creek holds approximately 18.5 miles of habitat once accessible to steelhead (Stoecker and Kelley 2005) but now blocked by in-channel structures that act as migration barriers. Prior mitigation of these barriers has included construction of fish ladders and drop structures. The recent record floods of January and February 2005 severely damaged these fish-passage facilities and caused major channel incision and bank erosion in the lower reaches of Santa Paula Creek, increasing the severity of existing blockages to the upstream steelhead migration corridor. Damaged and non-functioning facilities include the fish ladder at the upstream end of the U.S. Army Corps of Engineers channelization project in lower Santa Paula Creek, the Harvey Diversion fish ladder just above the confluence with Mud Creek, and the Highway 150 drop structure downstream of the confluence of Santa Paula and Sisar creeks. Failure of past fish passage structures, as well as damage to the natural functions and resources of the watershed, has been due in part to the lack of accounting for local- and watershed-scale geomorphic processes into structure design (M. Whitman, *pers. comm.*, 2007). This recognition has motivated the need for a more concentrated focus on large-scale, watershed-forming processes in future fish passage solutions.

Santa Paula Creek is a major tributary to the Santa Clara River, draining approximately 44.4 square miles (Figure 1-1). The headwaters are located along the south-facing slopes of the Topatopa Mountains where the maximum watershed elevation is over 6,500 above mean sea level [MSL]. The downstream limit of the watershed is at the creek confluence with the Santa Clara River. The major tributaries within the lower Santa Paula Creek watershed include Sisar Creek, Anlauf Canyon, and Mud Creek.

Santa Paula Creek experiences a high degree of annual flow variability, with multi-year droughts and extreme seasonal flooding. Annual precipitation within the watershed ranges from approximately 36 inches within the Topatopa Mountains to approximately 18 inches at the confluence with the Santa Clara River.

Land use within the watershed remains largely undeveloped compared to other Southern California coastal watersheds. Land use/vegetation cover within the watershed includes scrub/chaparral (52.2% of total area), mixed evergreen/deciduous forest (35.5% of total area), agriculture/herbaceous grasslands (10.5% of total area), and developed/residential (0.8% of total area) (NOAA 2002). The northern portion of the watershed is located within the Los Padres National Forest (approximately 65% of total area) and the vegetation cover is entirely chaparral/scrub and mixed forest. The agricultural/developed areas within the watershed are primarily along the lower Santa Paula Creek downstream of the Sisar Creek confluence, and within Anlauf Canyon and Mud Creek. Agriculture is dominated by citrus orchards and avocado fields (USACOE 1995).

Figure 1-1: Vicinity Map and Santa Clara River Watershed

1.2 Purpose and use of this plan

In 2005, The Santa Paula Creek Fish Ladder Joint Powers Authority received a grant from the California Department of Fish and Game (CDFG) to develop a complete and detailed watershed evaluation and assessment. The goal of the project is the completion of an integrated plan containing site-specific and clearly prioritized recommendations for work that will lead to the restoration of salmon and anadromous trout habitats in the Santa Paula Creek watershed. The final product is the Santa Paula Creek Watershed Assessment and Steelhead Restoration Plan (Plan).

The Santa Paula Creek Watershed Assessment and Steelhead Restoration Plan is the first step in the local planning process to identify problems, develop solutions, and focus efforts to restore, sustain, and enhance the watershed. The Plan has also been identified as the key to the pursuance of future Federal, State, and local grants and loans in order to implement management strategies important for the watershed.

The intent of the Plan is to provide guidance to Federal, State, and local governments, agencies, districts, and citizens in restoring, protecting, and enhancing the health of the Santa Paula Creek watershed and its associated aquatic resources.

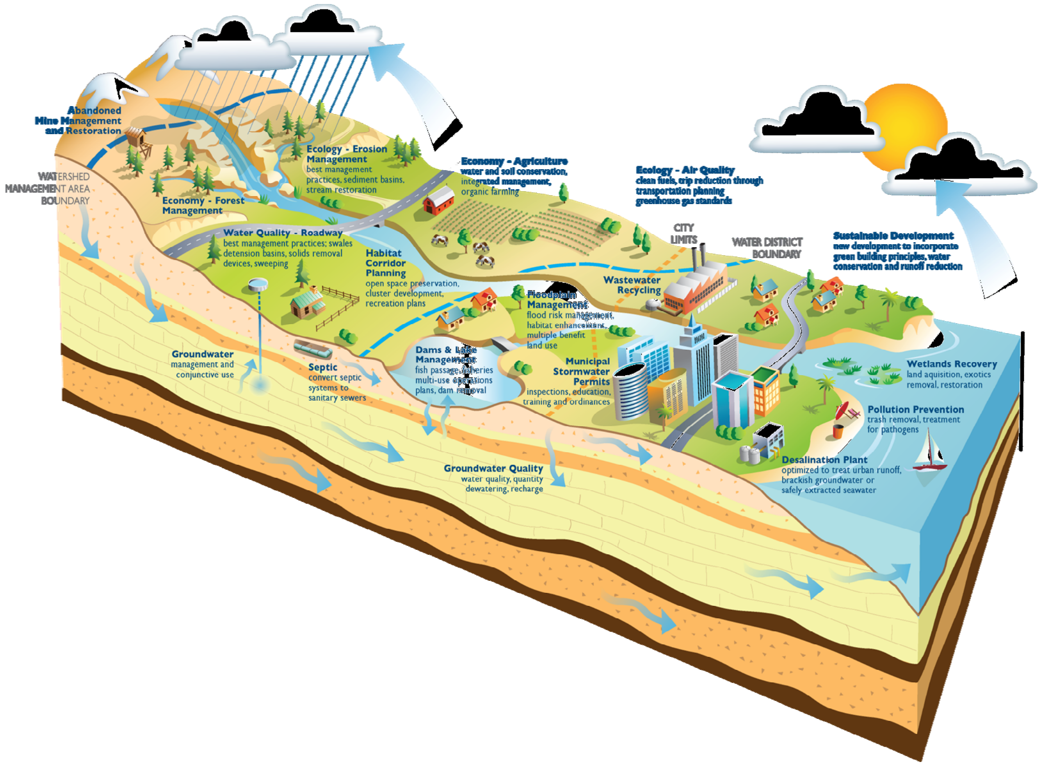
1.3 The Watershed Management Approach

The term "watershed" refers to an area of land that drains water from rainfall and snowmelt to a common point such as a stream, lake or ocean. Precipitation falling on any part of a watershed can travel quickly on the surface of the land, or underground, until it reaches creeks, rivers, and ultimately, the ocean. Any sort of activity in a watershed, ranging from agricultural to urban, can affect the quality of water in a watershed, in addition to the quantity and flow of water in surface channels, which wildlife depend on to survive.

Watershed management is a way of looking at relationships among people, land and water. Its focus is the integration of the efforts of landowners, land use agencies, water management experts, environmental specialists, water use purveyors and other community members. These stakeholders work together to ensure proper stewardship of our natural resources, compliance with regulation and efficient management. Watersheds are systems within which resources are connected and impacted by the complexities of development, agriculture, and resource management decisions. The underlying goal for watershed management is to strive toward efficient, sustainable and intelligent solutions to our watershed issues.

The watershed approach changes the fragmented approach we have used in the past. Historically, we have managed resources within specific disciplines, and within spheres of influence created by people, not by the laws of nature. We have developed separate laws to protect water, air, soils, fisheries, forests and communities. We have also created separate agencies to administer these laws at federal, state, and local levels and on public and private lands. Property and political boundaries are usually unrelated to watershed boundaries. Of particular note, many of our resources management programs are driven by regulation and enforcement, creating a mindset of seeking the minimum necessary compliance as the best way to "optimize" activities.

Figure 1-2: Watershed Management Concept Exhibit



The watershed approach changes this mindset to develop recognition among members of a community of the value of their own resources, and to guide a balanced program of stewardship that achieves community goals while complying with rules. A watershed approach will integrate biology, chemistry, hydrology, economics, and social considerations into decision-making. It recognizes needs for water supply, water quality, flood control, navigation, hydropower generation, fisheries, biodiversity, habitat preservation, recreation, and reasonable development; and it recognizes that these needs often compete. It establishes local priorities, accounts for state and national goals, and coordinates public and private actions.

Thus, while traditional approaches are reactive, precautionary, regulatory, single-purpose, and driven by enforcement, watershed management is proactive, scientific, uses agreement-based approaches to achieve multiple benefits, and is driven by the self-interest of stakeholders. The development of a watershed management plan is an important early step in a long-term effort to integrate the Santa Paula Creek watershed's stakeholders and management efforts.

1.4 Goals and Objectives

In an effort to improve fish passage along Santa Paula Creek, the Santa Paula Creek Fish Ladder Joint Powers Authority, in coordination with the California Department of Fish and Game, is sponsoring the Santa Paula Creek Watershed Planning Project. The project is being conducted by RBF Consulting Inc. and Stillwater Sciences. The overall goal of the project is to produce a detailed watershed assessment and a set of restoration alternatives with site-specific, prioritized recommendations for future work leading to restoration of southern steelhead passage throughout historically accessible reaches in the Santa Paula Creek watershed. First-phase project objectives to understand the baseline condition of the watershed include the preparation of the following technical studies:

- Develop a detailed watershed-scale geomorphic assessment as background to design of improved fish passage and diversion facilities
- Perform a detailed hydrologic and hydraulic analysis for current conditions, future land use conditions, and proposed modified channel conditions for each restoration alternative
- Conducted focused studies of southern steelhead and resident *O. mykiss* behavior, habitat, and population to support the provision of adequate passage and expand upon knowledge gained in previous studies

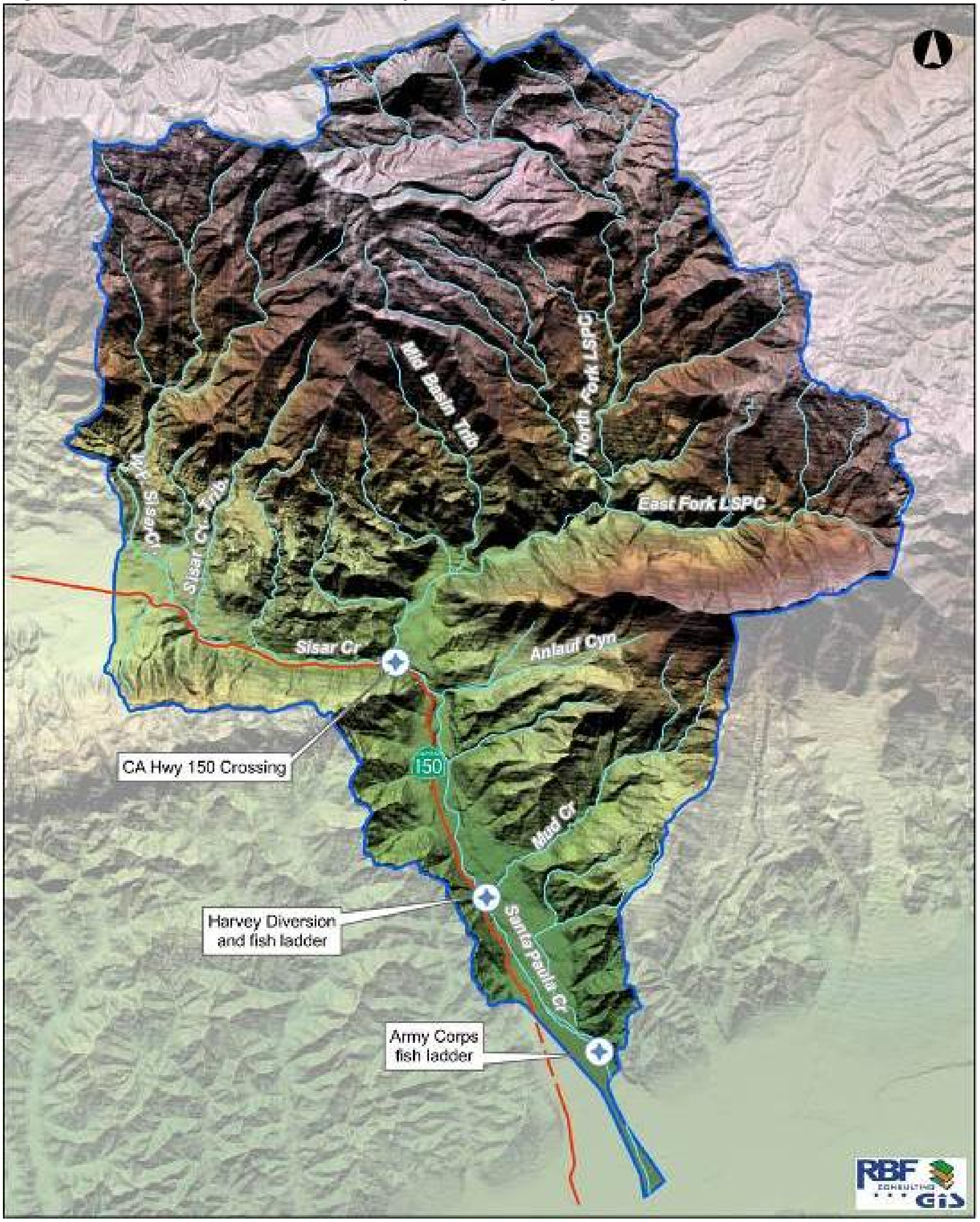
Together, the in-depth understanding of watershed geomorphology, hydrology and hydraulics, and steelhead ecology will guide the development of appropriate, long-term engineering solutions for improved fish passage in Santa Paula Creek while maintaining existing water-diversion rights, and flood protection requirements. In particular, the Plan takes into consideration the 4 stream reaches that in combination create a fish passage issue within Santa Paula Creek: 1) the USACE debris basin and associated grade controls, 2) the middle reach between the USACE project and the canyon reach, 3) the canyon reach and Harvey Diversion, and 4) the Highway 150 road crossing.

Objectives of the plan include:

1. To provide an overview of the baseline physical processes within Santa Paula and Sisar Creek.
2. To identify key issues affecting watershed health
3. To identify and prioritize projects to remedy problems identified in the watershed
4. To improve understanding, appreciation, and stewardship of the Santa Paula Creek watershed

The project was managed and coordinated by the Santa Paula Fish Ladder JPA staff. The JPA project coordinator consulted with the CDFG on all contractual matters and any coordination efforts required in carrying out the terms of the grant, including the submittal of progress payments and draft reports.

Figure 1-3: Santa Paula Watershed Map Showing Projects



2 STAKEHOLDER INVOLVEMENT AND PLAN DEVELOPMENT

2.1 Technical Advisory Committee (TAC) and Citizens Advisory Committee (CAC)

Under the conditions for receiving a grant from the California Department of Fish and Game, RBF Consulting, in conjunction with Stillwater Sciences and the Santa Paula Fish Ladder JPA, was tasked with convening a Technical Advisory Council (TAC) and a Citizens Advisory Council (CAC).

The TAC provided input to the project team for the development, shaping, review, ranking, screening analysis of alternative restoration and management techniques, and review. This was accomplished by conducting facilitated working meetings. This was achieved by the project team through the development and distribution of descriptive materials for TAC member review for meeting presentation. The TAC served as the clearinghouse for public outreach materials for distribution to TAC members, newspapers, speaking opportunities, and presentation to community groups. A total of five (5) TAC/CAC meetings were held.

1. January 2006 - Project presentation, background on Santa Paula Creek, and overview of technical study approach
2. May 2006 - Presentation of technical study results and implications, discussion of approach to identifying potential alternative solutions, and update on fisheries studies
3. December 2007 - Presentation and discussion of fisheries studies, summary of watershed geomorphology conclusions, presentation of preliminary alternative solutions, and evaluation and rank of alternatives
4. April 2008 - Presentation and discussion of details of potential alternatives at the Harvey Diversion, and review and discussion of draft report
5. November 2008 - Presentation of the watershed conclusions and summary of key issues, identification of preliminary alternatives for each of the key issue areas, and discussion of final report preparation

A TAC was convened consisting of the appropriate representatives from the following stakeholder sectors:

1. CDFG Fisheries Restoration Grant Program Representatives
2. Santa Paula Creek Fish Ladder Joint Powers Authority
3. Regional flood control: Ventura County Watershed Protection District
4. Federal regulatory agencies, i.e., U.S. Army Corps of Engineers and National Marine Fisheries Service
5. State regulatory agency: Regional Water Quality Control Board
6. Local municipal, i.e., City of Santa Paula
7. Local academia, i.e., University of California Santa Barbara
8. Transportation, e.g., California Department of Transportation and County Roads Department
9. Regional water management, i.e., United Water Conservation District
10. Local water management: Canyon Irrigation Company
11. Regional related projects, California State Coastal Conservancy's Santa Clara River Parkway Project
12. Project Consultants: RBF Consulting and Stillwater Sciences

13. Others: including Los Angeles County Department of Public Works, The Nature Conservancy, Friends of the Santa Clara River

A Citizen Advisory Committee (CAC) was convened consisting of appropriate representatives from the local community:

1. Agriculture and other land owners in the study area
2. Public interest groups

A key part of developing the watershed plan was facilitating dialogue among stakeholders within the watershed. This was needed to establish the watershed as a necessary focus of public attention, create an understanding of the watershed, establish a goal among different organizations, and to share perspectives for future change. RBF Consulting, Stillwater Sciences, and Santa Paula Creek Fish Ladder JPA staff worked with the participating organizations and individuals to identify areas of concern and potential projects during this process.

One public information meeting was held in conjunction with the Good Morning Santa Paula Forum, where information about the project was disseminated to the community, and 2 combined meetings were held with the TAC (Meeting Nos. 4 and 5).

2.2 Key dates in the development of this plan

The Santa Paula Fish Ladder Authority in conjunction with RBF Consulting and Stillwater Sciences prepared and submitted the Fisheries Restoration Grant Program proposal application in May 2005. Work on the Santa Paula Creek Watershed Management Plan began in August 2006. Key dates in the development of the plan are summarized below:

January 2007	TAC Meeting No. 1
May 2007	Preliminary hydrology and hydraulics evaluation technical memorandum
May 2007	Preliminary geomorphic assessment technical memorandum
May 2007	TAC Meeting No. 2
June 2007	Fish survey
November 2007	Fish survey
November 2007	Final geomorphic assessment technical memorandum
December 2007	Preliminary biological assessment technical memorandum
December 2007	Final Steelhead Habitat and Population Assessment
December 2007	Development of alternatives: canyon reach
December 2007	TAC Meeting No. 3
April 2008	Preliminary focused alternatives analysis technical memorandum: canyon reach
April 2008	TAC Meeting No. 4
November 2008	Draft Watershed Plan
December 2008	TAC Meeting No. 5 [still to be held]
December 2008	Pre-Final Santa Paula Creek Watershed Assessment and Steelhead Restoration Plan
January 2008	Final Watershed Assessment and Restoration Plan distributed

2.3 Plan contributors

Development of the watershed plan included input from both public and private organizations. Several landowners also provided information valuable to the plan formation. The following individuals were key contributors to the watershed plan:

Santa Paula Creek Fish Ladder JPA	Frank Brommenschenkel (project director)
RBF Consulting	John McCarthy, PE, CFM (project manager)
RBF Consulting	Howard Barndt, MS, PE (project engineer)
RBF Consulting	Richard Beck (environmental planner)
RBF Consulting	Jerome Ruddins (construction engineering)
RBF Consulting	Gabriela Brockhoff (watershed management)
Stillwater Sciences	Derek Booth, Ph.D., PG, PE (geologist)
Stillwater Sciences	Peter W. Downs, Ph.D. (geomorphologist)
Stillwater Sciences	Scott Dusterhoff (geomorphologist)
Stillwater Sciences	Yantao Cui, Ph.D. (sediment transport)
Stillwater Sciences	Matt Sloat (fisheries biologist)
Stillwater Sciences	Russ Liegig (fisheries biologist)
Stillwater Sciences	Ann-Marie Osterback (fisheries biologist)
Stillwater Sciences	William Sears (aquatic ecologist)
VCWPD	Sergio Vargas, PE
VCWPD	Vincent Su, Ph.D., PE
VCWPD	Theresa Stevens
CDFG	Mary Larson
CDFG	Kris Vyverberg
CDFG	Marcin Whitman
Army Corps of Engineers	Frank Mallette
Army Corps of Engineers	Darrell Buxton
Caltrans	Bruce Swanger

Several landowners and other members of the community and organizations also provided valuable input into the development of the plan.

3 HISTORY OF THE REGION AND WATERSHED

The Santa Paula Creek watershed lies within the larger Santa Clara River Watershed. The latter encompasses one of the largest river systems in southern California, and is the largest river system in southern California that remains in a largely natural state. The Santa Clara River's headwaters lie at Pacifico Mountain, located in the San Gabriel Mountains, and it discharges into the Pacific Ocean, draining a total area of 1,634 square miles. Approximately 90 percent of the Watershed is mountainous with a maximum elevation of 8800 feet (the higher elevations are mostly found in the Los Padres National Forest). The remaining valley floors and coastal plains make up 10 percent of the Watershed.

Like many other watersheds in the State, economic activities in the Santa Clara River Watershed have historical roots in subsistence agriculture, mining, ranching, and since Euro-American arrival, intensive agricultural production. Agriculture is still a major industry in the region, although increasing development pressure exists to accommodate population and urban economic growth in the region. Historical and future land use changes have important implications for the health of the Santa Clara River and Santa Paula Creek watersheds, and should be considered as factors in the creation of a watershed plan.

3.1 Land use and economic activities in the Santa Clara River Watershed

Early human settlers around the Santa Clara River include two Native American people groups, the Tatavian and Ventureno Chumash. The Tatavian lived on the upper Santa Clara River and west to Piru. The Ventureno Chumash lived west of Piru to the ocean. These communities utilized the river for their daily needs, and shaped their daily lives around the river's resources. Some plants known to be commonly used by these groups include: acorns, Carrizo grass, tule, Indian hemp, wild cherry, cattail, water cress, California Bay Laurel, and California Walnut.

Father Juan Crespi, who accompanied the Portola Expedition in 1796, gave the Santa Clara River its current name. After establishing Mission San Buenaventura in 1782, mission administrators, with the help of Chumash and Tatavian community members, created the first major diversion of the Santa Clara River (occurring at what is currently known as Santa Paula). This diversion was used as a reservoir to irrigate agricultural crops and to feed livestock. Over time, the laws and tradition of Spanish and Mexican law continued to shape the way people in this region used the river. Under this system, the river's water was considered a community resource, and its status as such trumped environmental and individual rights. Despite this, many rancho owners practiced unsanctioned water diversion methods in order to support their crops, livestock, and laborers through the end of the Spanish-Mexican era.

During the gold boom of California, mining became a popular activity. In 1842 an estimated 100 miners worked using dry washing methods in the canyons of the Santa Clara River Watershed, although that number dropped to 36 by 1845. After the gold rush, silver and copper were mined for a time near Santa Paula Creek and Soledad Canyon.

After 1870 and through the end of World War II, Euro-American immigrants contributed to substantial changes in the social and physical landscape of the Santa Clara River Watershed. With the establishment of larger and more intensive agricultural operations, along with oil drilling, settlers used water and land as a tool to support increased growth. Lima beans were introduced as a crop in the mid 1870s, gradually displacing grain as the primary agricultural product. Lima beans then reigned as the region's major crop for several decades. The turn of the twentieth century brought the introduction of sugar beets, an attractive crop that brought high market prices and did well in the ideal growing conditions of the Oxnard Plain. In the late 1890s, the Limoneira Company established a vibrant citrus-growing operation, whose production eventually surpassed other agricultural products. Triggered by the growth of the agricultural and oil industries in the area, the twentieth century also brought the Southern Pacific Railroad to the area, linking the region to the rest of Ventura County as well as California.

Thus began a long tradition of agriculture in this watershed (and in the region as a whole) and with it a tradition of diverting water from the creeks and rivers in the watershed to be used for subsistence, irrigation, and industrial uses.

3.2 Flood Risk and the City of Santa Paula

The City of Santa Paula lies at the confluence of Santa Paula Creek with the Santa Clara River. The city was laid out in 1873 (incorporated in 1902) over the alluvial fan of Santa Paula Creek which at that time was a multiple-threaded or anastomosing channel, so that multiple channel crossings were required when the Southern Pacific Railroad first arrived in 1887. At some time before about 1930 the multiple courses of Santa Paula Creek were channelized into a single channel to the east of the City, probably to accommodate the 1912 construction of the truss railroad bridge which presently creates the most critical flow constriction along the lower Santa Paula Creek (USACE 1995). Former channel courses are plainly evident across unbuilt city blocks in the earliest aerial photographs (circa 1930) so it is no wonder that the City of Santa Paula has a long history of flooding problems dating back to the initial settlement of the area. Early accounts of flooding indicate the violent nature of the fluvial processes at work in the watershed, most notably in relation to the shifting nature of the channel, its substantial erosive velocities, and the large size of the sediment in transport (USACE 1995).

Santa Paula Creek is a gaged watershed with a stream gage located on the lower main stem at Mupu Road Bridge, about 1.3 miles downstream from the Sisar Creek confluence. The Ventura County Watershed Protection District (VCWPD) operates the active streamflow-measuring device installed at this site, identified as Station 709B. Discharges recorded by this station are collected and compiled by the VCWPD. The streamflow record for this site is also maintained by the U.S. Geological Survey based on data provided by the VCWPD, and is identified as Station 11113500. The station has been recording mean daily and peak event discharges at or in the vicinity of this location since 1933, which accounts for about 72 years of compiled streamflow measurements.

