DONALD BREN SCHOOL OF ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Steelhead Passage Restoration Options for Cañada de Santa Anita, Santa Barbara County, California

Photograph courtesy of Mark Capelli, 2008.

Group Project
submitted in partial satisfaction of the requirements for the degree of
Master of Environmental Science and Management
March 21, 2008

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project report is authored by MESM students and has been reviewed and approved by:

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March 2008

ACKNOWLEDGEMENTS

We would like to thank our faculty advisor Tom Dunne, Bren School Professor, for his patience, support, and guidance on the project. We would also like to thank our clients, Anne Coates, Hollister Ranch Conservancy, and Hollister Ranch Owners' Association for proposing and funding the project. In addition, we would like to thank the Coastal Ranches Conservancy for their assistance in funding. Furthermore, we would like to thank our external advisors for their comments, guidance, and support: Mark Capelli, NMFS; Matt Stoecker, Stoecker Ecological, Inc.; Moe Gomez, Earth Island Institute; and Tim Robinson, Cachuma Water Board. Likewise, we would like to thank Greg Helmer, RBF Consulting, for taking the time to provide his survey experience and equipment for the project. Finally, we also want to thank our friends, fellow students, and families for their support.

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LIST OF ACRONYMS

DFG	California Department of Fish and Game
DEM	Digital Elevation Map
DPS	Distinct Population Segment
DO	Dissolved Oxygen
ESA	Endangered Species Act
F&WS	U.S. Fish and Wildlife Service
HRC	Hollister Ranch Conservancy
HROA	Hollister Ranch Owners’ Association
NED	National Elevation Dataset
NMFS	National Marine Fisheries Service
NFS	National Forest Service
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
SHMP	Sodium hexametaphosphate
TRT	Technical Recovery Team
USGS	United States Geological Survey

UNITS AND VARIABLES

D_{50}	Mean grain size
h	Height of flow
h_c	Critical depth of flow required to initiate particle motion for bed load
H_2O_2	Hydrogen peroxide
K_e	Inlet head loss coefficient
P	Suspendibility
Pa s	Pascal second(s)
Q	Discharge
Q_2	The peak discharge with a 2 year return interval
s	Slope of the stream
u	Flow velocity
U*	Flow shear velocity
w	Stream channel width
ρ_s	Density of sediment
ρ_w	Density of water
ω_s	Particle settling velocity

ABSTRACT

Over the past few decades, steelhead (*Oncorhynchus mykiss*) populations in southern California have declined to roughly one percent of their historical numbers, and the southern steelhead is now listed as an endangered species. Santa Anita Creek was identified as having the greatest potential for steelhead restoration on the privately-owned Hollister Ranch, located in Santa Barbara County, California. However, a 4.5 meter high dam and seven culverts block access to spawning habitat and have been identified as potential threats to steelhead upstream migration. To provide the Hollister Ranch Owner's Association and the Hollister Ranch Conservancy with steelhead passage restoration options we 1) analyzed the feasibility and consequences of a number of techniques for removing the dam and its impounded sediment, 2) assessed each culvert's impact to fish passage and recommended options for redesign, and 3) evaluated the current quality and quantity of spawning and rearing habitat in the creek. We predict that by removing the dam and six culverts Santa Anita Creek would provide 3.2 km of suitable steelhead spawning habitat. We define four dam removal and sediment management options, each with an associated level of risk and cost, for Hollister Ranch to weigh for their steelhead restoration endeavors.

EXECUTIVE SUMMARY

BACKGROUND AND SIGNIFICANCE

The recovery of viable populations of steelhead (*Oncorhynchus mykiss*) in southern California and elsewhere in the western United States is currently a high priority for local, tribal, state, and federal interests (NMFS, 2007b). The southern California steelhead was once abundant in coastal streams and rivers. Over the past few decades, southern steelhead populations have declined to roughly one percent of their historical numbers, and as a result, the southern California steelhead Distinct Population Segment (DPS) has been listed as endangered under the Endangered Species Act (ESA) (NMFS, 2007a). Obstacles that impede upstream migration to spawning habitat pose the most significant threat to steelhead populations within Santa Barbara County (Stoecker & the Conception Coast Project, 2002).

The Hollister Ranch Owners' Association (HROA) and its subcommittee, the Hollister Ranch Conservancy (HRC), have designated steelhead restoration as one of their top priorities. The Ranch is located on the Gaviota Coast 40 kilometers west of Santa Barbara. Santa Anita Creek, an 8.4 km long creek, has the highest potential for steelhead recovery within Hollister Ranch (Stoecker & the Conception Coast Project, 2002). However, a 4.5 m high dam and seven culverts have been identified as potential impediments to the upstream migration of steelhead. The restoration of fish passage to Santa Anita will require not only the removal of the dam and re-engineering of the culverts, but also the management of a large volume of sediment impounded behind the dam. Various options exist for removing these barriers and impounded sediment and improving habitat along Santa Anita Creek.

PURPOSE AND RESEARCH QUESTIONS

The purpose of this project was to provide our client, the HROA, with an evaluation of potential steelhead passage restoration options and an assessment of the current habitat quality in Santa Anita Creek. Specifically, we answered the following research questions:

1) What is the feasibility of removing barriers to steelhead migration in Cañada de Santa Anita?
2) If the barriers are removed, what is the quantity and quality of steelhead habitat that will become available?

APPROACH

To answer the above research questions, we took the following approach:

1) Using surveying and sampling techniques, we characterized the sediment impounded behind the dam to estimate its volume and grain size composition. With this information, we calculated the potential fate and transport of released sediment and assessed its potential impacts on habitat and

infrastructure downstream of the dam. These results, in combination with a review of relevant literature, allowed us to develop four dam removal and sediment management options for the HROA.

2) After characterizing the seven engineered barriers along Santa Anita Creek, we assessed the impact each barrier had on the upstream migration of steelhead using California Department of Fish and Game fish passage protocol. The fish passage modeling software, FishXing, was used to analyze the extent to which stream crossings blocked upstream migration. Barrier removal was then prioritized based on geographic location. Analysis of technical literature on barrier removal informed suggestions for retrofitting each barrier.
3) Field surveys were conducted to assess the current quality of habitat characteristics necessary to support steelhead, including water temperature, canopy cover, and the quantity and quality of pools and spawning gravel. From these measurements, the quantity and quality of steelhead habitat found within Santa Anita Creek was determined. In addition, predictions were made regarding the amount of spawning and rearing habitat that would become available if the dam and impounded sediment were removed and the stream channel was restored to pre-dam gradients.

Field work was limited to only two reaches of channel where we were granted access by Hollister Ranch landowners. When necessary, extrapolations were made to include the inaccessible areas of Santa Anita Creek.

DAM REMOVAL AND SEDIMENT MANAGEMENT

Results of the dam and impounded sediment survey allowed us to estimate that the impounded sediment volume is approximately 100,000 m^3, consisting of 62% silt and clays, 35% sands and 3% gravels.

Sediment transport calculations revealed that silt and clays would be transported to the estuary upon dam removal by average wet season stream flows. Once at the estuary, this fine sediment would be deposited until a combination of conditions including sufficient flows, low tide and a breached sand bar allowed it to flow to the ocean. Under commonly occurring flow conditions the remaining sediment, coarse sands, gravels, and cobbles, would deposit between the dam and the railroad crossing. Sorting of these materials would occur as cobbles and gravels deposited closer to the dam and the sands deposited closer to the railroad crossing.

Overall, release of sediment from behind the dam is expected to have short term (5 to 10 years) impacts on the steelhead corridor habitat found in Santa Anita Creek. A potential benefit of sediment release would be an increased spawning gravel supply to downstream reaches of the creek. This supply has been reduced by the low stream gradients found immediately behind that dam which cause stream velocities to slow and larger sediment particles, including gravels, to be impounded. Of primary concern is the deposition of sands between the railroad crossing and the dam, which could reduce the culverts' conveyance capacity. We predict the accumulation of up to 16,000 m^3 of sand and gravel in the vicinity of the railroad crossing as a result of Santa Anita Creek's most frequent stream flow conditions (one year recurrence interval). Even during less frequently occurring stream flow conditions (ten year recurrence interval), coarser sand and gravel deposition will threaten the conveyance capacity of downstream culverts.

Once sediment transport patterns of the creek were understood, we were able to identify four dam removal and sediment management options for the HROA. These options and their associated levels of risk and cost are listed below.

1) Complete dam removal with natural sediment transport: *High risk, low cost*
2) Complete dam removal with partial sediment excavation and bank stabilization: *Moderate risk, moderate cost*
3) Complete dam removal with complete sediment excavation: *Low risk, high cost*
4) Incremental dam removal with natural sediment transport: *Moderate risk, high cost over an extended period of time*

Cost estimates for the dam and sediment removal options range from one to three million dollars.

BARRIER ANALYSIS

Each of the seven culverts found in Santa Anita Creek were identified and assigned a number one through seven, with lowest number referencing the culvert with closest proximity to the ocean. Stream Crossing One was expected to provide passage for all steelhead age classes at all times. Stream Crossings 2-6 are essentially impassable. Stream Crossing Seven was expected to have 28, 17, and 0 days of passable flow for adult steelhead during the wettest, average and driest years on record, respectively. Stream Crossing Seven was not predicted to be passable by younger steelhead age classes.

The amount of habitat contributed by the removal of each barrier was the main driver for prioritizing stream crossing redesign. Based on California Department of Fish and Game (DFG) protocol, we recommended redesign of Stream Crossing Two to a natural-bottom arch culvert. We recommended replacing Stream Crossings Four, Five, and Six with pre-cast bridges and improving Stream Crossing Seven by replacing the barrier with a larger culvert embedded with natural substrate.

HABITAT ASSESSMENT

Results of our assessment of the estuary's capacity to rear steelhead demonstrate the occurrence of high water temperatures that create potentially lethal conditions during summer months. In addition, dissolved oxygen levels dropped below lethal limits for steelhead and 0% canopy cover was observed near the estuary mouth. However, temperature and dissolved oxygen can vary with location, time of day, and water depth. The extent of our analyses may not accurately depict the degree of environmental variability within the estuary. Therefore, a more detailed biological analysis of the estuary is needed to determine its level of suitability for steelhead rearing in the summer. While our initial analysis of the estuary suggests poor quality summer rearing habitat, it does not discount Santa Anita Creek's utility as a source of habitat for southern steelhead.

The reach of Santa Anita from the railroad crossing to the dam was assessed to be a supportive environment for the upstream migration of steelhead. On the other hand, the reach flowing through the impounded sediment just upstream of the dam was determined to be of lesser quality due to a lack of canopy cover and a lack of complex instream habitat. However, we predict that by removing the dam and allowing the channel to return to its natural gradient, 0.8 km of current migration corridor would be transformed into suitable spawning and rearing habitat.

The reach of Santa Anita Creek upstream of the impounded sediment was evaluated to be suitable spawning and rearing habitat. Water temperatures remained below stressful ranges for steelhead and canopy cover was dense. Two out of nine pools contained high quality spawning gravels. In addition, trout were observed in two pools during our study, indicating the stream's current ability to support steelhead.

Based on our analysis, we estimate that Santa Anita Creek currently provides a total of 2.4 km of suitable quality habitat capable of supporting spawning southern steelhead. In total, Santa Anita Creek is predicted to currently have a total of 43 pools, ten of which would contain gravel patches to facilitate spawning southern steelhead. Upon dam removal, an additional 0.8 km of spawning and rearing habitat could become available for a total of 3.2 km. This 3.2 km is predicted to contain a total of 53 pools and 13 pool tail-outs with patches of gravel for steelhead spawning.

RECOMMENDATIONS AND CONCLUSIONS

Restoration of fish passage to Santa Anita Creek could benefit the southern California steelhead by contributing to the currently limited amount of accessible spawning habitat available to steelhead, including those that stray from the major rivers of the region. Six of the seven stream crossings found on Santa Anita Creek currently impede upstream fish passage. We recommend that these barriers be replaced based on DFG protocols for fish passage restoration. In addition to the creek's six impassable stream crossings, the 4.5 m high dam would need to be removed in order for steelhead to access the suitable spawning and rearing habitat observed during our field assessment. Management of the 100,000 m^3 of sediment impounded behind the dam is the largest impediment to restoration because of its cost and potential for adverse effects downstream. We define and analyze four dam removal and sediment management options for the HROA to consider, each with an associated level of risk and cost. Ultimately, it will be up to Hollister Ranch to weigh the various risks and costs in order to decide which, if any, they will pursue to restore steelhead passage to Santa Anita Creek.

1.0 PROJECT OBJECTIVES

1.1 PROBLEM

The National Marine Fisheries Service (NMFS) has identified physical impediments to fish passage as one of the principal threats contributing to the destruction, modification, or curtailment of steelhead (*Oncorhynchus mykiss*) habitat in southern California (NMFS, 2007a). Dams, diversions, and other engineered barriers have blocked migration to the majority of southern steelhead spawning and rearing habitat in the mainstems and upstream tributaries of most of the watersheds in southern California (NMFS, 2007a).

Cañada de Santa Anita (Santa Anita Creek), located within Hollister Ranch on the Gaviota Coast approximately 40 kilometers (km) west of Santa Barbara, California, has been identified as having potential for restoration to promote the recovery of southern California steelhead (Stoecker & the Conception Coast Project, 2002) (Figure 1). A naturally occurring population of coastal rainbow trout/steelhead (*Oncorhynchus mykiss*) is thought to be supported by Santa Anita Creek (Boughton & Goslin, 2006). Coastal rainbow trout that migrate to the ocean are considered steelhead, and rainbow trout residing solely in freshwater are capable of reproducing offspring that will become anadromous southern steelhead (Santa Ynez Technical Advisory Council, 2000). Santa Anita Creek was designated as critical habitat for southern steelhead by the NMFS in 2005 (NMFS, 2005; NMFS, 2007a; Stoecker & the Conception Coast Project, 2002). However, Santa Anita Creek presently contains several engineered barriers, including one road crossing, one low-flow crossing, four Arizona crossings or culvert-road crossings, and a roughly 4.5 m high dam, which are suspected to block steelhead migration to upstream spawning and rearing habitat.

Figure 1: Location of Santa Anita Creek Watershed

The Hollister Ranch Conservancy (HRC), a subcommittee of the Hollister Ranch Owners' Association (HROA) committed to conservation of the Ranch's natural resources, has identified steelhead restoration on Santa Anita Creek as a priority. As a result, the HROA wishes to evaluate options for restoring steelhead migration to Santa Anita Creek. Voluntary restoration of steelhead passage to Cañada de Santa Anita will require a substantial amount of effort and resources from Hollister Ranch. As such, a careful evaluation of potential payoffs associated with various restoration options is necessary. In order to provide our client, the HROA, with a solid foundation on which to base their decision about whether and how to proceed with restoration goals, our group project will answer the following research questions:

1) What is the feasibility of removing barriers to steelhead migration in Cañada de Santa Anita?

2) If the barriers are removed, what is the quantity and quality of steelhead habitat that will become available?

1.2 PURPOSE

The purpose of this project is to provide the HROA with an evaluation of potential steelhead restoration options. We will determine the potential payoff in steelhead habitat through a variety of barrier removal methods. The word restoration has been used to describe a wide range of actions undertaken to enhance ecosystems. For the purposes of this project, we define the word restoration from the perspective of the southern steelhead, assigning it the following meaning the alteration of an ecosystem toward a preferred state.

Ultimately, Hollister Ranch's decision to proceed with a steelhead passage restoration project along Cañada de Santa Anita will require the consideration of many other concerns beyond the scope of this assessment. The restoration project would be subject to an intricate set of local, state, and federal regulations. In addition, the HROA would likely need to develop a coalition-building strategy among landowners in support of the project, especially those landowners whose property is located along the creek. Before addressing these time-consuming tasks, a prudent approach would be to first determine whether or not steelhead restoration is even a feasible and worthwhile option. Our goal is to provide the HROA with a focused evaluation to aid that first important decision.

2.0 PROJECT SIGNIFICANCE

2.1 SIGNIFICANCE TO SCIENCE AND SOCIETY

The recovery of steelhead in southern California and elsewhere in the western United States is currently a high priority for local, tribal, state, and federal interests (NMFS, 2007b). The southern California steelhead was once abundant in coastal streams and rivers. Over the past few decades, steelhead populations have declined to roughly 1% of their historical numbers, and as a result, the southern California steelhead Distinct Population Segment (DPS) has been listed under the Endangered Species Act (ESA) (NMFS, 2007a). In addition to their historical, cultural, and economic value, steelhead are important ecological indicators of the health of coastal freshwater streams and riparian habitats (NMFS, 2007b).

Federally sponsored steelhead restoration efforts are gaining momentum in southern California, as evidenced by the completion of the NMFS's 2007 *Federal Recovery Outline for the Distinct Population Segment of Southern California Coast Steelhead* (NMFS, 2007a). However, few local steelhead restoration projects have been completed, especially on smaller coastal streams. As a result, additional examples of steelhead passage improvement provide opportunities for study. Additionally, few dams have been removed from coastal California watersheds, and dam removal studies are limited in number and scope. An evaluation of the feasibility of barrier removal for steelhead passage restoration on Santa Anita Creek will apply current passage improvement theories and practices to a small dam and other passage impediments in southern California.

2.2 SIGNIFICANCE TO HOLLISTER RANCH

This project will create a foundation from which our client can address steelhead restoration projects on Hollister Ranch. The information gained through this study will identify the restoration options for Cañada de Santa Anita and contribute to the Hollister Ranch Watershed Management Plan. At the same time, this project will promote stewardship through restoration among private property owners and has the potential to further improve the working relationship between Hollister Ranch, the communities of Santa Barbara County, and state and local oversight agencies.

3.0 BACKGROUND

3.1 STEELHEAD AND THEIR RECOVERY

3.1.1 Rainbow Trout and Anadromous Steelhead

Oncorhynchus mykiss consists of both anadromous and non-anadromous populations (Santa Ynez River Technical Advisory Committee, 2002). Rainbow trout, individuals of the non-anadramous population, are fish that complete their entire life-history cycle in freshwater. These fish share many of the same ecological requirements as their anadromous relatives and are crucial in the sustainability of the steelhead population (Stoecker & the Conception Coast Project, 2002). Rainbow trout add genetic diversity to the steelhead population as they can produce steelhead as progeny, and vice versa (NMFS, 2007a; Boughton et al., 2006). Steelhead and rainbow trout can be found at the same time within a stream connected to the ocean and are indistinguishable as juveniles (Santa Ynez River Technical Advisory Committee, 2002).

3.1.2 Endangered Species Status

Steelhead trout are of the Salmonidae family and have a North American range that extends from Alaska to Baja California, Mexico. The southern California steelhead DPS was listed as endangered by the NMFS on August 18, 1997 and was reaffirmed on January 5, 2006. A DPS is a vertebrate population or group of populations that is discrete from other populations of the species and significant in relation to the entire species (NMFS, 2007c). The ESA provides for the listing of species, subspecies, or distinct population segments of vertebrate species. Of all 15 steelhead DPS, the southern steelhead is the only population listed as endangered. Extirpation rates of the species correspond with latitude, as the most southern range of the species experiences the highest extirpation rates (Boughton et al., 2005). As illustrated in Figure Two, the range of the southern steelhead DPS is confined between the Santa Maria River in San Luis Obispo County, California to the U.S. – Mexico Border (NMFS, 2007a).

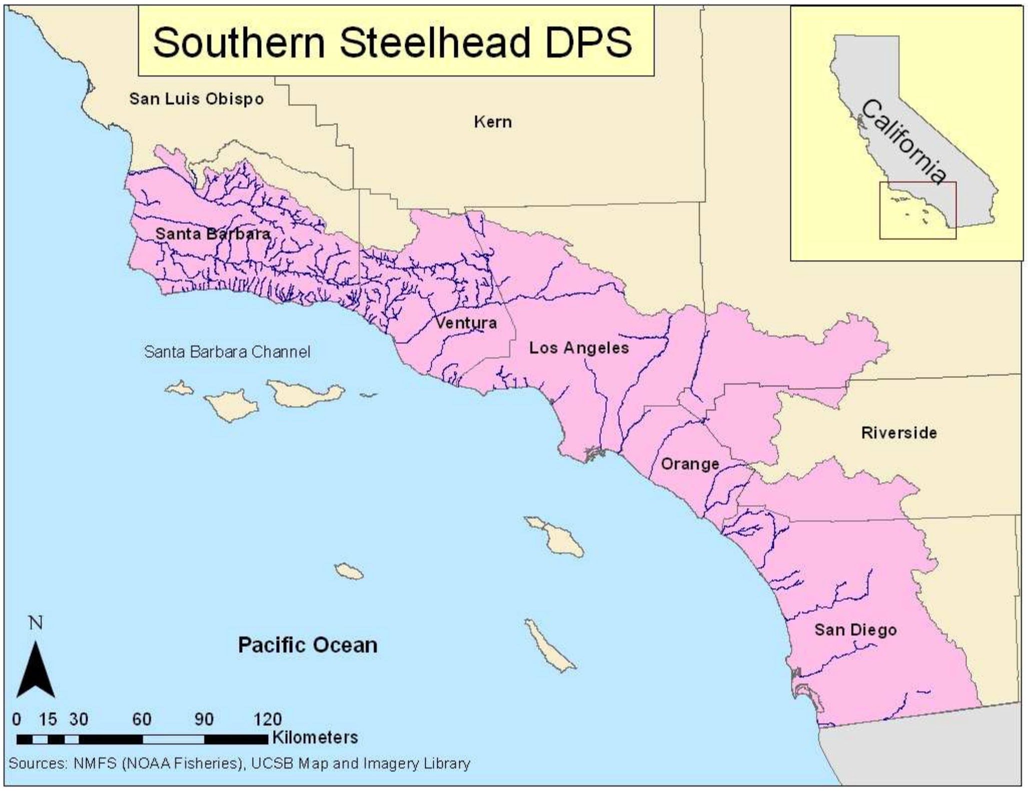

Figure 2: Range of southern steelhead DPS

Within this range, four main rivers constitute southern steelhead DPS habitat, including the Santa Maria, Santa Ynez, Ventura, and Santa Clara Rivers. The National Oceanic and Atmospheric Administration (NOAA) assigned southern steelhead a Recovery Priority Number of three, indicating that the population faces a high magnitude of threat, moderate recovery potential, conflict with future anthropogenic development and disturbance, and population extirpation through their historical range.

3.1.3 Population History

Pre-1960 southern steelhead runs in the four major rivers were estimated to be 32,000 to 46,000 individuals. Currently, southern steelhead populations, including both anadromous and landlocked fish, do not exceed 500 individuals (NMFS, 2007a). Therefore, approximately 1% of historical populations currently exist (Stoecker & the Conception Coast Project, 2002). River-specific estimates indicate the degree to which run sizes have been reduced. In the Santa Ynez River the adult steelhead run size was estimated to be less than 100 adults, and in the Santa Clara River run sizes were estimated to be less than 5 adults per year (Good, 2005). Such a dramatic population loss increases the threat of extinction due to a lack of genetic variability (F&WS, 1997).

3.1.4 Threats to Survival

The extensive loss of steelhead populations in the large regional rivers can be attributed to a number of factors, including urbanization, channelization of rivers and creeks, wetland loss, grazing, and the introduction of invasive species. However, the greatest threat to southern steelhead population viability in small Santa Barbara streams is the presence of engineered barriers to fish migration (Stoecker & the Conception Coast Project, 2002). These man-made barriers prevent access to prime spawning and rearing habitat, which is crucial to the steelhead lifecycle and critical to population viability. While the relative importance of restoring fish passage on one of the four major rivers within the southern steelhead DPS exceeds the contribution of dam removal on Santa Anita Creek, fish passage improvements on the creek increase the diversity of habitat options available to migrating southern steelhead in a region marked by unreliable stream flows.

In Cañada de Santa Anita, factors that may negatively impact southern steelhead include:

- One dam and seven engineered barriers that prevent upstream migration to suitable spawning habitat
- Potential high water temperature
- Limited presence of gravel for spawning
- Limited number of rearing sites
- Susceptibility of pools to sedimentation

3.1.5 Steelhead Life History

Steelhead trout are an anadromous species, meaning that they live the majority of their lives in the ocean but return to freshwater streams to spawn and rear their young (McEwan and Jackson, 1996). Alevins, a fish in the larval stage that has not yet emerged from the nesting area, hatch in freshwater streams three weeks to two months after fertilization, depending on water temperature (NMFS, 2007a). Approximately four weeks after hatching, fry leave the gravel nest, known as a redd, and form schools along the protected areas of the banks. Until one year of age, fry live in the deeper pools. In coastal southern California streams 67-96% of young-of-the-year steelhead reside in upstream pools (Stoecker & the Conception Coast Project, 2002). Eventually young steelhead migrate to the stream's estuary to adapt to the saline water conditions and continue to rear.

Many individuals move quickly through the estuary to reach the ocean, while others, particularly in northern California, remain in the estuary for 6 to 9 months (Bond, 2006). Estuaries provide important northern California steelhead habitat because they allow for both growth and adaptation to oceanic temperature and salinity. When smoltification occurs, steelhead migrate to the ocean to spend one to two years feeding, growing, and developing the blue-back coloration from which their name is derived (NMFS, 1996). Since mortality at sea is strongly size-dependent, fish that spend a greater amount of time in the estuary and grow to a larger size have a higher chance of surviving than the individuals that migrate directly to the ocean. Consequently, the estuary-reared northern California steelhead comprise 85% of the adult population returning to migrate upstream (Bond, 2006). However, summer estuarine environments in southern California do not always enhance steelhead growth due to unsupportive conditions, including higher water temperatures and lower dissolved oxygen (DO) concentrations (Boughton et al., 2007). As such, southern steelhead may not spend as much time rearing in the estuarine environment. Therefore, it is possible that estuaries play different roles in the steelhead life history in southern and northern California.

In general, steelhead return to their natal streams to spawn. However, if their natal streams are inaccessible, steelhead adapt and either wait for adequate flows to occur or migrate up another stream nearby. This opportunistic behavior is an important strategy for a species that faces extremely variable climatic conditions and anthropogenic habitat disturbance (Stoecker & the Conception Coast Project, 2002). Upstream migration depends greatly on stream flow and therefore varies seasonally. On average, upstream migration occurs between December and March when conditions are relatively favorable due to increased stream flows and the breaching of estuary sandbars that result from winter storms.

Once upstream, a female steelhead will find a patch of gravel of suitable size and hollow out a depression to deposit her eggs. A male then fertilizes the eggs, and the female covers the fertilized eggs with a shallow layer of gravel for protection (Shapovalov and Taft, 1954). The duration and success of egg incubation is highly variable and depends on water temperature, DO concentration, scour by high flows, predation, and suspended sediment deposition (Stoecker & the Conception Coast Project, 2002).

3.1.6 Habitat

Steelhead require clean, cool water that is high in DO and contains no harmful chemicals. Both water depth and velocity must be sufficient for the fish to by-pass barriers and for keeping channels open for passage. Also, food, such as macroinvertebrates, crustaceans and small fish, must be available for consumption by juveniles. The stream itself must have suitable gravels for spawning, periodic high water flows, cool summer water temperatures, and pools deep enough to provide refugia for hiding from predators. Specific water parameters and channel characteristics for southern steelhead habitat are listed below.

Water Parameters (Depth, Temperature, DO, Flow):

- Sufficient depth, 15 to 91 cm, for overcoming barriers, clearing passageways to and from estuaries, and spawning (Bovee, 1978; as cited in Stoecker, 2002)
- Temperature requirements for steelhead are uncertain, particularly for the southern steelhead population. Minimum water temperatures for steelhead are well below water temperatures observed in southern California coastal streams. As such, maximum temperatures for steelhead are of greater concern

for steelhead survival. A commonly cited upper incipient lethal temperature is 25 degrees Celsius (°C). However, steelhead in southern California have been observed in water temperatures as high as 32 °C (Santa Ynez River Technical Advisory Committee, 2002; Matthews and Berg, 1997; Spina, 2007)

- DO concentrations of at least 3 milligrams per liter (mg/L), depending on environmental conditions, including temperature (Matthews and Berg, 1997)
- Water velocity between 0.15 and 1.1 meters per second (m/s)

Channel characteristics (Gravels, Banks, Debris, Shade, Pools, and Riffles):

- Gravels of 5 to 100 mm diameter for spawning, with less than 5% sand and silt (Bovee, 1978; Reiser and Bjornn, 1979; as cited in McEwan and Jackson, 1996)
- Undercut banks and in-stream riparian vegetation for temperature regulation and security
- Boulders or woody debris for cover, to break current for rest, and to maintain pool formation processes (Stoecker & the Conception Coast Project, 2002; Harrison and Keller, 2003)
- Pools, runs, and riffles are all necessary for invertebrate (food) production and prey capture at different stages of development (Stoecker & the Conception Coast Project, 2002)

3.1.7 Steelhead Recovery Plan

In September 2007, NMFS wrote a Federal Recovery outline for the southern steelhead DPS. In this outline, NMFS states that southern steelhead recovery will require sustaining "sufficient numbers of viable populations…within each of the five Biogeographic Regions to conserve the natural diversity, spatial distribution, and redundancy of the populations, and thus the long term viability of the DPS as a whole" (NMFS 2007a).

NMFS Technical Recovery Teams (TRT) developed seven strategic recovery actions to help achieve viability of the southern California coast steelhead DPS. These seven actions are outlined below.

1) Core populations must be identified, and recovery efforts must focus on maintaining their viability. In general, larger watersheds are more likely to contain core populations because they are capable of sustaining larger numbers of fish.
2) Extant inland populations should be protected to maintain existing population diversity.
3) Sustainable refugia should be identified and maintained to protect the DPS from severe droughts and heat waves, even in the event of long-term changes of climate.

