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Bioassessment Monitoring of the Santa Clara River at Newhall Ranch"
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Information synthesis and priorities regarding steelhead trout (*Oncorhynchus mykiss*) on the Santa Clara River


Photo by: EJ Remson

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for

The Nature Conservancy

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Abbreviations

ACOE	Army Corps of Engineers
AF	Acre-feet
Caltrans	California Department of Transportation
CFG	California Fish and Game Department
cfs	Cubic feet per second
CSWRCB	California State Water Resources Control Board
FERC	Federal Energy Regulatory Commission
FOSCR	Friends of the Santa Clara River
LA-RWQCB	Los Angeles Regional Water Quality Control Board
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
pers. comm.	personal communication
POTWs	Publicly Owned Treatment Works
RT	Rainbow Trout
SCR	Santa Clara River
SCREMP	Santa Clara River Enhancement and Management Plan
SP	Santa Paula
TMDLs	Total Maximum Daily Loads
TNC	The Nature Conservancy
UWCD	United Water Conservation District
VFD	Vern Freeman Diversion
WRP	Water Reclamation Plants (or Wastewater Treatment Plants)

Introduction

The findings in this report reflect a 9-month investigation into the state of steelhead trout (*Oncorhynchus mykiss*) in the Santa Clara River of southern California. Prior to the 1940s, the Santa Clara River was the site of a large southern steelhead trout run each year. Southern steelhead are now listed as endangered by the National Marine Fisheries Service (NMFS) under the Endangered Species Act (ESA), and very few run up the Santa Clara. The recovery of this species will depend upon the re-establishment of viable spawning runs on rivers and creeks in southern California. The intent of this study was to understand the state of steelhead on the Santa Clara River, and to devise a list of actions that would lead to rehabilitation of a steelhead trout run on the river.

Information relevant to the restoration of southern steelhead trout was collected - including written and on-line materials, as well as interviews and conversations with people familiar with the Santa Clara River. The summary and findings are organized as follows:

1. **Executive Summary** – provides an overview of the findings of the study.
2. **Methods and Sources** – discusses the methods and sources used during the investigation.
3. **Analysis and Priorities** – presents an overview of all possible actions that could benefit steelhead and prioritizes them.
4. **Appendix** – summarizes and details the information obtained during the investigation.

Executive Summary

Prior to 1940, the Santa Clara River is estimated to have had more than 8,000 adult steelhead run its waters every year.
Next to the Santa Ynez River the Santa Clara was one of the largest steelhead runs in southern California. Fewer than 100 adult fish run either of these rivers' waters now. Unlike other major rivers in southern California, the Santa Clara retains much of its natural features, including major undamned tributaries, and could play an important role in the recovery of southern steelhead.

One of the major problems that steelhead face on the Santa Clara River is artificially reduced flows during migration periods.
The river reach between the estuary and the Vern Freeman Diversion (located approximately 14 miles above the estuary) is often reduced to shallow sheet flows, or becomes dewatered; the connectivity between the mainstem and tributaries is ephemeral and provides inadequate opportunity for either the upstream passage of adult, or the downstream passage of juvenile steelhead. Water is removed from both the surface flow and from groundwater basins for residential, commercial, and

agricultural use. Insufficient information is publicly available regarding the flows in the river, how much and where water is removed, and whether flows could be adjusted to provide sufficient water for migrations while still meeting human needs.

A second major difficulty during migrations is the anthropogenic and natural barriers to migration such as water diversions, road-crossings, and channel modifications for sand and gravel extraction or flood control purposes. While it is known these barriers and impediments exist, almost nothing is known about how significant these barriers are or what solutions there are to the migration difficulties they present.

The tributaries provide the majority of spawning and rearing habitat, while the mainstem of the Santa Clara River is primarily a migration corridor.
Santa Paula and Sespe Creeks are the main steelhead spawning tributaries, though Hopper Creek may also provide some spawning habitat. Piru Creek historically was a major spawning tributary but Santa Felicia Dam now blocks steelhead access. Little is documented about the resident trout populations in the tributaries, their location, the quality, quantity, or location of habitat, or the extent of the exotic fish predator threat from bullhead catfish, bullfrogs, green sunfish, and small and large mouth bass.

The Santa Clara River estuary has been significantly altered, and these changes may be impacting steelhead smolt survival.
A significant portion of the original Santa Clara estuary has been filled by adjacent development. Additionally, between seven to ten million gallons of nutrient-rich effluent are released per day into the estuary from the City of San Buenaventura's Wastewater Treatment Plant. While it is unknown to what extent Santa Clara River smolts used the estuary historically, it has been demonstrated that northern and central coast steelhead smolts use estuaries to gain size and acclimate to the higher concentrations of salt in ocean water. The impact of these changes on Santa Clara River steelhead smolt survival is unknown.

There are very few adult steelhead trout that have been counted making their way upstream in the Santa Clara River over the past ten years.
However, the number of smolts observed emigrating out of the system has increased by an order of magnitude over the same period. This indicates that there is natural reproduction of *Oncorhynchus mykiss* in the Santa Clara River watershed, and that if migration and habitat issues can be addressed there is a good possibility this fish stock can be rehabilitated.

Southern steelhead trout ecology and biology are generally unknown.
There is little data or information on life history, habitat usage, historical numbers, length of time required for up-stream migration, timing of downstream emigration, or the population age-class structure for southern steelhead. The majority of information and data regarding steelhead are the result of studies of northern pacific stocks. While the steelhead in southern California have been shown to be genetically and physiologically different from their northern counterparts, there is very little data or studies on southern

steelhead ecology or biology.

The LA-Regional Water Quality Control Board is establishing TMDLs (Total Maximum Daily Loads) for the Santa Clara River in order to lower the amounts of excess chlorides and other pollutants in the river.
A chloride TMDL of 100 mg/L, has been established for the upper river. Other TMDLS scheduled to be determined are: toxaphene, fecal coliform, and nitrate.

Methods and Sources

The sources for the documents and data obtained during this investigation included the Mark H. Capelli Southern California Steelhead Watershed Archive at the University of California at Santa Barbara's Davidson Library, the United Water Conservation District's (UWCD) library in Santa Paula, various websites on the Internet, and a variety of individuals. The documents that are a part of this summary are listed in the bibliography.

In addition to the documents, in-person or telephone interviews were conducted with 17 individuals who were familiar either with the Santa Clara River or southern steelhead. The findings from these interviews are incorporated into the Appendix.

The information from these documents and interviews were collated and organized into the various sections of the Appendix. The following section discusses the topical areas evaluated and potential actions for rehabilitating southern steelhead in the Santa Clara River. The actions discussed below were derived from individual suggestions, from work on other rivers, or are the result of conceptual analysis on the part of the author.

Analysis and Priorities

Potential issues for steelhead on the Santa Clara River were eventually organized into four categories: physical impediments to steelhead passage, steelhead ecology, water flow and balance, and point source and non-point source pollution. The issues discussed are either possible challenges that face steelhead on the Santa Clara River, ways to address challenges that face steelhead, or represent a lack of knowledge regarding steelhead and their environment.

These issues were reviewed and revised at a meeting at the University of California at Santa Barbara on May 28, 2003. Present at that meeting were Mark Capelli, Dr. Ramona Swenson, E.J. Remson, Dr. Elise Kelley, and Dr. Mark Reynolds and Dr. Scott Morrison via phone. Each of the issues was discussed in depth and prioritized. Reasons for an issue receiving either a high or low priority rating had to do with timing associated with it, the capacity of the organizations involved to address the issue, and the likelihood that resolution of the issue would increase the number of steelhead utilizing the Santa Clara River.

Dr. Peter Kareiva, Mark Capelli, Dr. Leal Mertes, Dr. Mark Reynolds, Dr. Scott Morrison, Dr. Elise Kelley, and E.J. Remson conducted a final review of the prioritized issues at the University of California at Santa Barbara on June 3, 2003.

In general it was realized that there was insufficient information in several areas to develop a steelhead restoration plan for the river, and that additional basic information was needed. Issues discussed at the June 3rd meeting are presented below within their category and as action items. The items determined as having the highest priority are discussed in greater depth following the initial presentation.

I. Physical Impediments To Steelhead Passage

The items in this category are focused on assessing anthropogenic and natural barriers to steelhead passage that occur on the river.

The action items are:

1. Encourage California Department of Transportation (Caltrans) to modify the apron of the Highway 150 bridge at Thomas Aquinas College. It has been noted that this apron is impassable to steelhead at certain flows, with some jump pools being too shallow among other problems.
2. Encourage the Army Corps of Engineers (ACOE) to repair and/or modify the fish passage facility in its flood control project on Santa Paula Creek. Currently the first jump pool in the “ladder” structure of this flood control project is too shallow to allow up-stream migrating adult steelhead to enter the facility.
3. Conduct a Steelhead Cumulative Impact Analysis. Given the challenges that steelhead encounter in their migrations it would be useful to know the amount of energy steelhead expend overcoming anthropogenic and natural barriers during their migration, and whether that energy expenditure adversely affects their reproductive success. This analysis would include the probability of steelhead making it past all barriers and spawning.
4. Monitor structures on the river to make sure that steelhead can get past these barriers.
5. Evaluate the benefits on steelhead passage of reducing sedimentation to Santa Paula Creek from Mud Creek.
6. Evaluate the role of sediment transport in the mainstem of the Santa Clara River, in steelhead migration.
7. Inventory and assess all physical barriers to steelhead passage within the mainstem of the Santa Clara River and on all major tributaries.

Of these potential actions, three have been selected as priorities.

Encourage Caltrans to modify the apron for the Highway 150 bridge at Thomas Aquinas College.

As of spring 2003, Caltrans had the funding available to correct this problem; however no action has been taken to remedy the situation.

Encourage ACOE to repair the first step in the ladder for the flood control project near the mouth of Santa Paula Creek.
At least an interim solution to the problem does not appear to be involved or costly. The first jump pool needs to be deepened by drilling and then reformed to prevent sediment accumulation.

Inventory and assess all physical barriers to steelhead passage.
It is unclear how much of a barrier the various diversions, flood control projects, and other facilities along the mainstem of the river or its major tributaries, present to steelhead passage. There is also the potential for natural barriers to occur. A barriers analysis would provide an understanding of the obstacles that affect the steelhead run, and a list of the actions that could be taken to eliminate or modify those obstacles.

II. Steelhead Ecology

The primary objective of these actions is to increase the understanding of southern steelhead trout ecology, especially the populations within the Santa Clara River watershed.

The eleven actions discussed include:

1. Assess the steelhead and rainbow trout population structure (age-class numbers and distribution, genetic make-up, etc.).
2. Study the in- and out-migration ecology of southern steelhead (timing and duration of adults and smolts, acclimation time in estuary, etc.).
3. Characterize and evaluate steelhead habitats (spawning, rearing, and refugia) on Santa Paula, Hopper, Sespe Creek, and Piru Creeks.
4. Identify non-native and native predators of southern steelhead, and survey population numbers, sources, and locations.
5. Assess smolt utilization and survival in the estuary.
6. Evaluate how the fish counters work at the Harvey and Freeman diversions and what, if anything, can interfere with a reliable count being obtained.
7. Compare how many adults spawn in other southern California rivers, along with egg, fry, and smolt numbers. This would provide general information regarding the southern steelhead population and would help put fish counts on the Santa Clara into perspective.
8. Study the ocean ecology of southern steelhead and their degree of straying from their natal streams.
9. Acquire properties in the tributaries that contain pristine or restorable steelhead habitat in order to protect spawning and rearing areas.
10. Assess the native gene pool of resident fish to determine the degree of introgression between native southern steelhead and descendants of hatchery trout.
11. Research historical evidence regarding steelhead runs in the Santa Clara River prior to 1955.

Of these eleven actions, six were selected as priorities. One other is discussed because it is going to be conducted by the NMFS.

Assess steelhead and rainbow trout population structure.
Locate and evaluate habitat on Santa Paula, Hopper, Sespe, and Piru Creeks.
Assess smolt utilization of and survival in the estuary.
Identify non-native and native predators, population numbers, sources, and locations.

These four actions were condensed into the single action of conducting habitat and population surveys in three of the tributaries (Santa Paula, Hopper and Sespe Creeks) and the estuary. The surveys will provide baseline information on trout survival, threats, and actions necessary to reduce those threats. It will provide the location of land within the tributaries that are good candidates for restoration. These actions were selected as priorities and are therefore discussed in the later section on habitat and population analyses in more detail.

Evaluate how the fish counters work at the Freeman and Harvey diversions.
It would be helpful to understand more clearly how effectively the fish counters operate, and what, if anything, might interfere with a reliable fish count.

Assess native gene pool in resident fish.
The NMFS will be conducting genetic studies of steelhead trout throughout southern California in the summer of 2003 and in the future. The Santa Clara River will be included in these genetic assessments with collections being conducted in Piru, Sespe, and Santa Paula Creeks.

III. River Water Flow and Balance

The objective of these actions is to evaluate water flow and balance in the river and determine sufficient flows for steelhead passage.

1. Assess and model water flow and usage for the mainstem and tributaries
    a. Determine when and for how long connectivity exists between the tributaries and the mainstem.
    b. Determine the amount of flow from Sespe, Santa Paula, and Piru creeks.
    c. Determine the amount of water historically available to steelhead from November to May.
    d. Determine the location and number of wells and diversions, and the amount diverted or pumped from the mainstem and the major spawning tributaries.
    e. Develop a water budget: determine how much surface water flow there is in normal years and in drought years, how much comes from the State Water Project; and how much water has been appropriated to support out-of-stream uses.
    f. Determine how much water is used residentially, agriculturally and industrially.

    g. Determine the effects on surface flows in the mainstem of the Santa Clara River resulting from the current pattern of releases from Santa Felicia dam.
    h. Model the amount of water necessary for steelhead to make it up and down the river and over what time periods.
2. Evaluate the suitability of different levels of flow downstream of the Vern Freeman Diversion to pass adult steelhead, with particular attention to flow depth and width. Until 2003 after a major storm when the river had dropped below 415 cfs, UWCD released 40 cfs for the first 24 hours post-storm, and 20 cfs for the second 24 hours after a storm. However it is unclear that this is enough water for a long enough period of time to allow steelhead migration to occur from the estuary (the distance from the estuary to the diversion itself is approximately 11 miles). UWCD has begun changing its flow regime to release more water post-storm, and this action will provide an evaluation of the ability of fish to make it from the estuary to the Vern Freeman Diversion.
3. Consider buying water rights on the mainstem and tributaries. Buying water rights might position The Nature Conservancy (TNC) to negotiate with UWCD to allow that water to remain in the river for fish passage, or to allow UWCD to take that water in the summer, but pass more along in the winter when steelhead are migrating. This idea has not been discussed yet with UWCD, and the details of whether and how it could work are unknown.
4. Inventory the types of crops in the valley (which are increasing or decreasing) and determine the amounts of water used by each.
5. Once the types of crops and water usage are determined, assess whether a demonstration project using soil sensitive irrigation equipment would be appropriate.
6. Assess potential for water saving measures such as xeriscaping; use of reclaimed water; water metering where it isn't currently being used; and consumer water saving fixtures.
7. Assemble a diverse working group that would evaluate sustainable water management in the Santa Clara River valley.

Of these eight actions only the first one was determined to be both a priority and within the scope of The Nature Conservancy. This action would be conducted in two parts. The first being a water balance and assessment of inflows and outflows to the Santa Clara surface and groundwater resources. The second would be a hydrological analysis with models to assess the amount of water flow necessary in all lower segments of the river in order to provide sufficient water for steelhead passage during the winter months.

For the purposes of re-licensing the hydro-facility at Santa Felicia Dam, UWCD is studying the effects of different levels of water releases. While the scope of this work is limited and is unlikely to provide a comprehensive review of fish flow requirements for the Santa Clara River, it should provide some data on the effects of certain release levels.

IV. Point source and non-point source pollution

The objective of these actions would be identify and evaluate the sources of pollutants into the mainstem of the Santa Clara River, and major tributaries.

The potential actions include:

1. Conduct water testing near landfills and wastewater recovery plants (WRPs) to determine if there is pollution or leaching.
2. Determine where and when water quality assessments are taking place in the tributaries.
3. Support the Los Angeles Regional Water Quality Control Board's designation of the Santa Clara River as a Significant Natural Resource. Obtaining such a designation for the Santa Clara River would be akin to a beneficial use designation and would limit the permissible hydrologic and water quality impacts of further urbanization on the watershed.
4. Assess contribution of non-point sources of pollution, including fine sediments stemming from various land use practices such as developments and agricultural crops on steep slopes.
5. Conduct a survey for evidence of species existing in the estuary prior to the presence of the wastewater treatment plant.
6. Summarize all water quality assessments on the Santa Clara River and identify gaps in collecting areas and tests.

Of these five actions, none was identified as being as critical to steelhead trout restoration as those prioritized above. Non-point sources of pollution, particularly find sediments, may limit rearing in some tributaries. These are issues that should be investigated, but were determined to be beyond The Nature Conservancy's current scope.

The Priority Actions

The three major actions that were selected as high priorities and that merit a more detailed discussion are habitat and population assessments, a steelhead barriers assessment, and water flow and management.

Habitat and Population Assessments

The objective of these assessments would be to provide baseline information regarding steelhead populations and habitat within the lower sections of the Santa Clara River, and major tributaries. Currently there is no baseline information on steelhead habitat or population structure that can be used for decision-making or to promote change in the facilities or activities that adversely affect steelhead within the watershed.

The main purpose of the assessments would be to document steelhead ecology. This would include gathering information on:

- Steelhead and resident rainbow trout age-class structure, density, genetic structure, and location
- Numbers and locations of predator species
- Location, quality and quantity of habitat, and habitat carrying capacity
- Quality and state of estuarine habitat
- Smolt utilization of and survival in the estuary

These assessments would be from the county line to the mouth of the river, including the tributaries and the mainstem.

This information would provide the foundation for monitoring the state of steelhead within the Santa Clara watershed, the basis for generating a list of potential lands for acquisition and/or restoration, and a list of activities related to improving the steelhead run.

Some of the issues that could arise with this study are gaining access to lands in order to conduct the surveys, difficulty conducting surveys on Sespe Creek due to the rugged terrain, and finding a cost-effective method of evaluating smolt utilization and survival in the estuary.

River Barriers Assessment

The objective of a river barriers assessment would be to identify both anthropogenic and natural impediments to steelhead passage. There are a number of known partial and potential anthropogenic barriers to steelhead passage on the mainstem and on the tributaries. There are also potential natural barriers within the mainstem and at the confluences of the mainstem and each tributary. A barriers analysis would provide:

- An inventory of all barriers, natural and manmade.
- An analysis of each individual barrier and specific problems related to that barrier.

The information from this assessment would be the first thorough, independent evaluation of the barriers to steelhead migration on the Santa Clara River. The likely biggest challenge facing steelhead on the Santa Clara River is being able to complete their migration runs, both as adults migrating to spawning areas, and as juveniles emigrating to the estuary and the ocean. Without an understanding of the challenges and obstacles that steelhead encounter during their migrations, it will be very difficult to rehabilitate a significant run of steelhead in the Santa Clara River.

Water Balance and Flow

Another obstacle to steelhead migration is a lack of adequate surface flows (timing, level and duration) during the migration season. The water balance and hydrology of the Santa Clara River have not been studied outside of a commercial or human use context. A study of water flow and the natural and anthropogenic impacts on water availability would assist in the development of a hydrologic regime that meets both steelhead and human needs.

Information on rainfall and pumping would be available from Ventura County Watershed Protection District and UWCD. UWCD has also done some modeling of groundwater and surface water interactions. A cooperative working relationship with the water agencies is important if we are to find a workable solution for all.

The deliverables associated with this work would be:

1. A mass water balance spreadsheet checked against existing data and information that encompasses the current flow scenario including information on water rights, inputs, outputs, wells, diversions, and trading. Alternative scenarios would also be considered for critical high and low water years.

2. A hydrologic model of flows on the Santa Clara River and scenarios for water management. These scenarios will determine amount of water needed for fish passage up to and including Hopper Creek.

Conclusion

A significant amount of information regarding the Santa Clara River and its steelhead populations has been compiled and synthesized through this effort. The main conclusions from that effort are that steelhead face three major challenges to increasing their population size and spawning runs. The first is a lack of adequate flows to reach prime spawning and rearing areas in major tributaries. The second is impacts on migratory, spawning, and rearing habitats from anthropogenic changes to the river such as flood control structures, water extraction facilities, the alteration of the estuary, and the introduction of exotic fish predators. The third challenge is a general lack of detailed information on the amount, location, and quality of spawning and rearing habitat. In order to assess the level of threats that these challenges represent, and to establish a foundation of knowledge regarding steelhead in this river the following it is proposed that the following be done:

1. An analysis of barriers to steelhead migration,
2. An assessment of the water balance and amount of water flow needed for steelhead passage, and
3. A steelhead habitat and population density survey.

Appendix

A Brief Introduction

This appendix synthesizes information gathered during a 9-month investigation into the state of steelhead trout on the Santa Clara River. Much of the information contained here is directly quoted from the original material. Seventeen people were also interviewed and their comments along with comments from other conversations and emails are noted as "personal communication".

Citations are provided for almost all the material with the references listed in the bibliography. The citation for a source generally follows the last sentence in a bulleted paragraph when all the information is from one source. Where different sources are used in a paragraph, the citations are contained within the relevant sentence.

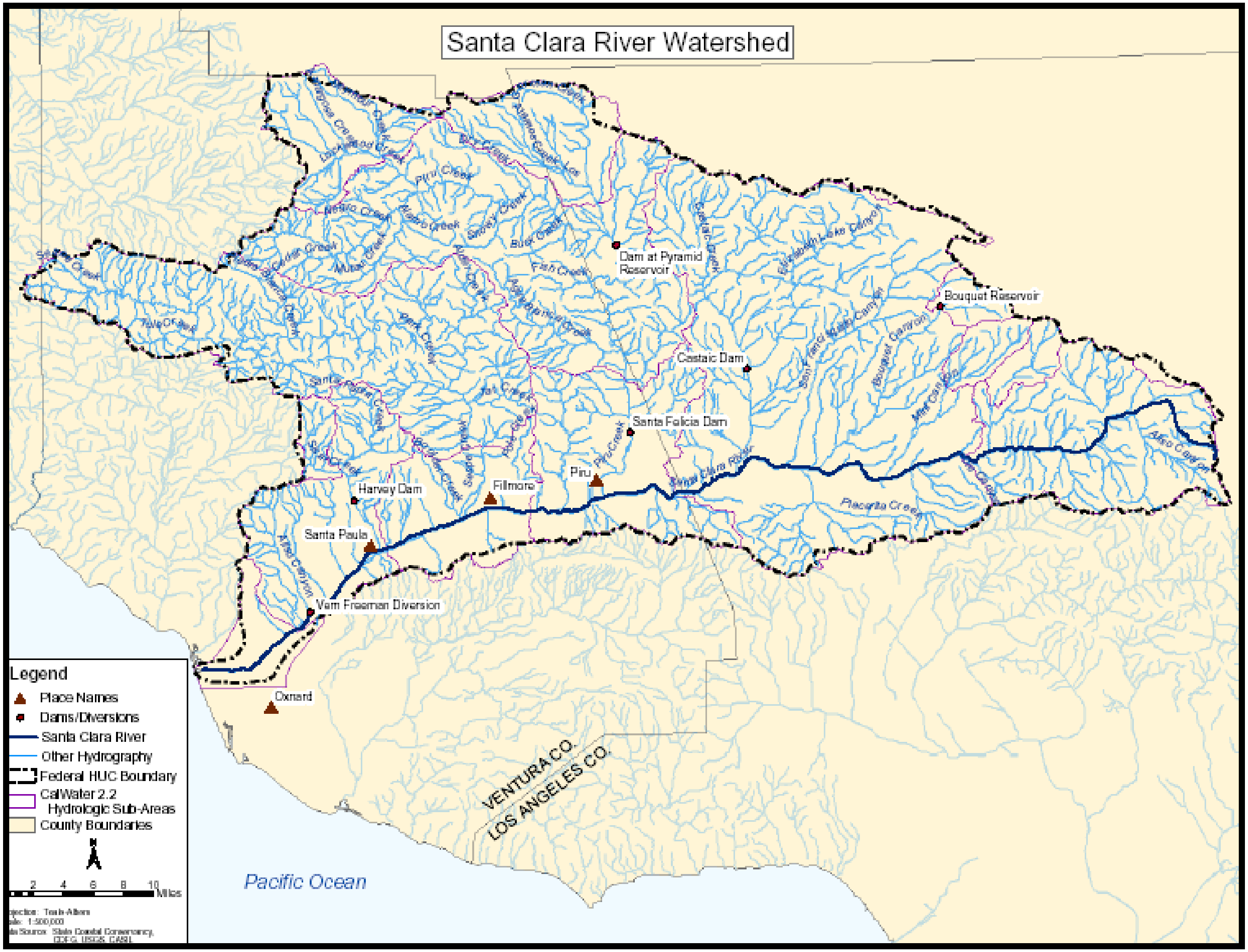
In general, the Appendix chapters conform to the following format:

1. **Issues** – a summary of the most important issues related to that topic. Issues are not listed in any particular order.
2. **Potential research questions** – a list of research areas and action items for that topic
3. **Section I. Santa Clara River** – information specific to that topic and the Santa Clara River
4. **Section II. General Information** – information specific to that topic, but more general in geography or scope than Section I.

Subheadings are contained within both Sections I and II, in order to better organize the material.

The information presented here was gathered from a variety of sources and these sources do not always agree with each other. The purpose of the Appendix is not to choose amongst these sources, but rather to present published reports or informed opinions regardless of their agreement.

Map


Santa Clara River Watershed
Dam at Pyramid Reservoir
Bouquet Reservoir
Castaic Dam
Santa Felicia Dam
Piru
Fillmore
Harvey Dam
Santa Paula
Vern Freeman Diversion
Oxnard
Piru Creek
Santa Clara River
Placerita Creek
Bouquet Canyon
San Francisquito Canyon
Castaic Creek
Mint Canyon
Aliso Canyon
Sespe Creek
Pacific Ocean
VENTURA CO.
LOS ANGELES CO.
Legend
Place Names
Dams/Diversions
Santa Clara River
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CalWater 2.2 Hydrologic Sub-Areas
County Boundaries
N
2 4 6 8 10 Miles
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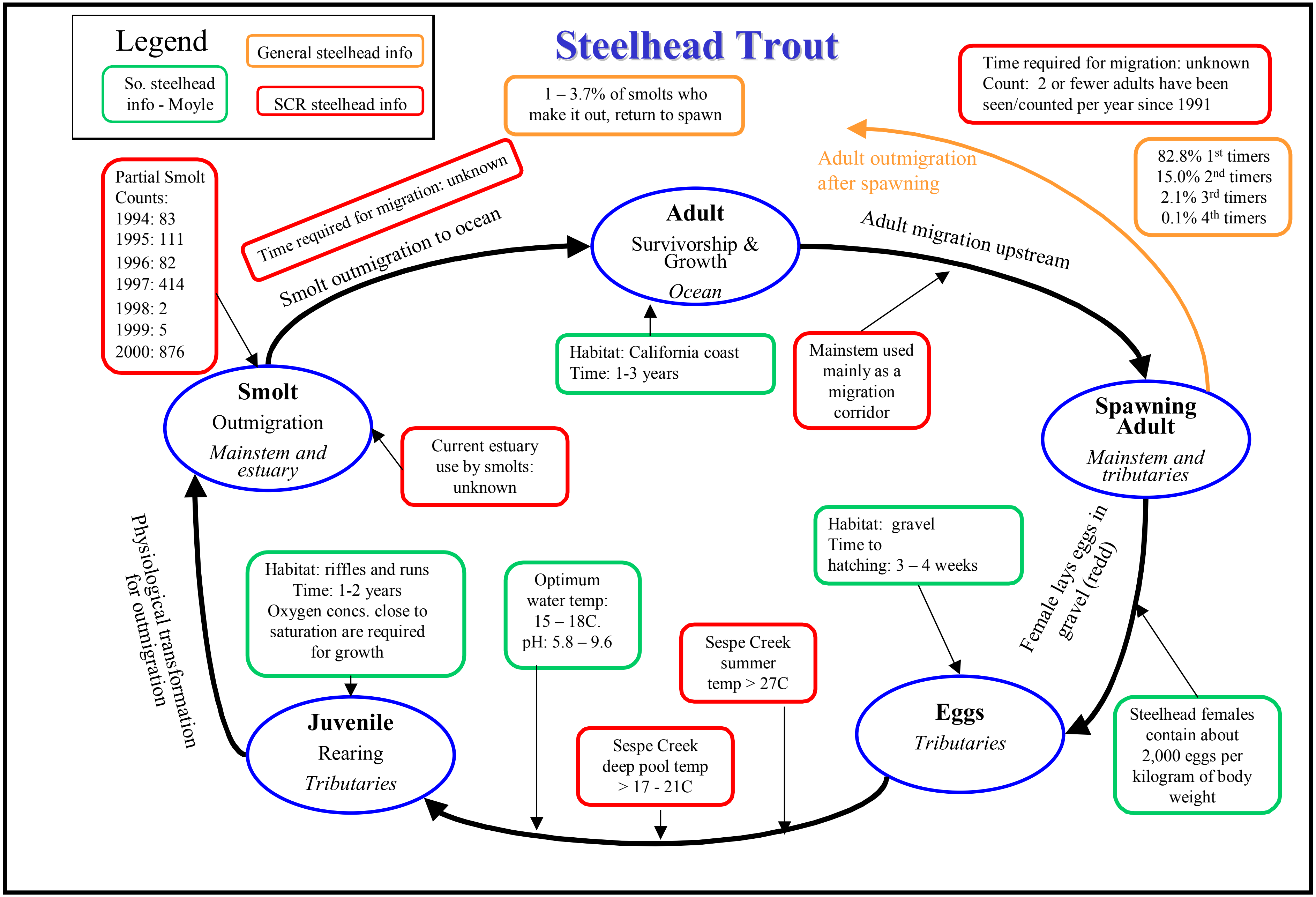
ta Source: State Coastal Conservancy, CDFG, USGS, CASIL

Conceptual Model of Steelhead Trout on the SCR

Steelhead Trout



Legend
- 🟧 General steelhead info
- 🟩 So. steelhead info - Moyle
- 🟥 SCR steelhead info

1 – 3.7% of smolts who make it out, return to spawn

Time required for migration: unknown
Count: 2 or fewer adults have been seen/counted per year since 1991

Adult outmigration after spawning

82.8% 1st timers
15.0% 2nd timers
2.1% 3rd timers
0.1% 4th timers

Partial Smolt Counts:
1994: 83
1995: 111
1996: 82
1997: 414
1998: 2
1999: 5
2000: 876

Time required for migration: unknown

Habitat: California coast
Time: 1-3 years

Mainstem used mainly as a migration corridor

Current estuary use by smolts: unknown

Habitat: gravel
Time to hatching: 3 – 4 weeks

Habitat: riffles and runs
Time: 1-2 years
Oxygen concs. close to saturation are required for growth

Optimum water temp: 15 – 18C.
pH: 5.8 – 9.6

Sesspe Creek summer temp > 27C

Sespe Creek deep pool temp > 17 - 21C

Steelhead females contain about 2,000 eggs per kilogram of body weight

Santa Clara River Timeline

1769	Observations by Father Juan Crespi of tall and thick cottonwoods and oaks in the Santa Clara riverbed. He described it as an arroyo with a great deal of water which runs in a moderately wide valley, well grown with willows and cottonwoods. [1]
1769	Father Juan Crespi names the river after Saint Clare of Assisi who had an upcoming feast day.[1]
1785	San Buenaventura Mission established by Spanish priests.[1]
1820s – 1860s	Livestock raised on large rancheros. [1]
1842	Gold mining begins. [1]
Mid-1800s	870 acres of estuary are estimated to have existed at the mouth of the river. [1]
1850s	Timber and willows along the creek filled the whole valley between the ridges on either side; freshwater marsh in the same region.[1]
1860s	Euro American immigrants began arriving. [1]
1870s	Agriculture and oil; dry farming techniques. [1]
1870's through the end of WWI	Arrival of Euro-American immigrants results in increasing control of water usage and land for agriculture. [1]
1870s	First artesian wells drilled in the Oxnard Plain.[1]
1876	Main line of the Southern Pacific railroad completed.[1]
1883	Water quality lowered by livestock waste; increased erosion resulting from grazing of riparian groundcover. Lowell Hardison recalled, "the valley was so full of dust that South Mountain was only an outline against the sky. The SCR became a dry bed of sand."[1]
1887	A Southern Pacific branch line extended from Newhall west down the length of the river to Ventura.[1]
1890s	Demand for water in Oxnard reduces water pressure and first pumps are installed.[1]
Early 1900s	Over 16,000 acres irrigated by the surface flows.[1]
Prior to 1910	Harvey Dam built.[2]
1917	29,000 acres of orchard land in Ventura County.[1]
Before 1920	Lowlands in the Oxnard Plain had a high water table.[1]
1918 – 1934	Increased use of groundwater.[1]
Mid-1920s	Water rights becoming an issue.[1]
1920s	Increased urban demand for dairy products led to increased planting of alfalfa for cattle feed.[1]
March 12, 1928	St. Francis Dam disaster.[1] Reshaped the topography of valley lands.[3]
1928	Water diversion commences east of Saticoy; precursor to Vern Freeman Diversion[12]
1930s	Seawater intrusion becomes an issue on Oxnard Plain.[1]
1938	Large flood, over 100, 000 cfs.[1]
1939 - 1969	Harvey Dam fish ladder operational.[2]
Early 1940's	Fish hatchery at Fillmore opened.[1]
1944	21,000 steelhead from Santa Ynez river were planted in the Santa Clara lagoon.[4]
1930s and 1940s	SCR estuary large; fresh/saline mixture; surrounding vegetation/ saltgrass, etc. variety of flora and fauna including smelt/grunion, etc.[5]
1930's to today	Loss of riparian thickets along gravel bars and floodplain; especially near aggregate extraction operations downstream because of lowered water tables from mining and natural scouring.[1]
Pre-1946	Large numbers of huge basking sharks started arriving in Pierpont Bay during the summer months.[6]
1946	Basking sharks in Pierpont Bay killed for industrial use (fertilizers, vitamins, etc.).[6]

1946	Water district started diverting water at the Saticoy Spreading Grounds during the winter months.[7]
1949	107,689 irrigated acres in Ventura County.[1]
Late 1940s	Many farms were under 100 acres.[1]
1950	66,000 acres of orchard land in Ventura County.[1]
1955	Santa Felicia Dam is constructed. [1]
1956	Fillmore WRP comes on-line.[8]
1958	Ventura WRP comes on-line. [8]
Post 1950s	River bed lowering occurred; sand and gravel extraction intensified.[1]
1960s	Surface flow had diminished and use of groundwater replaced earlier sources.[1]
1964	Interstate 5 constructed; Valencia development announced.[1]
1965	SCR surface flows irrigated 2,500 acres because of reduction of surface flow. Same amount irrigated in 1969. [1]
1966	Valencia WRP comes on-line.[8]
1969	Urban use of water along SCR is 39% of local water service.[1]
1969	Largest natural flood on the river.[9]
1970s/80s	A red line was created that limited mining in the river.[1]
Pre-1977	Cool, nutrient-rich ocean phase with high ocean salmon productivity.[10]
Post 1977	Low-production warm ocean phase.[10]
1978	Large flood, over 100, 000 cfs.[9]
1980	UWCD proposes the Pumping-Trough-Pipeline and the permanent Freeman Diversion to solve seawater intrusion problem.[1]
1983	Large flood, over 100, 000 cfs.[9]
1989	Vern Freeman Diversion fish ladder and intake screens installed.[2]
1986	Department of Water Resources – protested that the finding of three adult steelhead did not constitute a “run” and that all water should be diverted from the river to UWCDs percolation grounds.[11]
1991	VFD fish ladder and screen become operational.[12]
1991	Mobil spill. Pipeline ruptured most likely from poor maintenance, oil flowed toward and into the river, in same general area as the later Arco spill. Settlement recently arrived at with Exxon/Mobil. ~$2.7M [1]
1992	Large flood, over 100, 000 cfs.[9]
1992	31.5 miles of the Sespe is designated as Wild and Scenic.[13]
1992	Saugus WRP comes on-line.[8]
1994	Arco spill. Pipeline rupture as result of Northridge Earthquake. Settlement ~7.5M, at $9M as of 1995 due to interest accumulation.[1]
1995	Large flood, over 100, 000 cfs.[9]
As of 1995	There were cattle operations near Piru and in Los Angeles County with occasional cattle drives crossing the river.[1]

References

1. Schwartzberg and Moore 1995
2. National Oceanic and Atmospheric Administration and National Marine Fisheries Service 2000
3. Taylor 1994, as cited in Schwartzberg and Moore 1995
4. Carpanzano 1996
5. Henke 1995
6. Henke 1970
7. Outland 1971
8. Pers. comm. with respective WRP agencies/departments, 2003
9. Santa Clara River Project Steering Committee 1996
10. Reinard 2002
11. Kennedy April 1986
12. Pers. comm. Murray McEachron
13. Blecker 1997

Santa Clara River Watershed Factsheet

Headwaters	**Pacifico Mountain** in the San Gabriel Mountains		
Size	**Watershed Area:** 1,600 square miles		
	Naturally Occurring Waterways: 2623.92 miles		
	Percentage of Free Flowing River Miles: 94		
	Percentage of River Miles in Protected Lands: 21		
Main tributaries	Agua Blanca Creek	Aliso Canyon	Bouquet Canyon
	Canada De Los Alamos	Castaic Creek	Elizabeth Lake Canyon
	Gormon Creek	Lockwood Creek	Mint Canyon
	Piru Creek	Santa Paula Creek	Sespe Creek
	Seymour Creek	Snowy Creek	Hopper Creek
Average annual precipitation	Mean annual precipitation ranges from approximately 8 inches in the easternmost part of the watershed to more than 34 inches near the headwaters of Sespe Creek.		
Land	**Protected Lands:** 20%		
	47 percent, or 480,000 acres of land in the watershed is **publicly owned** (the Los Padres and Angeles National Forests)		
Dams	**7**		
	Vern Freeman, a diversion dam		
	Bouquet Canyon Reservoir (1934; 628 acres)		
	Pyramid and Castaic dams control about 37% of the watershed. **Castaic Lake** is created via an earthen dam across Castaic Creek (324,000 AF)		
	Lake Piru (used for groundwater replenishment)		
	Castaic Lagoon (197 acres)		
	Dry Canyon Reservoir (1,313 AF) is the terminus for the West Branch of the California Aqueduct.		
Species	**Number of Special Status Species:** 26		

Faults	**Santa Clara River Valley Fault Lines:** San Gabriel and Holser
Sea water intrusion	New facilities and management practices introduced in the 1980s and 1990s slowed seawater intrusion
Habitat	**Harbor Blvd. to the U.S. Highway 101 Bridge:** riparian woodland riparian scrub small pockets of *Arundo donax*
	Highway 101 to Saticoy vegetation sparse small pockets of riparian/oak woodland habitat areas infested with *Arundo donax*
	Saticoy to Santa Paula southern willow riparian woodland coastal sage scrub coast live oak woodland large *Arundo donax* infested areas
	Santa Paula to Fillmore vegetation changes to large concentrations of alluvial scrub watercress southern willow scrub large concentrations of *Arundo donax*
	Fillmore to Piru alluvial scrub
	Piru to the Ventura/Los Angeles County line southern willow scrub southern willow riparian woodland
	Los Angeles County line to the upper reaches alluvial scrub southern willow riparian woodland alluvial scrub southern willow scrub

*Main data sources for table were the Southern California Wetlands Recovery Project Information Station on-line at http://www.wrpinfo.scc.ca.gov/, Santa Clara River Enhancement and Management Plan (SCREMP) documents, and the McGrath State Beach Natural Resources Management Plan (April 2003).

Sespe Creek Subwatershed Factsheet

Headwaters	Northwestern corner of the Ojai Ranger District near Ventura/SB County boundary
Size	207,700 acres
Major tributaries	Lion Canyon, Hot Springs Canyon, Timber Creek, West Fork Sespe Creek
Small tributaries	Abadi, Adobe, Cherry, Ladybug, and Burro Creeks
Average annual volume	Near Wheeler Springs was 10,000 AF from 1947 to 1985. Near Fillmore was 86,220 AF from 1927 to 1985. Sespe Creek contributes 40% of the total natural runoff in the Santa Clara River Basin
Land uses	Campgrounds
	Urban (the City of Fillmore) and agricultural development
Water quality	Affected by the older marine sedimentary rocks. Hot Springs Creek is a major source of fluoride, chlorine, and boron.
Habitat	Established in 1992, the 219,700-acre Sespe Wilderness Area encompasses 31.5 miles of Sespe Creek and contains a 53,000-acre Sespe Condor Sanctuary. 31.5-mile reach of Sespe Creek from its confluence with Rock Creek and Howard Creek downstream to where Sespe Creek leaves Section 26, Township 5 N., Range 20 W. of the Fillmore USGS Quadrangle map.
Species	Common wildlife species observed within the subwatershed include black bears, deer, mountain lions, bobcats, coyotes, rattlesnakes, red-tailed hawks, and golden eagles. Black bear populations have maintained their numbers at a relatively constant level over the past few decades.
	Arroyo toad largest surviving populations: 15 miles of Sespe Creek from the mouth of the Tule Creek downstream to the Hot Springs Canyon vicinity
	Vireo and Flycatcher recovery: efforts have been focused at the mouth of Sespe Creek near the Fillmore Fish Hatchery
	Cowbird control: brood parasitism by cowbirds fell to less than 10%, with none detected since 1993
	Southwestern willow flycatcher: recovery team under leadership of the USFWS.
Fillmore Wastewater Treatment Plant	Discharges 1.33 million gallons per day of treated domestic and industrial wastewaters, and constitutes a threat to surface water quality in the lower Sespe Creek and Santa Clara River

*Main data sources for table were the Southern California Wetlands Recovery Project Information Station on-line http://www.wrpinfo.scc.ca.gov/, and Santa Clara River Enhancement and Management Plan (SCREMP) documents.

Santa Paula Creek Subwatershed Factsheet

Headwaters	Springs are on the southern slopes of the Topatopa Mountains in Los Padres National Forest. The headwaters are located near Hines Peak at an elevation of approximately 6,704 feet above MSL
Size	45-square miles or 75,050 acres
Tributaries	Sisar Creek, Mud Creek
Average annual precipitation	17.43 inches
Average annual volume	112 AF from 1927 to 1932
	300 AF from 1949 to 1985.
	No flows were recorded for long periods in most years
Land Uses	Residential development, campgrounds, fishing, swimming, hiking
Surface water quality	Good but not considered potable.
	High amounts of suspended clays, presence of natural oil and sulphur seeps (Sulphur Springs area).
	High biological oxygen demand believed to originate from anthropogenic sources (septic system leacheate and recreational uses at Steckel Park).
Habitat	The natural communities present in the Santa Paula Creek subwatershed include riparian woodland, riparian scrub, coast live oak-walnut woodland, coastal sage scrub-grassland, and chaparral.
Structures	CalTrans bridge for highway 150 near the Thomas Aquinas College. Footings for bridge are in a concrete apron just below the confluence of Santa Paula and Sisar Creeks.
	Harvey Diversion: Santa Paula Water Works, Ltd. Recently sold this diversion to Canyon Irrigation District. The diversion occurs approximately 1,000 feet south of Steckel Park just below a USGS gauging station and just upstream of the confluence with Mud Creek. It is a source of water for the City of Santa Paula. The diversion was built in 1923 and the fish ladder was recently rebuilt in 2000 on the southern wall of the approximately 30-foot dam. Downstream of the dam, the creek is deeply eroded for approximately one mile.
	A flood control channel built and operated by the ACOE. Occurs just prior to the confluence with the mainstem.
	Three road crossings consisting of fill with culverts occur within the streambed of the Santa Paula Creek

*Main data sources for table were the Southern California Wetlands Recovery Project Information Station on-line at http://www.wrpinfo.scc.ca.gov/ and Santa Clara River Enhancement and Management Plan (SCREMP) documents.

Piru Creek Subwatershed Factsheet

Headwaters	Lockwood Valley located northwest Los Angeles and approximately 25 miles northeast of the City of Ventura.
Size	318,000 acres
Tributaries	Lockwood, Alamo, Seymour, Amargosa, San Guillermo, Agua Blanca, and Fish Creeks
Average annual volume	Above Lake Piru, from 1956 – 2001, average annual streamflow: 66.8 cfs
Land uses	Camping, cattle grazing, urban development, citrus, avocado, pasture, small grains, and alfalfa
Water Quality	Threats include waste discharges from the Gorman Water Pollution Control Plant and Pyramid Power Plant; agricultural returns to the Pico Formation near the mouth of Piru Creek. Approximately 60,000 gallons of domestic wastewater is treated and discharged per day to the Peace Valley area.
Habitat	The upper portion of the subwatershed is rugged, undisturbed terrain located in the Los Padres National Forest. Open valleys and steep gorges before the Pyramid Lake Reservoir. Below Pyramid Dam scattered riffle-pool formations.
	Oaks, pines, fir, and juniper species occur above 5,000 feet while cottonwood, and willow communities occur within the streambed and near springs. Seasonal grasses are dominant on the soils formed on finer grained sedimentary rocks and alluvium. Adjacent upland terraces are relatively arid, supporting oaks, grassland and chaparral.
Dams	Pyramid Dam built in 1973; impounds water from the State Water Project (SWP) and subwatershed runoff. Santa Felicia Dam was built in 1955 and impounds runoff from the subwatershed. Approximately 87,000 acre-feet (AF) of water are stored in Lake Piru.
Species	Vegetation throughout lower Piru creek consists of white alders (*Alnus rhombifolia*), California sycamores (*Platanus racemosa*), arroyo willows (*Salix lasiolepis*), coast live oak (*Quercus agrifolia*) and mule fat (*Baccharis salicifolia*). The dominant overstory is alders and sycamores, with some portions being dominated by coast live oaks. The midstory is composed of smaller willows, mule fat, and poison oak (*Toxicodendron diversilobum*), with and understory of the aforementioned species as well as California wild rose (*Rosa californica*), California blackberry (*Rubus californicus*), cattails (*Typha sp.*), and other herbaceous species.
	Middle section of Piru creek (between Pyramid and Lake Piru) contains a wide diversity of aquatic species including abundant rainbow trout. Piru Creek has been stocked by the CDFG with small rainbow trout (*Oncorhynchus mykiss*) since the early 1950s. Stocking of fingerling brown trout (*Salmo trutta*) stopped in the late 1970s.
	Black bear; southwestern willow flycatcher, least Bell's vireo, Cooper's hawk (*Accipiter cooperii*), arroyo toad, and California red-legged frog are either known to occur or potentially occur within subwatershed.
Hydrology	Flow on Piru Creek is controlled by Pyramid and Santa Felicia Dams, which serve as both flood control and water supply reservoirs.

*Main data sources for table were the Southern California Wetlands Recovery Project Information Station on-line http://www.wrpinfo.scc.ca.gov/, the California Department of Water Resources, and Scott, K., J. Ritter, and J. Knott. 1968. *Sedimentation in the Piru Creek Watershed, Southern California*: U.S. Geological Survey, Water-Supply Paper 1798-E, 48 p.

Ecology and Population of Steelhead

Issues

1. Steelhead ecology and biology are poorly known in this river. There is little current data or information on life history, habitat usage, historical numbers, length of time to migrate, etc.
2. The utilization of the estuary by smolts is undocumented. Currently the estuary is shallow, lacks cover, is ¼ of its historical size, and the gravel bed has been covered by silt - removing food sources for smolts.
3. Southern steelhead ocean ecology is virtually unknown.
4. The most likely major cause of steelhead population decline in the SCR was the increase in water diverted at the Vern Freeman Diversion beginning in 1950s when it was operated without a fish screen (i.e. a significant majority of smolts and spawned adults were diverted into the percolation ponds and died) until 1991. Other potential impacts were increased use of water by agriculture and increased aggregate mining.
5. Sespe Creek harbors the largest and highest quality spawning opportunity for steelhead on this river.

Potential Research Questions

- ❑ Assess habitat quantity and quality in Santa Paula Creek, Sespe Creek, and Piru Creek including summer water temperatures, oxygen levels, etc.
- ❑ Assess carrying capacity of each of the tributaries in terms of food, habitat and water temperature.
- ❑ Investigate steelhead tolerances to turbidity, and water temperature.
- ❑ Assess historical use of river and estuary by smolts.
    - o How has the changing water chemistry in the estuary likely affected smolt utilization?
    - o What is the overall condition of the estuary?
    - o How much suitable estuarine habitat is available for smolts?
    - o How easily and quickly do smolts adapt to the estuary and then to the ocean?
    - o How much time do smolts spend in the estuary?
    - o What is an optimal size for ocean-going smolts? Do smolts in the SCR reach the necessary size in one year or do they need additional time in the estuary?
    - o Is there a beneficial level of freshwater input to the estuary?
- ❑ A count at the estuary of the number of smolts making it to the ocean, by size and sex.
- ❑ Where in the ocean do steelhead trout go? How well do they survive? What affects their population/survival?
- ❑ What is SCR's transportation efficiency? Do adults/juveniles get caught in shallows or hydrologically disconnected reaches and experience high mortality rates?

Section I. Santa Clara River

Fish Counts

- In 1997 there was a high kill of smolts in the out migrant trap at the VFD. UWCD and DFG took scales and used the opportunity to sex fish. There was an extremely skewed sex ratio with females making up 85 - 90%. The normal ratio in other rivers has been 1:1. Similar results to these found at VFD have also been found in Central Valley Coho salmon. It is unclear why the skewness occurred – it could have been an unrepresentative sample, or it could have been some effect of temperature that caused the females to smoltify and emigrate downstream, but not the males, etc. (Robert Titus, California Fish and Game, pers. comm. November 2002)
- Probably more than 1% of smolts make it back to spawn in general (Robert Titus, California Fish and Game, pers. comm. November 2002). Shapovalov and Taft (1954) stated that 3.5% made it back on Waddell Creek.
- Prior to 1954 the DFG required a screen over the VFD headworks to prevent the induction of downstream migrant steelhead. However after Jack White, the DFG warden who worked on the Santa Clara, retired the seasonal installation and maintenance of the screen was allowed to lapse. This change in operations, plus the enlargement of the diversion works, increased groundwater pumping, and the construction of reservoirs on the Piru and Castaic Creek tributaries led to a sharp decline in the SCR steelhead fishery in the late 1950s. (Capelli 1983)
- The size of the SCR drainage has been used to make some run-size estimates. A reasonable estimate is on the order of 1,000s of fish. (Robert Titus, California Fish and Game, pers. comm. November 2002)
- About 1946 the UWCD district started diverting water at the Saticoy Spreading Grounds during the winter months. Local historian Charles Outland never personally saw a native run trout after that time. (Outland 1971).
- 1946 was the beginning of one of the worst droughts on record (Murray McEachron, United Water Conservation District, pers. comm. January 2004).