There have been eight (8) major flood events since accurate flood records began in the 1930's, with the largest storm event occurring in January 2005. Figure 3-1 provides a plot of the peak storm events over the 72 years of recorded data at the gaging station. Table 3-1 provides a listing of the peak flow rates for the largest storms on record.

Figure 3-1: USGS Station 111135000 annual maximum recorded discharges

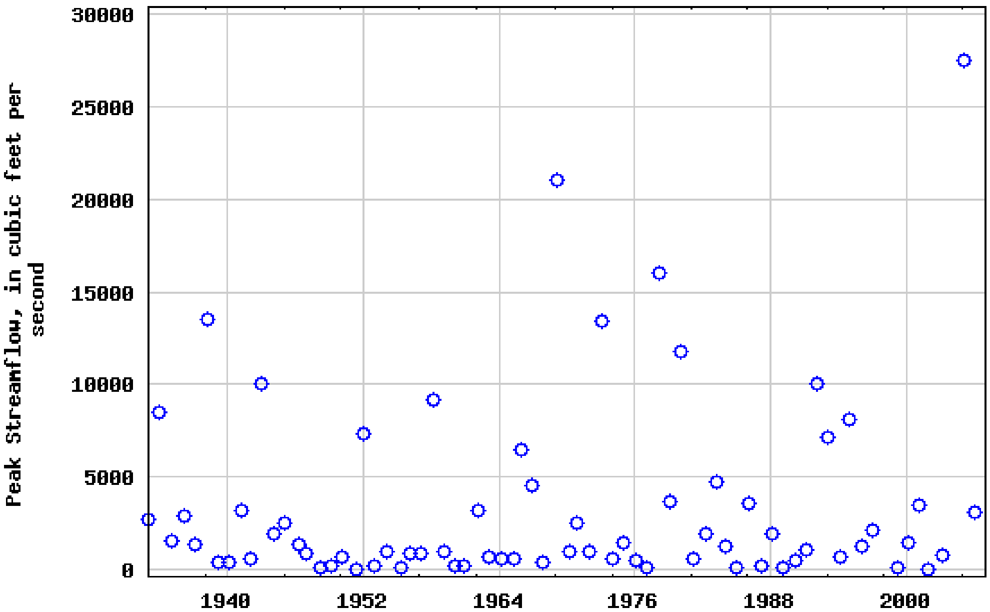


Table 3-1: Largest flood events on record (peak discharge >10,000 cfs).

Date	Peak Discharge (cfs)	Peak Discharge (m^3s^{-1})
Winter 1884	>10,000a	>319.3
March 2, 1938	13,500	431.1
January 22, 1943	10,000	319.3
January 25, 1969	19,000	606.7
February 25, 1969	21,000	670.6
February 10, 1978	16,000	510.9
February 16, 1980	11,800	376.8
February 12, 1992	10,000	319.3
January 10, 2005	27,500 (maximum of record)	878.2 (maximum of record)

[a] Value estimated from precipitation record and accounts of flood damage.

3.3 Channel Morphology and Change

The headwaters of Santa Paula Creek are located within the actively uplifting, steep south-facing slopes of the Topatopa Mountains where the maximum watershed elevation is over 2,000 m above mean sea level [MSL]. In the upper watershed, the creek flows through narrow bedrock canyons with steep channel gradients (>6%) and contains large bed particles (dominated by boulders and cobbles). Lower in the watershed, the creek flows through bedrock (narrow reaches) and cobble-dominant alluvial deposits (wide reaches) before entering into the Santa Clara River at the town of Santa Paula. Channel gradients in the lower watershed range from 1.5–2.5% and the channel has incised up to 10 m relative to the adjacent terrace with many reaches showing evidence of active incision and active channel widening. The major tributaries within the lower Santa Paula Creek watershed include (from upstream to downstream) Sisar Creek (29.7 km^2 watershed), Anlauf Canyon (3.7 km^2 watershed), and Mud Creek (7.0 km^2 watershed).

Channel morphologic characteristics (channel thalweg location, channel thalweg elevation/slope, and channel width) in Santa Paula Creek were compared over the past 100 years to determine how the channel has responded to watershed perturbations such as major storm events, changes in sediment and/or water input, and in-channel modifications (e.g., in-channel structures and sediment removal). Data sources included orthorectified topographic maps from 1901, 1947, and 2005, and aerial photography from 1969, 1998, and 2005. Over the past 100 years, Santa Paula Creek between the Sisar Creek confluence/Highway 150 bridge and the Mud Creek confluence/Harvey Diversion Dam has migrated within an active channel valley with pronounced incision at the upstream end followed by pronounced channel downstream aggradation and localized channel widening in downstream portion of the zone. Compared to the upstream geomorphic zone, Santa Paula Creek downstream of the Mud Creek confluence/Harvey Diversion Dam shows significant variations in position, elevation, and width from 1901 to 2005. Specifically, this geomorphic zone is characterized by a long depositional reach characterized by channel slope decrease and local widening located between reaches with significant channel incision. Figures 3-2 and 3-3 illustrate the changes visible in the creek's form and vegetation over several decades in the twentieth century. Further details are provided in the Geomorphology and Channel Stability Assessment Report (Stillwater Sciences 2007).

Figure 3-2: Historic (1969) and current (2005) channel width comparison in Reaches 2 and 7/8

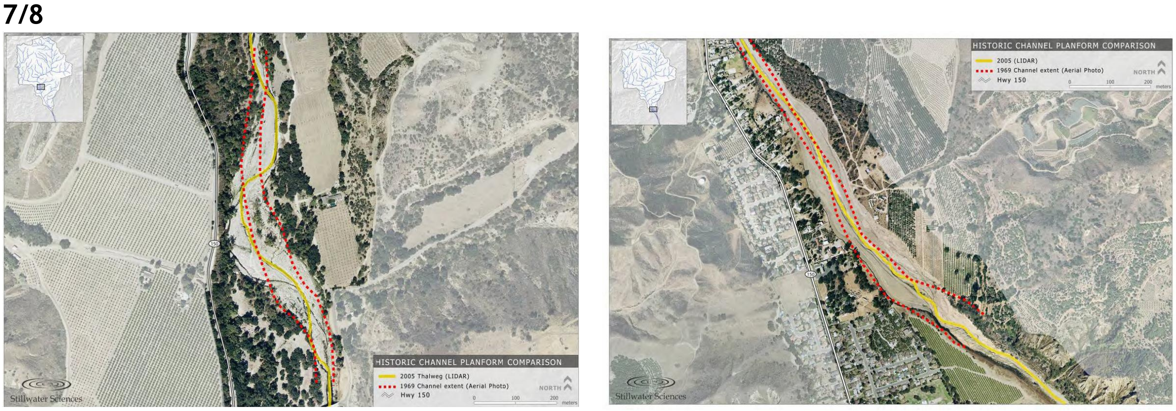


Figure 3-3: Aerial photographs of Reach 8 in (a) 1969 and (b) 2005

4 BASELINE WATERSHED CONDITIONS

4.1 Description

The Santa Paula Creek watershed is located in southwestern Ventura County, California, within the Transverse Ranges of Southern California. The watershed experiences a Mediterranean climate, which is characterized by warm, wet winters and moderate, dry summers, with 90% of annual rainfall occurring from November through April. The Santa Paula Creek is a major tributary to the Santa Clara River, draining approximately 44.4 square miles, or 75,050 acres (Figure 1-2). The major tributaries including Sisar Creek (11.5 sq. mi.), Anlauf Canyon (1.4 sq. mi.), and Mud Creek (2.7 sq. mi.).

The Santa Paula Creek watershed is a subwatershed within the larger Santa Clara River watershed (Figure 4-1), which is one of the largest watersheds in Southern California. The Santa Clara River Valley contains the city of Santa Paula, with a population of slightly less than 29,000 (US Census, 2000). The headwaters to the Santa Paula Creek are located along the south-facing slopes of the Topatopa Mountains where the maximum watershed elevation is over 6,500 above mean sea level [MSL]. The downstream limit of the watershed is at the creek confluence with the Santa Clara River. The major tributaries within the lower Santa Paula Creek watershed include the Upper Santa Paula Creek, Middle Santa Paula Creek, Lower Santa Paula Creek, Sisar Creek, Anlauf Canyon, and Mud Creek.

Santa Paula Creek is a perennial creek, traveling in a southeasterly direction through from the southern portion of Hines Peak towards the Santa Clara River, and providing various habitats to support fish and wildlife. The Creek currently has a variety of drainage patterns ranging from a braided stream morphology to a channelized system (within the last 1800 feet), as well as portions with a nearly vertical slant due to erosion and the natural flow of the Creek. Throughout the Twentieth Century, several changes have been made to the Creek bed, in particularly several engineered channelization and water diversion projects. The major infrastructure and channel modification projects which have affected the creek include the Highway 150 bridge crossings and grade control structures, the Harvey Diversion structure, the U.S. Army Corps of Engineers channelization and fish ladder project, and most recently the Ventura County Watershed Protection District's emergency bank protection project located upstream of the Army Corps fish ladder.

Santa Paula Creek is a perennial creek, traveling in a southeasterly direction through from the southern portion of Hines Peak towards the Santa Clara River. Along the way it travels through riffles and pools, which support wildlife and fish, granite boulders, and eventually merges with Mud Creek prior to its confluence with the Santa Clara River, east of the City of Santa Paula. The Creek currently has a variety of drainage patterns ranging from a braided stream morphology to a channelized system (within the last 1800 feet), as well as portions with a nearly vertical slant due to erosion and the natural flow of the Creek. Throughout the Twentieth Century, several changes have been made to the Creek bed, in particularly several engineered channelization and water diversion projects. The major infrastructure and channel modification projects which have affected the creek include the Highway 150 bridge crossings and grade control structures, the Harvey Diversion structure, the U.S. Army Corps of Engineers channelization and fish ladder project, and most recently the Ventura County Watershed Protection District's emergency bank protection project located upstream of the Army Corps fish ladder.

Figure 4-1: Relief Map of Southern California showing location of Santa Paula Creek watershed (or sub-basin) within the Santa Clara River Watershed

Santa Paula Creek experiences a high degree of annual flow variability, multi-year droughts, and extreme seasonal flooding. Annual precipitation within the watershed ranges from approximately approximately 36 inches within the Topatopa Mountains to approximately 18 inches at the mouth and confluence with the Santa Clara River, with over 90% of the annual precipitation occurring within 6 months at both locations (November to April) (USACE 1995). At the mouth of Santa Paula Creek, annual precipitation ranged from 6.6 inches (1961) to 44.8 inches (1998) over the past 80 years (VCWPD 2007). Extreme precipitation events (as recorded at the mouth of Santa Paula Creek) occurred in January 1969 (16.3 inches in 9 days), February 1969 (4.6 inches in 5 days), February 1978 (8.4 inches in 8 days), January 2005 (14 inches in 9 days), and February 2005 (9.5 inches in 6 days) (VCWPD 2007).

The creek is one of three historic spawning tributaries to the Santa Clara River for the endangered southern steelhead trout. The creek holds approximately 18.5 miles of habitat historically accessible to steelhead (Stoecker and Kelley 2005). The record floods of January and February 2005 severely damaged fish passage facilities and caused significant channel incision and bank erosion in the lower reaches of Santa Paula Creek, resulting in complete barriers to upstream fish passage and major damage to properties located within the floodplain. Damaged facilities include the fish ladder at the upstream end of the USACE channelization project in lower Santa Paula Creek, the Harvey Diversion fish ladder near the confluence with Mud Creek, and the Highway 150 drop structure near the confluence of Santa Paula and Sisar creeks (Figure 4-2).

Figure 4-2: Photographs of damaged fish ladder facilities (from left to right, Hwy 150 Bridge, Harvey Diversion, USACE Fish ladder).

4.2 Biological Resources

The Ventura County General Plan: Goals, Policies, and Programs and California Coastal Conservancy outline in detail, some important biological resources located within the Santa Paula Creek watershed.

4.2.1 Vegetation

Natural plant communities in the Santa Paula Creek watershed include: riparian woodland, coast live oak-woodland, coastal sage scrub-grassland, and chaparral. Figure 4-3 provides an overview of some major vegetation types in the watershed.

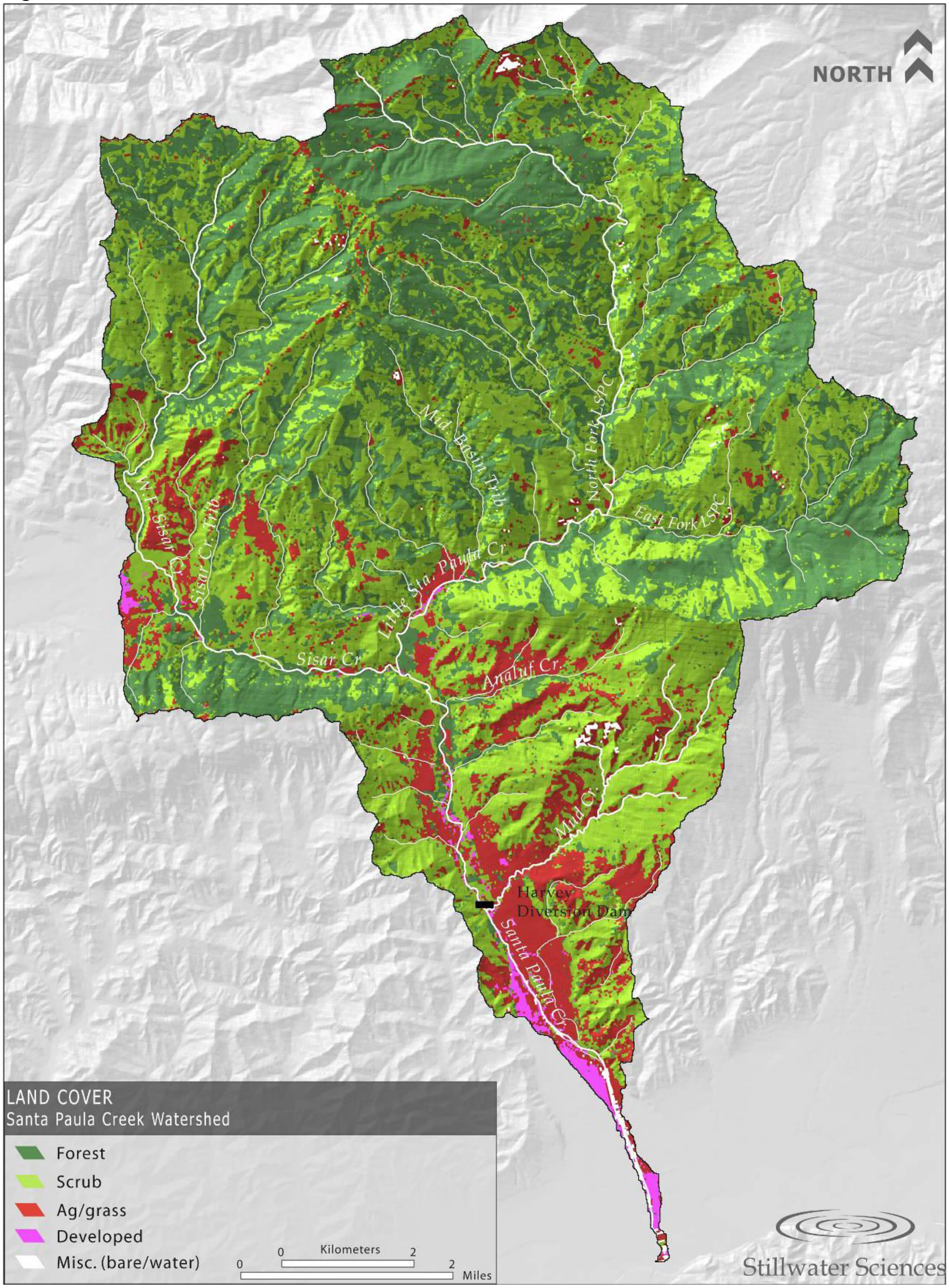
Coniferous trees are present in the upper mountainous elevations of the watershed. Riparian woodland and scrub habitat dominate in the upper parts of the watershed, and occur in narrow strips along the creek in the lower portions of the watershed. Upstream of Steckel Park, riparian habitat is intact and includes black cottonwood (*Populus trichocarpa*), western sycamore (*Platanus racemosa*), white alder (*Alnus rhombifolia*), Fremont conttonwood (*Populus fremontii*), willow specides (*Salix sp*.) , and mule fat (*Baccharis salicifolia*). There is also a mix of poison oak (*Toxicodendron diversilobum*), mugwart *(Artemesia douglasiana*), brome grasses (*Bromus sp*.), coclebur (*Xanthium strumarium*), wild celery (*Apium graveolens*), lotus (*Lotus sp.*) and locoweed (*Astragalus sp*.).

At Steckel Park, the Creek is surrounded by riparian and oak-walnut woodland habitats, including alluvial scrub habitat on the upper banks which are characterized by shrubs like California sagebrush (*Artemesia californica*), laurel sumac (*Malosma laurina*), black sage (*Salvia mellifera*), and buckwheat (*Erigonium sp*.).

Downstream of Steckel Park, located in the alluvial valley the vegetation in the watershed becomes primarily agricultural and urbanized. Crops include citrus and avocado orchards along both banks of Mud Creek and most of the eastern bank of the Santa Paula Creek. The remaining valley consists of urbanized, terraced hillsides.

There are a variety of sensitive plant species in the watershed, which include: slender-horned spineflower (*Dodecahma leptoceras*), Gamberll's water cress (*Rorippa gambelii*), and the Santa Paula Buckwheat (*Eriogonum parvidolium paynei*).

Figure 4-3: Santa Paula Creek Watershed Land Cover



4.2.2 Wildlife

Historically, the Santa Paula Creek has been home to a variety of wildlife species that are now of great interest to the community. Fish surveys performed by the California Department of Fish and Game (CDFG) in the early and mid 1900s demonstrated the use of the Santa Paula Creek as a southern steelhead (*Onocorhynchus mykiss trideus*) spawning area. The CDFG now stocks rainbow trout at Steckel Park (Carpanzano 1996).

Least Bell's vireo and the southwestern willow flycatcher are also native to the watershed, although the lower portion of the watershed does not support either species due to a lack of suitable habitat.

Additional wildlife species which occur in the Santa Paula Creek Watershed, and particularly in the Santa Paula and Mud Creeks, include:

- Santa Ana Sucker (*Catostomus santaanae*)
- Arroyo toad (*Bufo californicus*)
- California red-legged frog (*Rana aurora draytonii*)
- Southwestern pond turtle (*Clemmys marmorata pallida*)
- San Diego horned lizard (*Phyrnosoma coronatum blainvillei*)
- Two-striped garter snake (*Thanmophis hammondii*)
- Southwestern willow flycatcher (*Empidonax traillii extimus*)
- Peregine Falcon (*Falco peregrinus*)
- California condor (*Gymnogyps californianus*)

4.2.3 Steelhead

Steelhead are anadromous salmonids that are born and rear in freshwater, then migrate to the ocean as sub-adults (smolts) before returning to spawn in freshwater as adults. They may repeat this cycle several times over their life span, unlike salmon, which die after spawning. Rainbow trout are the same genetically as steelhead but follow a non-anadromous life history trajectory. Steelhead have unique resource requirements through their life history. Female steelhead construct redds in suitable gravels, often in pool tailouts and heads of riffles, or in isolated patches in cobble-bedded streams. Steelhead eggs incubate in the redds for 3–14 weeks, depending on water temperatures (Shapovalov and Taft 1954, Barnhart 1991). After hatching, alevins remain in the gravel for an additional 2–5 weeks while absorbing their yolk sacs, and then emerge in spring or early summer (Barnhart 1991). After emergence, steelhead fry move to shallow-water, low-velocity habitats, such as stream margins and low-gradient riffles, and forage in open areas lacking instream cover (Hartman 1965, Fontaine 1988). Juvenile steelhead (parr) rear in fresh water before outmigrating to the ocean as smolts when favorable conditions exist, likely spending time in the estuary or freshwater lagoon before entering the ocean (Shapovalov and Taft 1954, Barnhart 1991). Outmigration of smolts on the Santa Ynez River typically occurs between mid-March and early May (Stoeker and Kelly 2005).

Historically, steelhead were abundant in Southern California. The Santa Clara River once supported a run of 9,000, while the Santa Ynez River (Santa Barbara County) had the largest in southern California, an estimated 13,000-25,000 adults in 1943-1944 (Stoeker and Kelly 2005). Steelhead were once found in every major watershed along the southern California coast, but have since declined to less than one percent of their historical populations. As such, the Southern

California steelhead (Oncorhynchus mykiss) Distinct Population Segment (DPS) is listed as endangered under the federal Endangered Species Act.

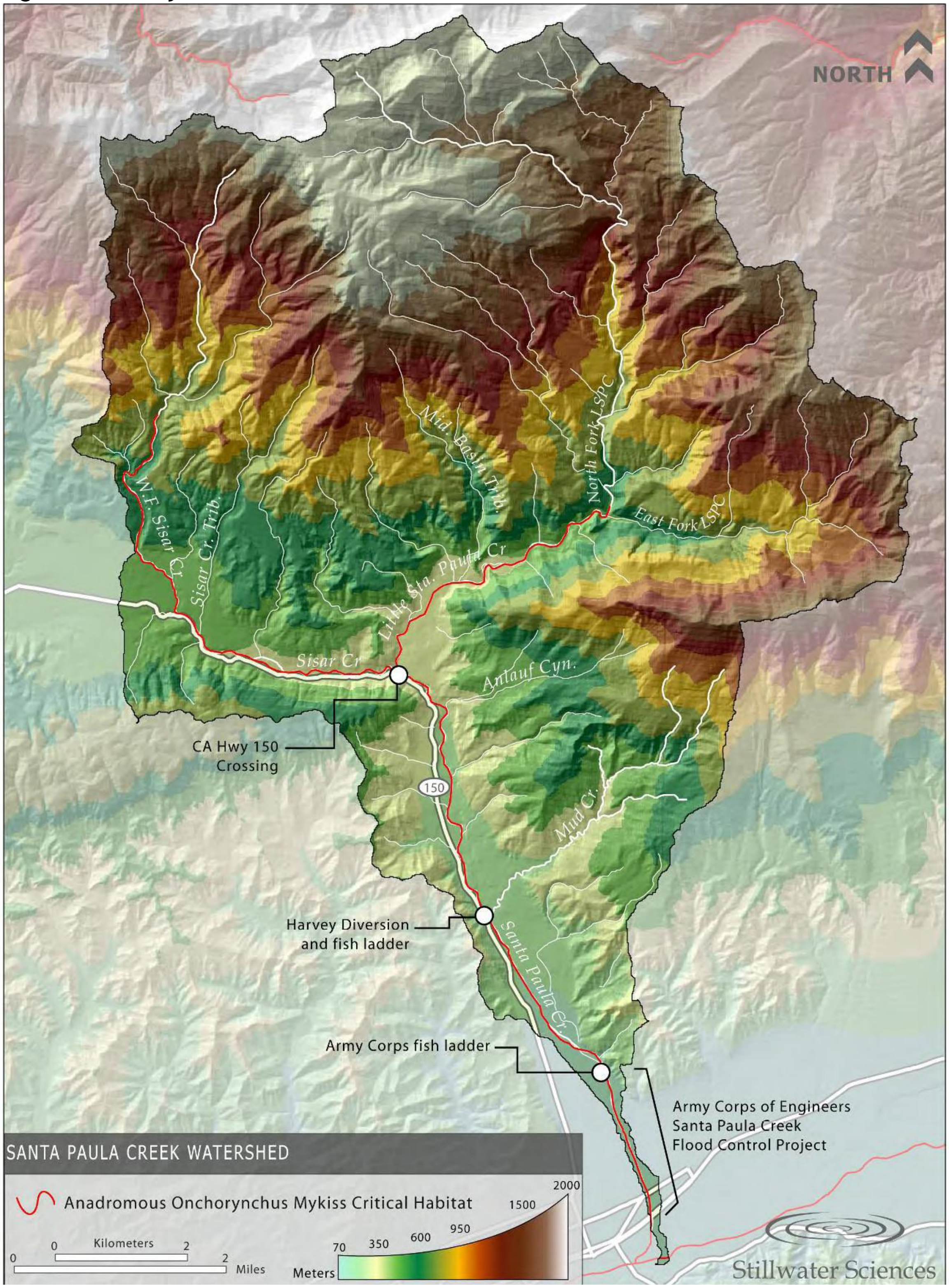
Stoecker and Kelley (2005) suggest that engineering projects (such as dams) along the Santa Clara River and its tributaries have contributed to depressed populations by creating migration barriers. Still, steelhead and rainbow trout, continue to be present, albeit in small numbers compared to historical levels, in many parts of the Santa Clara River Watershed, and particularly in the Santa Paula Creek watershed, lending support to the hypothesis that improving fish habitat in these areas is a worthwhile investment.

Existing impacts to Steelhead may include:

- Barriers to upstream passage
- Loss of native vegetation
- Influx of non-native, invasive plant species
- Increased scouring of creek beds and stream banks
- Diversions of stream flow and groundwater
- Modifications to the creek channel and stream banks
- Degraded water quality because of nutrient, sediment and other polluted runoff from agricultural and urban development

Stoecker and Kelley (2005) indicate that the Santa Paula Creek watershed contains the most productive habitat within the Santa Clara River watershed for salmonids. Critical habitat areas within the Santa Paula Creek watershed are illustrated on Figure 4-4.