4) More detailed population data should be acquired and population levels should be monitored to assess basin-specific effects of environmental stochasticity in order to provide a more robust viable population size.
5) Estuary and lagoon habitat should be protected and restored, allowing for juvenile growth and protection and the connection of the ocean to freshwater streams.
6) The desire for more research on the southern steelhead DPS must be balanced with beginning specific recovery actions. The creation of strategic plans and timelines will help inform whether to invest in more information collection or invest in recovery activities.
7) Ecosystem management programs should address the natural characteristics of individual stream's sediment and hydrographic regimes. Such programs will aid in understanding the large scale impacts of anthropogenic disturbance on the natural system, which, on its own, is complex and stochastic.

These seven strategies act as a central organizing tool for TRT to prioritize conservation action. By achieving these strategic recovery actions, NMFS is fulfilling southern steelhead recovery efforts under the ESA.

3.2 Regional Examples of Steelhead Recovery

The restoration of steelhead passage to Santa Anita Creek can complement the seven actions outlined by the NMFS. When proposing a project to enhance southern steelhead habitat through engineered barrier removal, guidance of proper steps to take can be garnered through researching similar studies in the region. The following three examples were chosen based on their close geographic proximity and similarity in basin and channel characteristics to Cañada de Santa Anita, as well as their range in project scale.

3.2.1 Arroyo Hondo Creek

Arroyo Hondo Creek, located in northern Santa Barbara County, features a 91 m long culvert that runs underneath California State Highway 101. Downstream of the culvert beneath the old Highway 101 Bridge, is a 61 m long semi-rounded culvert and concrete box channel. The Land Trust for Santa Barbara County has proposed a project to retrofit the culvert with concrete baffles to increase the occurrence of a range of flows through which steelhead can navigate the culvert to access upstream spawning and rearing habitat (Questa Engineering Corporation, 2004). Other objectives, such as coastal lagoon restoration and the construction of additional pool habitat, are proposed to enhance steelhead habitat and stream passage. The Land Trust evaluated numerous culvert modification, habitat enhancement, and pedestrian access alternatives to achieve the most cost-effective and appropriate project. Since fish passage was the project's top priority, structural engineers first evaluated the current culvert and determined that its concrete bottom was essential for culvert stability. The evaluation indicated that, without considering the expensive option of retrofitting the entire culvert, the best way to enhance fish passage was to add concrete baffles to increase depth and reduce velocities of low flows. This change in hydrology extends the window for which upstream fish migration can occur by increasing the range of flows adequate for fish passage from between 0.2 and 0.3 cubic meters/second (m^3/s) to between 0.03 and 2.8 m^3/s.

The Arroyo Hondo project illustrates the severity of threatening Union Pacific Railroad structures by releasing sediment from an engineered barrier removal. The Union Pacific Railroad essentially halted the Arroyo Hondo project due to concerns regarding the negative impacts of sediment clogging the culvert underneath the railroad tracks (J. Mazza, personal communication, June 13, 2007).

3.2.2 Horse Creek

The Horse Canyon dam, spanning 19 m, was demolished in October 2006 to re-establish access to 8 km of steelhead rearing and spawning habitat that had been inaccessible since the mid-1960s. The dam was located on Horse Creek, a tributary to the Sisquoc River in the San Rafael Wilderness of the Los Padres National Forest. Santa Barbara County Flood Control District built the dam to prevent channel-bed and bank erosion and the flow of debris into the river after a devastating fire in Horse Canyon. However, the dam quickly filled up with sediment and completely blocked upstream steelhead migration. Consequently, the decision was made to demolish the dam with explosives. Prior to the blast, biologists surveyed the area for threatened and endangered species. The blast broke the dam into small pieces and winter floods are expected to carry debris and rubble downstream, restoring the creek to natural conditions.

Prior to dam removal, a biological assessment was performed (NFS, 2006). The biological assessment determined that the likelihood of steelhead being present during dam removal was low, the impacted area would be small, the duration of the project would be short, and dam removal would ultimately benefit steelhead by opening up 8 km of previously inaccessible habitat. Furthermore, it was estimated that 11,800 cubic meters (m^3) of sediment, an additional 4-6% of the river's annual sediment load, would be mobilized downstream into the Sisquoc River. Since the amount of sediment expected is such a small portion of the annual average, it is anticipated that all of the sediment released due to the removal of Horse Creek Dam will be mobilized over a single year (Love & Llanos, 2005). Numerous stakeholders were involved in the project, including the California Department of Fish and Game (DFG), Pacific States Marine Fisheries Commission, California Conservation Corps, Community Environmental Council and Stoecker Ecological Consulting (Los Padres Forest Watch, 2007).

This case-study is unique in that the dam was actually removed. As such, this project offers the opportunity to consult with researchers studying the habitat area after dam removal to determine the effects of dam removal on southern steelhead.

3.2.3 Carpinteria Creek

Carpinteria Creek drains 38.8 km^2 (square kilometers) of high quality watershed habitat and ranks as having one of the highest habitat values and restoration potentials for steelhead among all south coast streams (Cachuma Resource Conservation District & the Carpinteria Creek Watershed Coalition, 2005; Stoecker & the Conception Coast Project, 2002). As part of a larger watershed plan, the Conception Coast Project inventoried the culverts on the creek that act as significant barriers to upstream migration. Eleven man-made stream crossings occur in the watershed (Cachuma Resource Conservation District & the Carpinteria Creek Watershed Coalition, 2005). Certain factors, such as effects on flow direction, sedimentation stability, and ecological effects on southern steelhead, were analyzed to determine the most appropriate recommendation for each culvert. Most analyses resulted in the recommendation to remove the culvert and replace it with a bridge to allow for upstream fish migration and sediment transport downstream. Other recommendations included modifying or retrofitting existing structures to improve fish passage. Many stakeholders are involved in the improvement of fish passage along Carpinteria Creek, and discussions with landowners are necessary to generate compromising results that allow for adequate fish passage (Cachuma Resource Conservation District & the Carpinteria Creek Watershed Coalition, 2005).

The restoration of Carpinteria Creek is proposed as part of a comprehensive Carpinteria Watershed Plan. The thoroughness of this plan indicates the complexity of watershed restoration and southern steelhead life-history cycles. Upon its completion our analysis would contribute as one part of a comprehensive watershed plan for Hollister Ranch. In addition, the Carpinteria Watershed Plan evaluates restoration on a culvert-by-culvert basis. Similarly, our project will evaluate each culvert for its restoration potential and recommend options for the removal or modification of each culvert to enhance future fish passage.

3.3 Summary

This section highlights the current, geographically-close, southern steelhead restoration projects. Each project provides insight regarding the process by which dam and culvert removal should take place in the southern California environment. Although the dams differ in size from the dam located on Santa Anita Creek, each project addresses the specific impacts of dam or culvert removal on southern steelhead at their sites. These projects provide a piece of the foundation from which steelhead restoration is understood at Santa Anita Creek.

4.0 BASIN DESCRIPTION: CAÑADA DE SANTA ANITA

4.1 Regional Setting

Cañada de Santa Anita, commonly referred to as Santa Anita Creek, drains a small watershed located on the Gaviota Coast, California, approximately 40 km west of the city of Santa Barbara. As illustrated in Figure 3, the Santa Anita Creek watershed is situated in roughly the middle of the Gaviota Coast and is characteristic of the coast's many small watersheds. When compared to the four larger primary steelhead rivers, Santa Anita Creek can be classified as a secondary steelhead creek.

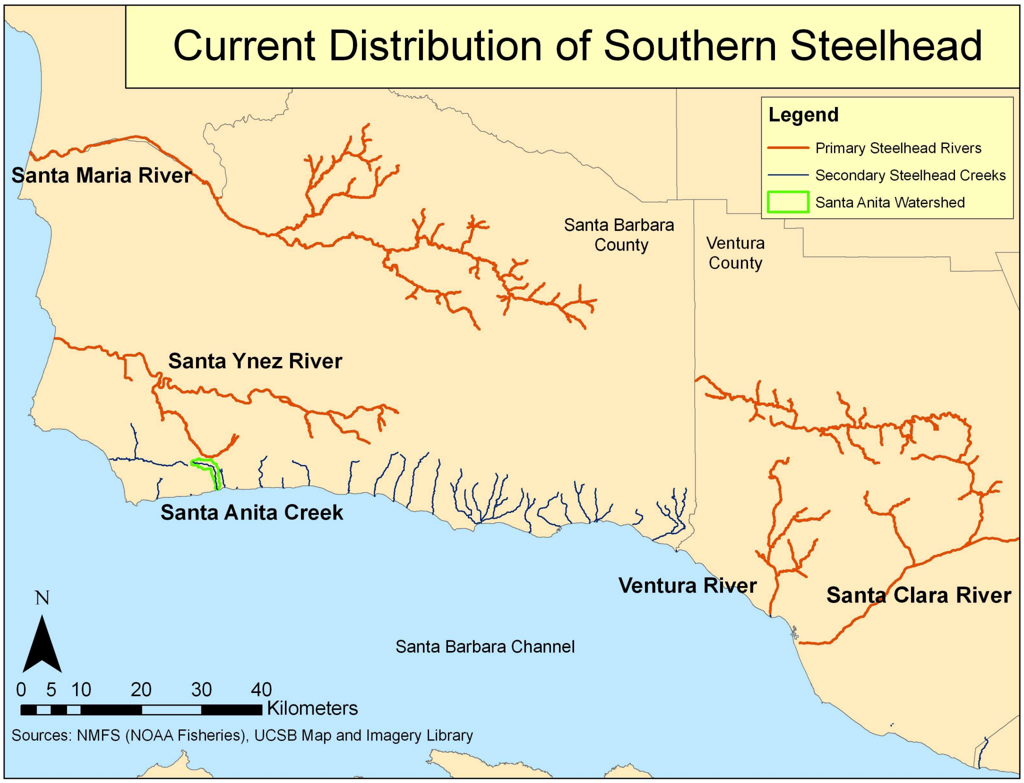

Figure 3: Santa Anita Creek is characteristic of the many small coastal streams located along the Gaviota Coast and can be considered a secondary stream for southern steelhead when compared to the larger rivers located to the north and east.

4.2 The Gaviota Coast

The Gaviota Coast is the longest undeveloped coastline in southern California (Gaviota Coast Conservancy, 2007). The Gaviota Coast has been recognized by the National Park Service (NPS) as a nationally significant resource worthy of preservation due to its unique biological and cultural richness. The coast is located within one of the rarest biomes on earth, the Evergreen Sclerophyllous Forest biome, which features Mediterranean-type vegetation. It is the only location in the United States that features an ecological transition zone between northern and southern Mediterranean communities. As a result of its unique geographic setting, the Gaviota Coast features two of the most biologically diverse ecoregions in the world and is home to 1,400 plant and animal species. Of these species, 24 have been listed as threatened or endangered by federal and/or state agencies (NPS, 2003).

4.3 HOLLISTER RANCH

Hollister Ranch occupies 58.7 km^2 spanning 13.7 km of the central portion of the Gaviota Coast. The lower half of the Santa Anita Creek watershed is located within Hollister Ranch, while the upper half is located primarily in the Poett Ranch. Hollister Ranch was subdivided into 0.4 km^2 parcels in the early 1970's with the intention of creating a new type of residential development that preserved a 200 year tradition of cattle ranching and the relatively unspoiled condition of its land (HRC, 2003). The Ranch continues to be a working cattle ranch under the Hollister Ranch Cattle Cooperative. The Hollister Ranch Owners' Association Board of Directors provides management oversight and develops Ranch policies. The HRC is an advisory subcommittee of the HROA, tasked with protecting and enhancing the Ranch environment (HROA, 2006).

4.4 CLIMATE

The Gaviota Coast has a Mediterranean climate characterized by mild, wet winters and warm, dry summers. Point Conception, located a few kilometers west of the ranch, is considered a major climatic boundary separating the relatively cool and moist conditions of northern California from the warmer, drier conditions found throughout southern California. There are no precipitation gauges located on Hollister Ranch; however, annual rainfall at the Point Arguello gauging station to the west has been recorded to range from 15 to 53 cm, and annual rainfall from the Salsipuedes gauging station to the north has ranged from 25 to 61 cm. Most precipitation falls in winter months. The average daily temperature at the ranch is 15°C, with an average daily low of 8.3°C and an average daily high of 21.1°C (Hendrickson, Farren Jr., & Klug, n.d.).

4.5 CAÑADA DE SANTA ANITA

4.5.1 Geologic and Hydrologic Setting

Santa Anita Creek flows 8.4 km from the Santa Ynez Mountains, part of the Transverse Mountain Range, to the Pacific Ocean, draining a watershed of approximately 8 km^2. Elevations in the watershed range from sea level to roughly 440 m. The Transverse Range represents the landward extension of major sea-floor structures. As a result, layered sedimentary rocks predominate in the watershed and constitute its dominant source of sediment. The lower watershed features various types of shale and minor amounts of limestone, while the upper watershed is comprised of siltstone and sandstone with minor amounts of gravel, as illustrated in Figure Four (Hendrickson et al., n.d.). The shales found in the watershed are easily eroded into clays and silts and, as a result, the majority of the watershed's sediment supply is fine-grained with little gravels. The sediment supply represents a potential management concern for steelhead, as the large amount of fine sediment and paucity of gravels may limit the amount of suitable substrate for steelhead spawning in Santa Anita Creek.

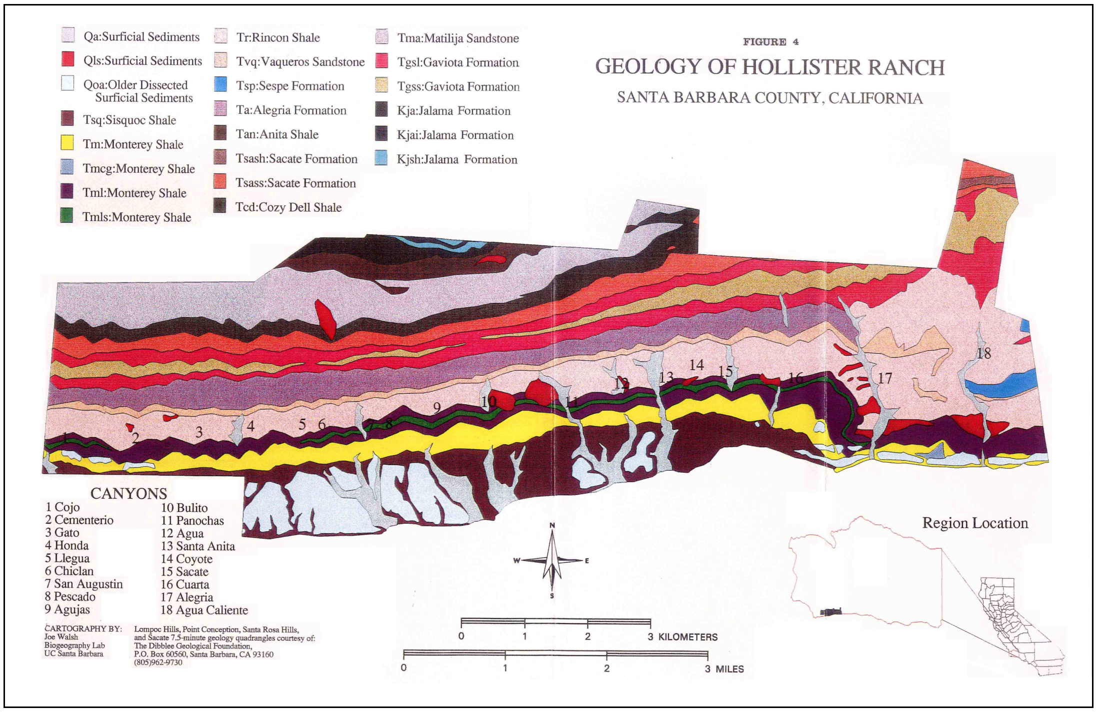

Figure 4: Geology of Hollister Ranch (Hendrickson et al., n.d.)

The management of Santa Anita Creek for steelhead requires an understanding of the watershed's stream flow patterns and their influence on steelhead habitat at various stages of the steelhead lifecycle. Precipitation in the watershed is characterized by large inter-seasonal variability, with almost all of the rainfall occurring during fall and winter months. This variability is reflected in the watershed's hydrograph, illustrated in Figure Five. Inter-annual variability also exists as a result of periodic El Niño Southern Oscillation events. The combination of variable precipitation patterns and steep slopes found within the watershed yields short bursts of high runoff and increased stream flows. These occasional high runoff events wash the watershed's fine sediments downstream and result in turbid stream flows, which can be exacerbated when rain events occur after a fire in the upper watershed's chaparral-dominated hill slopes. While grazing in the hill slopes of the lower watershed reduces fuel loads and the potential for fires, the upper watershed is ungrazed and has not burned in decades. In addition to causing turbid stream flows, large rain events move the creek's gravels downstream and organize them into spawning habitat.

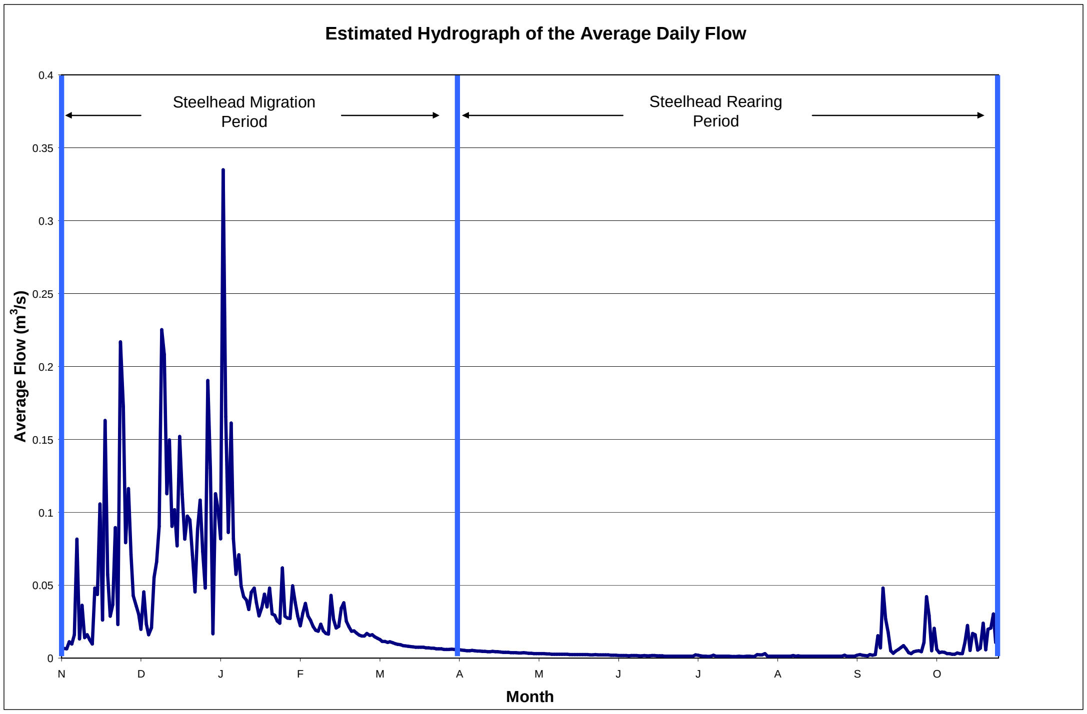

Figure 5: Estimated hydrograph of the average daily flow for Santa Anita Creek. Because Santa Anita Creek did not contain a stream gauge, average daily flow was estimated by scaling average daily flow data from Gaviota Creek and Jalama Creek to Santa Anita.

The southern steelhead has adapted to southern California's flashy hydrological regime, and its life stages are directly influenced by the variable flow patterns observed throughout the region's coastal streams. During wet winter months, stream flows can become great enough to breach the sandbars that separate creeks from the ocean throughout the rest of the year, allowing adult steelhead to migrate upstream to spawn and juvenile steelhead to migrate out to the ocean. During the summer, when stream flow is greatly reduced, steelhead rear in creeks and estuaries and grow stronger in preparation for their eventual migration to the ocean.

4.5.2 Steelhead Migration Barriers

The upstream migration of fish, including southern steelhead, in Santa Anita Creek is naturally limited by a bedrock and boulder waterfall located approximately 4.2 km upstream from the ocean (Stoecker, 2002). The natural barrier also approximately marks the upper limit of the portion of the Santa Anita Creek watershed located within Hollister Ranch, as illustrated in Figure Six. The remaining upper portion of the watershed is located on the Poett Ranch and Lloyd's Ranch. If full fish passage were restored to the creek, the natural barrier would represent the upstream limit of steelhead habitat in Santa Anita Creek.

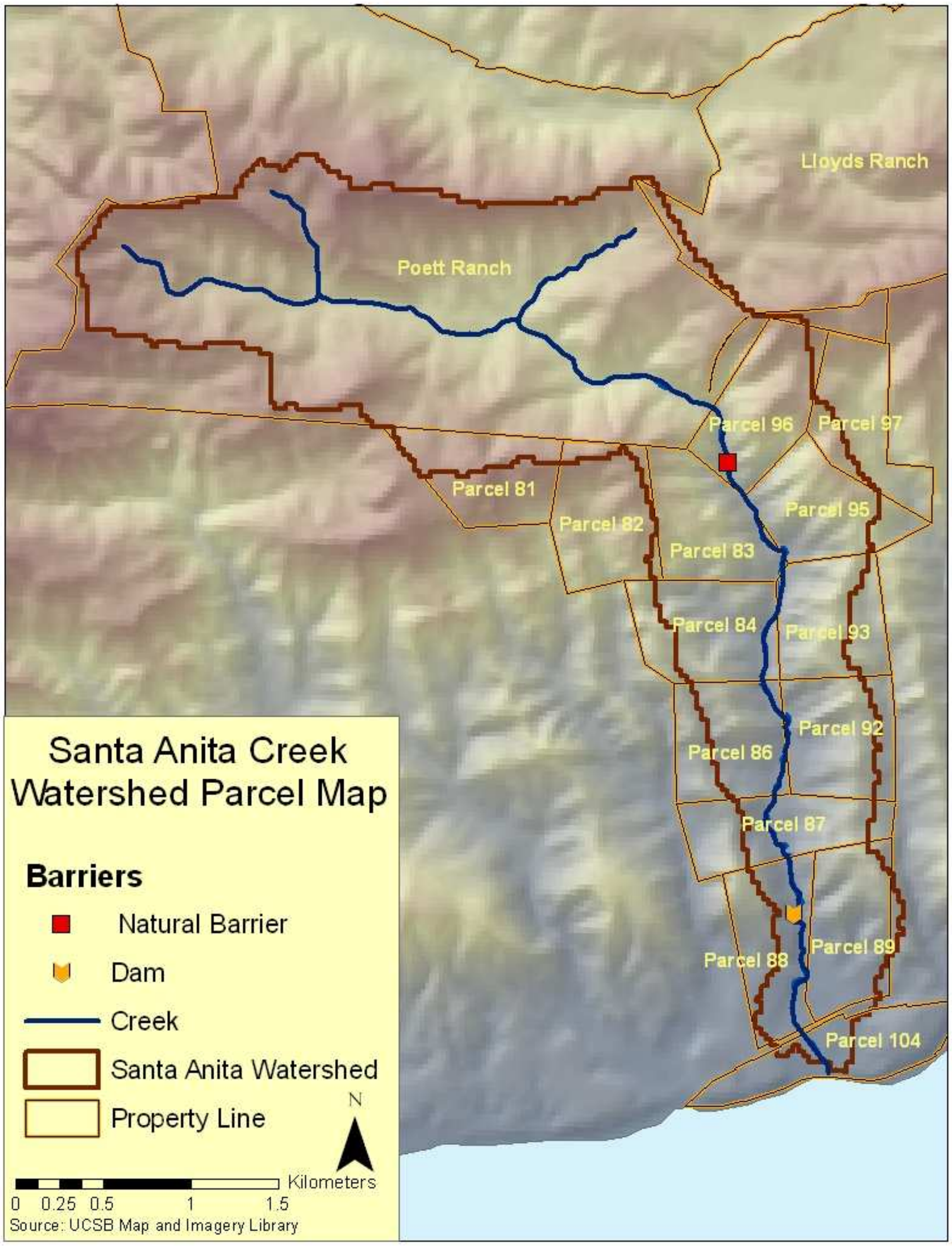

Figure 6: Property ownership in the Santa Anita Creek Watershed. All parcels are contained within Hollister Ranch and owned by individual property owners. The upper portion of the watershed is located on the Poett Ranch and Lloyd's Ranch, but steelhead habitat is restricted from these ranches by the natural barrier.

In addition to the natural barrier, steelhead migration is currently further limited in Santa Anita Creek by 8 engineered barriers, including an impassable 4.5 m high dam. The remaining 7 potential barriers include a culvert passing under the Union Pacific Railroad, an arch culvert passing under Rancho Real Road, and along Santa Anita Road are four Arizona crossings and one low flow crossing. Figure Four illustrates the location of Santa Anita Creek's natural barrier relative to the dam and 7 engineered barriers.

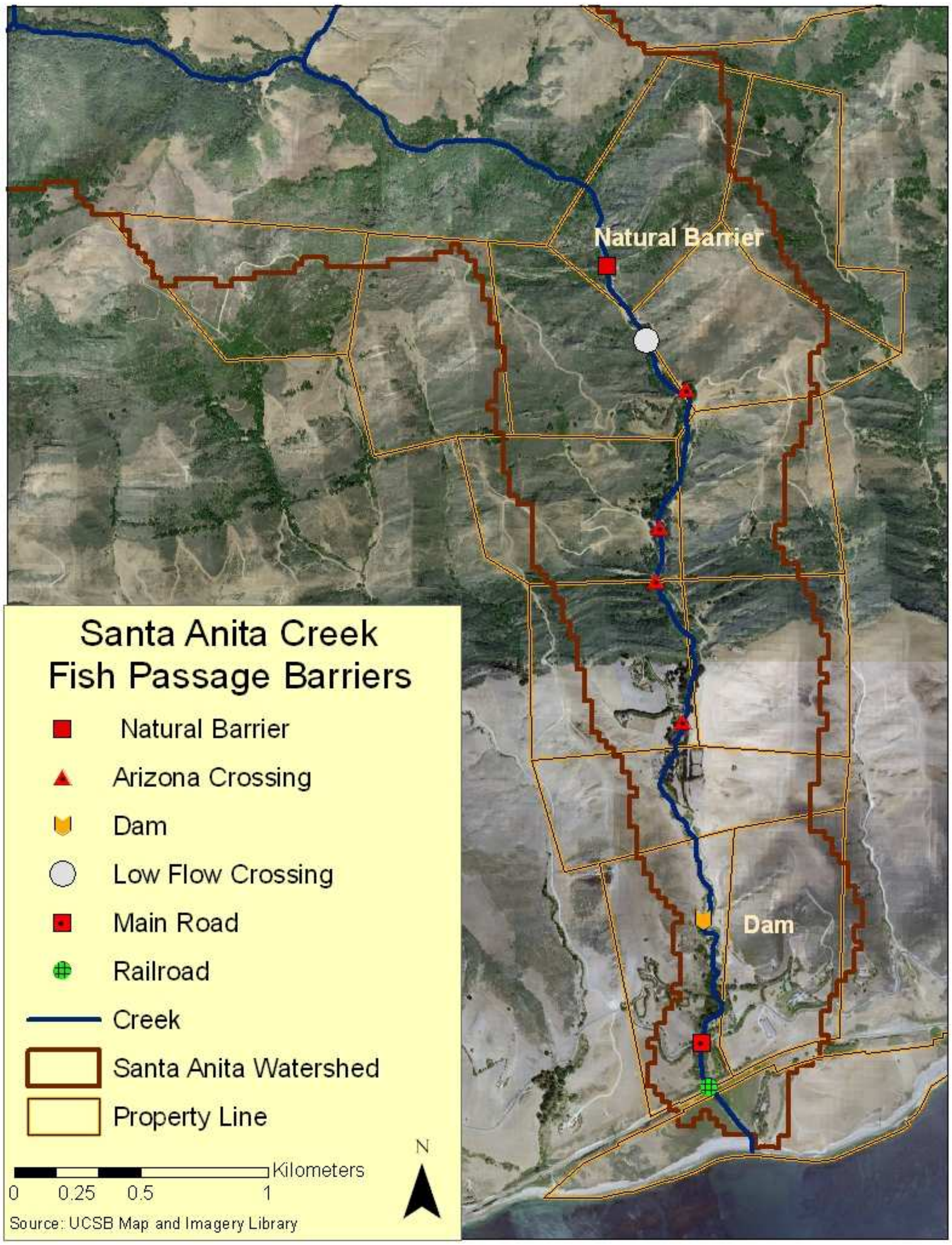

Figure 7: Locations of the engineered and natural barriers along Santa Anita Creek

4.5.3 Habitat Features

Santa Anita Creek drains into the Santa Barbara Channel in the Pacific Ocean at Little Drake's Beach, a popular location for local surfers. The approximately 700 m long beach consists primarily of fine to medium grained sands. Both ends of Little Drake's Beach feature complex intertidal habitat, including tide pools. The tide pools are the location of an outdoor education program facilitated by the Hollister Ranch Conservancy in which local school children are encouraged to explore and learn about intertidal ecosystems during docent-led field trips. In the short term, dam removal activities will increase sediment that is transported to the coast. Upon reaching the ocean, the sediment's fate must be understood so as to prevent unintended consequences to marine habitat, including the tide pools. Silt and clay particles will not settle in high energy beach environments. Instead, they will be carried further off shore by currents and will eventually settle on the deep sea floor. Sand-sized sediment is expected to remain in the coastal zone and gradually be moved alongshore by currents and wave action in a process known as littoral drift. Sand along the coast of Santa Barbara County is generally transported via littoral cells from the north to the south.