Migration timing

- In general, upstream migration of adult steelhead occurs from January through March. Downstream emigration of smolts and spawned out adult steelhead occurs from April through June. (Moore 1980c)
- Flow and hydrology are historically inconsistent throughout the SCR watershed. Both upstream and downstream migrating fish have likely developed migration behavior that accounts for the relatively short “migration windows” common to Southern California river systems (Rick Rogers, pers. comm. December 2003)

Return spawners

- ❑ It is unknown how likely SCR steelhead are to return to the SCR. Shapovalov and Taft (1954) found 98% of Waddell Creek spawned steelhead returned to their natal creek. However, flows in southern streams like the SCR are less reliable, and make it more likely that these fish seek whatever river openings they can find.

Habitat

- ❑ The mainstem of the SCR acts as a fish migratory corridor. Adults swim upstream and do not linger in the mainstem.
- ❑ Monitoring-oriented instream habitat surveys are difficult to execute in the SCR because the channel(s) shift(s) from year to year, along the mainstem. Not a static channel. Difficult to monitor. (Matt Carpenter, Entrix, pers. comm. November 2002)
- ❑ From above the estuary to the VFD the river is mostly low flows with warm water; lacks instream cover and deep pools. Predominantly sand substrate (Matt Carpenter, Entrix, pers. comm. November 2002).
- ❑ Main tributaries on the SCR provided 89 miles of spawning and rearing habitat prior to 1948 (Moore 1980c):

Drainage	SP creek	Sespe Creek	Piru Creek
Mile of historical habitat	11	53	25
Miles of current habitat	2	47	0

Santa Paula Creek

- ❑ Due to its smaller watershed size, SP creek was historically a minor contributor in steelhead runs compared to Sespe and Piru. (Rick Rogers, National Marine Fisheries Service, pers. comm. January 2003)
- ❑ Adult steelhead still occur but in low numbers. Heavily fished. About 10 – 11 miles of good habitat occurs above the Harvey Dam diversion. East Fork's habitat limiting factor is turbidity due to extensive mass wasting from unstable canyon walls. (The National Oceanic and Atmospheric Administration and the National Marine Fisheries Service 2000)
- ❑ ACOE did a wildlife assessment (invertebrates, fish, birds, etc.) from the mouth of SP Creek to Thomas Aquinas College. Pools, riffles, and glides probably not assessed.

Sespe Creek

- ❑ Sespe Basin is good rearing and spawning habitat up as far as Cherry Creek. (Buck Yedor, United Water Conservation District, pers. comm. December 2002)
- ❑ Sespe is naturally high in total dissolved solids (TDS), which makes for a productive aquatic environment. It is high in calcium and phosphorus. Rich macroinvertebrate community. Stream clears up quickly from a rain.

(Mark Moore, California Department of Fish and Game, pers. comm. December 2002)

- Timber Canyon creek is a cool water addition to Sespe. It has barriers in its middle section. (The National Oceanic and Atmospheric Administration and the National Marine Fisheries Service 2000)
- Coolest tributaries to the Sespe include Pine Canyon, Coldwater, and West Fork Creeks with summer temps generally staying below 64F. (Blecker *et al.* 1997)
- Maintaining migration access to Sespe creek is essential to restoration and recovery of southern California steelhead (Matt Carpenter, Entrix, pers. comm. November 2002). Sespe is the main spawning opportunity and is regarded as the crown jewel of the system (Rick Rogers, National Marine Fisheries Service, pers. comm. January 2003).
- Below Vantrees property, the Lower Sespe is probably only a migration corridor. (Mark Moore, California Department of Fish and Game, pers. comm. December 2002)
- On Sespe Creek, the most suitable steelhead spawning areas are the riffles of the mid to upper section of the Sespe, Lion and Tule Creeks. These areas support the highest trout fry densities. (Blecker *et al.* 1997)
- Sespe creek water chemistry suggests a moderately productive aquatic community with insects in moderate densities. (Blecker *et al.* 1997)
- On the Sespe there is 134,004 m^2 of available spawning habitat, and 242,270 m^2 rearing habitat. Therefore an estimated 94,772 smolts could potentially be supported to smoltification. These fish would equate to approximately 9,472 adults or 2% of the spawning potential of the creek. In drought years rearing capacity would be less. (Blecker *et al.* 1997)
- In the Sespe dead wood does not play a significant role as in-stream fish cover but it does contribute to the erosion potential of floods. (Blecker *et al.* 1997)
- Landslides do not play a long-term beneficial role in supplying the stream with bedload materials. (Blecker *et al.* 1997)
- 1992 – a major section of Sespe was given protection as a federally designated wilderness area, and at the same time a 31.5-mile section was given protected status as a Wild and Scenic River. (Blecker *et al.* 1997)
- Sespe watershed includes an unusually high concentration of perennial creeks and streams for Southern California. (Blecker *et al.* 1997)
- There is currently no active grazing within Sespe. (Blecker *et al.* 1997)
- There are 6 birds, 1 reptile, and 2 amphibian species listed or proposed as threatened, endangered or sensitive, known to potentially occur within the Sespe watershed. (Blecker *et al.* 1997)
- There is a general trend of declining riparian vegetation along the mainstem Sespe as a result of fires, roads, and trails. (Blecker *et al.* 1997)
- Efforts to return the watershed to a more natural or desirable cycle of fire return (i.e., more frequent, less large/hot) may be the most significant contribution to restoration of steelhead habitat. Siltation would be

lessened and hydrology could be improved to lessen the effects of drought and scouring floods. (Blecker *et al.* 1997)

- Water temperatures exceed 60F on the potential steelhead spawning areas approximately 20% of the days in Feb – June. Water temperatures regularly rise above 68F during July – September. Riparian canopies are not adequate to moderate summer water temperatures. (Blecker *et al.* 1997)
- Large boulder material frequently plays the role of large woody debris, and water temperatures are locally influenced by upwelling of cooler spring water. (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)
- Sespe creek and its tributaries (Dvorsky 2000):
  - The dominant habitat variable in the nine subwatersheds influencing fish densities was pool depth, and to a certain degree, pool volume.
  - Some Sespe tributaries may produce a large number of fry but show very few large individuals suggesting the spawning quality of the creek is good but other habitat characteristics are poor such as food production or temperature.
  - Alder Creek for example has low densities for the smaller trout sizes indicating that spawning success was relatively low yet densities for higher classes were fairly high suggesting that habitat is able to support adult rainbow trout populations in Alder Creek but that production of fry and juveniles is low. Creeks lined by alder trees are often associated with year-round surface flow, but sediment storage characteristics may limit the supply of gravel creating insufficient spawning habitat.
  - In Trout Creek small trout densities are relatively high, yet the larger size classes have small amounts of representation. This suggests that Trout Creek provides adequate spawning habitat as indicated by its sediment storage characteristics but may provide poor rearing and adult habitat.
- The middle reach of the Sespe is a demanding area to survey because of its very ruggedness and inaccessibility. Hasn't been done utilizing systematic survey methods such as the Habitat Suitability Index method. Middle reach is the main spawning area, from above and below Alder Creek downstream to Devil's Gate. Big water, deep ponds. May require diving. Smolt population is high. (Maurice Cardenas, California Department of Fish and Game, pers. comm. December 2002; Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)
- Bear Canyon Creek -1979 - Good habitat (summer nursery) and trout numbers in the lower river. (The National Oceanic and Atmospheric Administration and the National Marine Fisheries Service 2000)
- Lion Creek -1979 - rainbow trout abundant. (The National Oceanic and Atmospheric Administration and the National Marine Fisheries Service 2000)

Pole Creek

- Natural impassable 30 ft waterfall 3.9 miles upstream of Fillmore city limits. Potential artificial barrier 0.8 miles above Hwy 126. No fish observed in 1992 survey. (The National Oceanic and Atmospheric Administration and the National Marine Fisheries Service 2000)

Hopper Canyon Creek

- RT observed 1992. Fair to good spawning and rearing habitat throughout upper portions (The National Oceanic and Atmospheric Administration and the National Marine Fisheries Service 2000)
- Hopper Canyon has great wildlife habitat. Hopper Creek is a good creek, but there's no size to it. However, the creek has good potential to support trout and smolts. (Maurice Cardenas, California Department of Fish and Game, pers. comm. December 2002)

Piru Creek

- No steelhead were found below Santa Felicia Dam in 1978 seining survey. Abundance of naturally-reproduced RT found in 1987 in reaches near old Hwy 99. (The National Oceanic and Atmospheric Administration and the National Marine Fisheries Service 2000)
- Historical data on Piru Creek is spotty at best, but the current headwaters (above both Piru and Pyramid Lakes) contain stretches of suitable steelhead spawning and rearing habitat. (Rick Rogers, National Marine Fisheries Service, pers. comm. January 2003)
- Piru Creek contains approximately 30% of the total amount of historic steelhead spawning and rearing habitat in the Santa Clara River watershed. (Moore 1980c)

Estuary

- Estuary is shallow due to siltation; recent seining found no steelhead; lack of cover minimizes chances of a successful out-migration of smolts (National Oceanic and Atmospheric Administration and National Marine Fisheries Service 2000). Estuarine conditions in the SCR lagoon have changed dramatically over the past fifty years (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004). In particular the natural frequency of lagoon breaching has been disrupted. Levees, decreased river flows, and pollution have impacted the lagoon environment (Comstock 1992).
- The Santa Clara River Estuary formerly consisted of a series of shifting river mouths that have now been restricted by development to a single location and reduced to approximately 1/4 of its previous aerial extent. Prior to the late 1940s when upstream diversions altered the flow regime in the lower river, smolts were commonly seen in the estuary waiting for the sand bar to breach and allow their emigration to the ocean. The estuary bottom consisted of more coarse sediments than today, which

provided a suitable substrate for benthic organisms upon which smolts could feed. Currently, the silt-covered bottom of the estuary provides more suitable habitat for marine species of fish such as stripped mullet, which were not common before, but are now seen more frequently and in increasing numbers. (Mark Capelli, National Marine Fisheries Service, pers. comm. October 2003)

- Estuary lost part of its earthen levee on the east bank in 1995, and the rest of it is eroding back. Sediment is building up along the east (downcoast) bank. (Virginia Gardner, California State Parks, pers. comm., October 2003).
- Currently there is no authorized, artificial breaching of the levee by either California State Parks or the City of Ventura. (Virginia Gardner, California State Parks, pers. comm., October 2003)
- The Army Corps of Engineers has rejected McGrath Farms' claim that they have a right to breach the estuary. The Ventura County Resource Management Agency's Environmental Health Department has suggested artificial breaching of the sandbar as a means of mosquito control, however the California Department of Parks and Recreation manages the majority of the estuary as a Natural Preserve and does not support the practice. (Waln 2004)
- The City of Ventura's wastewater treatment plant's effluent is currently in violation of the copper limits established for a saltwater environment (i.e., for the estuary). The City commissioned a study of the estuary that showed that the majority of the species in this environment were either freshwater species tolerant of brackish conditions or brackish water species. (Entrix 2002)
- The Santa Clara River estuary is unique among other estuaries found in the Southern California Bight (Point Conception south to the California/Mexico border). Published information on invertebrate communities and hydrologic conditions was found on seven estuaries of similar size to the Santa Clara River estuary within the Southern California Bight. Among these estuaries, the SCR estuary is unique in that it receives constant year-round freshwater flows and does not have its mouth manually dredged for water quality purposes. The seven estuaries examined generally share many benthic invertebrate taxa in common. With the exception of San Dieguito Lagoon, the Santa Clara River estuary shares very few invertebrate taxa with these other estuaries. The species compositions of the other estuaries are in general more estuarine and marine than the SCR estuary. (Entrix 2002)
- During a recent water quality profile of the estuary, low salinities (1 to 4ppt) were observed near the discharge channel and upper estuary, where the Santa Clara River flows in. Brackish conditions (5 to 10 ppt) were observed in the middle of the Estuary. More marine-like (>10 ppt) conditions were isolated to the area near the mouth and far southwestern portion of the estuary, the highest salinity measurement being 30 ppt. (Entrix 2002)

- The temperature of the reclaimed water discharge (treatment plant effluent) is essentially identical to the temperature of upstream river flows. The city of Ventura has available extensive temperature, nutrient and chlorophyll A data that they have collected for upstream flow, estuary waters, and reclaimed water discharge. The upstream sampling sites for the City of Ventura are at the Harbor Blvd. bridge and 0.5 miles upstream of the Harbor Blvd. bridge. There are also four sampling sites within the estuary. (Waln 2004; Don Davis, City of Ventura, pers. comm. March 2004)
- UWCD no longer releases smolts near the outfall for the City of Ventura's wastewater treatment plant. Sampling from February through April of 2001 revealed the outfall water temperature to be 5°C warmer than that at the Vern Freeman Diversion. (Buck Yedor and Murray McEachron, United Water Conservation District, pers. comm. March 2004)
- The City of Ventura WRP's discharge directly to the Santa Clara River estuary has substantially altered the water chemistry and quality of the estuary. (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)

Aggregate Mining

- During the time when poorly-regulated, active gravel mining occurred in the active river channel and for as long as excavations remained, fish perished as a result of mining operations. Mining would disrupt surface flow continuity creating holes into which the surface water (and fish) would disappear. (Mark Moore, California Department of Fish and Game, pers. comm. December 2002)

Climate

- The Upper Santa Clara River is characterized by semi-arid Mediterranean-type climate and temperature ranges from 100° F to 30° F. Eighty percent of the average annual precipitation occurs between November and March. (United Water Conservation District and Castaic Lake Water Agency 1996)
- Lower Santa Clara River temperature ranges from 69° F near the coast to 61° F inland. Most precipitation occurs between December and March. Average annual rainfall from 1950 – 1992 was from 13.7 inches to 18.7 inches. (United Water Conservation District and Castaic Lake Water Agency 1996)

Section II. General Information

Southern Steelhead

- South of Point Conception the climate is much more hostile to steelhead. It is generally hotter, drier, and more variable, etc. Most habitat criteria developed for steelhead (i.e., temperature, instream shelter, etc.) are not always applicable to streams south of Point Conception. (Matt Carpenter, Entrix, pers. comm. November 2002)

- Steelhead were listed before systematic population and habitat monitoring studies were able to begin on southern steelhead, thus our ability to understand and recover the population is diminished due to a lack of long term monitoring data (Matt Carpenter, Entrix, pers. comm. November 2002).
- Southern steelhead show unique genetic characteristics as well as high genetic diversity, suggesting that they developed from a population that survived in a Baja California refuge during the Pleistocene and that has recently come into contact with steelhead of more northern origin (Nielsen 1999). This ESU's high diversity may help to explain its remarkable capacity to persist in seemingly unfavorable environments.
- Due to drought and/or human-related activities, southern steelhead are often impeded or blocked from accessing their natal streams due to low-flow conditions. It appears that when faced with this prospect southern steelhead adapt, and either delay their upstream spawning migration until adequate flows exist or enter and ascend another suitable stream nearby. This action of straying from their stream of birth appears to be an important survival technique for a species whose freshwater habitat is characterized by extremely variable climatic conditions and human competition for resources, which may effectively eliminate upstream migration for a number of years. (Stoecker 2002)
- Studies by Moore (1980b) and others have shown that length of residency decreases in the more southern drainages. This variety in time to reach the smolting stage is probably related directly to growth rates, which in turn are influence by the length of the growing season, water temperatures, and the abundance of aquatic food materials. Moore's (1980b) study on the Ventura River indicated that a juvenile steelhead might reach the smolting stage in a single growing season. (Capelli 1983; Moore 1980b).
- Biologically and genetically we don't know how resilient these fish are. Migration windows are tiny. (Mark Moore, California Department of Fish and Game, pers. comm. December 2002)
- In 1999 on the Santa Ynez River eight adult steelhead were counted below Bradbury Dam. While there are few rivers monitoring the number of steelhead that run each year, steelhead have been sighted in rivers ranging from the Santa Maria southward into Orange County.

Regulation

- In 1989 both the genus name and species name of the rainbow trout were changed from *Salmo gairdneri* to *Oncorhynchus mykiss*.
- Southern ESU declared endangered in 1997 (National Oceanic and Atmospheric Administration and National Marine Fisheries Service 2000).

Habitat Qualities

- Escape cover can exist in the form of boulders, logs, undercut banks and trees, root wads, and overhead riparian vegetation (Hager 2001). In southern California rivers, boulder debris can serve the same function as large woody debris in providing refugia for migrating and rearing steelhead (Mark Capelli, National Marine Fisheries Service, pers. comm, January 2004)
- Loss of riparian vegetation reduces shade, cover, food supply, and streambank stability. Vegetation provides habitat for insects upon which steelhead feed, nutrients to streams via detritus, and cover for predator avoidance. Vegetation also prevents erosion by slowing runoff rates and reducing soil loss. (Hager 2001)
- Habitats with increased current speeds and turbulence usually contain higher dissolved oxygen and food levels, and when steelhead have access they preferred such habitat, particularly under conditions of oxygen stress at higher temperatures. (White 1991, as cited in Stoecker 2002; Hill and Grossman 1993, as cited in Stoecker 2002)
- Juvenile steelhead require living space (different combinations of water depth and velocity), shelter from predators and harsh environmental conditions, food resources, and suitable water quality and quantity for development and survival. (Lent 2001)
- Wetlands, estuaries and lagoons provide critical nursery habitat for all juvenile salmonids migrating to the ocean, as a feeding area and in their acclimatization to higher salinities. The ocean survival for juvenile salmonids is greatly increased if rearing fish are able to attain larger size for an extended period in the estuary. (Bryant and Lynch 1996)
- In other southern California rivers, sewer treatment plant effluent has been noted to supply more surface water than was available historically. The water is often much warmer than natural waters emerging from underground sources. Its high nutrient load encourages a different suite of species and can put the native fauna (and flora) at a competitive disadvantage (Swift *et al.* 1993; Morris 1991 as cited in Swift *et al.* 1993).

Migration and Spawning

- Migration and life history patterns of southern California steelhead depend more strongly on rainfall and stream flow than is the case for steelhead populations further north (Moore 1980, as cited in Lent 2001).
- The CFG Salmonid Stream Habitat Restoration Manual (Flosi *et al.* 1998) reports that an adult steelhead can maintain a maximum swim speed of 6.0 ft/sec. for 30 minutes until exhaustion and a maximum burst speed of 10.0 ft/sec. For 5 seconds until exhaustion. The maximum leap, or jump, speed is listed as 12 ft/sec. Jumping upstream of a structure becomes difficult or impossible when the jump pool depth becomes less than 1.25 times the jump height of the structure from the pool surface.
- When migrating upstream, steelhead use up to 80% of their energy reserve. Any major changes in steelhead energy expenditure, such as

overcoming barriers, may prevent the success of migration and spawning. Steelhead are capable of leaping 6 to 10 feet, however this requires adequate pools for resting above and below the obstacle. (Hager 2001)

- ❑ Shapovalov and Taft (1954) caught steelhead with four age type combinations at maturity. The relative abundance of these types varies from river to river, but Shapovalov and Taft's abundances were:

Years in fresh water	Years in salt water	% of fish
2	1	30
2	2	27
3	1	11
1	2	8

- ❑ Waddell Creek in Santa Cruz County (Shapovalov and Taft 1954):
  - 82.8% = 1st time spawners
  - 15.0% = 2nd time spawners
  - 2.1% = 3rd time spawners
  - 0.1% = 4th time spawners
- ❑ Adult males predominate in the early portions of the run while females predominate in the latter portions.
- ❑ After spawning spent steelhead often move gradually downstream and hang out in pools for periods of time during the downstream migration.

Feeding

- ❑ After steelhead leave their home streams they feed on estuarine invertebrates and marine krill, but as they increase in size, fish gradually become more important to their diet (Moyle 2002).
- ❑ Spent adult steelhead typically do not resume feeding while in fresh water (Shapovalov and Taft 1954).

Native fish and hatchery stock

- ❑ Native fish are less susceptible to disease than hatchery fish (Bryant and Lynch 1996)
- ❑ Steward and Bjornn (1990, as cited in Bryant and Lynch 1996) found that hatchery stocks might produce fewer smolts and returning adults.

Effects of sediment and turbidity

- ❑ Effects of increased sedimentation include: clogging and abrasion of gills and other respiratory surfaces; adherence of grains to the chorion of eggs; increase in conditions conducive to entry and persistence of disease-related organisms; the inducement of behavioral modifications; the entombing of different life stages; alteration of water chemistry by the adsorption of chemicals; degradation of useable habitat by scouring and filling of pools and riffles and changing bedload composition; reduction in photosynthetic growth and primary production; and an affect on intergravel permeability and dissolved oxygen. (Bryant and Lynch 1996; Cordone and Kelley 1961; Walters 1995)

- Turbidity reduces drift feeding (Barrett *et al.* 1992).
- In a small coastal California stream, Cross (1975, as cited in Stoecker 2002) found that 67%-96% of young-of-the-year steelhead resided in pools. Similar results were reported by Spina (2003). Loss of pools due to excessive sediment input and filling can greatly reduce a streams capacity to rear steelhead to smolt size. Barnhart and Parson (1986) observed that dissolved oxygen be, at least, 80% of saturation for successful spawning to occur. Embryonic and alevin survival is highly dependent on intragravel, dissolved oxygen and concentrations of less than 7.2 mg/L can cause total mortality.
- Turbidity can reduce aquatic plant life by limiting photosynthetic growth, therefore reducing the number of aquatic invertebrates which are the primary food source for steelhead. An excess of sediment in spawning gravel can fill the interstitial spaces preventing water and oxygen from entering the redd. Egg survival increases with permeability. Sediment concentrations greater than 4,000 mg/L have been found to cause migration to cease. (Hager 2001)
- Sigler *et al*. (1984, as cited in Stoecker 2002) observed that chronic turbidity in streams during emergence and rearing of steelhead negatively affects the number and quality of fish produced. Suspended sediments can cause physiological damage to steelhead at concentrations of 3,000 parts per million or greater; when sediments settle out of suspension they frequently cover essential spawning sites, cover eggs, prevent emergence of recently hatched young, and decrease the amount of shelter available to fry that were able to hatch. Deposited sediment also reduces the production of aquatic insects that are essential prey to steelhead survival (Mark Capelli, National Marine Fisheries Service, pers. comm. 2004).

<u>Ocean Life</u>

- Southern steelhead are rarely caught by commercial or recreational fishers in the ocean, principally because adults do not tend to swim in large schools as do other pacific salmonids (Mark Capelli, National Marine Fisheries Service, pers. comm. 2004). However, high seas driftnet fishing has been implicated as a cause for decline of steelhead from coastal streams along the Pacific Coast since high seas steelhead distribution and driftnet fisheries overlap. Unauthorized high seas driftnet fisheries harvest between 2 percent (32,000) and 28 percent (448,000) of the steelhead that are destined to return to the Pacific Coast. Even the combined authorized and unauthorized take of steelhead in the open seas, at the highest estimate of 31%, cannot account for the greater than 50% decline observed in North American steelhead runs from 1986 – 1991. (Bryant and Lynch 1996)
- When northern steelhead smolts enter the Pacific Ocean they begin a directed movement into offshore waters of the Gulf of Alaska. California

steelhead stocks may have more restricted western migrations than do more northerly stocks due to sea surface isotherm temperatures. (Bryant and Lynch 1996).

- Steelhead experience most of their marine phase mortality soon after they enter the ocean. Ocean mortality is poorly understood however because few studies have been conducted. Predation is likely the primary cause of mortality among juveniles. (McEwan and Jackson 1996)
- There may be a tendency for populations of steelhead in the Southern California ESU to remain in close proximity to their natal streams within nearshore waters, which are vulnerable to upland runoff (Capelli 1999)

Ocean Climate

- El Nino is an environmental condition often cited as a cause for the decline of west coast salmonids. El Nino is an unusual warming of the Pacific Ocean off South America caused by atmospheric changes in the tropical Pacific Ocean (Southern Oscillation-ENSO). El Nino events occur when there is a decrease in the surface atmospheric pressure gradient from the normal-steady trade winds, there is a drop in pressure in the east off South America and a rise in the pressure in the western Pacific. The resulting decrease in the pressure gradient across the Pacific Ocean causes the easterly trade winds to relax, and even reverse in some years. When the trade winds weaken, sea level in the western Pacific Ocean drops, and a plume of warm sea water flows from west to east toward South America. Coast currents are changed as is upwelling. (Bryant and Lynch 1996)
- Good fish catches in Alaska generally reflect poor catches for the west coast of the U.S. and vice versa. One set of ocean conditions here, different from those in Alaska, persist 20 to 30 years. Then the conditions become reversed. The entire process of these cycling events is called the Pacific Decadal Oscillation. The abrupt reversal in a short time period is called a regime shift. (Reinard 2002)
- Before a 1977 regime shift occurred, the U.S. had a cool, nutrient-rich ocean phase with high ocean salmon productivity. The 1977 shift brought the low-production warm ocean phase to us. Meanwhile, pristine Alaska suffered alarmingly low salmon populations before the 1977 shift, after that, salmon productivity prospered. (Reinard 2002)

Fish surveys and counts on the Santa Clara River

Smolt Counts

Month	Year	# of days	Count	Source	Pub.	Notes
Apr - May	1981	12	21	CFG	1981	3 month survey on lower SCR; June 1981
May	1981	2	30	CFG	1981	Same study as above but at UWCD spreading grounds
Jan - June	1983	150	1	Puckett and Villa	1985	-
Feb - Apr	1984	60	1	Puckett and Villa	1985	-
Feb - May	1994	74	81	Entrix	1994	Vern Freeman Diversion; partial count
Jan - June	1995	141	111	Entrix	1995	Vern Freeman Diversion; partial count
Mar - Apr	1996	33	82	Entrix	1996	Vern Freeman Diversion; partial count
Nov - June	1997	187	414	Entrix	1999	Vern Freeman Diversion; partial count
Apr - July	1998	88	2	Entrix	2000	Vern Freeman Diversion; partial count
-	1999	-	5	UWCD	-	Vern Freeman Diversion; partial count
-	2000	-	876	UWCD	-	Vern Freeman Diversion; partial count
Nov - June	2003	-	35	UWCD	-	Vern Freeman Diversion; partial count

Adult Counts

Month	Year	# of days	Count	Source	Pub.	Notes
-	1978	-	0	Titus	2002	Bell 1978; mainstem only
May	1980	14	0	Titus	2002	Areta and Willsrud, 1980; mainstem only; sampling was done in backwaters, side streams, pools, etc. i.e., habitats that steelhead do not frequent.
Apr - May	1981	12	0	CFG	1981	3 month survey on lower SCR; June 1981
Jan - June	1983	150	2	Puckett and Villa	1985	Sespe creek: weir and hook and line
Nov - Apr	1983 - 84	152	1	Puckett and Villa	1985	weir
Apr	1986	?	0	McEwan	-	Sespe Canyon. Phone interview.
March	1987	-	2	Titus	2002	USFWS electrofishing survey SP creek
-	1987 - 1988	-	several	Comstock	1992	Kaufman 1989
Mar - Apr	1991	7	0	Entrix	1994	SCR didn't open to ocean until March
June	1992	30	0	Parmenter & McEwan	1999	Hopper, Pole and Santa Paula Creeks
Dec - Jan	1992	3	0	Entrix	1994	at Vern Freeman Diversion
Feb - May	1993	90	0	Entrix	1994	at Vern Freeman Diversion
Feb - Apr	1994	32	1	Entrix	1994	at Vern Freeman Diversion
Jan - May	1995	135	1	Entrix	1995	at Vern Freeman Diversion
Feb - Mar	1996	25	2	Entrix	1996	at Vern Freeman Diversion
Nov - Feb	1997	51	0	Entrix	1999	at Vern Freeman Diversion
-	1998	0	0	Entrix	2000	Upstream trap not operated
April	1999	-	1	UWCD	-	seen in bay area at Vern Freeman
March	2000	-	2	UWCD	-	seen in fish ladder
April	2001	-	2	UWCD	-	seen in fish ladder
-	2002	-	-	UWCD	-	too dry
-	2003	-	-	UWCD	-	fish counter operational

Mainstem: Hydrology and Human Impacts

Issues

1. Artificially altered surface flow is most likely the principal problem for steelhead in the Santa Clara River. It is probable that steelhead do not have an adequate opportunity to complete their upstream and downstream migrations.
2. There is no control over wells along the Santa Clara River or its tributaries, or how much water is removed through them. Nor is the total amount of surface water diverted from the river known, in part due to illegal diversions (though the amount is believed to be small).

Potential Research Questions

- ☐ How much water is being diverted (rates and timing) and by whom?
- ☐ An accurate accounting is needed of the amount of permitted water that is being removed, by both major and minor diverters, and an estimate of how much non-permittees are drawing from the river.
- ☐ How could discharges from Santa Felicia be modified to benefit the migration, spawning, and rearing of steelhead in both the Santa Clara River and Piru Creek?

Section I. Santa Clara River

Diverted Water

- ☐ UWCD is mandated by the State Water Resources Control Board to divert the maximum flow available for groundwater augmentation and to mitigate seawater intrusion into aquifers on the Oxnard Plain that are pumped for agricultural, industrial, and municipal uses. UWCD can also divert SCR flows during the winter months, notwithstanding requirements to maintain migration continuity, pursuant to approval/agreements with CFG and NMFS. (Matt Carpenter, Entrix, pers. comm. November 2002)
- ☐ The UWCD operates Santa Felicia Dam on Piru Creek conjunctively with the VFD. Generally water is only temporarily stored in the reservoir during winter, spring and summer months, and then released during the fall in a manner which allows the released water to either naturally percolate into the Santa Clara River aquifers, or be diverted through the VFD for percolation via the series of percolation ponds at Saticoy. (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)
- ☐ The highest average daily amount diverted at VFD for the years shown (Moore 1980c):

Years	Cfs/day
1932 - 1954	32
1955 - 1974	112

- ❑ The 1999 water year: 49,591 acre-feet of water was released from Lake Piru. The Piru spreading grounds received 3.5% of the released water. The upper basins of Piru, Fillmore and Santa Paula received 33.6% of the release water, which was naturally recharged, and the remaining 62.9% flowed to the VFD. (United Water Conservation District 2000)

In-stream Flow

- ❑ Annual mean outflow at the County Line gauging station has increased from 25,700 acre feet in 1972 (20 year mean) to 35,360 acre feet in 1988 (36 year mean). A difference of 9,660 acre-feet. Most likely all of it is from WRP effluent. (United Water Conservation District and Castaic Lake Water Agency 1996)
- ❑ Effluent from the Saugus and Valencia WRPs comprise a majority of the total flow in the upper SCR during summer months. Forty years of stream data indicate that effluent accounts for 40% of total stream flow during the wet season and 90% during the dry season. (United Water Conservation District and Castaic Lake Water Agency 1996)
- ❑ No record of streamflow was recorded at Montalvo during 1933 – 1950 (Taylor *et al.* 1977). This was due to the gauging station being inoperative, or non-existent; this time period experienced some record flood flows, e.g., 1938, (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004).
- ❑ Five cfs or natural stream inflow to Lake Piru, whichever is less, is required to outflow from Lake Piru (Murrray McEachron, United Water Conservation District, pers. comm. January 2004).
- ❑ Generally the channel of the SCR upstream from Bouquet Junction is dry except following storms. Downstream from Bouquet Junction, the combination of shallow bedrock, a reduced cross-sectional flow area and wastewater discharge to the streambed from two water reclamation plants creates a perennial flow condition in the river westward from the Saugus water reclamation plant past the LA – Ventura County Line. (United Water Conservation District and Castaic Lake Water Agency 1996)
- ❑ Castaic Dam seems to have little effect in reducing the annual flow at Montalvo due to percolation between Castaic Reservoir and Saticoy Taylor *et al.* 1977).
- ❑ Bouquet Dam is used primarily for storage of imported water. It controls less than 1% of the total drainage area and its influence on the streamflow at Montalvo has been considered negligible. (Taylor *et al.* 1977)
- ❑ The cumulative effects of the combined operation of Pyramid, Castaic, Bouquet, and Santa Felicia dams on the natural pattern of surface flows (level, duration, frequency, and timing) on the mainstem of the Santa

Clara River has not be investigated, or modeled. (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)

- Opinion differs on the flow available to the mainstem with the construction of the Santa Felicia dam. Taylor et al. (1977) state that all inflow to Lake Piru has been prevented from reaching Montalvo (with rare exceptions such as 1969 water year). UWCD states that on average Santa Felicia has spilled every six years (1969, 1978, 1979, 1980, 1983, 1993, 1995, 1998, and 2001 - essentially during big water years) (Murray McEachron, United Water Conservation District, pers. comm. January 2004).

Groundwater Basins

- The groundwater basins of the Santa Clara River starting in Los Angeles County and moving west into Ventura County are: Acton, Eastern, Piru, Fillmore, Santa Paula and Mound Basins. Moving south from the Santa Paula and Mound Basins are the Montalvo, Oxnard Plain and Pleasant Valley Basins. (United Water Conservation District and Castaic Lake Water Agency 1996; United Water Conservation District 1999)

Rising Groundwater

- Rising groundwater occurs at several points along the SCR. Rising groundwater is an area where groundwater is forced to the surface by some type of flow barrier and thus becomes surface water flow. Rising areas of groundwater are (United Water Conservation District and Castaic Lake Water Agency 1996 United Water Conservation District 1999):
  - At the mouth of Soledad Canyon caused by buried bedrock highs in the alluvium
  - Just west of the Los Angeles/Ventura County line
  - Just east of Fillmore at the Fillmore Fish Hatchery; considered to be the boundary between the Piru and Fillmore groundwater basins.
  - Just east of the city of Santa Paula in the vicinity of Willard Road
  - East of the unincorporated area of Saticoy near the toe of South Mountain.

How groundwater basins get replenished

- Acton Basin – deep percolation of rainfall and infiltration of surface water runoff; lawn and agricultural runoff; septic tank and leachfield system percolation. (United Water Conservation District and Castaic Lake Water Agency 1996; United Water Conservation District 1999)
- Eastern Basin – surface water runoff from SCR; rainfall; tributaries.
- Piru Basin – percolation of surface flows; rainfall; irrigation returns; spreading grounds located adjacent to Piru Creek just upstream of the confluence of Piru Creek and the Santa Clara River; water conservation releases from Santa Felicia Dam by UWCD. (United Water Conservation

District and Castaic Lake Water Agency 1996; United Water Conservation District 1999)

- Fillmore Basin - percolation of surface water from SCR and Sespe Creek and releases from Santa Felicia Dam; rainfall penetration; irrigation returns; effluent from sewage treatment plants. (United Water Conservation District and Castaic Lake Water Agency 1996; United Water Conservation District 1999)
- Santa Paula Basin – percolation of surface flows of SCR (including releases from Santa Felicia Dam), Santa Paula Creek and other tributaries; underflow from the Fillmore Groundwater Basin; agriculture returns. (United Water Conservation District and Castaic Lake Water Agency 1996; United Water Conservation District 1999)
- Montalvo Basin – UWCD's spreading grounds at Saticoy and El Rio; percolation of SCR flows; underflow from the Santa Paula Basin; rainfall; irrigation returns. (United Water Conservation District and Castaic Lake Water Agency 1996)
- Oxnard Plain Basin – Montalvo Basin. (United Water Conservation District and Castaic Lake Water Agency 1996; United Water Conservation District 1999)

Groundwater in the Oxnard Plain

- The Fox Canyon Groundwater Management Agency was established in the 1970s to deal with the problem of high chloride levels in Oxnard Plain groundwater. The solution chosen was additional yield from Vern Freeman Diversion supplied via the Pumping Trough Pipeline, and shifting pumping to the lower aquifer system from the upper aquifer system, which is determined to have 100 years of supply. A moratorium was established on new upper aquifer system wells, meters were installed on wells, rolling cutbacks were implemented of 25% over 20 years, and waivers or credits were established for cutbacks. The cutbacks started in the early 1990's and are in 5% increments every 5 years. If a users pumpage exceeds the cutback amount, there is a tiered penalty structure of up to $600/AF. (United Water Conservation District and Castaic Lake Water Agency 1996)
- Groundwater aquifers in the Oxnard Plain are in critical state of overdraft. Over the last 50 years, groundwater pumping from these aquifers has exceeded natural and artificial recharge. (Lent 2001)

Groundwater Overdrafts

- Annual overdraft = how much more water is taken out than put in during one water year. (United Water Conservation District Groundwater Department 2001)
- Accumulated overdraft = amount of water necessary to prevent seawater intrusion, or subsidence of land. (United Water Conservation District Groundwater Department 2001)

- For the eight groundwater basins that lie wholly or partially within UWCDs jurisdiction, and for the water year 2001, the (United Water Conservation District Groundwater Department 2001):
    - Average annual overdraft for prior 10 years was 600 AF.
    - Annual overdraft for 2002 was estimated to be 0 – 600 AF.
    - Accumulated overdraft is 30,000 – 35,000 AF.
    - Water needed to replenish the groundwater basins is estimated to be 846,000 AF.

Groundwater Usage

- Agriculture was estimated to use 155,300 AF in 2002 (United Water Conservation District Groundwater Department 2001).
- The concept of "safe yield" was discussed with Santa Clara River water agencies during the SCREMP process. Safe yield of an aquifer is the amount of water, usually expressed in acre-feet that may safely be withdrawn annually from an aquifer without causing depletion or long-term harm to the aquifer. However, water agencies would not agree to a safe yield level. (Ron Bottorff, Friends of the Santa Clara River, pers. comm. December 2002)

Geomorphology

- The upper river has typical braided stream deposits and a relatively wide floodplain area. The particle sizes of sediment in the streambed generally range from coarse sand sizes to gravel (pebble, cobble and boulder size). (United Water Conservation District and Castaic Lake Water Agency 1996)
- The SCR along its entire course consists of typical braided stream geomorphological characteristics such as point bar deposits, gravelly stream bottoms, and broad, wide washes. (United Water Conservation District and Castaic Lake Water Agency 1996)
- The SCR has been formed largely by stormwater flows emanating from highland areas caused by storms of short duration but great rainfall intensity. (United Water Conservation District and Castaic Lake Water Agency 1996)
- Where the SCR runs adjacent to South Mountain and has cut into sedimentary formations scour pools have formed with retain water through sub-surface flows during the during periods where continuous surface flows is otherwise non-existent. (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)

Water Use and Availability

- Nearly 10.7 million gallons of water are pumped through the raceways daily from the Fillmore Fish Hatchery's four wells. Some of the water is cycled back through the facility, and some is piped out and used for crop irrigation. (Whitnall 2003)

- FOSCR is in disagreement with several water agencies over the actual amount of water that is available to cities and those agencies. The agencies and cities claim there is more water available than FOSCR believes there is. (Ron Bottorff, Friends of the Santa Clara River, pers. comm. December 2002)
- There is no enforceable regulatory mechanism over how much water gets pumped out of the SCR aquifers by wells, nor is there monitoring of the level of groundwater extraction. (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)
- Trailer and RV parks along the river engage in unregulated or illegal activities that no agency oversees such as damming the river for swimming holes, etc. (Ron Bottorff, Friends of the Santa Clara River, pers. comm. December 2002; (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004).
- It is unknown how much water is taken from the upper SCR. UWCD has some information on water withdrawals from the lower river.
- The County of Ventura has transferred it long-term State Water Project (SWP) water supply contract for 20,000 acre-feet of water annually to the Casitas Municipal Water District. This water is available to UWCD (5,000 acre-feet), Casitas Municipal Water District (5,000 acre-feet), and the City of San Buenaventura (10,000 acre-feet). Only UWCD has taken delivery of SWP water. (United Water Conservation District and Castaic Lake Water Agency 1996; Ventura County Resource Management Agency 1994)
- Before the drilling of wells and production of underground water, the valley ground water basins were full to overflowing, resulting in a perennial surface flow in the river channel throughout the valley (Henke 1995). Other sources have noted that the flow was in some sections of the river channel, or below the Sespe Creek confluence (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004; Murray McEachron, United Water Conservation District, pers. comm. January 2004).

Urbanization Effects

- Impervious surfaces increase runoff, creating a greater flood hazard.
- Flood control and land drainage schemes may increase the flood risk downstream by concentrating runoff. A flashy discharge pattern results in increased bank erosion with subsequent loss of riparian vegetation, undercut banks and stream channel widening. (Bryant and Lynch 1996)
- Sediments washed from the urban areas and deposited in river waters include trace metals such as copper, cadmium, zinc and lead, as well as pesticides, herbicides, fertilizers, gasoline and other petroleum products. (Bryant and Lynch 1996)

- CSWRCB (1991, as cited in Bryant and Lynch 1996) reported that NPS (non point source) pollution is the cause of 50 – 80 percent of impairment of water bodies in CA.
- Increases in urban development are expected to result in an approximate 10 percent increase in peak discharges in the Santa Clara River (Ventura County Flood Control District and Los Angeles County Department of Public Works 1996).
- Proposed major projects as of 1996 (United Water Conservation District and Castaic Lake Water Agency 1996):
  - Newhall Ranch – 25,000 homes. Includes new wastewater treatment facility. Wastewater will be used to irrigate the golf course and other landscaped areas.
  - Tesoro del Valle – master planned community of 3,000 units. North of the City of Santa Clarita and south of the Angeles National Forest. Castaic Lake is to the northwest of the site. Consumption will be 2,800 AF per year.
  - Chiquita Canyon Landfill Expansion – near city of Santa Clarita. 154 acres. Located on Newhall property and operated by Laidlaw.
  - Reclaimed water system by Castaic Lake Water Assn. That will be used to serve Magic Mountain, golf courses and misc. irrigation uses. 1,700 less gallons of effluent will go into the SCR per year.
  - Aggregate mining and reclamation of a site known as Sycamore Ranch. Would enable continued operation of S.P. Milling's processing plant. Simultaneous agricultural, mining and reclamation activities. North of SCR at confluence with Sespe.
  - Toland Road Landfill Expansion – unincorporated area of Ventura County between Santa Paula and Fillmore. Serves the SC valley, which includes the communities of Santa Paula, Fillmore, Piru and other unincorporated areas of the county. Would increase capacity from 2.5 million tons of solid waste to 15 million tons. Would expand service to Oxnard, Port Hueneme, Ventura, Camarillo and Ojai.
  - Expansion of Valencia WRP

Agricultural Effects

- Citrus and irrigated agriculture in the SCR valley have overtaken earlier crops that required less water. Higher profits and yields come from irrigated crops (Schwartzberg and Moore 1995). Farmers are currently losing money on citrus. Some are switching over to avocado orchards.
- Fields were "tiled" starting at the turn of the century to deal with the problem of alkali accumulation. Tiling provides improved drainage and now underlies a vast portion of the Oxnard Plain and part of the river valley. Many ditches drain into the Pacific Ocean or McGrath Lake but a number runoff into the SCR. The nature/quality of this run-off differs from the river's water. (Schwartzberg and Moore 1995)

- Some agriculture like watercress farming and gathering is done within the riverbed itself. (Schwartzberg and Moore 1995)
- The harvesting of the exotic, invasive species *Arundo donax* is another use of river bottomland. The SCR is reputed to contain the finest reed source in the United States. (Gilday 1994, as cited in Schwartzberg and Moore 1995)
- The area generally referred to as the Oxnard Plain is actually part of a large marine deltaic formation which has been created by the periodic shift of the lower Santa Clara River channel, and the deposition sediments in the river's lower reaches and at its mouth at the Pacific Ocean. The arcuate shaped marine face of the Santa Clara River Delta extends along the coast between the Santa Monica Mountains on the east to the Ventura Foothills on the west, while the apex of the delta extends inland to the area around Saticoy. (Mark Capelli, National Marine Fisheries Service, pers. comm. October 2003)
- Primarily as a result of agricultural return waters there has been a general increase in TDS in groundwater basins. Few groundwaters in the Piru, Fillmore, Santa Paula, and Montalvo basins are now less than 1000 parts per million total dissolved solids, the maximum concentration permitted under United States Public Health Service Drinking Water Standards. (Mann 1975)
- The aquifers for the Santa Clara River Valley are marine deposits so we would always expect to see a certain concentration of TDS. Other potential causes for an increase of TDS could include an increase in the outfall of the sewage treatment plants along the river. (Murray McEachron, United Water Conservation District, pers. comm. February 2004)

Effects of Recreation

- Recreational use has included fishing, duck ponds/clubs, birding, hiking, golf courses, RV parks, ATVs in the river bottom and on surrounding lands, motocross racing at Indian Dunes on Newhall land took place in the river bottom, trail rides, and fishing/boating/camping/swimming at reservoirs. (Schwartzberg and Moore 1995; Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)

Homelessness

- The riverbed has been a de facto housing community for many years for the homeless. (Schwartzberg and Moore 1995)

Aggregate Mining Effects

- The river produces the best aggregate material in the county and much of the county's roads and other structures were built out of materials extracted from the river. (Schwartzberg and Moore 1995)
- Aerial photos of the river in the 1960s demonstrate the extent of mining in the Santa Clara River. Evidence of roads crossing the river bottom is pervasive, trucks are often present in the river bottom and extraction operations are clearly visible. (Schwartzberg and Moore 1995)
- Curtis Sand and Gravel has an in-river mining operation east of Santa Clarita. There is one inactive in-river operation in the Saugus-Newhall section of the Santa Clara River, and eight inactive in-river operations in western Ventura County. P. W. Gillibrand has an active out-of-river mining operation in the Saugus-Newhall area. (AMEC 2003)
- CEMEX, a giant cement company in Mexico recently purchased Southdown Corporation. Southdown's subsidiary Transit Mixed Concrete is planning to open an aggregate strip mine on 460 acres of public land just east of Santa Clarita's city limits in Soledad Canyon. Part of this mine project site is within the 500-year floodplain of the River. The proposed mining operation is planned to span 20 years in its initial phase and process 78 million tons of material. Excavation is planned to be six days a week, sixteen hours a day. Blasting is planned to occur twice a week for 10 years, then double for the subsequent 10 years. Materials transport is an estimated 694 trips per day mostly via the 14 Freeway. Currently there are about 9,600 residential units within a five-mile radius of the site. (AMEC 2003)

Section II. General Information

Habitat and water flow

- In California, diversion and transfer of water has resulted in depleted river flows necessary for migration, spawning, rearing, flushing of sediment from spawning gravels, gravel recruitment, and transport of large woody debris. (Bryant and Lynch 1996)
- It has been reported that 7 inches is the minimum depth required for successful migration of adult steelhead (Thompson 1972, as cited in McEwan 2001), although the distance fish must travel through shallow water areas is also critical.
- A primary characteristic of high quality aquatic ecosystems is an abundance of large pool habitats (particularly important for over-summering juvenile steelhead). Loss occurs by: filling by sediments, loss of pool-forming structures such as boulders and large wood, and loss of sinuosity by channelization. (Stoecker 2002; Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)
- Stream depth provides steelhead with shelter from extreme water temperatures, excessive water velocities, and predation. Southern California streams are often subjected to low flow conditions due to

drought, water extractions, and the annual summer-fall dry season. Survival during dry season stream conditions is believed to be a major limitation to steelhead and adequate depth is essential for survival (Douglas 1995, as cited in Stoecker 2002). Pools provide depth and habitat that is critical to steelhead survival during the dry season. An abundance of large pools has been shown to be an important characteristic in healthy aquatic ecosystems. (Stoecker 2002)

- Warmer water temperatures due to water diversion, water development and habitat modification may affect steelhead mortality from predation directly or indirectly through stress and disease associated with wounds inflicted by pinnipeds or piscivorous predators. (Bryant and Lynch 1996)
- Agricultural practices in general have contributed to the degradation of salmonid habitat through irrigation diversions, overgrazing in riparian areas, sedimentation, loss of riparian vegetation, loss of habitat complexity (Bryant and Lynch 1996).