Figure 4-4: *O. Mykiss* Critical Habitat in the Santa Paula Creek watershed.



4.2.3.1 Steelhead Migration Capabilities and Limitations

A detailed summary of the migration capabilities and limitations of the Steelhead is included the Stoecker and Kelley (2005) report. The following two paragraphs are excerpt from that report.

> Steelhead have physiological limitations that impede or prevent them from being able to migrate past certain natural and anthropogenic features and hydraulic conditions. It has been reported that 7 inches is the minimum water depth required for successful migration of adult steelhead (Thompson 1972, as cited in McEwan 2001). The distance fish must travel through shallow water areas is also critical. Water depth can be a significant barrier in streams that have been altered for flood control purposes (McEwan 2001). Inadequate downstream water releases from diversion dams can also present a severe migration barrier to steelhead. The California Department of Fish and Game (CDFG) Habitat Restoration Manual reports that an adult steelhead can maintain a maximum swim speed of 6.0 ft/sec. for 30 minutes until exhaustion and a maximum burst speed of 10.0 ft/sec. for 5 seconds until exhaustion. The maximum leap, or jump, speed is listed as 12 ft/sec. Jumping upstream of a structure becomes difficult or impossible when the jump pool depth becomes less than 1.25 times the jump height of the structure (measured from the pool surface to the top of the feature). For example, a barrier that has a vertical jump height of 4 feet above the surface of the downstream pool and has a jump pool depth of 5 feet, will be near the maximum jumping capability of an adult steelhead. Should the pool become shallower, the jump pool depth would decrease and the jump height would increase, likely resulting in an impassable structure.
>
> Natural channels often exhibit a high degree of physical channel complexity, which can present natural impediments to fish movement, particularly upstream migration. These physical impediments can be temporarily reduced as a result of the rise from natural rainfall and run-off, which generally coincides with the timing of upstream migration of adadromous salmonids. Similarly some artificial barriers such as low-head weirs or near at-grade crossings, which present a partial complete impairment of instream fish movement under base flow conditions, can be temporarily rendered passable, under high flow conditions. However, such impediments complicate the movement of fish through a watercourse, and collectively have the effect of narrowing the window of opportunity for successful migration.

4.2.3.2 Steelhead Migration Barriers

One of the primary objectives of the Stoecker and Kelley (2005) report was the identification and ranking of existing barriers along the Santa Clara River and its tributaries, including Santa Paula Creek. The purpose of the rankings was to prioritize fish passage improvement projects. The assessment included anthropogenic barriers, natural barriers, and limits to migration were identified to determine the amount of habitat available to steelhead. The term "barrier" in the report was used to refer to any structure in the stream that impedes, with varying degrees of difficulty, or completely blocks upstream adult steelhead migration.

The report used the California Department of Fish and Game's "Green-Gray-Red Passage Evaluation Filter" to identify the barrier severity where:

> Green: Conditions assumed adequate for passage of all salmonid life stages during low flow conditions.
>
> Gray: Conditions may not be adequate for all salmonid specifies at all their life stages.

Red: Conditions fail to meet DFG and NOAA passage criteria at all flows for strongest swimming species presumed present.

The identified barriers and their severity from the Stoecker and Kelley (2005) report are listed in table 4-1.

Table 4-1: Santa Paula and Sisar Creek Barriers.

Barrier Identifier	Stream Name	Barrier Type	Barrier Severity	Location[a]
BR-SC-SP-1	Santa Paula Creek	Channelization	Green	ACOE Channel
BR-SC-SP-2	Santa Paula Creek	Grade Control Structure	Red	ACOE Channel
BR-SC-SP-3	Santa Paula Creek	Grade Control Structure	Red	ACOE Fish Ladder
BR-SC-SP-4	Santa Paula Creek	Dam	Red	Harvey Diversion
BR-SC-SP-5	Santa Paula Creek	Grade Control Structure	Red	Hwy 150 Crossing
BR-SC-SP-SR-1	Sisar Creek	Grade Control Structure	Gray	Hwy 150 Crossing
BR-SC-SP-SR-2	Sisar Creek	Road Crossing	Gray	Road crossing
BR-SC-SP-SR-3	Sisar Creek	Culvert	Gray	Road crossing
BR-SC-SP-6	Santa Paula Creek	Bedrock Chute	Red	Upstream Limit
BR-SC-SP-SR-4	Sisar Creek	Cascade	Red	Upstream Limit

[a] Approximate location added to table for clarification.

The ranking method was originally developed as a guide for restoring fish passage within the Santa Clara River basin. The report subsequently noted that the winter storms of 2005 had severe impacts on several fish passage facilities. The following facilities were identified in the report as needing immediate attention if migration into important spawning and rearing tributaries is to be provided:

- The Vern Freeman Diversion Dam (SC-1)
- The ACOE Channel/Fishway (SC_SP_1, 2, 3) on Santa Paula Creek
- Harvey Diversion (SC_SP_4) on Santa Paula Creek
- Caltrans Highway 150 Bridge (SC_SP_5) on Santa Paula Creek

The ACOE Channel/Fishway, Harvey Diversion, and Caltrans Highway 150 barriers are located along the Santa Paula Creek within the study reaches.

4.3 Cultural Resources

Consistent with the history of the region, the Santa Paula Creek watershed is an area of high archaeological sensitivity with respect to prehistoric (Native American) sites. Four previous archaeological studies have been conducted within the Santa Paula Creek restoration area. These studies were completed between 1972 and 1993. The studies document the presence of a number of sites in and adjacent to the Santa Paula Creek. All or portions of three prehistoric sites are within the general vicinity of the study area. These sites include:

<u>CA-VEN-273</u> was recorded in 1972 as a sandstone boulder with a mortar and grinding stick. At the time of the discovery the boulder appeared to have been displaced by road grading. No additional artifacts were observed at this site.

CA-VEN-500 was recorded in 1977. The site was noted as consisting of a low density scatter of shell (Mytilus and Protothaca), covering an area approximately 50 by 30 m in size.

CA-VEN-501 was also recorded in 1977, with site information updated in 1992. The site consists of a habitation deposit estimated to cover an area about 180 by 100 m in size. Some of the artifacts present appear to date to the Middle Period (3800-800 YBP) although the site may also include later materials.

A review of historical maps (USGS 1903 and 1947 Quadrangles) shows that the study area had not been significantly developed by 1903. Roads and at least two structures were present near the Mud Creek confluence by 1947, suggesting that historical (Euro-American) sites may occur in the area. The locations of the archaeological sites are illustrated on Figure 4-5.

The archaeological records search indicates that the study area has a high archaeological sensitivity. Give the presence of three recorded historical sites; restoration work in the study area has the potential to impact significant/unique cultural resources.

4.4 Land Use

Land use within the watershed remains largely undeveloped compared to other Southern California coastal watersheds. Land use/vegetation cover within the watershed includes scrub/chaparral (52.2% of total area), mixed evergreen/deciduous forest (35.5% of total area), agriculture/herbaceous grasslands (10.5% of total area), and developed/residential (0.8% of total area) (NOAA, 2002). The northern portion of the watershed is located within the Los Padres National Forest (approximately 65% of total area) and the vegetation cover is entirely chaparral/scrub and mixed forest. The agricultural/developed areas within the watershed are primarily along the lower Santa Paula Creek downstream of the Sisar Creek confluence, and within Anlauf Canyon and Mud Creek. Citrus and avocado orchards dominate the agricultural industry in the watershed (USACE, 1995).

Santa Paula Creek Watershed's boundaries fall entirely within the jurisdiction of the County of Ventura. As such, the watershed's development activities are subject to the land use requirements of the County's General Plan (2005) and zoning regulations for the foreseeable future. The watershed's land use designations can be seen in Figure 4-6.

4.4.1 Open Space

The vast majority of the watershed is designated as open space. Under the guidance of Ventura County's General Plan, this means that the goals of the watershed in these zones are as follows:

1. Preserve for the benefit of all the County's residents the continued wise use of the County's renewable and nonrenewable resources by limiting the encroachment into such areas of uses, which would unduly and prematurely hamper or preclude the use or appreciation of such resources.
2. Acknowledge the presence of certain hazardous features which urban *development* should avoid for public health and safety reasons, as well as for the possible loss of public improvements in these areas and the attendant financial costs to the public.
3. Retain open space lands in a relatively undeveloped state so as to preserve the maximum number of future land use options.

4. Retain open space lands for outdoor recreational activities, parks, trails and for scenic lands.
5. Define urban areas by providing contrasting but complementary areas, which should be left generally undeveloped.
6. Recognize the intrinsic value of open space lands and not regard such lands as "areas waiting for urbanization.

The policy implications of these goals, as outlined by Ventura County's General Plan, are as follows:

1. Open Space should include areas of land or water which are set aside for the preservation of natural resources, including, but not limited to, areas required for the preservation of plant and animal life, including habitat for fish and wildlife species; areas required for ecologic and other scientific study purposes; rivers, streams, bays, and estuaries; and coastal beaches, lakeshores, banks of rivers and streams, and important watershed lands.
2. Open Space should also include areas set aside for managed production of resources, including, but not limited to, forest lands, rangeland, agricultural lands not otherwise designated Agricultural; areas required for the recharge of groundwater basins; bays, estuaries, marshes, rivers, and streams which are important for the management of commercial fisheries; and areas containing major mineral deposits, including those in short supply.
3. Open Space should also include areas within which recreational activities can be pursued, including, but not limited to, areas of outstanding scenic, historic, and cultural value; areas particularly suited for park and recreation purposes, including access to lakeshores, beaches, and rivers and streams; and areas which serve as links between major recreation and open space reservations, including utility easements, banks of rivers and streams, trails, and scenic highway corridors.
4. Open Space should also include areas of land or water which are set aside for public health and safety, thereby safeguarding humans and property from certain natural hazards, including, but not limited to, areas which require special management or regulation because of hazardous or special conditions such as earthquake fault zones, unstable soil areas, flood plains, watersheds, areas presenting high fire risks, areas required for the protection of water quality and water reservoirs, and areas required for the protection and enhancement of air quality.
5. Open Space should also include undeveloped natural areas surrounding urban designated areas, which have been set aside to define the boundaries of the urban designated areas, to prevent urban sprawl, and to promote efficient municipal services and facilities by confining the areas of urban development.
6. The smallest minimum parcel size consistent with the Open Space land use category is 80 acres. Sub-zones may require larger minimum parcel sizes.
7. The minimum parcel size for Open Space properties contiguous with the Agricultural land use designation shall be 20 acres.

Figure 4-5: Archaeological Site locations (Santa Paula Peak-USGS Quadrangle).

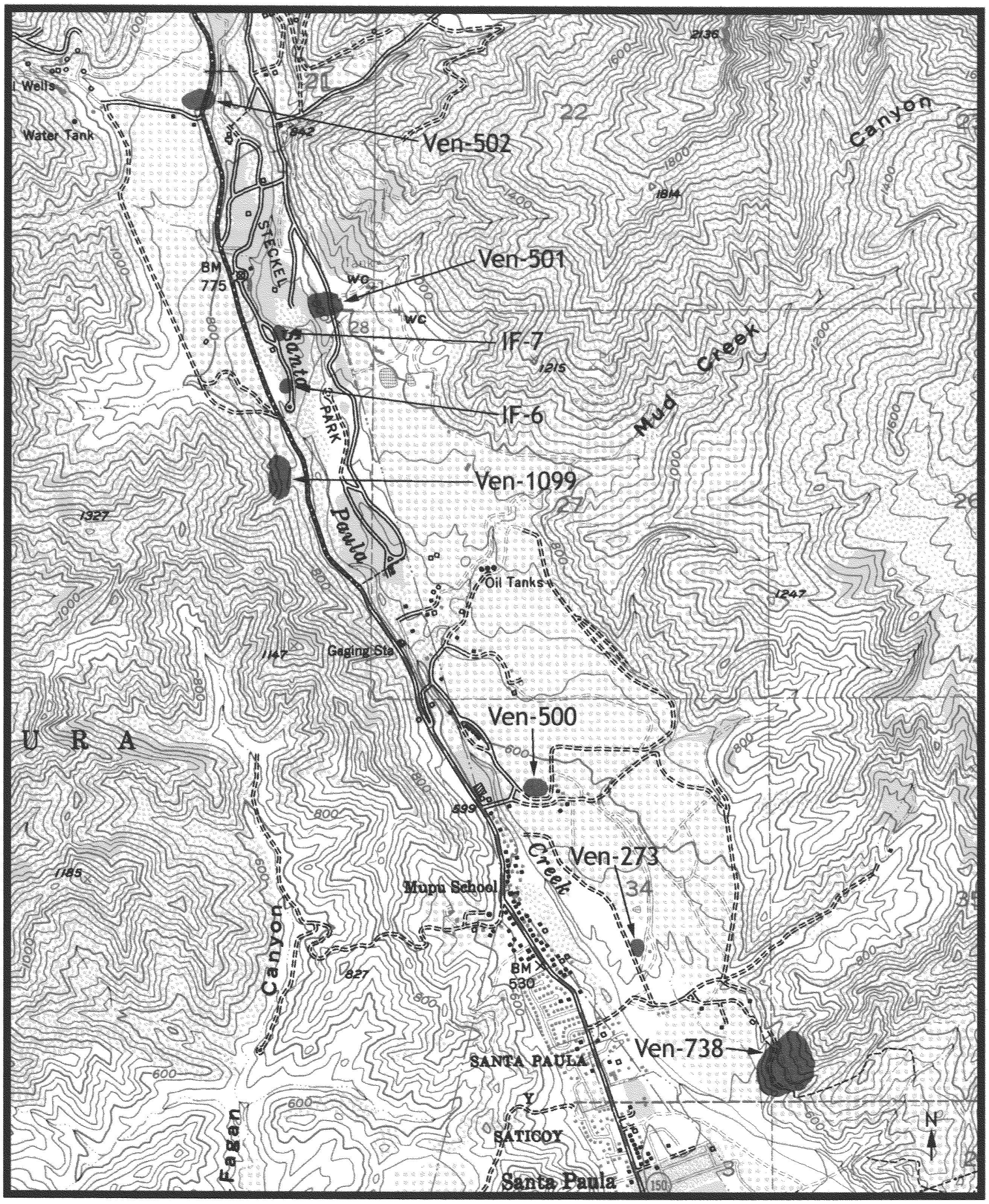
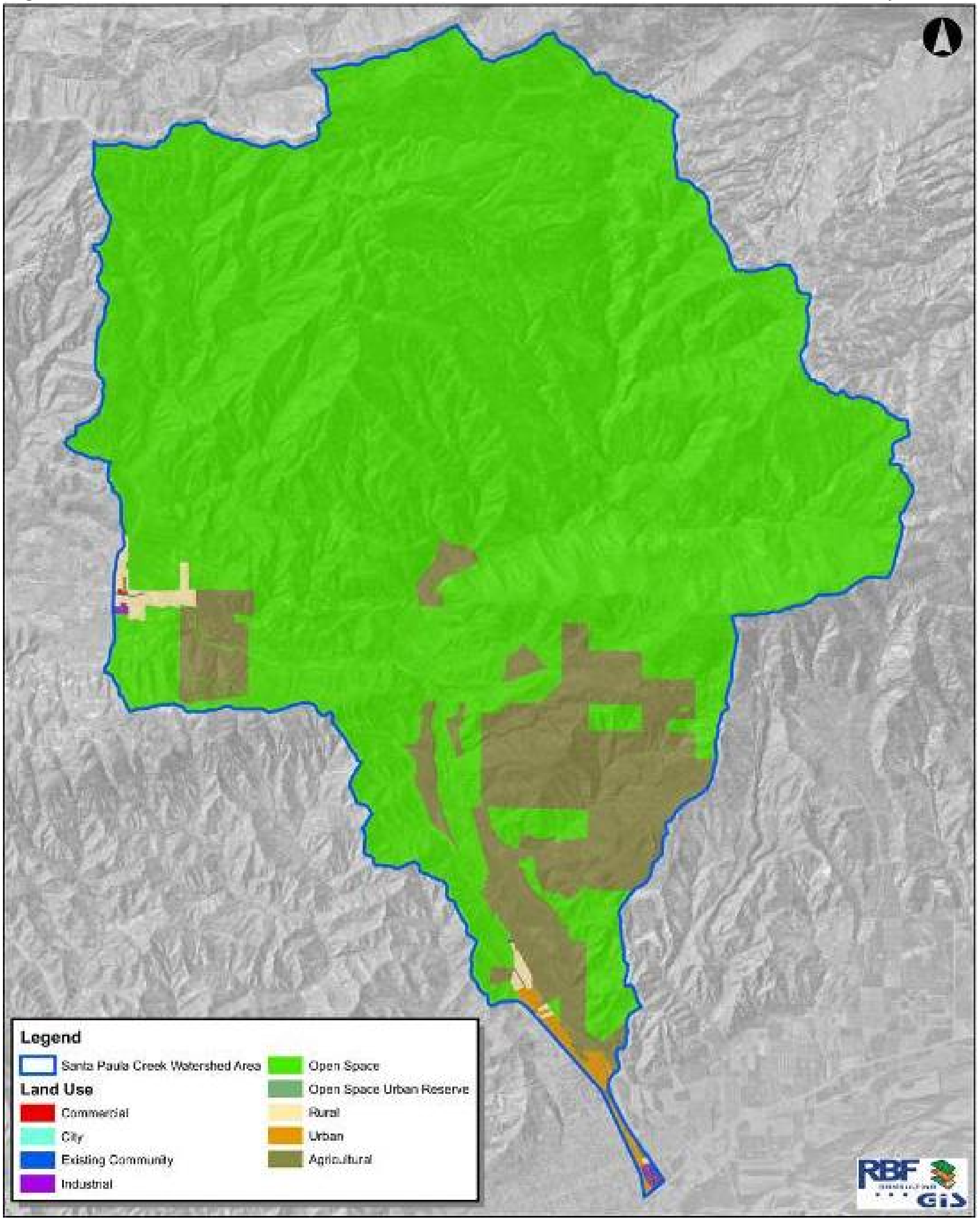


Figure 4-6: Land use delineation based on the 2001 General Plan for Ventura County



4.4.2 Agricultural Uses

After Open Space, agriculture is the use with the most area within the watershed. Under the guidance of Ventura County's General Plan, this means that the goals of the watershed in these zones are as follows:

1. Identify the *farmlands* within the County that are critical to the maintenance of the local agricultural economy and which are important to the State and Nation for the production of food, fiber and ornamentals.
2. Preserve and protect agricultural lands as a nonrenewable resource to assure their continued availability for the production of food, fiber and ornamentals.
3. Maintain agricultural lands in parcel sizes, which will assure that viable farming units are retained.
4. Establish *policies* and regulations, which restrict agricultural land to farming and related uses rather than other *development* purposes.
5. Restrict the introduction of conflicting uses into farming areas.

The General Plan's policy implications related to the Agricultural uses are:

1. The Agricultural land use designation shall primarily include lands which are designated as *Prime Farmlands, Farmlands of Statewide Importance* or *Unique Farmlands* in the State's Important Farmland Inventory (IFI), although land may not be designated Agricultural if small areas of agricultural land are isolated from larger blocks of farming land (in such cases, the agricultural land is assigned to the Open Space or Rural designation of the surrounding properties).
2. The smallest minimum parcel size consistent with the Agricultural land use designation is 40 acres. Subzones may require larger minimum parcel sizes.
3. Agricultural land shall be utilized for the production of food, fiber and ornamentals; animal husbandry and care; uses accessory to agriculture and limited temporary or public uses, which are consistent with agricultural or agriculturally related uses.

4.4.3 City of Santa Paula Land Use Plans

Santa Paula Creek sits directly east of the northern portion of the City of Santa Paula, and runs through the City along the southern portion of the City limits (at the confluence of the Santa Paula Creek and Santa Clara River). Since the creek is directly adjacent to the Santa Paula city limits, and is directly affected by land use choices in that area. Figures 4-7 and 4-8 show the current and projected land use map for the city of Santa Paula, respectively, and demonstrate the intention of the expansion of urban development along the southern border of the Santa Paula Creek, as allowed by specific plans that will address land use patterns within these areas of the city.

These future plans may add additional stress to the creek's ability to sustain native fish populations, due to potential water quality problems and changes to the creek's physical character, among other concerns. Furthermore, currently existing engineering projects, which to date seem to have impacted steelhead trout populations in the creek, fall within the zone of current and projected urban development. In combination, these factors have important implications for native fish and wildlife populations as well as other aspects of environmental quality.

Figure 4-7: City of Santa Paula Existing Land Use Patterns (1997)

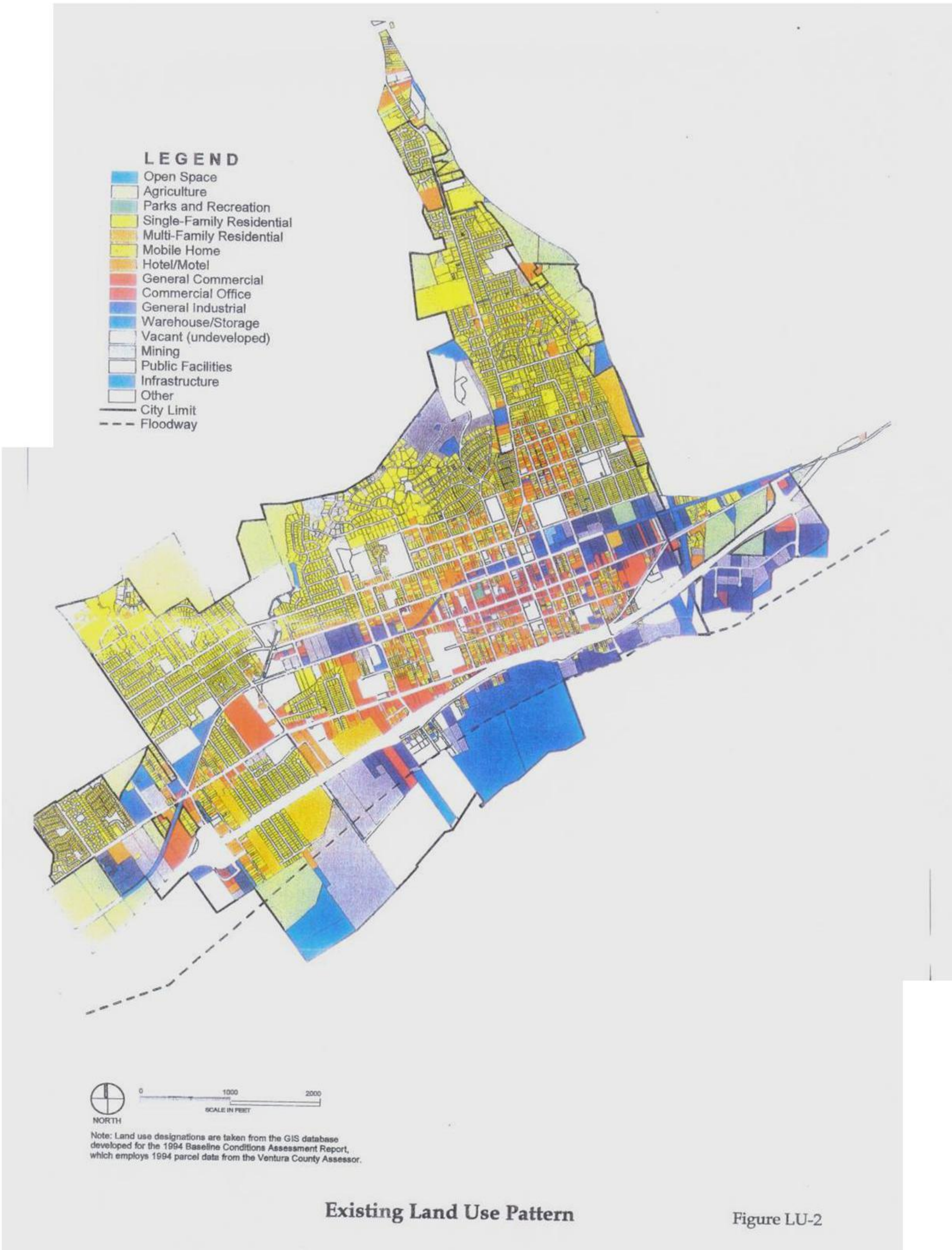
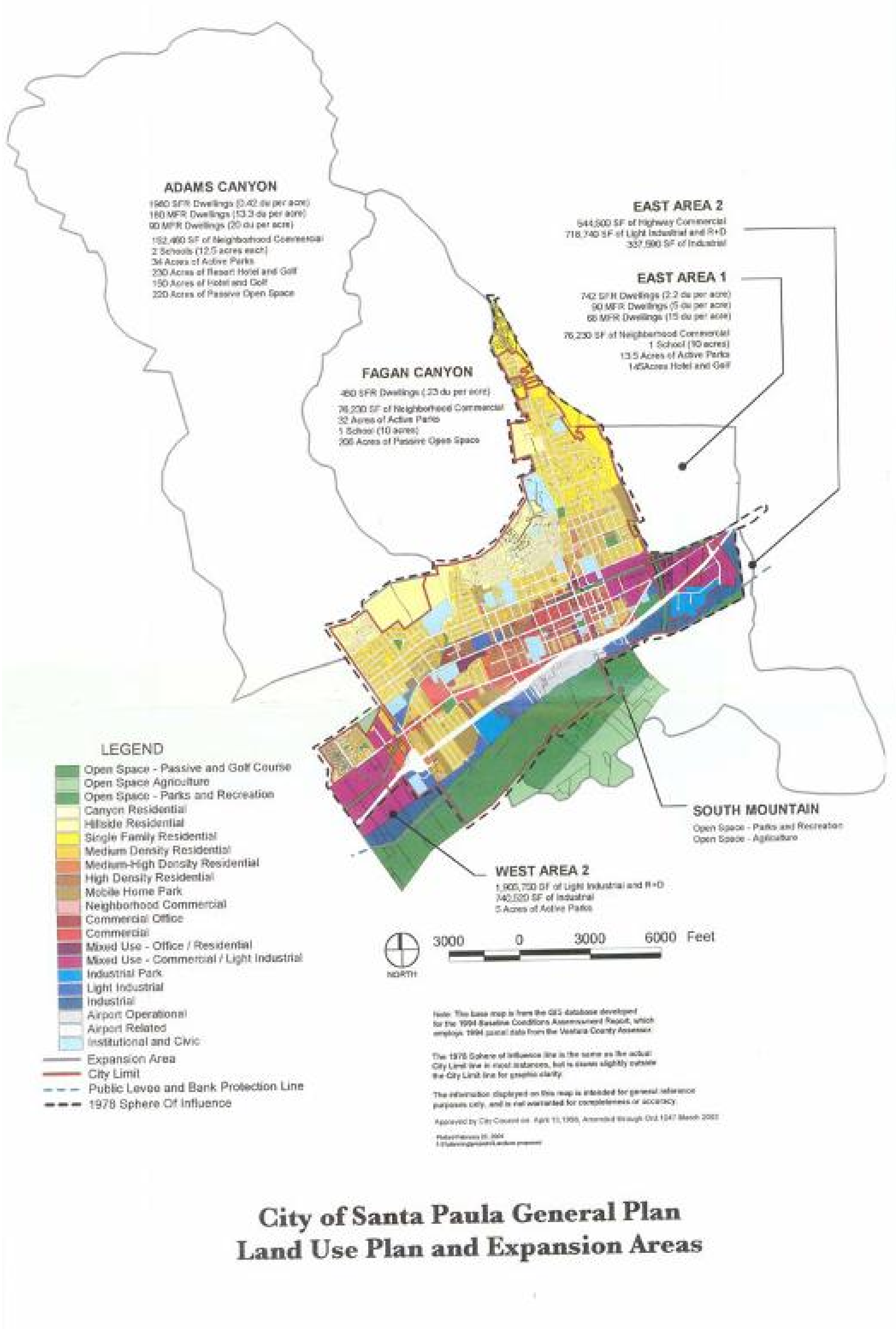


Figure 4-8: City of Santa Paula General Plan Land Use Plan and Expansion Areas



4.5 Infrastructure and channel modification

One of the most complex issues to address in the watershed is the impact of the infrastructure that has been installed within the Santa Paula Creek. In-channel structures and artificial modifications to the channel (*e.g.*, channelization, sediment removal, and bank alteration) can have significant and long-term effects on channel geomorphic conditions. Permanent structures within the channel affect local and reach-scale flood hydraulics, thereby impacting zones of in-channel and floodplain sediment deposition as well as areas of bed and bank erosion. Removal of in-channel sediment and/or the straightening and armoring of channel banks can destabilize channel gradients, causing channels to incise and local knickpoints to migrate upstream. This section describes the current channel infrastructure through the study reach that have the potential to affect long-term local and reach-scale geomorphic conditions within Santa Paula Creek.