Santa Anita Creek features a 125 m long and approximately 250 - 350 m^2 estuary located roughly in the center of Little Drakes Beach (Figure 8). The estuary is one of California's few remaining estuarine wetlands, 90% of which have been destroyed. Estuarine wetlands are a specific type of wetland found when stream flow mixes with the ebb and flow of the ocean. Santa Anita Creek's estuary has been identified as critical habitat for the federally endangered tidewater goby (USFWS, 2008). While the end of the estuary closest to the ocean is relatively shallow, approximately 0.3 to 0.6 m in the summer, and lacks canopy cover, the upstream margin of the estuary features an approximately 3 m deep pool, denser canopy coverage, and complex in-stream habitat, which may provide shelter for southern steelhead. Except for a few limited occurrences during high stream flows in the wet winter months, the estuary is separated from the ocean by a sand bar. In addition, just upstream of the estuary an approximately 0.16 km section of Santa Anita Creek was observed to be dry during the 2007 summer, disconnecting the estuary from upstream surface flows.

Figure 8: The Santa Anita Creek Estuary

Upstream of the estuary, the creek supports a relatively intact riparian corridor and suitable steelhead habitat. Canopy cover along the riparian corridor predominately consists of mature native species, including coast live oak (*Quercus agrifolia* ssp. *Agrifolia*), California sycamore (*Platanus racemosa* var. *racemosa*), and various riparian shrubs that provide a high level of canopy cover. Portions of the riparian corridor that have experienced a higher degree of disturbance, including those found surrounding the estuary and along the plain of impounded sediment behind the dam, feature a reduced amount of canopy cover and a higher proportion of non-natives including eucalyptus trees (*Eucalyptus* sp.), Peruvian pepper tree (*Schinus molle*), poison hemlock (*Conium maculatum*), sweet fennel (*Foeniculum vulgare*), and tree tobacco (*Nicotiana glauca*). The stream channel is relatively steep, with slopes ranging from approximately 0.05-2% below the dam and approximately 2 to 3 % above the dam. Low flow channel widths range from 2 to 4 meters, and in general, are wider below the dam than above it. Habitat above the dam features many boulder and log jam induced constrictions, creating stable step pools. Constrictions of stream flow have been shown to maintain pool habitat in coastal California streams (Harrison & Keller, 2007). The substrate in this portion of the creek consists of a mixture of bedrock, sands, cobbles and boulders. The pools and array of substrate observed above the dam constitute the creek's most suitable steelhead spawning and rearing habitat (Figure 9). Downstream of the dam, fewer cobbles and boulders are observed, and the substrate becomes finer with more sands and silts present. The finer sediments found in pools and pool tail-outs downstream of the dam make this section of the creek more suitable as a migration corridor for southern steelhead (Figure 10). However, dam removal and post-removal channel restructuring in the section of the channel immediately above the dam could increase stream gradients and allow for the transport of larger grained substrate, including gravel, further downstream, which could extend the amount of spawning and rearing habitat available within Santa Anita Creek. In addition to its valuable beach, estuarine, and riparian habitat types, Matt Stoecker and the Conception Coast Project (2002) identified Santa Anita Creek as having potential for steelhead recovery based on the stream's current ability to support a population of coastal rainbow trout.

Figure 9: Riffle found in the upstream end of Santa Anita Creek

Figure 10: Migration corridor found in the downstream end of Santa Anita Creek

5.0 DAM REMOVAL AND SEDIMENT MANAGEMENT

5.1 INTRODUCTION

The largest obstruction to fish passage on Santa Anita Creek is the small dam located in the lower portion of the watershed, 1 km upstream from ocean (Figure 11). The removal of Santa Anita dam would be a significant advancement for the restoration of the creek for the endangered southern steelhead. Several issues need to be addressed to ensure a successful completion of the project. There are a number of dam removal options to consider and important concerns for the management of the large amount of sediment impounded behind the dam (Figures 12a, 12b). This section of the report will address these concerns, as well as the hydrological processes associated with dam removal and the effects these processes can have on downstream habitat and infrastructure.

5.1.1 Santa Anita Dam

Santa Anita dam is a concrete structure measuring 14 m wide by 27 m long by 4.5 m high (Figure 5). The structure has been in place for about 35 years. However, no official Hollister Ranch documents exist outlining the dam’s construction, and the only information available on the dam’s history originates from aerial photos and interviews from longtime Ranch residents. Only a decade after its construction, the dam was rendered useless for storing water after winter storms completely filled in the reservoir with sediment (Hollister Ranch resident, personal communication, 2007). The presence of the dam has caused the channel upstream to aggrade and created a sediment plain that stretches 580 m upstream (Figures 12a, 12b). This sediment plain has become a convenient gathering place for cattle, which is a known concern for the water quality of the downstream reaches and estuary. In addition, the immediate downstream section of the creek has been affected by scouring of the stream dropping off the dam face without a sediment load, resulting in a down cutting of the streambed channel in a 400 m section below the dam. If the dam is removed, Santa Anita Creek will undergo a period of readjustment in which the original pre-dam stream gradient will be restored (Grant, 2005).

Figure 11: Santa Anita Dam located 1 km upstream from the ocean

Figure 12a: The impounded sediment plain looking downstream towards the dam
Figure 12b: Looking upstream on the impounded sediment plain

5.1.2 Dam Removal Options

There are a number of strategies for dam removal and sediment management. To determine which of these options were most appropriate for Santa Anita Creek, we first performed a literature review to gather general background information. To further refine these options, we applied the results of our field-based analyses to the results of our literature review to devise feasible dam removal and sediment management options for HROA.

Three options for dam removal were considered during the literature review, including full removal, incremental removal, and a no-removal option. In addition, three sediment management options were reviewed. Each of these options will have altering effects on the upstream and downstream reaches of the creek and nearby beach, potentially affecting water quality, wildlife, and vegetation. Additionally, each removal option will involve differing advantages and disadvantages regarding time and management intensity, maintenance, and cost. It is important to realize that a tradeoff may exist between negative short-term impacts and long-term benefits to the environment.

5.1.2.a Full Dam Removal

Small dams are often removed all at once using a number of demolition techniques, including blasting, hydraulic fracturing, or a cut and crane method (ASCE, 1997). Blasting involves using explosives to loosen and remove dam components. Hydraulic fracturing is also commonly used and utilizes heavy equipment, such as a hammer or claw backhoe attachment (Graber et al., 2001). Cutting blocks out of the concrete and removing them by crane or heavy equipment is referred to as a cut and crane approach.

Full removal has the greatest immediate impact to the stream, yet requires the least amount of time and project management to meet restoration goals. Following dam removal, water quality is affected by the initial pulse of sediment and debris released during the removal of the dam face and additional pulses coinciding with storm events (Grant, 2005). Altered turbidity and flow patterns have the potential to affect the habitat of aquatic organisms, including fish and other wildlife, dependent on the stream. Increased sediment transport has the potential to reduce culvert conveyance capacity and damage infrastructure. Costs associated with full dam removal depend largely on the type of removal method chosen.

5.1.2.b Incremental Removal

Incremental removal also results in a complete removal of the dam; however, it is executed over time in a progressive fashion. Notching or gradual breaching from the top of the dam is accomplished through the cut and crane method. Incremental removal offers a conservative approach when concerns exist regarding sediment effects on downstream habitat. The end result is similar to full removal; however, greater care can be directed toward potential downstream effects. Incremental removal may lessen negative impacts to water quality, fish, wildlife, and surrounding vegetation. However, this method does take longer and results in increased cost and time involvement. On the other hand, these costs may be offset by less sediment excavation and clean up work after the removal process is complete (ASCE, 1997).

5.1.2.c No Removal

No action options should be considered if removing the dam is not feasible due to concerns regarding the downstream effects of releasing impounded sediment, if upstream conditions do not warrant restoration efforts or if costs are unbearable. No removal maintains the creek's present state, including its current flows and water quality conditions. On one hand, this option prevents detrimental impacts to downstream reaches caused by increased sediment transport. On the other hand, fish passage is not restored. To mitigate the loss of passage, a fishway could be installed or a trap and transport program could be implemented. However, these measures to improve fish passage would likely entail a small return on investment. Fishways require maintenance to keep them free of debris and working properly. Similarly, a trap and transport program is likely to be difficult and time consuming due to the unpredictability of fish arrival and small number of potential migrating southern steelhead (ACSE, 1997).

5.1.3 Sediment Removal Options

Dam removal alternatives are closely tied to sediment management. Our literature review revealed three potential options for managing impounded sediment. These options are as follows:

1) Sediment removal by natural stream flows
2) Mechanical sediment removal
3) Partial mechanical removal with stabilization

This section will review the details of each sediment removal option.

5.1.3.a Natural Sediment Removal

Under a natural sediment removal scenario, the impounded sediment erodes through the process of knickpoint retreat (Grant, 2005). The stream channel cuts into the impounded sediment face and initiates erosion that progressively migrates upstream utilizing natural stream processes to transport the sediment. The sediment plain will erode through down cutting of the knickpoint, bank slope failures, and flushing from the channel bed. This type of erosion continues in episodic pulses, mimicking the flow pattern of the creek until the channel reaches its original pre-dam stream gradient and the remaining impounded sediment along the banks have failed back to a stable angle (Grant, 2005). At this time, all of the erodible sediment has either washed downstream and deposited elsewhere along the creek or washed out into the ocean. Typically, the total amount of eroded sediment from knickpoint retreat is less than the total volume of impounded sediment behind the dam (Grant, 2005).

5.1.3.b Mechanical Sediment Removal

Mechanical sediment removal needs to be considered when the risks associated with releasing sediment downstream are too great. Sediment can be mechanically removed by excavation, slurrying through a pipeline, or bucket dredging. Slurrying is only appropriate in streams with sufficient flow for transporting the sediment, and bucket dredging requires a significant amount of work-effort and machinery (ACSE, 1997). Under an excavation scenario, sediment plains could first be dewatered through the use of extraction wells. Dewatering is necessary to make the sediment plain accessible for the excavation equipment. Feasibility of lowering the groundwater table via extraction wells will depend on the composition of the impounded sediment. Following excavation, sediment can be trucked or moved on a conveyance system to a permanent storage area where it can be stabilized, or reused as fill dirt at a later time. If the impounded sediment cannot be stored or reused, then it will need to be trucked to a disposal facility.

5.1.3.c Partial Mechanical Sediment Removal and Bank Stabilization

Partial mechanical sediment removal combined with bank stabilization requires removing enough sediment to ensure bank and channel stability and the reengineering of a new channel that reflects the pre-dam stream gradient. Dewatering of the sediment plain may also be required to allow for the use of earth moving equipment in the excavation process. Once a new channel is created, the remaining sediment is stabilized by armoring the stream banks, planting vegetation, or a combination of both. The appropriate amount of stabilization depends on the volume of sediment that is required to be stabilized to minimize the impact of sedimentation on downstream infrastructure and habitat. Heavy armoring uses structures such as riprap or gabions to hold back the remaining sediment, while lighter armoring uses native vegetation to stabilize the banks. Enough sediment must be removed to ensure stable bank slope angles, which depend on the soil composition of the impounded sediment. For soils that consist of clays, the bank slope angle may need to be as shallow as 10 degrees (Skempton, 1953). Disposal of the excavated sediment involves the same issues described above.

5.2 METHODS

To further refine the dam and sediment options available to Hollister Ranch, a series of sediment calculations were performed to characterize the nature of the impounded sediment and its potential for transport through the downstream channel. Since the downstream impact of sediment is a key deciding factor in choosing a dam removal and sediment management strategy, calculations were necessary to model the behaviors of its movement.

5.2.1 Historic Discharge Calculation

Historic records of stream flow do not exist for Santa Anita Creek. However, an estimate of historic discharges is required to determine sediment transport capabilities within the creek and upstream migration opportunities.

Historic discharge for Santa Anita Creek was estimated by comparing United States Geological Survey (USGS) stream gauge data from two nearby watersheds, Gaviota Creek and Jalama Creek (Figure 13). Santa Anita Creek watershed encompasses an area of approximately 8.2 km^2 and ranges in elevation from sea level to approximately 440 m. The Gaviota Creek watershed boundary is approximately 3.5 km to the east of the Santa Anita watershed, ranges in elevation from sea level to 800 m, and has an area of 48.9 km^2 upstream from its stream gauge. Discharge records for Gaviota Creek span from 1966 to 1986. The Jalama Creek watershed boundary is approximately 0.7 km to the west of the Santa Anita watershed, ranges in elevation from sea level to 640 m, and has an area of 53.1 km^2 upstream from its stream gauge. Discharge records for Jalama Creek span from 1965 to 1982.

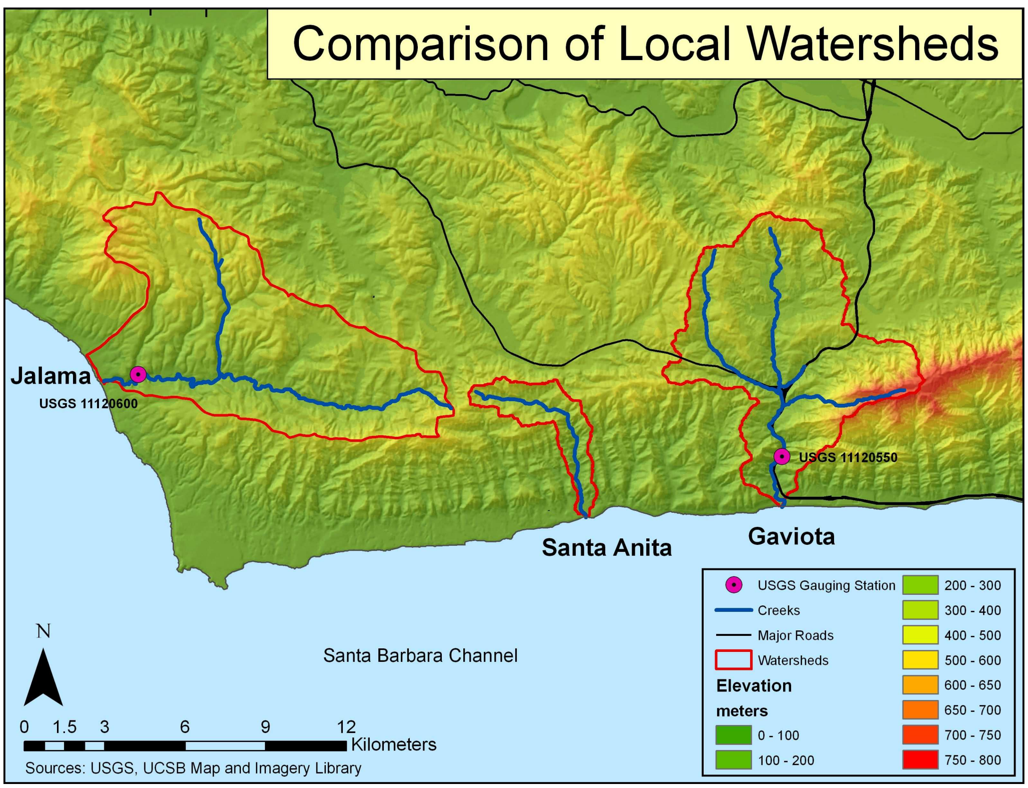

Figure 13: Nearby watersheds and USGS stream gauges used to compute Santa Anita Creek discharge

Santa Anita Creek's discharge was estimated by dividing the area of these nearby watersheds by the area of Santa Anita Creek's watershed to get a proportionate factor. The respective proportionate factor was then multiplied by the corresponding watershed's measured discharge of interest, either peak annual or mean daily discharge. This produced an estimated discharge for Santa Anita Creek. Using the estimated discharge from both watersheds allowed comparison of their predictions. The average value from this comparison was used as the estimated discharge of Santa Anita Creek over the relevant period of time of the original data.

The three watersheds differ in size and elevation, with Jalama and Gaviota having larger watersheds and higher elevations relative to Santa Anita. Consequently, we predict Santa Anita's stream flow to be overestimated because Jalama and Gaviota should receive a proportionately larger amount of precipitation at higher elevations. However, the assumption that Jalama and Gaviota's stream gauge data are representative of Santa Anita's stream flow is reinforced by the fact that both stream gauges produce similar data with similar peak flows and average discharge. Then again, the elevation differences in these watersheds compared to the Santa Anita Creek watershed are higher, and thereby overestimate discharge in Santa Anita Creek by small amounts. The average annual daily flow was used to estimate the average wet season flow for sediment transport calculations and exceedence flows for FishXing analysis.

5.2.2 Sediment Augering and Sampling

The sediment impounded behind the dam was delineated using field surveys (Appendix A), aerial photos, and a digital elevation map (DEM). The impounded area was hand augered and sampled to determine the impounded sediment volume and the grain size composition.

5.2.2.a Locations

A total of eight locations were hand augered to estimate volume and composition of sediment impounded behind the dam (Figure 14). Four locations were chosen along the centerline of the sediment plain (B, E, G, and H) (Figure 15). An additional four locations flanked the two centerline locations closest to the dam (A, C, D, and F). The first row of three hand auger locations (A, B, and C) were approximately 12 m upstream from the dam (Figure 16). The second row of three hand auger locations (D, E, and F) was an additional 36 m upstream (Figure 17). The next hand auger location (G) was an additional 73 m upstream. The final hand auger location (H) was located approximately 140 m further upstream. In total, the hand auger survey extended approximately 261 m upstream from the dam.

The rationale for the hand auger locations was as follows: A, C, D, and F were augered to locate side wall depths for determining pre-dam channel geometry. B, E, G, and H were augered to determine the maximum depth of impounded sediment and pre-dam channel gradient. All locations were used in calculating grain size composition and volume. Also, all holes were augered until drilling refusal were encountered.

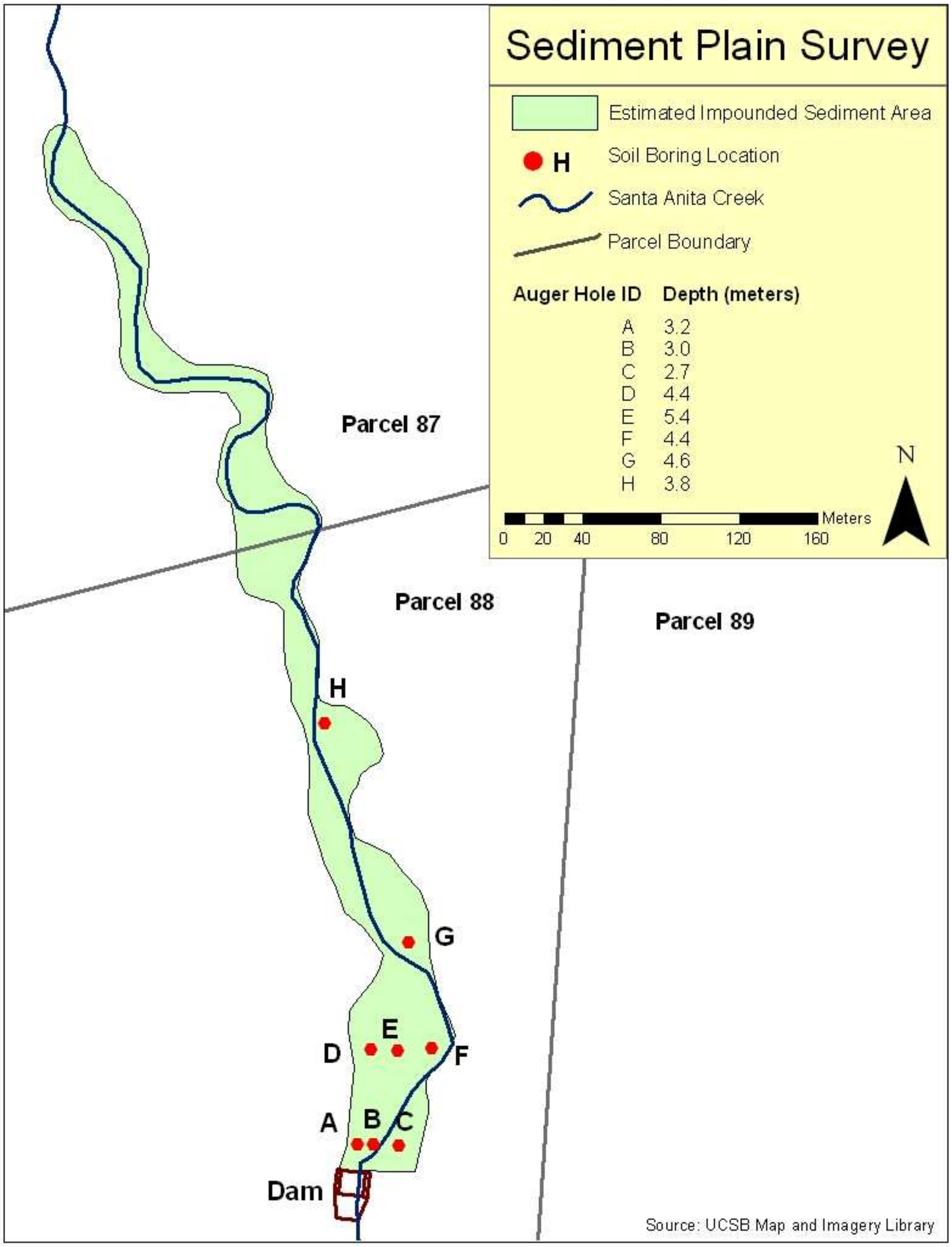

Figure 14: Impounded sediment area and hand auger/soil sample locations

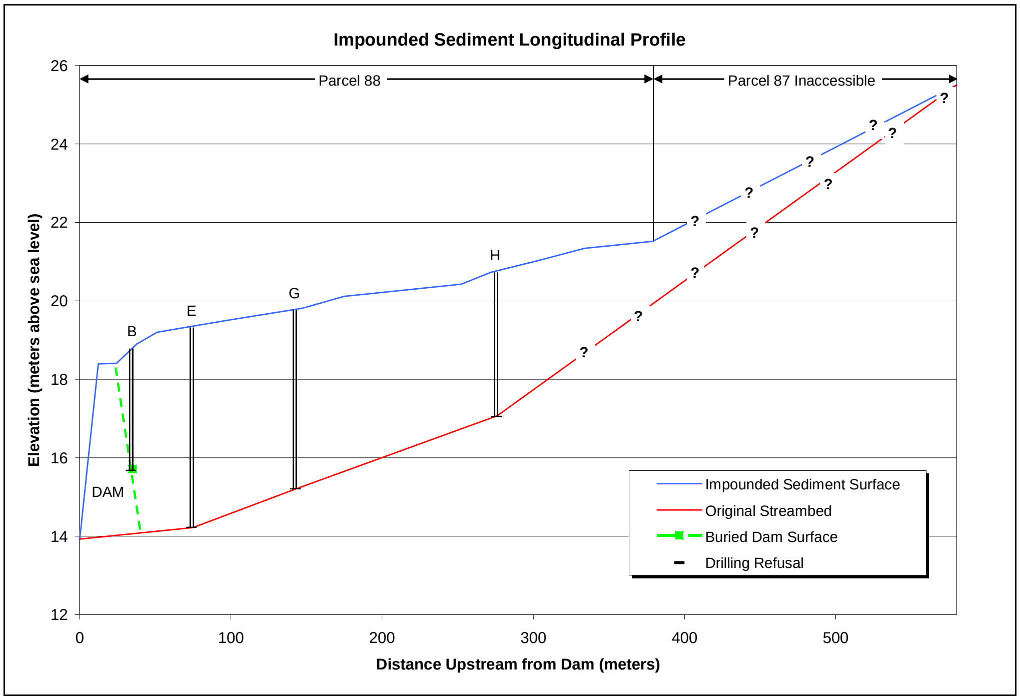

Figure 15: Longitudinal profile of impounded sediment with the pre-dam streambed located from the base of the dam and drilling refusal

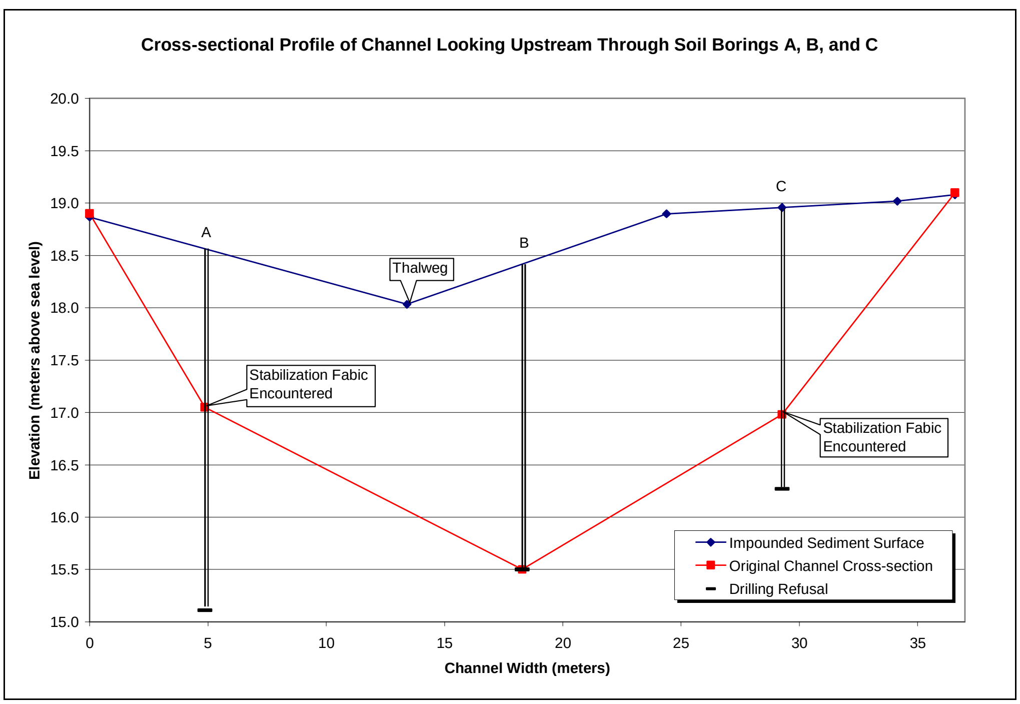

Figure 16: Cross-section of impounded sediment channel with the pre-dam stream channel located from soil borings A, B, and C

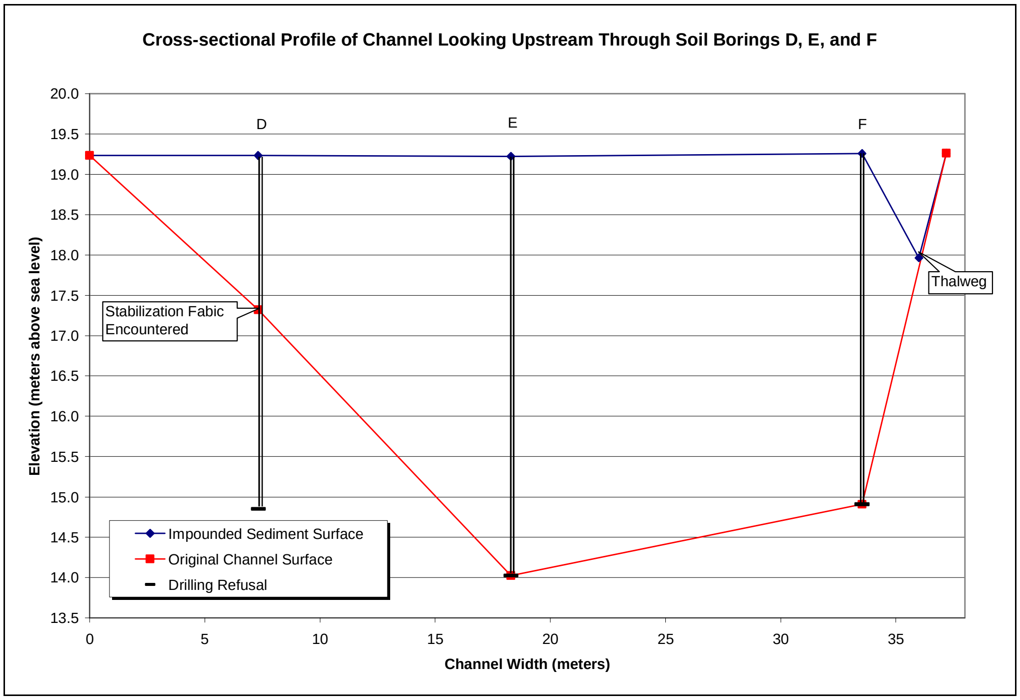

Figure 17: Cross-section of impounded sediment channel with the pre-dam stream channel located from soil borings D, E, and F

5.2.2.b Equipment

Each location was drilled using a hand auger. The hand auger consisted of an 8 cm core barrel and 1.2 m rod extensions.

5.2.2.c Sampling

Soil samples were collected from the auger's cuttings at approximately 0.15 m intervals. Characteristics such as depth, moisture, soil type, color, plasticity, permeability, odor, and other observable features were recorded. Each sample was collected and stored for future analysis in sealable Zip-lock™ bags. Each bag sample was labeled with a sample identification specific to its location, sample interval, date, and sampler's name. Each soil boring location was augered until drilling refusal was encountered.

5.2.3 Soil Sample Description

The clay, silt, sand, and gravel percentages were estimated for each sample. Clay and silt particles were defined as being less than 0.063 millimeters (mm) in diameter. Sand particles were defined to be between 0.063 mm and 2 mm in diameter. Gravel was defined to be greater than 2 mm in diameter. Soil material estimated to be predominantly clay and/or silt was analyzed for plasticity and rated either low, medium, or high plasticity based on the following method:

1) Roll a small amount of wet soil between a palm and fingers until it forms a long, round thread about 3 mm thick.