List of Major Water users along the Santa Clara River

(United Water Conservation District and Castaic Lake Water Agency 1996)

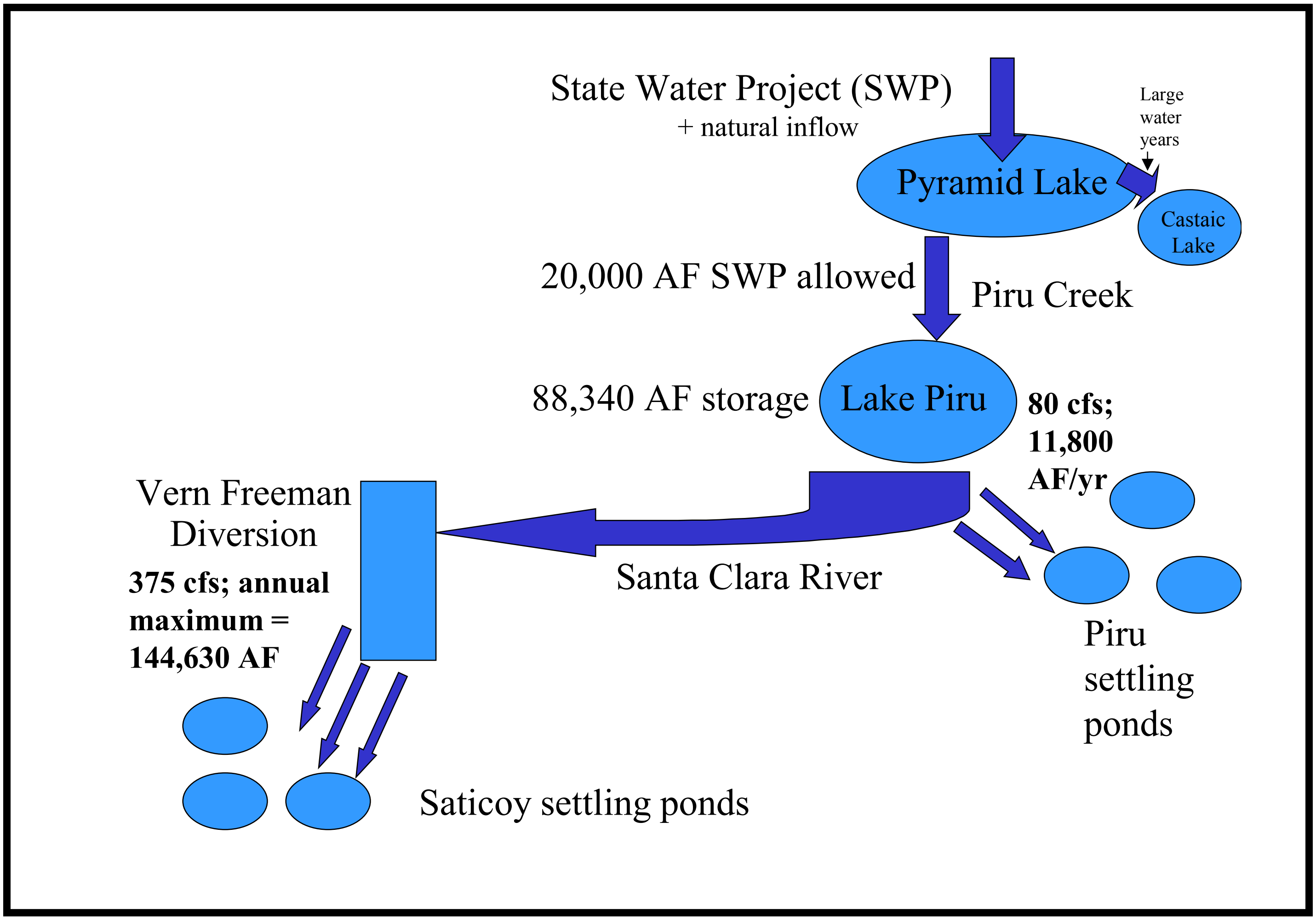
- California Watercress, Inc.
- Camulos Ranch
- Fillmore Irrigation Company
- Newhall Blue Cut and Isola Diversions
- Piru Mutual
- Ray and Elizabeth Billet
- Rio Dulce Ranch
- Santa Clarita Water Company
- Santa Paula Water Works
- Southside Improvement
- Transit Mixed Concrete Co
- Turner/Richardson Ditch
- United Water Conservation District

Smaller Diversions

(United Water Conservation District and Castaic Lake Water Agency 1996)

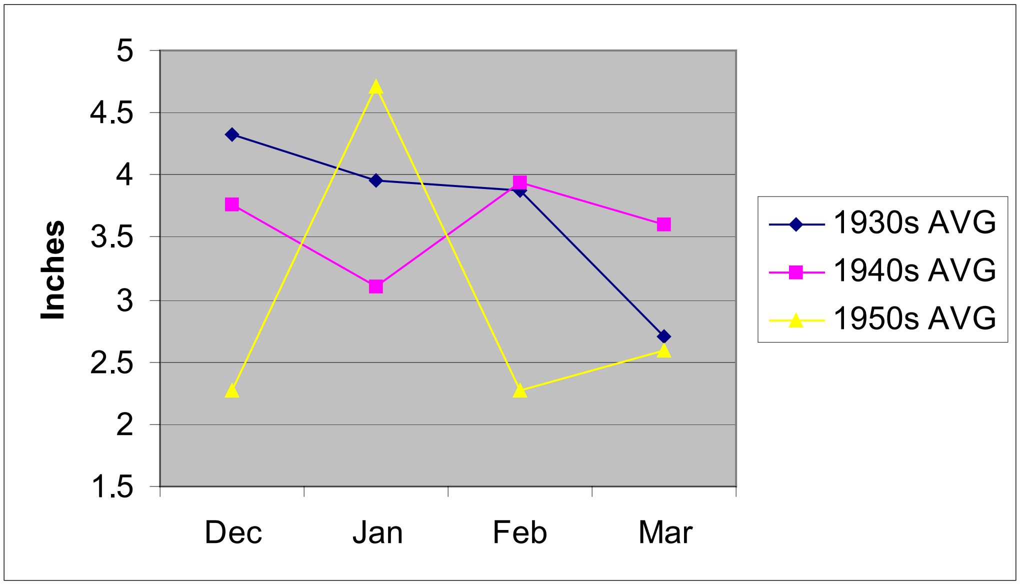
- Alfred and Francis Martinez, Pole Creek
- Central Coast Production Credit Assn., SCR
- CF&G, SCR
- Flying A Ranch, Pole Creek
- Pajaro Partners Inc, Santa Paula Creek
- Robert Asimow, Hopper Creek
- Sanford Drucker, Sespe Creek
- Santa Clara Water and Irr. District, SCR
- Steven and Robin Smith, Santa Paula Creek
- The Nature Conservancy, Hopper Creek

Graphic of Lower Santa Clara Flow of Water



Amount of rainfall in the Lower Santa Clara River

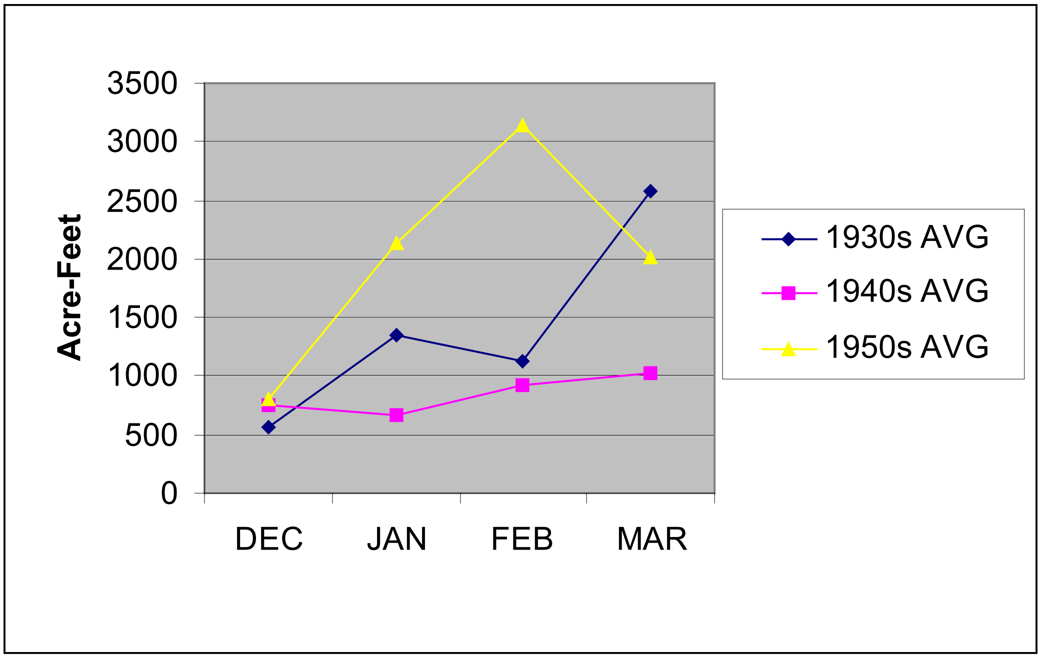
December through March, by decade



*Date source: United Water Conservation District

Amount of water diverted at the Vern Freeman Diversion

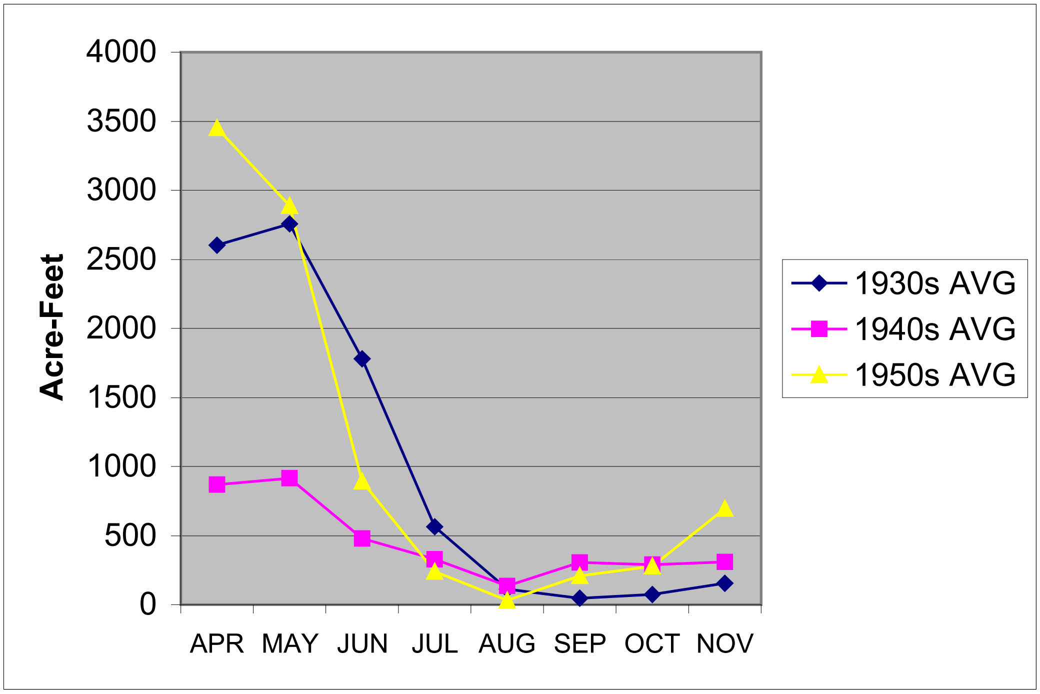
December through March, by decade



*Date source: United Water Conservation District

Average Acre-Feet diverted at VFD

April through November, by decade



*Date source: United Water Conservation District

Fish Passage

Issues

1. It is unclear how steelhead passage into and out of the tributaries from the mainstem is affected by flow regulation, flood control project/activities, or other types development.
2. There is no independent evaluation or assessment of the fish passage structures on the mainstem or tributaries. Opinions conflict regarding how well the fish ladder at VFD operates or how easily fish find the ladder, but the number of adult steelhead detected over the last 10 years since the commencement of the operation of the ladder is extremely low (<10).

Potential Research Questions

- ❑ What are the fish passage problems in the mainstem, between the mainstem and the tributaries, into the tributaries, and within the tributaries?
    - o Do transverse bars occur in the river? What is the impact of multiple ladders or passage difficulties on reproduction? What can be done to minimize the number of days it takes for fish to get up or down river? In what condition do fish arrive at the spawning areas after passing problem areas?
- ❑ For how long after storm flow do Santa Paula and Sespe creeks maintain a passable steelhead connection with the mainstem of the Santa Clara River?

Section I. Santa Clara River

The Vern Freeman Diversion Fish Ladder

- ❑ Discharge from VFD in the recent past has been 40 cfs for the 1st 24 hours and 20 cfs for the 2nd 24 hours post-storm. However, the National Marine Fisheries Services has indicated that increased levels and duration of flows are necessary to provide adequate opportunities for steelhead to reach the VFD and pass to upstream spawning and rearing areas. (Mark Capelli, National Marine Fisheries Service, pers. comm 2004.
- ❑ The VFD ladder incorporates a denil design, which operates at a maximum flow of approximately 40 cfs, with an additional artificial attraction flow capacity of approximately 80 cfs. As a consequence of these design limitations, the ladder operates over a relatively narrow range of natural river flows (approximately 200 to 1,200 cfs), based upon the attraction flow criteria used by the California Department of Fish and Game and the National Marine Fisheries Service (i.e., attraction flow associated with a ladder should not be less than 10% of the natural river flows). Its design does not allow for good trapping method, and the trap

that was used in the late 1990s caused problems. Currently, velocities can drop out and sediment can get into ladder shutting it down during the most critical time. (Maurice Cardenas, California Department of Fish and Game, pers comm. December 2002; Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)

- There are varying opinions on issues and/or functionality of the Vern Freeman diversion and the location of the ladder. Two of those opinions are:
    - VFD is a wide structure. Main channel tends to stick to opposite side of the river from the ladder. The fish swim up the opposite side and then have to traverse the face of the dam to get to the fish ladder. A second ladder or a fish ramp usable by fish during higher flow events may provide a means of supplementing the limited fish passage opportunities afforded by the current ladder. Problems with installing a second ladder are a productive marsh area that has been established above the VFD. (Rick Rogers, National Marine Fisheries Service, pers. comm. January 2003; Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)
    - The main channel above the Vern Freeman has always been on the fish ladder side. Only storms great than 50,000 cfs have caused water to go to the other side. Downstream of the diversion the main channel was almost in the middle prior to the Freeman, but has since moved to the fish ladder side. (Murray McEachron, United Water Conservation District, pers. comm. January 2004).

Santa Paula Creek

- DFG actively assisted ACOE in development of a fish passage at the transition between the upper end of the Santa Paula Creek Flood Control Project, and the unimproved portion of lower Santa Paula Creek. In general there are adequate jump pools, but the 1st jump pool is too shallow and needs to be fixed. A large boulder could block one of the low flow passage channels. (Mary Larson, California Department of Fish and Game, pers. comm.; Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)
- Harvey Diversion was built prior to 1910, the original fish ladder was built in 1939 and effective until 1969 floods made it unusable. The Canyon Irrigation District built a new fish ladder on the Harvey Diversion in the late 1990s. This second ladder requires a lot of maintenance. The area located directly downstream of the Harvey Diversion has highly erosive conditions and scoured out in 2000 - 2002. To keep the downstream entrance of the fish ladder in place and functioning properly, it has been anchored, and large boulders have been placed along the downstream bank to reduce scouring. “Rock glue”, drill, and cable were used to keep rocks in place. The bank underneath the fish ladder would be undermined

without this. DFG helped design and pay for the diversion ladder. A fish counter was installed on the ladder in 2003. (Rick Rogers, National Marine Fisheries Service, pers. comm. January 2003; Mary Larson, California Department of Fish and Game, pers. comm.; Buck Yedor, United Water Conservation District, pers. comm. December 2002; National Oceanic and Atmospheric Administration and National Marine Fisheries Service, 2000)

- The Highway 150 Bridge near Thomas Aquinas College presents steelhead passage problems. The supports are in a concrete apron. There are steps in the apron, and the modifications necessary are minor. The free-flowing oil seeps need to be channeled around the step pools. Some exposed rebar needs to be removed, an interim step pool needs to be built to correct one large jump, and the shape of another bowl needs to be changed so a deep pool is formed. (Mary Larson, California Department of Fish and Game, pers. comm.)
- DFG wants the city of Santa Paula to develop a restoration plan for the area from the debris basin upstream to the top of the Harvey diversion. (Mary Larson, California Department of Fish and Game, pers. comm.)

Sespe Creek

- Sespe has tremendous potential for steelhead production. There are no dams. The main obstacle is the correct management of the “window of opportunity” (i.e., sufficient duration and volume of streamflow) for adult steelhead to migrate between the estuary and the Vern Freeman Fish Ladder; and the control of introduced aquatic species (fish and amphibians) that prey upon juvenile steelhead. (Rick Rogers, National Marine Fisheries Service, pers. comm. January 2003; Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)
- Surface flow from Sespe Creek doesn't reach the mainstem during normal, baseflow (summer and fall) conditions. Water coming out of the Sespe usually disappears into a porous flood plain before it reaches the mainstem. There is a lack of connectivity between the Sespe and the mainstem, and Santa Paula Creek and the mainstem, except during storm events. (Steve Lee, University of California at Los Angeles, pers. comm. November 2002)
- Fillmore Diversion may impound juveniles in artificial pond, but its significance to adult passage is unknown. (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)
- There is a gravel operator on the lower Sespe who as of early 2003 was interested in extracting from the creek; this operation has the potential to further reduce steelhead passage from the mainstem to Sespe Creek (Rick Rogers, National Marine Fisheries Service, pers. comm. January 2003; Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004). However, this operator would need to obtain a new permit from Ventura County, with adequate CEQA review (Ron Bottoroff, Friends of the Santa Clara River, pers. comm. January 2004).

Piru Creek

- Owner of the lower section, Rancho Temescal, bought the property in 2000 and is developing it for agriculture and other commercial uses, e.g. an Equestrian Center for thoroughbred training and racing. The value of the 5cfs which is currently released from Santa Felicia Dam to protect aquatic resources in the lower two miles of Piru Creek from the dam to the confluence of the Santa Clara River may be compromised by proposed development and related activities. (Rick Rogers, National Marine Fisheries Service, pers. comm. January 2003; Mark Capellli, National Marine Fisheries Service, pers. comm. January 2004)

Section II. General Information

Dams/Barriers

- Dams can result in increased water temperatures, changes in fish community structure, and increased travel time by migrating adult and juvenile salmonids. (Bryant and Lynch 1996)
- Types of barriers include dams, culverts, diversions, flood control channels, flow dynamics, water quality, and natural features such as waterfalls (Stoecker 2002).

Exotic Species Predation and Competition

Issues

1. The impact of exotic species on different life stages of steelhead has been poorly documented.
2. Green sunfish and black bullhead catfish are known to prey on steelhead fry and eggs.

Potential Research Questions

- How many exotic species exist and what are their population numbers?
- What likely impact are they having on the different life stages of steelhead?
- What overall/accumulative effect do exotic species have? What are the impacts of predation and competition?

Section I. Santa Clara River

- Bullheads can be extremely voracious egg eaters. Bullheads are in high abundance in the middle Sespe from Timber to Lion Creeks and appear to be rapidly expanding in population and distribution into the lower Sespe; within the last 5 years black bullheads have spread down through the Sespe Gorge to Devils gate, and now dominate many of the shallow pools. (Blecker *et al.* 1997; Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)

Section II. General Information

Predation

- Low flow conditions in southern California streams can enhance predation opportunities where adult steelhead may congregate at the mouth of streams waiting for high flows. (Bryant and Lynch 1996)
- Most investigators believe that marine predation is a minor factor in steelhead declines. (Bryant and Lynch 1996)
- Two striped garter snakes (a native species) are highly effective predators, taking juvenile salmonids of up to 5 inches in length. Their impacts on local fish populations can be substantial. (Blecker *et al.* 1997)
- Bullfrogs (a non-native species) may also prey upon young trout and steelhead. (Blecker *et al.* 1997)
- During drought years green sunfish densities seem to increase and trout densities decline. Sunfish are better able to withstand higher temperatures and will prey upon large numbers of trout fry if they are crowded into the same habitat. (Blecker *et al.* 1997)

Competition

- ❑ Green sunfish are likely competitors with trout and juvenile steelhead, feeding on the limited caddisflies and terrestrial insects. The may also feed on salmonid eggs and very young fry. (Blecker *et al.* 1997)

Water Quality

Issues

1. The Stormwater program has found that copper, lead, nickel, selenium, and fecal coliform exceed allowable limits in the SCR.
2. The LA-RWQCB is establishing TMDLs (Total Maximum Daily Loads) for the Santa Clara River. A chloride TMDL of 100 mg/L, has been established for the upper river. Other TMDLS scheduled are: toxaphene, fecal coliform, and nitrate.
3. Many of the smaller communities in this watershed remain unsewered. In particular in the Auga Dulce area of the upper watershed and near the city of Acton.
4. Increase in urban areas has led communities to build sewage treatment plants along the river, adding flood protection structures and effluent to the river.
5. There are eight Wastewater Treatment Plants (or Water Reclamation Plants) along the river that are releasing at least 25 million gallons per day of effluent into the river or nearby percolation basins.
6. Over time there have been 14 landfills/dumps both legal and illegal associated with the river. It is unknown if contaminants are leaching into the surface or ground water.

Potential Research Questions

- ☐ How significant a problem is pollution in the Santa Clara River?
- ☐ What is the impact of agricultural chemicals on the river? How much is released into the river?
- ☐ Which WRPs are contributing excessive pollution to the river?
- ☐ What are the impacts of the WRPs impact on the estuarine environment at the mouth of the Santa Clara River?
- ☐ Are there pollutants/runoff in the tributaries?
- ☐ How do different pollutants impact steelhead adults, smolts, fry, and eggs?
- ☐ Are landfills contaminating surface and groundwater? What and how much?

Section I. Santa Clara River

Mainstem

- ☐ In the past LA-RWQCB considered the designation of the SCR as a Significant Natural Resource. This category would be similar to the unique natural resource designation at the federal level that declares a resource unlike any other in the region. A major component of the designation would be limiting the hydrologic and water quality impacts of further urbanization in the watershed. However, the LA Sanitation District said that LA-RWQCB didn't go through sufficient legal processes that such a designation would require more legal development of the category, and established strong adversarial legal challenge. Continuing this effort is beyond the staffing capabilities that LA-RWQCB has now. To make this happen the category would have to be adopted by the regional board, then the state board. They would also have to go through the process of a new beneficial use designation at the federal level.

Tributaries

- Since 1971, Piru Creek (between Pyramid Reservoir and Santa Felicia Reservoir) has shown improvements in water quality as a result of discharges from Pyramid Reservoir. (United Water Conservation District and Castaic Lake Water Agency 1996)
- Sespe Creek has a lower overall Total Dissolved Solids (TDS) and is a good source of higher quality water. (United Water Conservation District and Castaic Lake Water Agency 1996)

Estuary

- Water quality issues within the estuary are (United Water Conservation District and Castaic Lake Water Agency 1996):
  - Water level management – the estuary has been mechanically breached when it reaches 9 ft above sea level. Questions remain whether natural breaching is sufficient to avoid water quality problems at other times.
  - Eutrophication – high nutrient levels entering estuary from point source and non point source discharges could cause algal blooms and lead to eutrophication [not clear if this has actually happened].
  - Coliform bacteria – bacteria levels exceeding recreational standards have been recorded at receiving stations in the estuary and nearby ocean monitoring stations. High levels appear to be associated with non-point sources.
  - Pesticides – Agricultural activities may result in contamination of sediments in the estuary. Further investigation is needed. Agricultural runoff can alter chemistry of the water and may destroy aquatic life by adding pesticides, herbicides and fertilizers to the water.
- Wastewater treatment plant effluent is not a source of coliform bacteria in the estuary. Populations of native and migrating birds who use the estuary for feeding, resting, and breeding are a potential source of coliform. (Waln 2004)

Surface water quality monitoring occurs

- At the Vern Freeman Diversion for Ventura County Stormwater Program (the SCR receives municipal storm drain discharges from Fillmore, Oxnard, Ventura, Santa Paula and unincorporated Ventura County). (Darla Wise, Ventura County Flood Control District, pers. comm.)
- In the upper SCR by LA Sanitation District for Saugus and Valencia treatment plants. (Los Angeles Regional Water Quality Control Board date unavailable)
- Between Piru and Saticoy by UWCD. (Los Angeles Regional Water Quality Control Board date unavailable)
- At Santa Paula, for mid-river receiving water. (Los Angeles Regional Water Quality Control Board date unavailable)
- At Fillmore when they discharge to surface waters. (Los Angeles Regional Water Quality Control Board date unavailable)

Discharge Permits granted by the Los Angeles RWQCB

(Los Angeles Regional Water Quality Control Board date unavailable):

- 47 NPDES discharges – 33 go into mainstem, 14 go into tributaries
- 4 major discharges (POTWs, one discharging to estuary, one to middle reaches, two into upper watershed.
- 13 minor discharges
- 30 discharges covered under general permits
- 72 dischargers covered under an industrial storm water permit. Largest number of dischargers is located in the cities of Santa Paula and Valencia. Many of these businesses are involved with auto wrecking and food packing.
- 188 dischargers are covered under a construction storm water permit. The majority of these are located in the upper watershed especially within Santa Clarita and Valencia.

Pollution/contamination

- Natural oil seeps discharge significant amounts of oil into Santa Paula Creek. (Los Angeles Regional Water Quality Control Board date unavailable)
- In 1997, ammonium perchlorate was discovered in four Saugus Aquifer wells (Castaic Lake Water Agency 1997). Ammonium perchlorate is an inorganic chemical that is used in solid rocket propellants, fireworks and explosives (Castaic Lake Water Agency 1997). All currently contaminated Saugus wells are located south of the San Gabriel fault, many near the location of the former Whittaker-Bermite site where the perchlorate contamination originated (Castaic Lake Water Agency 1997). The five shut wells are located along San Fernando Road, Magic Mountain Parkway, and Soledad Canyon Road in the Santa Clarita Valley (Worden 2003).

- An oil spill occurred in Lake McGrath in 1993. Subsequent sampling after cleanup revealed no residual oil contamination remaining in the lake. Water sampling has demonstrated however, that pesticides are a problem particularly historically used pesticides such as DDT. California State Parks is the lead trustee agency for restoration planning efforts related to the oil spill settlement from the 1993 spill. (Denise Steurer, U.S. Fish and Wildlife Service, pers. comm. January 2004)
- Nitrates in specific areas (El Rio, Bardsdale near Fillmore and an area west of Fillmore) are in excess of the state drinking water standard of 45 mg/l. (United Water Conservation District and Castaic Lake Water Agency 1996)
- Higher water quality is present with higher in-stream flows, and lower water quality with lower in-stream flows. (United Water Conservation District and Castaic Lake Water Agency 1996)
- Potential sources of water quality problems in the lower Santa Clara River are: natural oil seeps in the Santa Paula Area, impacts from urbanization, impacts from agriculture, and effects of imported and reclaimed water. (United Water Conservation District and Castaic Lake Water Agency 1996)

Stormwater program

- On August 22, 1994 the California Regional Water Quality Control Board (RWQCB), Los Angeles Region, issued a NPDES permit to the Ventura County Flood Control District (VCFCD), the County of Ventura, and the cities of Camarillo, Fillmore, Moorpark, Ojai, Oxnard, Port Hueneme, San Buenaventura, Santa Paula, Simi Valley, and Thousand Oaks as Co-permittees, for discharges of stormwater and urban runoff into the receiving waters of the Santa Clara River. (Ventura County Flood Control District 2002)
- The presence of the following constituents are measured as part of the stormwater program (Ventura County Flood Control District 2002). Tables are shown as they appear in the 2003 mid-year monitoring report:

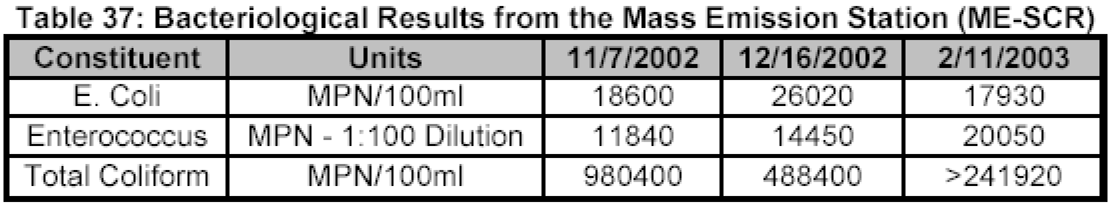


Table 37: Bacteriological Results from the Mass Emission Station (ME-SCR)

Constituent	Units	11/7/2002	12/16/2002	2/11/2003
E. Coli	MPN/100ml	18600	26020	17930
Enterococcus	MPN - 1:100 Dilution	11840	14450	20050
Total Coliform	MPN/100ml	980400	488400	>241920

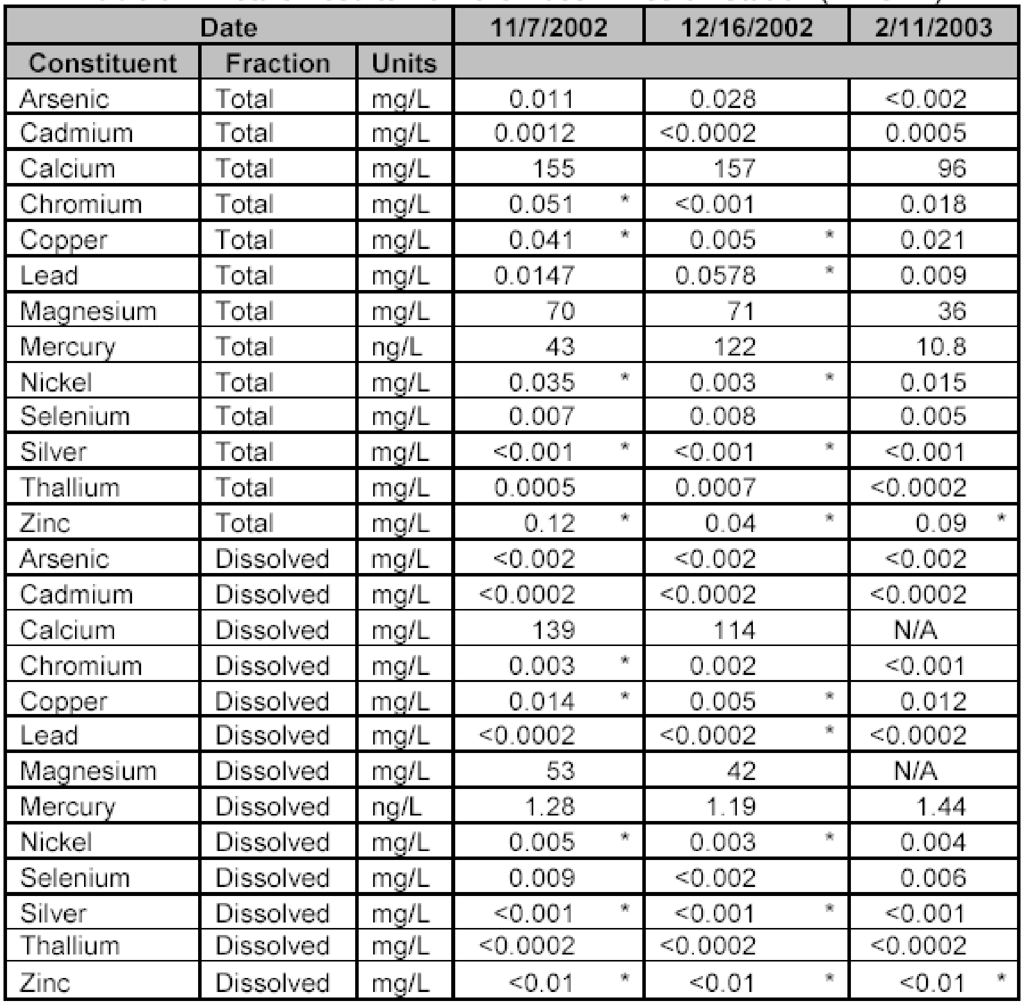
Table 34: Organics Results from the Mass Emission Station (ME-SCR*)*

Date			11/7/2002	12/16/2002	2/11/2003
Method	**Constituent**	**Units**			
EPA 8081	Endrin Ketone	ug/L	<0.01	<0.01	0.07
SM5310C	TOC	mg/L	6.8	7.6	7.3
Remaining EPA methods 8141/8151A, 8081, 8270C, 547, 418.1 are non-detect.					

Table 28: Conventional and Nutrient Results from Mass Emission Station (ME-SCR)

Date			11/7/2002	12/16/2002	2/11/2003
Constituent	**Fraction**	**Units**			
Ammonia-N	Total	mg/L	0.3	<0.2	0.5
BOD	Total	mg/L	6	4.8	5
Bromide	Total	mg/L	0.8 *	0.2	0.2
Chloride	Total	mg/L	75 *	56	44
Conductivity	Total	umhos/cm	1070	1000	797
Hardness	Dissolved	mg/L	565	457	N/A
Hardness	Total	mg/L	675	684	388
Nitrate Nitrogen	Total	mg/L	2.7	1.8	1.9
Nitrate+Nitrite as N	Total	mg/L	3.1	1.8	2
Nitrite Nitrogen	Total	mg/L	0.34	0.1 *	<0.1
Oil and Grease	Total	mg/L	<3	<3	<3
pH	Total	units	7.7	7.8	8
Phosphate	Total	mg/L	0.6	0.9	0.5
Phosphorus	Dissolved	mg/L	1.1	2.5	1.4
Phosphorus	Total	mg/L	3.4	5.5	3
TKN	Total	mg/L	3.1 *	4.2	2.3 *
Total Dissolved Solids	Total	mg/L	1210	870	750
Total Suspended Solids	Total	mg/L	420	2340	990

Table 31: Metals Results from the Mass Emission Station (ME-SCR)



Date			11/7/2002	12/16/2002	2/11/2003
Constituent	**Fraction**	**Units**			
Arsenic	Total	mg/L	0.011	0.028	<0.002
Cadmium	Total	mg/L	0.0012	<0.0002	0.0005
Calcium	Total	mg/L	155	157	96
Chromium	Total	mg/L	0.051 *	<0.001	0.018
Copper	Total	mg/L	0.041 *	0.005 *	0.021
Lead	Total	mg/L	0.0147	0.0578 *	0.009
Magnesium	Total	mg/L	70	71	36
Mercury	Total	ng/L	43	122	10.8
Nickel	Total	mg/L	0.035 *	0.003 *	0.015
Selenium	Total	mg/L	0.007	0.008	0.005
Silver	Total	mg/L	<0.001 *	<0.001 *	<0.001
Thallium	Total	mg/L	0.0005	0.0007	<0.0002
Zinc	Total	mg/L	0.12 *	0.04 *	0.09 *
Arsenic	Dissolved	mg/L	<0.002	<0.002	<0.002
Cadmium	Dissolved	mg/L	<0.0002	<0.0002	<0.0002
Calcium	Dissolved	mg/L	139	114	N/A
Chromium	Dissolved	mg/L	0.003 *	0.002	<0.001
Copper	Dissolved	mg/L	0.014 *	0.005 *	0.012
Lead	Dissolved	mg/L	<0.0002	<0.0002 *	<0.0002
Magnesium	Dissolved	mg/L	53	42	N/A
Mercury	Dissolved	ng/L	1.28	1.19	1.44
Nickel	Dissolved	mg/L	0.005 *	0.003 *	0.004
Selenium	Dissolved	mg/L	0.009	<0.002	0.006
Silver	Dissolved	mg/L	<0.001 *	<0.001 *	<0.001
Thallium	Dissolved	mg/L	<0.0002	<0.0002	<0.0002
Zinc	Dissolved	mg/L	<0.01 *	<0.01 *	<0.01 *

Constituents that exceeded water quality objectives under either dry or wet conditions in 2003 are:

Constituent	Most Likely Sources
Copper	WRPs (residential plumbing materials)
Lead and Nickel	Urban storm water runoff, industrial, or domestic wastewater discharges, oil and gas production, mining or farming.
Selenium	?
Fecal Coliform	Unknown. Possible sources include poorly functioning wastewater treatment plants, ranches (with horses, cattle or hogs), dogs, cats, wildlife (raccoons, coyotes, birds, etc.).
Total Dissolved Solids	Can have both natural and anthropogenic sources.
Chromium	Urban storm water runoff, industrial, or domestic wastewater discharges, oil and gas production, mining or farming.
Zinc	Urban storm water runoff, industrial, or domestic wastewater discharges, oil and gas production, mining or farming.

TMDLs

- The LA-RWQCB is establishing TMDLs for the Santa Clara River (Los Angeles Regional Water Quality Control Board date unavailable). A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. The schedule for setting TMDLs is listed below though it is subject to change:

Constituent	Area Affected	Standard or scheduled year	Probable Source	Most Likely Cause
Chloride	Upper SCR	100 mg/l	Saugus and Valencia WRPs	Residential water softeners
Toxaphene	Estuary	2007	Historical pesticide	
Fecal Coliform	Upper SCR and Estuary	2006	Unknown	
Nitrate	Upper and Lower SCR	2004	Unknown	WRPs, livestock, fertilizers
Eutrophication, fish kills, algae, trash	Lakes Elizabeth, Hughes, Munz	2004	Unknown	Recreational users. Other.

Sewage

- Sewage alters dissolved oxygen concentrations leading to near anaerobic conditions. (Hager 2001)
- Secondary water source usually sewer treatment plant effluent provide more surface water than was available historically. This water is often detrimental. It is much warmer than natural waters emerging from underground sources. Its high nutrient load encourages a different suite of species and can put the native fauna and flora at a competitive disadvantage. These conditions favor introduced aquatic vertebrates like red shiners, grass carp, goldfish, and clawed frogs. (Swift *et al.* 1993)
- Many of the smaller communities in this watershed remain unsewered. In particular, in the Auga Dulce area of the upper watershed, and near the city of Acton. (Los Angeles Regional Water Quality Control Board date unavailable)
- The effects of septic system use in the Oxnard Forebay area is also of concern. (Los Angeles Regional Water Quality Control Board date unavailable)
- Increase in urban areas has led communities to build sewage treatment plants along the river, adding flood protection structures and effluent to the river. (Schwartzberg and Moore 1995)

- The amount of sewage that plants along the river are capable of treating and releasing as effluent are (United Water Conservation District 2000; pers. comm. with respective facilities):

Location of Plant	Capacity
Saugus	5.43 million gallons per day (MGD)
Fillmore	0.15 MGD
Piru	0.11 MGD
Valencia	10.56 MGD. Expansion planned as of 1996.
Ventura	10.3 MGD. Significant upgrades are underway to increase capacity to14 MGD
Santa Paula	2.55 MGD
Newhall (proposed)	6.90 MGD

- Piru, Fillmore and Montalvo percolate secondary treated effluent into the ground near the Santa Clara riverbed (United Water Conservation District and Castaic Lake Water Agency 1996). Fillmore also has an NDPES permit to discharge directly into the river.
- Saticoy percolates primary treated effluent from a community septic tank. (United Water Conservation District and Castaic Lake Water Agency 1996)
- Santa Paula discharges tertiary treated water directly to the SCR. (United Water Conservation District and Castaic Lake Water Agency 1996)

Landfills/Dumps

- There have been huge landfills associated with the river (see following landfill table).

Table of present and past landfills located on or near the Santa Clara River
(Schwartzberg and Moore 1995; United Water Conservation District 2000)

Name	Present	Historic	Location	Serves/served/notes
Chiquita Canyon	X		Near Santa Clarita	Valencia, Newhall and eastern Ventura County
Elkins Ranch	X			
Toland Rd	X		Between Santa Paula and Fillmore	SC valley: Santa Paula, Fillmore, Piru and other unincorporated areas of the county. Oxnard, Port Hueneme, Ventura, Camarillo and Ojai.
Illegal dump site	X		South Mountain Road	A large amount of trash, including cars, boats and trailers have been found in the river's bed
Illegal dump site	X		Between Bailard Landfill and Ventura Marina	Casual dumping of trash on both sides of the river.
Torrey Rd		X	Piru	Piru
Highway 23		X	Near Fillmore	
12th St. and South Mountain		X	Santa Paula	Santa Paula
Saticoy Avenue		X	Saticoy	Saticoy
Wagon Wheel		X	Wagon Wheel	Oxnard, Ventura
Southern California Coastal landfill		X	Ventura Road to the Victoria/ River Ridge Golf Course	Ventura? Oxnard?
Borchard dump		X	Victoria Ave	Ventura? Oxnard?
Bailard Landfill		X	South of the SCR, approx. 1,500 feet west of Victoria Ave.	Ventura Regional Sanitation District
Sears-Walker		X	Site of Ventura Marina	Sea burn dump where trash was often bulldozed into the ocean.

Sediment Regime

Issues

1. Santa Felicia Dam has had the greatest impact on altering the SCR sediment regime and preventing delivery of sediment to beaches.
2. Total reduction in sand transport to the coast from 1928 – 1975 is estimated to be 15 million tonnes.

Section II. Santa Clara River

<u>*Sediment*</u>

- ☐ From 1928 to 1955 suspended sediment delivery to the ocean was reduced by only 6% due to anthropogenic influences. Since 1956 annual deliveries of sand sized material by have been reduce by about 37% or 15 million metric tonnes due to man-made upstream control structures. The Lower River Diversion Dam built in 1929, and Santa Felicia Dam built in 1956 on Piru Creek are the structures whose operations have been primarily responsible for this reduced shoreline sediment delivery. (Taylor *et al.* 1977)
- ☐ Total sediment discharge of the basin computed from records of SCR at Montalvo for water years 1968 – 75 was 63.5 million tons of which 59.5 million tons was carried in suspension. (Williams 1979)
- ☐ Total reduction in suspended sediment transport to the coast from 1928 – 1975 has been on the order of 50M tonnes. A ballpark estimate of the total reduction in sand transport to the coast during this period can be made as 30% of the suspended load, for a total of 15M tonnes. (Taylor *et al.* 1977)
- ☐ The major difference between natural and actual sediment discharges of the Santa Clara River Basin is the sediment intercepted upstream from Lake Piru behind the Santa Felicia Dam. The combined trap efficiency of Lake Piru and Pyramid Lake approaches 100 percent. Sediment deposited in these reservoirs resulted in about a 12 percent reduction of sediment to the SCR basin during the period 1953 – 75. (Williams 1979)
- ☐ VFD and the Santa Felicia dam are the main structures that reduce delivery of sediment to the beach. (Taylor *et al.* 1977)
- ☐ Sediment losses by gravel mining, diversion of flows and interception of sediment in the Castaic Creek basin resulted in additional reductions of 4 percent during the period 1953 – 75. (Williams 1979)
- ☐ Most of the sediment from the SCR was transported during only a few days of floodflow. The long-term average annual sediment discharge of the SCR is estimated at 3.67 million tons. (Williams 1979)

- Development on steep slopes (residential, industrial, and agricultural) can elevate the background levels of fine sediments in tributaries, particularly, Santa Paula, Pole, Hopper, and lower Piru Creeks, affecting steelhead spawning and rearing success. (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)
- Forest fires can have temporary, but substantial effects on sediment regimes in tributaries, particularly the Sespe and Santa Paula Creeks; their frequency and intensity have been significantly modified by forest management practices. (Mark Capelli, National Marine Fisheries Service, pers. comm. January 2004)

Section II. General Information

- Excessive sedimentation alters the entire hydrology of a watershed leading to channel widening, loss of the pool-riffle sequence, reduced pool depth, and decreased stability of substrate and banks. (Barnhart 1986, as cited in Stoecker 2002; Cordone and Kelley 1961; Walters 1995)

A partial list of Santa Clara River Species

Birds

Common Name	*Genus*	*Species*	Native?	Special Status?
California least tern	*Sterna*	*antillarum browni*	Y	Y
Least Bell's vireo	*Vireo*	*bellii pusillus*	Y	Y
Loggerhead shrike	*Lanius*	*ludovicianus*	Y	Y
Southwestern willow flycatcher	*Empidonax*	*trailii extimus*	Y	Y
Western least bittern	*Ixobrychus*	*exilis hesperis*	Y	Y
Western snowy plover	*Charadrius*	*alexandrinus nivosus*	Y	Y
Yellow warbler	*Dendroica*	*petechia breshteri*	Y	Y
Brown-headed cowbird			N	-

Fish

Common Name	*Genus*	*Species*	Native?	Special Status?
Pacific Lamprey	*Lampetra*	*tridentata*	Y	
Pacific staghorn sculpin	*Leptocottus*	*armatus*	Y	
Prickly sculpin	*Cottus*	*asper*		
Rainbow trout	*Salmo*	*gairdneri*	Y	N
Santa Ana sucker	*Catostomus*	*santaanae*	Y but invasive	Y
Southern steelhead trout	*Oncorhynchus*	*mykiss*	Y	Y
Tidewater goby	*Eucyclogobius*	*newberryi*	Y	Y
Unarmored threespine stickleback	*Gasterosteus*	*aculeatus williamsoni*	Y	Y
Black Bullhead	*Ameiurus*	*melas*	N	
Sacramento sucker	*Catostomus*	*occidentalis*	N	
Green sunfish	*Lepomis*	*cyanellus*		
Largemouth bass	*Micropterus*	*salmoides*		
Owens sucker	*Catostomus*	*fumeiventris*		
Threadfin shad	*Dorosoma*	*peteneses*		

Plants

Common Name	***Genus***	***Species***	**Native?**	**Special Status?**
Mule fat	*Baccharis*	*salicifolia*	Y	
Nevin's barberry	*Berberis*	*nevinii*	Y	Y
Ojai fritillary	*Fritillaria*	*ojaiensis*	Y	Y
Slender-horned spineflower	*Dodecahema*	*leptoceras*	Y	Y
Ventura marsh milkvetch	*Astragalus*	*pycnostchyus*	Y	Y
Bull Thistle			N	-
Castor Bean	*Ricinus*	*communis*	N	-
Fennel			N	-
Giant Cane	*Arundo*	*donax*	N	-
Pampas grass			N	-
Tamarisk	*Tamarix*	*sp.*	N	-

Reptiles and Amphibians

Common Name	***Genus***	***Species***	**Native?**	**Special Status?**
Arroyo toad	*Bufo*	*microscaphus californicus*	Y	Y
California red-legged frog	*Rana*	*aurora draytonii*	Y	Y
South coast garter snake	*Thamnophis*	*sirtalis sp.*	Y	Y
Southwestern pond turtle	*Clemmys*	*marmorata pallida*	Y	Y
Two striped garter snake	*Thamnnophis*	*hammondii*	Y	N
African clawed frog	*Xenopus*	*laevis*	N	-
Bullfrog	*Rana*	*catesbiana*	N	

Current Santa Clara River Studies

Name	Org	Date Begin	Date End	Summary
Watershed Plan	ACOE	Jan-04	Jan-07	Also referred to as the Feasibility study. Approximately ½ of the cost is being paid by ACOE with Ventura and Los Angeles Counties paying the other ½ mostly with in-kind services. Major components of the study include: surveys and mapping of the watershed; hydrologic, hydraulic, sediment, water quality, and coastal investigations; engineering and design analysis to identify flood control, erosion, sedimentation and environmental restoration projects; socioeconomic studies; environmental studies; and cultural resource studies. The six planning steps are: 1) specify problems and opportunities, 2) inventory and forecast conditions, 3) formulate alternative plans, 4) evaluate effects of alternative plans, 5) compare alternative plans, and 6) select recommended plan. The study will take 3 years to complete.
SCREMP	Ventura County			A management plan for the river up to the 500 year floodplain. Covers from the 500 - 25 year flood line for bank improvements and stabilization.
SCR EIR and Mapping	Arundo Task Force			EIR and mapping to match $1.3M Prop 13 funding that was given to the LA portion of the SCR for EIR, mapping and *Arundo* removal.
Steelhead Recovery Plan	NMFS			An endangered species recovery plan that will encompass the Southern California ESU and will address restoring southern steelhead trout.
Regional Wetlands and Watershed Management Plan for Southern California	Environment Now/ Wetlands Recovery Project	Apr 02	Nov 04	Funded by Environment Now. Watershed Coordinators, hired under the Wetlands Recovery Project Local Assistance Program, are focusing on project management and assistance for projects that are already on the Wetlands Recovery Project workplan. They will also promote the contribution of local resources to the development of watershed management planning tools under development by the Wetlands Recovery Project.
Steelhead Habitat and Barriers Assessment	UC Santa Barbara and The Nature Conservancy	Oct 03	Sept 05	Assessing steelhead habitats, populations, and barriers to migration. Evaluating and modeling hydrology as it relates to steelhead migration.

A partial list of potential funding sources

Sources of funding	Title	Contact	Type of funding	Amt	Notes
CA Water Quality Control Board	NPS				Prop 40.
CA Water Quality Control Board	Stormwater				Prop 40. Dry weather flow; diversions, acquisition and development of wetlands, implementation of BMPs
CA Wildlife Conservation Board	Habitat Enhancement and Restoration Program				
CFG	Fisheries Restoration Grant Program	Mary Larson	Barrier modification and removal, fish ladders, monitoring, education, demo projects.		Very competitive. Funding is not provided until the following summer, i.e. approved proposals from May 2003 will receive funds in summer 2004. $$ needs to be spent in 1 - 2 years.
Dept of Water Resources	Flood protection Corridor Program		Buy land, flood control		
National Fish and Wildlife foundation	Bring back the Natives	Don Glaser	Restoration Projects		On the ground habitat restoration projects for natives
National Fish and Wildlife foundation	Challenge Grants	Anna Weinstein	Cooperative parnerships		To conserve fish, wildlife, plants and their habitats.
National Fish and Wildlife foundation	Native Plant Conservation Initiative	Beth deCarolis	Conservation Projects		On the ground conservation projects that protect, enhance or restore native plant communities.
NOAA	Community Based Restoration Program		Cooperative		

Sources of funding	Title	Contact	Type of funding	Amt	Notes
NRCS	Wetlands Reserve Program	Alan Forkey	Wetland restoration		To establish long-term conservation practices and protection. Private landowners only.
NRCS	Wildlife Habitat Incentives Program (WHIP)	Lisa Roberts	Wildlife Habitat		Develop and improve habitat. 75% cost-share assistance. Like to fund multiple partner projects.
USFWS	ARCO oil spill	Denise Steurer	For land acquisition, invasive non-native species control, restoration projects, information and education, and watershed evaluation and monitoring	$7.1M	
USFWS	Private Stewardship		On the ground conservation projects	$10K	
USFWS	Partners for Fish and Wildlife	Kate Symonds	Projects		Conserve/protect fish and wildlife and their habitats

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January 22, 2007

Mr. Daniel Fierros
County of Los Angeles
Department of Regional Planning
Impact Analysis Section, Room 1348
320 West Temple Street
Los Angeles, A 90012

Re: Comments on the Landmark Village Draft Environmental Impact Report, County Project No. 00-196

Dear Mr. Fierros:

On behalf of Heal the Bay, we submit the following comments on the *Landmark Village* (“Project”) *Draft Environmental Impact Report, County Project No. 00-196* (“DEIR”). We appreciate the opportunity to provide these comments.

In general the DEIR does not adequately consider alternatives that would enable the project to proceed with the least environmental damage and does accurately describe the environmental risk to decision makers. Therefore, the Los Angeles County Regional Planning Commission should not certify the EIR as written. Our concerns with water quality, hydrology, and biological resources impacts are described in further detail below.

The Santa Clara River (“River”) is the largest wild river remaining in southern California. It provides crucial aquatic ecosystem functions in the region, including groundwater recharge and riparian habitat for endangered and rare species. It is also a significant input to southern California’s coastal waters at the City of San Buenaventura. Thus, it is imperative that development occurring within the Santa Clarita River watershed proceeds in a manner that protects and restores the water quality and aquatic ecosystem functions of this important river system. In 2005, the Santa Clara River was named the “10th Most Endangered River” in the Country by the American Rivers organization in part because of the imminent threat of development.

Our over-arching concern with this project as outlined in the DEIR is that it impinges upon the natural functioning of the River to such an extent that significant, immitigable damage will be done to water quality and aquatic habitat. Specifically:

- There is an insufficient buffer zone (undeveloped vegetated area) provided between developed areas and the River.
- There are extensive areas of stream bank alteration, in the form of hardened structures for stabilization, including buried bank stabilization, which are known to increase erosion/sedimentation problems and decrease aquatic and riparian habitat.

- The analyses are fatally flawed and do not accurately present the true impacts of the proposed development at the project site and downstream to water quality, biological resources and downstream property owners.
- Significant development occurs within the 100-year floodplain of the River.

Water Quality – Section 4.3

Integrated water resources planning should be considered in the project design.