4.5.1 Highway 150 bridges/grade control

Highway 150 crosses the Santa Paula and Sisar Creeks at three (3) locations near the confluence of the two creeks. Bridge Nos. 52-104 and 52-105 cross the Santa Paula Creek both upstream and downstream of the confluence with Sisar Creek, and Bridge No. 52-103 crosses Sisar Creek upstream of its confluence with Santa Paula Creek. These bridge facilities have been reconstructed over the years, with the current configuration of the bridges completed in the early 1970s. The 1947 USGS topographic map shows smaller bridge sections than the current configurations. The latest plans also show a straightening and realignment of the creek at the most downstream bridge section (52-105). Concrete in-channel bank protection and structures upstream and directly downstream of the bridge were installed as grade control; however, it is not known the date of installation of these structures as it was not possible to obtain detailed bridge information from the California Department of Transportation (Caltrans). The January 2005 storm event completely destroyed and washed downstream most of the grade control structures resulting in a critical barrier to upstream migrating steelhead. Upstream of the bridge, the channel appears to be actively aggrading; downstream, the channel has incised over 6 feet below the concrete in-channel structure (aerial photographs suggest that the channel was not incised at this location in 1978) causing a significant fish passage barrier. This bridge appears to be restricting flow during storm events, causing coarse sediment deposition upstream of the bridge and associated coarse sediment depletion and localized scour downstream of the bridge.

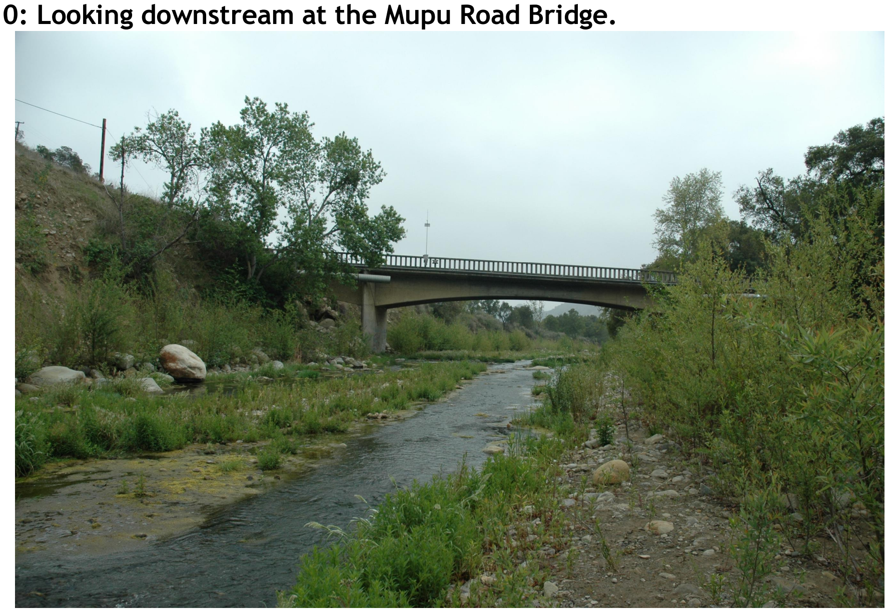
Caltrans is currently working on a project to restore fish passage through the bridge structures. The current concept for the improvements includes a series of 14 rock weir grade control structures on the downstream side of the bridge.

4.5.2 Mupu Road Bridge

The Mupu Road Bridge crosses Santa Paula Creek within Steckel Park (reach 3). The bridge was constructed in 1946 over a confined channel reach and includes a 3-span reinforced concrete section. Only minor riprap bank protection is included at the bridge to provide local scour protection for the bridge abutments.

Figure 4-9: Below the lower Highway 150 crossing (picture looking upstream).

Figure 4-10: Looking downstream at the Mupu Road Bridge.



4.5.3 Harvey Diversion

The Harvey Diversion is an agricultural diversion originally operated by Santa Paula Water Works for domestic as well as agricultural purposes. The Diversion currently diverts between 500 to 1,800 acre-feet of water per year for use by Canyon Irrigation Company (formerly Santa Paula Water Works) (USACE 1995). Santa Paula Water Works has diverted water from Santa Paula Creek since the 1860's and its water right was confirmed by the California Supreme Court in Santa Paula Water Works, v. Peralta (1896) 113 cal. 38 45 P. 168, as the first 600 miner's inches of flow in Santa Paula Creek. Prior to 1971, Santa Paula Water Works diverted much larger volumes of Santa Paula Creek water for domestic and agricultural uses. A December 23, 1907 agreement between Santa Paula Water Works and J. M. & Emily A. Carpenter (the property owner of the land where the diversion is located) page 6, the successors and assigns shall limit the height of the diversion to the highest portion of the head of the conduit as then constructed. The conduit taking water from the Diversion has been in continuous use since it was originally installed, taking diverted water to the reservoir at Bridge Road and then by gravity to the Santa Paula main domestic reservoir just below the hospital in Santa Paula, until 1971 when domestic use was discontinued for bacteriological reasons. It should be noted that neither this agreement nor the following reference speaks to an elevation, making it confusing as to the potential of the height of the Diversion being raised over the years. The following NMFS height reference probably is the height or depth of the concrete Diversion installed, both in reality being the same top elevation, as the piping taking the water away has remained the same over the years.

The original structure was built 6 ft high in 1910 and increased to 23 ft by 1923 (NMFS Southwest Regional Office website [http://swr.nmfs.noaa.gov/hcd/soCalDistrib.htm]). Repairs were made to the diversion in 1928, the facility was rebuilt in 1941, and additional cap repairs were made after major storm events in 1966, 1969, and 1987 (USACE 1995). Recently, sediment transported over the diversion during the 2005 storm event scoured a notch at the top of the diversion, prompting repairs. The fish ladder on the right-bank side of the diversion was initially constructed in 1939, rebuilt in 1950, and rebuilt again in 2000 to increase fish passage (USACE 1995, NMFS Southwest Regional Office website [http://swr.nmfs.noaa.gov/hcd/soCalHistoric.htm]). Subsequent storm events following construction of the new fish ladder in-filled the lower portion of the ladder with sediment and caused associated structural damage. Until recently, the fish ladder was disconnected from the Creek during all but moderate to high storm flows as a consequence of the 2005 storm. The 2007 diversion repair work included the installation of 4 rock weirs downstream of the existing ladder to re-establish the channel invert. However, based on a field review of the improvements, the rock weirs do not appear to provide fish passage in accordance with California Department of Fish and Game criteria, nor do they appear to be designed to withstand the impacts of a large storm event.

Figure 4-11: Below the Harvey Diversion (looking upstream).

4.5.4 Bridge Road Bridge

The Bridge Road Bridge is a historic structure that crosses the creek over the confined limits of the canyon reach downstream of the Harvey Diversion (reach 6). The bridge was originally constructed as a single-span truss bridge at the turn of the century. The bridge was rehabilitated in 1999 to stabilize the bridge abutments as a result of significant erosion and downcutting of the creek. The work included soil nails to stabilize the west abutment and shotcrete bank protection to prevent additional scour at the bridge abutments. In the current creek configuration, the bridge completely spans the channel section and provides no restriction to channel flow or sediment transport. However, the bridge does limit the potential for channel widening in this location.

Figure 4-12: Bridge Road Bridge crossing of the confined stream reach.

4.5.5 Channelization/sediment excavation projects

Due to concerns about damage to property and infrastructure during flood events, major channel modifications have occurred between Bridge Road and the Santa Clara River confluence over the last 35 years. Flooding as a result of the January and February 1969 storm events motivated regular sediment removal and/or redistribution within this lower portion of Santa Paula Creek. Between Bridge Road and the USACE fish ladder, the channel thalweg was until recently maintained at a 1977 channel thalweg elevation, which resulted in approximately 6,500 t a^{-1} of sediment that was excavated and placed at the channel margins to provide some protection to the eroding banks. In the past, channel excavation has been required only after flows exceeding 9,000 cfs and/or when the channel thalweg elevation is on average higher than the 1977 channel thalweg elevation (USACE, 1995). Under these conditions, the pilot channel can convey the 5-year flood event (HDR 2006).

Between the USACE fish ladder and the Telegraph Road Bridge, Ventura County has awarded gravel mining contracts to remove sediment deposited during flood events (USACE 1995). As in the upstream reach, sediment is removed to maintain the1977 thalweg elevation. Assuming a sediment bulk density of 1,900 kg m^{-3}, the average annual sediment removal rate between WY 1969 and 1992 was approximately 115,000 t a^{-1} and the long-term average annual sediment deposition within this reach is estimated to be approximately 65,000 t a^{-1} (USACE 1995). This long-term deposition rate represents approximately 25% of the total sediment load predicted by the analysis of hillslope sediment production; the remaining 75% of the predicted total sediment load is presumably transported downstream to the Santa Clara River. The channel within this reach was redesigned in 2000 as part of the USACE flood control project (USACE 1995).

4.5.5.1 Emergency Streambank Protection

The 2005 storm event caused severe erosion of stream banks along the Santa Paula Creek resulting in loss of property and threatened numerous residential homes, and public and private property (HDR 2006). As a result of this event, the Ventura County Watershed Protection District developed and installed an emergency streambank protection project that extends from the Bridge Road Bridge to approximately 4,600 feet downstream (reach 7). The improvements consisted of the construction of 24 (12 west bank and 12 east bank) rock spur dikes on the stream bed, and 730 feet of longitudinal bank protection. The design report (HDR 2006) indicates that the structures are oriented at a slight angle upstream near the banks to realign the channel flow to a path away from the banks, but change to an angle perpendicular to the flow closer to the banks of the low-flow channel, to ensure that the flow is oriented along the low-flow path. The report states that "Use of spur dikes in this configuration will promote stream flow to remain within the low-flow channel. This will lessen the potential for the flow to migrate to channel banks, further reducing erosion potential, but will also promote a cooler and more sustained flow for use by fish in passage upstream or downstream."

Figure 4-13: Emergency bank protection spur dikes.

4.5.5.2 USACE fish ladder/channel improvements

The USACE channel improvements include the construction of the Santa Paula Creek Channel Improvements Reaches 1, 2 and 3. These improvements were completed in 2002. The reach 1 improvements generally extend from the Santa Clara River confluence to downstream of Telegraph Road, and consist of a trapezoidal channel section with and without grouted riprap slope lining. A grouted riprap grade control structure was constructed at the lower end of the grouted riprap slope protection improvements, approximately 1,000 feet downstream of the Highway 126 crossing. Below this location, an earthen trapezoidal channel extends to the Santa Clara River confluence.

The reach 2 and 3 improvements extend from downstream of Telegraph Road approximately 7,000 feet upstream to the USACE fish ladder at the upstream terminus of the improvements. The channel along this reach has 2:1 side slopes, a maintained channel invert slope of 0.01193 to

0.03049 feet per foot, and a depth ranging from 23 ft (at the downstream end) to 36 ft (at the upstream end). The soft-bottom channel base width varies from 72 to 130 feet. The USACE fish ladder was constructed as part of the inlet stabilization (*i.e.*, grade control to prevent head cutting and incision) at the upstream end of the improvements. The fish ladder is built on bedrock, and is approximately 650 ft long, has a 2:1 side slope (top width = 25.5 ft, bottom width = 13.5 ft), and has a invert slope of 0.074. The fish ladder suffered structural damage during the 2003 and 2005 storm events. A grouted riprap grade control structure was also constructed across the channel bottom downstream of the fish ladder to stabilize the channel invert.

Figure 4-14: View of the existing USACE channelization (looking downstream at Hwy 126 crossing).

Subsequent to the construction of the channel improvements, significant erosion was identified along the channel improvements resulting from the 2002-2003 and 2003-2004 WY storm events. The peak flow rate associated with these events was estimated to be approximately 2,000 cfs, which was estimated to have a 3-year reoccurrence interval. These storm events resulted in degradation of up to 5 feet along reaches of the channel. This erosion had threatened to undermine the grouted riprap bank protection, and resulted to barriers to fish passage. The grade control structures and fish ladder improvements constructed as part of this project have been previously identified by Stoecker and Kelley (2005) as barriers to fish passage. As a result of the identified channel degradation problem, the Corps developed alternatives to modify the existing channel improvements. Up to 20 alternatives were developed for temporary or permanent modifications to the channel to limit the potential for scour. Memorandums from the USACE indicate that the severity of the degradation was unexpected as historically this reach of the creek has been subject to severe deposition of sediment. No modifications to the channel have been completed by the time of this study.

Observations of the channel completed in 2007 and 2008 as part of this study indicate that much of the channel appears to be restored back to the original grade. This appears to be a result of the larger storm events that have occurred after 2004. While this may validate the USACE assumption about sediment deposition during large events, it does not mitigate the fact that the channel may be subject to erosion during smaller, more frequent storm events. And that a continued period of smaller events could result in potential bank failure and fish passage barriers.

4.5.6 SPTC Railroad truss bridge & Telegraph Road Bridge

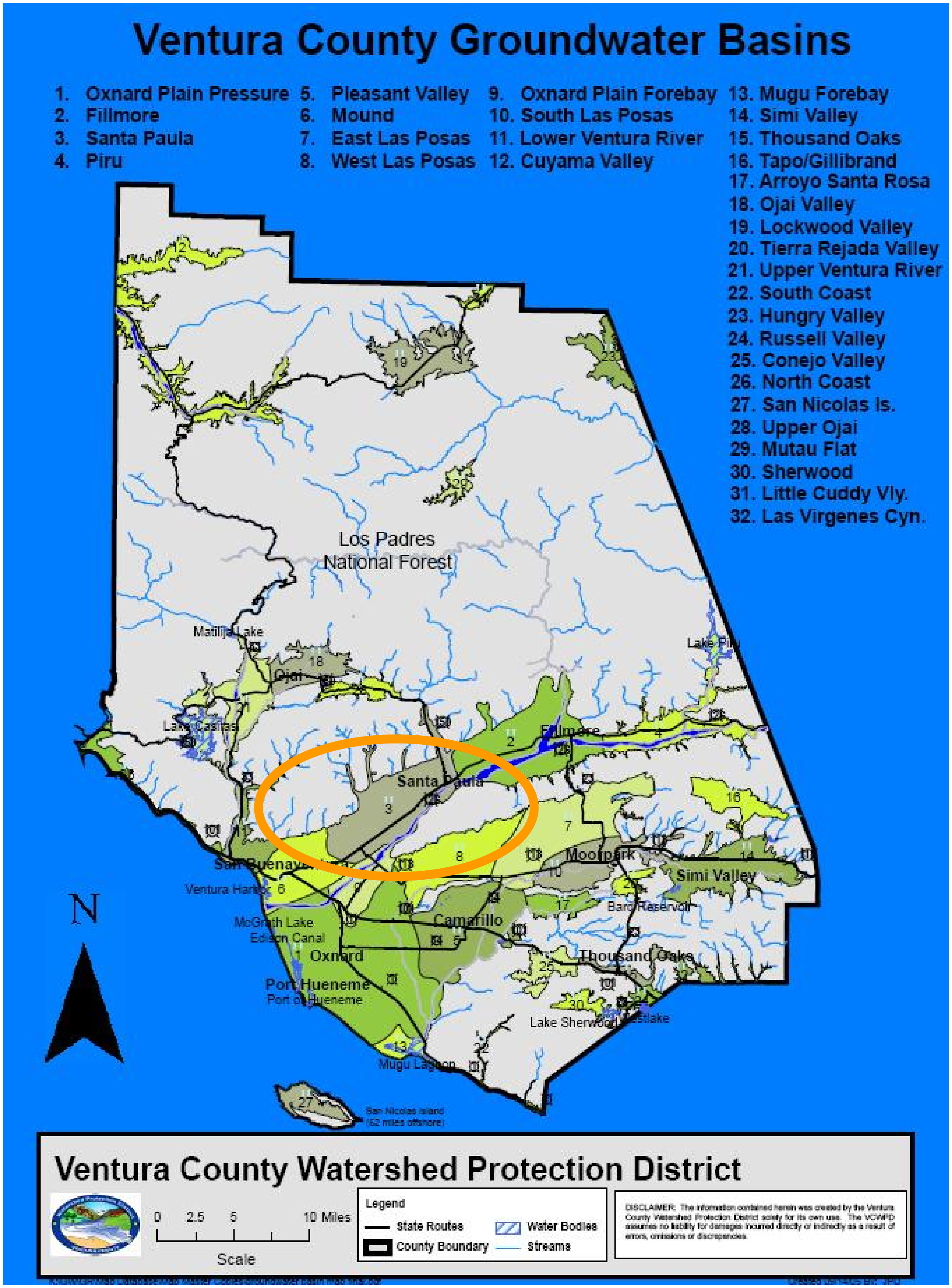
Within the lower portion of Santa Paula Creek (adjacent to the town of Santa Paula), the Southern Pacific Transportation Company (SPTC) truss Bridge and Telegraph Rd Bridge have been previously shown to impact flow hydraulics and sediment transport dynamics during high flow events. The SPTC truss bridge was constructed in 1912 as a 100-ft span with a channel capacity of approximately 10,000 cfs (i.e., the peak discharge for an 18-year flow event). This bridge span has been identified as the most critical flow constriction along the lower reach of Santa Paula Creek (USACE 1995). For example, the bridge caused significant flow impoundment and subsequent upstream flooding during the January 1969 flood event. The Telegraph Road Bridge (approximately 1,200 feet downstream of the SPTC truss bridge) was constructed sometime after 1960 and has a 120-ft span. Its capacity is larger than the SPTC truss bridge but it has been previously identified as the second most critical flow constriction in the lower reach of Santa Paula Creek, also contributing to localized flooding in Santa Paula during past flood events (USACE 1995). The impact of these two bridge structures on the creek hydraulics and sediment transports has been greatly reduced with the construction of the ASACE channel improvements.

Figure 4-15: Looking downstream at the Southern Pacific Transportation Company (SPTC) truss bridge.

4.6 Ground Water

Santa Paula Creek lies above one of the major groundwater basins in the Santa Clara River Valley: the Santa Paula Groundwater Basin. Figure 4-17 illustrates the position of this basin (see #3). The surface area of this basin is 13,700 acres, ranging in elevation from 270 feet above sea level (near the City of Santa Paula) to 130 feet above sea level (near the Town of Saticoy). The water in this basin is unconfined, moving in a westerly direction (CDWR 1989). The basin is also characterized by a composition and structure produced through fluvial processes as part of the Santa Clara River and fault system in the region. Groundwater is extracted from the basin for a variety of uses (agricultural, industrial, and domestic), and can be found at 50 feet from the ground surface. The Basin is recharged primarily from percolation from the Santa Clara River and Santa Paula Creek, as well as underflow from the Fillmore Groundwater Basin.

Figure 4-16: Ventura County Groundwater Basins.



The Santa Paula Basin Expert Group investigated the historical and current basin pumping efforts in the Santa Paula Groundwater Basin in 2003. Among their conclusions were the following applicable points:

- With significant history of reliance on pumped groundwater and the observed response of the groundwater system over that history, pumping at historical levels should not adversely affect the basin. However, changed conditions present now or in the future could affect the basin. Potential changed conditions include demand for pumped groundwater to support growth of the City of Santa Paula (to the extent that it increases the total demand for pumped groundwater in the basin), demand for pumped groundwater to supplement other supplies available to the City of Ventura, increased reliance on pumped groundwater in areas upstream of the basin and adjacent to the Santa Clara River (River), increased/decreased discharge of treatment plant effluent to upstream reaches of the River, and water quality changes and/or changes in water quality standards. This observation emphasizes the importance of monitoring both inside and outside of the basin.
- Most of the water pumped from the basin has been suitable for the overlying land uses; irrigated agriculture and urban. With proper design and construction, domestic wells are capable of producing water meeting all primary drinking water quality standards; however, secondary water quality standards can only be met with the removal of iron and manganese. The blended total dissolved solids concentration in the City of Santa Paula system during 2000 was about 940 parts per million. There has not been any apparent significant degradation in groundwater quality over the period of record.

Given the fact that agriculture and urban development will persist in the region in conjunction with an effort to sustain local water needs with local water resources, monitoring and sustenance of groundwater levels and recharge is vital to the economic and ecological sustainability within the watershed and the County.

4.6.1 Surface Water Quality

Although not considered potable without treatment, water quality within the Santa Paula Creek watershed is generally good. Water quality problems within the watershed include suspended clays, the presence of natural oil, sulfur seeps (in the Sulfur Springs Area), and high biological oxygen demand, which is attributed to anthropogenic sources, such as septic leachate and recreational uses at Steckel Park). In comparison to other nearby watersheds, the Santa Paula Creek demonstrate relatively low concentrations of TDS, sulfate, and boron (CDWR 1989). However, as flows decrease in the Santa Paula Creek, mineralization (TDS) increases.

Mud Creek is a major source of suspended solids within the Santa Paula Creek itself. Since Mud Creek is characterized by porous, sedimentary rock substrate, the Santa Paula Creek experiences year-round turbidity downstream of its confluence with Mud Creek (ACOE 1995). In addition, agricultural practices within the lower part of the Santa Paula Creek watershed have contributed to degraded water quality in the Santa Clara River. For example, reach 3 of the Santa Clara River, at and below Santa Paula, is included in the Total Maximum Daily Load (TMDL) for Nitrogen compounds, which is partially sourced from agricultural runoff in this area (RQWCB 2003).