2) Rate as follows:

- If the thread is formed, but easily broken and cannot be returned to its former state (Low Plasticity)
- If the thread is formed and not easily broken but, when attempted to be rolled to a thread-like state again, it cannot be formed (Medium Plasticity)
- If the thread is formed and, when broken, it can be reformed several times (High Plasticity)

The sand grain size was estimated by tactile and visual inspection. Sand sizes were classified as ranging from very fine, fine, medium, coarse, or very coarse. If gravel size particles were present, the largest diameter of the largest particle was measured and noted. In addition, moisture content was qualitatively described as dry, damp, moist, or wet. Determination of the samples' moisture content was made based on tactile and visual observations.

5.2.4 Wet Sieve Analysis

Wet sieve analyses were performed on six soil samples to calibrate the estimated soil classification made by tactile and visual observations. The analysis was performed using the laboratory methods as described in Appendix B. The percent retained was calculated by the following method:

1) The weight of the wet soil and the percent water weight of the wet soil were used to calculate the dry weight of the soil.

2) The percent of soil retained in each sieve was then calculated by dividing the weight retained from the dry weight.

3) The difference in the weight retained and the original dry soil weight was assumed to be less than 0.063 mm portion of sediment.

The sieve results were compared to visual and tactile estimates of percent composition. Any discrepancy was adjusted accordingly throughout the estimations.

5.2.5 Stream Survey Techniques

For the purpose of calculating sediment transport modes and rates, stream slope and width were measured and roughness was estimated. Slope was measured using a hand sight level, tape measure, and stadia rod. To measure stream slope the stadia rod was placed at water's edge, the hand level was used to measure height from the rod at a distance of approximately 15 m when possible. The distance between the rod and hand level were recorded using a tape measure. Slope measurements used in the calculation of suspendibility, threshold of motion, and rate of transport were averaged over approximately 40 to 63 m.

Stream channel roughness was also estimated later through field observations. Roughness estimates were made by comparing images of streams with known roughness to observed reaches of Santa Anita Creek (USGS, 1967). To account for potential sensitivity of the results based on the roughness coefficient, a range from 0.03 to 0.05 was used. It was determined that within this range there was relatively little difference in the suspendibility calculation's results.

5.2.6 Impounded Sediment Volume Calculation

In order to assess the potential magnitude of sediment that could impact downstream infrastructure and stream habitat, an impounded sediment volume calculation was performed. The downstream limit to impounded sediment was the dam. The upstream limit to impounded sediment was not as obvious. Due to access restrictions on Parcel 87, the impounded area was not fully investigated. In order to overcome this obstacle, 30 m resolution DEM was used to approximate a change in gradient. Approximately 580 m upstream of the dam a 3 m increase in elevation within 10 m of stream length was noted. This location was observed to be the beginning of large cobble and boulder elements uncharacteristic of the sediment plain. Therefore, this was assumed to be the upper limit of the impounded sediment. The border of the impounded area was then estimated using aerial photography and plotted up to the surveyed area (Figure 14).

It was assumed that the original stream bed beneath the impounded sediment was reached at the depths where drilling refusal was encountered during hand auguring. The bottom of the dam was also assumed to be the elevation of the original stream bed. The height of the dam and depth of the soil borings were used to estimate depth of impounded sediment (Figure 15).

The volume was then calculated by breaking the length of the impounded area into seven segments. Each segment's average width was then estimated. Each segment's average depth was estimated from local soil borings when available. A linear rate of decreasing depth was used between the surveyed area and the upstream impounded area limit, and from this, an average depth of each segment was estimated. By summing each segment's product of length, depth, and width, we estimated the volume of the impounded sediment.

5.2.7 Suspended Load Transport Calculation

Sediment can be transported along the stream bed as either suspended load or bed load. In order to assess the stream's potential to transport sediment, we started by calculating the suspendibility (P) for a range of sediment sizes. Suspendibility was determined from flow shear velocity (U^*) and particle settling velocity (ω_s) by the formula:

(1) $$P = \frac{\omega_s}{U^*}$$

Flow shear velocity (U^*) was calculated from the acceleration of gravity (*g*), the slope of the stream's water surface (*s*), and cross-sectional average depth of flow (*h*) from the following relationship:

$$U^* = \sqrt{ghs} \quad (2)$$

Flow depth was estimated using selected discharges (*Q*), stream channel width (*w*), and Manning's equation to solve for velocity (*u*). Manning's equation was used to calculate velocity from flow depth (*h*), slope (*s*), and a coefficient for roughness known as Manning's '*n*'. The resultant equation for estimating height of flow is:

$$h = \left[\frac{Q \cdot n}{w\sqrt{s}}\right]^{3/5} \quad (3)$$

Flow depth was calculated for a range of discharges and coefficients of roughness at three cross-sections downstream of the dam (Figure 18). At each of these cross-sections, measurements of channel slope and bankfull width were made. Cross-section locations were chosen where channel banks were clearly defined.

Using the Weibull method of computing recurrence intervals, four discharges, estimated to be the average wet season flow, and 1, 5, and 10 year recurrence floods, were used to calculate suspendibility. These discharges were 0.05, 0.8, 13, and 17 m^3/s, respectively. These discharges and respective recurrence intervals were estimated from 16 years of daily discharge data at Jalama Creek and Gaviota Creek.

Additionally, the average wet season flow was used. This was calculated from 183 days of an average year with the highest flow. The average of these days was calculated to be 0.05 m^3/s. This discharge represents a more common flow condition experienced in the wet season. Still this mean average wet season flow is greater than the estimated modal flow of 0.01 m^3/s. Therefore, there will be many days with less sediment transport occurring than predicted by the model.

For each cross-section the height of flow with each discharge was calculated. The flow shear velocity (U^*) was then determined for each cross-section and discharge using equation (2).

Particle settling velocity (ω_s) was calculated using Filtration & Separation.com's online tool for determining settling velocity with Stoke's equation for particles less than 0.063 mm in diameter and Heywood's tables for larger particles (Filtration and Separation.com, n.d.). Variables for determining settling velocity include particle size, particle density, fluid density, and fluid viscosity. The settling velocity was calculated for the following particle sizes: 0.063 mm, 0.125 mm, 0.25 mm, 0.50 mm, 1.0 mm, 2.0 mm, 4.0 mm, 8.0 mm, 16.0 mm, 22.6 mm, 32.0 mm, 45.0 mm, and 64.0 mm. Particle density, fluid density, and fluid viscosity were kept constant at 2,650 kilograms per cubic meter (kg/m^3), 1,000 kg/m^3, and 0.001 Pascal seconds (Pa s), respectively. Knowing the particle settling velocity and flow shear velocity and using equation (1), the suspendibility was calculated for each particle size at each cross-section for each discharge. See Appendix C for tabulated results.

5.2.8 Threshold of Motion Calculation

Bed load is the material that is moved along the stream bottom by rolling and sliding. Bed load also forms the channel bed when it is stored between transport events. In order to assess the discharges necessary to initiate motion of specific sizes of bed load particles, a calculation was performed to determine the critical depth of flow required. This calculation used the following formula:

$$(4) \qquad h_c = \frac{k(\rho_s - \rho)D_{50}}{s\rho}$$

where h_c is the critical depth of flow required to initiate particle motion for bed load with a specified mean grain size (D_{50}); ρ_s is the density of the sediment (assumed to be 2,650 kg/m^3); ρ is the density of water (1,000 kg/m^3); s equals the average slope of the stream surface through the cross-section; and k is a constant that ranges from 0.03 to 0.09, but is most commonly about 0.05.

By calculating the threshold of motion for a range of grain sizes, the critical depth of flow can be determined and compared to the flow depth at each cross-section and discharge. With the critical depth known for particle sizes, the discharge (Q) required to produce that depth of flow at each cross-section is determined from the following relationship:

$$(5) \qquad Q = \frac{h_c^{5/3} \cdot w \cdot s^{1/2}}{n}$$

where w equals channel width, s is the slope, and n is Manning's roughness coefficient assumed to equal 0.05. Once the discharge necessary to move a specific particle size was known, the percent of the average year at which that flow is exceeded were estimated from tabulated or plotted exceedence values versus flow values. See Appendix D for tabulated results.

5.2.9 Volume Bed Load Transport Rate Calculation

To understand the relationship of bed load transport rate and conditions measured at each cross-section, we used the online morphodynamic modeling program known as Acronym1_R (Parker, 1990), which computes sediment transport and bed grain size composition changes for a series of cross-sections along a channel. Calculations were made for four discharges: the estimated average wet season flow and the 1, 5, and 10 year estimated return interval flows of 0.05, 0.8, 13, and 17 m^3/s, respectively. These calculations were performed for three different grain size distributions to test for sensitivity. The grain size distribution differences included geometric means of 38.5 mm, 21.0 mm, and 9.62 mm with geometric standard deviations of 2.35, 2.4, and 2.61, respectively. These grain size distributions were chosen based on pebble count data from an upstream pool (geometric mean of 21.0 mm) and adjusted coarser and finer distributions (geometric means of 38.5 mm and 9.62, respectively) from the original pebble count data. These grain size distributions represent a range of possible conditions that were analyzed to evaluate sediment transport rate sensitivity to grain size distribution.

Additional variables necessary for the bed load transport rate calculation included the sediment's specific gravity, assumed to be 2.65, channel slope and width, and a roughness factor (n_k) of 2. This roughness value is suggested by the author (Parker, 1990). The output included the volume bed load transport rate per unit width, Shield's number based on surface geometric mean size, flow depth, shear velocity, and the resultant bed load grain size distribution, geometric mean, and standard deviation. See Appendix E for tabulated input and output for each trial run.

The purpose of these calculations is not to make a specific prediction of what will happen in Santa Anita Creek because the fate of the impounded sediment depends on the magnitude and sequence of rainstorms that occur over several years after dam removal. Since these factors are essentially unknowable in advance, the analysis is meant only to illustrate the general nature (such as distribution patterns of grain size and relative volumes accumulated or transported) of what is to be expected if selected discharges, typical of the region, were to occur. However, the 1, 5, and 10 year recurrence peak discharges chosen in these calculations have relatively short durations. Yet, flows of these magnitudes are known to carry most of the sediment from small watersheds in a Mediterranean climate.

5.3 RESULTS

5.3.1 Sediment Calculations

The fate and transport of the impounded sediment was modeled from the dam to the estuary using sediment transport calculations. Three channel cross-sections were located downstream of the dam (Figure 18). Cross-section One (20 m downstream from the dam) had a stream slope of approximately 0.02, width of 11.9 m, and estimated roughness of 0.05. Cross-section Two (120 m downstream of Cross-section One) had a stream slope of approximately 0.006, width of 3.5 m, and estimated roughness of 0.05. Cross-section Three (480 m downstream of Cross-section Two) had a stream slope of approximately 0.0004, width of 4.0 m, and estimated roughness of 0.05 (Table 1).

Table 1: Channel characteristics at each cross-section downstream of the dam

Cross-Section	Distance Downstream from Dam	Average Stream Slope	Channel Width	Manning's Roughness
1	20 m	2%	11.9 m	0.05
2	140 m	0.6%	3.5 m	0.05
3	620 m	0.04%	4.0 m	0.05

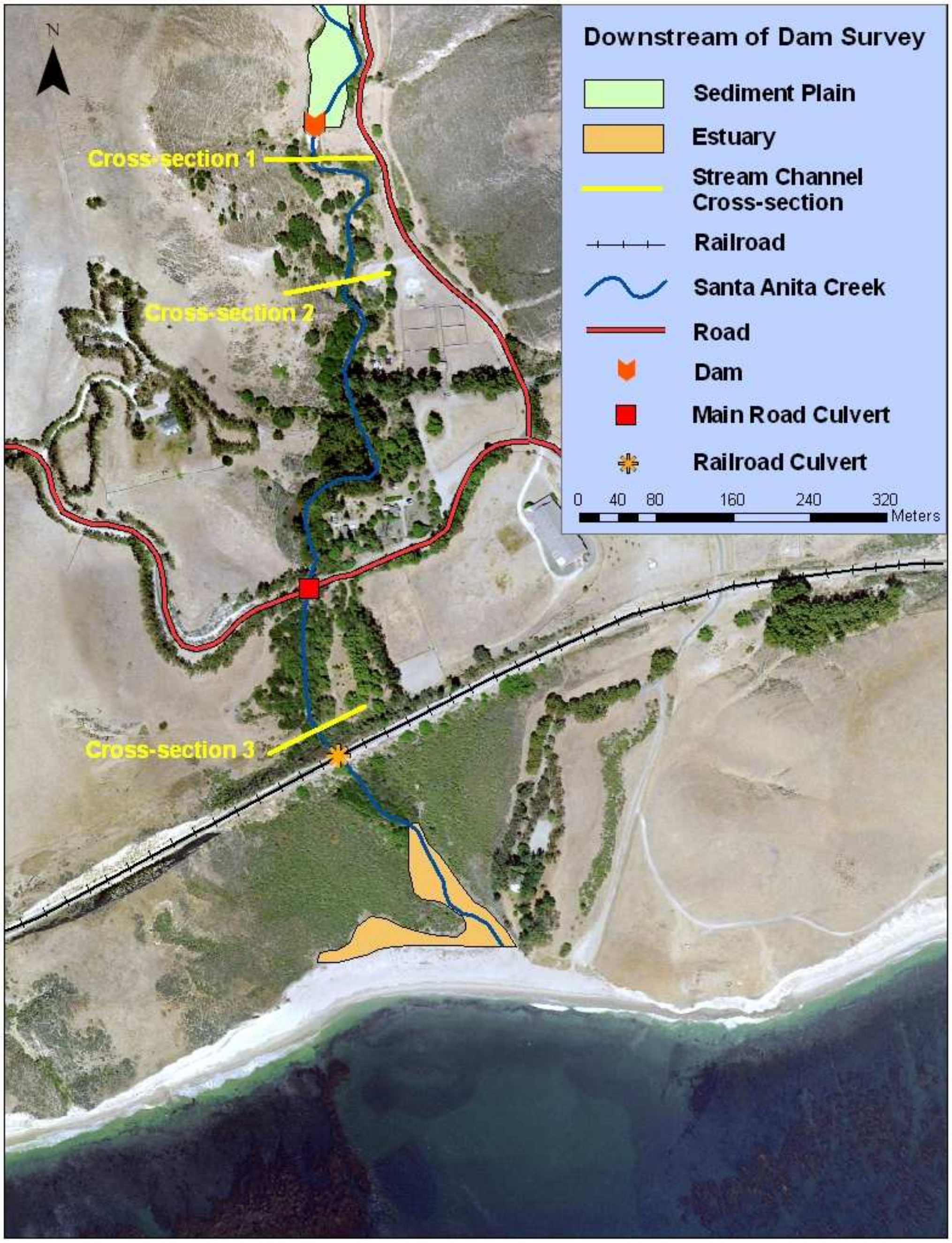

Figure 18: Location of cross-sections in the reach of Santa Anita Creek downstream of the dam

5.3.2 Impounded Sediment Volume

The estimated impounded sediment volume was calculated to be approximately 100,000 m^3.

5.3.3 Impounded Sediment Characterization

Original visual and tactile estimates of grain size composition tended to underestimate the amount of very fine to fine grained sand. As such, silt and clay percentages were slightly overestimated. This discrepancy was adjusted throughout the sample estimates (Appendix B). No other pattern of inaccuracy was noted in the samples' estimated composition.

The impounded sediment grain size distribution was estimated by summing up each sample's clay, silt, sand, and gravel percentages and averaging them. The estimated distribution was: 62% clay/silt, 35% sand, and 3% gravel (Figure 19 below).

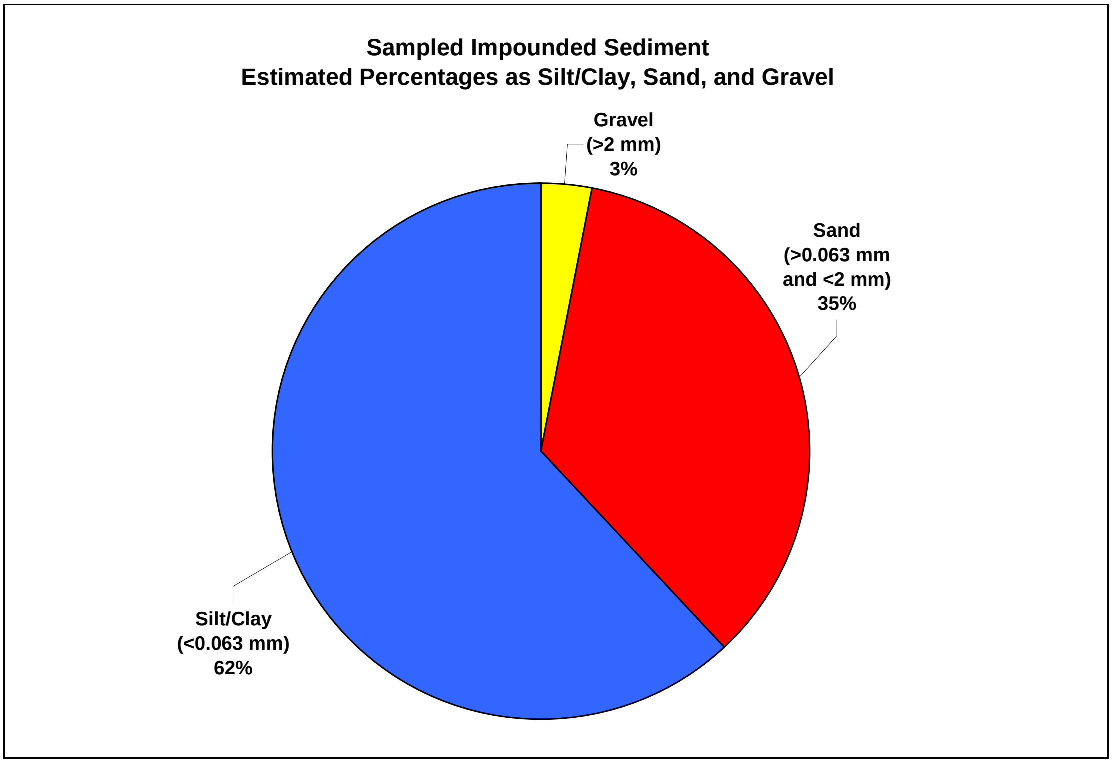

Figure 19: Sampled impounded sediment grain size distribution

To estimate very fine (0.063 mm), fine (0.125 mm), medium (0.250 mm), coarse (0.50 mm), and very coarse (1.0 mm) sand percentages the sieve results were used. Four of the sieve results were believed to have dependable results and were therefore used in this approximation. The percentage retained generally decreased as sieve size became coarser, indicating that the majority of the sediment was fine grained (Figure 20).

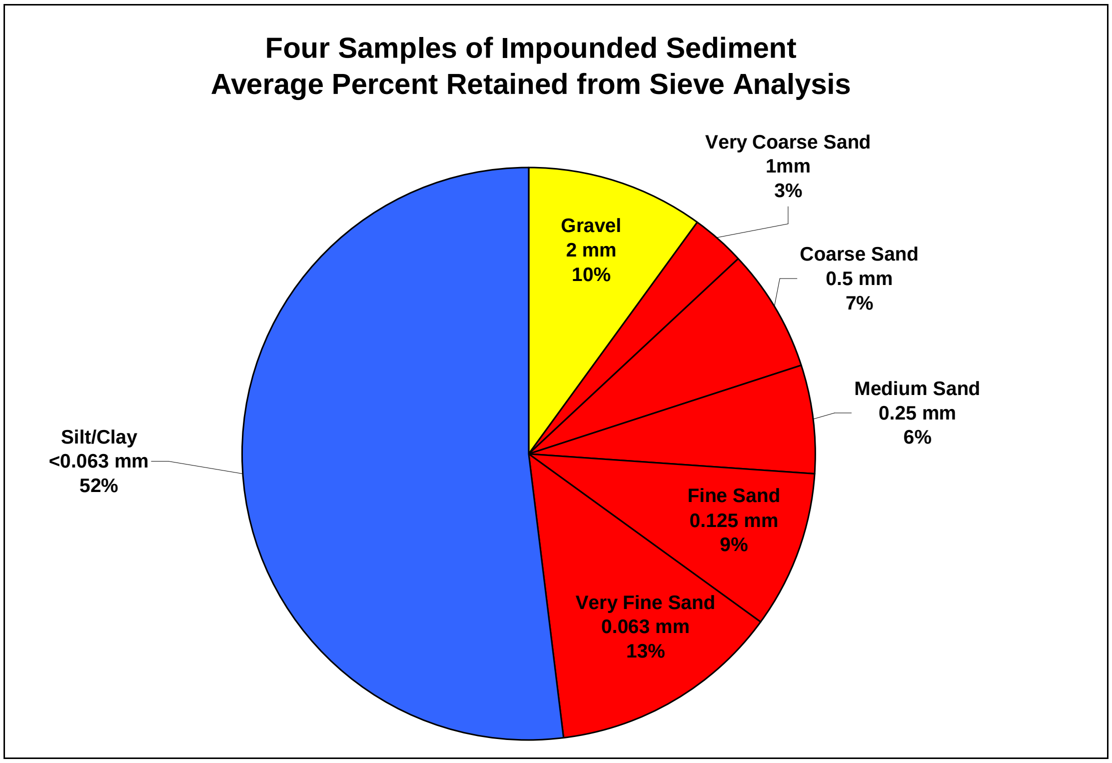

Figure 20: Average results from four sieve analyses of the impounded sediment

5.3.4 Soil Organic Content

Organic content of the six sieved samples ranged between 1.6% and 6.3%.

5.3.5 Suspendibility

The greater a particle's ability to suspend in stream flow, the higher its rate of removal to downstream reaches. Particles that are transported while fully suspended within the water column are known as the stream's wash load. Particles that are not suspendible and are instead transported by rolling and dragging along the stream's bed are known as bed load. Particles that are partially suspended and bounce along and become stored in the stream bed are considered suspendible bed-material load. Suspendibility increases with decreasing particle size and increasing discharge. The ability of Santa Anita Creek to suspend sediment was calculated for particle sizes ranging from very fine sand (0.063 mm) to 64 mm gravel for the three cross-sections at discharges of 0.05, 0.8, 13 and 17 m^3/s (Table 2). These discharges were estimated to be the average wet season flow and 1, 5, and 10 year return interval flows, respectively.

Table 2: Results from suspendibility calculations showing which particle sizes will transport via suspension or as bed load at three cross-sections under four flow conditions. These calculations used a Manning's roughness of 0.05; a slope of 0.02, 0.006, and 0.0004 for Cross-sections 1, 2, and 3, respectively; and a channel width of 11.9 m, 3.5 m, and 4 m for Cross-sections 1, 2, and 3, respectively.

	Average Wet Season Flow			Flow Recurrence of 1 Yrs		
	Cross-section			Cross-section		
	1	2	3	1	2	3
Flow (m^3/s)	0.05	0.05	0.05	0.8	0.8	0.8
Particle Size (µm)	Suspendibility			Suspendibility		
63	5.8E-02	5.8E-02	1.5E-01	2.5E-02	2.5E-02	6.7E-02
125	2.0E-01	2.0E-01	5.3E-01	8.6E-02	8.7E-02	2.3E-01
250	5.5E-01	5.5E-01	1.5E+00	2.4E-01	2.4E-01	6.4E-01
500	1.3E+00	1.3E+00	3.4E+00	5.6E-01	5.6E-01	1.5E+00
1000	2.6E+00	2.6E+00	6.9E+00	1.1E+00	1.1E+00	3.0E+00
2000	4.6E+00	4.7E+00	1.2E+01	2.0E+00	2.0E+00	5.4E+00
4000	7.6E+00	7.6E+00	2.0E+01	3.3E+00	3.3E+00	8.8E+00
	Flow Recurrence of 5 Yrs			Flow Recurrence of 10 Yrs		
	Cross-section			Cross-section		
	1	2	3	1	2	3
Flow (m^3/s)	13	13	13.	17	17	17
Particle Size (µm)	Suspendibility			Suspendibility		
63	1.1E-02	1.1E-02	2.9E-02	1.0E-02	1.0E-02	2.7E-02
125	3.7E-02	3.7E-02	9.8E-02	3.4E-02	3.4E-02	9.1E-02
250	1.0E-01	1.0E-01	2.7E-01	9.5E-02	9.5E-02	2.5E-01
500	2.4E-01	2.4E-01	6.3E-01	2.2E-01	2.2E-01	5.9E-01
1000	4.9E-01	4.9E-01	1.3E+00	4.5E-01	4.5E-01	1.2E+00
2000	8.7E-01	8.7E-01	2.3E+00	8.0E-01	8.1E-01	2.1E+00
4000	1.4E+00	1.4E+00	3.7E+00	1.3E+00	1.3E+00	3.5E+00

Notes:

Suspendibility should be <0.8 to 1.0 to be transportable

Wash load is approximately <0.1

Suspendible bed-material load is >0.1 and <1.0

Wash load (green)

Suspendible bed-material load (orange)

Non-suspendible bed load (pink)

Suspendibility calculations indicate whether particles will be transported as bed load, suspendible bed load, or wash load in each of the chosen flows at varying distances downstream of the dam. Cross-sections One and Two exhibit higher abilities to suspend sediment, while the lower most cross-section, Cross-section Three, has a shallower slope, resulting in decreased stream velocity and capacity for suspension. Therefore, gravels and cobbles will compose the bed material near the dam and sands will compose the bed material near the railroad culvert since larger particles will fall out of suspension at steeper slopes and finer will fall out with less steep slopes.

At average wet season flows very fine grained sands (0.063 mm) will be transported in suspension beyond Cross-sections One and Two and as suspendible bed-material load by the time they reach Cross-section Three. During these same flows 0.25 mm sands will be transported as suspendible bed-material load and slow in their rate of transport as bed load by the time they reach Cross-section Three. Particles greater than 0.5 mm will be transported as bed load through Cross-sections One and Two, and those greater than 0.25 mm will be transported as bed load through Cross-section Three.

At flows with estimated recurrence intervals of 1 year, fine grained sands (0.125 mm) will be transported in suspension beyond Cross-sections One and Two and as suspendible bed-material load by the time they reach Cross-section Three. During these same flows, 0.50 mm sands will be transported as suspendible bed-material load and slow in their rate of transport as bed load by the time they reach Cross-section Three. Particles greater than 1.0 mm will be transported as bed load through Cross-sections One and Two and those greater than 0.50 mm will be transported as bed load through Cross-section Three.

At flows with estimated recurrence intervals of 5 years, fine grained sands (0.125 mm) will be transported in suspension beyond Cross-sections One, Two, and Three. During these same flows 2.0 mm and 1.0 mm sands will be transported as suspendible bed-material load and slow in their rate of transport as bed load by the time they reach Cross-section Three. Particles greater than 4.0 mm will be transported as bed load through Cross-sections One and Two, and those greater than 1.0 mm will be transported as bed load through Cross-section Three.

At flows with estimated recurrence intervals of 10 years, medium grained sands (0.25 mm) will be transported in suspension beyond Cross-sections One and Two and as suspendible bed-material load by the time they reach Cross-section Three. During these same flows 2.0 mm and 1.0 mm sands will be transported as suspendible bed-material load and slow in their rate of transport as bed load by the time they reach Cross-section Three. Particles greater than 4.0 mm will be transported as bed load through Cross-sections One and Two, and those greater than 1.0 mm will be transported as bed load through Cross-section Three.

5.3.6 Summary of Transport Mode

Our calculations show that the majority (approximately 62 to 75%) of the impounded sediment will move in suspension when the creek flows, even at the estimated average wet season flows. The faster the creek is flowing, the more sediment will move, and the larger sediment particles will move farther. At the estimated 10 year recurrence flow, fine sand and finer materials (approximately 74 to 84%) will be transported quickly beyond Cross-section Three. But when the flow slows down it will move less sediment because slower stream velocities will not suspend larger sediment particles. As a result, larger sediment particles will deposit on the creek's bottom instead of moving fast with the suspended sediment. We expect gravel and cobbles to be stored between Cross-sections One and Two and sands to be stored between Cross-sections Two and Three. Since there is much more fine material than gravels and cobbles impounded behind the dam, we are concerned that sands might accumulate in a way that might harm downstream habitat or infrastructure. The clay, silt, and fine sand will make it past the railroad culvert and at least as far as the estuary during typical peak flows. Our expectations assume that the flows are diluted with enough water to prevent a highly viscous mud flow with a low flow velocity from flowing to downstream culverts or the estuary.

5.3.7 Threshold of Motion

We calculated the stream flow required to move particles of different sizes using equations (4) and (5). As bed load grain size increases at a single cross-section, fewer flows are capable of moving the larger particles. Table Three shows the number of days of a typical wet season's flow that would transport particles of each chosen grain size. The frequencies shown are slight underestimates of the expected frequency of transport because they are based on daily averages rather than instantaneous peak discharges, which are not available. However, the stream pattern and general magnitudes should be approximately correct. A comparison of Cross-sections One and Two indicates that there is no difference between the flows required to move a particle for any of the grain sizes analyzed even though there is a difference in gradient by a factor of three. The difference in slope is compensated by a decrease in channel width by a factor of 3.2 at Cross-section Two as compared to Cross-section One. The narrower channel creates a deeper, and therefore faster, flow as compared to the same flow through a wider channel. However, there is a noticeable difference between these upstream cross sections and downstream Cross-section Three. At Cross-section Three the majority of particles greater than 2 mm are unlikely to move during the average wet season flow. Meanwhile, these same flows will move up to 11 mm gravels at least once per year at Cross-sections One and Two.

Table 3: Days of the year the threshold of motion is exceeded based on calculated wet season average daily flow. The number of days exceeded underestimates the true frequency of transport because it is based on daily average discharges rather than instantaneous peak discharges, which would be larger than the daily average.