Efforts such as the Los Angeles County Integrated Regional Water Management Plan and the City of Los Angeles Integrated Resources Plan highlight the need for integrated water resources planning in the region. However, the DEIR does not appropriately address aspects of integrated planning for the project. For instance, why is all of the storm water being directed off-site? Are there no plans for water reclamation or infiltration? The DEIR should consider integrated water resources planning as a way to address some of the potential impacts from the project.

Fill and grading projects should be appropriately mitigated.

The project requires 5.8 million cubic yards of fill and significant grading activities at the Adobe Canyon Borrow Site and the Chiquito Canyon Grading Site. DEIR at 39. This is an enormous amount of cut and fill, yet there are no specific grading restrictions outlined in the DIER. For a proposed project of this magnitude in proximity to an important waterbody, extra precautions should be required. For example, there should be no grading within 500 feet of the River or any tributary or on steep slopes (steeper than 4:1). Also, there should be no grading activity during the rainy season (November through April). On many occasions Heal the Bay staff has witnessed the disastrous effect of grading, even at much smaller projects, when a rainstorm occurs. For instance, there were disastrous sediment discharges from the much smaller Shea Homes project in Agora Hills that were documented by the Regional Water Board and Fish and Game in 2003/2004. The basic best management practices (“BMPs”) are not sufficient to prevent massive sediment inputs to creeks when hillsides are graded and exposed to rainfall. These restrictions should be specified in the DEIR.

Pollutant concentrations and loadings should not be directly compared to the existing agricultural use pollutant concentrations and loadings.

The DEIR compares all pollutant concentrations and loadings to the existing conditions with the agricultural site. This comparison is inappropriate. Pollutant concentrations in the runoff should be evaluated based on potential impacts to water quality. Various reaches of the Santa Clara River are listed on the State’s 303(d) list as impaired by various constituents. Specifically Reach 5 is listed for chloride, high coliform and nitrate and nitrite, and a TMDL has been adopted for Nitrogen and Ammonia. Regardless of whether or not the land use remains agricultural or the proposed development takes place, the owners must comply with all existing TMDLs or will be in violation of the Clean Water Act.

Ultimately the County and City of Santa Clara will be responsible for meeting TMDLs that exist for waterbodies in the project area. Clean-up measures are extremely expensive. These costs will likely be passed on to the tax payers. We strongly urge that any development not further impair water quality in 303(d) listed waters. Any costs associated with runoff from the project should be placed on the property owners or the developers.

The estimated nutrient concentrations may lead to excess algal growth.

The DEIR predicts that average annual nitrate + nitrite concentrations will be 0.5 mg/l and total phosphorus will be 0.3 mg/l. Data show that these concentrations may impact the water quality. For instance, data collected in the Malibu Creek Watershed by Heal the Bay’s Stream Team between the period of November 1998 and November 2004 show that algal cover in Malibu Creek consistently exceeds 30% when nitrate is <0.05 mg/l and phosphate is above 0.15 mg/l. Lawn care practices in the development may increase the nutrient levels significantly. Thus, the discharges of nutrients from the development will likely contribute to water quality impacts.

BMPs should be maintained and monitored in perpetuity.

Some of the proposed water quality BMPs will be maintained by homeowner associations. This does not ensure ongoing water quality protection because there is no regulatory oversight of these associations. All water quality protection measures should be the responsibility of the developer. Alternatively the homeowners associations should at least be required to sign binding agreements with such government agencies requiring the homeowners associations to perform specific maintenance, monitoring and reporting requirements, depending on the BMP. Without maintenance, monitoring and reporting follow-up, there is no point in using BMPs since there will be no way of determining whether a given BMP is effective in mitigating water quality impacts.

The water quality impacts for all drainages in the project area should be evaluated.

The DEIR states that “[f]our other drainages within or adjacent to the project site are also considered ‘waters of the U.S’….” DEIR at 4.2-12. There is little to no mention of these drainages in the document. Were impacts to these considered in the DEIR and are there proposals for mitigation measures? This analysis should be included in the DEIR and appropriate mitigation measures and setbacks should be required.

Water quality impacts from the new wastewater treatment facility should be considered in the DEIR.

The downstream water quality impacts of increased nutrient and bacteria loading from the proposed wastewater treatment plant are not addressed in the DEIR. Will the combination of pollutants from wastewater discharges and storm water discharges prevent compliance with TMDLs? Also, where will the sewer lines and water supply lines be placed and how will this impact aquatic and riparian resources onsite and downstream? Without further details regarding discharges of wastewater and its impacts to water quality, there is not sufficient information for decision makers to evaluate impacts of this project. This constituents a fatal flaw in the DEIR.

Appropriate actions should be taken to avoid the spread of exotic species.

Recent aquatic invertebrate surveys in the Malibu Creek watershed have confirmed the presence of the New Zealand mudsnail, an insidious exotic invasive species that could potentially wreak havoc on the watershed's native organisms. The mudsnail has also been found in Piru Creek in the Santa Clara River watershed. The DEIR describes various construction activities that will take place in the River. In order to avoid the spread of this exotic species, the developer should include a strict protocol that will be implemented to prevent its spread. Anyone having contact with the River due to this project should complete a HACCP to prevent the spread of the mudsnail further into the watershed.

Hydrology – Section 4.2

The Project should avoid any hard armoring of the stream bank.

The DEIR estimates that there will be a 148 acre-ft per year increase in runoff, despite proposed mitigation measures. DEIR at 4.4-77. (The actual runoff and pollutant loading estimate would be greater if the applicant would use more appropriate models and not bulk and burn calculations.) Small increases in flow can result in massive erosion problems over time. In order to "mitigate" the impacts of these flows, the DEIR proposes the use of buried cement bank stabilization, bridge piers and abutments, rip-rap, and energy dissipaters. Specifically, 18,600 linear feet of buried soil cement and 11 bridge piers are proposed in the project area. DEIR at 4.2-35. Any of these structures or modifications will affect the hydrology of the stream even if only in localized areas. Anytime natural processes are altered, there are substantial downstream impacts.

The long-term effects of stream bank/bed modifications include increased scouring, increased erosion, and increased downstream deposition of eroded material, which degrades downstream habitat. As a result native vegetation are often washed out, eliminating the ability for pollutant removal. Also, eroding stream banks contribute fine sediment to streams. Fine sediments contribute nutrients, bacteria, and bury important spawning habitat for steelhead trout. Heal the Bay's Stream Team mapped 70 miles of stream in Malibu Creek Watershed between 2001 and 2003. They found that 19.8 (28%) linear stream miles of armoring resulted in 18.7 (27%) linear miles of eroding stream banks.

The best ways to avoid increased erosion/deposition effects are to (1) keep all structures and utilities outside the 100-year floodplain or the 500 foot riparian buffer of the River (whichever is greater); (2) use only soft bioengineering techniques to stabilize stream banks. (No armoring of stream banks). Bioengineering is preferable because it allows the river to maintain a natural dynamic balance. It also requires less maintenance over time as there are no concrete or other hard structures to eventually fail and be replaced. Bioengineering also provides natural riparian habitat that maintains water quality and wildlife habitat;

We strongly recommend that the space between vertical support columns be increased to the maximum extent possible to provide for less obstruction and less impact on wildlife migration. Additionally we believe that the bridge height should be increased to minimize noise and light impacts that could deter aquatic and terrestrial wildlife migration. A light-penetrating surface should also be used to provide light for the organisms below. Plant growth below the bridge will provide for migrating wildlife and enhance stabilization.

In sum, the Santa Clara River supports numerous endangered, threatened and rare aquatic species that must be protected from the deleterious erosion and deposition effects of stream bank/bed modifications. The DEIR fails to analyze the impacts that the project will have to both water quality and habitat quality in the Santa River and other impacted drainages. Without this information, decision makers can not evaluate the true impacts of this project, which is a fatal flaw of the DEIR. Therefore, the project must be modified to avoid all armoring.

The amount of impervious surface should be greatly decreased.

A key factor in the degradation of stream water quality is the proportion of impervious surfaces versus pervious surfaces in the watershed.[1] Heal the Bay's State of the Watershed concluded that "[o]ur imperviousness data and BMI data indicate a trend of increasing imperviousness associated with decreasing mean IBI scores." Further, the State of the Watershed Report finds that there is serious degradation to BMI with effective imperious surfaces as low as 5%. Hollis (1995) states that even "low levels of impervious cover (5 to 10 percent) are capable of increasing the peak discharge rate by a factor of 5 to 10 for storms smaller than the one year storm."

While Schueler (1995) comments that "more impervious cover directly translates into higher peak discharge rates, greater runoff volumes, and higher floodplain elevations," detention ponds are most commonly constructed to mitigate these effects. The primary goal of stormwater detention ponds is to reduce the peak discharge rate by slowly releasing water over a longer period of time. Therefore, the total volume of runoff is the same with or without the detention pond, the only difference is that discharge lasts for a longer amount of time. Thus, the proposed BMPs will not solve many of the problems created by increased runoff volumes from the development.

Table 4.2-1 provides the percent imperviousness for selected land uses. These numbers should be reduced. The DEIR should consider alternatives such as increasing the density of the housing or reducing the number of houses so that the % impervious is decreased below 5%. Maintaining 5% or less effective impervious area will ensure viable biological communities.

The DEIR's calculations for bulk and burn are misleading.

The DEIR states that "[o]nce developed, the Landmark Village project would reduce post-development stormwater flows during a capital storm event." DEIR at 4.2-1. Further, the DEIR asserts that the project will decrease the total debris volume and burned and bulked runoff. DEIR at 4.2-4. We completely disagree with this statement. Using this methodology, the DEIR concludes that a undeveloped site will be dirtier and produce more runoff than an developed site. This assertion is ridiculous.

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[1] Center for Watershed Protection, 2003. Impacts of impervious cover on aquatic systems. Watershed Protection Research Monograph 1, 158 pp. http://www.cwp.org/Downloads/

The pre-development pollutant loading analyses used the LA County "bulk and burn" runoff estimates, which provide unrealistically high flow and pollutant estimates most of the time. Given the return frequency of major fires in the region, it is extremely unlikely that most rain events will generate the equivalent of the amount of water and pollutants estimated in the "bulk and burn" method. We understand that this is the standard calculation used in the LA County stormwater manual; however, while it may be appropriate for sizing bridges and culverts, it is entirely inappropriate for calculating pollutant loads and runoff volumes at a development site. We feel it is imperative that the project proponent also analyze stormwater flow and loadings under normal, non-bulk and burned conditions and we urge the County to require such analyses for flow and pollutant loadings in this DEIR, in order to achieve a realistic estimate of pre- and post-development pollutant loads to the River. Without such an analysis, it is impossible for decision makers to evaluate on-site and downstream impacts that the project will have on water quality.

All development should take place out of the floodplain.

The proposed Landmark Village project impinges upon the 100-year floodplain of the River. As stated in the DEIR, 103.5 acres are within the FEMA floodplain. DEIR at 4.2-29. There is absolutely no reason why housing needs to be placed in the 100-year floodplain, thus necessitating stream bank stabilization measures (i.e. stream bank hardening) to then protect those homes in the floodplain. Any development in the Santa Clara River watershed must occur well outside the 100-year floodplain or outside of the 500 foot riparian buffer (whichever is greater) and as discussed below must maintain vegetated buffers in order to protect the water quality and ecosystem functions of the River.

Biota – Section 4.4

A 500 foot riparian buffer should be required for all development activities.

As acknowledged in the DIER, "[t]he river is an important migration and genetic dispersion corridor for many wildlife species, including aquatic taxa, riparian obligate species (resident and migratory), and larger more terrestrial animals." DEIR at 4.4-27. Numerous riparian plant communities have been observed on the project site. For instance, there are documented populations of elderberry scrub, mulefat scrub, southern willow scrub, river wash, freshwater marsh, alluvial scrub, great basin scrub, and scalebroom scrub. In addition, there are numerous special-status riparian plant species on-site such as the late-flowering mariposa lily, Los Angeles sunflower, southwestern spiny rush, Davidson's bush mallow, California Muhly, mud nama, spreading navarretia, Gambel's watercress and Sonoran maiden fern documented in the project area. DEIR at 4.4-33. In addition, there are numerous animal communities that inhabit the riparian corridor. Tables 4.4-5 and 4.4-6 of the DEIR outline the special-status wildlife species that were observed on-site or are likely to occur on-site. Many of these species inhabit the riparian zone such as the Lawrence's goldfinch, Northern harrier, Arroyo toad, Western spadefoot toad, and San Bernardino ringneck snake. There are also federally listed aquatic species present or that may be present at the project site or downstream.

Dr. Philip Rundel stated in his written comments on the proposed Ahmanson Ranch Project that "[r]iparian ecosystems are keystone habitats in Southern California and play a critical role in a variety of ecosystem processes… these ecosystems act to buffer hydrologic and erosional cycles, control and regulate biogeochemical cycles of nitrogen and other key nutrients, limit fire movements, and create unique microclimates for animal species. Both terrestrial and aquatic wildlife depend on riparian ecosystems with their year-round availability of water, nutrients, food sources, and organic sediments … It is not surprising, therefore, that riparian ecosystems are centers of high biodiversity."[2] In addition, scientific evidence clearly demonstrates that buffer zones, or intact areas of natural vegetation, are crucial to the protection of water quality.[3]

Although the DEIR claims that an appropriate riparian buffer is being included in the project design to protect these species, the impact analysis in Section 4.4 refutes this assertion. Table 4.4-8 shows the acreage of each plant community/land use that would be developed or temporarily disturbed. A large percentage of the riparian plant communities described above would be completely destroyed or severely impacted by the project. For example of the 6.93 acres of scalebroom scrub currently on-site, 4.27 acres will be permanently destroyed and 2.67 acres will be temporarily impacted. This means that the entire community will be impacted. If a riparian buffer is proposed, how is this riparian community completely impacted?

The DEIR acknowledges that the loss of habitat due to the project would be significant. "…[T]he loss of wildlife habitat would adversely affect numerous common and special-status wildlife species, including the silvery legless lizard, rosy boa, San Bernardino ringneck snake, coast horned lizard, coast patch-nosed snake, northern harrier, white-tailed kite, southern rufous-crowned sparrow, Bell's sage sparrow, western burrowing owl, San Diego desert woodrat, pallid bat, mountain lion, and San Diego black-tailed jackrabbit." Further, the document states that this loss is "unavoidable." DEIR at 4.4-59 and 60. This claim is completely unfounded, and the huge impact to wildlife species is unacceptable.

The developer has obviously not considered reasonable alternatives to lessen this impact such as increasing the riparian buffer, increasing the density of homes, and/or building fewer homes. If there is an appropriate riparian buffer, then the risk to these species - many of which are endangered or special-status - is greatly reduced. A minimum 500 foot buffer, as measured from the outside edge of the riparian canopy (not from the edge of the bank stabilization as proposed on page 4.4-61.), or a restriction to not build in the floodplain whichever is greater, should be required for this project due to its size and the nature of the River. This sizable buffer is

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[2] Letter from Dr. Philip Rundel to Dennis Hawkins, dates April 26, 2002.

[3] See these references: "National Management Measures to Control Nonpoint Source Pollution from Urban Areas" (http://www.epa.gov/owow/nps/urbanmm/index.html, last updated 8/8/2003); Herson-Jones et. al, 1995, cited in the aforementioned EPA document; Wenger, S. J. & Fowler, L. (2000) Protecting Stream and River Corridors. Creating Effective Local Riparian Buffer Ordinances. *Policy Notes*. Public Policy Research Series, Carl Vinson Institute of Governments, the University of Georgia. 1(1):1-2; Wegner, S. (1999) A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation. Office of Public Service & Outreach, Institute of Ecology, University of Georgia; Basnyat, P., Teeter, L. D., Flynn, K. M., & Graeme Lockaby, B. (1999). Relationships between Landscape Characteristics and Nonpoint Source Pollution Inputs to Coastal Estuaries. *Environmental Management* 23(4):539-549; and US EPA (2002) National Management Measures to Control Nonpoint Source Pollution From Urban Areas-Draft. Office of Wetlands, Oceans and Watersheds. Nonpoint Source Control Branch. Washington D.C.

necessary for many reasons including that "[a] number of studies have found that even the more riparian-dependent wildlife species also require adjacent upland habitats…" and "[a]rroyo toads have been found in agricultural fields and occur within portions of the site outside of the proposed riparian setback zones." DEIR at 4.4-60. In general, the purpose of the buffer is to protect the riparian areas from filling, devegetation and encroachment by human development. Grading, development, and BMPs should not be allowed in the buffer. Also, the fuel modification zone should not interfere with the buffer zone.

In addition, a mitigation ratio of 2:1 should be employed for disturbance to areas of riparian and oak habitat that can absolutely not be avoided. This ratio will ensure that in the long term, a 1:1 ratio will be established. Further, mitigation must occur on-site. The mitigation proposed is completely inadequate and should be dramatically increased.

The DEIR should address downstream species impacts.

The DEIR addresses species found in the immediate area of the project but fails to address potential impacts to those species located downstream such as steelhead and the red-legged frog. For example, Table 4.4-7 of the DEIR indicates that wildlife species such as the steelhead rainbow trout are "not expected on the Project Site." However, the steelhead trout is a federally listed species that is present downstream and thus should be evaluated. The steelhead will likely be affected by the changing stream flows, temperatures, and sedimentation rates. Why did the Newhall Ranch developers apply for a 1998 Incidental Take Permit for steelhead and red legged frog if the developer did not think downstream impacts would occur? These species should be considered as well.

If you have any questions or would like to discuss any of these comments, please feel free to contact us at (310) 451-1500. Thank you for your consideration of these comments.

Sincerely,

Kirsten James
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[Article]

Steelhead Growth in a Small Central California Watershed: Upstream and Estuarine Rearing Patterns

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Abstract.—We monitored growth and life history pathways of juvenile steelhead *Oncorhynchus mykiss* and compared growth rates between the upper watershed and estuary in Scott Creek, a typical California coastal stream. Growth in the upper watershed was approximately linear from May to December for age-0 fish. For passive integrated transponder (PIT) tagged, age-1+ fish, growth transitioned to a cyclic pattern, peaking at 0.2% per day during February–April, when maximum flows and temperatures of 7–12°C occurred. Growth of PIT-tagged fish then slowed during August–September (0.01% per day), when temperatures were 14–18°C and flows were low. During each spring, smolts (mean fork length [FL] ± SE = 98.0 ± 1.2 mm) and fry migrated to the estuary; some fish remained there during summer–fall as low flows and waves resulted in seasonal sandbar formation, which created a warm lagoon and restricted access to the ocean. Growth in the estuary–lagoon was much higher (0.2–0.8% per day at 15–24°C). Our data suggest the existence of three juvenile life history pathways: upper-watershed rearing, estuary–lagoon rearing, and combined upper-watershed and estuary–lagoon rearing. We present a model based upon the above data that reports size at age for each juvenile life history type. The majority of fish reaching typical steelhead ocean entry sizes (~150–250 mm FL; age 0.8–3.0) were estuary–lagoon reared, which indicates a disproportionate contribution of this habitat type to survival of Scott Creek steelhead. In contrast, steelhead from higher latitudes rear in tributaries during summer, taking several years to attain ocean entry size.

Growth rates, associated environmental influences, and subsequent effects on life history decisions have been extensively studied in Atlantic salmon *Salmo salar* and brown trout *Salmo trutta* in both the laboratory and the field by means of classical periodic sampling and more recently passive integrated transponder (PIT) tag recaptures (e.g., Elliott 1975; Thorpe 1977; Jones and Hutchings 2001; Jones et al. 2002; Arnekleiv et al. 2006;). Comparatively little data exist for Pacific salmonids in the field, and most work is limited to studies of coho salmon *Oncorhynchus kisutch* (Parker and Larkin 1959; Breuser 1961; Chapman 1962; Bustard and Narver 1975; Fransen et al. 1993; Peterson et al. 1994; Bilby et al. 1996). Because Pacific salmon populations exist across broad latitudinal ranges (reviewed in Quinn 2005), it is likely that juvenile growth and life histories vary in response to environmental differences and may have subsequent effects on marine survival and ultimately adult returns. Variation in juvenile growth and life history among populations of steelhead *O. mykiss* is typically evaluated in terms of size and age at ocean entry, measured either directly from smolts or more often estimated from analyses of scales from returning adults (Busby et al. 1996). It is suspected that the amount of time required to reach the size threshold for marine survival depends upon the length of the summer growing season and may take several years in northern latitudes (Withler 1966; Narver 1969; Narver and Andersen 1974; Busby et al. 1996). However, only limited data exist on year-round growth or habitat use for juvenile steelhead across their range, 34–60°N (Hartman 1965).

Environmental conditions may affect seasonal patterns of growth in ways that are not understood,

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possibly having both positive and negative effects in the southern part of the steelhead range where many populations are listed under the Endangered Species Act as endangered or threatened (NMFS 2006). Steelhead growth rate varies across temperature and probably among populations, but optimal growth is thought to occur between 15°C and 19°C and lethal temperatures are between 27.5°C and 29.6°C for one southern population (Wurtsbaugh and Davis 1977b; Railsback and Rose 1999; Myrick and Cech 2005). While little is known about steelhead growth in the wild, the longer growing season associated with mild climates at the southern portion of their range may enable the fish to reach smolt stage within a shorter period of time (Withler 1966; Busby et al. 1996). Connolly and Peterson (2003) proposed that overwintering survival might be especially tenuous for larger age-0 steelhead in warmer climates due to the "challenges" of the winter climate—specifically, elevated metabolic rate and limited food. Alternatively, winter conditions may be superior, potentially providing better growing conditions than those in northern-latitude streams due to mild temperatures and better food production. The real challenges faced by southern populations may be associated with summer, when warm temperatures may increase metabolic rates while extremely low flows result in reduced aquatic invertebrate production and terrestrial insect drift in upper watersheds. In fact, growth conditions for some southern populations have been reported as poor during summer and fall, causing scale annulus formation in September (Shapovalov and Taft 1954; Railsback and Rose 1999).

While estuarine use has been studied within the central and northern portions of Pacific salmonid ranges (e.g., Healey 1982; Levings et al. 1986; Tschaplinski 1987; Miller and Sadro 2003; Bottom et al. 2005), limited research exists on the use of coastal estuaries by southern salmonids and the associated effects on growth. Many coastal California streams have estuaries that lose surface connectivity with the ocean during the summer months, forming lagoons (Shapovalov and Taft 1954; Schwarz and Orme 2005). Temperatures in these estuaries and lagoons can range from 15°C to 24°C or more during summer months. Juvenile steelhead are known to use these estuaries, but the effects of estuarine rearing on steelhead growth and survival have been reported only rarely in peer-reviewed literature (e.g., Smith 1990; Cannata 1998).

In this study, we report growth rates of juvenile steelhead from emergence to ocean entry in a typical small stream along the central California coast and we provide a comparative analysis of upstream and estuarine rearing by similarly aged fish. From these results, we describe the associated habitat use patterns and construct growth models for the various life history paths followed by fish before reaching the ocean. Finally, we address how the southern environmental conditions affect steelhead growth and compare our results with the limited growth data available from the remainder of the species' range.

Study Area

Scott Creek is a small, 70-km^2 coastal watershed located 100 km south of San Francisco in central California. Anadromous fish can access approximately 23 km of stream between the estuary and natural upstream barriers of the main stem and the three main tributaries, Little, Big, and Mill creeks (Figure 1). The upper portion of the watershed consists of high-gradient stream dominated by a thick canopy of coastal redwoods *Sequoia sempervirens*. The main stem below the major tributary confluences tends to be characterized by a low gradient, a lower density overstory cover primarily produced by alders *Alnus* spp., and an understory dominated by willows *Salix* spp. A small estuary at the bottom of the watershed can become a freshwater lagoon during summer and fall when a sandbar builds up at the creek mouth, isolating the stream from the ocean. During the last two decades, natural and anthropogenic influences often interfered with lagoon formation (e.g., artificial breaching, water diversions, and drought; J.J.S., unpublished data). Stream width varies from approximately 40 m in the estuary when closed to about 10 m on the main stem, to less than 1 m in the upper tributaries. While the lagoon area and depth varied during the course of this study, measurements made in November 2003 at a typical size indicated an approximate surface area of 18,435 m^2, mean depth of 0.72 m, and a maximum depth of 2.1 m.

Methods

Environmental measurements.—Flows were measured on a cross section of the main stem downstream of major tributaries with a portable flowmeter (Marsh-McBirney, Inc., Frederick, Maryland; Model 2000 Flo-Mate). It was not possible to enter the stream at high-flow events ($>\sim 8$ m^3/s), and flows were estimated from cross-sectional area measurements of peak flow and approximated velocity measurements after flow subsided. Water temperatures were measured on an hourly basis upstream and at the estuary (Figure 1); we initially used IB-Cod temperature loggers (Alpha Mach, Mont St. Hilaire, Quebec; May 2002–June 2003) at both sites and then switched to Onset Tidbits (Onset Computer Corp., Pocasset, Massachusetts) in the upper watershed and YSI 600 XLM data loggers

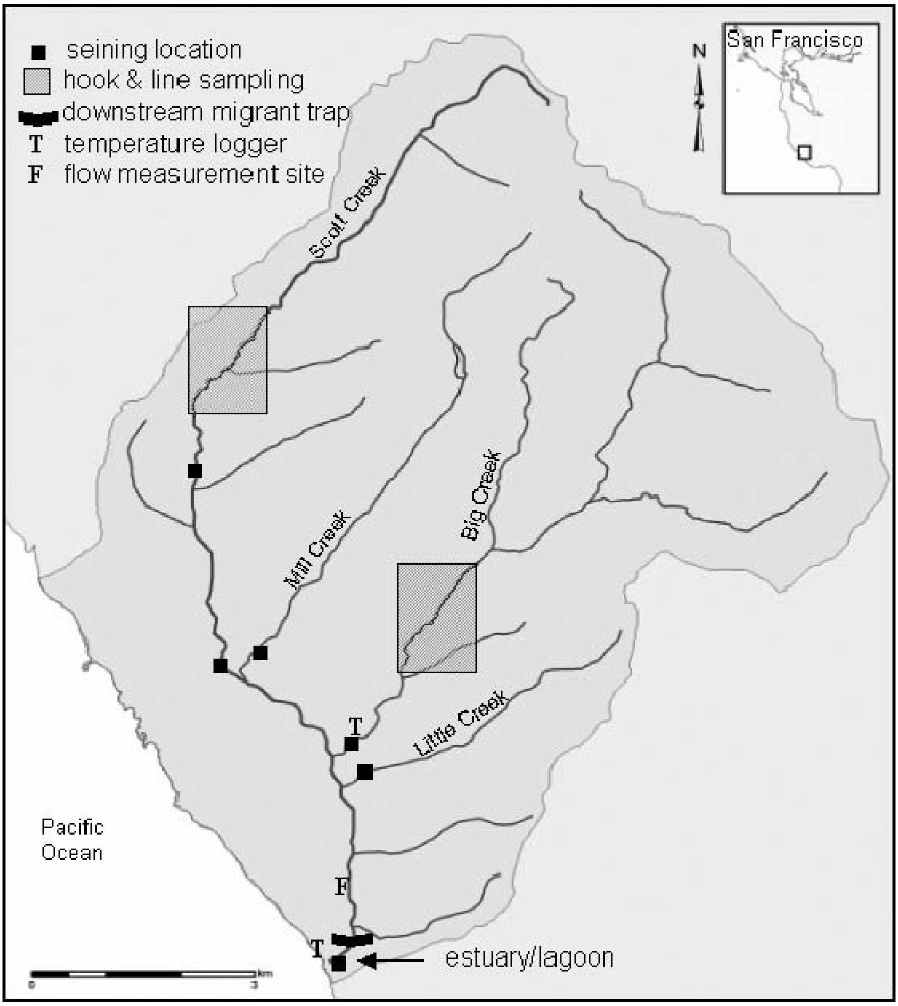

FIGURE 1.—Map of the Scott Creek watershed, California, showing locations where juvenile steelhead were sampled for a study of growth and rearing patterns.

(YSI, Inc., Yellow Springs, Ohio) in the estuary (July 2003–January 2005).

Fish sampling.—Sampling involved multiple methods and age-classes and was conducted in the upper watershed and estuary during May 2002 through November 2006. Specific time frames and methods are summarized in Table 1. Fish were sampled monthly at multiple locations throughout the upper watershed in pools with a 3.0 × 1.5-m beach seine (0.32-cm square mesh) and by hook and line (Figure 1). Downstream-

TABLE 1.—Summary of sampling effort used to determine growth and life history patterns in Scott Creek, California, juvenile steelhead, by age-class, location, tag type applied, collection method, and date range.

Age	Location	Tag type	Collection method	Date range
0	Upper watershed		Seine	May 2002–Dec 2004
0	Upper watershed	Elastomer	Seine	Jun 2003–Dec 2003
1+	Upper watershed	PIT	Seine, hook and line	May 2003–Oct 2004
All	Upper watershed		Electrofisher	Oct 2002–2004
All	Estuary	PIT	Seine	May 2003–Nov 2006
1+	Head of estuary	PIT	Hoop net (smolt trap)	Jan 2003–Nov 2005

migrating fish were trapped at the head of the estuary by means of a two-chambered hoop net (0.635-cm square mesh) with wings extending to each bank. The trap was operated 3 d/week throughout the year except during exceptionally high flows associated with winter storms. Fish in the estuary (downstream of the migrant trap) were captured with a 30 × 2-m beach seine (wings: 0.950-cm square mesh; bag: 0.635-cm square mesh).

Fish were handled according to the methods of Hayes et al. (2004). Specific details for this study are as follows. Up to 20 age-0 fish were randomly sampled for fork length (FL) and mass measurements at each seining site in the upper watershed. To determine whether (1) age-0 fish were remaining at the sample sites and (2) our assessments of age-0 growth by repeated sampling of untagged fish was accurate, we injected 200 age-0 steelhead (between 25 and 65 mm FL) with an elastomer dye (Northwest Marine Technology, Shaw Island, Washington) that was color coded to indicate 5-mm-FL bins. Elastomer injections took place during the second week of June 2003. All fish collected in the upper watershed that exceeded 65 mm FL received a PIT tag (Allflex, Boulder, Colorado; FDX-B Glass Transponder, 11.5 mm) injected intraperitoneally with a 12-gauge needle and were scanned for previously implanted PIT tags. Scale samples were taken from every PIT-tagged fish just posterior and ventral to the dorsal fin on the left side. The PIT tags were also implanted in fish caught at the downstream migrant trap and in the estuary. All collected fish were scanned for previously implanted PIT tags. A subset of untagged fish was sampled and tagged during each collection effort. All recaptured tagged fish were measured for FL and mass, and additional scale samples were taken from the right side of the fish.

In addition to our sampling efforts, relative abundance of juvenile fish was assessed each fall by one of us (J.J.S., unpublished data). Briefly, 12–14 reaches were blocked off and sampled with two passes of a backpack electrofisher (Smith-Root, Inc., Vancouver, Washington; Type 7, smooth pulse) to estimate the number of steelhead and coho salmon per unit length of stream.

Scale analysis.—Scales were flattened between two microscope slides and digitally photographed. Scale images were then analyzed using OPTIMAS software (Media Cybernetics, Silver Springs, Maryland) to measure scale radius, number and location of annuli, and number and distance between circuli. Where age information is reported in the text, a "+" sign is used to indicate all year-classes equal to or greater than the number given (e.g., age 1+).

Growth rate.—Fork lengths of age-0 fish (newly hatched fry to parr stage) were measured repeatedly at five upstream locations on a monthly basis. Growth rates were calculated by determining the temporal change in mean FL. Specific growth rate (SGR) could not be calculated for this size-class, since the calculation is most accurately done with repeated measures on known individuals and age-0 fish were too small to mark with unique identifiers such as PIT tags. During the late summer and fall months, fast-growing age-0 fish began to overlap in size with some age-1 fish. Scale analysis was used to distinguish between individuals in their first and second year. The general linear models (GLM) procedure in SYSTAT version 11 was used to test for significant differences in growth rate among different cohorts of age-0 steelhead and between elastomer-tagged and untagged age-0 steelhead. Hereafter, all means are reported with SEs.

For fish greater than 65 mm FL, SGR in mass and FL was calculated (Busacker et al. 1990) based upon the measured changes in mass and FL of recaptured – PIT-tagged individuals. Growth rate was then applied to the date intermediate between capture events. Only recaptures obtained 7–120 d after the previous capture were used in the analysis. Fish sampled in the upstream habitat were analyzed separately from those in the estuary. Growth rates between habitats and seasons were tested using analysis of variance (ANOVA) in SYSTAT 11. Only one recapture event per individual was used, and all recaptures between upstream and estuarine habitats were excluded.

Estuarine population size was estimated each year (2002–2005) with PIT tags and the Petersen mark–recapture method. After sandbar closure, we tagged a subset of the fish caught in the newly formed lagoon. Seining surveys were repeated each month until winter rains made seining of the estuary impossible. Population size and variance for each month after the initial survey was estimated using equations 3.5 and 3.6, respectively, from Ricker (1975).

It was not possible to quantify mortality due to handling and predation between seining efforts, and we assumed mortality of tagged and untagged fish was equal. In years when multiple samplings were done, estimates were pooled and mean values were used. Mark–recapture methods were not used to estimate population size before sandbar closure because of the possibility of individuals entering the ocean and leaving the population during that time. In addition, the rate of downstream migration drops rapidly after June and we assumed addition of new migrants to be negligible (Hayes et al. 2004). There may have been some movement from the estuary back upstream, which would result in an overestimation of the

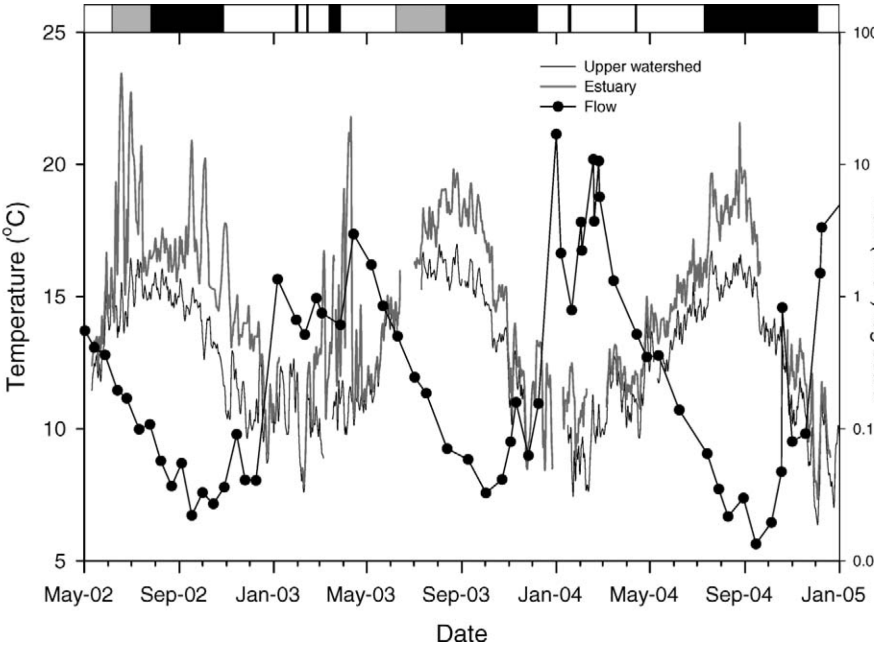

FIGURE 2.—Mean daily water temperature at upper and estuarine sites in the Scott Creek watershed, California (primary *y*-axis), and biweekly flow in the lower main stem (secondary *y*-axis) from May 2002 to January 2005. Shading in top bar represents estuarine status (white = open; gray = partially closed by sandbar; black = closed).

population, but this was assumed to be consistent across years.

Growth rate data were used to construct growth trajectories for various juvenile life history pathways. Initial age-0 growth rates were drawn from FL regressions developed from the results of upper-watershed growth. Confidence intervals (90% CIs) of the regressions were used to represent upper and lower growth curves. On this growth trajectory, age-0 fish were large enough to be PIT-tagged by the end of year 1. The SGR data from PIT tag recaptures were used to represent upstream growth (after December 31 of year 1) and estuarine growth. To obtain a daily estimate of growth, all intervals between successive recapture events greater than 7 d and less than 120 d from a given habitat were pooled, regardless of the number of recaptures per individual. Each interval spanning a particular day was interpreted as a growth rate observation on that day. Each day was spanned by a variable number of growth rate intervals (upstream mean = 15.7 d; estuarine mean = 34.1 d). We used a nonparametric smoother (Friedman 1984) to infer the central tendency of growth rate as a function of time. A 90% CI around this growth rate function was obtained by bootstrapping. Each bootstrap replicate was obtained by sampling with replacement from the pool of observed recapture intervals; the bootstrap intervals were converted as above to daily observations and a new growth-rate curve was estimated with the Friedman smoother for each bootstrap replicate. Two-hundred bootstrap replicates were made. For each day, the lower (upper) endpoint of the 90% CI for growth rate was the smoothed value for the 10th smallest (largest) of the 200 bootstrap-estimated growth rates. Bootstrapping and smoothing were done using the software package R (Ihaka and Gentleman 1996). Growth trajectories were completed by adding each day's growth to the sum of all previous days' growth. To portray these trajectories graphically, a base trajectory representing 4 years of growth in the upper watershed was plotted, and estuarine growth trajectories diverging from the upper-watershed line each summer were used to represent growth potentials of fish that migrated to the estuary.

Results

Environmental Data

Streamflow along the main stem varied by more than three orders of magnitude, from 0.013 m^3/s to over 17 m^3/s (Figure 2). Daily mean temperatures for the study period ranged from 5.6°C to 19°C in the upper watershed, and the overall mean was 10.3 ± 1.4°C. Daily mean temperatures in the estuary ranged from 7.4°C to 23.5°C and averaged 15.3 ± 3.1°C (Figure 2).

TABLE 2.—Growth rate estimates (±SE) for age-0 steelhead in Scott Creek, California, and multiple comparison test results for differences among years.

Year	Intercept Jan 1 (mm)	Growth rate (mm/d)[a]	R^2	*n*	Mean FL (mm)[b]	Date range
2002	20.73 ± 1.39	0.112 ± 0.006	0.203	1,370	46.12 ± 0.31	Jun–Nov 2002
2003	16.51 ± 1.63	0.139 ± 0.007	0.303	795	46.38 ± 0.45	Jun–Nov 2003
2004	22.32 ± 2.16	0.129 ± 0.010	0.280	471	50.72 ± 0.61	Jun–Nov 2004
Combined years	20.54 ± 0.72	0.119 ± 0.003	0.313	3,024	46.23 ± 0.23	Mar–Dec

[a] Multiple comparison tests: 2002 vs. 2003, $P = 0.004$; 2002 vs. 2004; $P = 0.101$; 2003 vs. 2004, $P = 0.417$.

[b] Multiple comparison tests: 2002 vs. 2003, $P = 0.878$; 2002 vs. 2004, $P = 0.001$; 2003 vs. 2004, $P = 0.001$.

During this study, a warm, relatively deep lagoon typically formed during summer (partially closed and closed; see Figure 2) when a sandbar formed at the mouth of the stream. However, the timing of formation varied from year to year. Except for occasional large wave events that pushed salt water over the sandbar and created haline stratification in deeper basins, the lagoon was primarily freshwater during summer and fall months.

Upstream Growth: Age-0 Fish

Newly emerged fry were observed between March and June of each year. We compared differences in growth rates for age-0 steelhead sampled at the upstream survey sites during June through November 2002–2004 (data were not consistently collected for all 3 years before June or after November; Table 2; Figure 3). Growth rates were approximately linear during the first 10 months of growth. Growth rates differed among the 3 years (heterogeneity of slopes test: $F = 4.288$, $P = 0.014$). A comparison of mean FLs revealed significant differences among years ($F = 26.309$, $P < 0.001$) as did comparisons using the Tukey post hoc analysis (Table 2). Mean growth rate per year was potentially influenced by several variables, including flow, temperature, age-0 coho salmon density, and age-0 steelhead density for each year (Table 3). Because only 3 years of data were available, no correlation analyses were performed and only raw data are presented.

We compared growth rates between untagged and elastomer-tagged individuals present at the same sites during June through November 2003. No significant

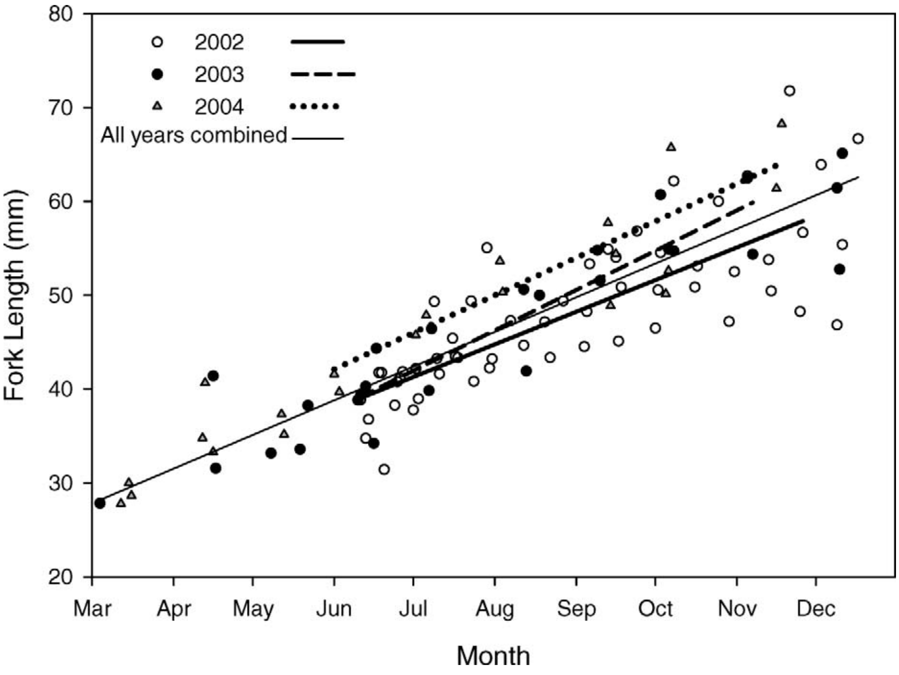

FIGURE 3.—Age-0 steelhead fork length (FL) over time in the upper Scott Creek watershed, California, 2002–2004. Symbols represent mean FL ($n \approx 20$ fish) at each of five age-0 sample sites. Linear regressions were calculated from raw data (not means) and are described in Table 2.

TABLE 3.—Age-0 steelhead growth rates relative to means of several biotic and abiotic variables measured in Scott Creek, California. Fish density is given as number of age-0 fish per 30.5 m.

Year	Growth rate (mm/d)	FL (mm)	Mass (g)	Water temperature (°C) (Jun–Nov)	Flow (m^3/s)	Coho salmon density	Steelhead density
2002	0.112	46.2	1.34	13.80	0.074	79.2	35
2003	0.139	46.4	1.63	14.44	0.132	1.5	55
2004	0.129	50.8	1.79	13.70	0.089	8.6	37

differences in growth rate between tagged and untagged fish were detected (heterogeneity of slopes test: $F = 0.953$, $P = 0.329$). The elastomer tagging of fish in June 2003 confirmed that many individuals remained at their original tagging sites and that growth measurements were at least partially based upon repeated captures of the same individuals.

Upstream Growth: Age-1 and Older Fish

We deployed 611 PIT tags in the upper watershed. We recaptured 114 fish at least once and several individuals were recaptured multiple times, yielding a total of 196 recaptures in the upper watershed between May 2003 and November 2004. The mean time interval between recapture events used in seasonal analysis was 55.3 ± 2.7 d ($n = 106$). At initial capture, mean FL was 104.3 ± 2.8 mm ($n = 106$) and mean mass was 15.6 ± 1.2 g ($n = 103$). With the onset of winter rains, mean individual growth rates increased, peaking at around 0.160% per day in April and then declining to less than 0.014% per day by August. Growth remained slow in the upper watershed until November. To compare growth rates for different times of year, data were binned into seasonal categories (fall = August–October; winter = November–January; spring = February–April; summer = May–July). Growth rates differed significantly among seasons for FL ($F = 12.5$, df = 4, $n = 106$, $P < 0.001$) and mass ($F = 8.4$, df = 4, $n = 99$, $P < 0.001$; Figure 4). Significance values for Tukey post hoc analysis of seasonal SGR differences in FL and mass are presented in Table 4.

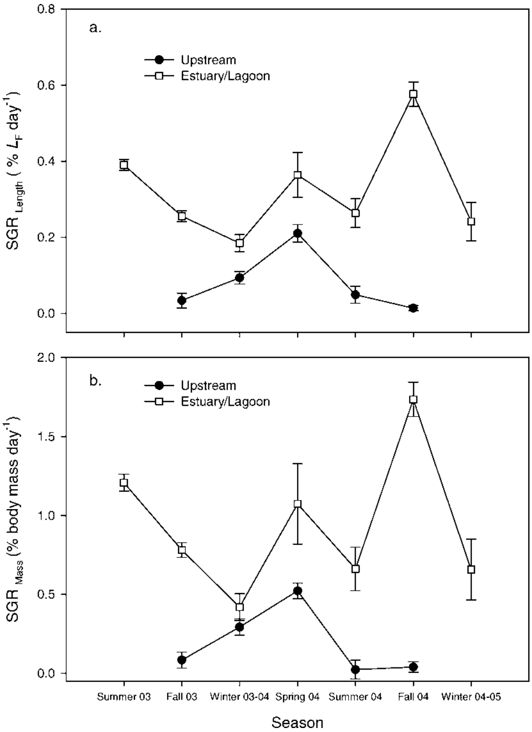

FIGURE 4.—Mean (±SE) specific growth rates (SGRs) of PIT-tagged steelhead recaptured in upper and estuary–lagoon habitats of the Scott Creek watershed, California, 2003–2005: (**a**) SGR_{FL} and (**b**) SGR_{mass}.

Estuarine Growth

We deployed 1,498 PIT tags in fish caught while seining the estuary or in the smolt trap at the head of the estuary between February 2003 and December 2004. Of these, 378 fish were recaptured at least once and some individuals were recaptured up to five times over the course of a year, resulting in a total of 994 recaptures in the estuary between May 2003 and December 2004 (mean recapture interval = 41.7 ± 1.6 d, $n = 311$). Mean FL at initial capture was 126.23 ± 2.0 mm ($n = 311$). Mean mass at initial capture was 28.4 ± 1.6 g ($n = 306$). To compare growth rates for different times of year, data were binned into the same seasonal categories defined above. Specific growth rates differed significantly among seasons for both FL ($F = 27.1$, df = 6, $n = 311$, $P < 0.001$: Figure 4) and mass ($F = 23.2$, df = 6, $n = 311$, $P < 0.001$). Results of Tukey post hoc analysis of seasonal SGR differences in FL and mass are presented in Table 5.

Mean SGRs (FL) in the estuary for summer and fall 2003 ($n = 147$), 2004 ($n = 104$), 2005 ($n = 87$), and 2006 ($n = 47$) were calculated and plotted against the number of fish in the estuary after the time of closure (Figure 5). This was accomplished by the PIT tagging of additional fish ($n = 1,205$) between January and November of 2005 and 2006. The difference in

TABLE 4.—Results of Tukey post hoc analysis testing for significant differences in juvenile steelhead growth between seasons in upstream habitat within Scott Creek, California. Bold type indicates P-values less than 0.05.

Season and year	Winter 2003–2004	Spring 2004	Summer 2004	Fall 2004
FL (mm)				
Fall 2003	0.178	**<0.001**	0.955	0.823
Winter 2003–2004		**0.012**	0.502	**0.018**
Spring 2004			**<0.001**	**<0.001**
Summer 2004				0.399
Mass (g)				
Fall 2003	0.115	**0.001**	0.905	0.944
Winter 2003–2004		0.295	**0.022**	**0.017**
Spring 2004			**<0.001**	**<0.001**
Summer 2004				0.999

estuarine growth rate among years is at least partially explained by differences in steelhead population size among years; there was a negative relationship between estuarine population size and growth ($R^2 = 0.9895$, $P = 0.005$), as described by the equation:

$$\mathrm{SGR_{FL}} = -0.0002(\text{population size}) + 0.8389. \quad (1)$$

Mean FL of smolts in the lagoon during the last fall sampling event was compared for 2003–2006 to determine whether length at the end of the summer–fall growing season varied between years. A significant difference was observed ($F = 29.3$, df = 3, $n = 526$, $P < 0.001$). However, Tukey post hoc analysis revealed that this effect was driven by 2003, which was the only year that differed; fish were significantly longer during that year than in the other 3 years ($P < 0.001$ for each comparison with 2003; Figure 5).

Comparisons of Estuarine versus Upstream Growth

Fish grew much faster in the estuary than upstream (Table 6; Figure 4). Coho salmon were typically absent from the estuary and were present in very low densities during the time upstream steelhead growth measurements were made with PIT tag recaptures. Summer temperatures in the upstream habitat were 14–18°C, while estuary–lagoon temperatures were warmer (from 15°C to ≥24°C).

Condition factor (mass/[length^3]) varied primarily as a function of season ($F = 14.26$, df = 6, $n = 1{,}204$, $P < 0.001$) and did not vary significantly between the two habitats ($F = 0.001$, df = 1, $n = 1{,}204$, $P = 0.971$). In general, the lowest condition factors in both habitats were observed in the spring and were presumably associated with smoltification (Hoar 1976).

Timing of Life History Decisions and Growth Trajectories

Most of the fish in this watershed migrate during the spring after their first or second winter, as shown in Figure 6, which provides the size frequency distribution of downstream migrants during spring 2004. Based on scale analysis ($n = 185$), fish under 120 mm FL were less than 2 years old. Once fish have begun the downstream migration, the tendency to

TABLE 5.—Results of Tukey post hoc analysis testing for significant differences in juvenile steelhead growth between seasons in the Scott Creek estuary, California. Bold type indicates P-values less than 0.05.