5 WATERSHED TECHNICAL ASSESSMENTS: METHODS

5.1 Introduction

The overall goal of the project is to produce a detailed watershed assessment and a set of restoration alternatives with site-specific, prioritized recommendations for future work leading to restoration of southern steelhead passage throughout historically accessible reaches in the Santa Paula Creek watershed. Three separate technical studies were prepared in support of the first-phase project objectives (watershed assessment). The technical studies include the following:

1. *Geomorphogy*: a detailed watershed-scale geomorphic assessment as background to design of improved fish passage, water diversion facilities, and flood protection systems - *"Santa Paula Creek Watershed Planning Project: Geomorphology and Channel Stability Assessment, Final Report"* (Stillwater Sciences, November 2007).
2. *Hydrology and Hydraulics:* a detailed hydrologic and hydraulic analysis for current conditions, future land use conditions, and proposed modified channel conditions for each restoration alternative -*"Santa Paula Creek Watershed Planning Project: Hydrology and Hydraulic Watershed Assessment, Technical Memorandum"* (RBF Consulting, May 2007).
3. *Steelhead Habitat and Population Assessment:* focused studies of southern steelhead and resident *O. mykiss* behavior, habitat, and population to support the provision of adequate passage and expand upon knowledge gained in previous studies. *"Santa Paula Creek Watershed Planning Project: Steelhead Habitat and Population Assessment, Technical Memorandum"* (Stillwater Sciences, December 2007).

Together, the in-depth understanding of the watershed geomorphology, hydrology and hydraulics, and steelhead ecology will guide the development of appropriate, long-term engineering solutions for improved fish passage in Santa Paula Creek while maintaining existing water-diversion rights, and flood protection requirements.

A summary of the technical assessment methods and conclusions from each of the three reports is referenced in the following sections.

5.2 Geomorphologic Assessment

To assess the geomorphic conditions in Santa Paula Creek watershed, geomorphic processes were assessed at both the hillslope and channel scale from an historical and present-day perspective. This assessment was conducted during the fall/winter of 2006/2007 and included a combination of field data collection, compilation of existing data compilation, air photo analysis, and use of empirical analyses related to watershed sediment yield and in-channel sediment transport. The specific methods used to assess the watershed geomorphic processes operating at both the hillslope and channel scale are detailed below.

In order to understand and quantify the impacts to and magnitude of sediment flux down the channel of Santa Paula Creek, the production of hillslope sediment across the watershed and the delivery of that sediment into the Santa Paula Creek channel network were evaluated. Over longer timescales, best represented by the geologic record of the past several million years, the average rate of annual watershed sediment production was approximated from the literature-derived rate of tectonically-driven landscape uplift. This essentially provided 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 timescales where human-induced impacts can become apparent, rates of watershed sediment production were determined using a "geomorphic landscape unit" approach in which sediment production across the watershed was assumed to be the same for individual geomorphic landscape units, or areas with the same combination of local geology, land use/vegetation, and hillslope gradient. Sediment production values for individual geomorphic landscape units were derived from a combination of field observations and average annual accumulation rates from debris basins in adjacent watersheds. The geomorphic landscape unit approach was used to determine the production of both fine sediment and coarse sediment, as the relative production of each has implications for channel geomorphic dynamics and aquatic ecology. Finally, to determine the relative sensitivity of sediment production to changes in vegetation patterns induced by extreme events, the impacts of wildfire and subsequent large storm events on watershed sediment production were analyzed by modifying the vegetation data in the geomorphic landscape unit analysis to reflect fire-induced vegetation removal, and by using an empirical analysis that gives watershed sediment yield as a function of watershed physical characteristics, storm characteristics, and the impact of recent fires on vegetation cover.

In addition to determining hillslope sediment production, an analysis of channel geomorphic condtion was also conducted. The analysis of channel geomorphic condition was divided into three parts: documentation of channel characteristics, analysis of sediment transport dyamics, and determination of channel geomorphic change over the past century. Determination of channel characteristics included analysis of discharge dynamics, assessment of of geomorphic condition of discrete channel reaches along the mainstem Santa Paula Creek, and documention of current and historic in-channel infrastructure and channel modifications and sediment removal that impact the current channel. Discharge through the mainstem Santa Paula Creek was analyzed by compiling annual maximum and daily mean flow and determining the daily mean flow duration curve, annual maximum flood frequency and annual maxium flow exceedence, and determining the impact of the ENSO cycle on these flow parameters. Discrete channel reaches were delineated in the field, based on local geoloic and hydraulic controls, and the geomorhic condition of these reaches were characterized as a function of channel width, channel depth, and channel substrate size.

The impacts of current and historic infrastructure and modification on channel geomorphic condition were determined from a combination of a field investigation an a compilation of existing information on in-channel infrasturcture and historic channelization and sediment removal. Assessment of sediment transport dynamics included a determination of average annual watershed sediment yield and the threhold discharge for coarse sediment mobility and the frequency with which the entire bed is mobilized and significant channel geomorphic change occurs. Annual average sediment yield was calculated from Santa Paula Creek watershed flow data and sediment yield data from the adjacent Sespe Creek watershed. The threshold for mobility for the coarser bed particles was determined by two separate emperical equations that are based on local channel hydraulics and bed sediment size. To identify the key controls on historic morphologic evolution and inform the projected trajectory future channel morphology, channel geomorphic change at the reach scale over the past century was assessed and the mechanisms for historic geomorphic change were determined. Channel geomorphic change was assesed using a series of topographic maps (1901, 1947, and 2005) and aeraial photographs (1969, 1998, and 2005) in concert with field-based observations. These data were then synthesized with the compiled data related to watershed geomorphic condition to determine the relative magnitude of both natural and human-induced influences to channel geomorphic change.

5.3 Hydrology and Hydraulic Watershed Assessment

The purpose of this study was to evaluate the hydrology and hydraulic characteristics of the Santa Paula Creek watershed. The following summarizes the tasks for the hydrology and hydraulic analysis outlined in the grant:

Hydrology Analysis: Evaluate the hydrologic characteristics of the creek during storm events, dry season low flows, and groundwater derived from existing reports by the Army Corps of Engineers, Ventura County Watershed Protection District (VCWPD), and other available studies. Collected hydrology information shall be used as much as possible. For channel restoration and flood control analysis, peak discharge shall be estimated for the baseline, annual flow, 2-year, 5-year, 10-year, 25-year, and the 100-year flood events for key concentration points within the watershed and along the channels within the project reach. The level of detail of the analysis shall be done as appropriate for watershed planning level. Future watershed conditions analysis shall be performed as appropriate based on the current land use map.

Hydraulic Analysis: Channel hydraulic characteristics will be determined for both current conditions and proposed channel modifications for each alternative proposed to ensure maintaining or improving the level of flood protection and meeting the goals of the restoration project. The level of analysis shall be done appropriate for watershed planning level. The results of the analysis shall be used as the basis for determining the level of flood protection, analyzing channel stability, estimation of sediment transport of the channels, bank protection and channel stabilization requirements. The hydraulic analysis shall be performed based on the available topographic maps and available FEMA floodplain maps.

The hydrology and hydraulic analysis prepared as part of this assessment were combined with the watershed geomorphology and steelhead ecology studies to guide the development of appropriate, long-term engineering solutions for improved fish passage in Santa Paula Creek while maintaining existing water-diversion rights and flood control requirements.

5.3.1 Hydrology Modeling

The hydrology focus for the Santa Paula Creek watershed keys on the estimation of frequency-specific peak discharges at five concentration points along the main stem, and are subsequently used to define the flow parameters for the hydraulic model of Santa Paula and Sisar Creeks. Guidelines for determining flood flow frequencies are presented in Bulletin 17B (WRC, 1981), which describes the application of the Log-Pearson Type 3 (LP3) distribution in the development of flood flow frequency curves. These guidelines have since become the standard of practice for developing flood flow frequencies, particularly in gaged watersheds, as a result of its continued implementation by federal, state, and local agencies. More specifically, these guidelines have been utilized in previous studies and projects in the Santa Paula Creek watershed, which were either sponsored by the United States Army Corps of Engineers or the Ventura County Watershed Protection District. Therefore, in the interest of consistency, Bulletin 17B (WRC, 1981) was applied herein. Since the record length exceeds 50 years, the adopted skew of –0.1000 is based solely on the at-site characteristics.

As an alternative, a cursory regional frequency analysis using the method of L-moments was performed to develop frequency curves at the rainfall stations located in the vicinity of the watershed. A detailed discussion of the L-moment analysis is included in the technical study.

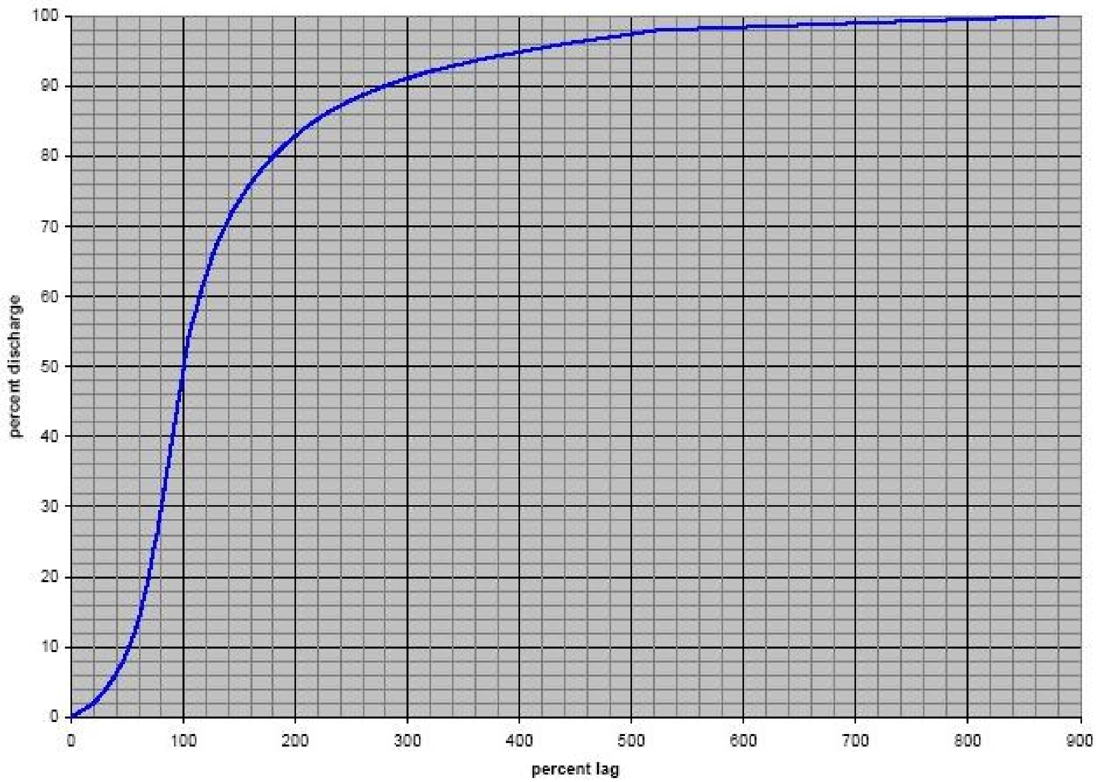
The flood flow frequency curve developed for the gaged site does not address variations in frequency-specific peak discharges along the main stem of Santa Paula Creek and thus, further analysis was necessary to estimate these variations.

5.3.1.1 Rainfall-Runoff Model Development

HEC-HMS (USACE, 2006) computer program was used to configure and analyze a rainfall-runoff model, which develops a single-area flood hydrograph for each specified frequency at each specified concentration point. A synthetic unit hydrograph method was applied, which requires a user-specified S-graph and lag time.

The S-graph deemed most appropriate for the Santa Paula Creek watershed is based on the average of five S-graphs in the Santa Clara River Basin (USACE Los Angeles District, 1986) shown in Figure 5-1.

Figure 5-1. Average of five S-graphs in the Santa Clara River Basin (USACE, 1986).



The 24-hour rainfall pattern was defined using the southern California intermediate storm, which occurred in the Los Angeles area on February 16, 1980 (USACE, 1986). This rainfall pattern is graphically shown in Figure 5-2.

The adopted rainfall frequency curve developed for CP 3.0, was used to estimate the point rainfall depth for each specified frequency at CP 3.0. The point rainfall depths estimated for CP 3.0 were then translated to other specified concentration points based on the ratio of rainfall frequency curves developed previously, for each concentration point, from the isopluvial maps (VCWPD, 2006). The resultant point rainfall depths are listed in Table 5-1.

The resultant point rainfall depths at each specified concentration point were adjusted to account for depth-areal effects based on the 24-hour depth-areal reduction factors shown in Table 5-2. The adjusted values are presented in Table 5-3.

Figure 5-2. Southern California 24-hour storm, February 16, 1980 (LADCOE, 1986).

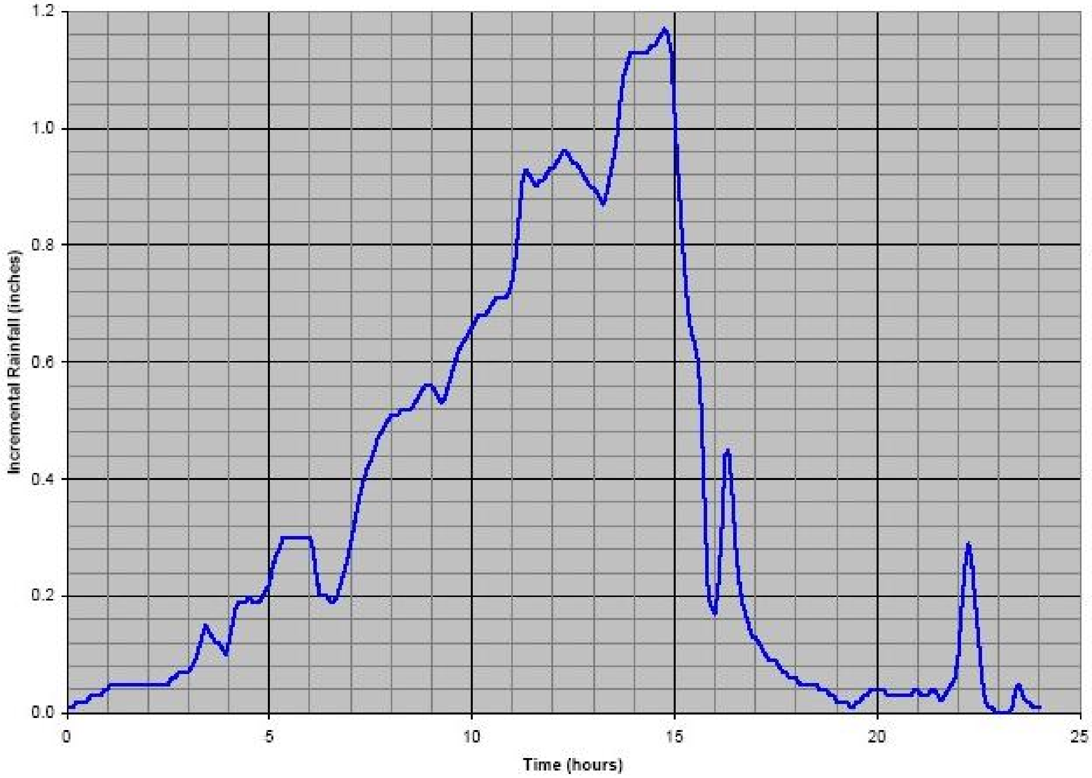


Table 5-1. Area-weighted average point rainfall in inches.

CP	Flood Event (year)							
	2	5	10	20	50	100	200	500
1.0	4.32	5.82	7.43	9.74	14.30	19.30	26.10	38.80
2.0	4.14	5.58	7.13	9.34	13.72	18.51	25.03	37.22
2.1	3.31	4.47	5.70	7.47	10.97	14.80	20.02	29.77
2.2	3.87	5.22	6.66	8.72	12.82	17.29	23.39	34.77
3.0	3.78	5.10	6.51	8.53	12.53	16.90	22.86	33.99
4.0	3.73	5.03	6.42	8.42	12.37	16.68	22.56	33.55
4.1	2.94	3.97	5.06	6.63	9.75	13.15	17.78	26.44
4.2	3.68	4.96	6.34	8.30	12.20	16.45	22.26	33.09
5.0	3.60	4.86	6.20	8.13	11.94	16.11	21.79	32.40

Table 5-2. Summary of 24-hour depth-areal reduction factors.

CP	Description	DA (sq mi)	24h DAR Factor
1.0	U/S from Echo Falls Canyon confluence	18.463	0.979
2.0	U/S from Sisar Creek confluence	23.156	0.975
2.1	Sisar Creek tributary	11.309	0.985
2.2	D/S from Sisar Creek confluence	34.465	0.967
3.0	Mupu Road bridge	37.658	0.965
4.0	Harvey Diversion	39.140	0.964
4.1	Mud Creek tributary	2.693	0.997
4.2	D/S from Mud Creek confluence	41.833	0.962
5.0	U/S from confluence with SCR	44.378	0.960

Table 5-3. Area-weighted average point rainfall in inches (depth-areal reduced).

CP	Flood Event (year)							
	2	5	10	20	50	100	200	500
1.0	4.23	5.70	7.27	9.53	14.00	18.89	25.55	37.99
2.0	4.04	5.44	6.95	9.10	13.37	18.04	24.40	36.29
2.1	3.26	4.40	5.61	7.36	10.81	14.58	19.72	29.32
2.2	3.74	5.04	6.44	8.44	12.39	16.72	22.61	33.62
3.0	3.65	4.92	6.28	8.23	12.09	16.31	22.06	32.80
4.0	3.60	4.85	6.19	8.11	11.92	16.08	21.75	32.34
4.1	2.93	3.95	5.05	6.61	9.72	13.11	17.73	26.36
4.2	3.54	4.77	6.09	7.99	11.73	15.83	21.41	31.83
5.0	3.46	4.66	5.95	7.80	11.46	15.46	20.92	31.10

The Green-Ampt infiltration method was used to simulate the rainfall loss mechanism in the rainfall-runoff model. The application of the Green-Ampt infiltration method in HEC-HMS (USACE, 2006) simulates rainfall loss in two phases. The initial abstraction of rainfall resulting from interception and surface retention occurs during the first phase. During this first phase, excess rainfall does not occur during the period from the beginning of the storm event up to the time the accumulated rainfall equals the specified initial abstraction. It is assumed, for modeling purposes, the infiltration of rainfall does not occur during this first phase. In the second phase, rainfall losses occur as result of infiltration into the soil matrix. For modeling purposes, infiltration begins immediately after the initial abstraction is exceeded.

An initial rainfall-runoff model was developed for the CP 3.0, the location of the streamflow gage. This model was used to calibrate the hydrologic parameters to reproduce the peak discharges estimated from the developed flood frequency curve based on the streamflow gage record at this site. Once achieved, additional concentration points of interest were analyzed using the calibrated rainfall-runoff model adjusted to reflect parameters specific to the concentration point.

5.3.2 Hydraulic Modeling

An existing conditions hydraulic model of Santa Paula Creek and its tributary, Sisar Creek, was prepared to evaluate and assess the Santa Paula Creek watershed. The US Army Corps of Engineers Hydrologic Engineering Centers River Analysis System (HEC-RAS) program was used to develop a model of Santa Paula Creek from its confluence with the Santa Clara River to upstream of the Sisar Creek confluence, and a portion of Sisar Creek. The HEC-RAS program is one of the most frequently used models for flood studies and developing water surface profiles for natural and improved open channels. The hydraulic model uses the flow rates developed in the hydrology analysis to estimate water surface elevations along the Santa Paula Creek. The model calculations are based on stream characteristics such as; cross-section shape, stream gradient; in-stream facilities such as channel improvements, spur dikes, bridge obstructions, and dams; and channel roughness.

HEC-RAS is designed to perform one-dimensional hydraulic calculations for natural and constructed channels. HEC-RAS generates steady flow water surface profiles for steady gradually varied flow using one-dimensional energy equations. Energy losses are evaluated by friction (Manning's Equation) and a contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e. hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions). The effects of various obstructions such as bridges, culverts, weirs, and structures in the floodplain may be considered in the computations. The steady flow system is designed for application in flood plain management and flood insurance studies to evaluate water surface profiles for streams or channel systems.

5.3.2.1 Model Development

A combination of resources including Light Detection and Ranging (LiDAR) topography, As-built plans, existing hydraulic studies, and field verifications were used to build the comprehensive HEC-RAS model. The following assumptions/guidelines were applied in developing the existing condition model:

1. Cross Section data to develop the channel geometry was taken from LiDAR topography for the watershed that was provided by the Ventura County Watershed Protection Agency.

2. Channel roughnesses in the hydraulic calculations were varied depending on the material and location. Manning's n-values for the channel roughness coefficients were determined based on field investigations, and pictures and descriptions in Ven Te Chow's book Open-Channel Hydraulics (Chow, 1959), and the United States Geological Survey (USGS) "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains (USGS). N-values of 0.030 to 0.050 were used primarily for natural streambed and banks. An n-value of 0.025 was used for the excavated streambed condition, engineered banks, and smooth-grouted rock surfaces. An n-value of 0.015 was used for concrete surfaces.

3. All California Department of Transportation bridges including the Highway 150 bridges, the Railroad Bridge, the Telegraph Road Bridge, and Santa Paula Freeway Bridge were coded in using California Department of Transportation Bridge Inspection Records Information System (BIRIS) As-builts for reference.

4. Army Corps Santa Paula Creek Improvements for Reaches 1, 2, and 3 were used to build Reach 9 of the HEC-RAS model. The model was based on an as-built condition, and does not reflect any sediment or debris build-up that may have occurred in the reach.

5. An existing hydraulic study by HDR Engineering, Inc. (HDR, 2006) was incorporated into Reaches 7 and 8 of the model. The existing model reflects improvements to the channel such as the construction of spur dikes and the installation of longitudinal toe rock.

6. Hydrologic flow conditions were taken from the results of the hydrology analysis. Multi-frequency profiles were developed to analyze the effects of various storm events.

Available stream gage data was unsatisfactory for calibrating the water surface profiles for the hydrologic flows entered in the HEC-RAS model. The active stream gage located at Mupu Bridge has been effective since 1998, however the water surface elevation readings showed to be merely 2 to 5 feet above the existing channel invert per the LiDAR topography, even for the largest recorded storm of 27, 500 cfs in January of 2005. With the same flow, the HEC-RAS model showed depths to be approximately 15 feet.

5.4 Biological Assessment/Fish Study

Coastal populations of *Oncorhynchus mykiss* may be composed of both anadromous and freshwater resident life histories. Individuals expressing anadromous life histories are referred to as steelhead, while those that remain in freshwater for the duration of their life cycle are referred to as rainbow trout. In Santa Paula Creek, a tributary to the Santa Clara River, Ventura County, California, opportunities for expression of the anadromous life history are restricted by migration barriers preventing the upstream return of adult steelhead. A residual population of *O. mykiss* now persists in suitable stream habitat above the Harvey Diversion (Stoecker and Kelley, 2005).

Restoring the migratory component of *O. mykiss* within the watershed has been identified as a priority management goal. In support of feasibility studies concerning the restoration of migratory fish passage within Santa Paula Creek, the California Department of Fish and Game requested an assessment of the residual rainbow trout population be conducted to meet the following objectives:

1. Determine the spatial distribution of *O. mykiss* in Santa Paula Creek and key tributaries.
2. Determine key habitat characteristics of stream reaches occupied by *O. mykiss*.
3. Determine the relative abundance and age class structure of *O. mykiss*.

Stream habitat and fish surveys were conducted in May and November 2007 within the Santa Paula Creek watershed. Stream habitat surveys were conducted to identify dry stream reaches, determine maximum daily stream temperatures throughout the watershed, and continuously monitor temperature throughout the summer months. Fish surveys were conducted to determine the distribution, relative abundance, and age class structure of *O. mykiss*. High stream temperatures have been identified as a factor that may limit availability of summer rearing for *O. mykiss* in the southern end of their range (Boughton *et al.* 2006), and was therefore chosen as a key characteristic of summer rearing habitat to monitor within the Santa Paula Creek watershed.

Surveys were conducted in three portions of the Santa Paula Creek watershed. A map of the survey areas is included in Technical Appendix B-Steelhead Habitat and Population Assessment Maps (Steelhead Assessment Map 1). Each portion was selected to include potential rearing habitat for anadromous *O. mykiss* above Harvey Diversion (RM 3.9), and therefore did not extend past natural (*e.g.*, waterfall) migration barriers identified by previous surveys (Stoecker and Kelly, 2005). Accessible portions of Santa Paula Creek extend from Harvey Diversion (RM 3.9) to the natural waterfall barrier upstream (RM 9.8). Accessible portions of Sisar Creek extend from the confluence (RM 0.0) to barriers identified by Stoecker and Kelly (2005) in Sisar Creek (RM 5.9) and East Fork Sisar Creek (RM 0.5). The survey reaches are:

- **Little Santa Paula Creek:** from the confluence with Sisar Creek (RM 6.6) to the East Fork of Santa Paula Creek just upstream of the natural waterfall barrier (RM 9.8).
- **Sisar Creek:** beginning at the confluence with Santa Paula Creek (RM 0.0) upstream past the Forest Service Gate (RM 4.1).
- **Mainstem Santa Paula Creek:** downstream of the Sisar Creek confluence, near the downstream end of Steckel Park (RM 4.5) upstream to the confluence with Santa Paula Creek and Sisar Creek (RM 6.6).

A more detailed description of the methods used in the Biological Assessment/Fish Study can be found in Stillwater Sciences (2007).

6 WATERSHED TECHNICAL ASSESSMENTS: SUMMARIES

The following sections present a summary of the conclusions from the technical studies. Additional details can be found in the technical study reports.

6.1 Geomorphologic Assessment

Stillwater Science performed a Geomorphology Assessments for the Santa Paula Creek watershed, and served as the basis for understanding the geomorphological dynamics and historical flows within the basin. The full report can be found as an appendix to this document.