Cross-section	**1**	**2**	**3**
Slope	0.018	0.0062	0.0004
Mean Particle Size (mm)	**Days Exceeded**		
128	<1	<1	<1
90	<1	<1	<1
64	<1	<1	<1
45	<1	<1	<1
32	<1	<1	<1
22.6	<1	<1	<1
16	<1	<1	<1
11	2	2	<1
8	6	6	<1
5.6	17	17	<1
4	29	29	<1
2.8	49	49	<1
2	67	67	<1
1	96	96	1
0.5	175	175	36

Overall, the threshold of motion results predict particles equal to or greater than 16 mm will not be moved during average wet season flows. Additionally, any particle greater than 1 mm will rarely move beyond Cross-section Three. Therefore, we expect coarse sand and larger particles that transport through Cross-sections One and Two to deposit between Cross-sections Two and Three.

5.3.8 Bed Load Transport Rate Calculation

Since the results of our bed load transport rate calculations are not calibrated to steep, gravel bedded streams, we use the results to make qualitative conclusions that are relative to the difference in flux between pairs of cross-sections (Table 4). The bed load transport rate results show that, under most conditions analyzed, the range of grain size has a large effect on the volume of material transported. In the lower discharge scenarios (average wet season and 1 year recurrence flows), as the mean grain size increased, the bed load transport rate decreased by several orders of magnitude. This effect was reduced as discharge increased. However, even under the higher discharge scenarios increased mean grain size causes a several order of magnitude drop in the rate of transport at Cross-section Three. Therefore, we can conclude that the greater the mean grain size being transported downstream of the dam the longer it will take to transport beyond Cross-section Three.

During the average wet season flow, differences in grain size did not affect the percent of bed load sediment stored at each reach. Comparing the other discharge results, a pattern was observed of increased percent stored between Cross-sections One and Two as the mean particle size increased. In other words, the larger the average particle size the more likely it is to be stored in the area just downstream of the dam. Alternatively, the finer the average particle size the more likely it will be transported past Cross-section Two.

Under average wet season flow conditions, 77 % of the bed load (particles greater than 0.50 mm) volume transported through Cross-section One is retained before reaching Cross-section Two. Similarly, 77% of particles greater than 1.0 mm are retained between these cross-sections under 1 year return interval flows with the smaller mean particle size. As flows increase, the percentage of bed load volume that is retained before reaching Cross-section Two increases. In all cases, virtually all of the bed load volume transported through Cross-section Two is retained before reaching Cross-section Three.

From our results of the sediment analysis we anticipate the majority of the impounded sediment that will be transported as bed load to be finer than gravel size particles and therefore closer to the finer grain size distribution of 9.6 mm. Under this scenario we see the transport rates decrease significantly as the sediment moves downstream under all discharge scenarios. This is especially the case, between Cross-sections Two and Three. Since the higher discharge events with recurrence intervals of 5 and 10 years are only expected to occur over the course of a day or two per 5 and 10 years on average, respectively, the highest probability of occurrence are the lower discharge events, average wet season flow and the 1 year recurrence flow. Under these lower flow conditions the difference in transport rate at Cross-sections One and Two versus Cross-section Three is between 11 and 13 orders of magnitude. However, during the higher flow conditions the difference in transport rate at Cross-sections One and Two versus Cross-section Three is between 6 and 7 orders of magnitude. This result suggests that the larger recurrence interval flow events will transport a relatively larger proportion of the delivered and stored sediments beyond Cross-section Three than the higher probability and lower discharge events. Therefore, bed load sediments will be transported beyond Cross-sections One and Two and be stored between Cross-sections Two and Three until large infrequent 5 year recurrence or greater storm events are able to flush a relatively larger proportion of the held up sediment beyond Cross-section Three. See Appendix E for tables of the bed load transport rate calculations and resulting bed load grain size distributions.

Table 4: Bed load transport rate results for the average wet season, and 1, 5 and 10 year recurrence flows; for substrate with geometric mean distributions of 9.5 mm, 21 mm, and 39 mm; and at each cross-section. Additionally, the difference in percent retained between cross sections for each scenario is presented. Note: the model used to calculate bed load transport rates is not calibrated to Santa Anita Creek. Therefore, the results should be compared for relative differences and not as an anticipated actual rate of bed load transport.

Return Interval Scenario	Avg Wet Season Flow			Q1			Q5			Q10		
Cross-Section	1	2	3	1	2	3	1	2	3	1	2	3
Discharge (m^3/s)	0.05			0.8			13			17		
	Geometric Mean of Grain Size Distribution = 9.6 mm											
Bed Load Transport Rate (m^3/day)	1.0E-07	2.4E-08	1.3E-21	2.2E+01	5.1E+00	9.6E-11	6.6E+03	9.3E+02	2.3E-04	9.1E+03	1.1E+03	2.1E-04
Flux Retained Before Downstream Cross-section	77%	100%		77%	100%		86%	100%		88%	100%	
	Geometric Mean of Grain Size Distribution = 21 mm											
Bed Load Transport Rate (m^3/day))	4.0E-12	9.1E-13	5.0E-26	5.3E-01	8.4E-02	3.3E-15	3.7E+03	3.5E+02	1.5E-12	2.1E+03	6.4E+01	5.3E-08
Flux Retained Before Downstream Cross-section	77%	100%		84%	100%		90%	100%		97%	100%	
	Geometric Mean of Grain Size Distribution = 39 mm											
Bed Load Transport Rate (m^3/day)	1.6E-15	3.8E-16	2.0E-29	3.2E-04	4.2E-05	1.3E-18	1.4E+03	7.6E+01	9.7E-13	2.5E+03	8.2E+01	4.4E-12
Flux Retained Before Downstream Cross-section	77%	100%		87%	100%		95%	100%		97%	100%	

5.4 SEDIMENT DISCUSSION

5.4.1 Rate of Impounded Sediment Erosion

By comparing the estimated volume of stored sediment (100,000 m^3) with measured suspended sediment loads of nearby streams, we can get an idea of the significance of releasing the impounded sediment as a result of dam removal. The USGS has monitored suspended sediment discharge at four creeks near the town of Goleta and one creek in the City of Santa Barbara. These creeks are Atascadero, San Jose, Tecolotito, and Mission Creeks, respectively. In order to compare these discharges with that of Santa Anita Creek, we scaled the area of each basin to Santa Anita's. Results, scaled to Santa Anita Creek Watershed area, indicated a range from 45 to 660 m^3 of suspended sediment per year (m^3/yr). Unfortunately, these creeks were monitored during non El Niño years (Golden Gate Weather Services, 2007). As a result, the upper magnitudes of sediment yield cannot be compared. This range gives an estimate background suspended transport rates for Santa Anita Creek during non-El Nino years (USGS, 2005).

To better understand a long-term average sediment discharge rate that includes effects of El Niño cycles, we looked at long term records of basins with similar characteristics. Santa Barbara County Water Agency calculated a sedimentation rate of 640 m^3 per km^2 per year over 25 years for Gibraltar Reservoir in central Santa Barbara County (Gabet & Dunne, 2003). The Gibraltar Watershed has average slope angles of 36 degrees on shales and sandstones under chaparral. Calibrating this rate to Santa Anita Creek watershed, we expect an average sediment delivery rate of 5,200 m^3 per year. At this average rate of sediment transport, the impounded sediment would be removed in 19 years.

On the other hand, a study determined sedimentation rates of closer to 12,000 m^3 per year (calibrated to Santa Anita Creek watershed area) averaged over two years for the combined Maria Ygnacio, Atascadero, San Antonio, and San Jose watersheds after a fire burned approximately 24% of their combined areas. During these two years these watersheds received 100% and 115% of their average annual rainfall with a 10-year return period storm and several two year return period storms. The more heavily burned sub-basins are made up of easily erodible siltstones and sandstones, have channels with widths ranging from 3 to 6 m and depths of 2 to 5 m, and are approximately 20 km east of Santa Anita Creek watershed (Keller et al., 1997). Using this average rate of sediment transport, the impounded sediment would be removed from the impounded area in 8 years.

5.4.2 Bed Load Depositional Pattern

Bed load material composed of sand and gravel larger than 0.5 mm was analyzed for the probability of flows large enough to exceed its threshold of motion. The results show gravel sized particles will move downstream more frequently closer to the dam as opposed to near the estuary. Again, this finding indicates a transport rate reduction between Cross-sections One and Two. However, there is uncertainty about the rate at which the impounded sediment will be mobilized. If, in the most extreme scenario, all the impounded sediment were to mobilize in a single event, then 13,000 to 20,000 m^3 is predicted to reduce its rate of transport downstream of Cross-section Two to non-wash load or bed load and potentially impact the culvert's ability to manage the discharge. This impact would include a reduction in the culverts' flow conveyance capacity. Such a reduction in conveyance capacity would cause increased flood risk and associated damages from water and silt inundation.

Conversely, sorting of gravels near the dam may increase steelhead spawning habitat closer to the estuary. Steelhead can reach this area even during the driest wet seasons. As a result, gravels stored between Cross-sections One and Two might provide conditions suitable enough for spawning, pending upstream culvert regrade activities or future wetter seasons.

5.4.3 Suspendible Sediment Depositional Pattern

Since the majority of the sampled impounded sediment is considered to be transportable as suspended sediment, we expect this portion to be transported downstream even during normal wet season flows. However, peak flows are expected to move more material. These peak flows will transport larger particles as suspended load, thereby transporting them faster and farther. But even under the largest peak flow analyzed (the flood that is predicted with a recurrence of 10 years on average), we expect coarse sand to drop out of suspension before the railroad culvert. This trend was confirmed by observations of the bed material in this area. Coarse sand was found deposited upstream of the culvert and throughout the length of the culvert. Coarse sand and coarser material made up approximately 6 to 13% (6,000 to 13,000 m^3) of the impounded sediment composition. In addition, under lower flow conditions, finer sand materials will also accumulate in this area. Finer sand makes up an additional 25% of the impounded sediment (25,000 m^3).

The above analysis suggests that there is a potential for up to 38,000 m^3 of sand and gravel to accumulate in the vicinity of the railroad culvert. Depending on rate of deposition near the culvert and transport through the culvert, such a volume could potentially block the culvert entrance, rendering the culvert useless. Furthermore, blocking the culvert would act to store stream water behind the railroad fill like a dam. It is not known to what degree this fill can support accumulated water without causing damage to the railroad. Also, infrastructure upstream from the culvert and on the floodplain may become inundated and potentially damaged by flood waters and silt.

5.4.4 Habitat Impacts

Because it is possible for a significant amount of sediment impounded behind the dam to flow in a single wet season (El Niño year), it is important to understand the mode of transport and corresponding rates. By understanding the mode and rate of transport we can make inferences as to where various types of material might possibly be stored.

The sediment analysis and suspendibility calculations determined that the majority of the sampled sediment will be transported in suspension. However, our suspendibility calculations indicated that a portion of the impounded material that is suspendible closer to the dam will not be suspendible downstream near the railroad crossing (Cross-section Three). This result suggests that the rate of sediment transport will decrease as it makes its way downstream. This rate of decrease appears to be slight but could be problematic. For example, based on the high probability 1-year recurrence discharge approximately 74% of this sediment will be transported as wash load. As it moves toward Cross-section Three the wash load fraction will decrease to 65%. In other words, approximately 9% (maximum of 9,000 m^3) of the sediment will be retained for some time as stream bed material and therefore will travel more slowly than the water, accumulating briefly as it travels between Cross-sections Two and Three. During the same size flow, nearly all of the remaining size classes of impounded sediment will transport downstream as suspended bed load. Similarly, a small fraction of the sediment (~7%, maximum of 7,000 m^3) between Cross-sections Two and Three will become bed load material with a reduced transport rate.

Additionally, based on the lower probability 10-year recurrence discharge approximately 80% of this sediment will be transported as wash load. As it moves toward Cross-section Three the wash load fraction will decrease to 74%. In other words, approximately 6% (maximum of 6,000 m^3) of the sediment will be retained for some time as stream bed material and therefore will travel more slowly than the water, accumulating briefly as it travels between Cross-sections Two and Three. During the same size flow, nearly all of the remaining size classes of impounded sediment will transport downstream as suspended bed load. Similarly, a small fraction of the sediment (~6%, maximum of 6,000 m^3) between Cross-sections Two and Three will become bed load material with a reduced transport rate. However, this flow scenario has an estimated 10% chance of occurring in any given year.

Considering the volume of the channel downstream of Cross-section Two is estimated to be 5,400 m^3 (assuming an average width of 3.75 m, depth of 3 m, and a length of 480 m), we can see that the 16,000 m^3 or 12,000 m^3 of sediment that could be deposited during the 1- and 10-year recurrence floods could fill the channel and clog the railroad culvert. The consequences of this risk would be clogging the railroad culvert, channel habitat destruction, damages from inundation and siltation of the flood plain and infrastructure, and labor and cost to clear the culvert and channel.

At minimum, these results suggest that upstream of Cross-section Three the stream bed will increase in elevation. This aggradation of the stream bed is a normal occurrence for streams before they return to their natural state after dam removal. Initial expected changes to the stream include obliteration and then re-establishment of a wider channel than the current channel downstream of the dam. During these conditions there will be no pools and overall a shallower stream channel, which will block steelhead migration upstream. However, these conditions will likely be temporary, lasting on the order of 5 to 10 years, depending on the weather and resulting flow conditions, as channels deepen and the stream equilibrates to its natural state. Therefore, releasing the entire impounded sediment volume by rapid dam removal will have a catastrophic impact on Santa Anita Creek's habitat and will cause high turbidity and sedimentation in the estuary and in the surf zone adjacent to the tide-pools for at least several years. Weather creates the biggest uncertainty in predicting the duration of these conditions.

5.5 Discussion of Dam and Sediment Removal Options

Based on the results of the sediment calculations, we were able to refine the dam removal and sediment management options identified during the literature review into four feasible options for the restoration of steelhead passage on Santa Anita Creek. The four dam and sediment removal options that are applicable for Santa Anita Creek are as follows:

1) Complete dam removal with natural sediment transport
2) Complete dam removal with partial sediment excavation combined with bank stabilization
3) Complete dam removal with complete sediment excavation
4) Incremental dam removal with natural sediment transport

In evaluating these four dam and sediment removal options, it is important to understand the risks associated with each option. Once the dam is removed there will inevitably be upstream and downstream impacts to the stream channel. The sediment analysis described above provides a starting point for understanding where and how the impounded sediment will flush downstream once the dam is removed. Concerns exist on the rate of erosion and the impact this could have on the downstream road and railroad culverts. In addition, there are water quality concerns due to the persistent flow of turbid water that will adversely affect downstream habitat. This section of the report will examine the potential risks associated with each dam removal and sediment management option. Table Five summarizes the following dam and sediment removal options.

5.5.1 Option 1: Complete Dam Removal with Natural Sediment Transport

Natural sediment transport provides the lowest cost option in managing the impounded sediment due to its utilization of natural processes to erode and flush the impounded sediment downstream. While it is the least expensive option, this approach has a high risk associated with where and how the sediment will erode and be deposited.

Sediment calculation results reveal up to 74% of the impounded sediment will likely stay in suspension all the way to the estuary, while the remaining 26% of coarser material will likely aggrade reaches upstream of the railroad culvert. The stream gradient at the railroad culvert is too shallow to pass any sediment as suspendible load larger than fine sand, even under a ten year recurrence flood. This raises concerns that as much as 16,000 m^3 of sand and gravel could accumulate in the vicinity of the railroad culvert. Depending on the rate of deposition of sediment near the culvert and transport rate through the culvert, this volume could block the railroad culvert entrance. Blocking the culvert would cause water to accumulate upstream of the railroad, causing flooding and threats to the structural integrity to the railroad crossing and nearby property. Although significant threats to the structural integrity of the railroad is low, any potential negative impact is worthy of concern. As illustrated by the Arroyo Hondo steelhead restoration project, potential threats to Union Pacific Railroad structures can halt restoration projects in their tracks, making this a very high risk option in terms of project goals.

Another risk associated with natural sediment transport involves the potential effects of released sediment on downstream habitat. The estuary at the mouth of Santa Anita has been designated critical habitat by the F&WS for the endangered tidewater goby (F&WS, 2006). Even during average wet season flow, the fine sediment impounded behind the dam will be transported at least as far as the estuary. A turbid flow of water entering the estuary and the ocean raises concerns about the persistent impact sediment might have on the downstream reaches of Santa Anita Creek, the estuary, and offshore tide pools found along the coast. Based on the most probable annual sediment yield for Santa Anita creek, we estimate a highly turbid flow of water would persist for between 8 and 19 years. Hollister Ranch and permitting agencies need to be comfortable with the potential habitat impacts associated with natural sediment transport if this option is to be considered further.

Risk is also associated with the unstable nature of the impounded sediment immediately following the dam removal. The impounded sediment primarily consists of silts, clays and fine sands, which are extremely unstable at slopes greater than ten degrees (Skempton, 1953). The risk of a potential mud flow becomes a serious concern if the saturated soil behind the dam is not dewatered prior to dam removal. Even under a dewatered scenario, the impounded sediment will remain highly unstable, especially during precipitation events when the saturated soils pose a risk of mud flows which could clog the downstream road culvert and railroad culvert. Additionally, a large mudflow might completely fill the channel, effectively blocking the migration of steelhead.

5.5.2 Option 2: Complete Dam Removal with Partial Sediment Excavation and Bank Stabilization

Another option involving complete dam removal is to remove a portion of the impounded sediment mechanically through excavation. This approach allows for the engineering of an upstream channel, which reduces the uncertainty of where and how the stream channel would form through the sediment plain. However, this approach does not resolve the risk of how the remaining sediment will be loaded into the stream. Because the grain size distribution of the impounded sediment consists primarily of silts, clays, and fine sands, the remaining sediment will be very unstable and need to be reinforced to minimize the risks of bank sloughing and mud flows. Mechanically removing a portion of the sediment also mitigates some of the potential impacts to the downstream culverts and habitat because less sediment is available to flow downstream. This could result in a shortened duration of impact on the downstream habitat that is roughly proportional to the amount of sediment removed.

A likely scenario of complete dam removal with a partial sediment removal would first involve dewatering the sediment plain prior to any excavation work. The sediment plain could then be excavated and a new channel could be engineered to match the surrounding stream gradient and characteristics. The downstream portion of the sediment plain currently contains the majority of the impounded sediment and, as a result, would require a substantial amount of excavation and bank stabilization to prevent sloughing and mud flows of the highly unstable sediment. Trucking would be required to remove a portion of the excavated sediment, which has the potential to be stored and used as a source of fill dirt or soil amendment on the Ranch. The remaining sediment could be stabilized along the banks through both structural and vegetated reinforcement. The upstream portion of the sediment plain, where the stream channel is only partially filled with sediment, could then be left to erode by natural processes. Assuming that half of the sediment will need to be mechanically removed, 3,100 dump truck loads of sediment would be transported through the Hollister Ranch.

Using a partial mechanical removal with some type of bank stabilization is considered a moderate risk and cost option for Santa Anita Creek. This approach would be appropriate if sediment management were required to reduce the negative effects on downstream habitat and culverts. While downstream effects would be minimized, this option still results in the release of some sediment downstream. If the management of the impounded sediment through bank stabilization is too expensive, the stabilization of the impounded sediment is not possible, or the potential effects on downstream habitat and infrastructure are too high, complete sediment removal should be considered.

5.5.3 Option 3: Complete Dam Removal with Complete Sediment Excavation

Complete dam and sediment removal has high cost; however, this option also has the lowest level of risk. Complete mechanical removal provides the greatest control on the fate and transport of the impounded sediment. The benefit from this approach is that it minimizes the impact on the road and railroad culverts and reduces the impact to the migration corridor and estuary habitat. In addition, full excavation allows for the opportunity to define the upstream channel and eliminate the uncertainty in how the channel might form naturally. After the excavation process, a gravel-bed channel with natural dimensions, pool morphology, and channel-bed sediment can be engineered and reinforced with native vegetation, which will increase habitat value for the southern steelhead. This option also has the shortest duration, lasting only a few months. As a result, the dam and the impounded sediment could be completely removed and passable to fish in a very short period. Furthermore, the impounded sediment has the potential to be stored and used as a source of fill dirt or soil amendment on the Ranch. If the impounded sediment could not be used as fill dirt, it would have to be trucked off site.

Complete dam and sediment removal is considered the most conservative option because it manages the fate of the impounded sediment to the highest degree possible, and therefore has the lowest level of risks. However, this option also has higher costs.

5.5.4 Option 4: Incremental Dam Removal with Natural Sediment Transport

Incremental dam removal combined with natural sediment transport offers the most controlled scenario for managing downstream impacts of the impounded sediment, a significant benefit from a biological and geotechnical standpoint. In addition, this option minimizes the risk of clogging or filling the downstream culverts or estuary. However, impacts from sediment and mud flows, increasing turbidity, would exist over a longer time period. In addition, extending the dam removal phase creates a different set of uncertainties. Costs and uncertainties are expected to increase due to a longer project management period, requiring teams of biologists, engineers, and contractors to make many trips to the job site and to monitor the impacts. Also, prolonging the removal process could threaten the stability and safety of the remaining dam structure, due to flooding or erosion events. The prolonging of the removal process increases monitoring, stabilization and engineering requirements. Finally, steelhead passage on Santa Anita Creek will not be restored until the dam was completely removed, postponing the achievement of restoration goals.

Table 5: Pros and Cons of Dam Removal Options

Dam & Sediment Management Options	Considerations	Costs*	Risk
Complete Dam Removal with Natural Sediment Transport	• Longest impact of high turbidity on downstream habitat • Large amounts of sediment may clog downstream culverts causing flooding • Least invasive to the project site and least time intensive • Highest concern for potential mudflows	Lower	Higher
Complete Dam Removal with Partial Sediment Excavation and Bank Stabilization	• Greater engineering expertise and artificial stabilization materials required • Increased amount of stabilization to prevent bank failure • Shorter duration of downstream turbidity • Medium concern regarding mudflows and sediment	Moderate	Moderate
Complete Dam Removal with Complete Sediment Excavation	• Longer time and higher effort • Less stabilization required, excavation and disposal of majority of sediment • Less monitoring and risk from remaining sediment impacts	Higher	Lower
Incremental Dam Removal with Natural Sediment Transport	• Dam site may not remain stable for duration of project • Requires numerous visits over the course of years • Long term impacts to water quality	Higher	Moderate

*Cost estimates for the dam and sediment removal options range from one to three million dollars

6.0 BARRIER ASSESSMENT

DFG protocol was followed to evaluate the extent to which each stream crossing acts as a barrier to upstream steelhead migration. A flow diagram outlining the steps taken to complete this overall process is found in Appendix F.

6.1 METHODS ONE

6.1.1 Stream Crossing Identification

The first task necessary in the assessment of the impact of Santa Anita Creek's barriers on steelhead upstream migration was to identify the barriers. Discussions with our client and site reconnaissance revealed seven stream crossings, including one railroad culvert, one main road arch culvert, four Arizona crossings and one low flow crossing (Figure 21).

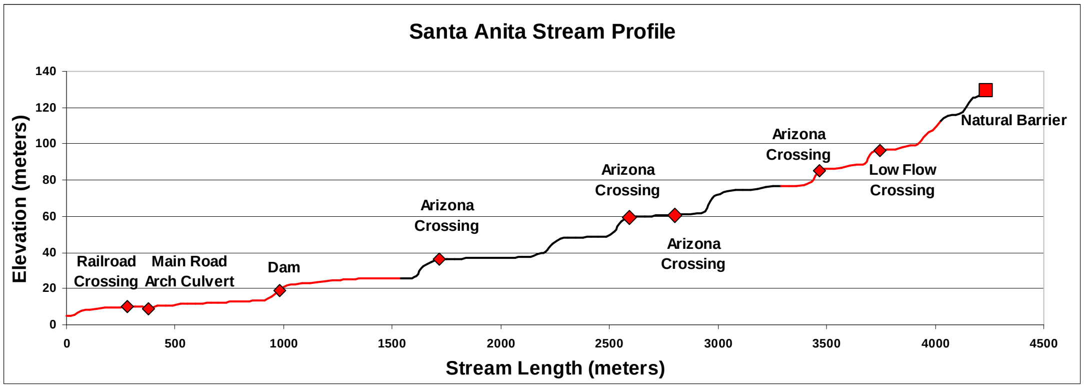

Figure 21: The stream profile of Santa Anita Creek, calculated from the National Elevation Dataset (NED) (USGS, 2008a). The stream profile, due to the NED's coarser resolution (30 m) and averaged raster cell values, has inherent error within the curve – creating misleading results, including step-like jumps in profile elevation. The main purpose of the profile is to indicate the location of the various fish passage barriers. The red line indicates the study areas of this project and the black line indicates reaches that were inaccessible to us.

Once identified, the following measurements of culvert characteristics were taken at each stream crossing:

- Culvert length, height (or diameter), and width
- Culvert slope (the difference between inlet and outlet invert elevations)
- Culvert type, installation, and material
- Culvert condition

6.1.2 Fish Passage through Stream Crossings

Following DFG protocol, each stream crossing was evaluated using the first-phase passage evaluation filter. See Appendix F for a flow diagram outlining this evaluation filter (Love & Taylor, 2003). This flow diagram allows for the initial assessment of fish passage at each culvert by evaluating specific culvert parameters, including culvert slope, channel width, and culvert outlet drops to downstream pools. With this information, the flow diagram assigns each culvert a color: GREEN, GRAY or RED. GREEN indicates that all species of fish throughout all life stages can pass through the crossing. GRAY indicates that the crossing may be a partial or temporary barrier to passage. RED indicates that the culvert fails to meet fish passage criteria (Love & Taylor, 2003).

GREEN-ranking culverts have inlet widths that are equal to or greater than the channel width and/or have minimal slopes, as measured by the elevation of the inlet and outlet of the culvert relative to the elevation of the tail-water end of the downstream pool. GRAY-ranking culverts are floored with natural substrate and have an outlet drop less than 0.6 m, or are not floored with natural substrate but have a slope less than 3% and an outlet drop less than 0.6 m. RED-ranking culverts have either an outlet drop greater than 0.6 m and/or slopes greater than 3% (Appendix F).

Once assigned a color, only the GRAY culverts need to be further analyzed to assess the extent that the stream crossing is an impediment to fish passage using the computer software, FishXing. The following section lists a description of each of the seven stream crossings and their scoring results.

6.2 RESULTS ONE

6.2.1 Stream Crossing One (Railroad Crossing)

Stream Crossing One, the stream crossing underneath the Union Pacific Railroad tracks, is located 0.25 km from the ocean and 0.75 km downstream of the dam (Figure 21). The culvert is currently floored with 60 - 120 cm of sand and is 3.05 m wide, 3.05 m tall and 40.5 m long (Figures 22a, 22b, Table 6). This culvert was the only crossing to receive a GREEN fish passage ranking because the difference in the elevation of the inlet and outlet of the culvert relative to the height of the tail-end of the downstream pool is greater than 0.15 m (Table 7). As such, Stream Crossing One is not a barrier to upstream steelhead migration.

Figure 22a: Stream Crossing One, looking downstream (left)
Figure 22b: The outlet of Stream Crossing One (right)

6.2.2 Stream Crossing Two (Rancho Real Road Arch Culvert)

The Rancho Real Road crossing is located 0.4 km from the ocean and 0.6 km downstream of the dam (Figure 21). An arch culvert has a flat bottom – consisting of either natural sediment or concrete – and rounded sides and top. Currently, the inside of this arch culvert contains remnants of a previous, smaller culvert. However, the current understanding is that this debris will be removed in the future. For the purpose of this analysis, fish passage was evaluated as if this debris was not present. The culvert is 5.79 m wide, 3.28 m high and 12.8 m long (Figures 23a, 23b, Table 6). This arch culvert received a RED scoring because its inlet and outlet depths relative to the elevation of the tail-end of the downstream pool are less than 0.15 m (Table 7). As such, this culvert is not considered to support upstream steelhead passage.


Figure 23a: The downstream portion of Stream Crossing Two (left)
Figure 23b: The inside of Stream Crossing Two from the downstream side (right)

6.2.3 Stream Crossing Three (Perched Arizona Crossing)

Stream Crossing Three is located 1.72 km from the ocean and 0.72 km upstream of the dam (Figure 21). A perched Arizona crossing is a raised concrete ford that has a small pipe through its middle. In other words, low flows drain through the corrugated metal pipe, but the crossing is designed to withstand higher flows by allowing water to go directly over the crossing and to the other side. These crossings are perched above the stream channel, thus making fish passage even more difficult. This culvert is the first crossing steelhead would encounter upstream of the dam. Although we did not have property access to measure this culvert, assuming that this crossing contains similar characteristics as the other culverts upstream of the dam, it would receive a RED ranking (Table 7). Therefore, fish passage is not expected at any time.

6.2.4 Stream Crossing Four (Perched Arizona Crossing)

Stream Crossing Four is located 2.59 km from the ocean and 1.59 km upstream of the dam (Figure 11). This Arizona crossing passes under Santa Anita Road and, due to limited access, culvert measurements were visually estimated from the public road. The length of the pipe is approximately 7 m long and the pipe is approximately 80 cm in diameter (Figures 24a, 24b, Table 6). Stream Crossing Four has the steepest slope of all the culverts analyzed (14%), which is greater than 3% and consequently received a RED scoring (Table 7). Therefore, fish passage is not expected at this stream crossing.

Figure 24a: The inlet to Stream Crossing Four (left)
Figure 24b: The outlet of Stream Crossing Four (right)

6.2.5 Stream Crossing Five (Perched Arizona Crossing)

Stream Crossing Five is located 2.8 km from the ocean and 1.8 km upstream of the dam (Figure 21). Like Stream Crossing Four, this Arizona crossing goes under Santa Anita Road and was also measured visually from the car. The length of the pipe is approximately 9 m long and the pipe is approximately 80 cm in diameter (Figures 25a, 25b, Table 6). Its slope, although not as steep as Stream Crossing Five, warrants a RED scoring for fish passage (Table 7). As such, upstream steelhead migration through this culvert is not expected.