	Fall 2003	Winter 2003–2004	Spring 2004	Summer 2004	Fall 2004	Winter 2004–2005
FL (mm)						
Summer 2003	**<0.001**	**<0.001**	0.999	**0.012**	**<0.001**	**0.039**
Fall 2003		0.583	0.557	1.000	**<0.001**	1.000
Winter 2003–2004			0.081	0.598	**<0.001**	0.949
Spring 2004				0.703	**0.007**	0.609
Summer 2004					**<0.001**	1.000
Fall 2004						**<0.001**
Mass (g)						
Summer 2003	**0.002**	**<0.001**	0.995	**0.001**	**<0.001**	**0.024**
Fall 2003		0.137	0.818	0.981	**<0.001**	0.993
Winter 2003–2004			0.059	0.743	**<0.001**	0.885
Spring 2004				0.538	**0.028**	0.645
Summer 2004					**<0.001**	1.000
Fall 2004						**<0.001**

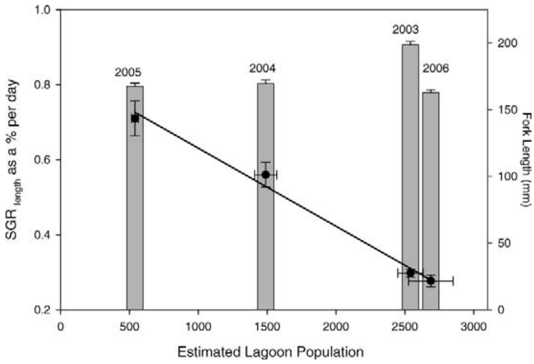

FIGURE 5.—Estimated annual lagoon population sizes and mean growth rates from 2003 to 2006 (left *y*-axis) The bar graph (right *y*-axis) represents mean fork length of fish sampled in the estuary in late fall of each year just before winter storm season and lagoon opening. Years match points within labeled columns. All data are means ± SE, $R^2 = 0.99$; regression $P = 0.005$.

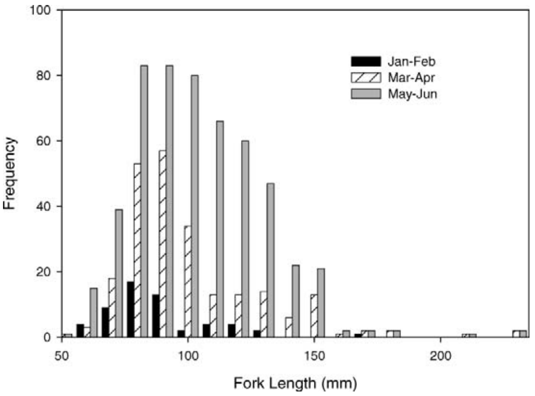

FIGURE 6.—Fork length frequency distribution (10-mm bins) for downstream-migrating steelhead in Scott Creek, California, during spring 2004. Data are grouped by 2-month intervals.

remain in the estuary or go to sea appears to be influenced by the timing of lagoon formation, which typically occurs sometime between May and August (Figure 2). In years when the lagoon forms later, juvenile steelhead densities are much lower, as many of the age-1+ downstream migrants appear to have left the watershed. Recruitment of age-0 steelhead to the estuary after the smolt run ends presumably occurs in response to reduced competition and predation from older fish in the lagoon or may simply be due to higher flows in wetter years, which contribute to delayed lagoon formation. These differences in density and age of recruitment to the estuary were observed during this study. The lagoon formed early (June) and recruitment was high (~2,540 fish) in 2003, whereas the lagoon formed later (July) and recruitment was much lower (~1,489 fish) in 2004. In addition, estuarine fish were significantly older ($t = 2.23$, $P < 0.002$, $n = 28$) and larger ($t = 2.04$, $P < 0.001$, $n = 124$) at the time of recruitment in 2003 (mean age = 1.52 years; mean FL = 152 mm) than in 2004 (mean age = 0.57 years; mean FL = 93 mm), confirming the large proportion of age-0 fish in 2004. This trend continued into 2005 (Figure 5), when the lagoon formed even later (August 26) and recruitment was limited to about 540 fish. In 2006, lagoon formation began in early June and followed a pattern similar to that in 2003. It is unlikely that recruitment to the lagoon was strongly influenced by total number of smolts. Although good estimates of smolt abundance among years were not available due to varying trap efficiency, the age-0 steelhead densities from the electrofishing surveys in the previous fall (Table 3) showed no relationship with lagoon population size observed during the subsequent summer.

TABLE 6.—Results of two-way ANOVA of the effect of habitat type (estuary and upstream) and season (fall 2003, winter 2003–2004, and spring–fall 2004) on juvenile steelhead specific growth rates (SGR) in Scott Creek, California (SS = sum of squares; MS = mean squares).

Factor	df	SS	MS	*F*	*P*
		SGRFL			
Habitat	1	3.031	3.031	106.336	<0.001
Season	4	1.465	0.366	12.848	<0.001
Habitat × season	4	2.382	0.595	20.892	<0.001
Error	303	8.637	0.029		
		SGRmass			
Habitat	1	24.392	24.392	72.095	<0.001
Season	4	16.368	4.092	12.095	<0.001
Habitat × season	4	22.587	5.647	16.691	<0.001
Error	296	100.144	0.338		

In this watershed, juvenile steelhead exhibit three life history pathways before ocean entry. The first pathway is direct recruitment to the estuary after spending only a few months in the upper watershed (Figure 7, pathway A). The second pathway is to spend 1–2 years rearing in the upper watershed, migrate downstream to the estuary, and remain there for an additional 1–10 months before ocean entry (Figure 7, pathway B). The third is to spend one or more years rearing in the upper watershed, migrate downstream, and enter the ocean (Figure 7, pathway C). Alternatively, fish exhibiting pathway C might never migrate and instead will carry out their life cycle in freshwater as residents. Based upon the growth rate data from this study, it is possible to model fish demonstrating different life history pathways and compare those with observations of the population at a given time. After

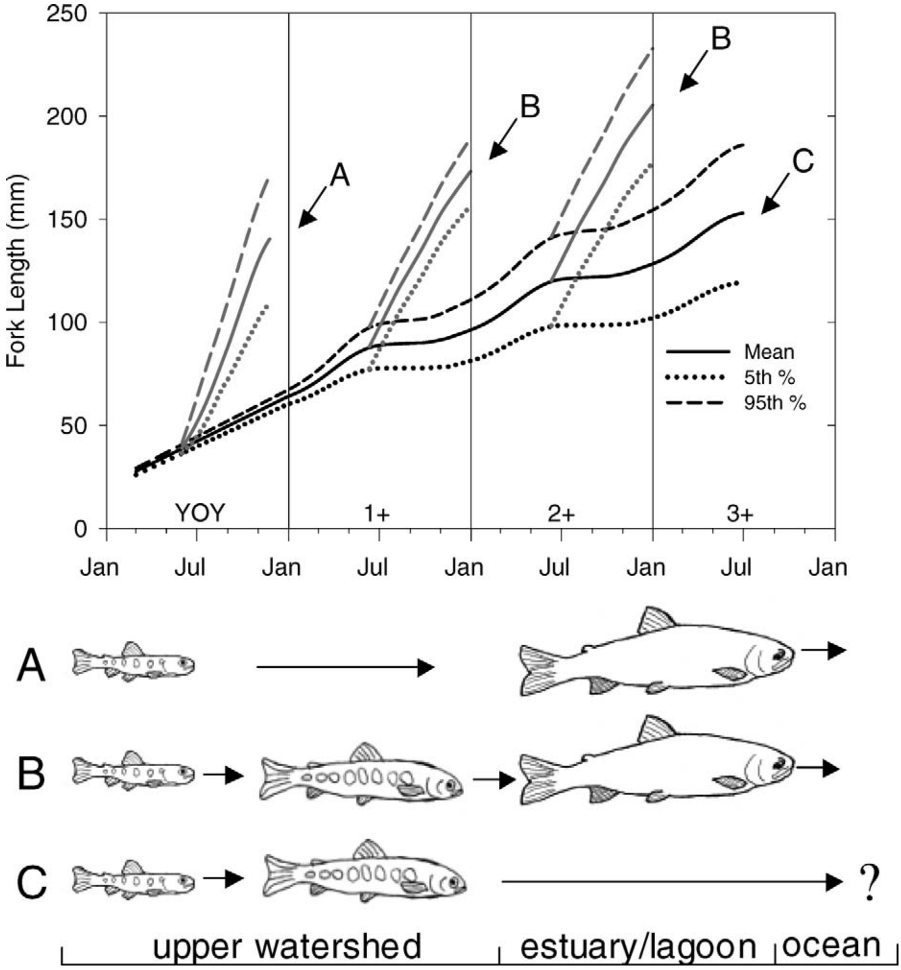

FIGURE 7.—Upper panel: growth trajectories of juvenile steelhead in the Scott Creek watershed, California, showing observed changes in FL determined from resampling of age-0 fish during the first 8–10 months and larger PIT-tagged individuals (ages 1–3 and older) that were recaptured in the upper watershed (black lines) or estuary (gray lines). All PIT tag recaptures were pooled within each habitat and were bootstrap sampled to determine central tendencies. Lower panel: the three freshwater life history pathways corresponding to A–C in the upper panel are illustrated (from left to right, size-classes are fry–age-0, parr, and estuary–lagoon residents). The question mark at the end of pathway C indicates the possibility that fish remain as residents in the creek.

hatching in the spring (Table 2), steelhead fry could migrate to the estuary during the summer (pathway A) and switch to an estuarine growth trajectory based on low densities (using data from summer 2004) or they could remain in the upper watershed, where growth is slower (see Table 2), and would reach 65 mm by the end of their first year. As fish entered their first winter, our measurements of growth transitioned from population means to measurements of known individuals (identified by PIT tags). Data collected from fish that were PIT-tagged in the upper watershed can approximate the size of fish during the subsequent May (the peak of the spring downstream migration). At this point, fish either spend another year in the upper watershed or begin their spring downstream migration. The predicted size range after 1–2 years of upstream growth (Figure 7) corresponds well with the observed downstream migrant sizes at ages 1 and 2 in this population (mean FL = 96.8 ± 1.1 mm, n = 641; Figure 6). After downstream migration, fish remaining in the estuary would probably follow a growth trajectory similar to that observed in the summer of 2003, when the lagoon began forming in June. While timing of lagoon formation tends to influence recruitment and growth rate, as the two are inversely related, the end result is that fish are of similar size by late fall

(Figure 5). Some larger downstream migrants may also depart the estuary before lagoon formation with only 1–2 months of additional growth.

Discussion

In this study, we reported growth rates of wild, free-ranging juvenile steelhead from the time of emergence to ocean entry in both upstream and estuarine habitats in a small stream along the central California coast. Growth rates were heavily influenced by local habitat and seasonal climate patterns. Specifically, growth in the upper watershed was limited and somewhat out of seasonal phase (mild winter, dry summer) with what would be expected from populations at higher latitudes or elevations, where fish exhibit slow growth during harsh winter periods (Chapman and Bjornn 1969; Wurtsbaugh and Davis 1977b). Estuarine growth, which has not been reported for steelhead previously, was much higher overall than growth in the upper watershed. Finally, growth patterns and movement suggest that steelhead pursue one of three life history pathways while rearing in various combinations of upper watershed and estuarine habitats. From the data collected, we were able to construct a growth model showing size at age for each freshwater life history pathway observed.

Growth of age-0 fish was measured over 3 years and varied significantly. While 3 years was insufficient to compare mean annual trends, several potential influences were apparent. For instance, age-0 steelhead growth was negatively associated with juvenile coho salmon density, which varied dramatically among years in this watershed due to the near extirpation of two year-classes (Hayes et al. 2004). This result was not surprising (Fraser 1969; Hearn 1987), and the reverse effect (i.e., steelhead density affecting coho salmon growth) has also been observed in other populations (Harvey and Nakamoto 1996). In addition, age-0 growth was positively associated with mean annual flow and mean summer–fall temperature in the upper watershed.

Growth of age-1+ fish in the upper watershed was slowest during the summer and fall, and in some cases individual fish actually decreased in FL. Age-0 steelhead densities were typically an order of magnitude higher than those of all older age-classes combined (J.J.S., unpublished data). Also, the majority of surviving fish migrated downstream after their first winter (Figure 6). In combination, these results indicate that the upstream watersheds are not very productive, presumably because of the low-flow environment and a low nutrient input under redwood canopies (Romero et al. 2005). This pattern of accelerated growth in the winter and spring (0.3–0.6% per day) and limited growth in the summer (0–0.2% per day) has been reported for foothill streams of the Sierra Nevada Mountains (Railsback and Rose 1999; Merz 2002) and other coastal California streams (Harvey et al. 2005), where growth rates were only 10–20% of potential maxima of 2.5–3.0% per day (Wurtsbaugh and Davis 1977b; Myrick and Cech 2005). These patterns are confounded by the fact that growth was slowest when temperatures were near the thermal optimum. While not quantified in this study, low summer flows in the upper tributaries may contribute to reduced wetted surface area for aquatic invertebrate production and terrestrial invertebrate drift, resulting in less food during a time when warmer temperatures are increasing metabolic rates of fish. Limited growth data exist across the latitudinal range of *Oncorhynchus* spp.; however, similar growth patterns were observed for coho salmon in coastal streams in Oregon and Washington (Breuser 1961; Bilby et al. 1996).

In comparison with upstream growth, growth rates in the estuary were much higher, which is probably due in part to the warmer summer and fall temperatures and differences in food availability as was reported for Atlantic salmon (Cunjak 1992). In Scott Creek, coho salmon did not use the estuary, presumably due to thermal preferences or tolerances (Stein et al. 1972); however, temperatures were at the thermal optimum for steelhead (17–19°C; Wurtsbaugh and Davis 1977b; Myrick and Cech 2005). Competition with coho salmon was probably not a major influence on differences in age-1+ steelhead growth between upstream and estuarine habitats, since the steelhead were larger than coho salmon fry and growth upstream was measured during a period of low coho salmon density. The estuary seemed to be a very productive habitat, particularly when in a lagoon state. Seining efforts were often difficult due to the large volumes of freshwater algae growing there and marine algae that were deposited by waves. Large numbers of invertebrates (amphipods *Eogammarus* spp. and *Corophium* spp.; shrimp *Neomysis* spp.; and isopods *Gnorimosphaeroma* spp.) were regularly observed in association with the algae. While comprising less than 5% of the total stream area, the estuary may be the most important habitat for steelhead growth in this watershed.

Estuarine growth rates were among the fastest reported for wild steelhead in the literature (1–2% per day), but did not reach the maximum (2.5–3.0% per day) observed in captivity for this species (Wurtsbaugh and Davis 1977b; Myrick and Cech 2005). Growth rates in the estuary varied among years and appeared to be density dependent: fish grew much faster in the estuary during years when recruitment was lower.

Recruitment was related to the timing of lagoon formation, when water began backing up behind a sandbar on the beach, forming a warm deep environment. Among years, the timing of sandbar formation varied by several months. The earlier the lagoon formed, the greater the population size. Although the growth rate was lower in these years, the longer growing season appeared to compensate for this, and fish were the same size or larger by the end of the season (Figure 5). In addition, short-term recruitment periods on the order of weeks to a couple of months have been observed in Scott Creek and other coastal California watersheds, wherein steelhead take advantage of a brief growth period and enter the ocean before sandbar formation (Smith 1990; Bond 2006).

A secondary issue explaining differences in estuarine growth rates among years relates to the age of fish recruiting to the estuary. In years when the lagoon formed late, age-0 fish recruited to the lagoon in higher proportions than in years when it formed early. In the laboratory, small fish grow faster than large fish under similar ration levels (Wurtsbaugh and Davis 1977a; Connolly and Peterson 2003). The age-0 steelhead that reared in the estuary entered the ocean 6–10 months after recruitment at a greater size with potentially greater chances of marine survival than the age-1+ fish that left before lagoon formation.

The high-resolution growth data collected over the entire juvenile life history cycle in this study enabled the construction of growth trajectories for this population. While not discussed here, it should be acknowledged that the decision to follow a particular pathway is probably due in large part to individual fish behavior and this system is more complex that fish simply growing in response to basic habitat conditions. The scope of this paper was to describe the common trajectories observed in this system. Independent confirmation of these trajectories was provided by data collected on the size and age of downstream migrants in the population (Figure 6), which were not used in creating the trajectories but match the predictions in Figure 7. These trajectories led to several different life history pathways. While such data have been collected for Atlantic salmon (Arnekleiv et al. 2006) and brown trout (Ombredane et al. 1998), comparable data sets are not common for Pacific salmon, presumably due to harsh winters that make the logistics of monitoring growth on a year-round basis more challenging.

In general, it appears that juvenile steelhead from this population migrate downstream before age 2,as very few fish greater than 150 mm or older than age 2 are observed among smolts. While the fish are still relatively small in size, their strategy is to take advantage of lagoon growth opportunities; overall, these fish probably enter the ocean within 6–10 months, and a majority enter the ocean before age 3. Detailed estimates of the relative proportion of fish following each strategy were beyond the scope of this study. In general, the distribution of size and age for downstream migrants was consistent between years (Bond 2006) and the age of fish recruiting to the estuary–lagoon was probably influenced by the timing of lagoon formation and varied between years. Withler (1966) and Busby et al. (1996) reviewed steelhead smolt age along the West Coast of North America and indicated that there is a general cline in freshwater residence time; steelhead from Alaska and British Columbia stay in freshwater for 3 years, whereas fish from Washington, Oregon, and California typically remain for 2 years and the frequency of 1-year-old smolts increases in southern parts of the range. It is unknown whether fish in southern populations are truly younger at ocean entry than those from northern populations. Fish in Scott Creek migrate downstream or undergo parr–smolt transformation at a younger age but then often spend additional time rearing in the estuary before ocean entry, an observation possibly missed by previous studies due to location of smolt traps upstream of the estuary (Shapovalov and Taft 1954), a lack of additional annulus formation, or both, as emigrating smolts transition from peak upper-watershed growth rates to even faster estuarine growth rates.

Marine survival measured in the Scott Creek watershed and across the steelhead range appears to be influenced by size at ocean entry, and generally fish smaller than 150 mm are unlikely to survive (Ward et al. 1989; Bond 2006). The southern coastal estuaries that form lagoons provide the opportunity for fish to achieve the necessary size for marine survival, which heavily influences adult escapement and possibly defines adult production from the watershed. However, it is not known how coastal California steelhead achieve sufficient size for marine survival in watersheds where upstream growth is limited and where estuaries dos not form summer lagoons, either due to natural geological and hydrological processes or anthropogenic processes (e.g., water consumption, stream mouth modifications, artificial breaching of sandbars). Even if very few adults are produced from systems without lagoons, there may still be sufficient numbers available in most years to replenish the stream with juveniles. At Scott Creek, lagoons suitable for rearing have been absent in many years over the last two decades due to artificial sandbar breaching, water diversion, and drought. However, juvenile abundance upstream was fairly consistent from 1988 to 2007 (J.J.S., unpublished data), possibly buffered by the iteroparous nature of steelhead. Alternatively, it may be that without a reliable presence of lagoons from year to year, populations may not be able to maintain anadromy. We could expect to see a higher proportion of fish pursuing resident life history paths in southern populations from systems where estuaries are lacking or have been compromised by development. Finally, estuaries in many systems also provide important growth opportunities for out-migrating smolts and brackish areas for the fish to adjust to salt water (Healey 1982); this would improve the ocean survival of the relatively small smolts reared in some watersheds like Scott Creek.

The steelhead population in this study and most California coastal stocks are federally listed as threatened under the Endangered Species Act, and stocks situated farther south are listed as endangered. As flows in these watersheds are at constant risk of being reduced even more by human consumption demands, this has become a critical management issue that will probably only increase in importance over time. In addition to the challenges of low flows in the upper watershed, there is a need to maintain connectivity with the estuary. Fish may need to take refuge from the estuary by moving upstream during periods of extreme temperature or low oxygen levels. In addition, summer flows must be low enough for sandbars to build up (thus forming the lagoon) but high enough that the lagoon does not leach through the sand bar (thus leaving only a shallow or dry creek bed).

Presumably, with increasing flows and nutrient contributions from marine (salmon carcasses) and terrestrial sources, upper-watershed habitats will become more productive as one moves north, trading off the loss of coastal summer lagoons as flows become too high for sandbars to close off streams. In addition, winter temperatures become limiting in the north, while summer temperatures are near the growth optimum (Hartman 1965). Therefore, fish in high-altitude or high-latitude river systems will probably grow better in summer than in winter and will follow different growth trajectories from those reported here.

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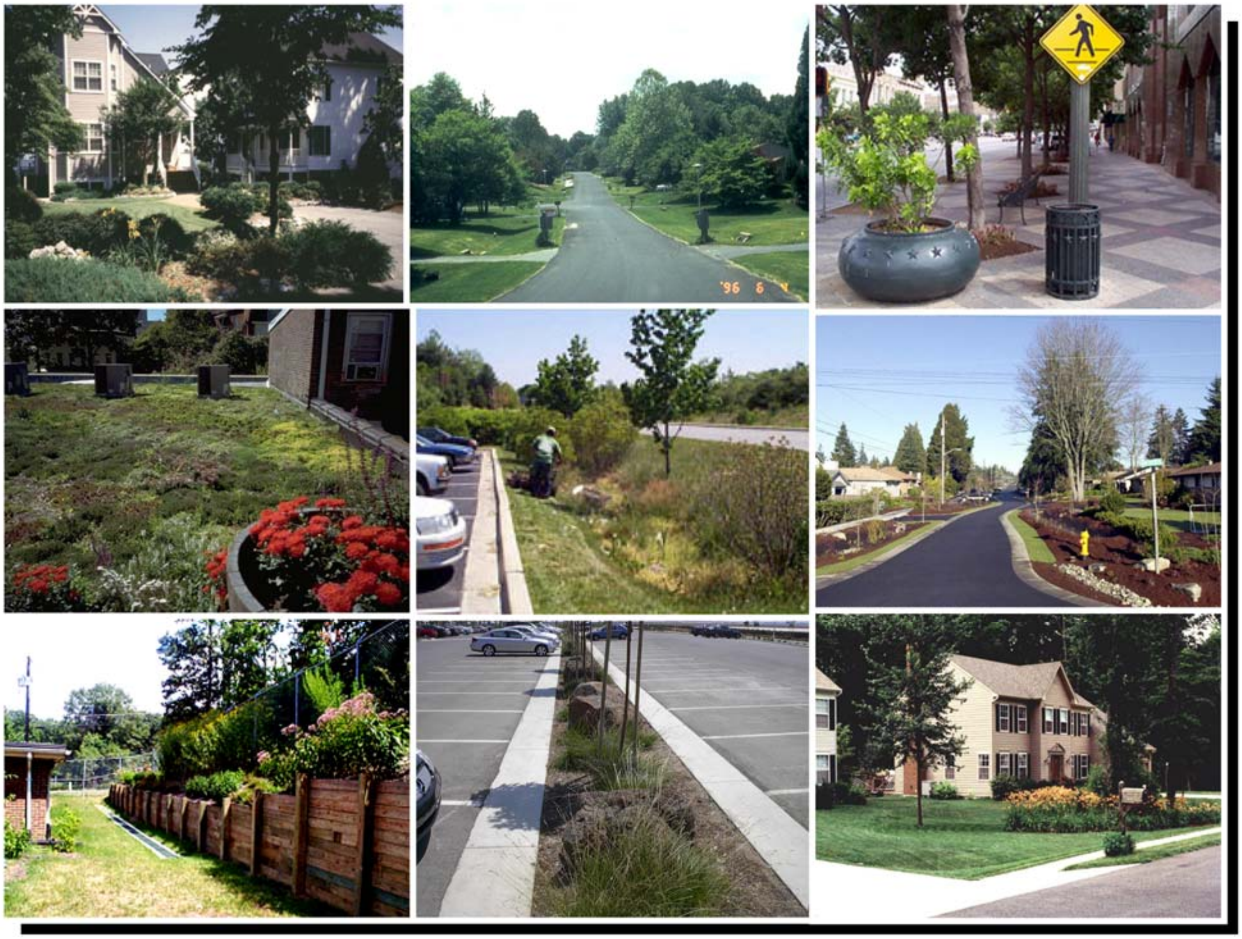
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices



Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices

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United States Environmental Protection Agency

Nonpoint Source Control Branch (4503T)

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CONTENTS

TABLES

FOREWORD

One of the most exciting new trends in water quality management today is the movement by many cities, counties, states, and private-sector developers toward the increased use of Low Impact Development (LID) to help protect and restore water quality. LID comprises a set of approaches and practices that are designed to reduce runoff of water and pollutants from the site at which they are generated. By means of infiltration, evapotranspiration, and reuse of rainwater, LID techniques manage water and water pollutants at the source and thereby prevent or reduce the impact of development on rivers, streams, lakes, coastal waters, and ground water.

Although the increase in application of these practices is growing rapidly, data regarding both the effectiveness of these practices and their costs remain limited. This document is focused on the latter issue, and the news is good. In the vast majority of cases, the U.S. Environmental Protection Agency (EPA) has found that implementing well-chosen LID practices saves money for developers, property owners, and communities while protecting and restoring water quality.

While this study focuses on the cost reductions and cost savings that are achievable through the use of LID practices, it is also the case that communities can experience many amenities and associated economic benefits that go beyond cost savings. These include enhanced property values, improved habitat, aesthetic amenities, and improved quality of life. This study does not monetize and consider these values in performing the cost calculations, but these economic benefits are real and significant. For that reason, EPA has included a discussion of these economic benefits in this document and provided references for interested readers to learn more about them.

Readers interested in increasing their knowledge about LID and Green Infrastructure, which encompasses LID along with other aspects of green development, should see www.epa.gov/npdes/greeninfrastructure and www.epa.gov/nps/lid. It is EPA's hope that as professionals and citizens continue to become more knowledgeable about the effectiveness and costs of LID, the use of LID practices will continue to increase at a rapid pace.

EXECUTIVE SUMMARY

This report summarizes 17 case studies of developments that include Low Impact Development (LID) practices and concludes that applying LID techniques can reduce project costs and improve environmental performance. In most cases, LID practices were shown to be both fiscally and environmentally beneficial to communities. In a few cases, LID project costs were higher than those for conventional stormwater management practices. However, in the vast majority of cases, significant savings were realized due to reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping. Total capital cost savings ranged from 15 to 80 percent when LID methods were used, with a few exceptions in which LID project costs were higher than conventional stormwater management costs.

EPA has identified several additional areas that will require further study. First, in all cases, there were benefits that this study did not monetize and did not factor into the project's bottom line. These benefits include improved aesthetics, expanded recreational opportunities, increased property values due to the desirability of the lots and their proximity to open space, increased total number of units developed, increased marketing potential, and faster sales. Second, more research is also needed to quantify the environmental benefits that can be achieved through the use of LID techniques and the costs that can be avoided. Examples of environmental benefits include reduced runoff volumes and pollutant loadings to downstream waters, and reduced incidences of combined sewer overflows. Finally, more research is needed to monetize the cost reductions that can be achieved through improved environmental performance, reductions in long-term operation and maintenance costs, and/or reductions in the life cycle costs of replacing or rehabilitating infrastructure.

INTRODUCTION

BACKGROUND

Most stormwater runoff is the result of the man-made hydrologic modifications that normally accompany development. The addition of impervious surfaces, soil compaction, and tree and vegetation removal result in alterations to the movement of water through the environment. As interception, evapotranspiration, and infiltration are reduced and precipitation is converted to overland flow, these modifications affect not only the characteristics of the developed site but also the watershed in which the development is located. Stormwater has been identified as one of the leading sources of pollution for all waterbody types in the United States. Furthermore, the impacts of stormwater pollution are not static; they usually increase with more development and urbanization.

Extensive development in the United States is a relatively recent phenomenon. For the past two decades, the rate of land development across the country has been twice the rate of population growth. Approximately 25 million acres were developed between 1982 and 1997, resulting in a 34 percent increase in the amount of developed land with only a 15 percent increase in population.[1,2] The 25 million acres developed during this 15-year period represent nearly 25 percent of the total amount of developed land in the contiguous states. The U.S. population is expected to increase by 22 percent from 2000 to 2025. If recent development trends continue, an additional 68 million acres of land will be developed during this 25-year period.[3]

Water quality protection strategies are often implemented at three scales: the region or large watershed area, the community or neighborhood, and the site or block. Different stormwater approaches are used at different scales to afford the greatest degree of protection to waterbodies because the influences of pollution are often found at all three scales. For example, decisions about where and how to grow are the first and perhaps most important decisions related to water quality. Growth and development can give a community the resources needed to revitalize a downtown, refurbish a main street, build new schools, and develop vibrant places to live, work, shop, and play. The environmental impacts of development, however, can pose challenges for communities striving to protect their natural resources. Development that uses land efficiently and protects undisturbed natural lands allows a community to grow and still protect its water resources.

Strategies related to these broad growth and development issues are often implemented at the regional or watershed scale. Once municipalities have determined where to grow and where to preserve, various stormwater management techniques are applied at the neighborhood or community level. These measures, such as road width requirements, often transcend specific development sites and can be applied throughout a neighborhood. Finally, site-specific stormwater strategies, such as rain gardens and infiltration areas, are incorporated within a particular development. Of course, some stormwater management strategies can be applied at several scales. For example, opportunities to maximize infiltration can occur at the neighborhood and site levels.

Many smart growth approaches can decrease the overall amount of impervious cover associated with a development's footprint. These approaches include directing development to already degraded land; using narrower roads; designing smaller parking lots; integrating retail, commercial, and residential uses; and designing more compact residential lots. These development approaches, combined with other techniques aimed at reducing the impact of development, can offer communities superior stormwater management.

Stormwater management programs have struggled to provide adequate abatement and treatment of stormwater at the current levels of development. Future development will create even greater challenges for maintaining and improving water quality in the nation's waterbodies. The past few decades of stormwater management have resulted in the current convention of control-and-treatment strategies. They are largely engineered, end-of-pipe practices that have been focused on controlling peak flow rate and suspended solids concentrations. Conventional practices, however, fail to address the widespread and cumulative hydrologic modifications within the watershed that increase stormwater volumes and runoff rates and cause excessive erosion and stream channel degradation. Existing practices also fail to adequately treat for other pollutants of concern, such as nutrients, pathogens, and metals.

LOW IMPACT DEVELOPMENT

Low Impact Development (LID)[4] is a stormwater management strategy that has been adopted in many localities across the country in the past several years. It is a stormwater management approach and set of practices that can be used to reduce runoff and pollutant loadings by managing the runoff as close to its source(s) as possible. A set or system of small-scale practices, linked together on the site, is often used. LID approaches can be used to reduce the impacts of development and redevelopment activities on water resources. In the case of new development, LID is typically used to achieve or pursue the goal of maintaining or closely replicating the predevelopment hydrology of the site. In areas where development has already occurred, LID can be used as a retrofit practice to reduce runoff volumes, pollutant loadings, and the overall impacts of existing development on the affected receiving waters.

In general, implementing integrated LID practices can result in enhanced environmental performance while at the same time reducing development costs when compared to traditional stormwater management approaches. LID techniques promote the use of natural systems, which can effectively remove nutrients, pathogens, and metals from stormwater. Cost savings are typically seen in reduced infrastructure because the total volume of runoff to be managed is minimized through infiltration and evapotranspiration. By working to mimic the natural water cycle, LID practices protect downstream resources from adverse pollutant and hydrologic impacts that can degrade stream channels and harm aquatic life.

It is important to note that typical, real-world LID designs usually incorporate more than one type of practice or technique to provide integrated treatment of runoff from a site. For example, in lieu of a treatment pond serving a new subdivision, planners might incorporate a bioretention area in each yard, disconnect downspouts from driveway surfaces, remove curbs, and install grassed swales in common areas. Integrating small practices throughout a site instead of using extended detention wet ponds to control runoff from a subdivision is the basis of the LID approach.

When conducting cost analyses of these practices, examples of projects where actual practice-by-practice costs were considered separately were found to be rare because material and labor costs are typically calculated for an entire site rather than for each element within a larger system. Similarly, it is difficult to calculate the economic benefits of individual LID practices on the basis of their effectiveness in reducing runoff volume and rates or in treating pollutants targeted for best management practice (BMP) performance monitoring.

The following is a summary of the different categories of LID practices, including a brief description and examples of each type of practice.

Conservation designs can be used to minimize the generation of runoff by preserving open space. Such designs can reduce the amount of impervious surface, which can cause increased runoff volumes. Open space can also be used to treat the increased runoff from the built environment through infiltration or evapotranspiration. For example, developers can use conservation designs to preserve important features on the site such as wetland and riparian areas, forested tracts, and areas of porous soils. Development plans that outline the smallest site disturbance area can minimize the stripping of topsoil and compaction of subsoil that result from grading and equipment use. By preserving natural areas and not clearing and grading the entire site for housing lots, less total runoff is generated on the development parcel. Such simplistic, nonstructural methods can reduce the need to build large structural runoff controls like retention ponds and stormwater conveyance systems and thereby decrease the overall infrastructure costs of the project. Reducing the total area of impervious surface by limiting road widths, parking area, and sidewalks can also reduce the volume of runoff that must be treated. Residential developments that incorporate conservation design principles also can benefit residents and their quality of life due to increased access and proximity to communal open space, a greater sense of community, and expanded recreational opportunities.

Examples of Conservation Design

- Cluster development
- Open space preservation
- Reduced pavement widths (streets, sidewalks)
- Shared driveways
- Reduced setbacks (shorter driveways)
- Site fingerprinting during construction

Examples of Infiltration Practices

- Infiltration basins and trenches
- Porous pavement
- Disconnected downspouts
- Rain gardens and other vegetated treatment systems

Infiltration practices are engineered structures or landscape features designed to capture and infiltrate runoff. They can be used to reduce both the volume of runoff discharged from the site and the infrastructure needed to convey, treat, or control runoff. Infiltration practices can also be used to recharge ground water. This benefit is especially important in areas where maintaining drinking water supplies and stream baseflow is of special concern because of limited precipitation or a high ratio of withdrawal to recharge rates. Infiltration of runoff can also help to maintain stream temperatures because the infiltrated water that moves laterally to replenish stream baseflow typically has a lower temperature than overland flows, which might be subject to solar radiation. Another advantage of infiltration practices is that they can be integrated into landscape features in a site-dispersed manner. This feature can result in aesthetic benefits and, in some cases, recreational opportunities; for example, some infiltration areas can be used as playing fields during dry periods.

Runoff storage practices. Impervious surfaces are a central part of the built environment, but runoff from such surfaces can be captured and stored for reuse or gradually infiltrated, evaporated, or used to irrigate plants. Using runoff storage practices has several benefits. They can reduce the volume of runoff discharged to surface waters, lower the peak flow hydrograph to protect streams from the erosive forces of high flows, irrigate landscaping, and provide aesthetic benefits such as landscape islands, tree boxes, and rain gardens. Designers can take advantage of the void space beneath paved areas like parking lots and sidewalks to provide additional storage. For example, underground vaults can be used to store runoff in both urban and rural areas.

Examples of Runoff Storage Practices

- Parking lot, street, and sidewalk storage
- Rain barrels and cisterns
- Depressional storage in landscape islands and in tree, shrub, or turf depressions
- Green roofs

Runoff conveyance practices. Large storm events can make it difficult to retain all the runoff generated on-site by using infiltration and storage practices. In these situations, conveyance systems are typically used to route excess runoff through and off the site. In LID designs, conveyance systems can be used to slow flow velocities, lengthen the runoff time of concentration, and delay peak flows that are discharged off-site. LID conveyance practices can be used as an alternative to curb-and-gutter systems, and from a water quality perspective they have advantages over conventional approaches designed to rapidly convey runoff off-site and alleviate on-site flooding. LID conveyance practices often have rough surfaces, which slow runoff and increase evaporation and settling of solids. They are typically permeable and vegetated, which promotes infiltration, filtration, and some biological uptake of pollutants. LID conveyance practices also can perform functions similar to those of conventional curbs, channels, and gutters. For example, they can be used to reduce flooding around structures by routing runoff to landscaped areas for treatment, infiltration, and evapotranspiration.

Examples of Runoff Conveyance Practices

- Eliminating curbs and gutters
- Creating grassed swales and grass-lined channels
- Roughening surfaces
- Creating long flow paths over landscaped areas
- Installing smaller culverts, pipes, and inlets
- Creating terraces and check dams

Filtration practices are used to treat runoff by filtering it through media that are designed to capture pollutants through the processes of physical filtration of solids and/or cation exchange of dissolved pollutants. Filtration practices offer many of the same benefits as infiltration, such as reductions in the volume of runoff transported off-site, ground water recharge, increased stream baseflow, and reductions in thermal impacts to receiving waters. Filtration practices also have the added advantage of providing increased pollutant removal benefits. Although pollutant build-up and removal may be of concern, pollutants are typically captured in the upper soil horizon and can be removed by replacing the topsoil.

Examples of Filtration Practices

- Bioretention/rain gardens
- Vegetated swales
- Vegetated filter strips/buffers

Low impact landscaping. Selection and distribution of plants must be carefully planned when designing a functional landscape. Aesthetics are a primary concern, but it is also important to consider long-term maintenance goals to reduce inputs of labor, water, and chemicals. Properly preparing soils and selecting species adapted to the microclimates of a site greatly increases the success of plant establishment and growth, thereby stabilizing soils and allowing for biological uptake of pollutants. Dense, healthy plant growth offers such benefits as pest resistance (reducing the need for pesticides) and improved soil infiltration from root growth. Low impact landscaping can thus reduce impervious surfaces, improve infiltration potential, and improve the aesthetic quality of the site.

Examples of Low Impact Landscaping

- Planting native, drought-tolerant plants
- Converting turf areas to shrubs and trees
- Reforestation
- Encouraging longer grass length
- Planting wildflower meadows rather than turf along medians and in open space
- Amending soil to improve infiltration

EVALUATIONS OF BENEFITS AND COSTS

To date, the focus of traditional stormwater management programs has been concentrated largely on structural engineering solutions to manage the hydraulic consequences of the increased runoff that results from development. Because of this emphasis, stormwater management has been considered primarily an engineering endeavor. Economic analyses regarding the selection of solutions that are not entirely based on pipes and ponds have not been a significant factor in management decisions. Where costs have been considered, the focus has been primarily on determining capital costs for conventional infrastructure, as well as operation and maintenance costs in dollars per square foot or dollars per pound of pollutant removed.

Little attention has been given to the benefits that can be achieved through implementing LID practices. For example, communities rarely attempt to quantify and monetize the pollution prevention benefits and avoided treatment costs that might accrue from the use of conservation designs or LID techniques. To be more specific, the benefits of using LID practices to decrease the need for combined sewer overflow (CSO) storage and conveyance systems should be factored into the economic analyses. One of the major factors preventing LID practices from receiving equal consideration in the design or selection process is the difficulty of monetizing the environmental benefits of these practices. Without good data and relative certainty that these alternatives will work and not increase risk or cost, current standards of practice are difficult to change.

This report is an effort to compare the projected or known costs of LID practices with those of conventional development approaches. At this point, monetizing the economic and environmental benefits of LID strategies is much more difficult than monetizing traditional infrastructure costs or changes in property values due to improvements in existing utilities or transportation systems. Systems of practices must be analyzed to determine net performance and monetary benefits based on the capacity of the systems to both treat for pollutants and reduce impacts through pollution prevention. For example, benefits might come in the form of reduced stream channel degradation, avoided stream restoration costs, or reduced drinking water treatment costs.

One of the chief impediments to getting useful economic data to promote more widespread use of LID techniques is the lack of a uniform baseline with which to compare the costs and benefits of LID practices against the costs of conventional stormwater treatment and control. Analyzing benefits is further complicated in cases where the environmental performance of the conservation design or LID system exceeds that of the conventional runoff management system, because such benefits are not easily monetized. The discussion below is intended to provide a general discussion of the range of economic benefits that may be provided by LID practices in a range of appropriate circumstances.

OVERVIEW OF BENEFITS

The following is a brief discussion of some of the actual and assumed benefits of LID practices. Note that environmental and ancillary benefits typically are not measured as part of development projects, nor are they measured as part of pilot or demonstration projects, because they can be difficult to isolate and quantify. Many of the benefits described below are assumed on the basis of limited studies and anecdotal evidence.

The following discussion is organized into three categories: (1) environmental benefits, which include reductions in pollutants, protection of downstream water resources, ground water recharge, reductions in pollutant treatment costs, reductions in the frequency and severity of CSOs, and habitat improvements; (2) land value benefits, which include reductions in downstream flooding and property damage, increases in real estate value, increased parcel lot yield, increased aesthetic value, and improvement of quality of life by providing open space for recreation; and (3) compliance incentives.

Environmental Benefits

Pollution abatement. LID practices can reduce both the volume of runoff and the pollutant loadings discharged into receiving waters. LID practices result in pollutant removal through settling, filtration, adsorption, and biological uptake. Reductions in pollutant loadings to receiving waters, in turn, can improve habitat for aquatic and terrestrial wildlife and enhance recreational uses. Reducing pollutant loadings can also decrease stormwater and drinking water treatment costs by decreasing the need for regional stormwater management systems and expansions in drinking water treatment systems.

Protection of downstream water resources. The use of LID practices can help to prevent or reduce hydrologic impacts on receiving waters, reduce stream channel degradation from erosion and sedimentation, improve water quality, increase water supply, and enhance the recreational and aesthetic value of our natural resources. LID practices can be used to protect water resources that are downstream in the watershed. Other potential benefits include reduced incidence of illness from contact recreation activities such as swimming and wading, more robust and safer seafood supplies, and reduced medical treatment costs.

Ground water recharge. LID practices also can be used to infiltrate runoff to recharge ground water. Growing water shortages nationwide increasingly indicate the need for water resource management strategies designed to integrate stormwater, drinking water, and wastewater programs to maximize benefits and minimize costs. Development pressures typically result in increases in the amount of impervious surface and volume of runoff. Infiltration practices can be used to replenish ground water and increase stream baseflow. Adequate baseflow to streams during dry weather is important because low ground water levels can lead to greater fluctuations in stream depth, flows, and temperatures, all of which can be detrimental to aquatic life.

Water quality improvements/reduced treatment costs. It is almost always less expensive to keep water clean than it is to clean it up. The Trust for Public Land[5] noted Atlanta’s tree cover has saved more than $883 million by preventing the need for stormwater retention facilities. A study of 27 water suppliers conducted by the Trust for Public Land and the American Water Works Association[6] found a direct relationship between forest cover in a watershed and water supply treatment costs. In other words, communities with higher percentages of forest cover had lower treatment costs. According to the study, approximately 50 to 55 percent of the variation in treatment costs can be explained by the percentage of forest cover in the source area. The researchers also found that for every 10 percent increase in forest cover in the source area, treatment and chemical costs decreased approximately 20 percent, up to about 60 percent forest cover.

Reduced incidence of CSOs. Many municipalities have problems with CSOs, especially in areas with aging infrastructure. Combined sewer systems discharge sanitary wastewater during storm events. LID techniques, by retaining and infiltrating runoff, reduce the frequency and amount of CSO discharges to receiving waters. Past management efforts typically have been concentrated on hard engineering approaches focused on treating the total volume of sanitary waste together with the runoff that is discharged to the combined system. Recently, communities like Portland (Oregon), Chicago, and Detroit have been experimenting with watershed approaches aimed at reducing the total volume of runoff generated that must be handled by the combined system. LID techniques have been the primary method with which they have experimented to reduce runoff. A Hudson Riverkeeper report concluded, based on a detailed technical analysis, that New York City could reduce its CSO's more cost-effectively with LID practices than with conventional, hard infrastructure CSO storage practices. [7]

Habitat improvements. Innovative stormwater management techniques like LID or conservation design can be used to improve natural resources and wildlife habitat, maintain or increase land value, or avoid expensive mitigation costs.

Land Value and Quality of Life Benefits

Reduced downstream flooding and property damage. LID practices can be used to reduce downstream flooding through the reduction of peak flows and the total amount or volume of runoff. Flood prevention reduces property damage and can reduce the initial capital costs and the operation and maintenance costs of stormwater infrastructure. Strategies designed to manage runoff on-site or as close as possible to its point of generation can reduce erosion and sediment transport as well as reduce flooding and downstream erosion. As a result, the costs for cleanups and streambank restoration can be reduced or avoided altogether. The use of LID techniques also can help protect or restore floodplains, which can be used as park space or wildlife habitat.[8]

Real estate value/property tax revenue. Homeowners and property owners are willing to pay a premium to be located next to or near aesthetically pleasing amenities like water features, open space, and trails. Some stormwater treatment systems can be beneficial to developers because they can serve as a "water" feature or other visual or recreational amenity that can be used to market the property. These designs should be visually attractive and safe for the residents and should be considered an integral part of planning the development. Various LID projects and smart growth studies have shown that people are willing to pay more for clustered homes than conventionally designed subdivisions. Clustered housing with open space appreciated at a higher rate than conventionally designed subdivisions. EPA's *Economic Benefits of Runoff Controls*[9] describes numerous examples where developers and subsequent homeowners have received premiums for proximity to attractive stormwater management practices.

Lot yield. LID practices typically do not require the large, contiguous areas of land that are usually necessary when traditional stormwater controls like ponds are used. In cases where LID practices are incorporated on individual house lots and along roadsides as part of the landscaping, land that would normally be dedicated for a stormwater pond or other large structural control can be developed with additional housing lots.

Aesthetic value. LID techniques are usually attractive features because landscaping is an integral part of the designs. Designs that enhance a property's aesthetics using trees, shrubs, and flowering plants that complement other landscaping features can be selected. The use of these designs may increase property values or result in faster sale of the property due to the perceived value of the "extra" landscaping.

Public spaces/quality of life/public participation. Placing water quality practices on individual lots provides opportunities to involve homeowners in stormwater management and enhances public awareness of water quality issues. An American Lives, Inc., real estate study found that 77.7 percent of potential homeowners rated natural open space as "essential" or "very important" in planned communities.[10]

Compliance Incentives

Regulatory compliance credits. Many states recognize the positive benefits LID techniques offer, such as reduced wetland impacts. As a result, they might offer regulatory compliance credits, streamlined or simpler permit processes, and other incentives similar to those offered for other green practices. For example, in Maryland the volume required for the permanent pool of a wet pond can be reduced if rooftop runoff is infiltrated on-site using LID practices. This procedure allows rooftop area to be subtracted from the total impervious area, thereby reducing the required size of the permanent pool. In addition, a LID project can have less of an environmental impact than a conventional project, thus requiring smaller impact fees.

COST CONSIDERATIONS

Traditional approaches to stormwater management involve conveying runoff off-site to receiving waters, to a combined sewer system, or to a regional facility that treats runoff from multiple sites. These designs typically include hard infrastructure, such as curbs, gutters, and piping. LID-based designs, in contrast, are designed to use natural drainage features or engineered swales and vegetated contours for runoff conveyance and treatment. In terms of costs, LID techniques like conservation design can reduce the amount of materials needed for paving roads and driveways and for installing curbs and gutters. Conservation designs can be used to reduce the total amount of impervious surface, which results in reduced road and driveway lengths and reduced costs. Other LID techniques, such as grassed swales, can be used to infiltrate roadway runoff and eliminate or reduce the need for curbs and gutters, thereby reducing infrastructure costs. Also, by infiltrating or evaporating runoff, LID techniques can reduce the size and cost of flood-control structures. Note that more research is needed to determine the optimal combination of LID techniques and detention practices for flood control.

It must be stated that the use of LID techniques might not always result in lower project costs. The costs might be higher because of the costs of plant material, site preparation, soil amendments, underdrains and connections to municipal stormwater systems, and increased project management.

Another factor to consider when comparing costs between traditional and LID designs is the amount of land required to implement a management practice. Land must be set aside for both traditional stormwater management practices and LID practices, but the former require the use of land *in addition to* individual lots and other community areas, whereas bioretention areas and swales can be incorporated into the landscaping of yards, in rights-of-way along roadsides, and in or adjacent to parking lots. The land that would have been set aside for ponds or wetlands can in many cases be used for additional housing units, yielding greater profits.

Differences in maintenance requirements should also be considered when comparing costs. According to a 1999 EPA report, maintenance costs for retention basins and constructed wetlands were estimated at 3 to 6 percent of construction costs, whereas maintenance costs for swales and bioretention practices were estimated to be 5 to 7 percent of construction costs.[11] However, much of the maintenance for bioretention areas and swales can be accomplished as part of routine landscape maintenance and does not require specialized equipment. Wetland and pond maintenance, on the other hand, involves heavy equipment to remove accumulated sediment, oils, trash, and vegetation in forebays and open ponds.

Finally, in some circumstances LID practices can offset the costs associated with regulatory requirements for stormwater control. In urban redevelopment projects where land is not likely to be available for large stormwater management practices, developers can employ site-dispersed BMPs in sidewalk areas, in courtyards, on rooftops, in parking lots, and in other small outdoor spaces, thereby avoiding the fees that some municipalities charge when stormwater mitigation requirements cannot otherwise be met. In addition, stormwater utilities often provide credits for installing runoff management practices such as LID practices.[12]

CASE STUDIES

The case studies presented below are not an exhaustive list of LID projects nationwide. These examples were selected on the basis of the quantity and quality of economic data, quantifiable impacts, and types of LID practices used. Economic data are available for many other LID installations, but those installations often cannot be compared with conventional designs because of the unique nature of the design or the pilot status of the project. Table 1 presents a summary of the LID practices employed in each case study.

Table 1. Summary of LID Practices Employed in the Case Studies

	LID Techniques							
Name	Bioretention	Cluster Building	Reduced Impervious Area	Swales	Permeable Pavement	Vegetated Landscaping	Wetlands	Green Roofs
2nd Avenue SEA Street	✓		✓	✓				
Auburn Hills	✓		✓	✓		✓	✓	
Bellingham Parking Lot Retrofits	✓							
Central Park Commercial Redesigns	✓			✓				
Crown Street	✓		✓	✓				
Gap Creek			✓			✓		
Garden Valley	✓	✓		✓	✓		✓	
Kensington Estates		✓	✓		✓	✓	✓	
Laurel Springs	✓	✓	✓	✓				
Mill Creek		✓	✓	✓				
Poplar Street Apartments	✓			✓			✓	
Portland Downspout Disconnection*			✓					
Prairie Crossing	✓		✓	✓		✓		
Prairie Glen	✓	✓	✓	✓		✓	✓	
Somerset	✓			✓				
Tellabs Corporate Campus	✓			✓		✓	✓	
Toronto Green Roofs								✓

*Although impervious area stays the same, the disconnection program reduces directly connected impervious area.

The case studies contain an analysis of development costs, which are summarized in Table 2. Note that some case study results do not lend themselves well to a traditional vs.

LID cost comparison and therefore are not included in Table 2 (as noted). *Conventional development cost* refers to costs incurred or estimated for a traditional stormwater management approach, whereas *LID cost* refers to costs incurred or estimated for using LID practices. *Cost difference* is the difference between the conventional development cost and the LID cost. *Percent difference* is the cost savings relative to the conventional development cost.