The Santa Paula Creek watershed is characterized by very high sediment yields. Estimates of hillslope sediment delivery rate derived in this study range from approximately 500 to 20,000 t km^{-2} a^{-1} (1,400 to 57,000 ton/sq. mi./year), depending on geology, hillslope gradient, and land cover. Integrating the hillslope sediment yield results for individual process domains (*i.e.*, combinations of geology, gradient and land cover) over sub-watershed areas suggests that Sisar Creek yields on the order 2,000 t km^{-2} a^{-1} (5,700 tons/sq. mi./year), while (for example) the chronically-eroding Mud Creek yields closer to 6,000 t km^{-2} a^{-1} (17,000 tons/sq. mi./year). The hillslope sediment yield for the entire Santa Paula Creek watershed is approximately 2,000 t km^{-2} a^{-1} (5,700 tons/sq. mi./year). Active tectonic uplift in the watershed results in the steep slopes that contribute to the high sediment yield. Over the long-term, the sediment yield is in approximate accordance with the ~1 mm a^{-1} rate of active uplift in the watershed. Our calculated hillslope sediment yield is also consistent with estimates of sediment yields from gaging records for the lower Santa Clara River by Warrick (2002) (although, as it is partly calibrated by this research, such an outcome is expected). The estimated sediment yields are listed in table 6-1.

Table 6-1. Santa Paula Creek sediment yields.

Tributary	Total annual load ($t\ a^{-1}$)	Annual load ($t\ km^{-2}\ a^{-1}$)	Landscape lowering rate ($mm\ a^{-1}$)
Sisar Creek	44,000	2,300	0.9
Upper Santa Paula Creek (to Sisar Ck. confluence)	73,000	1,700	0.7
SPC at Harvey Diversion Dam	146,000	2,100	0.8
Mud Creek	24,000	5,800	2.2
Santa Paula Creek at mouth (*i.e.*, whole watershed)	252,000	2,200	0.8

Geologically, in-stream sediment is derived from a combination of easily erodible, fine-grained siltstone beds and more slowly eroding but durable sandstone beds that provide very coarse grained material (boulders to cobbles) that pervasively influence channel morphology. The siltstone beds are the dominant source of sediment, in part because they constitute over 50% of the watershed geology; in contrast, coarse sediment delivery is more a function of fracturing by cross-cutting joints in conjunction with oversteepened bedrock slopes. Coarse sediment reaches the riverbed either as large blocks that fall directly into the channel or as material that is entrained from coarse talus accumulations from the base of steep slopes.

Rates of sediment production are also dependent on land cover characteristics, with higher yields emanating from "cleared" land (agriculture and grasslands) than under forest. Because there has not been an extensive land cover change in the upper Santa Paula watershed in the last century, it is probable that the anthropogenic influence on overall watershed sediment yields in the upper watershed largely reflect changes brought about in the period not long following Euro-American land occupation rather than more recent changes. In the lower watershed, continued agriculture and watershed development have likely increased hillslope sediment yields, especially of fine sediment. On shorter timeframes, wildfire has a profound effect on sediment delivery: simulating the impact by decreasing vegetation cover for all hillslopes that are currently well vegetated and have a hillslope gradient >10% results in a seven-fold increase in hillslope sediment delivery for a fire than burns 100% of the watershed. This figure, if accurate, thus represents a likely upper bound on the effect of fire in the watershed.

The mainstem of lower Santa Paula Creek (*i.e.*, below the confluence of Sisar Creek and "upper" Santa Paula Creek) has very high rates of sediment transport, which is a function of a relatively high gradient (0.0145–0.0229) and the high sediment yields from upstream. The channel bed surface is characterized primarily by cobble deposits, but even the coarsest (90th percentile) of these sediments are estimated to be mobile in floods with a return period of 1–3 years. This is consistent with other evidence for very high rates of sediment transport and significant morphological change in large flood events. The mainstem channel also contributes to the watershed sediment yield through active channel incision and widening. Evidence from topographic maps, air photographs and recent LiDAR images indicate that the lower mainstem has predominately incised since the earliest records since 1901 (with a maximum of 12 m), although aggradation has occurred behind flow constrictions, and the channel has widened a maximum of 200 m in the past 40 years between Harvey Diversion and the USACE fish ladder. Overall, the dynamics of flow and sediment transport in the creek mean that the largest single flow is also the dominant, channel-forming discharge, whereas in many rivers a more moderate ("bankfull") flood flow usually represents the dominant discharge.

Recent changes in channel morphology in the lower Santa Paula Creek mainstem are driven by both natural and anthropogenic factors. In terms of natural factors and over the long term, the channel morphology shows an adjustment to regional patterns of faulting and tectonic activity, whereby bedrock channel constrictions resulting from upthrust blocks restrict the connectivity of coarse sediment to downstream reaches and thus contribute to local incision. More recently, a strong ENSO climatic signal over the last 40 years has promoted a clustering of large flood events (*i.e.*, 1969, 1973, 1978, 1980, 1983, 1992, 1992, 1995, 1998, and 2005) that have transported more sediment than would otherwise have occurred over the period, and have increased the ability of the channel to erode its bed and banks. Bed erosion is most pronounced where the channel is confined either by bedrock or by levees and bank protection, and bank erosion (widening) is commonly at a maximum upstream of flow constrictions.

Anthropogenic influences include in-channel structures that serve to constrict flow and sediment transport, especially at the Highway 150 bridge and at the Harvey Diversion. Such structures function rather like anthropogenic counterparts of fault-related bedrock outcrops: flow constrictions at the approach to these structures during large flood events result in sediment deposition upstream of the structure, and incision immediately downstream of the structure. The channel is likely to meander as the gradient reduces approaching the structure from upstream (forcing sediment deposition), and downstream the sediment derived from local channel incision will be deposited and may result in aggradation and channel widening.

Removal of in-channel sediment, channel straightening, and bank armoring near the mouth of Santa Paula Creek have served to locally increase channel gradients and confine flood flow widths, resulting an in increased ability to erode the channel bed in flood events and knickpoint migration upstream, which in turn causes further channel incision and bank widening in reaches that are not bedrock-controlled. Several phases of knickpoint migration may have occurred, potentially relating to efforts in straightening and confining the channel in the early twentieth century, following channelization and dredging efforts in the early 1970s, and following recent re-design of the channelized reaches.

6.1.1 Conceptual Understanding and Trajectory of Channel Morphology

The general morphology of lower Santa Paula Creek (LSPC, below the confluence with Sisar Creek) is largely controlled by regional geological characteristics. The channel receives a high sediment load from the hillslopes as a consequence of high rates of tectonic uplift in the upstream watershed. The delivery of hillslope sediment from the upper watershed to the channel is highly dependent on land cover and hillslope gradient (for fine sediment) and local geologic controls (for coarse sediment). The steep gradient of the creek enables it to transport this load to the Santa Clara River in a series of concentrated pulses occurring during high-intensity rainfall events, especially those associated with the ENSO phenomenon. Paleochannels clearly evident on historic aerial photographs indicate that, under pre-settlement conditions, the lower Santa Paula Creek would periodically switch courses during flood events, entering the Santa Clara River at different locations. The lower Santa Paula Creek therefore used to operate as an alluvial fan, albeit one affected by regional tectonic activity. While, on millennial timeframes, tectonic uplift has resulted in a series of clearly evident terraces on the margins of the valley of the upper LSPC, photographic and topographic evidence indicates that the mainstem active channel was unlikely to have been incised. Instead, flood flows would disperse across the alluvial fan during high-magnitude events, allowing sediment deposition and preventing significant erosion of the active channel. This condition, which may have existed until the time of extensive Euro-American settlement of the watershed, which probably also resulted in a higher water table that supported riparian vegetation and buffered the creek against the erosive forces of high flows.

In contrast, the morphology of the current LSPC alternates between bedrock-confined reaches and incised alluvial reaches, and it is largely confined to a single high-gradient channel disconnected from its floodplain. Upstream of flow constrictions, local aggradation causes extensive channel widening. Evidence from the upper watershed indicates that bedrock outcrops associated with upthrust faults act naturally as hydraulic constrictions on the channel, reducing coarse sediment connectivity and indirectly causing local scour and downstream incision. In the lower LSPC, bedrock outcrops located near the Highway 150 bridge, the Harvey Diversion Dam, and upstream of the USACE fish ladder have a functionally similar affect; but the lower two of these outcrops were probably buried then exposed by channel bed erosion following in-channel modification and structure installation. Such incision means that flood flows in the LSPC are now flashier and run deeper in the active channel. This allows the mainstem to maintain higher flood flow velocities than would earlier have been the case in earlier times, develop higher shear stresses on the channel bed, and thus transport higher rates of sediment (including sediment scoured from the bed and banks of the channel). In addition, channelization of the lowest reaches of the LSPC appears to have prompted more, or more active, knickpoints, which in turn are further incising the channel bed.

The Project study area was divided by Stillwater Sciences into 8 separate reaches between the Highway 150 crossing on the upstream end, and the Army Corps of Engineers channel improvements at the downstream limits. The 8 reaches are separated based on alluvial\bedrock-confined setting and infrastructure influence. In addition to these 8 reaches, RBF Consulting studied the Army Corps of Engineers channel improvements to the confluence with the Santa Clara River, identified as Reach 9. The location of the reaches is illustrated in Figure 6-1.

Coincident with these in-channel conditions, a series of large rainfall events over the last 40 years associated with a strong multi-decadal occurrence of the ENSO phenomenon has resulted in numerous high-magnitude flood events. The flood events have caused considerable incision in some parts of Santa Paula Creek, which serves to increase further the sensitivity of the channel to subsequent large flood events. The natural geomorphic control on such incision is for the channel to widen by eroding its channel banks and so create a new floodplain onto which to disperse flood flow energy. A combination of bank revetment and bedrock constraints on the LSPC mean that widening of the channel has only been possible in select locations (*e.g.*, Reach 7), thus perpetuating the condition as a positive feedback loop. Overall, the "morphodynamics" of the LSPC (*i.e.*, the changeability of the channel form) is now far more sensitive to flood flows than prior to significant human settlement.

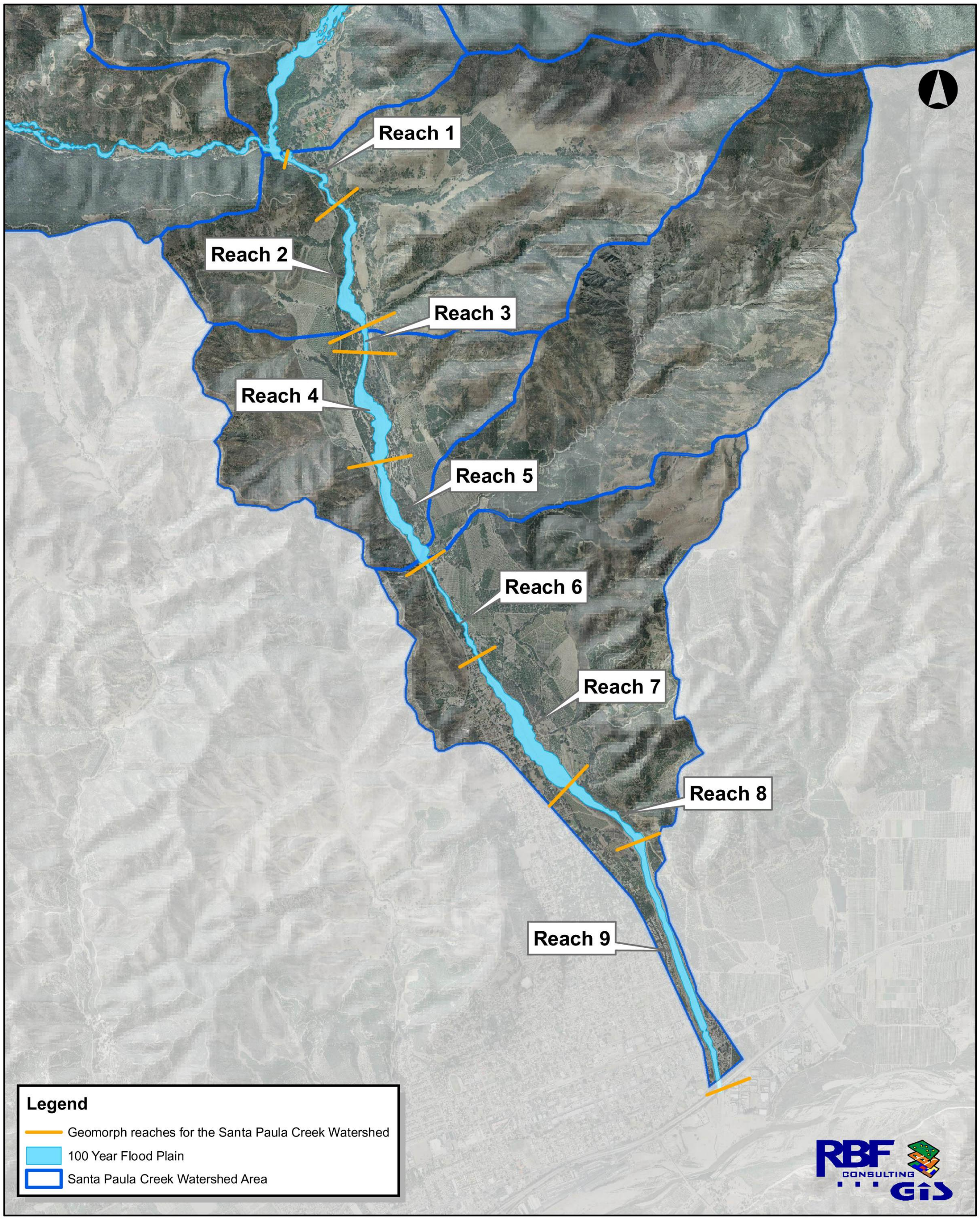
In the technical assessment, available historical data was used to reconstruct historical changes to the morphology of Santa Paula Creek to the extent possible. The primary data sources included long profiles and centerline traces of the channel bed, at approximate 50-year intervals from topographic maps as far back as 1850, and aerial photographs, especially those from 1969, 1998 and 2005. These were used to detail changes in planform and provide further clues to the timing of changes in bed elevation. In conjunction with other analyses in this report, this reconstruction helps us to understand the dominant processes in the Santa Paula Creek watershed and to project a potential scenario of future change in lower Santa Paula Creek.

Reaches 1 and 6 seem unlikely to change from their current trajectory of channel incision while the Highway 150 bridge drop structures and the Harvey Diversion Dam remain in their current form. Both reaches are now highly incised into bedrock, which reduces the chance of significant channel widening. As such, both creeks will remain as highly efficient conduits for sediment transport downstream of a control on sediment passage, and incision is the most likely continuing response. In Reach 6, incision may be enhanced if knickpoints currently in reaches 7 and 8 migrate upstream into the reach.

Reaches 2 to 5 appear to have their gradient controlled regionally by the crest of Harvey Diversion Dam. Because these reaches have lower gradients and less confinement than those immediately above Reach 1, the limited aggradation and widening in these reaches may continue. Bed levels will also presumably aggrade further were the crest elevation of the Harvey Diversion Dam ever increased.

Future morphological change in Reach 7 may reflect several competing factors. The recent trend of aggradation and channel widening may reverse into incision in moderate flood events, because the flow is now directed towards the channel center by the recently constructed dikes. This trend will be accentuated if the knickpoint currently at the boundary of Reach 7 and 8 erodes upstream and into the reach. Incision during large flood events may be partly controlled by the resistance to flow provided by the constructed dikes, being greater if the dikes retain their form for longer periods. However, because Reach 8 is now a bedrock-influenced reach, further incision in Reach 8 may impart an increasing level of flow constriction in Reach 7 and so encourage upstream sediment deposition, especially at the downstream end of the reach which may then widen.

Figure 6-1: Santa Paula Creek Study Reaches



Reach 8 looks set to continue a trend for slight incision because the exposed erodible bedrock will limit the amount of channel widening possible during flood events, and so focus erosion on the channel bed. If the USACE fish ladder retains its structural stability and so maintains a fixed bed elevation at the downstream end of Reach 8, the amount of incision possible will be limited and, over the longer term, a trend of aggradation may begin.

In every location, the rate of morphological change will be determined by the frequency of large, sediment-laden flood events. Changes will be rapid while frequent ENSO events occur, such as in the period since 1969, or in flood events following fire in the upper watershed.

6.2 Hydrology and Hydraulic Watershed Assessment

6.2.1 Hydrology Assessment

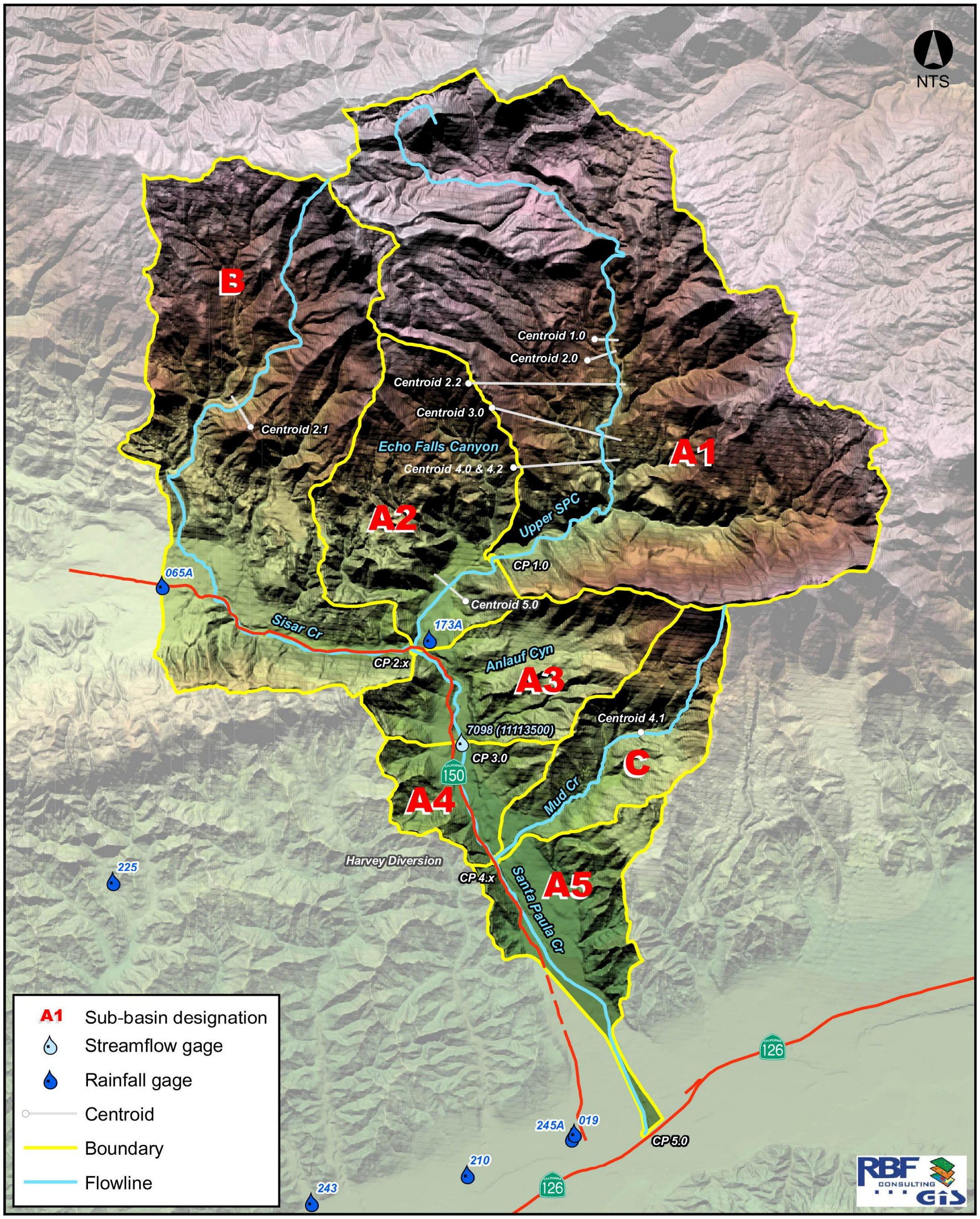
Discharge within the Santa Paula creek is characterized by long durations of little to no flow punctuated by flood events triggered by short-duration, high-intensity precipitation events that travel relatively quickly through the watershed. Flood flows within the watershed are extremely ‘flashy,’ meaning that there is a rapid increase in discharge over a short time period with a quickly developed peak discharge in relation to normal base flow (Ward 1978). A measurement of ‘flashiness’ is the ratio of the annual maximum instantaneous discharge to the associated daily mean discharge for the day in which the annual maximum instantaneous discharge occurred. Within Santa Paula Creek, this ratio averages 3.6 (range = 1.6 to 8.4 from WY 1933–2005), where as ratios for other coastal watersheds of similar size can be much less. For comparison, the unregulated and undeveloped Big Sur River watershed (Monterey County, CA) has an average ‘flashiness’ ratio of 2.4. The difference in the ‘flashiness’ ratios among these watersheds is a function of local storm intensity, topographic relief, geology and soil development, and land use (*i.e.*, vegetation type and distribution, extent of impervious surfaces).

Information for the estimates of average flow rates and statistical analysis for the flood-frequency evaluation were taken from USGS gage 11113500 located approximately 1.6 miles upstream from the Harvey Diversion structure. The annual maximum discharge for Santa Paula Creek has ranged over approximately 3 orders of magnitude (35 to 27,500 cfs) over the past 73 years (1933 to 2006). Compiling the annual maximum data show that the discharge expected to be equaled or exceeded at least once in one-half of all years (*i.e.*, $Q_{2\text{-yr}}$) is approximately 1,254 cfs. Mean daily discharge data (WY 1927–2006) show that, on average, the annual daily mean flow stays below 500 cfs, most (approximately 99%) of the daily mean flow values over the period of record were at or below 202 cfs, and over 2/3 (approximately 70%) of daily mean discharge values for the entire period of record were at or below 10 cfs. Mean daily discharge during days with the highest peak discharge values for the period of record (1969, 1978, and 2005) was well above 5,000 cfs.

6.2.2 Rainfall-Runoff Model Analysis Summary

The hydrologic focus for the Santa Paula Creek watershed keys on the estimation of frequency-specific peak discharges at five concentration points along the main stem, and are subsequently used to define the flow parameters for the hydraulic model of Santa Paula and Sisar Creeks. The hydrologic delineation of the watershed is shown in Figure 6-2, which identifies the five concentration points along the main stem, the centroids for each cumulative sub-basin, the streamflow gage location, and rainfall gages located in the vicinity of the watershed

Figure 6-2: Hydrologic delineation of the Santa Paula Creek watershed.



The summary results of the calibrated rainfall-runoff model for CP 3.0 are presented in Table 6-2. The developed flood hydrograph for each specified frequency for CP 3.0 is graphically displayed in Figure 6-3. The computed peak flows listed in Table 6-2 are equal to the discharges produced by the corresponding flood flow frequency curve at the stream gage. The computed peak flows for each specified frequency at each concentration point of interest are presented in Table 6-3.