Figure 25a: The inlet of Stream Crossing Five (left)
Figure 25b: The outlet of Stream Crossing Five (right)

6.2.6 Stream Crossing Six (Perched Arizona Crossing)

Stream Crossing Six is located 3.5 km from the ocean and 2.5 km above the dam (Figure 21). This Arizona crossing is 7 m long and its pipe is 61 cm in diameter (Figures 26a, 26b, Table 6). Because its inlet and outlet depths relative to the tail-end of the downstream pool are less than 0.15 m, the crossing receives a RED scoring and upstream steelhead passage through the culvert is not expected (Table 7).

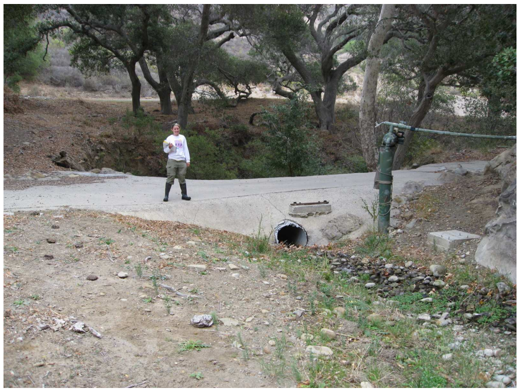


Figure 26a: The inlet of Stream Crossing Six (left)
Figure 26b: The outlet of Stream Crossing Six (right)

6.2.7 Stream Crossing Seven (Low Flow Crossing)

Stream Crossing Seven is located 3.75 km from the ocean and 2.75 km from the dam (Figure 21). A low flow crossing consists of a small culvert pipe and is covered with a concrete apron. Like the perched Arizona crossing, the low flow crossing allows for average water flows to pass through the culvert. In current form, the pipe is 100% blocked with sediment. For the FishXing model, the analysis assumes that the sediment is removed completely, unlike its current condition. The pipe is 4.5 m long and 30.5 cm in diameter (Figures 27a, 27b, Table 6). Its slope is ~3% and is the only crossing to receive a GRAY scoring, indicating that Stream Crossing Seven is a partial and/or temporary barrier to upstream steelhead migration (Table 7).


Figure 27a: The outlet of Stream Crossing Seven (left)
Figure 27b: The length of Stream Crossing Seven (right)

Table 6: Collected data for all accessible stream crossings

Parameters	**Stream Crossing**					
	1	**2**	**4**	**5**	**6**	**7**
Culvert type	300 cm Arch	434.3 x 279.4 cm Pipe-Arch	76.2 cm Circular	76.2 cm Circular	61 cm Circular	30.5 cm Circular
Material	Concrete	Annular 127 x 25 mm	Annular 68 x 13 mm	Annular 68 x 13 mm	Annular 68 x 13 mm	Annular 68 x 13 mm
Installation	Embedded	Not embedded	Not embedded	Not embedded	Not embedded	Not embedded
Culvert length	40 m	12.8 m	7 m	9 m	7 m	4.5 m
Culvert slope	0.01%	2%	14%	6%	7%	3%
Culvert roughness coefficient	0.02	0.025	0.024	0.024	0.024	0.024
Inlet invert elevation	10.01 m	11.8 m	12.3 m	13.1 m	11.7 m	10.4 m
Outlet invert elevation*	10 m	11.6 m	11.3 m	12.6 m	11.2 m	10.2 m
Inlet head loss coefficient (K_e)	0.5	0.5	0.9	0.9	0.9	0.9

*Determined by setting the outlet-pool bottom elevation arbitrarily at 10 m and measuring the other elevations relative to this reference.

As outlined in Table 2, Stream Crossing One was the only crossing to receive a GREEN score, indicating that fish passage is not a concern at this crossing. Stream Crossings Two through Six received a RED score, implying that current conditions do not support upstream steelhead migration. Consequently, the fish passage analysis of these six stream crossings ends here. Stream Crossing Seven received a GRAY score due to its 3% slope and lack of an outlet drop. This crossing must be further analyzed with FishXing so that specific steelhead biology data can be considered in the final assessment of fish passage.

Table 7: GREEN-GRAY-RED first-phase ranking of each stream crossing

Stream Crossing	Color Ranking
Stream Crossing One (Railroad Crossing)	GREEN
Stream Crossing Two (Main Road Arch Culvert)	RED
Stream Crossing Three (Perched Arizona Crossing)	Unable to rank / likely RED
Stream Crossing Four (Perched Arizona Crossing)	RED
Stream Crossing Five (Perched Arizona Crossing)	RED
Stream Crossing Six (Perched Arizona Crossing)	RED
Stream Crossing Seven (Low Flow Crossing)	GRAY

6.3 Methods Two

6.3.1 FishXing Fish Passage Analysis

FishXing was used to evaluate the fish passage of the GRAY-scoring culvert, Stream Crossing Seven. FishXing is a computational program produced by the Six Rivers National Forest, U.S. Forest Service and available online to assess the extent of a stream crossing's impact on fish passage. This planning tool, commonly used by technical experts in the field, models the hydraulics of culverts. The expected culvert hydraulic conditions are then compared with data on steelhead swimming and leaping abilities and minimum water depth requirements (FishXing, 1999). The model requires data about steelhead and the culverts, provided in Tables Six and Eight, which are used to assess the passable flow range for each culvert. In addition, FishXing classifies each culvert as a water depth, leap, velocity, and/or pool depth barrier to fish passage. Three factors – velocity, discharge, and water depth – directly influence fish passage.

Table 8: Steelhead biological data, taken from DFG, entered into FishXing for different age classes. Q2 was used in the calculation of the maximum passage flow because this flow is an easily available and uniform index by which to bracket the maximum range of flow for steelhead upstream migration (Source: Love & Taylor, 2003; Ross Taylor and Associates, 2004).

Parameters	**Steelhead Age Class**		
	Adult Steelhead	**2+ Juvenile Steelhead/Resident Trout**	**Young-of-Year and 1+ Juvenile Steelhead**
Fish length	50 cm	20 cm	8 cm
Minimum water depth	~0.20 m	~0.20 m	0.10 m
Prolonged swimming speed	1.83 m/s	1.22 m/s	0.46 m/s
Prolonged time to exhaustion	30 minutes	30 minutes	30 minutes
Burst swimming speed	3.05 m/s	1.52 m/s	0.91 m/s
Burst time to exhaustion	5 s	5 s	5 s
Maximum leaping speed	3.66 m/s	1.83 m/s	0.91 m/s
Velocity reduction factors: Inlet Barrel Outlet	 1.0 1.0 1.0	 0.8 0.6 0.8	 0.8 0.6 0.8
Minimum passage flow	0.085 m^3/s	0.057 m^3/s	0.028 m^3/s
Maximum passage flow	2.05 m^3/s 50% of Q_2	1.22 m^3/s 30% of Q_2	0.41 m^3/s 10% of Q_2

6.3.2 Q_2 Flow Calculation Methodology

The FishXing analysis required the calculation of Q_2 of Santa Anita Creek, or the peak flow that has the probability of being met or exceeded once every two years. The Weibull method was used to calculate Q_2 for Santa Anita Creek, a parameter in the equation to estimate the maximum passage flow value (Table 3). First, peak discharges for every year of record were identified. Then, these peak discharges were ranked in descending order. The ranks were then divided by the number of years of record plus one. To determine each peak discharge's return interval, the reciprocal of the fraction – ranks to number of years plus one – was taken. The result of this reciprocal gave the return interval of each peak flow discharge, as indicated in Figure Twenty Eight.

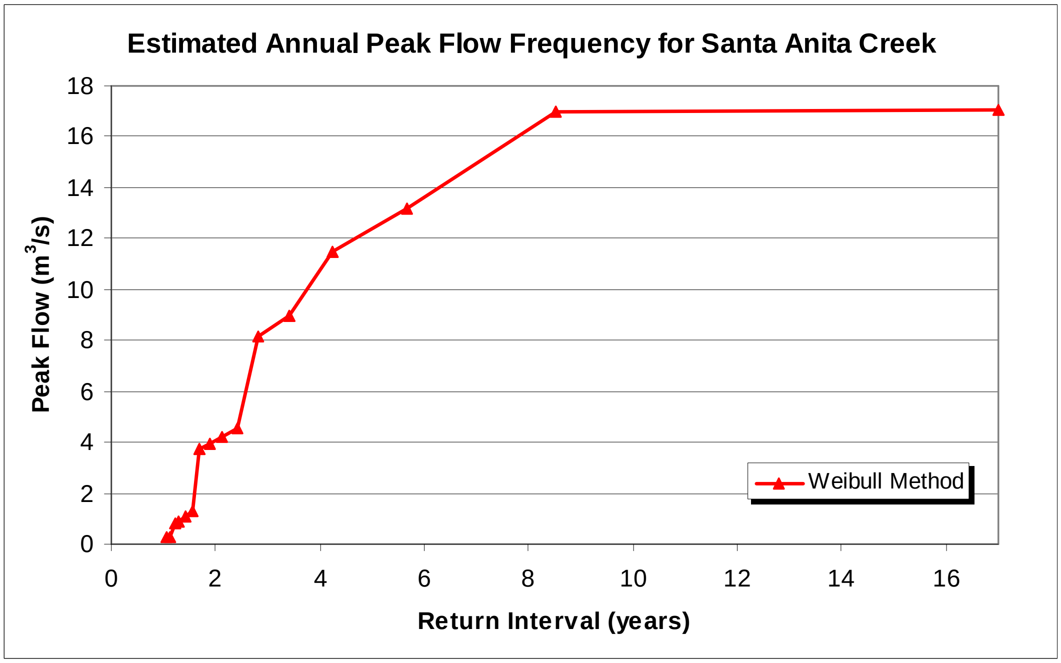

Figure 28: The return intervals of the peak discharge flows calculated from 16 years of basin-scaled Santa Anita Creek peak flow data.

6.3.3 Exceedence Flow Calculation Methodology

To calculate the number of days that fall within the passable flow range as indicated from the FishXing results, percent annual exceedence flows were calculated. The estimated average annual daily discharge for Santa Anita Creek was used to calculate percent annual exceedence flows. For example, the 5% exceedence flow is defined as the stream flow that is exceeded on average 5% of the time during a year. The average daily flows were computed by averaging 16 years of daily stream flow data from the estimated discharge of Santa Anita Creek. To calculate percent annual exceedence flows, the average annual daily flows were ranked from highest to lowest. A rank of 1 was given to the highest flow. A rank (n) of 365 was given to the lowest flow, which equaled the total number of flows considered. The following equations were used to identify the rank (i) associated with a particular exceedence flow, such as the ranks of the 5% and 90% exceedence flows ($i_{95\%}$ and $i_{90\%}$, respectively; Flosi, G., et al., 1998):

$$i_{5\%} = 0.5(n+1) \text{ and } i_{90\%} = 0.90(n+1)$$

Exceedence flows were used to calculate the number of days of fish passage expected in culverts during the passable flow range (Figure 24, Table 8). By taking the passable flow range and matching it up to the percentage of time during the average, wet and dry years that the range occurs, passable days were determined.

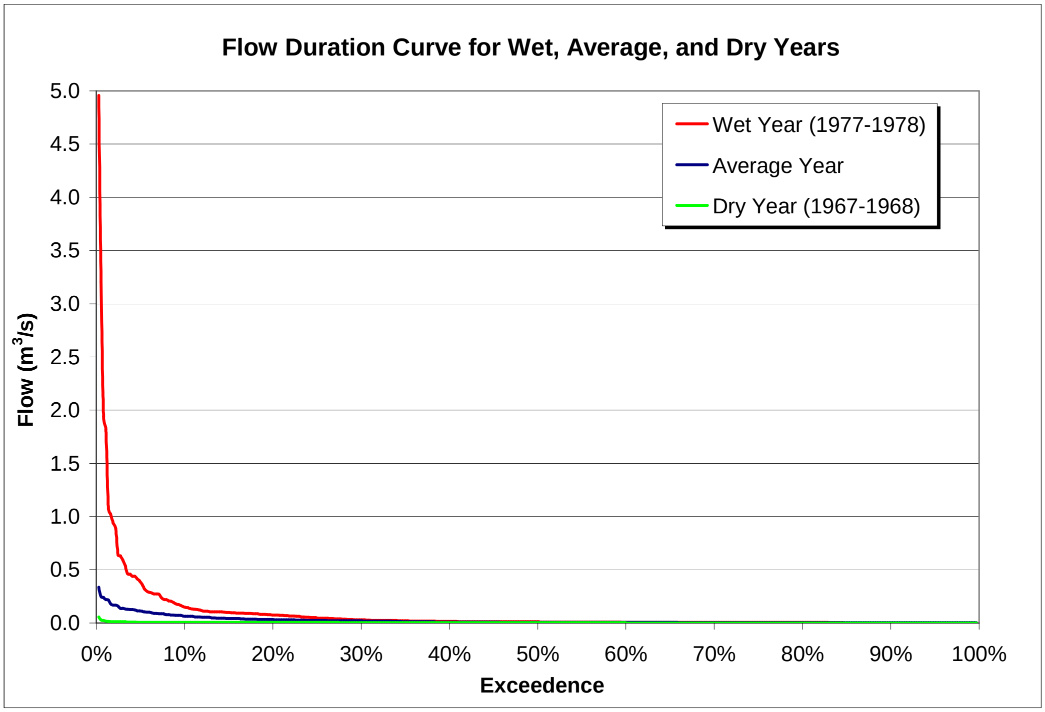

Figure 29: The Santa Anita Creek flow duration curve for the historic mean daily flow of the average year, the wettest year (1977-1978) and the driest year (1967-1968) on record. The exceedence curve of the average daily flow of the average year was computed by calculating each day's average discharge over the period of record, ranking the averaged daily flow from highest to lowest and plotting the percent of days exceeded versus flow.

6.4 Results two

6.4.1 FishXing Results

6.4.1.a Stream Crossing Seven (Low Flow Crossing)

Stream Crossing Seven meets the water depth, discharge and velocity criteria for adult steelhead passage at flows between 0.08 and 0.15 m^3/s (Table 5). A velocity barrier through the 30.5 cm pipe is the limiting factor for all steelhead age classes. Stream Crossing Seven is expected to have 17 days of passable flow during the average year, 28 days of flow during the wettest year on record and 0 days of flow during the driest year on record (USGSb and USGSc, 2008; Table 8, Figures 24 & 25).

Table 9: FishXing results for the analysis of adult salmonid fish passage

Stream Crossing Seven	Adult Steelhead	Resident Trout and Juvenile 2+ Steelhead	Juvenile 1+ and Young-of-the-Year Steelhead
Percent of Flows Passable	3%	0%	0%
Passable Flow Range	0.08 to 0.15 m^3/s	None	None
Depth Barrier	None	None	None
Leap Barrier	None	None	None
Velocity Barrier	0.14 to 4.08 m^3/s	All Flows	All Flows
Pool Depth Barrier	None	None	None

Table 10: Passable days of the average, wet and dry years on record for Stream Crossing Seven, derived by comparing the passable flow range from FishXing with the Santa Anita Creek flow hydrograph.

Stream Crossing	Passable Days of the Average Year	Passable Days of the Wet Year (1977-1978)	Passable Days of the Dry Year (1967-1968)
Stream Crossing 7	17 Days	28 Days	0 Days

6.5 Prioritization of Stream Crossing Redesign

Once potential steelhead passage opportunities were identified with the FishXing software, the next step was to prioritize the redesign of each of Santa Anita Creek's culvert. DFG outlines various criteria by which to generate the prioritization of culvert redesign, including the stream crossing's impact to fish passage, current condition and habitat contribution. The culverts along Santa Anita Creek only varied in one criterion, the amount of habitat becoming available if the crossing no longer blocked fish passage. This criterion was the basis for the prioritization of stream crossing redesign.

6.5.1 Habitat Contribution

The Habitat Contribution criterion gives a higher score to those stream crossings that, when redesigned, make a greater amount of habitat accessible to steelhead. The following equation, taken from DFG protocol, was used to scale the quantity of habitat contribution of each stream crossing (Love & Taylor, 2003):

$$HabitatContribution = 0.5\left(\frac{HabitatLength}{152meters}\right)$$

The stream crossings were given Habitat Contribution values ranging from one to eight, with a higher score indicating a higher priority for stream crossing redesign. This criterion was set under an assumed scenario in which that the dam no longer prevented fish passage along Cañada de Santa Anita and that both the main road arch culvert and first Arizona crossing were deemed passable. Only under these conditions would steelhead have access to any upstream habitat. Results of this scoring are found in Table 10.

Table 11: The scoring of Habitat Contribution for prioritizing stream crossing redesign

Stream Crossing	Habitat Contribution
2	8
3	8
4	5
5	5
6	2
7	1

Therefore, the barriers closest to the ocean have the highest priority for redesign. Stream Crossing Seven has the least priority for redesign due to its geographic location and the resulting limited contribution to steelhead habitat availability.

6.6 DISCUSSION

Fish passage projects that involve alterations to stream crossings are expected to adhere to the criteria and recommendations developed by DFG in cooperation with NOAA NMFS, which are directly outlined in the section below (2001). The guidelines are general in nature and variances can be considered on a project-by-project basis (NMFS, 2001). However, following these guidelines would improve upstream passage of migrating salmonids. Likewise, improving upstream passage would allow for young-of-the-year and juvenile steelhead to swim upstream to find additional food, avoid predators, and seek refuge in pools with cool temperatures.

6.6.1 Criteria for Fish Passage at Stream Crossings

Stream crossing alterations are considered at each specific location. Many characteristics need to be reviewed prior to selecting the type of crossing to install, such as local geology, channel confinement, slope of the natural channel, and the possibility of channel incision that may occur from the removal of a perched culvert. Furthermore, adverse conditions should be avoided, such as introducing skew or veering from the natural stream channel when realigning the stream, altering alignment within the culvert itself, and the presence of trash racks and livestock fences (Love & Taylor, 2003). In addition to these considerations, fish friendly crossings should include:

- Crossing widths at least as wide as the active channels
- Natural substrate along the bottom of the crossings
- Smooth transitions between upstream and downstream water surfaces
- No excessive scour in the tailwater pool
- Culvert designed to withstand the 100 year peak flood flow without structural damage
- Stable stream banks above and below the crossings (Love & Taylor, 2003)

After evaluation of the site, the following alternatives and structure types proposed by DFG should be considered in order of preference depending on location constraints:

1. Nothing - road realignment to avoid crossing the stream
2. Bridge - spanning the stream to allow for long term dynamic channel stability
3. Stream simulation method - streambed simulation strategies, such as bottomless arch or embedded culvert design
4. Non-embedded culvert - hydraulic design method, limited to low slopes (<3%)
5. Baffled culvert or fishway structure - for steeper slopes (NMFS, 2001)

6.6.2 Application of Stream Crossing Criteria to Santa Anita Creek

When determining the appropriate alternative for each crossing that requires retrofit or replacement on Santa Anita Creek, the second and third alternatives were the most preferred options for all crossings. The thought process outlining this conclusion is found in the flow-diagram in Figure Thirty.

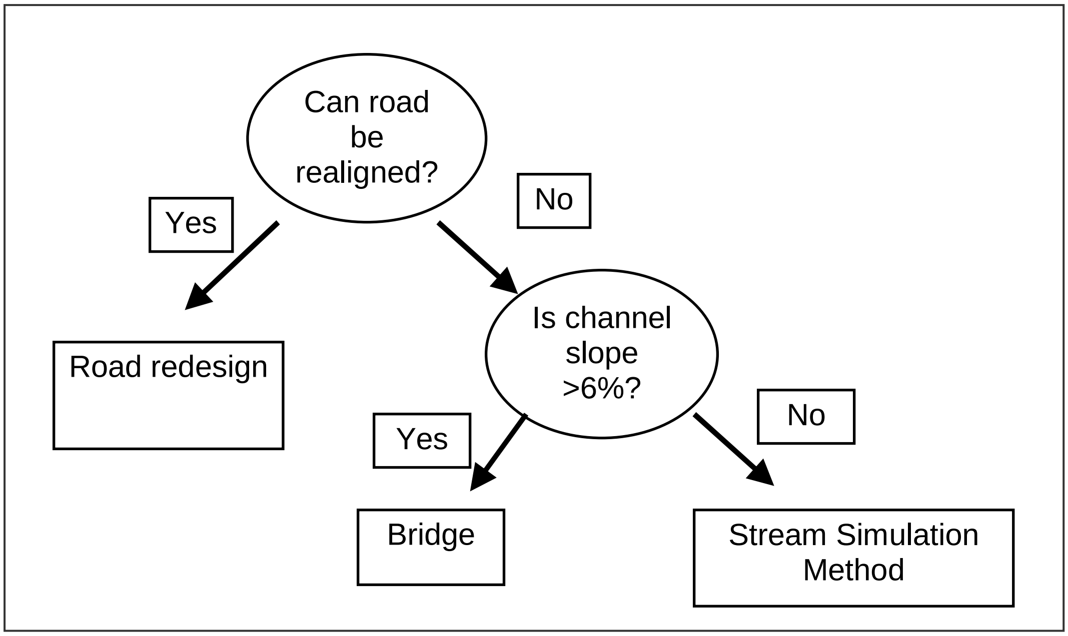

Figure 30: Flow-diagram used to determine the best alternative to increase fish passage for each barrier.

The first question we posed was, “Is road realignment a possible alternative to increase fish passage?” We concluded that road realignment was not a viable alternative for the crossings specific to Santa Anita Creek. First, Rancho Real Road must cross the creek to allow for access to the remainder of Hollister Ranch. Furthermore, Santa Anita Road follows the creek from the Rancho Real Road up the canyon to the vicinity of the natural barrier. Since Santa Anita Road traverses a steep, narrow walled canyon and property parcels lie on both sides of the creek, rerouting the road is not a feasible alternative to improve fish passage.

The next question we asked was, “Is the channel slope at the culvert less than 6%?” (Figure 30). For crossings that have a steeper slope, the preferred alternative is a bridge (Figure 31). Bridges offer many benefits in that they span the entire stream, provide a wide natural bottom, and allow for long term, active channel stability (NMFS, 2001). Bridges are specifically considered when the crossing width exceeds six meters, stream channel slope exceeds 6%, the crossing is prone to debris flows and/or flooding, or channel incision is likely after removal of a perched culvert (Love & Taylor, 2003). Precast concrete bridges are a practical solution for small stream crossings such as the crossings found on Santa Anita Creek. They are usually more cost effective, efficient, and less difficult to install and maintain than culvert replacement methods. In contrast to the stream simulation method, a precast bridge can be installed with much less channel engineering, site preparation, and stabilization. Since natural stream processes are allowed to occur, this alternative only requires the installation of proper footings and the bridge placed over the stream.

As such, bridges can be installed in a shorter time period, impact the job site to a lesser degree, and still effectively achieve fish passage goals.

Figure 31: Precast Bridge Stream Crossing

The preferred alternative for crossings that have a slope less than 6% is the stream simulation method (Figure 30). This option still utilizes a culvert for water flow and fish passage, but emulates natural stream processes within the culvert. This emulation allows for fish passage, flood and debris events, and sediment transport. Structures that are recommended from the stream simulation method are usually natural bottom arch culverts or embedded bottom culverts (Figure 32). The bottoms are to have a streambed mixture of native substrate, or sediment that is similar to the upstream and downstream channel. The following is required for the stream simulation design method, one specific method to emulate natural stream processes (Figure 33):

- Culvert width - minimum culvert width shall be equal to or greater than bankfull channel width; minimum culvert width shall not be less than two meters
- Culvert slope - culvert slope shall approximate the slope of the stream through the reach in which it is being placed; maximum slope shall not exceed 6%
- Embedment - bottom of the culvert shall be buried into the streambed not less than 30% and not more than 50 % of the culvert height; footings or foundation should be designed for largest anticipated scour depth

Figure 32: Example of an embedded culvert

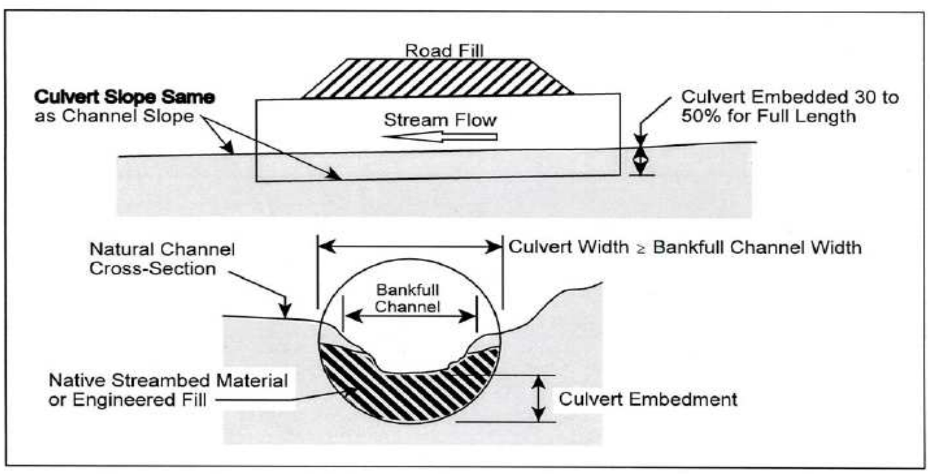

Figure 33: Stream Simulation Design Criteria (Love & Taylor, 2003)

6.6.3 Preferred Alternatives for Each Santa Anita Crossing

The following elucidates how Hollister Ranch can meet the stream crossing criteria and improve fish passage using the second and third preferred alternatives.

6.6.3.a Stream Crossing One (Railroad Crossing)

Because the railroad culvert received a green fish passage score according to DFG protocol, it does not need retrofitting or replacement. Since accumulated sands currently exceed one meter in depth in places within the culvert, monitoring is recommended to ensure debris does not accumulate and consequently limit fish passage. The risk of blocking this culvert would increase dramatically if sediment were to be released from the dam as described above.

6.6.3.b Stream Crossing Two (Rancho Real Road Arch Culvert)

Since this crossing is a large arch culvert with a flat concrete bottom, a retrofit is the best option to enhance fish passage. The rubble, old culvert debris, and concrete bottom should be removed and replaced with a natural bottom resembling channel substrate found in the nearby stream reach. This alternative entails minor channel engineering to maintain a slope less than 6% and adding coarse substrate to create a roughened channel bed.

6.6.3.c Stream Crossings Three, Four, Five and Six (Perched Arizona Crossings)

Due to the size, slope and channel width of the four Arizona crossings, a bridge replacement is the appropriate alternative. These four crossings are considered perched, meaning that the upstream elevation is considerably greater than the downstream outlet. This condition is usually caused by scouring of the tail-water pool due to excessive slope, turbulence, and water velocity and the trapping of coarse sediment on the upstream side of the crossing. A large amount of regrading and channel engineering would be required if a culvert replacement were chosen to allow for fish passage. Additionally, some of these crossings are of substantial size warranting a bridge as the best alternative. Bridges allow for large, unobstructed opening of the channel in sites with a slope over 6%. This alternative will minimize debris and flood problems on these important crossings that allow for access along Santa Anita Road and into residences.

6.6.3.d Stream Crossing Seven (Low Flow Crossing)

Due to the smaller size and mild slope of this low flow crossing, a culvert redesign incorporating the stream simulation method would be the most appropriate solution. A natural bottom culvert sized to allow for debris and high flows would allow for fish passage as well as ensure long term access to the well site, located further up the road.

The following table (Table 11) summarizes the characteristics of stream crossings along Santa Anita Creek and their preferred alternative to increase fish passage.

Table 11: Santa Anita Stream Crossing Properties

Stream Crossing	Culvert Slope (%)	Crossing Length (m)*	Stream Channel Slope	Other Issues	Preferred Alternative	Costs ($)
1	~0.01%	~5.8	< 3%	Sandy substrate covering flat stone bottom	None	-
2	2	5.8	< 6%	Large arch culvert	Natural Bottom Arch Culvert	~100,000
3	-	-	> 6%	No access, assume similar to other 3 AZ crossings.	Bridge	~500,000
4	14	16	> 6%	Perched AZ crossing Debris flows	Bridge	~500,000
5	6	17	> 6%	Perched AZ crossing Debris flows	Bridge	~500,000
6	7	13.5	> 6%	Perched AZ crossing Debris flows	Bridge	~500,000
7	3	12	< 6%	Low water crossing on well road	Embedded Culvert	~200,000

* Crossing length is an approximation of the entire span of the crossing, including width across the stream and road fill.

7.0 BARRIER REMOVAL COST CONSIDERATIONS

There are numerous factors that will affect cost within this project on Hollister Ranch. However, at this stage costs are only quantifiable at a macro scale due to a high level of uncertainty stemming from a lack of detailed engineering and biological assessment. A detailed assessment will need to be completed before any tangible values can be assigned specific to Santa Anita Creek. Generally, costs related to small dam and fish barrier removal projects can be categorized into the following:

1. Engineering
   - Planning and design, geotechnical and environmental assessment and documentation
2. Permitting and management
   - Project management and administrative duties, permit fees and planner time
3. Construction

    - Supervision, contractors, materials and labor
4. Monitoring and maintenance
    - Repairs, adaptation and stabilization

In addition to the above categories, Hollister Ranch needs to consider issues specific to the setting of the Ranch and Santa Anita Creek. Costs for Hollister Ranch to consider can include:

> Assessment of geomorphic and biological conditions, grant writing and fundraising, personnel and support staff, permitting and documentation from county, state, and federal agencies, site preparation such as dewatering the impounded sediment and creating access, demolition of existing structures, excavation and disposal of sediment, materials, equipment operation, stabilization, and restoration to desired finished state.