Table 2. Summary of Cost Comparisons Between Conventional and LID Approaches[a]

Project	Conventional Development Cost	LID Cost	Cost Difference[b]	Percent Difference[b]
2nd Avenue SEA Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Bloedel Donovan Park	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Garden Valley	$324,400	$260,700	$63,700	20%
Kensington Estates	$765,700	$1,502,900	–$737,200	-96%
Laurel Springs	$1,654,021	$1,149,552	$504,469	30%
Mill Creek[c]	$12,510	$9,099	$3,411	27%
Prairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	$2,700,650	$461,510	15%

[a] The Central Park Commercial Redesigns, Crown Street, Poplar Street Apartments, Prairie Crossing, Portland Downspout Disconnection, and Toronto Green Roofs study results do not lend themselves to display in the format of this table.
[b] Negative values denote increased cost for the LID design over conventional development costs.
[c] Mill Creek costs are reported on a per-lot basis.

2ND AVENUE SEA STREET, SEATTLE, WASHINGTON

The 2nd Avenue Street Edge Alternative (SEA) Street project was a pilot project undertaken by Seattle Public Utilities to redesign an entire 660-foot block with a number of LID techniques. The goals were to reduce stormwater runoff and to provide a more "livable" community. Throughout the design and construction process, Seattle Public Utilities worked collaboratively with street residents to develop the final street design.[13]

The design reduced imperviousness, included retrofits of bioswales to treat and manage stormwater, and added 100 evergreen trees and 1,100 shrubs.[14] Conventional curbs and gutters were replaced with bioswales in the rights-of-way on both sides of the street, and the street width was reduced from 25 feet to 14 feet. The final constructed design reduced imperviousness by more than 18 percent. An estimate for the final total project cost was $651,548. A significant amount of community outreach was involved, which raised the level of community acceptance. Community input is important for any project, but because this was a pilot study, much more was spent on communication and redesign than what would be spent for a typical project.

The costs for the LID retrofit were compared with the estimated costs of a conventional street retrofit (Table 3). Managing stormwater with LID techniques resulted in a cost savings of 29 percent. Also, the reduction in street width and sidewalks reduced paving costs by 49 percent.

Table 3. Cost Comparison for 2nd Avenue SEA Street [15]

Item	Conventional Development Cost	SEA Street Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$65,084	$88,173	–$23,089	–35%	–11%
Stormwater management	$372,988	$264,212	$108,776	29%	50%
Site paving and sidewalks	$287,646	$147,368	$140,278	49%	65%
Landscaping	$78,729	$113,034	–$34,305	–44%	–16%
Misc. (mobilization, etc.)	$64,356	$38,761	$25,595	40%	12%
Total	$868,803	$651,548	$217,255	—	—

* Negative values denote increased cost for the LID design over conventional development costs.

The avoided cost for stormwater infrastructure and reduced cost for site paving accounted for much of the overall cost savings. The nature of the design, which included extensive use of bioswales and vegetation, contributed to the increased cost for site preparation and landscaping. Several other SEA Street projects have been completed or are under way, and cost evaluations are expected to be favorable.

For this site, the environmental performance has been even more significant than the cost savings. Hydrologic monitoring of the project indicates a 99 percent reduction in total potential surface runoff, and runoff has not been recorded at the site since December 2002, a period that included the highest-ever 24-hour recorded rainfall at Seattle-Tacoma Airport.[16] The site is retaining more than the original design estimate of 0.75 inch of rain. A modeling analysis indicates that if a conventional curb-and-gutter system had been installed along 2nd Avenue instead of the SEA Street design, 98 times more stormwater would have been discharged from the site.[17]

AUBURN HILLS SUBDIVISION, SOUTHWESTERN WISCONSIN

Auburn Hills in southwestern Wisconsin is a residential subdivision developed with conservation design principles. Forty percent of the site is preserved as open space; this open space includes wetlands, green space and natural plantings, and walking trails. The subdivision was designed to include open swales and bioretention for stormwater management. To determine potential savings from using conservation design, the site construction costs were compared with the estimated cost of building the site as a conventional subdivision.[18] Reduced stormwater management costs accounted for approximately 56 percent of the total cost savings. A cost comparison is provided in Table 4. Other savings not shown in Table 4 were realized as a result of reduced sanitary sewer, water distribution, and utility construction costs.

Table 4. Cost Comparison for Auburn Hills Subdivision [19]

Item	Conventional Development Cost	Auburn Hills LID Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$699,250	$533,250	$166,000	24%	22%
Stormwater management	$664,276	$241,497	$422,779	64%	56%
Site paving and sidewalks	$771,859	$584,242	$187,617	24%	25%
Landscaping	$225,000	$240,000	–$15,000	-7%	-2%
Total	$2,360,385	$1,598,989	$761,396	—	—

* Negative values denote increased cost for the LID design over conventional development costs.

The clustered design used in the development protected open space and reduced clearing and grading costs. Costs for paving and sidewalks were also decreased because the cluster design reduced street length and width. Stormwater savings were realized primarily through the use of vegetated swales and bioswales. These LID practices provided stormwater conveyance and treatment and also lowered the cost of conventional stormwater infrastructure. The increase in landscaping costs resulted from additional open space present on-site compared to a conventional design, as well as increased street sweeping. Overall, the subdivision's conservation design retained more natural open space for the benefit and use of the homeowners and aided stormwater management by preserving some of the site's natural hydrology.[20]

Bellingham, Washington, Parking Lot Retrofits

The City of Bellingham, Washington, retrofitted two parking lots—one at City Hall and the other at Bloedel Donovan Park—with rain gardens in lieu of installing underground vaults to manage stormwater.[21] At City Hall, 3 parking spaces out of a total of 60 were used for the rain garden installation. The Bloedel Donovan Park retrofit involved converting to a rain garden a 550-square-foot area near a catch basin. Both installations required excavation, geotextile fabric, drain rock, soil amendments, and native plants. Flows were directed to the rain gardens by curbs. An overflow system was installed to accommodate higher flows during heavy rains.

The City compared actual rain garden costs to estimates for conventional underground vaults based on construction costs for similar projects in the area ($12.00 per cubic foot of storage). Rain garden costs included labor, vehicle use/rental, and materials. Table 5 shows that the City Hall rain garden saved the City $22,000, or 80 percent, over the underground vault option; the Bloedel Donovan Park installation saved $40,000, or 76 percent.

Table 5. Cost Comparison for Bellingham's Parking Lot Rain Garden Retrofits[22]

Project	Conventional Vault Cost	Rain Garden Cost	Cost Savings	Percent Savings
City Hall	$27,600	$5,600	$22,000	80%
Bloedel Donovan Park	$52,800	$12,800	$40,000	76%

CENTRAL PARK COMMERCIAL REDESIGNS, FREDERICKSBURG, VA (A MODELING STUDY)

The Friends of the Rappahannock undertook a cost analysis involving the redesign of site plans for several stores in a large commercial development in the Fredericksburg, Virginia, area called Central Park.[23,24] Table 6 contains a side-by-side analysis of the cost additions and reductions for each site for scenarios where LID practices (bioretention areas and swales) were incorporated into the existing, traditional site designs. In five of the six examples, the costs for the LID redesigns were higher than those for the original designs, although they never exceeded $10,000, or 10 percent of the project. One example yielded a $5,694 savings. The fact that these projected costs for LID were comparable to the costs for traditional designs convinced the developer to begin incorporating LID practices into future design projects.[25]

Table 6. Site Information and Cost Additions/Reductions Using LID Versus Traditional Designs

Name	Total BMP Area (ft²)	Total Impervious Area Treated (ft²)	Percent of Impervious Area Treated	Cost Additions[a]	Cost Reductions[b]	Change in Cost After Redesign
Breezewood Station Alternative 1	4,800	64,165	98.4%	$36,696	$34,785	+ $1,911
Breezewood Station Alternative 2	3,500	38,775	59.5%	$24,449	$21,060	+ $3,389
Olive Garden	1,780	31,900	59.1%	$14,885	$11,065	+ $3,790
Kohl's, Best Buy, & Office Depot	14,400	354,238	56.3%	$89,433	$80,380	+ $9,053
First Virginia Bank	1,310	20,994	97.7%	$6,777	$1,148	+ $5,629
Chick-Fil-A[c]	1,326	28,908	82.2%	$6,846	$12,540	– $5,694

[a] Additional costs for curb, curb blocks, storm piping, inlets, underdrains, soil, mulch, and vegetation as a result of the redesign.
[b] Reduced cost for curb, storm piping, roof drain piping, and inlets as a result of the redesign.
[c] Cost reduction value includes the cost of a Stormceptor unit that is not needed as part of the redesign.

CROWN STREET, VANCOUVER, BRITISH COLUMBIA

In 1995 the Vancouver City Council adopted a Greenways program that is focused on introducing pedestrian-friendly green space into the City to connect trails, environmental areas, and urban space. As a part of this program, the City has adopted strategies to manage stormwater runoff from roadways. Two initiatives are discussed here.

The Crown Street redevelopment project, completed in 2005, retrofitted a 1,100-foot block of traditional curb-and-gutter street with a naturalized streetscape modeled after the Seattle SEA Street design. Several LID features were incorporated into the design. The total imperviousness of the street was decreased by reducing the street width from 28 feet to 21 feet with one-way sections of the road narrowed to 10 feet. Roadside swales that use vegetation and structural grass (grass supported by a grid and soil structure that prevents soil compaction and root damage) were installed to collect and treat stormwater through infiltration.[26]

Modeling predicts that the redesigned street will retain 90 percent of the annual rainfall volume on-site; the remaining 10 percent of runoff will be treated by the system of vegetated swales before discharging.[27,28] The City chose to use the LID design because stormwater runoff from Crown Street flows into the last two salmon-bearing creeks in Vancouver.[29] Monitoring until 2010 will assess the quality of stormwater runoff and compare it with both the modeling projections and the runoff from a nearby curb-and-gutter street.

The cost of construction for the Crown Street redevelopment was $707,000. Of this, $311,000 was attributed to the cost of consultant fees and aesthetic design features, which were included in the project because it was the first of its kind in Vancouver. These added costs would not be a part of future projects. Discounting the extra costs, the $396,000 construction cost is 9 percent higher than the estimated $364,000 conventional curb-and-gutter design cost.[30] The City has concluded that retrofitting streets that have an existing conventional stormwater system with naturalized designs will cost marginally more than making curb-and-gutter improvements, but installing naturalized street designs in new developments will be less expensive than installing conventional drainage systems.[31,32]

One goal of Vancouver's Greenways program is to make transportation corridors more pedestrian-friendly. A method used to achieve this goal is to extend curbs at intersections out into the street to lessen the crossing distance and improve the line of sight for pedestrians. When this initiative began, the City relocated stormwater catch basins that would have been enclosed within the extended curb. Now, at certain intersections, the City uses the new space behind the curb to install "infiltration bulges" to collect and infiltrate roadway runoff. The infiltration bulges are constructed of permeable soils and vegetation. (The City of Portland, Oregon, has installed similar systems, which they call "vegetated curb extensions.") The catch basins are left in place, and any stormwater that does not infiltrate into the soil overflows into the storm drain system.[33]

The infiltration bulges have resulted in savings for the City. Because the stormwater infiltration bulges are installed in conjunction with planned roadway improvements, the only additional costs associated with the stormwater project are the costs of a steel curb insert to allow stormwater to enter the bulge and additional soil excavation costs. These additional costs are more than offset by the $2,400 to $4,000 cost that would have been required to relocate the catch basins. To date, the City has installed nine infiltration bulges, three of which are maintained by local volunteers as part of a Green Streets program in which local residents adopt city green space.[34]

GAP CREEK SUBDIVISION, SHERWOOD, ARKANSAS

Gap Creek's original subdivision plan was revised to include LID concepts. The revised design increased open space from the originally planned 1.5 acres to 23.5 acres. Natural drainage areas were preserved and buffered by greenbelts. Traffic-calming circles were used, allowing the developer to reduce street widths from 36 to 27 feet. In addition, trees were kept close to the curb line. These design techniques allowed the development of 17 additional lots.

The lots sold for $3,000 more and cost $4,800 less to develop than comparable conventional lots. A cost comparison is provided in Table 7. For the entire development, the combination of cost savings and lot premiums resulted in an additional profit to the developer of $2.2 million.[35,36]

Table 7. Cost Comparison for Gap Creek Subdivision[37]

Total Cost of Conventional Design	Gap Creek LID Cost	Cost Savings	Percent Savings	Savings per Lot
$4,620,600	$3,942,100	$678,500	15%	$4,800

GARDEN VALLEY, PIERCE COUNTY, WASHINGTON (A MODELING STUDY)

The Garden Valley subdivision is a 9.7-acre site in Pierce County, Washington. A large wetland on the eastern portion of the site and a 100-foot buffer account for 43 percent of the site area. Designers evaluated a scenario in which roadway widths were reduced and conventional stormwater management practices were replaced with swales, bioretention, and soil amendments. The use of these LID elements would have allowed the cost for stormwater management on the site to be reduced by 72 percent. A cost comparison is provided in Table 8.[38] Other costs expected with the LID design were a $900 initial cost for homeowner education with $170 required annually thereafter. Annual maintenance costs for the LID design (not included above) were expected to be $600 more than those for the conventional design, but a $3,000 annual savings in the stormwater utility bill was expected to more than offset higher maintenance costs.

Table 8. Cost Comparison for Garden Valley Subdivision[39]

Item	Conventional Development Cost	Garden Valley LID Cost	Cost Savings*	Percent Savings*
Stormwater management	$214,000	$59,800	$154,200	72%
Site paving	$110,400	$200,900	–$90,500	–82%
Total	$324,400	$260,700	$63,700	—

* Negative values denote increased cost for the LID design over conventional development costs.

The design incorporated the use of narrower roadways coupled with Grasscrete parking along the roadside, which increased the overall site paving costs. However, this added cost was more than offset by the savings realized by employing LID for stormwater management. The LID practices were expected to increase infiltration and reduce stormwater discharge rates, which can improve the health and quality of receiving streams.

KENSINGTON ESTATES, PIERCE COUNTY, WASHINGTON (A MODELING STUDY)

A study was undertaken to evaluate the use of LID techniques at the Kensington Estates subdivision, a proposed 24-acre development consisting of single-family homes on 103 lots. The study assumed that conventional stormwater management practices would be replaced entirely by LID techniques, including reduced imperviousness, soil amendments, and bioretention areas. The design dictated that directly connected impervious areas on-site were to be minimized. Three wetlands and an open space tract would treat stormwater discharging from LID installations. Open space buffers were included in the design. The LID proposal also included rooftop rainwater collection systems on each house.[40,41]

The proposed LID design reduced effective impervious area from 30 percent in the conventional design to approximately 7 percent, and it was approximately twice as expensive as the traditional design. A cost comparison is provided in Table 9.

Table 9. Cost Comparison for Kensington Estates Subdivision[42]

Item	Conventional Development Cost	Kensington Estate LID Cost	Additional Cost
Stormwater management	$243,400	$925,400	$ 682,000
Site paving	$522,300	$577,500	$55,200
Total	$765,700	$1,502,900	$737,200

Although the study assumed that roadways in the LID design would be narrower than those in the conventional design, site paving costs increased because the LID design assumed that Grasscrete parking would be included along the roadside to allow infiltration. The use of Grasscrete increased the overall site paving costs.

The avoidance of conventional stormwater infrastructure with the use of LID afforded significant cost savings. The LID measures eliminated the need for a detention pond and made more lots available for development. The significant cost for the rooftop rainwater collection systems was assumed to be offset somewhat by savings on stormwater utility bills.[43]

The study also anticipated that the use of LID would reduce stormwater peak flow discharge rates and soil erosion. Furthermore, greater on-site infiltration increases ground water recharge, resulting in increased natural baseflows in streams and a reduction in dry channels. Proposed clustering of buildings would allow wetlands and open space to be preserved and create a more walkable community. The reduced road widths were anticipated to decrease traffic speeds and accident rates.

LAUREL SPRINGS SUBDIVISION, JACKSON, WISCONSIN

The Laurel Springs subdivision in Jackson, Wisconsin, is a residential subdivision that was developed as a conservation design community. The use of cluster design helped to preserve open space and minimize grading and paving. The use of bioretention and vegetated swales lowered the costs for stormwater management.

The costs of using conservation design to develop the subdivision were compared with the estimated cost of developing the site with conventional practices (Table 10).[44] The total savings realized with conservation design were just over $504,469, or approximately 30 percent of the estimated conventional construction cost. Savings from stormwater management accounted for 60 percent of the total cost savings. Other project savings were realized with reduced sanitary sewer, water distribution, and utility construction costs.

Table 10. Cost Comparison for Laurel Springs Subdivision[45]

Item	Conventional Development Cost	Laurel Springs LID Cost	Cost Savings	Percent Savings	Percent of Total Savings
Site preparation	$441,600	$342,000	$99,600	23%	20%
Stormwater management	$439,956	$136,797	$303,159	69%	60%
Site paving and sidewalks	$607,465	$515,755	$91,710	15%	18%
Landscaping	$165,000	$155,000	$10,000	6%	2%
Total	$1,654,021	$1,149,552	$504,469	—	—

In addition to preserving open space and reducing the overall amount of clearing and grading, the cluster design also reduced street lengths and widths, thereby lowering costs for paving and sidewalks. Vegetated swales and bioswales largely were used to replace conventional stormwater infrastructure and led to significant savings. Each of these factors helped to contribute to a more hydrologically functional site that reduced the total amount of stormwater volume and managed stormwater through natural processes.

MILL CREEK SUBDIVISION, KANE COUNTY, ILLINOIS

The Mill Creek subdivision is a 1,500-acre, mixed-use community built as a conservation design development. Approximately 40 percent of the site is identified as open space; adjacent land use is mostly agricultural. The subdivision was built using cluster development. It uses open swales for stormwater conveyance and treatment, and it has a lower percentage of impervious surface than conventional developments. An economic analysis compared the development cost for 40 acres of Mill Creek with the development costs of 30 acres of a conventional development with similar building density and location.[46]

When compared with the conventional development, the conservation site design techniques used at Mill Creek saved approximately $3,411 per lot. Nearly 70 percent of these savings resulted from reduced costs for stormwater management, and 28 percent of the savings were found in reduced costs for site preparation. A cost comparison is provided in Table 11. Other savings not included in the table were realized with reduced construction costs for sanitary sewers and water distribution.

Table 11. Cost Comparison for Mill Creek Subdivision[47]

Item	Conventional Development Cost per Lot	Mill Creek LID Cost per Lot	Cost Savings per Lot	Percent Savings per Lot	Percent of Total Savings
Site preparation	$2,045	$1,086	$959	47%	28%
Stormwater management	$4,535	$2,204	$2,331	51%	68%
Site paving and sidewalks	$5,930	$5,809	$121	2%	4%
Total	$12,510	$9,099	$3,411	—	—

The use of cluster development and open space preservation on the site decreased site preparation costs. The majority of the cost savings were achieved by avoiding the removal and stockpiling of topsoil. In addition to cost savings from avoided soil disturbance, leaving soils intact also retains the hydrologic function of the soils and aids site stormwater management by reducing runoff volumes and improving water quality. The site’s clustered design was also responsible for a decrease in costs for paving and sidewalks because the designers intentionally aimed to decrease total road length and width.

The designers used open swales as the primary means for stormwater conveyance. Coupled with other site techniques to reduce runoff volumes and discharge rates, significant savings in stormwater construction were avoided because of reduced storm sewer installation; sump pump connections; trench backfill; and catch basin, inlet, and cleanout installation.

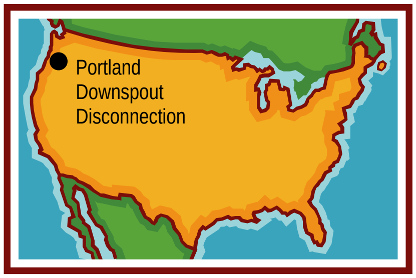
In addition to the cost savings, the conservation design at Mill Creek had a positive effect on property values: lots adjacent to walking/biking trails include a $3,000 premium, and lots adjacent to or with views of open space include a $10,000 to $17,500 premium. The

600 acres of open space on the site include 127 acres of forest preserve with quality wetlands, 195 acres of public parks, and 15 miles of walking/biking trails.[48]

POPLAR STREET APARTMENTS, ABERDEEN, NORTH CAROLINA

The use of bioretention, topographical depressions, grass channels, swales, and stormwater basins at the 270-unit Poplar Street Apartment complex improved stormwater treatment and lowered construction costs. The design allowed almost all conventional underground storm drains to be eliminated from the design. The design features created longer flow paths, reduced runoff volume, and filtered pollutants from runoff. According to the U.S. Department of Housing and Urban Development, use of LID techniques resulted in a $175,000 savings (72 percent).[49]

PORTLAND DOWNSPOUT DISCONNECTION PROGRAM, PORTLAND, OREGON

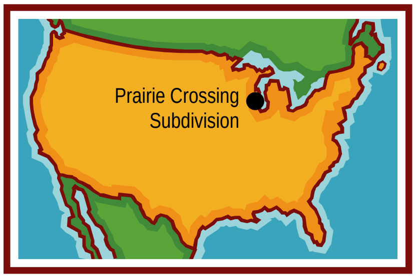


The City of Portland, Oregon, implemented a Downspout Disconnection Program as part of its CSO elimination program. Every year, billions of gallons of stormwater mixed with sewage pour into the Willamette River and Columbia Slough through CSOs. When roof runoff flows into Portland's combined sewer system, it contributes to CSOs. The City has reduced the frequency of CSOs to the Columbia Slough and hopes to eliminate 94 percent of the overflows to the Willamette River by 2011.[50]

The Downspout Disconnection Program gives homeowners, neighborhood associations, and community groups the chance to work as partners with the Bureau of Environmental Services and the Office of Neighborhood Involvement to help reduce CSOs. Residents of selected neighborhoods disconnect their downspouts from the combined sewer system and allow their roof water to drain to gardens and lawns. Residents can do the work themselves and earn $53 per downspout, or they can have community groups and local contractors disconnect for them. Community groups earn $13 for each downspout they disconnect. (Materials are provided by the City.)

More than 44,000 homeowners have disconnected their downspouts, removing more than 1 billion gallons of stormwater per year from the combined sewer system. The City estimates that removing the 1 billion gallons will result in a $250 million reduction in construction costs for an underground pipe to store CSOs by reducing the capacity needed to handle the flows. The City has spent $8.5 million so far to implement this program and will continue to encourage more homeowners and businesses to disconnect their downspouts to achieve additional CSO and water quality benefits.

PRAIRIE CROSSING SUBDIVISION, GRAYSLAKE, ILLINOIS



The Prairie Crossing subdivision is a conservation development on 678 acres, of which 470 acres is open space. The site was developed as a mixed-use community with 362 residential units and 73 acres of commercial property, along with schools, a community center, biking trails, a lakefront beach, and a farm. The site uses bioretention cells and vegetated swales to manage stormwater.[51]

A cost analysis was performed to compare the actual construction costs of Prairie Crossing with the estimated costs of a conventional design on the site with the same layout. Cost savings with conservation design were realized primarily in four areas: stormwater management, curb and gutter installation, site paving, and sidewalk installation. The total savings were estimated to be almost $1.4 million, or nearly $4,000 per lot (Table 12). Savings from stormwater management accounted for approximately 15 percent of the total savings. The cost savings shown are relative to the estimated construction cost for the items in a conventional site design based on local codes and standards.

Table 12. Cost Comparison for Prairie Crossing Subdivision[52]

Item	Cost Savings	Percent Savings
Reduced Road Width	$178,000	13%
Stormwater Management	$210,000	15%
Decreased Sidewalks	$648,000	47%
Reduced Curb and Gutter	$339,000	25%
Total	$1,375,000	—

Reduced costs for sidewalks accounted for nearly half of the total cost savings. This savings is attributed in part to the use of alternative materials rather than concrete for walkways in some locations. In addition, the design and layout of the site, which retained a very high percentage of open space, contributed to the cost savings realized from reducing paving, the length and number of sidewalks, and curbs and gutters. The use of alternative street edges, vegetated swales, and bioretention and the preservation of natural areas all reduced the need for and cost of conventional stormwater infrastructure.[53] Benefits are associated with the mixed-use aspect of the development as well: residents can easily access schools, commercial areas, recreation, and other amenities with minimal travel. Proximity to these resources can reduce traffic congestion and transportation costs. Also, mixed-use developments can foster a greater sense of community and belonging than other types of development. All of these factors tend to improve quality of life.

PRAIRIE GLEN SUBDIVISION, GERMANTOWN, WISCONSIN

The Prairie Glen subdivision is nationally recognized for its conservation design approach. A significant portion of the site (59 percent) was preserved as open space. Wetlands were constructed to manage stormwater runoff, and the open space allowed the reintroduction of native plants and wildlife habitat. The site layout incorporated hiking trails, which were designed to allow the residents to have easy access to natural areas.[54]

To evaluate the cost benefits of Prairie Glen's design, the actual construction costs were compared with the estimated costs of developing the site conventionally. When compared with conventional design, the conservation design at Prairie Glen resulted in a savings of nearly $600,000. Savings for stormwater management accounted for 25 percent of the total savings. Table 13 provides a cost comparison. Other savings not included in the table were realized with reduced sanitary sewer, water distribution, and utility construction costs.

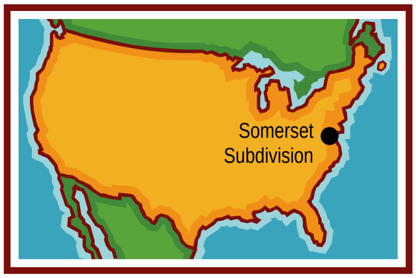
Table 13. Cost Comparison for Prairie Glen Subdivision[55]

Item	Conventional Development Cost	Prairie Glen LID Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$277,043	$188,785	$88,258	32%	22%
Stormwater management	$215,158	$114,364	$100,794	47%	25%
Site paving and sidewalks	$462,547	$242,707	$219,840	48%	54%
Landscaping	$50,100	$53,680	–$3,580	–7%	–1%
Total	$1,004,848	$599,536	$405,312	—	—

* Negative values denote increased cost for the LID design over conventional development costs.

The cluster design and preservation of a high percentage of open space resulted in a significant reduction in costs for paving and sidewalks. These reduced costs accounted for 54 percent of the cost savings for the overall site. Reduced costs for soil excavation and stockpiling were also realized. The use of open-channel drainage and bioretention minimized the need for conventional stormwater infrastructure and accounted for the bulk of the savings in stormwater management. Landscaping costs increased due to the added amount of open space on the site.

SOMERSET SUBDIVISION, PRINCE GEORGE'S COUNTY, MARYLAND



The Somerset subdivision, outside Washington, D.C., is an 80-acre site consisting of nearly 200 homes. Approximately half of the development was built using LID techniques; the other half was conventionally built using curb-and-gutter design with detention ponds for stormwater management. Bioretention cells and vegetated swales were used in the LID portion of the site to replace conventional stormwater infrastructure. Sidewalks were also eliminated from the design. To address parking concerns, some compromises were made: because of local transportation department concern that roadside parking would damage the swales, roads were widened by 10 feet.[56] (Note that there are alternative strategies to avoid increasing impervious surface to accommodate parking, such as installing porous pavement parking lanes next to travel lanes.)

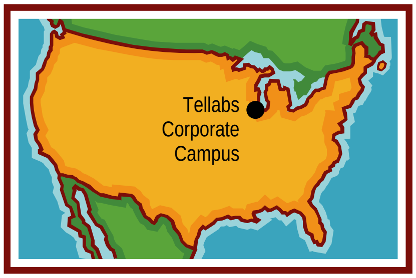
Most of the 0.25-acre lots have a 300- to 400-square-foot bioretention cell, also called a rain garden. The cost to install each cell was approximately $500—$150 for excavation and $350 for plants. The total cost of bioretention cell installation in the LID portion of the site was $100,000 (swale construction was an additional cost). The construction cost for the detention pond in the conventionally designed portion of the site was $400,000, excluding curbs, gutters, and sidewalks.[57,58] By eliminating the need for a stormwater pond, six additional lots could be included in the LID design. A comparison of the overall costs for the traditional and LID portions of the site is shown in Table 14.

Table 14. Cost Comparison for Somerset Subdivision

Conventional Development Cost	Somerset LID Cost	Cost Savings	Percent Savings	Savings per Lot
$2,456,843	$1,671,461	$785,382	32%	$4,000

In terms of environmental performance, the LID portion of the subdivision performed better than the conventional portion.[59] A paired watershed study compared the runoff between the two portions of the site, and monitoring indicated that the average annual runoff volume from the LID watershed was approximately 20 percent less than that from the conventional watershed. The number of runoff-producing rain events in the LID watershed also decreased by 20 percent. Concentrations of copper were 36 percent lower; lead, 21 percent lower; and zinc, 37 percent lower in LID watershed runoff than in conventional watershed runoff. The homeowners' response to the bioretention cells was positive; many perceived the management practices as a free landscaped area.

TELLABS CORPORATE CAMPUS, NAPERVILLE, ILLINOIS



The Tellabs corporate campus is a 55-acre site with more than 330,000 square feet of office space. After reviewing preliminary planning materials that compared the costs of conventional and conservation design, the company chose to develop the site with conservation design approaches. Because the planning process included estimating costs for the two development approaches, this particular site provides good information on commercial/industrial use of LID.[60]

Development of the site included preserving trees and some of the site's natural features and topography. For stormwater management, the site uses bioswales, as well as other infiltration techniques, in parking lots and other locations. The use of LID techniques for stormwater management accounted for 14 percent of the total cost savings for the project. A cost comparison is provided in Table 15. Other cost savings not shown in Table 15 were realized with reduced construction contingency costs, although design contingency costs were higher.

Table 15. Cost Comparison for Tellabs Corporate Campus[61]

Item	Conventional Development Cost	Tellabs LID Cost	Cost Savings	Percent Savings	Percent of Total Savings
Site preparation	$2,178,500	$1,966,000	$212,500	10%	46%
Stormwater management	$480,910	$418,000	$62,910	13%	14%
Landscape development	$502,750	$316,650	$186,100	37%	40%
Total	$3,162,160	$2,700,650	$461,510	—	—

Savings in site preparation and landscaping had the greatest impact on costs. Because natural drainage pathways and topography were maintained to the greatest extent possible, grading and earthwork were minimized; 6 fewer acres were disturbed using the conservation design approach. Landscaping at the site maximized natural areas and restored native prairies and wetland areas. The naturalized landscape eliminated the need for irrigation systems and lowered maintenance costs when compared to turf grass, which requires mowing and regular care. In the end, the conservation approach preserved trees and open space and provided a half acre of wetland mitigation. The bioswales used for stormwater management complemented the naturalized areas and allowed the site to function as a whole; engineered stormwater techniques augmented the benefits of the native areas and wetlands.[62]

TORONTO GREEN ROOFS, TORONTO, ONTARIO (A MODELING STUDY)

Toronto is home to more than 100 green roofs. To evaluate the benefits of greatly expanded use of green roofs in the city, a study was conducted using a geographic information system to model the effects of installing green roofs on all flat roofs larger than 3,750 square feet. (The model assumed that each green roof would cover at least 75 percent of the roof area.) If the modeling scenario were implemented, 12,000 acres of green roofs (8 percent of the City's land area) would be installed.[63] The study quantified five primary benefits from introducing the green roofs: (1) reduced stormwater flows into the separate storm sewer system, (2) reduced stormwater flows into the combined sewer system, (3) improved air quality, (4) mitigation of urban heat island effects, and (5) reduced energy consumption.[64]

The study predicted economic benefits of nearly $270 million in municipal capital cost savings and more than $30 million in annual savings. Of the total savings, more than $100 million was attributed to stormwater capital cost savings, $40 million to CSO capital cost savings, and nearly $650,000 to CSO annual cost savings. The cost of installing the green roofs would be largely borne by private building owners and developers; the cost to Toronto would consist of the cost of promoting and overseeing the program and would be minimal. Costs for green roof installations in Canada have averaged $6 to $7 per square foot. The smallest green roof included in the study, at 3,750 square feet, would cost between $22,000 and $27,000. The total cost to install 12,000 acres of green roofs would be $3 billion to $3.7 billion.[65,66] Although the modeled total costs exceed the monetized benefits, the costs would be spread across numerous private entities.

CONCLUSION

The 17 case studies presented in this report show that LID practices can reduce project costs and improve environmental performance. In most cases, the case studies indicate that the use of LID practices can be both fiscally and environmentally beneficial to communities. As with almost all such projects, site-specific factors influence project outcomes, but in general, for projects where open space was preserved and cluster development designs were employed, infrastructure costs were lower. In some cases, initial costs might be higher because of the cost of green roofs, increased site preparation costs, or more expensive landscaping practices and plant species. However, in the vast majority of cases, significant savings were realized during the development and construction phases of the projects due to reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping. Total capital cost savings ranged from 15 to 80 percent when LID methods were used, with a few exceptions in which LID project costs were higher than conventional stormwater management costs.

EPA has identified several additional areas that will require further study. First, in all the cases, there were benefits that this study did not monetize and factor into the project's bottom line. These benefits include improved aesthetics, expanded recreational opportunities, increased property values due to the desirability of the lots and their proximity to open space, increased number of total units developed, the value of increased marketing potential, and faster sales.

Second, more research is also needed to quantify the environmental benefits that can be achieved through the use of LID techniques and the costs that can be avoided by using these practices. For example, substantial downstream benefits can be realized through the reduction of the peak flows, discharge volumes, and pollutant loadings discharged from the site. Downstream benefits also might include reductions in flooding and channel degradation, costs for water quality improvements, costs of habitat restoration, costs of providing CSO abatement, property damage, drinking water treatment costs, costs of maintaining/dredging navigable waterways, and administrative costs for public outreach and involvement.

Finally, additional research is needed monetize the cost reductions that can be achieved through improved environmental performance, reductions in long-term operation and maintenance costs and/or reductions in the life cycle costs of replacing or rehabilitating infrastructure.

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[1] D. Beach, *Coastal Sprawl: The Effects of Urban Design on Aquatic Ecosystems in the United States* (Arlington, VA: Pew Ocean Commission, 2002).

[2] USDA, *Summary Report: 1997 National Resources Inventory* (Washington, DC: U.S. Department of Agriculture, Natural Resources Conservation Service, 1999 [revised 2000]).

[3] Beach, 2002.

[4] The term *LID* is one of many used to describe the practices and techniques employed to provide advanced stormwater management; *green infrastructure*, *conservation design*, and *sustainable stormwater management* are other common terms. However labeled, each of the

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identified practices seeks to maintain and use vegetation and open space, optimize natural hydrologic processes to reduce stormwater volumes and discharge rates, and use multiple treatment mechanisms to remove a large range of pollutants. In the context of this report, case studies ascribing to one of the above, or similar, labels were evaluated, and these terms are used interchangeably throughout the report.

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The Economics of Low-Impact Development: A Literature Review

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Low-impact development (LID) methods can cost less to install, have lower operations and maintenance (O&M) costs, and provide more cost-effective stormwater management and water-quality services than conventional stormwater controls. LID also provides ecosystem services and associated economic benefits that conventional stormwater controls do not.

The available economic research on some of these conclusions is preliminary or limited in scope. For example, most economic studies of LID describe the costs of installing LID, or compare the costs of installing LID with the costs of installing conventional controls. Few reports quantify the economic benefits that LID can provide in addition to managing stormwater. Fewer researchers report results of studies that measure at least some costs *and* at least some benefits of LID vs. conventional controls.

The costs and benefits of LID controls can be site specific and will vary depending on the LID technology (e.g., green roof vs. bioswale), and local biophysical conditions such as topography, soil types, and precipitation. Including developers, engineers, architects and landscape architects early in the design process can help minimize the LID-specific construction costs.

Despite the fact the LID technologies have been promoted and studied since the early 1990s, for many stormwater managers and developers, LID is still a new and emerging technology. As with most new technologies, installation and other costs of LID are highest during the early phases of development and adoption. Over time, as practitioners learn more about the technology, as the number of suppliers of inputs expands, and as regulations adapt to the new technology, costs will likely decline.

Combined sewer overflows (CSO), and the resulting biophysical and economic consequences, are major concerns for municipal stormwater managers. LID can help minimize the number of CSO events and the volume of contaminated flows by managing more stormwater on site and keeping flows out of combined sewer pipes. Some preliminary evidence exists that LID can help control CSO volumes at lower cost than conventional controls.

Many municipalities have zoning and building-inspection standards in place that were adopted many years ago, long before LID was an option. Municipalities with outdated stormwater regulations typically require that builders file variances if they want to use LID controls. This can increase a builder's design and regulatory costs, which delays construction and can increase a builder's financing costs. Updating building regulations to accommodate LID can help reduce the regulatory risk and expense that builders face.

The large majority of the economic studies on LID focus on the costs of including LID in new construction. Replacing curbs, gutters and stormwater pipes with bioswales, pervious pavers and other LID controls can reduce construction costs. Protecting a site's existing drainage patterns can reduce the need for pipe infrastructure and a developer may be able to do away with surface stormwater ponds, which also increases the number of developable lots. Some researchers report that developments that emphasize LID controls and protected natural grass and forest drainage areas cost less to develop and sell for more than traditionally-developed lots with conventional stormwater controls.

Few studies considered the economic outcomes of including LID in urban redevelopment projects. Some evidence exists that LID controls cost more than conventional controls under these conditions, however, these studies excluded O&M costs of the two alternatives and the economic benefits that the LID controls can provide.

I. INTRODUCTION

Conventional stormwater controls collect stormwater from impervious surfaces, including roads, parking lots and rooftops, and transport the flow off site through buried pipes to treatment facilities or directly to receiving bodies of water. This approach efficiently collects and transports stormwater, but also can create high-velocity flows polluted with urban contaminants, including sediment, oil, fertilizers, heavy metals, and pet wastes. Such flows can erode stream banks and natural channels, and deposit pollutants that pose ecosystem and public health risks (Kloss and Calarusse 2006).The resulting ecosystem and public health consequences can create significant economic costs.

A study of the biophysical and public health damages and associated economic costs of stormwater runoff in the Puget Sound estimates these costs at over $1 billion during the next decade (Booth et al. 2006). These costs include flood-related property damage and financial losses, capital costs of new stormwater infrastructure, cleaning up stormwater-polluted water resources, and habitat restoration and protection efforts. The Natural Resources Defense Council (Kloss and Calarusse 2006) describes similar impacts attributed to conventional controls across the U.S.: stormwater sewers collect and discharge untreated stormwater to water bodies, while combined sewer and stormwater systems overflow during heavy rains, discharging both untreated sewage and stormwater into the nation's rivers and lakes. Both contribute to impaired water quality, flooding, habitat degradation, and stream bank erosion. The U.S. Environmental Protection Agency (EPA) estimates the costs of controlling combined sewer overflows (CSO) throughout the U.S. at approximately $56 billion. Developing and implementing stormwater-management programs and urban-runoff controls will cost an additional $11 to $22 billion (Kloss and Calarusse 2006).

In contrast to conventional stormwater controls, low-impact development (LID) techniques emphasize on-site treatment and infiltration of stormwater. The term low-impact development encompasses a variety of stormwater-management techniques. Examples include bioswales, rain gardens, green streets, and pervious pavers (U.S. EPA 2000). The name LID came into use around the late 1990s, however stormwater managers employed LID techniques prior to this. Technicians in Prince George's County, Maryland were some of the first to install what eventually became known as LID techniques in the early 1990s as an alternative to conventional stormwater controls. Soon after, a few communities in the Chesapeake Bay area followed, experimenting with a number of LID demonstration projects. Over time, interest in LID as an alternative or complement to conventional controls grew, and so did the number of LID demonstration projects and case studies across the United States. The EPA reviewed the early literature on LID and described their assessment of this literature in a report released in 2000 (U.S. EPA and Low Impact Development Center 2000). Their review assessed the availability and reliability of data on LID projects and the effectiveness of LID at managing stormwater. While this report focused primarily on the potential stormwater-management benefits of LID, it concluded that LID controls can be more cost effective and have lower maintenance costs than conventional stormwater controls. In December of the following year, the Center for Watershed Protection published one of the earliest studies that focused primarily on the economic aspects of "better site design," which included many LID principles (Center for Watershed Protection 2001).

The amount of information available on the economics of managing stormwater using LID has grown since the publication of these first reports. Most studies describe the costs of installing LID, or compare the costs of installing LID with the costs of installing conventional controls. Other reports focus on the economic benefits that LID can provide in addition to managing stormwater. These benefits include mitigating flooding, improving water-quality, and providing amenity values for properties adjacent to LID, such as green streets. A few—very few—researchers report results of studies that attempt to characterize at least some costs *and* at least some benefits of LID vs. conventional controls in a *single* study. In this report we summarize our review of the literature on the economic costs and benefits of managing stormwater by LID.

This literature review has three objectives. First, to describe briefly, and in plain language, the methods economists use when measuring the costs and benefits of LID and conventional stormwater controls. This information provides the reader with a context for the economic descriptions of costs and benefits that follow. Second, to summarize the literature that identifies and measures the economic costs and benefits of managing stormwater using LID, or that compares costs or benefits, or both, between LID and conventional controls. Third, to organize and present this information in a way that non-economist municipal officials, stormwater managers, ratepayer stakeholders and others can use as they consider and deliberate stormwater-management plans.

This literature review differs from literature reviews that accompany academic studies. Typically, academic literature reviews provide an introduction and a context for an analysis of a specific economic issue, e.g., a new analytical technique that measures economic benefits. In this case, the literature review is a stand-alone document that summarizes information on the broad issue of economic costs and benefits of LID. Academic literature reviews also target academic and professional economists. This literature review targets non-economist readers.

The technical effectiveness of LID stormwater controls is outside the scope of our review. Our analysis assumes that the LID techniques described in the economic studies that we reviewed provide the necessary or expected stormwater controls. As we understand, there is a growing body of literature on LID effectiveness, and we include some of these references in the Appendix to this report. Also, the more general topic of the economic values of ecosystem services, while somewhat related, was outside the scope of our review. Our analysis focused on the values of ecosystem services as affected by LID techniques.

We began our search for relevant literature by developing a list of key words with which to find reports or articles that contained relevant information. After a cursory search of LID literature, we identified LID- and economics-related key words that researchers and practitioners use when describing LID projects and analyses. The list includes words often used synonymously with LID (i.e., source control, natural drainage systems, sustainable stormwater management), or that describe a set of conservation-design strategies that include LID techniques (i.e., green infrastructure and conservation development). We also searched the literature using economics-related terms (i.e., costs, benefits, and savings). Table 1-1 lists the LID- and economics-related search terms we used in our search of the literature.

Using the terms listed in Table 1-1, we searched databases that contained the widest-possible range of sources including academic literature, reports produced by government agencies and non-profit organizations, news coverage, and articles in the popular press. These databases include information published in peer-reviewed articles, books, reports, conference papers and presentations, and web pages. Table 1-2 lists the databases included in our search.

Table 1-1: Search Terms

LID-Related Search Terms	Economics-Related Search Terms
Low-impact development	Economics
Source control	Benefits, economic benefits
Green infrastructure	Costs, economic costs
Natural drainage systems	Cost comparison
Sustainable stormwater management	Savings
Conservation development	Benefit cost analysis, cost benefit analysis
Alternative stormwater management	Cost effectiveness
Better site design	
Low-impact urban design and development	

Source: ECONorthwest

Table 1-2: Databases

Database	Description
Academic Search Premier	Index of 8,000 academic journals in the social sciences, humanities, and general science, back to 1965.
Article First	Index of 16,000 journal titles in business, humanities, popular culture, science, social science, and technology, back to 1990.
Econlit	American Economic Association's index of economic research, back to 1969.
Environmental Protection Agency (EPA) website	Database of studies, reports, educational material, and newsletters authored or supported by the EPA.
Environmental Valuation Reference Inventory (EVRI)	Database of empirical studies conducted internationally on the economic values of ecosystem services.
Google	Source for non-peer reviewed reports, articles, websites and other publications.
Journal Storage (JSTOR)	Index of over 100 major research journals in a variety of academic disciplines, some back to 1870.
Web of Science	Index of science and social science journals, back to 1975.
WorldCat	Index of bibliographic records of books, journals, manuscripts, etc. archived in university, public and private library catalogs around the world.

Source: ECONorthwest

We reviewed potential sources for relevance. If a source contained LID-related cost or benefit information, we indexed it in our own database, summarized the information on costs or benefits, and reviewed its bibliography for additional sources of information.

This report of our review of the literature is organized as follows. The next two sections provide background information to the discussion of the economic costs and benefits of managing stormwater. This background information provides a context or economic frame-of-reference that will help the reader consider the descriptions of costs and benefits that follow.

In **Section II** we list the range of benefits associated with LID, as identified in the LID literature, along with illustrations of the values of these benefits as reported in the economic literature. We found that many more reports simply list these benefits rather than quantify them.

In **Section III** we describe two of the more common methods of measuring the economic costs and benefits of stormwater controls: the cost-effectiveness and benefit-cost methods. As the names imply, cost-effectiveness studies compare alternatives looking exclusively at the alternatives' costs. This method assumes away benefits or holds them constant across alternatives. A benefit-cost analysis considers the range of costs and benefits for each alternative. The benefit-cost method has greater data demands and can be more expensive than the cost-effectiveness approach—primarily because it adds benefits into the analysis—but it can also yield a more accurate economic picture of the full range of economic consequences of implementing the alternatives.

In **Section IV** we summarize the literature that considers the costs and benefits of LID. The large majority of these studies focus exclusively on the costs of installing LID, or compare the costs of installing LID with the costs of installing conventional controls. Some studies look beyond installation costs to include operations and maintenance costs. Few studies consider both the costs and benefits of LID or compare costs and benefits of LID with conventional controls.[1] When the literature allowed, we described the economic aspects of adopting LID from the perspective of municipal decisionmakers, ratepayer stakeholders, and private developers.

In **Section V** we describe LID from the perspective of property developers. As with other new technologies, adopting LID includes opportunities and risks. We describe the risks and challenges that developers face when they include LID controls in their projects and the successes developers have had adopting LID.

In **Section VI** we discuss areas of future research that would increase our understanding of the economics of LID. For example, limited information exists on the life-cycle costs of LID, the economic benefits of LID beyond stormwater control, and the economic impacts of installing LID in urban-redevelopment settings.

The **Bibliography** lists the references we cite in this report. During our search for information on the economic aspects of LID, we encountered non-economic information that supports the use of LID. We list this information in the **Appendix** to this report.

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[1] We list the reported dollar amounts of costs and benefits without converting to current, 2007-year, dollars because in most cases, the available information prevented such a conversion.

II. ECOSYSTEM SERVICES PROVIDED OR ENHANCED BY LOW-IMPACT DEVELOPMENT

Conventional controls and LID techniques both manage stormwater flows. By promoting stormwater management on site using a variety of techniques, LID controls can provide a range of ecosystem services beyond stormwater management. Braden and Johnston (2004), Coffman (2002), and the Natural Resources Defense Council (Lehner et al. 2001) list and describe the kinds of ecosystem services that LID can provide or enhance. Taken together, these researchers describe the following ecosystem services: reduced flooding, improved water quality, increased groundwater recharge, reduced public expenditures on stormwater infrastructure, reduced ambient air temperatures and reduced energy demand, improved air quality, and enhanced aesthetics and property values. We briefly describe each of these services below.

Reduced Flooding

Braden and Johnston (2004) studied the flood-mitigation benefits of managing stormwater on site, including reduced frequency, area, and impact of flooding events. In a follow-up study, Johnston, Braden, and Price (2006) focus on the downstream benefits accrued from flood reduction accomplished by greater upstream on-site retention of stormwater. These benefits include reduce expenditures on bridges, culverts and other water-related infrastructure.

Improved Water Quality

Brown and Schueler (1997), Center for Watershed Protection (1998), U.S. EPA and Low Impact Development Center (2000), and Braden and Johnston (2004) describe the water-quality benefits that LID stormwater controls can provide. These benefits include effectively capturing oil and sediment, animal waste, landscaping chemicals, and other common urban pollutants that typically wash into sewers and receiving water bodies during storm events. Plumb and Seggos (2007) report that LID controls that include vegetation and soil infiltration, e.g., bioswales, can prevent more stormwater pollutants from entering New York City's harbor than conventional controls.

Increased Ground Water Recharge

On-site infiltration of stormwater helps recharge groundwater aquifers. According to a report by American Rivers, the Natural Resources Defense Council, and Smart Growth America (Otto et al. 2002), areas of impervious cover can significantly reduce ground water recharge and associated water supplies. The study found that impervious surfaces in Atlanta reduced groundwater infiltration by up to 132 billion gallons each year—enough water to serve the household needs of up to 3.6 million people per year.

Braden and Johnston (2004) distinguish between two services associated with increased groundwater recharge: the increased volume of water available for withdrawal and consumption, and maintaining a higher water table, which reduces pumping costs and increases well pressure.

Reduced Public Expenditures on Stormwater Infrastructure

The Center for Watershed Protection (1998), Lehner et al. (2001), and U.S. EPA (2005) report that LID techniques, such as bioswales, rain gardens, and permeable surfaces, can help reduce the demand for conventional stormwater controls, such as curb-and-gutter, and pipe-and-pond infrastructure. Braden and Johnston (2004) report that retaining stormwater runoff on site reduces the size requirements for downstream pipes and culverts, and reduces the need to protect stream channels against erosion.

Two recent studies by the Natural Resources Defense Council (Kloss and Calarusse 2006) and Riverkeeper (Plumb and Seggos 2007) report that by managing stormwater on site, LID techniques can help reduce combined sewer overflows. Combined sewer systems transport both sewage and stormwater flows. Depending on the capacity of the pipes and the amount of rainfall, the volume of combined sewer and stormwater flows can exceed the capacity of the pipes when it rains. When this happens, overflows of sewage and stormwater go directly to receiving bodies of water untreated. LID helps to keep stormwater out of the combined system, which reduces CSO events. Thurston (2003) found that decentralized stormwater controls, such as LID, can control CSO events at a lower cost than conventional controls.

Reduced Energy Use

LID techniques, such as green roofs and shade trees incorporated into bioswales and other controls can provide natural temperature regulation, which can help reduce energy demand and costs in urban areas. Plumb and Seggos (2007) estimate that covering a significant amount of the roof area in New York City with green roofs could lower ambient air temperatures in summer by an estimated 1.4 degrees Fahrenheit. The U.S. EPA and Low Impact Development Center (2000) report that the insulation properties of vegetated roof covers can help reduce a building's energy demand, and notes that green roofs in Europe have successfully reduced energy use in buildings.

Improved Air Quality

Trees and vegetation incorporated into LID help improve air quality by sequestering pollutants from the air, including nitrogen dioxide, sulfur dioxide, ozone, carbon monoxide, and particulate matter (American Forests 2000-2006). In a study by Trees New York and Trees New Jersey, Bisco Werner et al. (2001) report similar air-quality benefits of trees and vegetation in urban areas. Plumb and Seggos (2007) cite one study that found that a single tree can remove 0.44 pounds of air pollution per year.