Table 6-2. Flood hydrograph data comparison at CP 3.0 (Mupu Road Bridge)

Flood Event (year)	Peak Flow (cfs)	Peak Time (hours)	Total Rainfall (inches)	Rainfall Loss (feet)	Direct Runoff (inches)	Volume (ac-ft)
2	1300	17.833	3.65	3.32	0.33	658
5	4580	16.667	4.92	3.95	0.97	1958
10	8900	16.167	6.30	4.39	1.91	3835
20	15400	15.750	8.23	4.81	3.42	6868
50	28500	15.417	12.09	5.32	6.77	13596
100	42900	15.250	16.31	5.77	10.54	21172
200	62600	15.167	22.08	6.17	15.91	31949
500	99200	15.083	32.81	6.65	26.16	52542

Figure 6-3. Flood hydrograph comparison at CP 3.0 (Mupu Road Bridge)

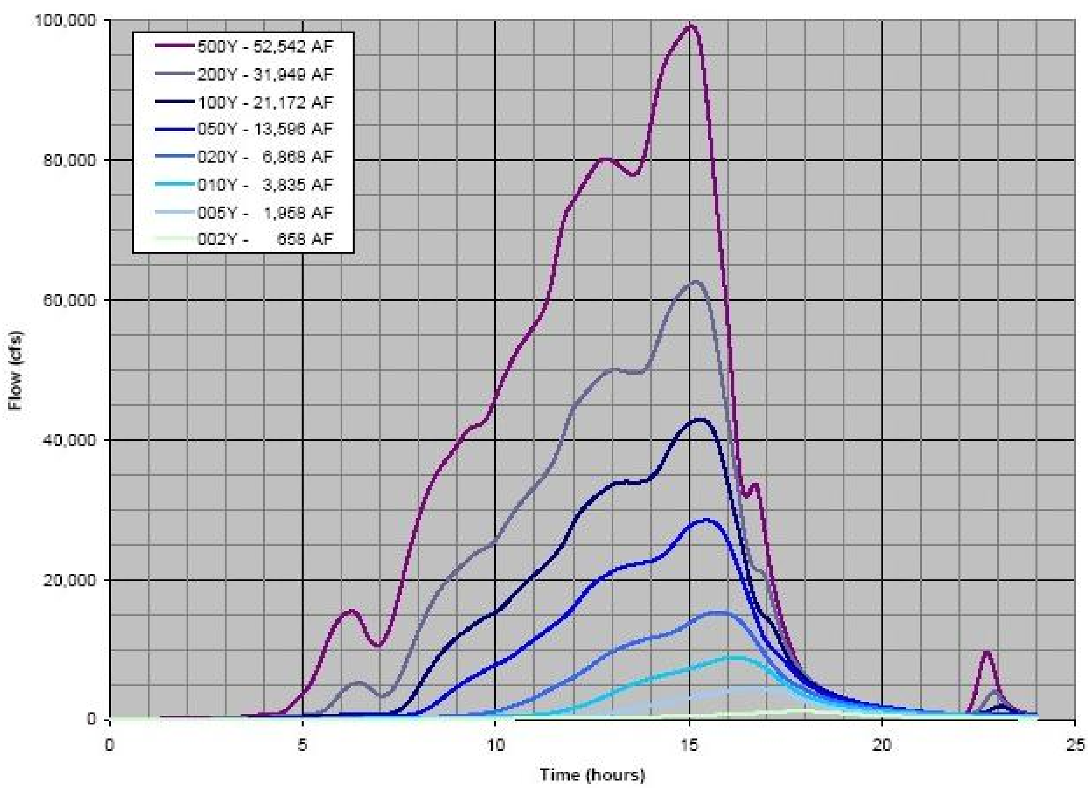


Table 6-3. Summary of computed peak flows in cfs

CP	Flood Event (year)							
	2	5	10	20	50	100	200	500
1.0	1,230	3,450	6,050	9,840	17,300	25,600	36,700	57,600
2.0	1,140	3,570	6,570	11,000	19,900	29,700	43,100	68,000
2.1	230	1,110	2,320	4,120	7,680	11,600	16,900	26,700
2.2	1,300	4,550	8,720	14,900	27,200	40,800	59,300	93,600
3.0	1,260	4,580	8,900	15,400	28,500	42,900	62,600	99,200
4.0	1,140	4,340	8,610	15,100	28,500	43,100	63,200	100,800
4.1	180	430	710	1,110	1,880	2,710	3,850	5,960
4.2	1,260	4,650	9,170	16,100	30,100	45,500	66,700	106,200
5.0	1,130	4,330	8,820	15,800	30,200	46,000	67,900	108,800

There is a hesitation to recommend the flood frequency curve, which was developed based on Bulletin 17B (WRC, 1981), as the foundation for estimating frequency-specific peak flows along the main stem of Santa Paula Creek (table 6-3) on the sole basis Bulletin 17B has been established as the standard of practice for this watershed. The cursory analysis, based on the method of L-moments, leading to the development of the PE3-based flood frequency curve, which appears to be more appropriate at first glance, requires a more rigorous evaluation prior to its acceptance as a more fitting alternative to past precedence.

6.2.3 Hydraulic Assessment

The Technical Memorandum prepared by Stillwater Sciences "Santa Paula Creek Watershed Planning Project: Geomorphology and Channel Stability Assessment," (Stillwater, 2007) divided the Project study area into 8 separate reaches between the Highway 150 crossing on the upstream end, and the Army Corps of Engineers channel improvements at the downstream limits. The 8 reaches are separated based on alluvial\bedrock-confined setting and infrastructure influence. In addition to these 8 reaches, RBF Consulting studied the Army Corps of Engineers channel improvements to the confluence with the Santa Clara River, identified as Reach 9.

The location of the reaches is illustrated in Figure 6-1. A hydraulic characterization and summary of results of the existing watershed condition for each of the 9 reaches is provided below. A photographic survey of the reaches and a flood profile for the 100-year storm event are included in Technical Appendix A-Photographic Survey of Study Reaches. Additional information and copies of the hydraulic analysis can be found in the technical study.

6.2.3.1 Reach 1

Reach 1 is approximately 2100 feet long with the Highway 150 crossing as the upstream boundary. The majority of this reach is an unimproved, narrow, natural streambed with steep banks. As a result of the large cobble deposits and a medium vegetation cover along the channel bottom, a "Manning's n" value of 0.03 was assumed. The average slope throughout this reach is relatively steep, 0.0238 with a 100 year flow rate of 42,900 cfs.

Table 6-4. Average Hydraulics (Reach 1).

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	3.19	64	1.82	13.16	9.09	1.81	8.38	169
5	4580	5.48	76	3.68	18.68	6.56	1.79	12.45	322
10	8900	7.58	84	5.30	22.47	5.84	1.80	15.66	472
20	15400	10.08	92	7.19	25.85	5.47	1.79	19.03	662
50	28500	13.86	112	9.83	28.06	3.40	1.60	18.11	602
100	42900	17.21	126	11.86	30.24	2.68	1.54	18.15	600
200	62600	20.86	139	14.17	33.07	2.38	1.55	19.33	665
500	99200	26.58	156	17.88	37.06	2.20	1.56	21.50	813

6.2.3.2 Reach 2

Reach 2 is approximately 3900 feet of natural streambed. The reach transitions from a narrow (approximately 100 feet wide) streambed to a wide channel (approximately 230 feet wide) at the downstream end. The Anlauf Creek confluences the Santa Paula Creek at the downstream end of this reach via box culvert through the east channel wall about 30 feet above channel invert. The average slope throughout this reach is relatively steep, 0.0219 with a 100-year flow rate of 43,100 cfs.

Table 6-5. Average Hydraulics (Reach 2).

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	2.76	125	1.49	7.36	2.23	1.07	2.03	15
5	4580	4.45	170	2.59	11.12	2.42	1.24	3.73	44
10	8900	5.83	201	3.66	13.64	2.31	1.28	4.98	71
20	15400	7.27	220	4.90	16.70	2.31	1.35	6.73	118
50	28500	9.53	234	6.86	21.07	2.38	1.45	9.51	211
100	42900	12.10	240	9.14	23.68	2.26	1.44	11.18	286
200	62600	14.34	272	10.18	27.36	2.34	1.52	12.46	360
500	99200	18.01	305	12.66	31.67	2.44	1.61	15.29	512

6.2.3.3 Reach 3

Reach 3 is a short reach, approximately 750 feet, of natural streambed with a relatively gradual slope 0.0131. Mupu Bridge Crossing is a 3-span crossing and does not cause significant disturbance in flow and therefore there are no backwater effects. A stream flow gage is mounted on the upstream side of Mupu Bridge. The channel bottom is covered with medium sized cobble deposits and medium vegetation, therefore a Manning’s n value of 0.03 was assumed.

Table 6-6. Average Hydraulics (Reach 3).

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	2.40	114	1.72	6.90	1.87	0.95	1.84	13
5	4580	4.38	134	3.36	10.60	1.74	1.04	3.40	37
10	8900	6.28	146	5.00	12.97	1.57	1.05	4.42	58
20	15400	8.51	151	7.01	15.53	1.50	1.07	5.65	89
50	28500	12.13	160	10.13	18.71	1.30	1.07	7.11	135
100	42961	22.71	267	14.21	12.04	0.30	0.53	2.41	39
200	62782	25.53	283	15.98	14.38	0.33	0.59	2.80	45
500	99686	33.08	303	22.52	15.37	0.28	0.55	2.99	52

6.2.3.4 Reach 4

Reach 4 is approximately 3500 feet of mostly unimproved natural channel and some improved channel. At the upstream limit, 6 slope protection groins have been constructed with large rock on the west bank, adjacent to Steckel Park. The groins are approximately 5' high and extend to mid streambed. The flow line throughout this reach is meandering and the average slope is 0.0199.

Table 6-7. Average Hydraulics (Reach 4).

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	3.04	140	1.52	6.89	2.15	1.00	1.89	14
5	4580	4.64	213	2.38	10.29	2.60	1.20	3.51	39
10	8900	5.87	241	3.24	12.97	2.65	1.29	4.93	68
20	15400	7.26	264	4.33	15.52	2.57	1.33	6.43	108
50	28500	9.41	294	5.95	18.81	2.49	1.38	8.40	171
100	43100	11.29	306	7.57	21.57	2.41	1.41	10.19	239
200	63200	13.47	355	8.03	24.17	2.29	1.43	10.70	279
500	100800	16.43	420	9.40	26.94	2.16	1.46	11.94	341

6.2.3.5 Reach 5

Reach 5 is approximately 3300 feet long and extends to the Harvey Diversion. The channel throughout this reach is wide and has an average slope of 0.020. Water is diverted out at the downstream end for irrigation.

Table 6-8. Average Hydraulics (Reach 5).

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	3.21	120	1.70	7.61	2.09	1.04	2.19	18
5	4580	5.19	183	2.56	10.33	2.15	1.14	3.39	36
10	8900	6.84	218	3.63	11.87	1.93	1.12	4.00	48
20	15400	8.42	241	4.57	14.29	1.89	1.17	5.15	76
50	28500	10.80	279	6.21	17.23	1.87	1.25	6.60	119
100	43100	12.87	317	7.44	19.44	1.90	1.30	7.70	157
200	63200	15.06	353	8.67	22.01	1.92	1.35	9.13	214
500	100800	20.15	436	11.83	22.34	1.42	1.17	8.50	224

6.2.3.6 Reach 6

Reach 6 is a confined reach approximately 3100 feet long from the Harvey Diversion to the Bridge Road Bridge. The channel is deeply incised along this reach with the mildest slope of the study area. However, the confined stream conditions result in the largest flow depths and highest flow velocities along the study reach.

Table 6-9. Average Hydraulics (Reach 6)

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	2.93	64	2.28	9.88	2.21	1.22	2.42	31
5	4650	5.56	73	4.45	15.99	2.47	1.43	5.13	109
10	9170	7.89	80	6.29	20.38	2.43	1.52	7.32	191
20	16100	11.32	89	8.87	22.21	1.63	1.39	7.33	178
50	30200	14.68	96	11.53	29.78	2.12	1.62	12.00	405
100	46000	19.89	107	15.11	30.75	1.57	1.46	11.53	389
200	67900	24.83	136	16.69	33.58	1.42	1.44	12.19	458
500	108800	31.57	177	19.21	36.93	1.27	1.41	12.25	500

6.2.3.7 Reach 7

Reach 7 is an alluvial reach of approximately 4500 feet in length. The County emergency streambank protection improvements span the entire length of this reach. Improvements include constructed spur dikes and longitudinal toe rock. Bridge Road Bridge is located at the upstream end of Reach 7 and is a clear span crossing. Average 100-year flow for the reach is 46,000 cfs.

Table 6-10. Average Hydraulics (Reach 7).

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	2.44	114	1.99	6.48	2.03	0.81	2.42	17
5	4650	4.80	148	3.70	9.84	1.98	0.89	4.36	46
10	9170	6.85	195	4.91	12.12	1.92	0.92	5.71	77
20	16100	9.06	255	6.00	14.20	1.86	0.94	6.57	106
50	30200	12.12	322	8.17	17.13	1.80	0.98	8.39	164
100	46000	15.06	349	10.60	19.31	1.74	0.98	10.09	228
200	67900	18.86	379	13.56	21.09	1.61	0.95	11.45	299
500	108800	24.98	425	17.44	21.86	1.24	0.85	11.08	316

6.2.3.8 Reach 8

Reach 8 is an actively incising reach of approximately 2500 feet in length. Reach 8 transitions from the County spur dike sections to a narrow natural streambed to just upstream of the Army Corps fish ladder and channel improvements. The channel through this reach is relatively steep with an average slope of 0.028 feet per foot. Average 100-year flow rate for the reach is 46,000 cfs.

Table 6-11. Average Hydraulics (Reach 8).

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	3.05	88	1.87	9.92	2.93	1.34	3.09	40
5	4650	5.41	121	3.48	14.10	2.40	1.39	4.68	75
10	9170	7.39	135	4.76	17.36	2.28	1.45	6.00	113
20	16100	9.54	156	5.96	20.51	2.18	1.49	7.21	157
50	30200	12.61	188	7.72	24.58	2.14	1.56	9.11	236
100	46000	15.44	210	9.20	27.05	2.07	1.57	10.31	294
200	67900	18.87	241	11.00	28.73	1.84	1.51	10.71	335
500	108800	23.54	292	13.06	31.04	1.64	1.47	11.39	392

6.2.3.9 Reach 9

Reach 9 is approximately 7500 feet long and includes all of the Army Corps channel improvements to just downstream of the Santa Paula Freeway crossing. Channel improvements include a fish ladder at the upstream end that was also damaged severely in the 2005 winter storms. The channel transitions from a natural channel into a trapezoidal channel with an average base width of 90 feet and then into a rectangular channel with an average base width of 130 feet just upstream of the railroad crossing. The channel transitions back to a trapezoidal channel downstream of the Telegraph Road crossing and upstream of the Santa Paula Freeway crossing. The channel bottom throughout the reach is relatively smooth gravel bottom and excavated channel, resulting in an assumed Manning's n value of 0.02. The average slope is 0.015 to 0.030 through the reach and flow eventually confluences with the Santa Clara River.

Table 6-12. Average Hydraulics (Reach 9).

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	1.65	105	1.54	8.82	1.82	1.30	1.56	15
5	4650	3.46	113	3.15	14.17	1.75	1.45	3.10	46
10	9170	5.17	119	4.61	17.96	1.67	1.52	4.32	81
20	16100	7.26	127	6.32	21.56	1.58	1.56	5.54	126
50	30200	10.36	138	8.71	26.63	1.54	1.64	7.40	206
100	46000	13.91	324	10.81	28.70	1.43	1.60	8.41	268
200	67900	18.58	838	11.98	27.86	1.25	1.43	8.75	321
500	108800	25.94	1310	14.94	26.27	0.97	1.22	8.17	353

The results of the hydrology and hydraulic analysis provide an understanding of the existing flow rates and flooding conditions that need to be considered in the design of any improvements to restore fish passage or provide flood protection.

6.3 Biological Assessment/Fish Study

6.3.1 Dry Reach and Stream Temperature Surveys

The length of length dry reaches in Santa Paula Creek increased from May to November 2007. In May 2007, all tributaries to the Little Santa Paula Creek reach were completely dry, with the exception of Sisar Creek. An additional dry reach of 0.06 miles was identified within Little Santa Paula Creek (near RM 7.1) and two dry reaches were identified within Sisar Creek (RM 0.6 to RM 1.4 and RM 2.5 to RM 3.2). By November 2007, the length of the dry reaches in Little Santa Paula and Sisar creeks increased to 0.3 miles, extending from RM 7.0 to RM 7.3. In Sisar Creek, and 0.6 miles, respectively, with the two reaches in Sisar Creek extending from RM 0.2 to RM 1.4, and from RM 2.4 to RM 3.3. Cumulatively, the dry reaches in Sisar Creek reduced the available summer rearing habitat by 2.1 miles, which is equivalent to 32% of the stream length potentially accessible to anadromous *O. mykiss* in Sisar Creek. Dry reaches observed in May and November 2007 are shown in Steelhead Assessment Maps 1 and 2 (Technical Appendix B).

6.3.2 May Maximum Daily Stream Temperatures

Maximum daily stream temperatures in May ranged from 16 to 28 °C within the study reaches. Little Santa Paula Creek had the highest maximum daily stream temperatures and the highest variability in daily temperature. Maximum daily stream temperatures in Little Santa Paula Creek ranged from 19 to 28 °C. Measurements in Little Santa Paula Creek demonstrate a repeating pattern of cooling and warming of surface temperatures (Steelhead Assessment Map 3). This pattern appears to correspond with variation in valley-bottom width (defined as the distance between valley walls perpendicular to the stream channel) and surface flow volume. As the valley-bottom widens, surface flow diminishes and maximum daily stream temperatures increase rapidly due to a combination of diminishing flow and direct insolation to the entire wetted channel (riparian shading is currently negligible). In areas where the valley-bottom width narrows, surface flow increases and temperatures cool abruptly, presumably due to increasing groundwater contributions to surface flow.

Sisar Creek maintained cooler and less variable stream temperatures than Little Santa Paula Creek, likely due to the extensive riparian cover throughout Sisar Creek. Maximum daily stream temperatures in May were below 18.0°C (Map 3) with the exception of the lower 0.6 miles of Sisar Creek, in which temperatures reached 21°C. Within this portion of Sisar Creek stream temperature increased from 16.0°C to 19.0°C within 330 ft, likely due to a near total absence of riparian shading. Variation in valley-bottom width was less significant in Sisar Creek than in Little Santa Paula Creek, and although groundwater recharge was observed, it was less obvious from field observations how the geology and geomorphology of Sisar Creek contribute to patterns of surface flow. Dry reaches tended to be found in areas where water diversions or in-channel pumping occurred, suggesting that human water use contributes to stream drying in Sisar Creek. Mainstem Santa Paula Creek had consistently high maximum daily stream temperatures ranging from 21.6°C to 26°C (Map 3), although fewer stream measurements were taken in this reach due to the small number of *O. mykiss* observed (see *O. mykiss presence and absence surveys* below).

6.3.3 Continuous Temperature Monitoring

Temperature was monitored continuously from May through November. Stream temperatures reached maximum weekly average temperatures (MWAT) in early September. The greatest variability in MWAT occurred in Little Santa Paula Creek, ranging from 21.4°C to 25.8°C. Sisar Creek had lower and more consistent MWAT values than Little Santa Paula Creek, ranging from 20.4°C to 21.8°C. Longitudinal patterns in MWAT were similar to the repeated cooling and warming observed in maximum daily temperature in May. Two thermographs were deployed in mainstem Santa Paula Creek but only one was retreived in November 2007. The only retrieved thermograph was immediately below the confluence and was not representative of the reach, therefore preventing comparisons of MWAT to other creeks. The retrieved thermograph was located just downstream of the confluence with Little Santa Paula Creek and resulted in an MWAT of 22.0°C, a value in-between the most downstream sites in both creeks above the confluence. Although the most downstream thermograph was not retrieved, we can infer by the close relationship of MWAT to maximum daily measurements in May that stream temperatures warm with distance downstream from the confluence of Sisar Creek and Santa Paula Creeks.

6.3.4 O. Mykiss Presence and Absence Surveys

Potential summer rearing habitat for anadromous fish is primarily limited to Little Santa Paula Creek extending upstream 3.2 miles from the confluence with Sisar Creek to waterfall barriers, and all portions of Sisar Creek below the barriers at RM 5.9 All other tributaries to Santa Paula Creek were completely dry by May. A total of 278 pools were surveyed for *O. mykiss* within the Santa Paula Creek watershed. The rates of observation for age 1+ *O. mykiss* in May were highest in Sisar Creek (75 out of 86 pools), lower in Little Santa Paula Creek (102 out of 148 pools), and extremely low in mainstem Santa Paula Creek, where only two age 1+ *O. mykiss* were observed (2 out of 44 pools). A summary of pools with observed age 1+ *O. mykiss* is provided in Table 6-13. See Steelhead Assessment Maps 4, 5, and 6 for spatial distribution of age 1+ *O. mykiss* in mainstem Santa Paula, Sisar, and Little Santa Paula creeks.

In Little Santa Paula Creek, age 1+ *O. mykiss* were observed throughout the reach for the exception of one portion, between the confluence with Sisar Creek (RM 6.6; Steelhead Assessment Map 6) and La Broche Creek (RM 7.9). The relatively low rate of occurrence in this section of Little Santa Paula Creek could be related to high stream temperatures in that reach. At the time of the May survey, maximum daily stream temperatures were already at 27.8°C, approaching previously reported lethal limits for *O. mykiss* (29.6°C; Myrick and Cech 2001). Even though there was a low rate of occurrence in this reach, *O. mykiss* were present, indicating these temperatures did not exceed lethal values during May.

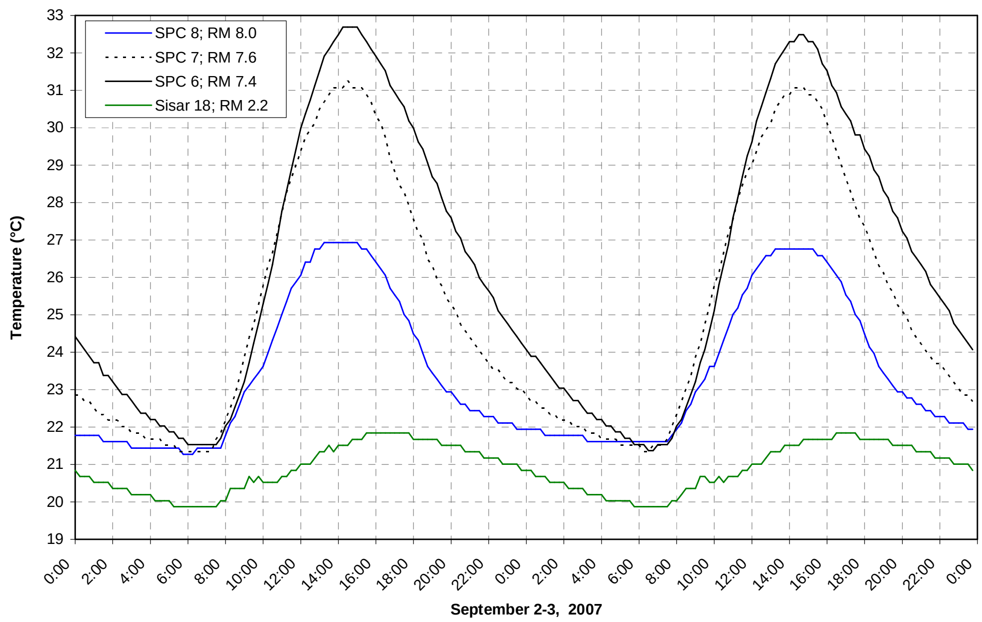
Table 6-13. Pools in Santa Paula Watershed with observations of O. mykiss May 2007.

Reach	# of Pools with Age 1+	Total Pools Surveyed	% of Total Pools with Age 1+
Little Santa Paula	102	148	69%
Sisar Creek	75	86	87%
Mainstem Santa Paula	2	44	<1%
Totals	**179**	**278**	**64%**

During our November 2007 survey, *O. mykiss* were not present in the warmest location where relatively low rate of occurrence was observed in May, near thermograph Site 6 (RM 7.4; Steelhead Assessment Map 7).

This location consistently exceeded 30.0°C for three months, from July through August, with maximum temperatures over 33°C during the hottest day of the year (Figure 6-4; Steelhead Assessment Map 7). However, *O. mykiss* were observed just upstream near thermograph Site 7 (RM 7.6), where temperatures exceeded 30°C for a much shorter duration (only 6 days out of the summer), but reached 31.4°C during the hottest day of the year. These temperatures and the presence of *O. mykiss* are not consistent with laboratory experiments where 29.6°C is defined as the critical thermal maximum temperature for steelhead (Myrick and Cech 2001), and indicates southern steelhead may have higher critical thermal maximum temperature than northern populations.

Figure 6-4: Continuous stream temperature in 15-minute intervals at four locations within the Santa Paula Creek watershed, September 4-5, 2007.



An exception to these patterns of temperature and O. mykiss presence was the observation of one age 1+ *O. mykiss* that was observed in an isolated pool in the middle of the dry reach (RM 7.1; Steelhead Assessment Map 7). Although data on small seeps was not gathered, some observations of local pockets of cool water in warm pools was observed during the previous survey, and may explain the rare presence of age 1+ *O. mykiss* within the dry reach. Stream temperature data is not available within the proximity of this isolated pool, making it difficult to come to conclusions on thermal tolerances at this location.

6.3.5 O. mykiss Population Surveys

A total of 18 units (nine pools and nine pocketwaters) were surveyed for *O. mykiss* densities within Little Santa Paula Creek and Sisar Creek. Densities were similar in Little Santa Paula Creek (ranging from 0.10 fish/m² to 0.96 fish/m²) and in Sisar Creek (ranging from 0.31 fish/m² to 0.87 fish/m²). Densities were also similar between habitat types, although pool habitats resulted with the highest densities of *O. mykiss* in both creeks. Since age classes were difficult to distinguish (see *O. mykiss* Age Class Structure), *O. mykiss* densities were inclusive of all age classes.

6.3.6 O. mykiss Age Class Structure

A total of 440 *O. mykiss* were captured during the electrofishing surveys. Throughout the watershed, fork lengths ranged from 52–214 mm, with over 90% of all captured *O. mykiss* measuring between 70–140 mm. Length frequency histograms can usually be used to determine length at age for *O. mykiss* populations, however differentiating length at age for populations in Santa Paula Creek watershed is difficult.

Up to four age classes are potentially identifiable from the length frequency data. In Little Santa Paula Creek, over 62% of the *O. mykiss* measured ranged from 70–145 mm (FL) and most likely were comprised of a combination of age 0+ and age 1+fish (Figure 6-5).

Similar to Little Santa Paula Creek, a majority of *O. mykiss* were in a similar range of 55–145 mm and also display a possible overlap of age 0+ and age 1+ fish. The exact size range of each age class is difficult to determine because of the lack of obvious modes in length frequencies. In more northern populations such as Devil's Gulch, a tributary to Lagunitas Creek (Marin County, California), length at age is better identifiable because seasonality separates growing seasons and results in a clearer separation in modes for each age class.

The difficulty in distinguishing between the age 0+ and age 1+ fish length frequency graphs could indicate that sublethal effects of temperature have influenced the growth potential for *O. mykiss*. The length frequencies indicate age 0+ *O. mykiss* are large at the end of their first summer suggesting good growth opportunities, however, age 1+ fish are relatively small. Previous studies in the Napa River (Napa County, California) have found that smaller fish are able to achieve positive growth under warm conditions whereas the larger age 1+ fish have difficulty achieving bioenergetic demands in warm reaches. Without scale analyses, it is impossible to reach conclusions about age class structure and to determine whether the growth of age 1+ *O. mykiss* is reduced due to bioenergetic limitations in Santa Paula Creek.