Many costs associated with planning and construction are high in Santa Barbara County due to the cost of living and strong regulatory conditions and oversight. Furthermore, the distance and rural nature of the Ranch will greatly increase mobilization and transportation costs to and from the site. Finally, there are usually incidental expenses to account for such as accidents, damage to roads, habitat, or property, and mitigation of dust, traffic or other unwanted occurrences.

While it is not yet possible to estimate specific costs for Santa Anita Creek steelhead restoration, Appendix G illustrates a number of costs as estimated for similar landscape and fish passage restoration projects occurring in Santa Barbara County. Appendix G, Arroyo Hondo Culvert Modification/Steelhead Passage Construction Estimate, is particularly related to Santa Anita and is helpful in making comparisons and projections for cost estimates to the Hollister Ranch project on a per unit basis. Furthermore, a local contractor experienced in fish passage construction projects provided qualitative comment after a site visit with group project members, numerous staff and affiliates from Hollister Ranch to Santa Anita Creek.

Using cost comparisons with similar projects, and comments taken from the site visit with the contractor, we estimate that the total cost of restoring fish passage to Santa Anita Creek may range from 3 to 8 million dollars. This is a conservative estimate due to the current amount of uncertainty explained above. The estimate encompasses the removal of the dam and related sediment excavation and disposal, modifying the Rancho Real Road crossing, replacing the four Arizona crossings with bridges, and modifying the low flow crossing to allow for greater fish passage.

Table Twelve reports construction costs for the dam and sediment removal as an estimate ranging from 1 to 3 million dollars, depending greatly on the sediment management option chosen. Costs will be less if much of the sediment can be disposed of, or stored nearby to be reused as clean fill or top amendment within the ranch. Altering the other stream crossings ranges between 400,000 and 600,000 dollars. These costs depend on the removal of the existing structure, the amount of grading, channel engineering, infill and stabilization of the bridge or new culvert. The remaining costs are allocated to the engineering, permitting, management, and monitoring of the project.

Table 12: Estimated construction costs

Barrier	Cost ($)
Rancho Real Road	~100,000
Dam and Sediment	1,000,000 - 3,000,000
AZ crossings	~500,000 each
Low flow crossing	~200,000
Total	~5,500,000

Much of the uncertainty in our current cost estimate can be lessened early in the next steps of the project during the initial engineering assessment. It will be possible to more clearly estimate costs once initial engineering assessments have been made and when specific design options for restoring steelhead passage to Santa Anita Creek have been detailed.

8.0 HABITAT ASSESSMENT

A habitat assessment was performed with the objective of documenting the extent and current quality of southern steelhead habitat provided by Santa Anita Creek. Because the stream reaches assessed are not all thought to be currently available to steelhead, this assessment was conducted to answer our second research question by providing insight into the quality and quantity of steelhead habitat that could become available if passage was restored to the creek.

8.1 METHODS

8.1.1 Area Assessed

The habitat assessment was carried out along all reaches of Santa Anita Creek downstream of the natural barrier to which group members were granted access by the HROA and individual Hollister Ranch property owners. Access to the creek was granted on parcels 83, 88, 89, and 104, as illustrated in Figure 34. For the purposes of this report, results and pictures obtained during the habitat assessment are ordered as if the reader is walking upstream from the estuary. Stream reaches were separated into three sections, which were discovered to have similar habitat characteristics and were expected to support different stages of the steelhead lifecycle. For easier identification each section was assigned a number. The three sections and their associated Hollister Ranch parcel numbers are:

- Section One: The estuary to the Union Pacific maintained railroad crossing (Parcel 104);
- Section Two: Upstream of the Union Pacific railroad crossing to the upstream property boundary of parcel 88, including the impounded sediment plain behind the dam (Parcels 88 and 89); and
- Section Three: The section of creek passing through parcel 83.

In total, 2.2 km of Santa Anita Creek were assessed. A section approximately 1.8 km long flowing through parcels 84, 86, 87, 92, and 93 was not assessed due to lack of access. Similarly, an approximately 0.3 km length of creek located upstream of parcel 83 and below the natural barrier was not accessible for assessment. Consequently, the location of the natural barrier could not be confirmed on the ground. However, an analysis of aerial photographs and USGS topographical 7.5 minute quad maps (USGSd, USGSe) confirmed that the waterfall barrier is located approximately 4.2 km upstream of the ocean.

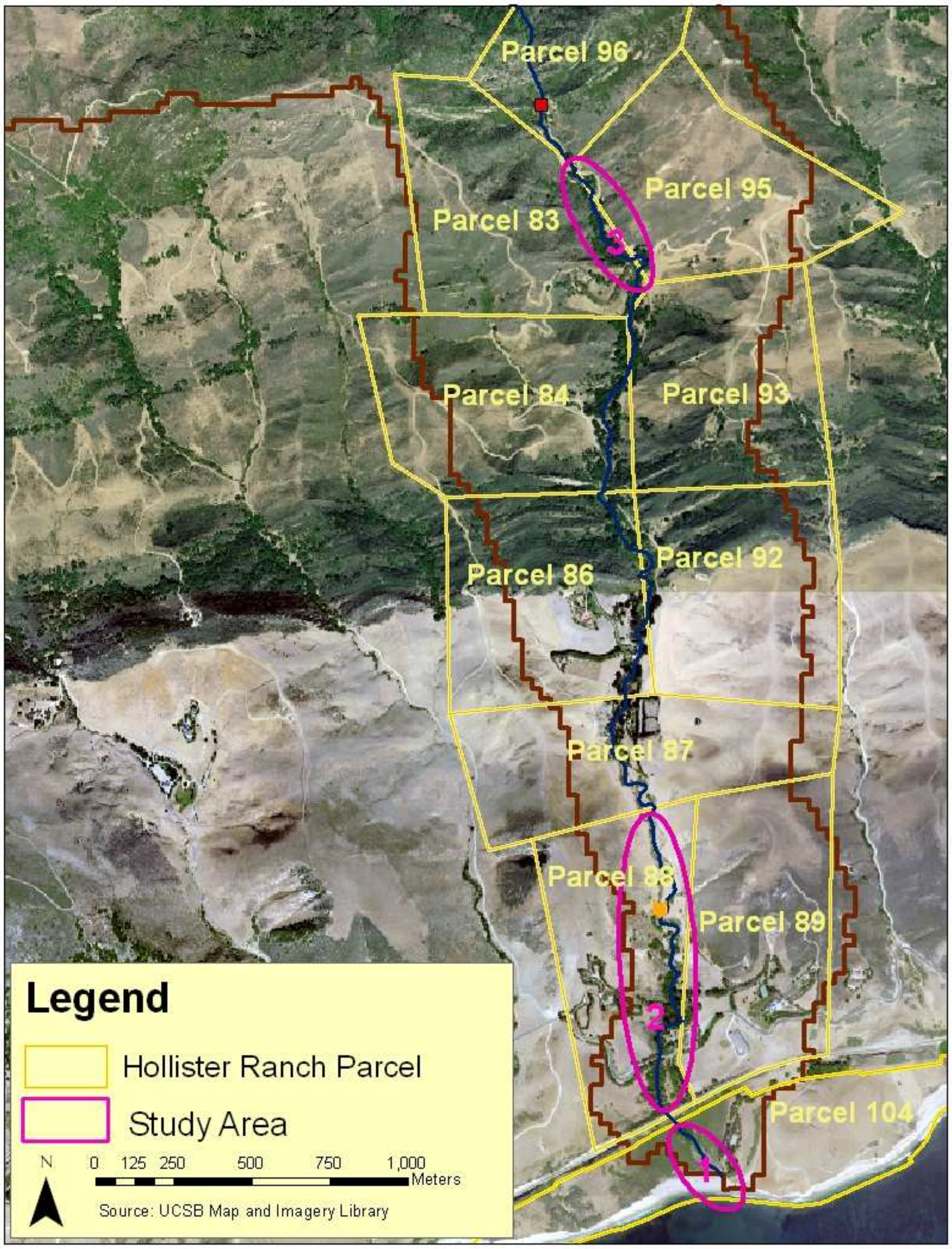

Figure 34: Map of study area (indicated in pink) with an overlay of Hollister Ranch parcel numbers (indicated in yellow). The natural barrier is indicated in red and the dam is identified in yellow.

Before beginning a more detailed habitat assessment of Santa Anita Creek, we performed a pre-assessment walk-through to broadly characterize the three study sections and the potential types of habitat available to southern steelhead within each section. Following the walk-through, we identified the steelhead life stages that could be supported by each section in their current state. Despite our observation of its separation from upstream surface flows, Section One, the estuary, was identified as a potential rearing site for juvenile steelhead waiting to enter the ocean. Section Two was identified as a migration corridor for adult steelhead based on a lack of appropriate spawning substrate, and in some locations, reduced canopy cover. While Section Two was characterized as migration corridor during our walk-through, we recognized its potential for future post dam removal restoration efforts, including channel design and revegetation, that could increase its suitability for spawning and rearing. Section Three was identified as potential spawning and rearing habitat due to its dense canopy cover, consistent pool habitat, and observed spawning substrate. Our habitat assessment was designed to assess the ability of each section to support the steelhead life stages identified above. As such, the level of analysis undertaken in each section varied. To determine the quality of steelhead habitat available in each section, the following measurements were taken:

8.1.2 Pools and Spawning Gravels

Steelhead use pools for different purposes at different stages in their lifecycle. Young-of-the-year rear and take refuge in the deeper, cooler waters found in pools over the summer months, migrating adults use the slower waters to rest as they proceed upstream, and spawning adults create redds in gravel-lined pool tail-outs. The minimum depth of water needed for stream passage and spawning is 15 cm (Bovee, 1978; as cited in Stoecker, 2002). In southern California's coastal streams, juvenile steelhead have been observed rearing in pools with depths as shallow as 20 cm (A. Spina, NOAA, personal communication, March, 10, 2007). Such an observation may establish a lowest limit of short-term viability, but not necessarily a favorable condition for rearing steelhead. Thus, we took a slightly more conservative approach and defined pools based on a minimum depth of 30 cm, assuming that the additional depth would provide an increased level of protection from predation for juvenile steelhead rearing in the creek over the summer. On October 27, 2007, in record low flow, pools and patches of spawning gravels were identified and catalogued. Pool depth was measured with a stadia rod, while length and width were measured with a survey tape. Pool tail-outs with gravels of sufficient size and quantity for spawning were identified. Patches of gravel found at pool tail-outs in Santa Anita Creek were approximately 4 m^2 in size.

8.1.3 Pebble Count

The Wolman pebble count method, which utilizes random sampling of gravel particles and a gravel-o-meter, was employed to classify streambed particles into a size distribution on January 17, 2008. Particle size distribution information can be used to assess the amount of appropriately-sized gravel available for spawning steelhead. Steelhead prefer gravels ranging from 5 mm to 100 mm for spawning (Bovee, 1978; Reiser and Bjornn, 1979; as cited in McEwan and Jackson, 1996). Sample sites consisted of pool tail-outs located in Section Three. Pool tail-outs that featured predominately sand-sized particles were not assessed and, as a result, were not counted as spawning sites.

8.1.4 Embeddedness

Embeddedness, an indicator of a streambed's spawning suitability, is the degree to which larger particles, including boulders, cobbles, and gravels, are surrounded or covered by fine sediment. Embeddedness was visually estimated following DFG protocol on January 17, 2008 (Flosi et al., 1998). Small cobbles, about 5 to 13 cm in diameter, were chosen from pool tail-outs. The percentage of the stone buried by sediment was estimated by examining the portion of the cobble that was shiny below the algae or sediment line. Values of 1 through 5 were assigned to each cobble based on the percentage of shininess observed with the following ranges: 1 = 0 to 25% shiny; 2 = 26 to 50% shiny; 3 = 51 to 75% shiny; 4 = 76 to 100% shiny; 5 = unsuitable for spawning. The 5 value was assigned to tail-outs that were deemed unsuitable for spawning due to inappropriate substrate particle size or the presence of a bedrock tail-out. The DFG considers an embeddedness rating of 1 to indicate good quality spawning substrate for steelhead (Flosi et al., 1998). Embeddedness was estimated for gravel tail-outs found in Section Three.

8.1.5 Canopy Density

Overhead vegetation density was measured using a convex spherical densiometer and the modified Strichler measurement technique at regular points along the stream channel. Canopy density was measured in all areas along the creek to which access was granted. Canopy cover was measured in Sections One and Two on September 20, 2007 and in Section Three on October 27, 2007. Canopy coverage of 80% or more is thought to provide high habitat value for southern steelhead (Flosi et al., 1998).

8.1.6 Temperature and Dissolved Oxygen (DO)

HOBO™ data loggers were placed in the estuary, immediately downstream of the dam, and in the fourth pool upstream of Stream Crossing Six to record water temperature on an hourly basis. The estuary data logger recorded data from September 13, 2007 to January 17, 2008. It was located approximately 10 m inland from the estuary mouth and was positioned within 13 cm of the estuary bed. Unfortunately, this data logger was washed out of the estuary and onto a nearby bank during a large storm on December 4, 2007, making this date the extent of our estuary data. While the duration of water temperature measurements recorded in the estuary was shorter than water temperature assessments performed upstream, the period of measurement was sufficient to capture late summer conditions when temperatures in the estuary were expected to be highest, and therefore the most stressful for southern steelhead, due to a lack of water supply from Santa Anita Creek and increased solar radiation. The data logger located below the dam recorded data from August 30, 2007 to January 17, 2008 and was positioned approximately 30 cm below the water's surface. A data logger was also placed approximately 30 cm deep in the fourth pool upstream of Stream Crossing Six on parcel 83 to record water temperature. This data logger recorded data from August 24, 2007 to January 17, 2008.

Temperature and DO measurements were also taken in pools along Santa Anita Creek using an YSI™ water quality instrument. Pools downstream of the dam were measured on September 19th, 2007, between 11:30 AM and 2:00 PM. Pools upstream of the dam were measured on October 27, 2007, between 10:00 AM and 3:00 PM. The depth at which DO was measured varied. DO varies with time of day, water depth, and water temperature. Santa Anita Creek's DO was measured once in the middle of the day. As a result, while we report our DO measurements, the data collected on DO in Santa Anita Creek is too limited to draw any significant steelhead habitat conclusions.

While water temperature range limits for steelhead residing in the northwestern United States are relatively well understood, incipient lethal limits for southern steelhead remain uncertain. The coastal streams of southern California are often shallow and clear in the summer, resulting in water temperatures in exceedence of incipient lethal water temperatures reported for northern steelhead. Despite water temperatures approaching 30 °C, juvenile southern steelhead are often observed in coastal southern California streams (Matthews & Berg, 1997; Spina, 2007). This finding has led some fisheries biologists to suggest that southern steelhead accept elevated body temperatures in exchange for maintaining an expanded geographic (latitudinal) range (Spina, 2007). Current literature suggests an upper range of incipient lethal temperatures for southern steelhead from 25 °C to 32 °C (Spina, 2007). Results of our habitat analysis were interpreted with consideration for this uncertainty.

8.2 RESULTS

8.2.1 Channel Section One

For detailed habitat assessment data records, see Appendix H.

8.2.1.a Canopy Coverage

Canopy coverage increased with distance away from the ocean, ranging from 0 % near the estuary mouth to 100% at the estuary's upstream end near the Railroad Crossing. Non-native plants were observed interspersed with native vegetation along the estuary. It was estimated that non-natives comprised approximately 10-15% of the vegetation cover surrounding the estuary. Non-native plants included eucalyptus trees (*Eucalyptus* sp.), giant reed (*Arundo donax*), pampas grass (*Cortaderia selloana*), Peruvian pepper tree (*Schinus molle*), poison hemlock (*Conium maculatum*), sweet fennel (*Foeniculum vulgare*), and tree tobacco (*Nicotiana glauca*). Examples of native species observed near the estuary include coyote brush (*Baccharis pilularis*), poison oak (*Toxicodendron diversilobum*), toyon (*Heteromeles arbutifolia*), and California sagebrush (*Artemisia californica*).

8.2.1.b Temperature, DO, and Salinity

The average temperature recorded by the HOBO™ data logger located in the estuary between September 13, 2007 and December 4, 2007 was 16.9°C. Temperatures ranged from 10.2°C to 27.4°C. As illustrated in Figure Thirty Five, the highest estuary temperatures recorded occurred from mid September to the beginning of October, while the lowest temperatures occurred at the beginning of December. Estuary temperatures fell within the range of reported incipient lethal temperatures for steelhead for a total of 28 non-continuous hours, indicating that the estuary may experience conditions lethal to rearing juvenile steelhead over the summer months.

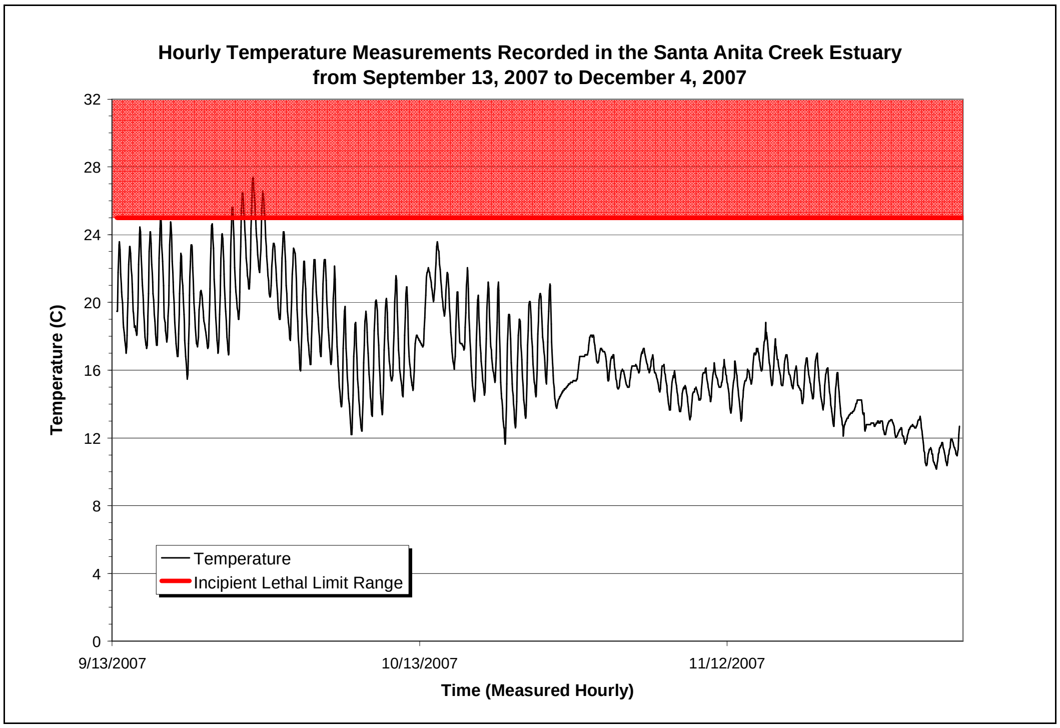

Figure 35: Temperature of Santa Anita Creek estuary measured hourly from September 13, 2007 to January 17, 2008 using a HOBO™ data logger.

The average temperature measured in the estuary using the YSI™ water quality instrument on September 19th, 2007 was 21.4°C, with very little variation from the mouth to its upstream end. Moving upstream from the ocean, DO decreased significantly. The four measurements obtained starting at the estuary mouth and proceeding upstream were 12.1 mg/L, 15.3 mg/L, 2.3 mg/L, and 2.1 mg/L. The incipient lethal level of DO for adult and juvenile steelhead is 3 mg/L or less, depending on environmental conditions, particularly temperature (Matthews & Berg, 1997). While our measurements suggest that DO may have reached steelhead lethal limits in the estuary, DO in southern California streams fluctuates on a diurnal cycle and, as a result, varies greatly throughout the day. Our measurements were only taken on one day over a short time period, and we recommend further long-term monitoring of DO in the estuary and the rest of Santa Anita Creek before any conclusions are drawn.

8.2.2 Channel Section Two

For detailed habitat assessment data records, see Appendix H.

8.2.2.a Canopy Coverage

Illustrated in Figure 36, canopy coverage varied greatly in this portion of Santa Anita Creek. In the 0.75 km section of creek located below the dam, average canopy cover was determined to be 70 % with canopy coverage exceeding the 80 % coverage amount preferred by southern steelhead 50 % of the time. Canopy coverage was measured to be 0% through the section of the creek flowing through the impounded sediment behind the dam, indicating the need for restoration of vegetation throughout this section.

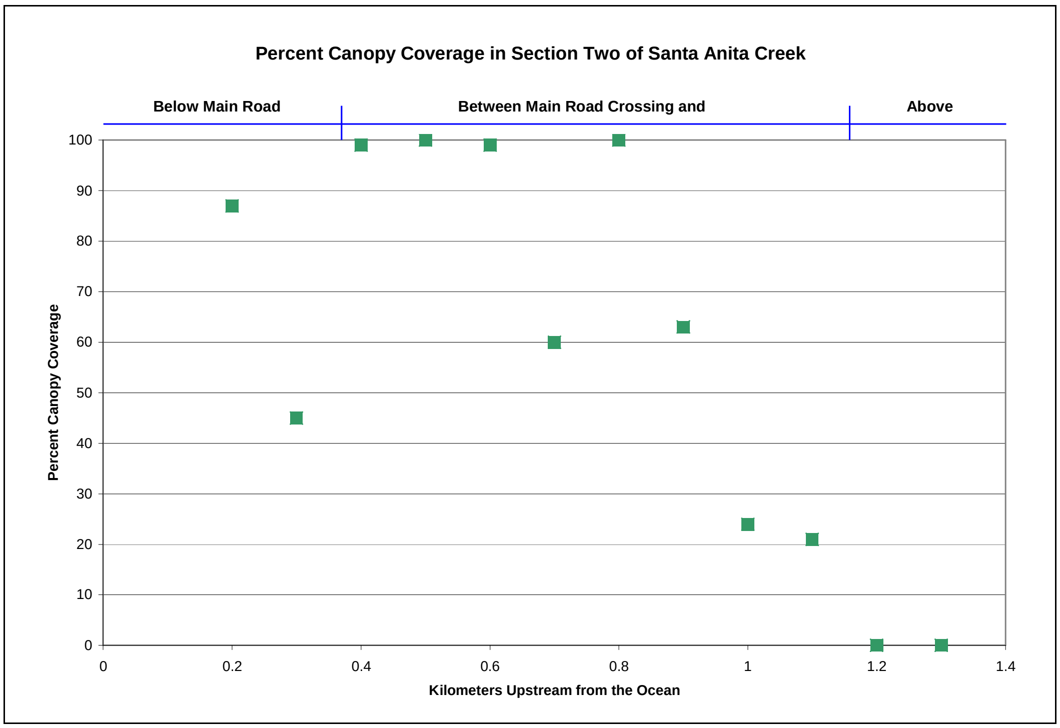

Figure 36: Canopy coverage measurements taken in Section Two of Santa Anita Creek. Distance upstream of the ocean of each measurement point is approximate and barrier locations are provided in blue for spatial reference.

8.2.2.b Temperature and DO

The average stream temperature recorded by the HOBO™ data logger located immediately below the dam between August 30, 2007 and January 17, 2008 was 13.9°C. Temperatures ranged from 4.7°C to 23.9°C. The highest stream temperatures recorded occurred over a few days at the end of August and the beginning of September, while the lowest stream temperatures occurred over a few days at the end of December, as illustrated in Figure 37. Stream temperatures in Section Two did not, however, fall within the incipient lethal water temperature range for southern steelhead, 26°C, at any time in the measurement period.

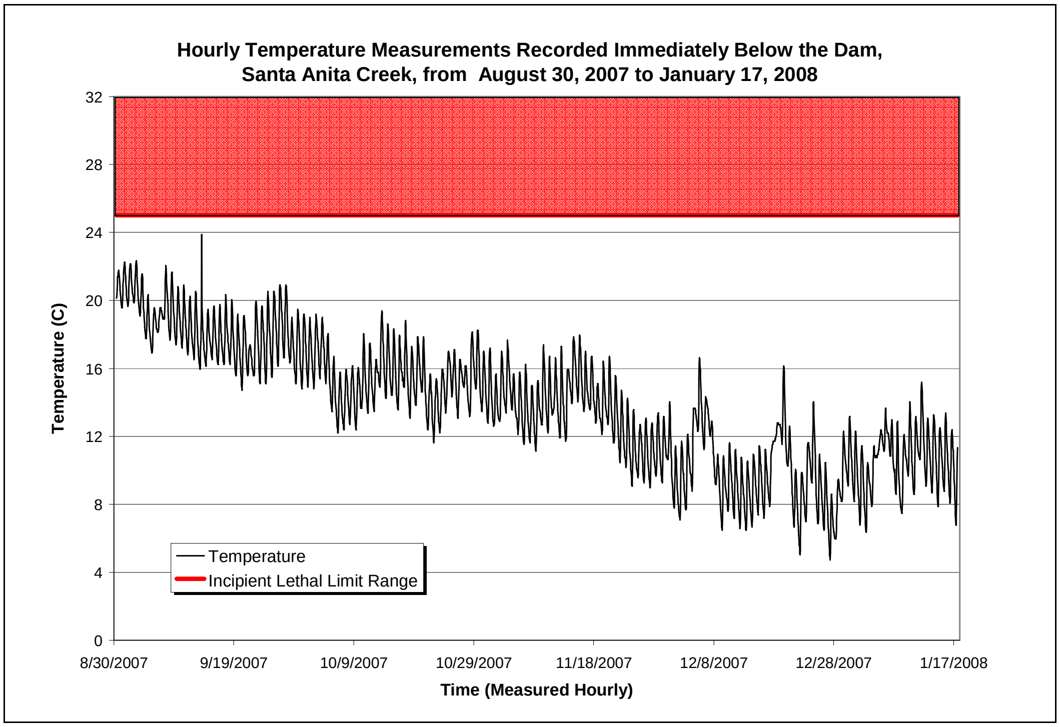

Figure 37: Temperature of Santa Anita Creek immediately below the dam measured hourly from August 30, 2007 to January 17, 2008 using a HOBO™ data logger.

Little temperature variation was observed along this section of the creek on September 19, 2007. Average stream temperature obtained while using the YSI™ water quality instrument was 16°C. Dissolved oxygen was measured to be higher in the section of creek flowing through the impounded sediment above the dam, with an average of 7.4 mg/L, than below the dam, which had an average DO of 5.4 mg/L. A range of DO values from 3.3 to 7.2 mg/L were measured below the dam, while variation in DO measurements above the dam was minimal, from 6.8 to 8.1 mg/L. The creek bed was observed to be dry from below Stream Crossing One, the railroad crossing, to just upstream of Stream Crossing Two, the main road arch culvert, during all visits that occurred in the middle of September 2007. Surface flow still occurred elsewhere along the creek, but this dry stretch disconnected the estuary from upstream flows.

8.2.3 Channel Section Three

For detailed habitat assessment data records, see Appendix H.

8.2.3.a Channel Dimensions

The low flow width in Section Three ranged from 1.8 to 9.3 m, with an average width of 4.1 m. Average bankfull channel width was 7.8 m, ranging from 5.5 to 10.5 m. Surface flow occurred continuously in this section of the stream, despite the region's dry conditions.

8.2.3.b Pool Characteristics

Nine pools were identified in this 500 m section of the stream. Boulder and log jam-induced constrictions represented the upstream boundary of many of the pools observed. Pool depths ranged from 39 to 83 cm. Average pool depth was 57 cm. Shallow runs and riffles were also observed between pools.

8.2.3.c Substrate Characteristics

Cobble to boulder-sized substrate was predominant throughout the reach; however, pool-bed substrate consisted mainly of sand to gravel-sized particles. Bedrock was observed periodically. Of the nine pools identified in this section of Santa Anita Creek, two pools had grains course enough for a pebble count. All grains sampled in the pebble count were classified as gravels based on their diameter. Results of the pebble count are outlined in Table 12. Gravels ranging in diameter from 5 to 100 mm are appropriate for steelhead spawning (Bovee, 1978, Reiser and Bjornn, 1979, as cited in McEwan and Jackson, 1996). Therefore, over 99 % of the gravels measured in the second pool downstream of Stream Crossing Six and over 98 % of the gravels measured in the fourth pool upstream of Stream Crossing Six were appropriate for spawning steelhead.

Table 12: Pebble count results

Pool	Median Substrate Size (D_{50})	Diameter of Grain	Gravel Type	Percent Observed
Second pool downstream of Crossing Six	19 mm	16 – 22.6 mm	Very coarse gravel	30%
		11.3 – 16 mm	Coarse gravel	27%
		8 – 11.3 mm	Medium gravel	32%
		5.7 – 8 mm	Fine gravel	10%
		4 – 5.7 mm	Very fine gravel	1%
Fourth pool upstream of Crossing Six	13 mm	16 – 22.6 mm	Very coarse gravel	5%
		11.3 – 16 mm	Coarse gravel	34%
		8 – 11.3 mm	Medium gravel	37%
		5.7 – 8 mm	Fine gravel	22%
		4 – 5.7 mm	Very fine gravel	2%

Three pool tail-outs had particles appropriately-sized for inclusion in an embeddedness estimate. Of these three pool tail-outs, the fourth pool upstream of Stream Crossing Six was determined to have an embeddedness value of 1 (Figure 38), the second pool downstream from Stream Crossing Six had a value of 2 (Figure 39), and the second pool upstream of Stream Crossing Six had a value of 3 (Figure 40). The remaining pool tail-outs were assigned values of 5 because the substrate observed was not large enough to be included in an embeddedness estimate. The DFG considers an embeddedness rating of 1 to indicate good quality spawning substrate for steelhead, suggesting that only one of the nine pools observed in this section features spawning substrate of a good quality for steelhead.