Enhanced Aesthetics and Property Values

Several studies including Lacy (1990), Mohamed (2006), U.S. Department of Defense (2004), and Bisco Werner et al. (2001) report that the natural features and vegetative cover of LID can enhance an area's aesthetics, and increase adjacent property values. The U.S. Department of Defense (2004) highlights how LID can improve the aesthetics of the landscape and increase adjacent property values by providing architectural interest to otherwise open spaces. On commercial sites, Bisco Werner et al. (2001) found that LID on commercial sites provided amenities for people living and working in the area and complemented the site's economic vitality, which improved its competitive advantage over similar establishments for customers and tenants.

III. ECONOMIC FRAMEWORK: MEASURING COSTS AND BENEFITS OF LOW-IMPACT DEVELOPMENT

Researchers and practitioners assess the economic aspects of LID using several methodologies. These methodologies range from rough cost evaluations, that compare a subset of costs of LID against the same costs for conventional management techniques, to benefit-cost analyses, that compare a range of costs and benefits of LID to the same for conventional stormwater controls. This section examines the differences in these methodologies.

Most economic evaluations of LID reported in the literature emphasize costs. The overwhelming majority of these studies confined their analyses to measuring installation costs. Evaluators prefer this method perhaps because from a developer's perspective, installation cost is one of the most important considerations when choosing between LID or conventional controls. LID can compare favorably with conventional controls in a side-by-side analysis of installation costs (*see for example* Foss 2005; Conservation Research Institute 2005; U.S. EPA 2005; Zickler 2004), however, focusing on installation costs misses other relevant economic information. For example, such a focus excludes operation and maintenance (O & M) costs, differences in the effectiveness of LID versus conventional systems, and the environmental and economic benefits that LID can provide, but which conventional controls cannot.

Evaluating projects based on installation costs has advantages of costing less than studies that include other economic factors, e.g., O & M costs, taking less time than more extensive analyses, and relying on readily available construction-cost data. The tradeoff for stormwater managers is an incomplete and possibly biased description of economic consequences, especially over the long term.

Some researchers look beyond comparisons of installation costs and evaluate LID and conventional controls using a method know as a life-cycle cost analysis (LCCA) (Powell et al. 2005; Sample et al. 2003; Vesely et al. 2005). This approach considers a comprehensive range of stormwater-management costs including planning and design costs, installation costs, O & M costs, and end-of-life decommissioning costs. An LCCA method requires more data than a comparison of installation costs, and this data, particularly data on lifetime O & M costs, may not exist or is difficult and costly to obtain. The tradeoff for policy makers is more accurate information on the cost implications of alternative stormwater-management options. However, LCCA, like more limited cost comparisons, excludes measures of economic benefits.

Another limitation of cost comparisons is that they ignore differences in effectiveness between LID and conventional controls. For this reason, researchers recommend that LCCA should compare projects that provide the similar levels of services (Powell et al. 2005). Brewer and Fisher (2004), Horner, Lim, and Burges (2004), and Zielinski (2000) found, however, that LID approaches can manage stormwater quantity and quality more effectively than the conventional approaches, either controlling more flow, or filtering more pollutants, or both. In these cases, an LCCA study could conclude that an LID option costs more than the conventional control, without accounting for the fact that the LID option can manage a larger volume of stormwater.

The benefit-cost approach overcomes the limitations of simple cost comparisons or LCCA by considering the full range of costs and benefits of alternative management options. The tradeoff is that the benefit-cost approach requires more data than cost comparison, which increases the time and costs of conducting the economic analysis.

The benefit-cost approach evaluates the net economic benefits of a project, or compares outcomes among projects, by comparing relevant costs with relevant economic benefits (Boardman et al. 2005; Field and Field 2006; Gramlich 1990; Kolstad 2000). Economic researchers in academic, business, and public-policy sectors have for many years conducted benefit-cost analyses in a wide variety of applications. Since at least the middle of the twentieth century, economic evaluations of large-scale public projects included some type of benefit-cost analysis, and since 1981, the federal government required that new programs and regulations include a benefit cost analysis (Freeman 2003). The U.S. Office of Management and Budget (OMB) considers the benefit-cost method the "recommended" technique when conducting formal economic analyses of government programs or projects (U.S. OMB 1992). Over the years, the technique has grown more sophisticated, especially with respect to measuring and incorporating non-market goods and services, such as the values of ecosystem services (Croote 1999).

The economic literature on benefit-cost analysis is voluminous and growing, but the basic process can be broken into four steps (Field and Field 2006).[2]

1. The first step defines the scope of the analysis, including the population that will experience the benefits and costs, and the elements of the project, including location, timing, and characteristics of the work to be done.

2. The second step determines a project's full range of inputs and effects, from the planning and design phase through the end of the project's lifespan.

3. The third step identifies and, where possible, quantifies the costs and benefits resulting from the project's inputs and effects. Where quantification is not possible, qualitatively describe the cost or benefit in as much detail as possible, including degree of uncertainty and expected timing of impacts (long-term or short-term).

4. The final step compares the benefits and costs of the project, either in terms of net benefits (the total benefits minus the total costs) or in terms of a benefit-cost ratio (the amount of benefits produced per unit of cost). If relevant, compare results among alternative projects.

We found few benefit-cost evaluations of LID projects. The large majority of studies estimate installation costs, a few consider additional costs, such as O & M costs, and a handful compared some measures of costs against some measures of benefits. The reported benefit-cost studies of LID include Bachand (2002) and Fine (2002),[3] Devinny

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[2] For a more complete discussion of benefit-cost analysis, see Field and Field (2006), Gramlich (1990) and Harberger and Jenkins (2002).

[3] We reviewed summaries of Bachand (2002) and Fine (2002) because we were unable to acquire copies of the full articles.

et al. (2005), and Doran and Cannon (2006). Data limitations may explain part of the reason for the limited number of benefit-cost analyses of LID. This is especially true for lifetime O & M costs and the economic importance of LID benefits. Sample et al. (2003), Powell et al. (2005), Johnston, Braden, and Price (2006), and Conservation Research Institute (2005), among others, describe the need for more research quantifying the benefits of LID practices.

Another reason may be that economic benefits or lifetime O & M costs have no relevance to a given economic study. For example, property developers pay installation costs of stormwater controls, but not lifetime O & M costs. Nor do they benefit directly from the ecosystem services that LID can enhance or provide. Economic results reported by developers will therefore likely focus exclusively on installation costs of LID or compare installation costs for LID and conventional controls.

Using the benefit-cost approach has challenges that the other analytical methods do not. However, benefit-cost analysis has advantages in that it can provide decisionmakers, ratepayers and other stakeholders with a more complete picture of the economic consequences of stormwater-management alternatives than other analytical methods. This is especially true for costs and benefits of alternatives over the long term. In situations in which time, budget, or other information constraints limit quantifying economic benefits or costs, the next best alternative is identifying the range of costs and benefits, quantifying what can be measured and describing the remaining impacts qualitatively. The federal government takes this approach in that the OMB recommends that when benefits and costs cannot be quantified, agencies should provide qualitative descriptions of the benefits and costs. These qualitative descriptions should include the nature, timing, likelihood, location, and distribution of the unquantified benefits and costs (U.S. OMB 2000).

IV. COSTS AND BENEFITS OF LOW-IMPACT DEVELOPMENT

The large majority of literature that describe economic assessments of LID focus on the costs of installing the technology. Most studies report the costs of building LID stormwater controls, or compare the costs of installing LID to the costs of conventional controls. The organization of this section reflects this emphasis in the literature. We begin by summarizing studies that list the costs of installing various LID techniques. Most of these reports describe the outcomes of case studies of LID installed as new or developing stormwater-management technologies. We then discuss studies that compare the costs of building LID controls with the costs of building conventional controls.

A number of researchers looked beyond installation costs and considered the impacts that operations and maintenance costs can have on economic evaluations of LID. Analysts sometimes refer to these as life-cycle studies because they consider the relevant costs throughout the useful life of a technology. We summarize three studies that took this approach with LID evaluations.

Combined sewer overflows, and the resulting biophysical and economic consequences, are major concerns for municipal stormwater managers. LID can help minimize the number of CSO events and the volume of contaminated flows by managing more stormwater on site and keeping flows out of combined sewer pipes. We summarize five studies that evaluated the costs of managing CSO events using LID.

A relatively small percentage of the economic evaluations of LID reported in the literature include assessments of the economic benefits of the technology. We summarize a number of these reports at the end of this section.

A. Cost of Low-Impact Development

Brown and Schueler (1997) surveyed construction costs for different methods of managing stormwater in urban areas. Their survey emphasized conventional controls but also included a number of LID techniques. At the time of their study, LID techniques were considered “next generation” best-management practices (BMPs). The report lists construction costs for sixty-four BMPs including wet and dry stormwater ponds, bioretention areas, sand filters and infiltration trenches. The authors’ major conclusion is that a BMP’s construction cost increases with the volume of stormwater the BMP stores. The report’s construction costs may be out-of-date, however they provide insights into relative cost differences between LID and other controls listed in the report.

In a more recent study, Tilley (2003) reports construction costs for LID case studies implemented in Puget Sound and Vancouver, B.C. The report describes a range of case studies from small-scale projects implemented by homeowners to large installations completed by universities, developers and municipal governments. The LID techniques studied include rain gardens, permeable pavement and green roofs. The amount of cost information varies by case study. In some cases the report lists per-unit costs to install an LID, e.g., a pervious concrete project cost $1.50 per square foot for materials (excluding labor). Other descriptions report costs generally, but not costs specific to the case study described, e.g., the cost for pervious concrete is typically $6 to $9 per square foot. Some descriptions have no cost information, and others list total construction costs without a detailed breakdown of cost components.

The U.S. Department of Defense (DoD) (2004) developed a manual of design guidelines to incorporate LID into DoD facilities. The manual describes 13 stormwater-management techniques and their most appropriate uses, maintenance issues, and cost information. The list of LID techniques includes bioretention, grassed swales, and permeable pavers. The manual describes costs in some detail but also notes the site-specific nature of construction costs and factors that can influence construction costs for certain LIDs.

Liptan and Brown (1996) describe one of the earliest comparisons of construction costs for LID with that for conventional controls.[4] They focus on two projects in Portland, Oregon, which they refer to as the OMSI and FlexAlloy projects, and the Village Homes development in Davis, California. In all cases, the LID option cost less. The LID design implemented at the OMSI project saved the developer $78,000 in construction costs by reducing manholes, piping, trenching, and catch basins. At the FlexAlloy site, the City of Portland conducted a retrospective study of LID vs. conventional development, after the builder installed conventional controls. The City calculated that the developer could have saved $10,000 by implementing the LID option. The description of the FlexAlloy case study includes a detailed comparison of construction costs for the two options. The Village Homes case study concluded that by using vegetated swales, narrow streets, and a cluster layout of building lots, the developer saved $800 per lot, or $192,000 for the development. The Village Homes description includes no additional details on construction costs for the two options. The report also includes brief descriptions of other LID case studies, some with cost comparisons for LID vs. conventional controls. The authors conclude that involving developers, engineers, architects and landscape architects early in the design of a development that includes LID can help minimizing the LID-specific construction costs.

Hume and Comfort (2004) compared the costs of constructing conventional roads and stormwater controls with the costs of building LID options, such as bioretention cells and pervious pavement. The researchers added complexity to some of their comparisons by paring the same conventional and LID controls, e.g., infiltration trench (conventional) vs. bioretention cell (LID) on a different soil types and with different sources of stormwater runoff (e.g., driveway vs. roof top) to see how this affected construction costs. In some comparisons the LID option cost more than the conventional option, in other cases the results were opposite. These comparisons illustrate the site-specific nature of LID construction costs. Local conditions, e.g., less pervious soils, can influence the costs of LID controls.

In some cases, LID can help lower construction costs by making use of a site's existing or undisturbed drainage conditions in ways that conventional controls cannot. Planners of a 44-acre, 80-lot residential development in Florida took advantage of the site's natural drainage patters to help lower stormwater-management costs (PATH 2005). The site's low-lying areas convey the large majority of stormwater runoff to forested basins. The developer minimized disturbing natural drainage patterns by clustering building sites and connecting sites with narrow roads. Relying on natural infiltration and drainage patterns help the developer save $40,000 in construction costs by avoiding the costs of constructing stormwater ponds.

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[4] In this Section we describe some of the developments associated with costs comparisons reported in the LID literature. The next Section focuses on LID from the perspective of property developers and contractors. In that Section we list results for a larger number of cost comparisons

Comparing construction costs between LID and conventional options, while informative, provides no information on the relationship between the cost and effectiveness. For example, in cases where the LID option costs more to build, it may also control a larger volume of stormwater relative to the conventional option. LID that keeps stormwater out of pipes and treatment facilities help lower operations and maintenance (O & M) costs, and help extend the useful life of the infrastructure, which can reduce future construction costs. The relative importance of construction or O & M costs depends on who pays for them. Builders likely focus exclusively on construction costs, however, cost and effectiveness information would help stormwater managers better evaluate control options and plan for future demands on stormwater infrastructure.

Brewer and Fisher (2004) report the results of four case studies that compared the cost and effectiveness of LID to that of conventional controls. The case studies modeled stormwater costs and conditions on four developments: high- and medium-density residential, an elementary school, and a commercial development. In both residential developments LID controls cost less than conventional controls. LID cost more for the school and commercial development. However, in all four cases, the LID option managed a larger volume of stormwater than the conventional option. We reproduce Brewer and Fisher's results in Table 4-1.

Table 4-1: Comparison of Runoff Controlled and Cost Savings for Conventional and LID Design.

Site Example	Runoff Storage (acre-feet)		LID Net Cost or Savings
	Conventional	LID	
Medium Density Residential	1.3	2.5	$476,406
Elementary School	0.6	1.6	$(48,478)
High Density Residential	0.25	0.45	$25,094
Commercial	0.98	2.9	$(9,772)

Source: Brewer and Fisher 2004

We calculated the economic value of the additional storage provided by the LID designs reported in Brewer and Fisher (2004), using data on the national average of construction costs as reported by American Forests. American Forests' CITYgreen analyses calculate the national-average cost of storing 1 acre-foot of runoff at $87,120.[5] American Forests uses a value of $2.00 per cubic foot of storage, obtained from national estimates of stormwater construction costs. This amount represents the avoided costs of not building stormwater detention ponds. This value may vary, depending on a project's location. In some of its analyses, American Forests uses local estimates of construction costs, which can be lower or higher than the national average. For example, American Forests uses

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[5] *See, for example,* American Forests. 2003. *Urban Ecosystem Analysis: San Diego, California*. July. Retrieved August 2, 2007, from http://www.americanforests.org/downloads/rea/AF_SanDiego.pdf, American Forests. 2003. *Urban Ecosystem Analysis: Buffalo-Lackawanna Area, Erie County, New York*. June. Retrieved August 2, 2007, from http://www.americanforests.org/downloads/rea/AF_Buffalo.pdf.

$0.66 per cubic foot of storage in Houston, TX,[6] $5.00 per cubic foot of storage in the Washington D.C. Metro Area,[7] and $6.00 per cubic foot of storage in Portland, OR.[8] Table 4-2 shows the results of our calculation.

Table 4-2: Value of the Difference in Runoff Storage Provided by LID Designs.

Site Example	Runoff Storage (acre-feet)			Runoff Storage Difference (cubic-feet)[a]	Value of Difference in Runoff Storage ($2/cf)
	Conventional	LID	Difference		
Medium Density Residential	1.3	2.5	1.2	52,272	$104,544
Elementary School	0.6	1.6	1	43,560	$87,120
High Density Residential	0.25	0.45	0.2	8,712	$17,424
Commercial	0.98	2.9	1.92	83,635	$167,270

Source: ECONorthwest
Notes: [a] To convert from an acre foot to cubic feet, multiply by 43,560 (the number of cubic feet in an acre-foot).

Based on the results reported in Table 4-1, and taking the perspective of a builder, LID is the higher-cost alternative for the school and commercial development. Including the results from Table 4-2, and taking the perspective of a municipal stormwater manager—that is, considering construction costs and the cost savings associated with reductions in stormwater volume in our example calculation above—the LID option dominates the conventional choice in all four cases. The LID options control a larger volume of stormwater, which helps avoid municipal expenditures on stormwater management.

Doran and Cannon (2006) studied the relationship between construction costs of LID and conventional controls and effectiveness as measured by improvements in water quality. They studied the impacts of incorporating LID into a downtown redevelopment project in Caldwell, Idaho. The analysis modeled construction costs and improvements to water quality as measured by reduced concentrations of sediment and phosphorus in stormwater runoff. The LID techniques used in the project included permeable pavers, bioretention swales, riparian wetlands, and plantings of restored native vegetation. The study evaluated the LID and conventional controls using the cost of a 1-percent reduction in sediment and phosphorus concentrations. Conventional stormwater controls had lower

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[6] American Forests. 2000. *Urban Ecosystem Analysis for the Houston Gulf Coast Region*. December. Retrieved August 2, 2007, from http://www.americanforests.org/downloads/rea/AF_Houston.pdf.

[7] American Forests. 2002. *Urban Ecosystem Analysis: The District of Columbia*. February. Retrieved August 2, 2007, from http://www.americanforests.org/downloads/rea/AF_WashingtonDC2.pdf.

[8] American Forests. 2001. *Regional Ecosystem Analysis for the Willamette/Lower Columbia Region of Northwestern Oregon and Southwestern Washington State*. October. Retrieved August 2, 2007, from http://www.americanforests.org/downloads/rea/AF_Portland.pdf.

installation costs, but also had a lesser impact on water quality. Conventional controls cost $8,500 and reduced sediment and phosphorus concentrations by 5 percent, or $1,700 per percent reduction. LID stormwater controls cost more, $20,648, but had a greater impact on water quality, reducing sediment by 32 percent and phosphorus by 30 percent. The authors calculated a cost of $645 per percent reduction for the LID option. The LID option produced a better return on initial investment, as measured by improvements to water quality, than did investments in conventional controls.

As the previous two studies illustrate, comparing LID and conventional controls based on costs may bias the assessment against the most effective management option, and the option that yields the greatest return on investment. LID may cost more to build, but from an investment perspective, it may also control more stormwater and better improve water quality. The studies above considered separately LID effectiveness as measured by volume of stormwater managed and improvements in water quality of stormwater runoff. A more complete and accurate assessment of effectiveness and costs would consider the impacts on both in a single study. That is, compare LID and conventional controls based on costs and effectiveness as measured by volume of stormwater *and* water quality. We found no such studies in the literature.

Looking beyond construction costs to O & M and other costs gives a more complete description of the economic consequences of adopting LID or conventional controls. Sample et al. (2003) promotes evaluating stormwater BMPs using life-cycle-cost (LCC) analysis. LCC analysis includes the initial capital expenditures for construction, planning, etc., and the present value of lifetime O & M costs, and the salvage value at the end of the BMP's useful life. In addition, the authors suggest including the opportunity cost of land in the cost analysis. BMPs that occupy more land area have a higher opportunity cost valued at the next-best use for the land, e.g., residential value.

Vesely et al. (2005) compared the LCC for LID controls in the Glencourt Place residential development in Auckland, New Zealand with LCC results for conventional controls. The LID option had the added benefit of reusing stormwater collected on site as grey water for laundry, flushing toilets and irrigation. The LID option had LCCs that were 4 to 8 percent higher than the conventional option, depending on the discount rate and number of years in the analysis. These results do not account for the value of recycled stormwater. Including the avoided cost associated with water saved by recycling stormwater as household gray water, the LCC for the LID option were 0 to 6 percent higher, again, depending on the discount rate and number of future years in the analysis. The authors conclude that accounting for the value of water saved, the LID option was cost competitive with the conventional approach, as measured by the LCC method.

Data constraints on this study included difficulty estimating current and future maintenance costs and future decommissioning costs. Accounting for the opportunity cost of land also proved challenging give the available data. Data limitations also prevented the authors from considering the economic aspects of environmental externalities associated with the LID and conventional options.

LCC evaluations are an improvement over comparisons of construction costs in that they provide a more comprehensive assessment of relevant costs. On the other hand, LCC analyses require more data and results are sensitive to the discount rate applied to future values and the number of years of the analysis. Powell et al. (2005) underscore these advantages and challenges associated with LCC analysis. They recommend a checklist of factors to consider when conducting a LCC for LID and conventional controls. The checklist includes *quantitative* assessments of the components of LCC costs including acquisition, construction, O & M, and salvage value. Also included are *qualitative* assessments of the effectiveness of managing stormwater and the benefits attributed to the management option. The authors note that effectively and accurately implementing LCC analyses for LID will require more research into the costs of LID design, construction and O & M. Further research is also need in assessing the monetary benefits of LID controls.

Despite the fact that LID technologies have been promoted and studied since the early 1990s, in many ways, and to many stormwater managers, LID is still a new and emerging technology (Coffman 2002). As with most new technologies, installation and other costs for LID are highest during the early phases of development and adoption. Over time, as practitioners learn more about the technology, as the number of suppliers of inputs increases, and as regulations adapt to the new technology, costs will likely decline.

Foss (2005) describes this relationship between a learning curve and construction costs for greenstreet technology in Seattle. The city spent $850,000 implementing a greenstreet pilot project, known as the “Street Edge Alternative” (SEA) street. The City’s street planners expect that based on their experience with the pilot project, building greenstreets in the future will cost substantially less. Foss quotes the manager of the City’s surface water program on this point:

> *“You could take $200,000 off the price just from what we didn’t know. ... The pilot phases that we are currently in are more expensive, but as the project becomes institutionalized, all the costs will come down. Even still, these projects are less expensive than standard projects.” (p. 7)*

B. Costs of Managing Combined Sewer Overflows By Low-Impact Development

One of the earliest studies of the economic aspects of managing combined sewer overflows by LID evaluated a project that disconnected downspouts as a means of reducing the number of CSO events and costs (Kaufman and Wurtz 1997). In 1994, the Beecher Water District (BWD) near Flint, Michigan, provided free downspout diversions from home sites to sanitary-sewer pipes for the 6,020 residential customers in their service area. The purpose of the program was to reduce the volume of sewer flows from the BWD to the City of Flint’s stormwater facility—and reduce the fees that BWD paid the city to manage these flows—and reduce the number and volume of CSO events in the BWD.

The program was a success on many levels and is an example of a small-scale and inexpensive approach that effectively managed CSO events. Disconnecting downspouts cost the BWD just over $15,000. After the diversions, the mean volume of sewer flows measured across all precipitation events decreased 26 percent. The program saved the BWD over $8,000 per month in reduced fees to the City of Flint’s stormwater facility, and in reduced costs of managing CSO events. The program paid for itself in two months. Other benefits included reduced CSO-related customer complaints, improved recharge of groundwater and reduced pollution of the Great Lakes, the receiving waters for CSO from the District.

In another study looking at controlling CSO events on a smaller scale, Thurston et al. (2003) modeled the costs of CSO controls for a small watershed in Cincinnati, Ohio. The modeling exercise was part of a study that evaluated the theoretical considerations of developing a market for tradable stormwater credits as a means of reducing CSO events and costs. One part of the study compared the construction costs of controlling CSO events by building tunnels and storage vaults with the costs of building LID controls on each of the 420 mostly-residential lots in the study area.

They calculated that building the tunnel and vault option would cost between $8.93 to $11.90 per cubic foot of storage capacity. Building LID controls on individual lots would cost $5.40 per cubic foot of capacity. Based on these results the researchers suggest that the costs of managing CSOs by implementing LID throughout the watershed would cost less than building a large centralized tunnel and vault system to store excess flows. They also note, however that their analysis does not include the opportunity cost of land that the LID controls would occupy, and so the cost of the LID option would be higher than they report. Their analysis also excludes O & M costs for both options, as well as the costs of education and outreach to property owners, and managing the construction of a large number of dispersed LID projects as components of the LID option. The project also excludes the economic benefits of the LID option.

Kloss and Calarusse (2006) developed a set of policy guidelines for decisionmakers interested in implement LID controls as a means of reducing CSO events in their jurisdictions. Regarding the costs of LID controls, the authors distinguish between new and retrofit construction projects. In new developments, they conclude, LID typically cost less than conventional stormwater controls. They note, however, that retrofit developments in urban areas that include LID typically cost more than conventional controls. This is especially true for individual, small-scale retrofit projects. The relative costs of LID controls can be reduced when they are incorporated into larger-scale redevelopment projects. The report provides conclusions with limited details on cost information. The report also describes the experiences of nine municipalities across the country that include LID in their policies to control CSO events and related costs.

Montalto et al. (2007) described the relationship between public agencies tasked with controlling CSO events, and private land owners on whose property the large majority of LID controls would be sited. The public agencies benefit from the reduced stormwater flows and CSO events that LID provides. The land owner, however, pays the LID installation and O & M costs, but may see little benefit beyond reduced stormwater fees or increased property values from LID such as greenstreets. These benefits may not outweigh the costs to the land owner, and so they may choose not to install LID controls. Given this disconnect, the authors note the benefits of public policies, incentives and subsidies to promote LID adoptions by private-property owners.

In an effort, in part, to measure the amount of subsidy that may be required, the authors developed a model to assess the cost-effectiveness of mitigating CSO events in urban areas using LID. They applied their model to a case study in the Gowanus Canal area of Brooklyn, NY. The case study compared the costs of installing porous pavement, green roofs, wetland developments and other LID throughout the study area to the costs of installing storage tanks to catch excess stormwater flows. As part of their analysis they collected and report installation and O & M costs for a range of LID techniques.

They conclude that under a range of cost and performance assumptions, LID installed throughout the study area could potentially reduce the number of CSO events and volume at a cost that would be competitive or less than the costs of the conventional storage-tank option. They note that they could improve the performance of their model if more data were available on LID performance, costs and public acceptance.

Plumb and Seggos (2007) studied the impacts of diverting monies currently designated to building storage tanks and other conventional CSO controls for New York City to building LID controls throughout the city. They compared the effectiveness of storage tanks and LID controls based on gallons of stormwater managed per $1,000 invested. We reproduce their results in Table 4-3 below. Except for greenroofs, the LID options control more stormwater per $1,000 invested than the conventional storage-tank option.

Table 4-3: Gallons of Stormwater Managed per $1,000 Invested.

Stormwater Control	Gallons per $1,000 Invested
Conventional Storage Tanks	2,400
Greenstreet	14,800
Street Trees	13,170
Greenroof	810
Rain Barrel	9,000

Source: Plumb and Seggos 2007

They describe their analysis as a simple and preliminary cost comparison and conclude that their results demonstrate that LID controls can be cost competitive with conventional controls, if not more so. The authors recommended further detailed study of the issue. Their analysis focused on the costs of LID vs. conventional controls and did not consider economic benefits of the LID techniques.

C. Economic Benefits of Low-Impact Development

Many reports and articles describe the potential benefits that LID stormwater controls can provide—benefits that conventional controls can not offer.[9] Very few studies, however, quantify these benefits, either in biophysical measures or in dollar amounts. A study by CH2MHill (2001) is a typical example. The analysis compared the costs and benefits of managing stormwater in two residential developments using LID or conventional controls. The cost analysis included detailed information for the LID and conventional controls. In this case, results of the cost analysis were mixed. In one development the LID option cost less to build and in the other development the conventional control cost less. In both cases the LID option had higher maintenance costs but homeowners would benefit from lower stormwater and water fees.

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[9] We list a number of these sources in Section II of this report.

The analysis of benefits included much less detailed information. The study lists the benefits that the LID option would provide, benefits that the conventional approach would not. These benefits include reduced auto traffic, increased open space, improved downstream water quality, and increased groundwater recharge. However, the benefits were not quantified in dollar amounts.

In another example, Bachand (2002) studied the costs and benefits of developing wetlands as a stormwater management option. The analysis described the construction and O & M costs associated with the wetlands option, and the benefits including adding new recreational opportunities, increased wildlife habitat and increase property values for near-by homeowners. However, they did not measure the benefits in economic terms. An accompanying study by Fine (2002) quantified some of the recreational benefits that derive from wildlife watching in the wetlands, but left unquantified the benefits of other direct uses of the wetlands, as well as the value of habitat improvements and other non-use benefits.[10]

When researchers cite the needs for further research into LID-related topics, quantifying benefits and measuring their economic importance invariably makes the list. For example, Sample et al. (2003) cites the need for more research into measuring the technical and economic benefits of LID, including benefits to downstream receiving waters. Powell et al. (2005) note the need for more research into monetary measures of the benefits of LID, e.g., the impact that a greenstreet can have on adjacent property values. Vesely et al. (2005) state that future studies should include not only the economic benefits of LID but also the negative economic impacts of conventional controls. Failing to do so will continue biasing management decisions in favor of conventional controls:

> *"Exclusive reliance on profitability and market value will favour [sic] the conventional approach to stormwater management by disregarding both the negative environmental externalities associated with this approach, and the positive environmental externalities associated with the low impact approach." (page 12)*

A number of studies do measure some of the economic benefits of on-site stormwater controls. For example, Braden and Johnson (2004) studied the economic benefits that on-site stormwater management could have on properties downstream. The researchers first estimated the impacts that on-site stormwater controls could have on the frequency and extent of downstream flooding. Using information reported in the literature on the extent to which property markets discount the value of properties in a floodplain, they approximated the economic value of reduced flooding attributed to on-site management of stormwater. They then calculated the value of avoided flood damage as a percentage of property values. They estimate that a marginal reduction in flooding would increase property values 0 to 5 percent for properties in a floodplain, depending on the extent to which the on-site controls reduce stormwater runoff.

They then took a similar approach to valuing improvements in water quality. Based on values reported in the literature, they estimate that the benefits of improved water quality could reach 15 percent of market value for properties that border the water body at issue

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[10] We were unable to obtain a copy of the full report. We base our description on a summary of the analysis.

if water quality improves significantly. The increase is much less for smaller improvements in water quality, for undeveloped properties, and for properties not adjacent to the water body.

They conclude with a best-guess estimate of a 2 to 5 percent increase in property values for properties in a floodplain from on-site management of stormwater. Other benefits that could not be quantified or valued given available information include reduced infrastructure expenditures for culverts, bridges and other drainage infrastructure.

In a follow-up case study, Johnston, Braden, and Price (2006) applied the analytical method developed in the previous study to properties in the one-hundred-year floodplain portion of a watershed in the Chicago area. They estimate the economic benefit of avoided flooding two ways and extend the analysis to approximate reduced municipal expenditures on culverts.

Applying the 0 to 5 percent impact on property values calculated in the previous study to properties in the case study, the researchers estimated an economic benefit of $0 to $7,800 per acre of increased property value attributed to reduced flooding. They also calculated the economic benefit of reduced flooding based on the avoided flood damage to structures and contents for properties in the floodplain. This analytical method included data compiled by the U.S. Army Corps of Engineers on the relationship between flooding and damages to properties in floodplains. This approach yields an economic benefit of avoided flooding of $6,700 to $9,700 per acre for properties in the floodplain.

The researchers approximate that for the case-study portion of the watershed, conservation-design practices such as LID techniques that retain more stormwater on site and reduce flooding could generate $3.3 million in avoided costs for road culverts.

The estimated economic benefit of increased on-site management of stormwater for properties in the case study for both avoided flooding and reduced municipal expenditures on culverts is $380 to $590 per acre.

A series of analyses by American Forests (2000-2006) report the economic benefits of stormwater services provided by trees in various cities and regions throughout the United States. These reports describe results from American Forests' CITYgreen model, which calculates the volume of stormwater absorbed by existing tree canopies and estimates the avoided costs in stormwater management that the trees provide. The model includes city-specific per-unit stormwater-management costs when available. The model substitutes national per-unit costs when city-specific data are not available. In Table 4-4 below we report the results for some of American Forests' city and regional analyses. The dollar amounts represent the costs of expanding stormwater infrastructure to manage the stormwater that existing trees otherwise absorb and transpire.

Table 4-4: Avoided stormwater-construction costs attributed to trees, as measured by the American Forests' CITYgreen model.

Urban Area	Amount that trees save in one-time stormwater-construction costs
Houston, Texas	$1.33 billion
Atlanta, Georgia	$2.36 billion
Vancouver, Washington/ Portland-Eugene, Oregon	$20.2 billion
Washington D.C. Metro Area	$4.74 billion
New Orleans, Louisiana	$0.74 billion
San Antonio, Texas	$1.35 billion
San Diego, California	$0.16 billion
Puget Sound Metro Area, Washington	$5.90 billion
Detroit, Michigan	$0.38 billion
Chesapeake Bay Region	$1.08 billion

Source: American Forests 2000-2006

The Bisco Werner et al. (2001) analysis of the economic benefits of trees attributed to stormwater management also employed the CITYgreen model. Researchers applied the CITYgreen model to a case study that included the commercial corridor along a major highway through central New Jersey. The analysis modeled the change in tree canopy between 1975 and 1995, and calculated the value of lost stormwater services. During this time, the value of services declined from $1.1 million to $896,000, a 19-percent reduction. If existing trends continue, the expected value in 2015 will be $715,000, a 35-percent reduction relative to the value of services available in 1975. As services supplied by street trees declines, demand on municipal stormwater controls, and associated costs, increase.

The researchers extended their study to include the economic benefits of tree cover attributed to removing air pollutants. This portion of their analysis studied the tree cover at a number of commercial properties in the New York and New Jersey area. In this case the CITYgreen model calculated avoided stormwater-construction costs associated with stormwater services provided by trees on site and, using values reported in the literature, the amounts of air pollutants absorbed by trees, and the per-unit value for each pollutant.

In one case study of a shopping mall, the analysis estimated that the trees currently on the site manage approximately 53,000 cubic feet of stormwater. The CITYgreen model estimated the value of the associated avoided infrastructure costs at just over $33,000. The value of air-pollutant removed is estimated at $1,441 per year. The report lists results for fifteen such case studies.

Wetlands that absorb stormwater runoff can help minimize stormwater-related management and infrastructure costs. Depending on their location and makeup, wetlands may provide other benefits, such as wildlife habitat and recreational opportunities. Fine (2002)[11] studied the recreational benefits provided by wetlands proposed as part of the Treasure Island redevelopment in San Francisco Bay. The analysis assumes that the wetlands will attract visitors year round, with the winter months providing the best opportunity to view migratory birds. Based on recreational expenditures for similar sites in the San Francisco Bay area, Fine calculates that area visitors will spend $4 to $8 million annually. Other benefits that Fine was unable to quantify and value include fisheries enhancement and water-quality services.

Devinny et al. (2005) developed a first-approximation of a benefit-cost analysis of complying with water-quality requirements throughout Los Angeles County using LID and other stormwater BMPs. They present their analysis as an alternative to the approach described by Gordon et al. (2002), which relies on collecting and treating the county's stormwater using conventional controls. The Devinny et al. approach assumes widespread adoption of LID and other on-site stormwater BMPs.

The Devinny et al. analysis accounts for the fact that the density of existing development will limit the extent to which LID and other BMPs can be retrofitted into developments. As an alternative they propose a combination of LID and BMPs along with directing stormwater to regional wetlands and other infiltration systems. As the density of development increases, so does the size and costs of developing regional wetlands.

This study differs from other benefit-cost analyses of stormwater-management options in that the researchers quantify a range of potential benefits associated with the approach that emphasizes on-site treatment of stormwater. They estimate the cost of their approach at $2.8 billion if disbursed LID and other on-site BMPs sufficiently control stormwater quality. Costs increase to $5.7 to $7.4 billion if regional wetlands and other infiltration systems are needed. This approach costs less than the estimated cost of $44 billion to implement the option that emphasizes conventional controls (California Department of Transportation 2005).

The estimated value of the economic benefits of implementing LID, other on-site BMPs and regional wetlands range from $5.6 to $18 billion. Benefits include the economic aspects of reduced flood control, increased property values adjacent to new greenspaces and wetlands, additional groundwater supplies, improved beach tourism, and reduced sedimentation of area harbors. The conventional approach would provide none of these economic benefits.

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[11] We were unable to obtain a copy of the full report. We base our description on a summary of the analysis.

V. DEVELOPERS' EXPERIENCES WITH LOW-IMPACT DEVELOPMENT

Baring regulations that mandate LID controls, developers adopt LID because they help reduce construction costs, increase sales, boost profits, or some combination of the three. These deliberations focus primarily on the extent to which local property markets account for the direct costs and benefits that LID can provide. Typically these deliberations do not include indirect costs and benefits and the potential non-market impacts of LID that may be important to others such as municipal stormwater managers and area residents. These non-market impacts may include reduced downstream flooding, improved water quality and habitat of water bodies that receive stormwater, reduced CSO events, or impacts on the costs of operating municipal-stormwater infrastructure.

In this section we summarize developers' experiences installing LID. As with other new technologies, adopting LID includes opportunities and risks. We begin by describing the risks and challenges that developers face by including LID in their projects. These risks include uncertain construction delays as the developer applies for variances to local zoning codes because the codes do not explicitly recognize LID as an accepted stormwater control.

Next, we describe some of the efforts by municipal governments to reduce the developers' regulatory risk and uncertainty of using LID. Finally, we list some of the successes developers have had adopting LID and the resulting impacts on construction costs, sales, and profits.

A. Challenges Developers Face Using LID

Much of the general public is still unaware of LID attributes, the benefits they can provide, or their O & M costs. As such, they may not understand or appreciate why a developer included LID in a project. This may give developers pause because they supply products that they believe their customers—homebuyers—want and will purchase. Potential buyers may shy away from homes that include an unfamiliar technology.

A general lack of understanding of LID may concern developers in part because including on-site treatment of stormwater will also require on-site management of stormwater facilities, the LID technologies. Homeowners unfamiliar with LID likely will have no understanding of their maintenance requirements (Lewis 2006; England 2002; Foss 2005). For example, a bioswale clogged with sediment may not control stormwater volume or quality, which could negatively reflect on the builder. Another concern has to do with the lack of understanding as to the life-expectancy of LID controls (Lewis 2006). A builder may be concerned that an untimely failure of stormwater controls could negatively affect their reputation.

Similar to the public's general lack of understanding of LID, many builders are also unfamiliar with the technology. A builder may not be able to identify the most effective and least-cost LID technology for a given development from the wide variety of possible LID controls (Foss 2005; Lewis 2006). A related point is that construction costs for LID technologies are site specific. For example, not all soils can support LID technologies that emphasize stormwater infiltration. Assessing a site and designing LID technologies that will function on the site may also increase a builder's design costs (Coffman 2002; Strassler et al. 1999).

A much-mentioned impediment to builders' adoption of LID is building codes that do not account for LID as stormwater controls. Many municipalities have zoning and building-inspection standards in place that were adopted many years ago, long before LID was an option (Coffman 2002; NAHB Research Center Inc. 2003; Foss 2005; Lewis 2006). These standards emphasize conventional stormwater controls that collect stormwater and transport it off site to a receiving body of water or to a treatment facility. Municipalities with outdated stormwater regulations typically require that builders file variances if they want to use LID controls. Filing variances for LID increases design and regulatory costs, which delays construction and can increase a builder's financing costs (Clar 2004; Coffman 2002; Lewis 2006; NAHB Research Center Inc. 2003).

A related constraint in some jurisdictions with outdated regulations is a lack of technical expertise or understanding by regulators regarding LID stormwater controls. In some cases, regulators unfamiliar with LID technology must be convinced of their effectiveness, which also increases a builder's design and regulatory costs (Coffman 2002; NAHB 2003; Lewis 2006).

B. Municipal Actions To Increase LID Adoption On Private Developments

Some jurisdictions help promote LID adoption on private lands and take steps that reduce the regulatory uncertainty and risk that builders face when including LID in private developments. These jurisdictions may have CSO problems, or are trying to extend the useful life of their stormwater infrastructure in the face of increasing population and economic activity. In any case, they recognize the importance of managing as much stormwater on site as possible and keeping it out of the jurisdiction's stormwater pipes.

One way that jurisdictions promote LID adoption on private lands is by updating their zoning codes and building-inspection standards to explicitly address LID stormwater controls (Coffman 2002; NAHB Research Center Inc. 2003; Foss 2005; Lewis 2006). This helps reduce a builder's regulatory risk because it eliminates the need to file variances. Rather than spending time convincing regulators as to the desirable stormwater attributes or effectiveness of LID controls, builders can instead proceed with their development.

Granting density bonuses for developments that install LID stormwater controls is another way jurisdictions encourage the proliferation of LID techniques. In this case, the jurisdiction grants the developer a greater number of individual building lots than would have been allowed if the development relied on conventional stormwater controls (Coffman 2002; NAHB Research Center Inc. 2003). This type of incentive not only reduces a builder's regulatory risk, and associated costs, but also increases the number of lots that can be sold, which can increase the builder's revenue and profits. Jurisdictions also promote LID installation on private lands by reducing development-related fees, such as inspection fees (Coffman 2002; NAHB Research Center Inc. 2003).

C. Benefits To Developers of Including LID Controls in Their Projects

Developers who accept the regulatory uncertainty and other challenges of adopting LID do so with the expectation that controlling stormwater on site can have economic advantages. These advantages include increasing the number of developable lots and reducing expenditures associated with stormwater infrastructure. Managing stormwater on site using LID controls can mean doing away with stormwater ponds, thus increasing a site's developable area (Coffman 2002; NAHB Research Center Inc. 2003). Selling additional lots can increase a builder's revenues and profits. Replacing curbs, gutters and stormwater pipes with bioswales, pervious pavers and other LID controls reduces construction costs for some developers (Coffman 2002; NAHB Research Center Inc. 2003; Center for Watershed Protection 2001).

An analysis of a development in Prince George's County, Maryland, documented the impacts that controlling stormwater on site with LID can have on the site's buildable area and construction costs. The Somerset Community development installed rain gardens, grass swales along streets, and other LID controls. Substituting LID for conventional controls saved the developer approximately $900,000. Doing away with the site's stormwater ponds gave the developer six additional lots (Foss 2005).

A study of the Pembroke Woods Subdivision in Frederick County, Maryland found similar results (Clar 2004). The developer substituted LID for conventional controls, doing away with curbs, gutters, sidewalks, and eliminated two stormwater ponds. Eliminating the curbs and gutters saved the developer $60,000. Installing narrower streets eliminated impervious area and reduced paving costs by 17 percent. Excluding the stormwater ponds saved $200,000 in construction costs and added two developable lots, valued at $45,000 each. Other economic benefits to the developer include reduced costs of clearing land for development of $160,000, and adding 2.5 additional acres of open space, which reduced the developer's wetland-mitigation requirements.

Conservation subdivisions take a comprehensive approach to stormwater management by combining LID controls with a site design that takes advantage of existing drainage patterns. Narrow streets and clustered building lots make maximum use of natural stormwater controls, thus reducing construction costs (Center for Watershed Protection 2001). A study of ten subdivisions found that conservation subdivisions that emphasized LID and protected natural drainage patterns cost, on average, thirty-six percent less than subdivisions that relied on conventional stormwater controls (Conservation Research Institute 2005).

Researchers note that some conservation subdivisions have an additional benefit in that there's greater demand for lots in these subdivisions compared with the demand for lots in conventional subdivisions. Greater demand for lots means the developer can charge more for the lot and lots may sell faster (Center for Watershed Protection 2001).

A case study of conservation and conventional subdivisions in South Kingstown, Rhode Island quantified the market benefits of conservation developments. The study compared the costs of developing the lots and the market value of the lots (Mohamed 2006). Results show that conservation lots cost less to develop and sell for a higher price. On average, conservation lots cost $7,400 less to produce than lots in conventional subdivisions, and sold for 12 to 16 percent more, per acre, than conventional lots. Lots in the conservation subdivision also sold in approximately half the time as lots in conventional subdivisions.

Another study of cluster developments in New England found that houses in these types of developments appreciate faster than houses in conventional developments (Lacy 1990). Lacy identified developments in Concord and Amherst, Massachusetts that were characterized by smaller individual lots surrounded by natural open space, limited lot clearing, and narrower streets. He compared these with nearby conventional developments. The Concord cluster development appreciated 26 percent more than conventional developments over an eight-year study period. The Amherst cluster development also yielded a higher rate of return on investment over a 21-year study period, compared to nearby conventional development.

In Tables 5-1 and 5-2 below we summarize the results of studies that compared construction costs using LID vs. conventional stormwater controls for residential and commercial developments (respectively). We included information in the tables if a study described the source of the cost difference, e.g., substituting a bioswale for curbs and gutters saved $Z. We excluded studies that reported a cost difference, but did not describe the details of the cost comparison. We found many studies in the literature that did not provide details of cost comparisons.

We distinguish between study results for built developments from results for proposed or modeled developments. In some cases the studies report total cost savings for a development but not savings per lot in the development. In these cases we calculated the per-lot cost savings. We recognize that the cost savings values reported below are in dollars from different years, and so comparisons of cost savings between examples may not be appropriate. We found insufficient data in most case studies to convert all values to the same-year dollars.

The large majority of studies listed in Tables 5-1 and 5-2 describe LID installed or proposed to be installed in new developments. We found very few studies that measured the economic outcomes of including LID stormwater controls in urban, redevelopment projects. We identified these studies as “retrofits” in the tables.

Table 5-1: Cost savings attributed to installing LID stormwater controls in residential developments.

Location	Description	LID Cost Savings[a]
Meadow on the Hylebos Residential Subdivision Pierce County, WA	9-acre development reduced street width, added swale drainage system, rain gardens, and a sloped bio-terrace to slowly release stormwater to a creek. Stormwater pond reduced by 2/3, compared to conventional plan. (Zickler 2004)	LID cost 9% less than conventional
Somerset Community Residential Subdivision Prince George's Co., MD	80-acre development included rain gardens on each lot and a swale drainage system. Eliminated a stormwater pond and gained six extra lots. (NAHB Research Center Inc. 2003)	$916,382 $4,604 per lot
Pembroke Woods Residential Subdivision Frederick County, MD	43-acre, 70-lot development reduced street width, eliminated sidewalks, curb and gutter, and 2 stormwater ponds, and added swale drainage system, natural buffers, and filter strips. (Clar 2004; Lehner et al. 2001)	$420,000 $6,000 per lot[b]
Madera Community Residential Subdivision Gainesville, FL	44-acre, 80-lot development used natural drainage depressions in forested areas for infiltration instead of new stormwater ponds. (PATH 2005)	$40,000 $500 per lot[b]
Prairie Crossing Residential Subdivision Grayslake, IL	667-acre, 362-lot development clustered houses reducing infrastructure needs, and eliminated the need for a conventional stormwater system by building a natural drainage system using swales, constructed wetlands, and a central lake. (Lehner et al. 2001; Conservation Research Institute 2005)	$1,375,000-$2,700,000 $3,798-$7,458 per lot[b]
SEA Street Retrofit Residential street retrofit Seattle, WA	1-block retrofit narrowed street width, installed swales and rain gardens. (Tilley 2003)	$40,000
Gap Creek Residential Subdivision Sherwood, AK	130-acre, 72-lot development reduced street width, and preserved natural topography and drainage networks. (U.S. EPA 2005; Lehner et al. 2001; NAHB Research Center Inc. 2003)	$200,021 $4,819 per lot
Poplar Street Apartments Residential complex Aberdeen, NC	270-unit apartment complex eliminated curb and gutter stormwater system, replacing it with bioretention areas and swales. (U.S. EPA 2005)	$175,000
Kensington Estates* Residential Subdivision Pierce County, WA	24-acre, 103-lot hypothetical development reduced street width, used porous pavement, vegetated depressions on each lot, reduced stormwater pond size. (CH2MHill 2001; U.S. EPA 2005)	$86,800 $843 per lot[b]
Garden Valley* Residential Subdivision Pierce County, WA	10-acre, 34-lot hypothetical development reduced street width, used porous paving techniques, added swales between lots, and a central infiltration depression. (CH2MHill 2001)	$60,000 $1,765 per lot[b]
Circle C Ranch Residential Subdivision Austin, TX	Development employed filter strips and bioretention strips to slow and filter runoff before it reached a natural stream. (EPA 2005)	$185,000 $1,250 per lot

Location	Description	LID Cost Savings[a]
Woodland Reserve* Residential Development Lexana, KS	Reduced land clearing, reduced impervious surfaces, and added native plantings. (Beezhold 2006)	$118,420
The Trails* Multi-Family Residential Lexana, KS	Reduced land clearing, reduced impervious surfaces, and added native plantings. (Beezhold 2006)	$89,043
Medium Density Residential* Stafford County, VA	45-acre, 108-lot clustered development, reduced curb and gutter, storm sewer, paving, and stormwater pond size. (Center for Watershed Protection 1998b)	$300,547 $2,783 per lot[b]
Low Density Residential* Wicomico County, MD	24-acre, 8-lot development eliminated curb and gutter, reduced paving, storm drain, and reforestation needs. Eliminated stormwater pond and replaced with bioretention and bioswales. (Center for Watershed Protection 1998b)	$17,123 $2,140 per lot[b]

Source: ECONorthwest, with data from listed sources.
Notes: * indicates hypothetical or modeled project, not actually constructed.
[a] Dollar amounts as reported at the time of study.
[b] Per-lot cost savings calculated by ECONorthwest.

Table 5-2: Cost savings attributed to installing LID stormwater controls in commercial developments.