Scale samples were taken from each unit during the electrofishing surveys, but the limitations of the scope of this project did not include analyses of these samples. Future studies could potentially analyze these scale samples, resulting in determination of age class specific densities and to determine difference in growth rates for each age class.

Figure 6-5: *O.mykiss* populations within creeks of the Santa Paula Creek Watershed.

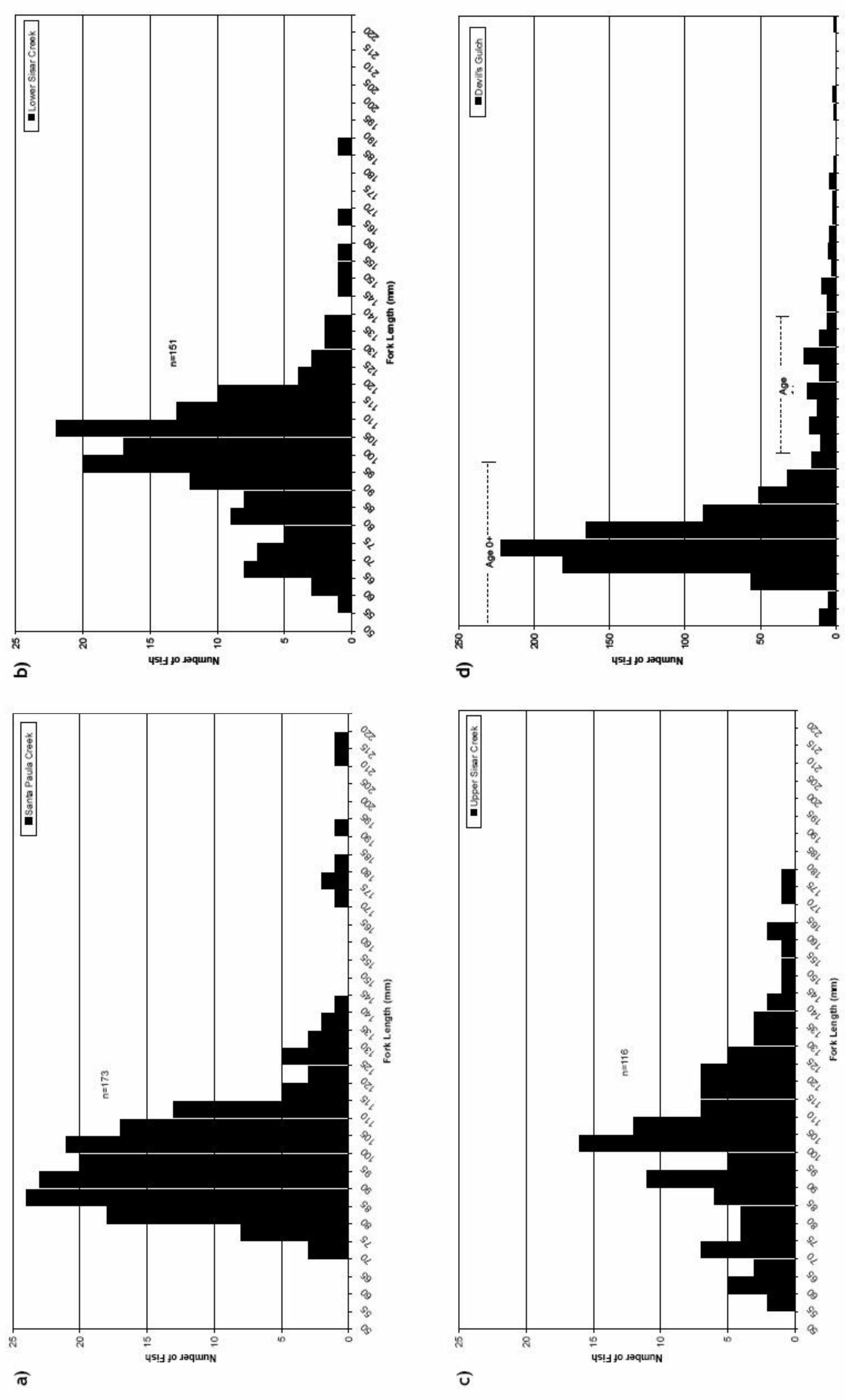


Figure 3-5. Comparison of length frequency histograms for O. mykiss in a) Little Santa Paula Creek, b) Lower Sisar Creek, and c) Upper Sisar Creek in November 2007, and d) Devil's Gulch (Lagunitas Creek, Marin Co.) in October 2006 (Stillwater Sciences, *in progress*).

14 December 2007 *Stillwater Sciences*

7 WATERSHED MANAGEMENT ISSUES AND RECOMMENDATIONS

Like all fluvial systems, Santa Paula Creek responds to numerous natural and human influences across its watershed. Here, highly influential factors include geological type, bedrock exposure and active tectonics, the natural function of lower Santa Paula Creek as an alluvial fan, the semiarid climate and ENSO influence on the frequency of storm events, the frequency of wildfire in the upper watershed, the extent of flow constriction provided by in-channel infrastructure, the history of channelization, and the extent of sediment dredging from the bed of the channel.

The technical reports prepared as part of this study are designed to assist in identifying key management challenges for the Santa Paula Creek watershed. Our focus is to provide a balance between (1) site specific, prioritized recommendations for restoration alternatives that can return southern steelhead passage throughout historically accessible reaches in the Santa Paula Creek watershed, (2) the need to maintain and sustain existing water-diversion rights, and (3) the desire to accommodate and mediate hazards associated with channel erosion and flood risk.

7.1 Summaries of Key Issues

7.1.1 Issues Related to Steelhead Restoration

Studies undertaken as part of this management plan (Stillwater Sciences 2007) provide evidence that Sisar and Little Santa Paula creeks have substantial habitat amenable to Steelhead trout, consistent with previous reports that suggest that the Santa Paula Creek watershed has high habitat quality relative to other Santa Clara River tributaries and is one of the greatest potential creeks for recovery of the Southern California *O. mykiss* DPS (Stoecker and Kelley 2005).

However, habitat quality varies throughout the watershed. Holding and rearing habitat is generally poor in the mainstem Santa Paula Creek (based on the few observations of age 1+ fish during the May 2007 survey), possibly as a consequence of habitat modification, relatively warm water temperatures in this reach, and the occurrence of natural oil and tar seeps (as well as milky sulfur seeps).

In Sisar and Little Santa Paula creeks below the natural passage barriers, habitat quality may vary directly with water temperature. In Sisar Creek, extensive riparian shading maintains relatively cool stream temperatures in the majority of the wetted reaches despite the stream losing surface flow in two locations. The effects of riparian shading are evident in the lower portion of Sisar Creek, which in May heated from approximately 16.0°C to 19.0°C in just 330 ft along a reach that completely lacked riparian vegetation. Because Little Santa Paula Creek currently has virtually no riparian vegetation, water temperature heats rapidly in wider valley segments, and some *O. mykiss* juveniles were observed in habitat with stream temperatures exceeding 29.6°C, the reported lethal limit for the Central Valley steelhead (Myrick and Cech, 2001: we are not aware of published temperature thresholds for southern steelhead). Overall, Little Santa Paula Creek has much greater variability in stream temperature, including a repeated downstream pattern of cyclical warming and cooling. This pattern is predictable, with warmer temperatures occurring in reaches with wider valley-bottom widths and diminishing surface flow, and cooler temperatures occurring in reaches with narrower valley-bottom widths where cool hyporheic flow resurfaces.

The consequence of these temperature dynamics is both that *O. mykiss* may be restricted from some reaches due to high stream temperatures and that there may be sublethal effects of high stream temperature on fish growth. Despite potential adaptation for warmer conditions, fish did not persist over the summer in the warmest reach of Little Santa Paula Creek: the results of a comparison of fish presence in May and November suggest that fish were found in pools where maximum daily stream temperature approached 31.5°C but were absent in pools exceeding 33°C, suggesting upper thermal limits for *O. mykiss* in Santa Paula Creek may be within this range. It was not possible to conclusively differentiate between age 0+ and age 1+ fish from their length frequencies; the unimodal pattern in November suggests that growth of age 0+ fish was good but growth of age 1+ and older fish may be limited by high temperatures. Together, these results suggest that, to the extent possible, maintenance of riparian vegetation and protection of groundwater resources would be important components of planning for *O. mykiss* restoration in the watershed.

Earlier studies (e.g., Stoecker and Kelley 2005) identified three significant passage barriers in the lower Santa Paula Creek that restrict the ability of steelhead to migrate to higher quality habitat within Sisar and upper Santa Paula creeks. These barriers include the USACE channel and fish ladder, the Harvey Diversion structure, and the Caltrans Highway 150 crossings. All three of these facilities require immediate attention in the re-design and the construction of improvements or modifications if passage into the high quality habitat is to be restored.

The study undertaken as part of this report suggests that, in addition to these barriers, maintenance of riparian vegetation and protection of groundwater resources may be critical in maintaining stream temperatures amenable to steelhead holding and rearing.

7.1.2 Issues Related to Water Diversion and Instream Structures/Channelization

Santa Paula Creek receives an extremely high sediment load from the hillslopes as a consequence of its flashy rainfall regime and high rates of tectonic uplift in the upstream watershed, which make abundant sediment available for transport. The steep gradient of the creek enables it to transport this load to the Santa Clara River in a series of concentrated pulses of very coarse sediment occurring during high-intensity rainfall events. Instream structures, including those related to water diversion, have both a profound impact on sediment dynamics, with deposition upstream of the structure and erosion and significant incision in the downstream reach, and can be profoundly affected by sediment dynamics, attested to by damage to the Hwy 150 bridge apron and the USACE fish ladder, and repeated damage to the Harvey Diversion structure.

Geomorphological studies undertaken as part of this watershed plan (Stillwater Sciences 2007b) indicate that ensuring connectivity of course sediment transport may be the single most important factor in preventing abrupt changes in channel morphology, especially associated with channel incision. The impact is consistent both between constrictions caused by natural rock outcrops in the upper watershed and constrictions caused by instream structures in the mainstem Santa Paula Creek. Therefore, the direct maintenance of channel infrastructure and the prevention of deleterious channel morphology modifications both rely on retaining or improving coarse sediment connectivity throughout the watershed.

The effects of interrupting the transport of course sediment can be observed at both the Caltrans Highway 150 crossings and the Harvey Diversion structure. Field observations and historic data suggest that these restrictions are causing a backwater effect during high flow events, which in turn causes upstream sediment deposition and channel aggradation and channel incision directly downstream of the structures. These structures have contributed to the significant channel incision in reach 1 (downstream of the Highway 150 crossings), and reach 6 (downstream of Harvey Diversion), and apparently to subsequent downstream channel aggradation in recent years through reach 7 as eroded sediments from reach 6 are deposited out in the wider channel. Several other structures have had less significant impact, such as the Mupu Road Bridge, which spans the channel at an approximate channel width. The Bridge Road Bridge is constructed into bedrock and was retrofitted in 1999 to offset the impacts of incision occurring downstream of the Harvey Diversion structure. While these structures may not have had a significant affect on the channel morphology, they will provide potential constraints on channel restoration activities and need to be considered in the recommendations of any improvements.

The effects of the emergency bank protection constructed in reach 7 following the 2005 storm event have not yet been determined. The recent trend of aggradation and channel widening may reverse into incision in moderate to small storm events, because the flow is now directed towards the channel center by the constructed spur dikes. This trend could be accentuated if the knickpoint currently at the boundary between reaches 7 and 8 erodes upstream and into this area. Incision during large storm events may be partly controlled by the resistance to flow provided by the dikes, being greater if the dikes retain their form for longer periods. Monitoring of both reaches 7 and 8 is recommended to ensure that knickpoint migration and potential channel incision do not create subsequent passage impediments.

USACE Channel and Fish Ladder was constructed in 2002. Subsequent to the construction of the channel improvements, significant erosion was identified along the channel improvements resulting from the 2002-2003 and 2003-2004 WY storm events. The peak flow rate associated with these events was estimated to be approximately 2,000 cfs, which was estimated to have a 3-year reoccurrence interval. These storm events resulted in degradation of up to 5 feet along reaches of the channel. This erosion had threatened to undermine the grouted riprap bank protection, and resulted to barriers to fish passage. Memorandums from the USACE indicate that the severity of the degradation was unexpected as historically this reach of the creek has been subject to severe deposition of sediment.

Observations of the USACE channel completed in 2007 and 2008 as part of this study indicate that much of the channel appears to be restored back to the original grade. This appears to be a result of the larger storm events that have occurred after 2004. While this may validate the USACE assumption about sediment deposition during large events, it does not mitigate the fact that the channel may be subject to erosion during smaller, more frequent storm events. And that a continued period of smaller events could result in potential bank failure and fish passage barriers. Due to the random and uncertain nature of the sediment transport through this reach on a year to year basis, modifications to the channel, and an adaptive management plan may be required to ensure that the channel is maintained at an appropriate level for flood conveyance, and fish passage.

Improvements to the USACE fish ladder should also consider the high sediment load and assess alternatives to locate the fish ladder outside of the main channel conveyance areas.

Overall, the downstream connectivity of coarse sediment transport may be the single most important factor in preventing damaging morphological changes, especially associated with channel incision—the most severely incised reaches are those just downstream of hydraulic obstructions, both natural (*i.e.*, faults) and constructed (*i.e.*, Highway 150 bridge and Harvey Diversion). Therefore, all future channel infrastructure and channel modifications must be designed to retain or improve coarse sediment connectivity, while opportunities should be taken to redesign existing infrastructure that disrupts sediment connectivity. As such, predicted rates and caliber of sediment transported down the mainstem Santa Paula Creek should constrain the hydraulic design characteristics of any future in-channel structures or modification.

7.1.3 Issues Related to Channel Stability and Flood Risk

The mainstem Santa Paula Creek is highly dynamic, not only because it transports a large amount of coarse sediment in short-lived rainfall events, but also because the sediment load vary considerably between events. For instance, sediment yields from hillslopes may well increase seven-fold until such time that vegetation has recovered after a major fire (under a hypothetical 100% burn scenario), so that floods occurring shortly after fires may be particularly effective at causing morphological change to Santa Paula Creek. Likewise, high-magnitude flood events have been more frequent in the last 40 years due to intense ENSO activity. Periodic revision of flood frequency statistics has been necessary, with the 2005 event (~780 m^3s^{-1}; 27,500 cfs) now considered to be about a 50-year flood event. With the continuation of strong ENSO activity, rates of channel morphological change will be enhanced.

In alluvial and unconfined river systems, river channels are expected to "recover" (at least partially) from passages of incision through a set of processes that include channel widening, aggradation, and the creation of a new floodplain. In many reaches of Santa Paula Creek, however, incision has persisted for decades or centuries, and under current conditions the channel does *not* have a tendency to recover, despite large volumes of incoming sediment available to facilitate recovery. Recovery is impeded by (1) the channel incising (or being dredged) to exposed bedrock, which does not allow significant additional channel widening; (2) channelization and bank armoring, which prevents channel widening; and (3) the existence of hard points on the channel bed from channel infrastructure, which perpetuate channel bed discontinuities (*e.g.*, Highway 150 bridge drop structures, Harvey Diversion, USACE fish ladder).

Therefore, management measures related to channel stability and flood risk should be designed to function within the context of prospective future channel morphologies, or to promote "assisted recovery" of channel form as part of the project. Expenditure on erosion control and flood repairs can perhaps best be minimized by creating a corridor of flood-amenable land uses in the immediate vicinity of Santa Paula Creek.

7.2 Recommended Watershed Actions

From the results of the technical studies, it is clear that the general approach should be in the provision of a wide river corridor without infrastructure constraints in which natural river recovery is possible, flood-related hazards are minimized, and fish passage is assured. Such an approach, of course, must be tempered by existing constraints including land ownership, water rights, and floodplain development. Where possible, however, management actions should seek opportunities to remove existing constraints. In this regard, priority actions would logically include:

1. Encourage a long-term watershed planning effort through a stakeholder process for the Santa Paula Creek watershed (perhaps linked to the Santa Clara River Parkway project, because steelhead restoration requires passage to the mouth of the Santa Clara River).
2. Removal or re-design of the grade control structures under the Highway 150 bridges to present fewer impediments to sediment transport, and to restore fish passage. Without

modifications to the bridge structures to reduce or eliminate these in-stream constrictions, reach 1 will likely continue its current trajectory of channel incision, perpetuating passage barriers to migrating steelhead.

Caltrans is currently designing improvements at the highway crossings to restore fish passage, and the current schedule anticipates construction in summer 2010. The current design includes the construction of 14 rock weir structures downstream of the lower Santa Paula Creek Bridge crossing to re-establish connectivity between the channel grade at the bridges and the downstream channel elevations. The design of the improvements should consider alternatives to improve sediment transport connectivity and reduce the hydraulic impact of the stream constriction through the bridge sections.

3. Re-design or widen the Harvey Diversion facility to present less impediment to sediment transport and fish passage, and to reduce the maintenance costs associated with recent repeated damage to the diversion crest caused by large boulders in transport exasperated by the fish ladder wing wall.

4. Modification of the USACE channel reach, and re-design of the USACE fish ladder.

   Reconstruction of a similar fishway facility will continue to have inherent failure risks, annual debris blockage, and require continual maintenance, or result in limiting or preventing upstream steelhead passage (Stoecker and Kelley, 2005). Improvements to the existing fish ladder should consider the high sediment load and assess alternatives to locate the fish ladder outside of the main channel conveyance areas.

   Modifications to the channel reach need to consider the episodic nature of sediment transport during both large and small scale storm events, and its affects on erosion and deposition in the channel system.

5. Adaptive management of sediment removal activities within the USACE channel reach to maintain the design channel invert, and eliminate potential fish passage barriers resulting from local channel erosion.

   One prospect is to consider long-term agreements for a mining contract within the channel reach that jointly maintains appropriate flood conveyance capacity, channel stability, and fish passage. The agreement might include stipulations on elevations of the channel invert to ensure flood conveyance and scour protection, require channel inspections prior to the steelhead migration season to ensure no fish passage barriers are present, use the proceeds from the contracts to further fish passage projects within the Santa Paula Creek watershed.

6. Monitoring of bed level changes in reaches 7 and 8 to ensure that knickpoint migration does not create steelhead passage impediments.

7. Develop a program to ensure channel stability and flood risk management based on accommodating changes in the frequency of flood events, the sediment loading under individual flood events, and the potential of further climate change.

7.3 Exploratory Analysis of Action #3: re-design or relocation of the Harvey Diversion

Since its original construction in 1910, the Harvey Diversion and subsequent fish ladders have needed frequent repair and modification following large floods. Recent downcutting below the diversion may be related to the installation of the current fish ladder and wing wall in 2000 which further constricted the stream width at this location. The ladder and dam crest were also damaged by the large sediment transported by the creek. Downstream incision exacerbated by the fish ladder and wing wall structure, and structural damage resulting from large sediment transported during major storm events will likely continue while the structure is maintained in its current configuration. The Bridge Road Bridge downstream has also needed repair, and it is possible that incision in the mainstem Santa Paula Creek promoted the extensive watershed destabilization evident in the Mud Creek tributary. Because the current Diversion results in a significant impediment to sediment connectivity, the likelihood of channel recovery is remote, while the likelihood of future damage to the structure including to the fish ladder is high – higher still if intense ENSO conditions continue and/or progressive climate change occurs. It is conceivable that significant expenditure will be required to maintain the viability of either or both of water diversion or fish passage after each large flood event. Reducing the channel constriction in this area by increasing the width of the opening over the diversion and existing ladder, and widening the downstream channel reach may improve coarse sediment connectivity in this area and reduce future stream incision.

7.3.1 Potential Alternatives

A conceptual alternatives analysis was prepared for the Harvey Diversion, and the associated fish ladder and water diversion facilities. For the variety of alternatives considered, excluding the "no action" alternative, the primary goal is to establish long-term sustainable fish passage throughout the main stem of Santa Paula Creek in conjunction with maintaining the existing water rights diversion from the creek.

The following five alternatives were formulated and evaluated:

HD-1: No action: the channel system will remain in its current configuration. Maintenance and repairs will continue to be required on a per annual basis or as needed to restore connectivity to the existing fish ladder. Existing fish passage and grade control features will continue to be impacted during major storm events.

HD-2: Complete removal of the Harvey Diversion and existing fish ladder: including installation of an infiltration gallery and control house further upstream for water diversion, realignment and extension of the irrigation water supply pipeline, and potential channel widening along the west bank upstream of the Bridge Road crossing.

HD-3: Partial removal of the Harvey Diversion combined with mechanical stabilization in the downstream canyon reach: including removal of the upper 10 feet of the Harvey Diversion, complete removal of the existing fish ladder and wing wall, installation of an infiltration gallery and control house further upstream for water diversion, realignment and extension of the irrigation water supply pipeline, potential channel widening along the west bank upstream of the Bridge Road crossing, construction of 18 grade control structures combined to provide 51 feet of elevation drop, construction of rock ramp enhancements at each grade control structure location to promote fish passage.

HD-4: Preservation of the Harvey Diversion in place, combined with mechanical stabilization in the downstream canyon reach: including, complete removal of the existing fish ladder and wing wall, installation of an infiltration gallery and control house for water diversion, realign the irrigation water supply pipeline, potential channel widening along the west bank upstream of the Bridge Road crossing, construction of 22 grade control structures combined to provide 66 feet of elevation drop, construction of rock ramp enhancements at each grade control structure location to allow fish passage.

HD-5: Realignment of the channel and reconnection to the historical floodplain, with preservation of the Harvey Diversion in place: including: complete removal of the existing fish ladder and wing wall, installation of an infiltration gallery and control house for water diversion, realign the irrigation water supply pipeline, grading of a new 500' wide flood plain corridor alignment which begins at the Harvey Diversion, extends along the lower historic floodplain limits marked by the lower terrace to the east, and reconnects to the existing Creek nearly one mile downstream from the Bridge Road crossing, grading of a mildly meandering low-flow channel within the limits of the new floodplain corridor, construction of 3 grade control structures evenly spaced along the new floodplain alignment, construction of bank protection measures at key locations to control/limit movement of the new floodplain alignment boundaries, restoration and landscaping of floodplain corridor.

An alternative analysis technical memorandum was prepared that includes a description, graphic exhibit, and general notes for each of the alternatives, along with discussion of potential advantages, discharges, and project concerns. A preliminary California Environmental Quality Act (CEQA) evaluation and probable project cost estimate was also performed for each alternative. The proposed alternatives identified above primarily focus on the channel reach immediately below the Harvey Diversion, i.e., reach 6, but may also directly and/or indirectly impact reaches 5 and 7 as well. A detailed discussion and assessment of the alternatives is included in Technical Appendix C.

The alternatives analysis identified the use of an in-stream infiltration gallery as an alternative means of diverting water from the creek. In support of the alternatives analysis, a preliminary study for potential locations for an infiltration gallery was performed by Fugro West, Inc., based on available data and limited field investigations. A memorandum of the findings is included in Technical Appendix E. The purpose of the study was to provide a preliminary assessment of the depth of alluvial deposits along Santa Paula Creek near Steckel Park related to the possible location of an infiltration gallery. It is desirable that the infiltration gallery be located in a relatively stable area not subject to seasonal erosion, scour and/or damage from large storm events, and be able to provide up to 3,500 gpm to meet the peak irrigation season demand of the irrigation company. The results of the study indicate that infiltration galleries may be a feasible method for water diversion. Four potential sites were identified upstream of the Harvey Diversion in reaches 2, 4, and 5. The proposed location for an infiltration gallery will need to be based on the final solution for the Harvey Diversion structure, and will require additional field investigations to confirm the site suitability.

7.3.2 Recommendations

Initial stakeholder review revealed no clear preference between the alternatives without further study. However, the dynamic nature of the watershed and the destructive power of the frequently mobilized large sediment make it important for watershed management that the stream constriction above the Harvey Diversion is removed. As such, a preferred solution is likely to require removal of the existing water diversion facilities and associated wing walls and fish ladder on the west bank of the creek. The water diversion facilities could most effectively be replaced by an upstream underground infiltration system with a pumped discharge piping system for water delivery. This would limit future impacts to fish passage and eliminate annual streambed preparation associated with the current diversion system. If the existing Harvey Diversion is to remain in place, the infiltration system could be potentially located on the upstream side of the existing concrete structure providing grade control and associated scour protection for the infiltration system.

If the Harvey Diversion structure is left in place, grade control structures will likely be required downstream to assist in progressively filling the canyon reach, potentially in combination with widening of the west side of the canyon reach. A phrased approach is proposed, funded over a period of years allowing time to review the effectiveness of completed work and allowing the potential for adaptive changes to the engineering design in response to monitored response of the channel. Property acquisition or easement arrangements should be considered to enable necessary channel widening.

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TECHNICAL APPENDIX A
Photographic survey of study reaches

TECHNICAL APPENDIX B
Steelhead Habitat and Population Assessment Maps

TECHNICAL APPENDIX C

Harvey Diversion Alternatives Analysis Technical Memorandum

TECHNICAL APPENDIX D
Cultural Assessment

TECHNICAL APPENDIX E

Fugro West Memorandum – Santa Paula Creek Watershed Planning Project, Potential Locations for an Infiltration Gallery

TECHNICAL APPENDIX F
Floodplain Mapping and Stream Profiles