Figure 38: The fourth pool upstream of Stream Crossing Six was assigned an embeddedness score of 1.

Figure 39: The tail end of the second pool downstream of Stream Crossing Six, which received an embeddedness value of 2.

Figure 40: The second pool upstream of Stream Crossing Six, which was assigned an embeddedness value of 3.

8.2.3.d Canopy Coverage

Riparian canopy cover was high, with an average canopy cover of 90%. Only three out of 17 measurements of canopy cover fell below the 80% coverage criterion for steelhead habitat. The vegetation lining the stream was predominantly native and included coast live oak (*Quercus agrifolia* ssp. *agrifolia*) and California sycamore (*Platanus racemosa* var. *racemosa*) trees.

8.2.3.e Temperature and DO

The average stream temperature recorded by the HOBO™ data logger located in the fourth pool upstream of Stream Crossing Six between August 21, 2007 and January 17, 2008 was 13.2°C. Temperatures ranged from 6.2°C to 22.1°C. The highest stream temperatures recorded occurred over a few days at the end of August and the beginning of September, while the lowest stream temperatures occurred over a few days at the end of December, as illustrated in Figure 41. Stream temperatures in Section Two did not fall within the incipient lethal water temperature range for southern steelhead at any time during the measurement period, indicating that water temperature should not be a stressor for juvenile steelhead rearing in the upper portion of the creek over the summer.

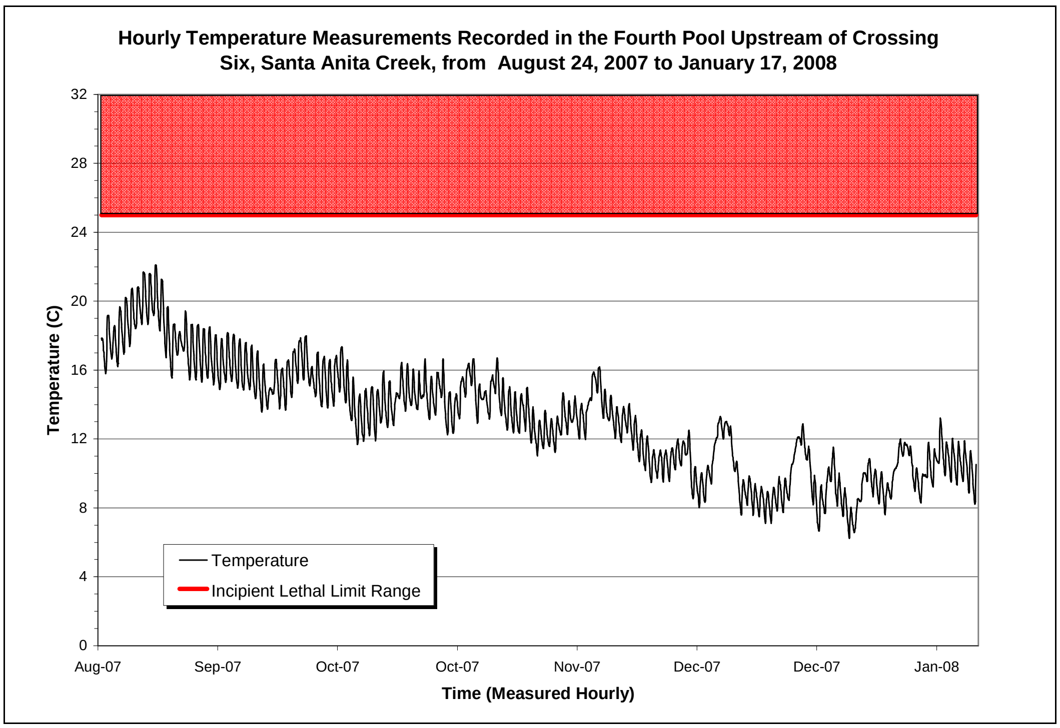

Figure 41: Temperature of Santa Anita Creek in the fourth pool upstream of Stream Crossing Six measured hourly from August 24, 2007 to January 17, 2008 using a HOBO™ data logger.

Temperature measurements obtained on October 27th, 2007 using the YSI™ water quality instrument varied little throughout the property, with an average temperature of 14.6°C. Average DO was measured to be 7.4 mg/L and ranged from 6.5 to 8.1

mg/L. While these DO measurements suggest that DO should also not be a stressor for juvenile steelhead rearing in Santa Anita Creek over the summer, further long-term DO monitoring is needed to account for daily fluctuations.

8.2.3.f Trout

Small trout, about 15 cm in length were observed swimming in two pools located in Section Three. Two trout were observed in the fourth pool above Stream Crossing Six, the same pool in which the data logger was located (Figure 37). On October 27th, 2007, the day that the trout were observed, this pool was measured with the YSI™ water quality instrument to have a temperature of 14.7°C, and a DO level of 7.7 mg/L. The pool's depth was 70 cm. An additional trout was observed in the second pool upstream of the low flow crossing on the same day (Figure 38). This pool was measured to have a depth of 55 cm. The YSI™ water quality instrument provided a temperature measurement of 14.7°C, and a DO level of 7.1 mg/L. The observance of trout in two of the pools in Section Three of Santa Anita creek suggests that this section of the creek offers conditions suitable for over summer rearing of juvenile steelhead. In addition to the trout observed in this section of the creek, local resident Lee Harrington has observed trout in Santa Anita Creek in pools located on parcel numbers 95 and 96 (L. Harrington, personal communication, February 26, 2008). Due to a lack of access, we were unable to confirm these observations.

Figure 42: Two trout were observed in the fourth pool upstream of Stream Crossing Six pictured here.


Figure 43: One trout was observed in the second pool upstream of the low flow crossing pictured here.

8.3 Habitat Discussion

8.3.1 Channel Section One

Results of our assessment suggest that the quality of summer rearing habitat provided by the Santa Anita Creek estuary is rather low. Temperatures in the estuary fell within the range of incipient lethal temperatures for southern steelhead over a total of 28 hours during our September 2007 to December 2007 measurement period. In addition, DO levels dropped below lethal limits for steelhead, and 0% canopy cover was observed near the estuary mouth. While estuary water temperatures can become stratified during the summer, our temperature measurements were conducted within 13 cm of the estuary bed. At this depth, the coolest waters should have been measured, even within a highly stratified water body.

Estuaries can be an important source of habitat for steelhead. Of the steelhead returning to freshwater streams to spawn in northern California, Bond (2006) found that 80% were reared in the estuary. Steelhead primarily use estuaries during the rearing phase of their lifecycle where they feed, grow, acclimate to higher salinity levels, and wait for estuaries closed by sand bars to be breached so they can enter the ocean. For this reason, further investigation into the quality of habitat provided by the estuary is warranted.

While estuary temperatures fell within the 25° C to 32°C range of incipient lethal temperatures, juvenile southern steelhead have been observed rearing in water temperatures approaching 30 °C in other coastal southern California streams (Spina, 2007; Matthews & Berg, 1997). The maximum temperature recorded in the Santa Anita estuary was 27.4 ° C. In addition, temperature was not measured in an approximately 3 m deep pool located at the upstream end of the estuary. This pool may feature cooler water temperatures in the summer due to its greater depth and canopy coverage. There is also the possibility that the pool features a groundwater seep, an important source of cooler water found in many of southern California's coastal streams (Matthews & Berg, 1997). Summer temperatures should be measured in this pool at several depths to account for possible stratification and to identify groundwater seeps, if they are present. Despite the potential for lower temperatures in the most upstream end of the estuary, DO measurements taken in this portion of the estuary were measured to be 2.3 mg/L and 2.1 mg/L, both below the incipient lethal level of 3 mg/L. DO fluctuates throughout the day, and a more detailed assessment of DO in the upstream ends of the estuary may reveal higher quality summer rearing habitat. Research by Matthews and Berg (1997) suggests that juvenile southern steelhead may make trade-offs between warm water temperatures and low levels of DO to increase their chance of survival in southern California streams. There may be locations within the Santa Anita Creek estuary where such trade-offs are possible. Furthermore, the estuary was cut off from surface flows during our measurements. In non-record low stream flow years, stream flows may remain great enough to keep the estuary connected to the creek's surface water supply, which could result in higher levels of DO in the upstream end of the estuary. For these reasons, extended investigation of the summer rearing habitat provided by the estuary should be conducted.

While our initial analysis of the estuary suggests poor quality summer rearing habitat, it does not discount Santa Anita Creek's utility as a source of habitat for southern steelhead. Sixty-seven to 96% of young-of-the-year steelhead resided in pools upstream of the estuary in another small coastal California stream (Cross, as cited in Stoecker & the Conception Coast Project, 2002).

8.3.2 Channel Section Two

Further analysis of the middle portion of Santa Anita Creek, from the railroad crossing upstream through the impounded sediment plain, supports our initial assumption that this portion of the creek currently provides important corridor habitat for southern steelhead migration. Complex in-stream habitat features, including logs and overhanging banks, were detected throughout this section, especially below the dam. Canopy cover was higher below the dam than above it. In the 0.75 km section of creek located below the dam, average canopy cover was determined to be 70% with canopy coverage exceeding the 80% coverage amount preferred by southern steelhead 50% of the time. However, canopy coverage was measured to be 0% through the section of the creek flowing through the impounded sediment upstream of the dam. Despite a dearth of canopy cover along this section, temperature measurements indicate non-lethal conditions even during the height of summer.

Average water temperature in this section of the creek, 13.9 °C, was only slightly higher than the average water temperature upstream in Section Three, 13.2 °C, suggesting the presence of (a) groundwater seep(s) or that increased solar radiation due to a lack of canopy cover was not significant. High water temperatures would certainly not be a threat during the winter wet season when adult steelhead would be expected to use the corridor for migration. While the sandy and silty substrate observed in this section of Santa Anita Creek is not appropriate for spawning, the creek features characteristics that would support steelhead as they migrate upstream to spawn.

Special attention should be called to the portion of Santa Anita Creek flowing through the sediment impounded behind the dam. This section of the creek currently lacks canopy coverage and features little habitat complexity, providing steelhead minimal protection from predators. A few overhanging banks were observed in this portion of the stream, but no pools were detected. Migrating adult steelhead require pools for resting as they make their way upstream toward spawning habitat. If the dam and the impounded sediment were removed from Santa Anita, the creek would be expected to return to its original pre-dam slope and associated pattern of pool habitat, either over time through natural sediment transport or more quickly through mechanical design of the channel. Figure 44 illustrates an estimate of Santa Anita Creek's pre-dam slope in this section of the creek based on hand augering results and aerial photographs.

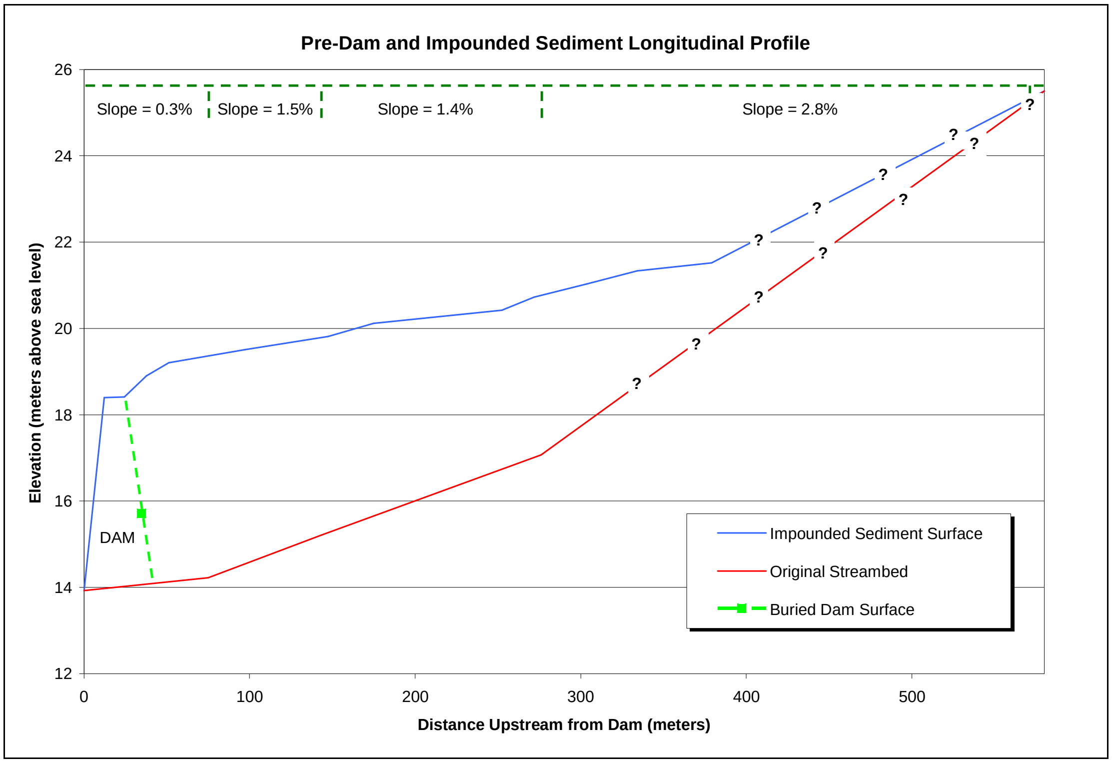

Figure 44: Pre-dam streambed profile (red) estimated using maximum auger depths and aerial photographs. Pre-dam channel slope is indicated at the top of the figure (green) and current sediment surface is shown (blue) for comparison.

Upon dam removal, the slope of Santa Anita Creek behind the dam would be expected to increase from its current impounded state. Slopes would be expected to be steeper in what is now the more upstream end of the impounded sediment, decreasing downstream. This prediction is supported by measurements upstream of the impounded sediment in Section Three and downstream of the dam, which show that slope decreases as you proceed downstream in Santa Anita Creek. In addition to a decreased slope downstream, the stream channel would be expected to widen. A wider channel would result in a decreased frequency of pools and an increased stream flow depth. As a result, deeper pools would be expected to occur. Gravels appropriately sized for steelhead spawning would be expected to occur further downstream than they do now due to increased transport capacity resulting from an increased channel slope. Buffington and Montgomery (1999) have shown that gravel should be expected along stream beds a few meters wide down to slopes of 0.6%, indicating that patches of spawning gravel may become available downstream to roughly the current location of the dam. Sediment transport calculations described earlier support this prediction, estimating the deposition of gravels near the dam's current location upon dam removal. An increased number of pools and associated patches of gravel in pool tail-outs would transform Section Two of Santa Anita Creek from a migration corridor to spawning and rearing habitat. For this reason, it would be important to revegetate the section. Vegetated riparian corridors shade streams, reducing water temperature. In addition, mature vegetation that dies and falls into the stream channel creates increased complexity in the channel, providing additional cover for rearing steelhead.

8.3.3 Channel Section Three

Suitable steelhead habitat was observed throughout Section Three of Santa Anita Creek. The DFG classifies steelhead habitat from poor to excellent and defines excellent steelhead habitat to be relatively undeveloped with pristine watershed conditions. Excellent habitat should also include the following habitat features: dense riparian zones with a mix of mature native species, frequent pools, high quality spawning areas, cool summer water temperatures, complex in-stream habitat, and a relatively intact floodplain. While habitat receiving a rating of good must also be relatively intact, it differs from excellent habitat in that it may have been and may continue to be altered by erosion processes. Habitat classified as good should also contain the same habitat features found in excellent quality habitat (Love & Taylor, 2003).

While the portion of Santa Anita Creek flowing through Section Three contains one Arizona crossing and one low flow crossing and is flanked by a road approximately 5 m from its bank, our assessment shows that this section of the creek features an intact floodplain. Applying DFG classification of habitat quality to Santa Anita Creek without considering southern California's other coastal streams suggests a ranking of good to excellent is appropriate. However, relative to the large primary steelhead streams located in southern California, including the Santa Maria, Santa Ynez, Ventura, and Santa Clara, labeling Santa Anita as an excellent quality southern steelhead stream seems less appropriate. Despite the quality of habitat provided by Santa Anita Creek relative to the four primary steelhead streams, the habitat features found in Section Three of Santa Anita Creek, including canopy cover, native vegetation, summer water temperatures, embeddedness, spawning areas and gravels, pools, and a complex in-stream environment are present within suitable ranges to support southern steelhead, as indicated by Table 12.

Table 13: Parameters measured in Section Three indicated suitable steelhead habitat

Habitat Feature	Parameter Ranges Considered Supportive for Southern Steelhead	Section 3 Parameter Measurement/Observations
Canopy Cover Density	80% or greater	Average of 90%.
Mature, Native Vegetation	No specific parameter available.	Present, as indicated by mature native oak and sycamore.
Cool Summer Water Temperatures	0 to 22℃.	13.23℃ on average, with a range of 6.23℃ to 22.10℃.
Embeddedness	A rating of 1 is considered good for spawning.	One pool was rated with an embeddedness value of 1.
High Quality Spawning Areas	No specific parameter available.	Present, as indicated by the presence of pools with adequately-sized spawning gravels.
Frequent Pools	No specific parameter available.	Present, as indicated by the presence of 9 pools in a 500m length of stream.
Presence of Spawning Gravels	0.5 to 10.2 cm.	Present in appropriate sizes in 2 pools.
Complex In stream Habitat	No specific parameter available.	Present, as indicated by several boulders and wood-debris features observed within the stream channel.
Intact Floodplain	No specific parameter available.	Present, as indicated by a lack of observed streambed erosion and mature streamside vegetation.

Boulder and log-jam induced constrictions were observed at the upstream edge of several of the pools located in Section Three. Constrictions of stream flow such as these have been shown to maintain pool habitat in coastal California streams (Harrison & Keller, 2007). The observation of upstream constrictions in pools indicates that the habitat features observed during our assessment of Section Three are likely stable in that pools suitable for spawning will be maintained over time.

The observation of three juvenile rainbow trout in two different pools offers further support that the habitat quality in Section Three is suitable. Coastal rainbow trout share the same ecological requirements as anadromous steelhead, and rainbow trout that migrate to the ocean to feed are considered steelhead (Stoecker & the Conception Coast Project, 2002). The presence of rainbow trout indicates that the upper reaches of Santa Anita Creek would be capable of supporting anadromous southern steelhead if they were able to access this section of the creek. Furthermore, native rainbow trout populations currently residing in the creek could constitute a source population of southern steelhead if passage up and down the creek were possible. Steelhead originating in Santa Anita would potentially return to spawn in their natal creek or would spawn in other nearby creeks and streams, depending on the availability of passage opportunities.

8.3.4 Extrapolated Extent of Habitat Quality

While we were unable to assess the approximately 1.9 km of Santa Anita Creek flowing through parcels 84, 86, 87, 92, and 93, we assume that a portion of this stream length is similar in habitat quality to Section 3, located immediately upstream. Analysis of aerial photographs revealed that the dense canopy coverage measured in Section Three extends downstream approximately 1.6 additional kilometers. Beyond this distance, the canopy coverage becomes noticeably less dense both along the creek and further out into the hillsides. Also, an analysis of the extrapolated area using the National Elevation Dataset (NED) revealed a relatively consistent slope of 2%. In addition to the suitable habitat suspected below Section Three, 0.3 km of additional habitat is suspected above Section Three and below the natural barrier. Based on our analysis, we estimate that Santa Anita Creek currently provides a total of 2.4 km of habitat capable of supporting spawning southern steelhead.

In the 500 m of Santa Anita Creek analyzed in Section Three, two pool tail-outs out of 9 pools were identified as having gravels of sufficient size and quality for southern steelhead spawning. Extrapolating this same pool frequency to the predicted additional suitable habitat on Santa Anita Creek, reveals that 34 additional pools should be present. Of these 34 additional pools, eight should have pool tail-outs suitable for spawning. In total, Santa Anita Creek is predicted to have a total of 43 pools, ten of which would support spawning southern steelhead.

Removal of the dam and the subsequent post-dam removal steepening of the channel expected throughout Section Two is predicted to increase the total amount of suitable steelhead spawning and rearing habitat on available on Santa Anita Creek by approximately 0.8 km. Extrapolating the same pool frequency observed in Section Three, an additional 14 pools would be expected to occur, three of which would be expected to have pool tail-outs suitable for spawning. This prediction of amount of additional spawning and rearing habitat that would be created by the removal of the Santa Anita Creek dam might be slightly overestimated, as pool frequency decreases with decreasing slope and the slope of the lower portion of Section Two is predicted to be less than that observed upstream in Section Three. With this uncertainty as a caveat, we expect Santa Anita Creek to provide a total of 3.2 km of suitable spawning and rearing habitat for southern steelhead if the dam is removed. Within this 3.2 km, 57 pools are estimated to occur, 13 of which are expected to contain suitable spawning gravel in their tail-outs.

8.3.5 Weather Influences on Habitat Parameters

The majority of the measurements made to assess the quality of habitat in Santa Anita Creek were taken in the summer and fall of 2007. The 2007 water year was a record-making dry year with the lowest recorded amount of rainfall in 100 years (City of Santa Barbara, 2007). As a result, flow in Santa Anita was extraordinarily low during the assessment, and some of the characteristics measured likely represent the lower end of the naturally occurring range of steelhead habitat quality within the creek. For example, steelhead prefer cool summer stream temperatures and stream temperature measurements reported here represent the upper end of the creek's natural temperature range. Additionally, measurements of stream width and depth, both measurements of habitat availability, represent minimum values in the creek's naturally occurring range. However, 2007 was not preceded by multiple drought years, and baseflow in the stream might not have been at its lowest possible value.

Despite the low flow conditions observed in Santa Anita Creek during the habitat assessment, water temperature measurements taken upstream of the railroad crossing were within the acceptable range for southern steelhead. Such a finding provides additional strength to the assertion that the uppermost portions of Santa Anita Creek located below the natural barrier contain suitable spawning habitat for southern steelhead and that suitable corridor habitat exists between the spawning habitat and the estuary.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

The Hollister Ranch Owners' Association and the Hollister Ranch Conservancy have identified steelhead restoration as a conservation priority for Hollister Ranch. Our analyses were designed to aid the HROA and the HRC in their decision to undertake a steelhead passage restoration project for Cañada de Santa Anita. Specifically, we set out to determine whether or not steelhead restoration was a feasible option. We also assessed the amount and quality of steelhead habitat that would become available if the creek's barriers to fish passage were removed.

Our habitat analysis indicates that 2.4 km of suitable quality spawning and rearing habitat currently exists in Santa Anita Creek. The canopy cover along this region of the creek is dense and mature, and summer pool temperatures never approached levels lethal to steelhead during the study period, which occurred over the summer and fall of a record dry year. The observation of rainbow trout in two of the nine pools assessed supports our conclusions that the upper reaches of Santa Anita are capable of supporting steelhead. Because the amount of high quality habitat had to be extrapolated beyond the 500 m long reach to which access was allowed, further assessment is warranted to confirm our expectations. In total, we expect that Santa Anita Creek contains approximately 43 pools suitable for summer steelhead rearing and refuge and 10 pool tail-outs with patches of suitable spawning gravels.

While the total amount of habitat available in the upper reaches of Santa Anita Creek is small relative to that which is, or could be, provided within the four major rivers known to support southern steelhead, restoration of fish passage to Santa Anita Creek would provide additional spawning options for the opportunistic southern steelhead when passage is unavailable elsewhere. Likewise, Santa Anita Creek can enhance habitat diversity and provide refuge for steelhead that stray from the major rivers, thereby contributing to the resilience of the population. In addition, the resident rainbow trout observed living in the upper reaches of the creek could make a small contribution to the genetic diversity among local steelhead populations.

Six of the seven stream crossings found on Santa Anita Creek currently impede upstream fish passage. Of these six barriers, five are completely impassable for all age classes at all flow ranges, while one offers limited opportunity for fish passage. These barriers could be replaced according to DFG protocols for fish passage restoration at an estimated total cost of approximately $2.5 million. Based on our preliminary analysis, which focused on the slope of the channel at each crossing, we expect appropriate retrofits to include bridges for the creek's four Arizona Crossings, a natural-bottom arch for the main road crossing, and a larger, partially embedded culvert for the low flow crossing. However, further engineering and hydraulic analyses will be required to determine suitable retrofits for each barrier on a case-by-case basis. These analyses would consider the creek's stream type and natural tendencies toward channel-structure stability in order to design retrofits that are appropriate specifically for Santa Anita's and hydrology and geomorphology.

In addition to the creek's six impassable stream crossings, the 4.5 m high dam would have to be removed in order for steelhead to access the habitat documented in our constrained field survey. The 100,000 m^3 of sediment impounded behind the dam would have be managed to minimize adverse effects downstream. Once the dam was removed and Santa Anita Creek was allowed to return to its pre-dam gradient, either through natural sediment transport or through excavation and restructuring of the channel, at a cost of approximately $3 million, we predict that an additional 0.8 km of spawning and rearing habitat suitable for southern steelhead could be created. Within this 0.8 km stretch of spawning and rearing habitat, we predict the occurrence of an additional 14 pools and 3 pool tail-outs with patches of gravel suitable for spawning. We propose four recommendations for Hollister Ranch to consider, each with a different level of cost and risk.

Ultimately, it will be up to Hollister Ranch to weigh the various risks and costs associated with the restoration of steelhead passage to Santa Anita Creek against the steelhead benefits predicted in this report in order to decide whether or not they will move forward on this project. If the HROA deems steelhead passage restoration on Santa Anita Creek to be a worthwhile pursuit, next steps should include a detailed engineering analysis and further biological assessment. Because the creek flows through several privately-owned parcels, a coalition-building effort will likely be required to foster cooperation among landowners, as these analyses and assessments must include the entire creek. The unique organizational structure of the Hollister Ranch may provide an increased opportunity for these efforts through pre-established connections among private property owners through the Hollister Ranch Owners' Association and the Hollister Ranch Conservancy.

9.2 Recommendations

If Hollister Ranch does decide to continue with this steelhead restoration project, we suggest they consider four options for dam removal and sediment management, each with a different level of cost and risk. These options include:

1) Complete dam removal with natural sediment transport. *High risk*, *low cost*.

2) Complete dam removal with partial sediment excavation and bank stabilization. *Moderate risk, moderate cost*.

3) Complete dam removal with complete sediment excavation. *Low risk, high cost*.

4) Incremental dam removal with natural sediment transport. *Moderate risk, high cost over an extended period of time.*

We further recommend retrofitting of the six impassable stream crossings analyzed in this report, according to DFG protocol. Dam removal and the enhancement of steelhead habitat in the portion of the channel currently impounded with sediment will result in no benefit to southern steelhead if the barriers downstream of the dam are not first made passable. For this reason, we recommend the highest priority to barrier retrofits the furthest downstream, with decreasing priority proceeding upstream.

In addition to the restoration options listed above, we recommend the following actions to enhance the restoration efforts proposed for Santa Anita Creek:

- *Revegetation of the section of stream currently located behind the dam:* The section of Santa Anita Creek located immediately behind the dam was measured to have in-adequate canopy cover for southern steelhead. We recommend that this section be replanted once the dam is removed and the stream channel stabilizes. We predict this section of Santa Anita Creek to transform from a migration corridor to additional spawning and rearing habitat post dam removal. A dense canopy cover keeps a creek's summer temperatures cooler for rearing southern steelhead, as our temperature measurements show, and can provide additional shelter for steelhead year-round. Native vegetation may serve to help in the stabilization process, depending on the level of engineering undertaken.

- *Continued monitoring and stream gauge installation:* Continued monitoring of conditions within Santa Anita Creek with the HOBO^{TM} data loggers would provide data that would be useful for future restoration efforts. A prolonged record of temperature and water-level data would be useful for future habitat assessments, as these characteristics can vary greatly over time. In addition, we recommend that a stream gauge be installed on Santa Anita Creek. An accurate assessment of stream flow is valuable for the design of barrier retrofits and channel modifications. Monitoring, including water temperature measurements and steelhead counts, would allow the Ranch to measure the success of their restoration efforts. Steelhead counts that included both spawning adults and rearing juveniles would be particularly useful. The regular bio-assessment sampling planned to begin in the current year, 2008, on Santa Anita Creek could also provide useful habitat quality information.

- *Further analysis and possible restoration of the estuary*: The creek's estuary is one of the few remaining estuarine wetlands in California. Estuaries can be important during the rearing stage of steelhead development, as they are a place to feed and adapt to saline conditions. Our preliminary habitat assessment revealed that the estuary currently lacks canopy coverage except for along its most upstream end. Near the downstream end of the estuary, temperatures that fell within the range of incipient lethal limits for southern steelhead were measured within 13 cm of the bed. In addition, limited DO measurements taken at the upstream end of the estuary fell below the lethal limit for steelhead. Further analysis could be undertaken to determine whether or not the estuary is a suitable environment for over-summer rearing juvenile steelhead. This analysis could be conducted over multiple summers to determine whether or not habitat quality in the estuary is higher when low stream flows do not disconnect it from Santa Anita Creek. If deemed necessary, vegetation along the banks of the estuary could be increased to increase canopy cover, providing shade for cooler water temperatures. The downstream end of the estuary is narrower than portions of the creek located further upstream with adequate canopy coverage, suggesting increased vegetation could bring canopy coverage in this part of the estuary within ranges preferred by southern steelhead. As an added bonus, the location of the Santa Anita Creek estuary at one of Hollister Ranch's frequently visited group areas provides potential for showcasing the Ranch's restoration and conservation efforts. Informative signage could be created and installed near the estuary to educate residents and visitors about the Ranch's restoration work.

By addressing these specific recommendations, the Hollister Ranch Conservancy could improve passage and rearing conditions in Santa Anita Creek by the amounts indicated in this report, and enhance the creek's riparian habitat from the ocean to the natural barrier.

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