Location	Description	LID Cost Savings[a]
Parking Lot Retrofit Largo, MD	One-half acre of impervious surface. Stormwater directed to central bioretention island. (U.S. EPA 2005)	$10,500-$15,000
Old Farm Shopping Center* Frederick, MD	9.3-acre site redesigned to reduce impervious surfaces, added bioretention islands, filter strips, and infiltration trenches. (Zielinski 2000)	$36,230 $3,986 per acre[b]
270 Corporate Office Park* Germantown, MD	12.8-acre site redesigned to eliminate pipe and pond stormwater system, reduce impervious surface, added bioretention islands, swales, and grid pavers. (Zielinski 2000)	$27,900 $2,180 per acre[b]
OMSI Parking Lot Portland, OR	6-acre parking lot incorporated bioswales into the design, and reduced piping and catch basin infrastructure. (Liptan and Brown 1996)	$78,000 $13,000 per acre[b]
Light Industrial Parking Lot* Portland, OR	2-acre site incorporated bioswales into the design, and reduced piping and catch basin infrastructure. (Liptan and Brown 1996)	$11,247 $5,623 per acre[b]
Point West Shopping Center* Lexana, KS	Reduced curb and gutter, reduced storm sewer and inlets, reduced grading, and reduced land cost used porous pavers, added bioretention cells, and native plantings. (Beezhold 2006)	$168,898
Office Warehouse* Lexana, KS	Reduced impervious surfaces, reduced storm sewer and catch basins, reduced land cost, added bioswales and native plantings. (Beezhold 2006)	$317,483
Retail Shopping Center*	9-acre shopping development reduced parking lot area, added porous pavers, clustered retail spaces, added infiltration trench, bioretention and a sand filter, reduced curb and gutter and stormwater system, and eliminated infiltration basin. (Center for Watershed Protection 1998b)	$36,182 $4,020 per acre[b]
Commercial Office Park*	13-acre development reduced impervious surfaces, reduced stormwater ponds and added bioretention and swales. (Center for Watershed Protection 1998b)	$160,468 $12,344 per acre[b]
Tellabs Corporate Campus Naperville, IL	55-acre site developed into office space minimized site grading and preserved natural topography, eliminated storm sewer pipe and added bioswales. (Conservation Research Institute 2005)	$564,473 $10,263 per acre[b]
Vancouver Island Technology Park Redevelopment Saanich, British Columbia	Constructed wetlands, grassy swales and open channels, rather than piping to control stormwater. Also used amended soils, native plantings, shallow stormwater ponds within forested areas, and permeable surfaces on parking lots. (Tilley 2003)	$530,000

Source: ECONorthwest, with data from listed sources.
Notes: * indicates hypothetical or modeled project, not actually constructed.
[a] Dollar amounts as reported at the time of study.
[b] Per-acre cost savings calculated by ECONorthwest.

VI. DIRECTIONS FOR FUTURE RESEARCH

Despite the increasing use of LID stormwater controls, and the growing number of economic studies of this technique, our literature review found areas for further research. These areas include:

- Additional research that quantifies the costs and benefits of stormwater management. This includes economic research on the lifetime O & M costs for LID and conventional controls, as well as, studies that quantify the economic benefits of LID methods.

- More detailed information on costs associated with LID. Specifically, information on the factors that contribute to cost savings or cost increases of LID relative to conventional controls.

- Economic studies of LID and conventional methods that control for the effectiveness of the techniques regarding managing stormwater volumes and improving water quality. Comparing LID techniques that cost more to install than conventional methods, but control larger amounts of stormwater, is an apples-to-oranges comparison.

- The large majority of economic studies of LID methods apply to new construction. More research is needed on the economic outcomes of including LID methods in urban redevelopment projects.

- Some preliminary evidence exists that LID can help control CSO volumes at a lower cost than conventional controls. Stormwater managers and public-policy decisionmakers would benefit from additional economic research on this topic.

- Economic studies that model theoretical LID and conventional controls, while informative, may be less convincing to some stormwater managers, decisionmakers and ratepayer stakeholders than retrospective studies of installed controls.

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3. WATER QUALITY OBJECTIVES

Table of Contents

Introduction

The Clean Water Act (§303) requires states to develop water quality standards for all waters and to submit to the USEPA for approval all new or revised water quality standards which are established for inland surface and ocean waters. Water quality standards consist of a combination of beneficial uses (designated in Chapter 2) and water quality objectives (contained in this Chapter).

In addition to the federal mandate, the California Water Code (§13241) specifies that each Regional Water Quality Control Board shall establish water quality objectives. The Water Code defines water quality objectives as "the allowable limits or levels of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area." Thus, water quality objectives are intended (i) to protect the public health and welfare and (ii) to maintain or enhance water quality in relation to the designated existing and potential beneficial uses of the water. Water quality objectives are achieved through Waste Discharge Requirements and other programs outlined in Chapter 4, Strategic Planning and Implementation. These objectives, when compared with future water quality data, also provide the basis for identifying trends toward degradation or enhancement of regional waters.

These water quality objectives supersede those contained in all previous Basin Plans and amendments adopted by the Los Angeles Regional Board. As new information becomes available, the Regional Board will review the objectives contained herein and develop new objectives as necessary. In addition, this Plan will be reviewed every three years (triennial review) to determine the need for modification.

Statement of Policy with Respect to Maintaining High Quality of Waters in California

A key element of California's water quality standards is the state's Antidegradation Policy. This policy, formally referred to as the *Statement of Policy with Respect to Maintaining High Quality Waters in California* (State Board Resolution No. 68-16), restricts degradation of surface or ground waters. In particular, this policy protects waterbodies where existing quality is higher than is necessary for the protection of beneficial uses.

STATE WATER RESOURCES CONTROL BOARD
RESOLUTION NO. 68-16

STATEMENT OF POLICY WITH RESPECT TO MAINTAINING HIGH QUALITY OF WATERS IN CALIFORNIA

WHEREAS the California Legislature has declared that it is the policy of the State that the granting of permits and licenses for unappropriated water and the disposal of wastes into the waters of the State shall be so regulated as to achieve highest water quality consistent with maximum benefit to the people of the State and shall be controlled so as to promote the peace, health, safety and welfare of the people of the State; and

WHEREAS water quality control policies have been and are being adopted for waters of the State; and

WHEREAS the quality of some waters of the State is higher than that established by the adopted policies and it is the intent and purpose of this Board that such higher quality shall be maintained to the maximum extent possible consistent with the declaration of the Legislature;

NOW, THEREFORE, BE IT RESOLVED:

1. Whenever the existing quality of water is better than the quality established in policies as of the date on which such policies become effective, such existing high quality will be maintained until it has been demonstrated to the State that any change will be consistent with maximum benefit to the people of the State, will not unreasonably affect present and anticipated beneficial use of such water and will not result in water quality less than that prescribed in the policies.

2. Any activity which produces or may produce a waste or increased volume or concentration of waste and which discharges or proposes to discharge to existing high quality waters will be required to meet waste discharge requirements which will result in the best practicable treatment or control of the discharge necessary to assure that (a) a pollution or nuisance will not occur and (b) the highest water quality consistent with maximum benefit to the people of the State will be maintained.

3. In implementing this policy, the Secretary of the Interior will be kept advised and will be provided with such information as he will need to discharge his responsibilities under the Federal Water Pollution Control Act.

BE IT FURTHER RESOLVED that a copy of this resolution be forwarded to the Secretary of the Interior as part of California's water quality control policy submission.

CERTIFICATION

The undersigned, Executive Officer of the State Water Resources Control Board, does hereby certify that the foregoing is a full, true, and correct copy of a resolution duly and regularly adopted at a meeting of the State Water Resources Control Board held on October 24, 1968.

Dated: October 28, 1968

Original signed by
Kerry W. Mulligan, Executive Officer
State Water Resources Control Board

Under the Antidegradation Policy, any actions that can adversely affect water quality in all surface and ground waters (i) must be consistent with the maximum benefit to the people of the state, (ii) must not unreasonably affect present and anticipated beneficial use of such water, and (iii) must not result in water quality less than that prescribed in water quality plans and policies. Furthermore, any actions that can adversely affect surface waters are also subject to the federal Antidegradation Policy (40 CFR 131.12), developed under the CWA. The USEPA, Region IX, has also issued detailed guidance for the implementation of federal antidegradation regulations for surface waters within its jurisdiction (USEPA, 1987).

Regional Objectives for Inland Surface Waters

Narrative or numerical water quality objectives have been developed for the following parameters (listed alphabetically) and apply to all inland surface waters and enclosed bays and estuaries (including wetlands) in the Region. *Water quality objectives are in italics.*

Ammonia

The neutral, un-ionized ammonia species (NH_3) is highly toxic to fish and other aquatic life. The ratio of toxic NH_3 to total ammonia ($NH_4^+ + NH_3$) is primarily a function of pH, but is also affected by temperature and other factors. Additional impacts can also occur as the oxidation of ammonia lowers the dissolved oxygen content of the water, further stressing aquatic organisms. Ammonia also combines with chlorine (often both are present) to form chloramines - persistent toxic compounds that extend the effects of ammonia and chlorine downstream.

Oxidation of ammonia to nitrate may lead to groundwater impacts in areas of recharge.

In order to protect aquatic life, ammonia concentrations in receiving waters shall not exceed the values listed for the corresponding instream conditions in Tables 3-1 to 3-4.

Timing of compliance with this objective will be determined on a case-by-case basis. Discharges will have up to 8 years following the adoption of this plan by the Regional Board to (i) make the necessary adjustments/improvements to meet these objectives or (ii) to conduct studies leading to an approved site-specific objective for ammonia. If it is determined that there is an immediate threat or impairment of beneficial uses due to ammonia, the objectives in Tables 3-1 to 3-4 shall apply.

In order to protect underlying groundwater basins, ammonia shall not be present at levels that when oxidized to nitrate, pose a threat to groundwater.

Bacteria, Coliform

Total and fecal coliform bacteria are used to indicate the likelihood of pathogenic bacteria in surface waters. Water quality objectives for total and fecal coliform vary with the beneficial uses of the waterbody and are described below:

In waters designated for water contact recreation (REC-1), the fecal coliform concentration shall not exceed a log mean of 200/100 ml (based on a minimum of not less than four samples for any 30-day period), nor shall more than 10 percent of total samples during any 30-day period exceed 400/100 ml.

In waters designated for non-water contact recreation (REC-2) and not designated for water contact recreation (REC-1), the fecal coliform concentration shall not exceed a log mean of 2000/100 ml (based on a minimum of not less than four samples for any 30-day period), nor shall more than 10 percent of samples collected during any 30-day period exceed 4000/100 ml.

In all waters where shellfish can be harvested for human consumption (SHELL), the median total coliform concentration throughout the water column for any 30-day period shall not exceed 70/100 ml, nor shall more than ten percent of the samples collected during any 30-day period exceed 230/100 ml for a five-tube decimal dilution test or 330/100 ml when a three-tube decimal dilution test is used.

Table 3-1. One-hour Average Concentration for Ammonia[1,2] for Waters Designated as COLD (Salmonids or Other Sensitive Coldwater Species Present).

pH	Temperature, °C						
	0	5	10	15	20	25	30
Un-ionized ammonia (mg/liter NH_3)							
6.50	0.0091	0.0129	0.0182	0.026	0.036	0.036	0.036
6.75	0.0149	0.021	0.030	0.042	0.059	0.059	0.059
7.00	0.023	0.033	0.046	0.066	0.093	0.093	0.093
7.25	0.034	0.048	0.068	0.095	0.135	0.135	0.135
7.50	0.045	0.064	0.091	0.128	0.181	0.181	0.181
7.75	0.056	0.080	0.113	0.159	0.22	0.22	0.22
8.00	0.065	0.092	0.130	0.184	0.26	0.26	0.26
8.25	0.065	0.092	0.130	0.184	0.26	0.26	0.26
8.50	0.065	0.092	0.130	0.184	0.26	0.26	0.26
8.75	0.065	0.092	0.130	0.184	0.26	0.26	0.26
9.00	0.065	0.092	0.130	0.184	0.26	0.26	0.26
Total ammonia (mg/liter NH_3)							
6.50	35	33	31	30	29	20	14.3
6.75	32	30	28	27	27	18.6	13.2
7.00	28	26	25	24	23	16.4	11.6
7.25	23	22	20	19.7	19.2	13.4	9.5
7.50	17.4	16.3	15.5	14.9	14.6	10.2	7.3
7.75	12.2	11.4	10.9	10.5	10.3	7.2	5.2
8.00	8.0	7.5	7.1	6.9	6.8	4.8	3.5
8.25	4.5	4.2	4.1	4.0	3.9	2.8	2.1
8.50	2.6	2.4	2.3	2.3	2.3	1.71	1.28
8.75	1.47	1.40	1.37	1.38	1.42	1.07	0.83
9.00	0.86	0.83	0.83	0.86	0.91	0.72	0.58

1 To convert these values to mg/liter N, multiply by 0.822

2 Source: USEPA, 1986

Table 3-2. One-hour Average Concentration for Ammonia[1,2] for Waters Designated as WARM (Salmonids or Other Sensitive Coldwater Species Absent).

pH	Temperature, °C				
	0	5	10	15	20
	Un-ionized ammonia (mg/liter NH_3)				
6.50	0.0091	0.0129	0.0182	0.026	0.036
6.75	0.0149	0.021	0.030	0.042	0.059
7.00	0.023	0.033	0.046	0.066	0.093
7.25	0.034	0.048	0.068	0.095	0.135
7.50	0.045	0.064	0.091	0.128	0.181
7.75	0.056	0.080	0.113	0.159	0.22
8.00	0.065	0.092	0.130	0.184	0.26
8.25	0.065	0.092	0.130	0.184	0.26
8.50	0.065	0.092	0.130	0.184	0.26
8.75	0.065	0.092	0.130	0.184	0.26
9.00	0.065	0.092	0.130	0.184	0.26
	Total ammonia (mg/liter NH_3)				
6.50	35	33	31	30	29
6.75	32	30	28	27	27
7.00	28	26	25	24	23
7.25	23	22	20	19.7	19.2
7.50	17.4	16.3	15.5	14.9	14.6
7.75	12.2	11.4	10.9	10.5	10.3
8.00	8.0	7.5	7.1	6.9	6.8
8.25	4.5	4.2	4.1	4.0	3.9
8.50	2.6	2.4	2.3	2.3	2.3
8.75	1.47	1.40	1.37	1.38	1.42
9.00	0.86	0.83	0.83	0.86	0.91

[1] To convert these values to mg/liter N, multiply by 0.822

[2] Source: USEPA, 1986

Table 3-3. Four-day Average Concentration for Ammonia[1,2] for Waters Designated as COLD (Salmonids or Other Sensitive Coldwater Species Present).

pH	Temperature, °C						
	0	5	10	15	20	25	30
	Un-ionized ammonia (mg/liter NH_3)						
6.50	0.0008	0.0011	0.0016	0.0022	0.0022	0.0022	0.0022
6.75	0.0014	0.0020	0.0028	0.0039	0.0039	0.0039	0.0039
7.00	0.0025	0.0035	0.0049	0.0070	0.0070	0.0070	0.0070
7.25	0.0044	0.0062	0.0088	0.0124	0.0124	0.0124	0.0124
7.50	0.0078	0.0111	0.0156	0.022	0.022	0.022	0.022
7.75	0.0129	0.0182	0.026	0.036	0.036	0.036	0.036
8.00	0.0149	0.021	0.030	0.042	0.042	0.042	0.042
8.25	0.0149	0.021	0.030	0.042	0.042	0.042	0.042
8.50	0.0149	0.021	0.030	0.042	0.042	0.042	0.042
8.75	0.0149	0.021	0.030	0.042	0.042	0.042	0.042
9.00	0.0149	0.021	0.030	0.042	0.042	0.042	0.042
	Total ammonia (mg/liter NH_3)						
6.50	3.0	2.8	2.7	2.5	1.76	1.23	0.87
6.75	3.0	2.8	2.7	2.6	1.76	1.23	0.87
7.00	3.0	2.8	2.7	2.6	1.76	1.23	0.87
7.25	3.0	2.8	2.7	2.6	1.77	1.24	0.88
7.50	3.0	2.8	2.7	2.6	1.78	1.25	0.89
7.75	2.8	2.6	2.5	2.4	1.66	1.17	0.84
8.00	1.82	1.70	1.62	1.57	1.10	0.78	0.56
8.25	1.03	0.97	0.93	0.90	0.64	0.46	0.33
8.50	0.58	0.55	0.53	0.53	0.38	0.28	0.21
8.75	0.34	0.32	0.31	0.31	0.23	0.173	0.135
9.00	0.195	0.189	0.189	0.195	0.148	0.116	0.094

[1] To convert these values to mg/liter N, multiply by 0.822.

[2] Source: USEPA, 1992

Table 3-4. Four-day Average Concentration for Ammonia[1,2] for Waters Designated as WARM (Salmonids or Other Sensitive Coldwater Species Absent).

pH	Temperature, °C						
	0	5	10	15	20	25	30
Un-ionized ammonia (mg/liter NH_3)							
6.50	0.0008	0.0011	0.0016	0.0022	0.0031	0.0031	0.0031
6.75	0.0014	0.0020	0.0028	0.0039	0.0055	0.0055	0.0055
7.00	0.0025	0.0035	0.0049	0.0070	0.0099	0.0099	0.0099
7.25	0.0044	0.0062	0.0088	0.0124	0.0175	0.0175	0.0175
7.00	0.0078	0.0111	0.0156	0.022	0.031	0031	0.031
7.75	0.0129	0.0182	0.026	0.036	0.051	0.051	0.051
8.00	0.0149	0.021	0.030	0.042	0.059	0.059	0.059
8.25	0.0149	0.021	0.030	0.042	0.059	0.059	0.059
8.50	0.0149	0.021	0.030	0.042	0.059	0.059	0.059
8.75	0.0149	0.021	0.030	0.042	0.059	0.059	0.059
9.00	0.0149	0.021	0.030	0.042	0.059	0.059	0.059
Total ammonia (mg/liter NH_3)							
6.50	3.0	2.8	2.7	2.5	2.5	1.73	1.23
6.75	3.0	2.8	2.7	2.6	2.5	1.74	1.23
7.00	3.0	2.8	2.7	2.6	2.5	1.74	1.23
7.25	3.0	2.8	2.7	2.6	2.5	1.75	1.24
7.50	3.0	2.8	2.7	2.6	2.5	1.76	1.25
7.75	2.8	2.6	2.5	2.4	2.3	1.65	1.18
8.00	1.82	1.70	1.62	1.57	1.55	1.10	0.79
8.25	1.03	0.97	0.93	0.90	0.90	0.64	0.47
8.50	0.58	0.55	0.53	0.53	0.53	0.39	0.29
8.75	0.34	0.32	0.31	0.31	0.32	0.24	0.190
9.00	0.195	0.189	0.189	0.195	0.21	0.163	0.133

[1] To convert these values to mg/liter N, multiply by 0.822.

[2] Source: USEPA, 1992

Bioaccumulation

Many pollutants can bioaccumulate in fish and other aquatic organisms at levels which are harmful for both the organisms as well as organisms that prey upon these species (including humans).

Toxic pollutants shall not be present at levels that will bioaccumulate in aquatic life to levels which are harmful to aquatic life or human health.

Biochemical Oxygen Demand (BOD_5)

The 5-day BOD test indirectly measures the amount of readily degradable organic material in water by measuring the residual dissolved oxygen after a period of incubation (usually 5 days at 20 °C), and is primarily used as an indicator of the efficiency of wastewater treatment processes.

Waters shall be free of substances that result in increases in the BOD which adversely affect beneficial uses.

Biostimulatory Substances

Biostimulatory substances include excess nutrients (nitrogen, phosphorus) and other compounds that stimulate aquatic growth. In addition to being aesthetical unpleasant (causing taste, odor, or color problems), this excessive growth can also cause other water quality problems.

Waters shall not contain biostimulatory substances in concentrations that promote aquatic growth to the extent that such growth causes nuisance or adversely affects beneficial uses.

Chemical Constituents

Chemical constituents in excessive amounts in drinking water are harmful to human health. Maximum levels of chemical constituents in drinking waters are listed in the California Code of Regulations and the relevant limits are described below.

Surface waters shall not contain concentrations of chemical constituents in amounts that adversely affect any designated beneficial use.

Water designated for use as Domestic or Municipal Supply (MUN) shall not contain concentrations of chemical constituents in excess of the limits specified in the following provisions of Title 22 of the California Code of Regulations which are incorporated by reference into this plan: Table 64431-A of Section 64431 (Inorganic Chemicals), Table 64431-B of Section 64431 (Fluoride), and Table 64444-A of Section 64444 (Organic Chemicals). This incorporation by reference is prospective including future changes to the incorporated provisions as the changes take effect. (See Tables 3-5, 3-6, and 3-7.)

Table 3-5. The Maximum Contaminant Levels: Inorganic Chemicals (for MUN beneficial use) specified in Table 64431-A of Section 64431 of Title 22 of the California Code of Regulations as of 9-8-94.

Constituent	Maximum Contaminant Level mg/L
Aluminum	1.
Antimony	0.006
Arsenic	0.05
Asbestos	7 MFL*
Barium	1.
Beryllium	0.004
Cadmium	0.005
Chromium	0.05
Cyanide	0.2
Mercury	0.002
Nickel	0.1
Nitrate (as NO_3)	45.
Nitrate + Nitrite (sum as nitrogen)	10.
Nitrite (as nitrogen)	1.
Selenium	0.05
Thallium	0.002

* MFL = million fibers per liter; MCL for fibers exceeding 10 μm in lenght

Table 3-6. The Limiting and Optimum Concentrations for Fluoride (for MUN beneficial use) specified in Table 64431-B of Section 64431 of Title 22 of the California Code of Regulations as of 9-8-94.

Annual Average of Maximum Daily Air Temperature (°F)	Fluoride Concentration (mg/L)			
	Lower	Optimum	Upper	Maximum Concentration Level
53.7 and below	0.9	1.2	1.7	2.4
53.8 to 58.3	0.8	1.1	1.5	2.2
58.4 to 63.8	0.8	1.0	1.3	2.0
63.9 to 70.6	0.7	0.9	1.2	1.8
70.7 to 79.2	0.7	0.8	1.0	1.6
79.3 to 90.5	0.6	0.7	0.8	1.4

Chlorine, Total Residual

Disinfection of wastewaters with chlorine produces a chlorine residual. Chlorine and its reaction products are toxic to aquatic life.

Chlorine residual shall not be present in surface water discharges at concentrations that exceed 0.1 mg/L and shall not persist in receiving waters at any concentration that causes impairment of beneficial uses.

Color

Color in water can result from natural conditions (e.g., from plant material or minerals) or can be introduced from commercial or industrial sources. Color is primarily an aesthetic consideration, although extremely dark colored water can limit light penetration and cause additional water quality problems. Furthermore, color can impact domestic and industrial uses by discoloring clothing or foods. The secondary drinking water standard is 15 color units (DHS, 1992).

Waters shall be free of coloration that causes nuisance or adversely affects beneficial uses.

Exotic Vegetation

Exotic (non-native) vegetation introduced in and around stream courses is often of little value as habitat (food and cover) for aquatic-dependent biota. Exotic plants can quickly out-compete native vegetation and cause other water quality impairments.

Exotic vegetation shall not be introduced around stream courses to the extent that such growth causes nuisance or adversely affects beneficial uses.

Floating Material

Floating materials can be an aesthetic nuisance as well as provide substrate for undesirable bacterial and algal growth and insect vectors.

Waters shall not contain floating materials, including solids, liquids, foams, and scum, in concentrations that cause nuisance or adversely affect beneficial uses.

Table 3-7. The Maximum Contaminant Levels: Organic Chemicals (for MUN beneficial use) specified in Table 64444-A of Section 64444 of Title 22 of the California Code of Regulations as of 9-8-94.

Constituent	Maximum Contaminant Level mg/L
A. Volatile Organic Chamicals (VOCs)	
Benzene	0.001
Carbon Tetrachloride	0.0005
1,2-Dichlorobenzene	0.6
1,4-Dichlorobenzene	0.005
1,1-Dichloroethane	0.005
1,2-Dichloroethane	0.0005
1,1-Dichloroethylene	0.006
cis-1,2-Dichloroethylene	0.006
trans-1,2-Dichloroethylene	0.01
Dichloromethane	0.005
1,2-Dichloropropane	0.005
1,3-Dichloropropene	0.0005
Ethylbenzene	0.7
Monochlorobenzene	0.07
Styrene	0.1
1,1,2,2-Tetrachlorethane	0.001
Tetrachloroethylene	0.005
Toluene	0.15
1,2,4-Trichlorobenzene	0.07
1,1,1-Trichloroethane	0.200
1,1,2-Trichloroethane	0.005
Trichloroethylene	0.005
Trichlorofluoromethane	0.15
1,1,2-Trichloro-1,2,2-Trifluoroethane	1.2
Vinyl Chloride	0.0005
Xylenes (single isomer or sum of isomers)	1.750
B. Non-Volatile Synthetic Organic Chemicals (SOCs)	
Alachlor	0.002
Atrazine	0.003
Bentazon	0.018
Benzo(a)pyrene	0.0002
Carbofuran	0.018
Chlordane	0.0001
2,4-D	0.07
Dalapon	0.2
1,2-Dibromo-3-chloropropane	0.0002
Di(2-ethylhexyl)adipate	0.4
Di(2-ethylhexyl)phthalate	0.004
Dinoseb	0.007
Diquat	0.02
Endothall	0.1
Endrin	0.002
Ethylene Dibromide	0.00005
Glyphosate	0.7
Heptachlor	0.00001
Heptachlor Epoxide	0.00001
Hexachlorobenzene	0.001
Hexachlorocyclopentadiene	0.05
Lindane	0.0002
Methoxychlor	0.04
Molinate	0.02
Oxarnyl	0.2
Pentachlorophenol	0.001
Picloram	0.5
Polychlorinated Biphenyls	0.0005
Simazine	0.004
Thiobencarb	0.07
Toxaphene	0.003
2,3,7,8-TCDD (Dioxin)	$3X10^{-8}$
2,4,5-TP (Silvex)	0.05

Methylene Blue Activated Substances (MBAS)

The MBAS procedure tests for the presence of anionic surfactants (detergents) in water. Positive results can indicate the presence of domestic wastewater. This test can be used to indicate impacts from septic systems. Surfactants disturb the surface tension which affects insects and can affect gills in aquatic life. The secondary drinking water standard for MBAS is 0.5 mg/L (DHS, 1992).

Waters shall not have MBAS concentrations greater than 0.5 mg/L in waters designated MUN.

Mineral Quality

Mineral quality in natural waters is largely determined by the mineral assemblage of soils and rocks and faults near the land surface. Point and nonpoint source discharges of poor quality water can degrade the mineral content of natural waters. High levels of dissolved solids renders waters useless for many beneficial uses. Elevated levels of boron affect agricultural use (especially citrus).

Numerical mineral quality objectives for individual inland surface waters are contained in Table 3-8.

Nitrogen (Nitrate, Nitrite)

High nitrate levels in drinking water can cause health problems in humans. Infants are particularly sensitive and can develop methemoglobinemia (blue-baby syndrome). Excess nitrogen in surface waters also leads to excess aquatic growth and can contribute to elevated levels of NO_3 in ground water as well. The primary drinking water standard for nitrate (as NO_3) is 45 mg/L (DHS, 1992).

Waters shall not exceed 10 mg/L nitrogen as nitrate-nitrogen plus nitrite-nitrogen (NO_3-N + NO_2-N)*, 45 mg/L as nitrate* (NO_3)*, 10 mg/L as nitrate-nitrogen* (NO_3-N)*, or 1 mg/L as nitrite-nitrogen* (NO_2-N) *or as otherwise designated in Table 3-8.*

Oil and Grease

Oil and grease are not readily soluble in water and form a film on the water surface. Oily films can coat birds and aquatic organisms, impacting respiration and thermal regulation, and causing death. Oil and grease can also cause nuisance conditions (odors and taste), are aesthetically unpleasant, and can restrict a wide variety of beneficial uses.

Waters shall not contain oils, greases, waxes or other materials in concentrations that result in a visible film or coating on the surface of the water or on objects in the water, that cause nuisance, or that otherwise adversely affect beneficial uses.

Oxygen, Dissolved (DO)

Adequate dissolved oxygen levels are required to support aquatic life. Depression of dissolved oxygen can lead to anaerobic conditions resulting in odors or, in extreme cases, in fish kills. Dissolved oxygen requirements are dependent on the beneficial uses of the waterbody.

*At a minimum (see specifics below), the **mean** annual dissolved oxygen concentration of **all** waters shall be greater than 7 mg/L, and no single determination shall be less than 5.0 mg/L, except when natural conditions cause lesser concentrations.*

The dissolved oxygen content of all surface waters designated as WARM shall not be depressed below 5 mg/L as a result of waste discharges.

The dissolved oxygen content of all surface waters designated as COLD shall not be depressed below 6 mg/L as a result of waste discharges.

The dissolved oxygen content of all surface waters designated as both COLD and SPWN shall not be depressed below 7 mg/L as a result of waste discharges.

For that area known as the Outer Harbor area of Los Angeles-Long Beach Harbors, the mean annual dissolved oxygen concentrations shall be 6.0 mg/L or greater, provided that no single determination shall be less than 5.0 mg/L.

Table 3-8. Water Quality Objectives for Selected Constituents in Inland Surface Waters[a].

Reaches are in upstream to downstream order.

WATERSHED/STREAM REACH[b]	TDS (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Boron[c] (mg/L)	Nitrogen[d] (mg/L)	SAR[e] (mg/L)
Miscellaneous Ventura Coastal Streams	*no waterbody specific objectives* [f]					
Ventura River Watershed:						
Above Camino Cielo Road	700	300	50	1.0	5	5
Between Camino Cielo Road and Casitas Vista Road	800	300	60	1.0	5	5
Between Casitas Vista Road and confluence with Weldon Canyon	1000	300	60	1.0	5	5
Between confluence with Weldon Canyon and Main Street	1500	500	300	1.5	10	5
Between Main St. and Ventura River Estuary	*no waterbody specific objectives* [f]					
Santa Clara River Watershed:						
Above Lang gaging station	500	100	50	0.5	5	5
Between Lang gaging station and Bouquet Canyon Road Bridge	800	150	100	1.0	5	5
Between Bouquet Canyon Road Bridge and West Pier Highway 99	1000	300	100	1.5	10	5
Between West Pier Highway 99 and Blue Cut gaging station	1000	400	100	1.5	5	10
Between Blue Cut gaging station and A Street, Fillmore	1300	600	100	1.5	5	5
Between A Street, Fillmore and Freeman Diversion "Dam" near Saticoy	1300	650	80	1.5	5	5
Between Freeman Diversion "Dam" near Saticoy and Highway 101 Bridge	1200	600	150	1.5	-	-
Between Highway 101 Bridge and Santa Clara River Estuary	*no waterbody specific objectives* [f]					
Santa Paula Creek above Santa Paula Water Works Diversion Dam	600	250	45	1.0	5	5
Sespe Creek above gaging station, 500' downstream from Little Sespe Creek	800	320	60	1.5	5	5
Piru Creek above gaging station below Santa Felicia Dam	800	400	60	1.0	5	5
Calleguas Creek Watershed:						
Above Potrero Road	850	250	150	1.0	10	f
Below Potrero Road	*no waterbody specific objectives* [f]					

Table 3-8. Water Quality Objectives for Selected Constituents in Inland Surface Waters[a] (cont.)

Reaches are in upstream to downstream order.

WATERSHED/STREAM REACH[b]	TDS (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Boron[c] (mg/L)	Nitrogen[d] (mg/L)	SAR[e] (mg/L)
Miscellaneous Los Angeles County Coastal Streams	*no waterbody specific objectives* [f]					
Malibu Creek Watershed	*2000*	*500*	*500*	*2.0*	*10*	-
Ballona Creek Watershed	*no waterbody specific objectives* [f]					
Dominguez Channel Watershed	*no waterbody specific objectives* [f]					
Los Angeles River Watershed:						
Above Figueroa Street	950	300	150	g	8	g
Between Figueroa Street and Los Angeles River Estuary (Willow Street). Includes Rio Hondo below Santa Ana Freeway	1500	350	150	g	8	g
Rio Hondo above Santa Ana Freeway [h]	750	300	150	g	8	g
Santa Anita Creek above Santa Anita spreading grounds	250	30	10	g	f	g
Eaton Canyon Creek above Eaton Dam	250	30	10	g	f	g
Arroyo Seco above spreading grounds	300	40	15	g	f	g
Big Tujunga Creek above Hansen Dam	350	50	20	g	f	g
Pacoima Wash above Pacoima spreading grounds	250	30	10	g	f	g
San Gabriel River Watershed:						
Above Morris Dam	250	30	10	0.6	2	2
Between Morris Dam and Ramona Blvd.	*450*	*100*	*100*	*0.5*	8	g
Between Ramona Blvd. and Firestone Blvd.	750	300	150	*1.0*	8	g
Between Firestone Blvd. and San Gabriel River Estuary (downstream from Willow Street) including Coyote Creek	*no waterbody specific objectives* [f]					
All other minor San Gabriel Mountain streams tributary to San Gabriel Valley [i]	300	40	15	g	f	g
Island Watercourses:						
Anacapa Island	*no waterbody specific objectives* [f]					
San Nicolas Island	*no waterbody specific objectives* [f]					
Santa Barbara island	*no waterbody specific objectives* [f]					
Santa Catalina Island	*no waterbody specific objectives* [f]					
San Clemente Island	*no waterbody specific objectives* [f]					

Table 3-8. Water Quality Objectives for Selected Constituents in Inland Surface Waters[a] (cont.)

Reaches are in upstream to downstream order.

WATERSHED/STREAM REACH[b]	TDS (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Boron[c] (mg/L)	Nitrogen[d] (mg/L)	SAR[e] (mg/L)
Other Watercourses:						
San Antonio Creek[j]	225	25	6	–	–	–
Chino Creek[j]	–	–	–	–	–	–

a. As part of the State's continuing planning process, data will continue to be collected to support the development of numerical water quality objectives for waterbodies and constituents where sufficient information is presently unavailable. Any new recommendations for water quality objectives will be brought before the Regional Board in the future.

b. All references to watersheds, streams and reaches include all tributaries. Water quality objectives are applied to all waters tributary to those specifically listed in the table. See Figures 2-1 to 2-10 for locations.

c. Where naturally occurring boron results in concentrations higher than the stated objective, a site-specific objective may be determined on a case-by-case basis.

d. Nitrate-nitrogen plus nitrite-nitrogen (NO3-N + NO2-N). The lack of adequate nitrogen data for all streams precluded the establishment of numerical objectives for all streams.

e. Sodium adsorption ratio (SAR) predicts the degree to which irrigation water tends to enter into cation-exchange reactions in soil.

SAR = Na+/((Ca++ + Mg++)/2)1/2

f. Site-specific objectives have not been determined for these reaches at this time. These areas are often impaired (by high levels of minerals) and there is not sufficient historic data to designate objectives based on natural background conditions. The following table illustrates the mineral or nutrient quality necessary to protect different categories of beneficial uses and will be used as a guideline for establishing effluent limits in these cases. Protection of the most sensitive beneficial use(s) would be the determining criteria for the selection of effluent limits.

Recommended objective (mg/L)	Beneficial Use Categories				
	MUN (Drinking Water Standards) ^{1}	PROC	AGR	AQ LIFE*(Frshwtr)	GWR
TDS	500 (USEPA secondary MCL)	50-1500 ^{2,7,9}	450-2000 ^{2,3,6}		Limits based on appropriate groundwater basin objectives and/or beneficial uses
Chloride	250 (USEPA secondary MCL)	20-1000 ^{2,9}	100-355 ^{2,3,8}	230 (4 day ave. continuous conc) ^{4}	
Sulfate	400-500 (USEPA proposed MCL)	20-300 ^{2,9}	350-600 ^{2,8}		
Boron			0.5-4.0 ^{2,6,8}		
Nitrogen	10 (USEPA MCL)				

References: 1) USEPA CFR § 141 et seq., 2) McKee and Wolf, 1963, 3) Ayers and Westcot, 1985, 4) USEPA, 1988, 5) Water Pollution Control Federation, 1989, 6) USEPA, 1973, 7) USEPA 1980, 8) Ayers, 1977.

* Aquatic life includes a variety of Beneficial Uses including WARM, COLD, SPWN, MIGR and RARE.

g. Agricultural supply is not a beneficial use of the surface water in the specified reach.

h. Rio Hondo spreading grounds are located above the Santa Ana Freeway

i. The stated objectives apply to all other surface streams originating within the San Gabriel Mountains and extend from their headwaters to the canyon mouth.

j. These watercourses are primarily located in the Santa Ana Region. The water quality objectives for these streams have been established by Santa Ana Region. Dashed lines indicate that numerical objectives have not been established, however, narrative objectives shall apply. Refer to the Santa Ana Region Basin Plan for more details.

Pesticides

Pesticides are used ubiquitously for a variety of purposes; however, their release into the environment presents a hazard to aquatic organisms and plants not targeted for their use. The extent of risk to aquatic life depends on many factors including the physical and chemical properties of the pesticide. Those of greatest concern are those that persist for long periods and accumulate in aquatic life and sediments.

No individual pesticide or combination of pesticides shall be present in concentrations that adversely affect beneficial uses. There shall be no increase in pesticide concentrations found in bottom sediments or aquatic life.

Waters designated for use as domestic or municipal supply (MUN) shall not contain concentrations of pesticides in excess of the limiting concentrations specified in Table 64444-A of Section 64444 (Organic Chemicals) of Title 22 of the California Code of Regulations which is incorporated by reference into this plan. This incorporation by reference is prospective including future changes to the incorporated provisions as the changes take effect. (See Table 3-7.)

pH

The hydrogen ion activity of water (pH) is measured on a logarithmic scale, ranging from 0 to 14. While the pH of "pure" water at 25 °C is 7.0, the pH of natural waters is usually slightly basic due to the solubility of carbon dioxide from the atmosphere. Minor changes from natural conditions can harm aquatic life.

The pH of inland surface waters shall not be depressed below 6.5 or raised above 8.5 as a result of waste discharges. Ambient pH levels shall not be changed more than 0.5 units from natural conditions as a result of waste discharge.

The pH of bays or estuaries shall not be depressed below 6.5 or raised above 8.5 as a result of waste discharges. Ambient pH levels shall not be changed more than 0.2 units from natural conditions as a result of waste discharge.

Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a highly toxic and persistent group of organic chemicals that have been historically released into the environment. Many historic discharges still exist as sources in the environment.

The purposeful discharge of PCBs (the sum of chlorinated biphenyls whose analytical characteristics resemble those of Aroclor-1016, Aroclor-1221, Aroclor-1232, Aroclor-1242, Aroclor-1248, Aroclor-1254, and Aroclor-1260) to waters of the Region, or at locations where the waste can subsequently reach waters of the Region, is prohibited.

Pass-through or uncontrollable discharges to waters of the Region, or at locations where the waste can subsequently reach water of the Region, are limited to 70 pg/L (30 day average) for protection of human health and 14 ng/L and 30 ng/L (daily average) to protect aquatic life in inland fresh waters and estuarine waters respectively.

Radioactive Substances

Radioactive substances are generally present in natural waters in extremely low concentrations. Mining or industrial activities increase the amount of radioactive substances in waters to levels that are harmful to aquatic life, wildlife or humans.

Radionuclides shall not be present in concentrations that are deleterious to human, plant, animal, or aquatic life or that result in the accumulation of radionuclides in the food web to an extent that presents a hazard to human, plant, animal, or aquatic life.

Waters designated for use as domestic or municipal supply (MUN) shall not contain concentrations of radionuclides in excess of the limits specified in Table 4 of Section 64443 (Radioactivity) of Title 22 of the California Code of Regulations which is incorporated by reference into this plan. This incorporation by reference is prospective including future changes to the incorporated provisions as the changes take effect. (See Table 3-9.)

Table 3-9. The Maximum Contaminant Levels: Radioactivity (for MUN beneficial use) specified in Table 4 of Section 64443 of Title 22 of the California Code of Regulations as of 12-22-88.

MCL Radioactivity	Maximum Contaminant Level pCi/L
Combined Radium-226 and Radium-228	5
Gross Alpha particle activity (including Radium-226 but excluding Radon and Uranium)	15
Tritium	20,000
Strontium-90	8
Gross Beta particle activity	50
Uranium	20

(pCi/L = picocuries = curies x 10^{-12})

Solid, Suspended, or Settleable Materials

Surface waters carry various amounts of suspended and settleable materials from both natural and human sources. Suspended sediments limit the passage of sunlight into waters, which in turn inhibits the growth of aquatic plants. Excessive deposition of sediments can destroy spawning habitat, blanket benthic (bottom dwelling) organisms, and abrade the gills of larval fish.

Waters shall not contain suspended or settleable material in concentrations that cause nuisance or adversely affect beneficial uses.

Taste and Odor

Undesirable tastes and odors in water are an aesthetic nuisance, can impact recreational and other uses, and can indicate the presence of other pollutants.

Waters shall not contain taste or odor-producing substances in concentrations that impart undesirable tastes or odors to fish flesh or other edible aquatic resources, cause nuisance, or adversely affect beneficial uses.

Temperature

Discharges of wastewaters can cause unnatural and/or rapid changes in the temperature of receiving waters which can adversely affect aquatic life.

The natural receiving water temperature of all regional waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Board that such alteration in temperature does not adversely affect beneficial uses. Alterations that are allowed must meet the requirements below.

For waters designated WARM, water temperature shall not be altered by more than 5 °F above the natural temperature. At no time shall these WARM-designated waters be raised above 80 °F as a result of waste discharges.

For waters designated COLD, water temperature shall not be altered by more than 5 °F above the natural temperature.

Temperature objectives for enclosed bays and estuaries are specified in the "Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays of California" (Thermal Plan), including any revisions thereto. See Chapter 5 for a description of the Thermal Plan.

Toxicity

Toxicity is the adverse response of organisms to chemical or physical agents. When the adverse response is mortality, the result is termed acute toxicity. When the adverse response is not mortality but instead reduced growth in larval organisms or reduced reproduction in adult organisms (or other appropriate measurements), a critical life stage effect (chronic toxicity) has occurred. The use of aquatic bioassays (toxicity tests) is widely accepted as a valid approach to evaluating toxicity of waste and receiving waters.

All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in, human, plant, animal, or aquatic life. Compliance with this objective will be determined by use of indicator organisms, analyses of species diversity, population density, growth anomalies, bioassays of appropriate duration or other appropriate methods as specified by the State or Regional Board.

The survival of aquatic life in surface waters, subjected to a waste discharge or other controllable water quality factors, shall not be less than that for the same waterbody in areas unaffected by the waste discharge or, when necessary, other control water.

There shall be no acute toxicity in ambient waters, including mixing zones. The acute toxicity objective for discharges dictates that the average survival in undiluted effluent for any three consecutive 96-hour static or continuous flow bioassay tests shall be at least 90%, with no single test having less than 70% survival when using an established USEPA, State Board, or other protocol authorized by the Regional Board.

There shall be no chronic toxicity in ambient waters outside mixing zones. To determine compliance with this objective, critical life stage tests for at least three species with approved testing protocols shall be used to screen for the most sensitive species. The test species used for screening shall include a vertebrate, an invertebrate, and an aquatic plant. The most sensitive species shall then be used for routine monitoring. Typical endpoints for chronic toxicity tests include hatchability, gross morphological abnormalities, survival, growth, and reproduction.

Effluent limits for specific toxicants can be established by the Regional Board to control toxicity identified under Toxicity Identification Evaluations (TIEs).

Turbidity

Turbidity is an expression of the optical property that causes light to be scattered in water due to particulate matter such as clay, silt, organic matter, and microscopic organisms. Turbidity can result in a variety of water quality impairments. The secondary drinking water standard for turbidity is 5 NTU (nephelometric turbidity units).

Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses. Increases in natural turbidity attributable to controllable water quality factors shall not exceed the following limits:

Where natural turbidity is between 0 and 50 NTU, increases shall not exceed 20%.

Where natural turbidity is greater than 50 NTU, increases shall not exceed 10%.

Allowable zones of dilution within which higher concentrations may be tolerated may be defined for each discharge in specific Waste Discharge Requirements.

Regional Narrative Objectives for Wetlands

In addition to the regional objectives for inland surface waters (including wetlands), the following narrative objectives apply for the protection of wetlands in the Region.

Hydrology

Natural hydrologic conditions necessary to support the physical, chemical, and biological characteristics present in wetlands shall be protected to prevent significant adverse effects on:

- *natural temperature, pH, dissolved oxygen, and other natural physical/chemical conditions,*
- *movement of aquatic fauna,*
- *survival and reproduction of aquatic flora and fauna, and*
- *water levels.*

Habitat

Existing habitats and associated populations of wetlands fauna and flora shall be maintained by:

- *maintaining substrate characteristics necessary to support flora and fauna which would be present naturally,*
- *protecting food supplies for fish and wildlife,*
- *protecting reproductive and nursery areas, and*
- *protecting wildlife corridors.*

Regional Objectives for Ground Waters

The following objectives apply to all ground waters of the Region:

Bacteria

Total and fecal coliform bacteria are used to indicate the likelihood of pathogenic bacteria in waters.

In ground waters used for domestic or municipal supply (MUN) the concentration of coliform organisms over any seven day period shall be less than 1.1/100 ml.

Chemical Constituents and Radioactivity

Chemical constituents in excessive amounts in drinking water are harmful to human health. Maximum levels of chemical constituents in drinking waters are listed in the California Code of Regulations and the relevant limits are described below.

Ground waters designated for use as domestic or municipal supply (MUN) shall not contain concentrations of chemical constituents and radionuclides in excess of the limits specified in the following provisions of Title 22 of the California Code of Regulations which are incorporated by reference into this plan: Table 64431-A of section 64431 (Inorganic chemicals), Table 64431-B of Section 64431 (Fluoride), Table 64444-A of Section 64444 (Organic Chemicals), and Table 4 of Section 64443 (Radioactivity). This incorporation by reference is prospective including future changes to the incorporated provisions as the changes take effect. (See Tables 3-5, 3-6, 3-7, and 3-9.)

Ground waters shall not contain concentrations of chemical constituents in amounts that adversely affect any designated beneficial use.

Mineral Quality

Inorganic constituents in ground waters are largely influenced by thermodynamic reactions that occur as ground water comes into contact with various rock and soil types. For example, ground water that flows through beds of gypsum ($CaSO_4 \cdot 2H_2O$) typically has relatively high levels of calcium cations and sulfate anions. Ground water flowing through limestone ($CaCO_3$) also has relatively high levels of calcium cations, but coupled with bicarbonate anions instead of sulfate. Ground waters with these ions at levels greater than 120 mg/L (expressed as $CaCO_3$) are considered hard waters (Hem, 1989).

Human activities and land use practices can influence inorganic constituents in ground waters. Surface waters carrying abnormally high levels of salts (e.g., irrigation return flows) can degrade the ground waters that they recharge. Abnormally high levels of inorganic constituents can impair and preclude beneficial uses. For example, high levels of boron preclude agricultural use (especially for citrus crops) of ground waters. Hard waters present nuisance problems and may require softening prior to industrial use.

Numerical mineral quality objectives for individual groundwater basins are contained in Table 3-10.

Nitrogen (Nitrate, Nitrite)

High nitrate levels in drinking water can cause health problems in humans. Infants are particularly sensitive and can develop methemoglobinemia (blue-baby syndrome). The primary drinking water standard for nitrate (as NO_3) is 45 mg/L (DHS, 1992).

Human activities and land use practices can also influence nitrogen concentration in ground waters. For example, effluents from wastewater treatment plants, septic tanks and confined animal facilities can add high levels of nitrogen compounds to the ground water that they recharge. Irrigation water containing fertilizers can add high levels of nitrogen to ground water.

Ground waters shall not exceed 10 mg/L nitrogen as nitrate-nitrogen plus nitrite-nitrogen (NO_3-N + NO_2-N), 45 mg/L as nitrate (NO_3), 10 mg/L as nitrate-nitrogen (NO_3-N), or 1 mg/L as nitrite-nitrogen (NO_2-N).

Taste and Odor

Undesirable tastes and odors in water are an aesthetic nuisance and can indicate the presence of other pollutants.

Ground waters shall not contain taste or odor-producing substances in concentrations that cause nuisance or adversely affect beneficial uses.

Table 3-10. Water Quality Objectives for Selected Constituents in Regional Ground Waters[a].

DWR Basin No.[b]	BASIN	OBJECTIVES (mg/L)			
		TDS	Sulfate	Chloride	Boron
	Pitas Point Area [c]	None specified			
	Ojai Valley				
4-1	Upper Ojai Valley				
	West of Sulfur Mountain Road	1,000	300	200	1.0
	Central area	700	50	100	1.0
	Sisar area	700	250	100	0.5
4-2	Lower Ojai Valley				0.5
	West of San Antonio--Senior Canyon Creeks	1,000	300	200	0.5
	East of San Antonio--Senior Canyon Creeks	700	200	50	
4-3	Ventura River Valley				
	Upper Ventura	800	300	100	0.5
	San Antonio Creek area	1,000	300	100	1.0
	Lower Ventura	1,500	500	300	1.5
	Ventura Central [d]				
4-4	Santa Clara--Piru Creek area				
	Upper area (above Lake Piru)	1,100	400	200	2.0
	Lower area east of Piru Creek	2,500	1,200	200	1.5
	Lower area west of Piru Creek	1,200	600	100	1.5
	Santa Clara--Sespe Creek area				
	Topa Topa (upper Sespe) area	900	350	30	2.0
	Fillmore area				
	Pole Creek Fan area	2,000	800	100	1.0
	South side of Santa Clara River	1,500	800	100	1.1
	Remaining Fillmore area	1,000	400	50	0.7
	Santa Clara--Santa Paula area				
	East of Peck Road	1,200	600	100	1.0
	West of Peck Road	2,000	800	110	1.0
	Oxnard Plain				
	Oxnard Forebay	1,200	600	150	1.0
	Confined aquifers	1,200	600	150	1.0
	Unconfined and perched aquifers	3,000	1,000	500	--
4-6	Pleasant Valley				
	Confined aquifers	700	300	150	1.0
	Unconfined and perched aquifers	--	--	--	--
4-7	Arroyo Santa Rosa	900	300	150	1.0
4-8	Las Posas Valley				
	South Las Posas area				
	NW of Grimes Cyn Rd & LA Ave & Somis Rd	700	300	100	0.5
	E of Grimes Cyn Rd and Hitch Blvd	2,500	1,200	400	3.0
	S of LA Ave between Somis Rd & Hitch Blvd	1,500	700	250	1.0
	Grimes Canyon Rd & Broadway area	250	30	30	0.2
	North Las Posas area	500	250	150	1.0
4-5	Upper Santa Clara				
	Acton Valley	550	150	100	1.0
	Sierra Pelona Valley (Agua Dulce)	600	100	100	0.5
	Upper Mint Canyon	700	150	100	0.5
	Upper Bouquet Canyon	400	50	30	0.5
	Green Valley	400	50	25	--
	Lake Elizabeth--Lake Hughes area	500	100	50	0.5

Table 3-10. Water Quality Objectives for Selected Constituents in Regional Ground Waters[a] (cont.)

DWR Basin No.[b]	BASIN	OBJECTIVES (mg/L)			
		TDS	Sulfate	Chloride	Boron
4-4.07	**Eastern Santa Clara**				
	Santa Clara--Mint Canyon	800	150	150	1.0
	South Fork	700	200	100	0.5
	Placerita Canyon	700	150	100	0.5
	Santa Clara--Bouquet & San Francisquito Canyons	700	250	100	1.0
	Castaic Valley	1,000	350	150	1.0
	Saugus Aquifer	--	--	--	--
4-9	**Simi Valley**				
	Simi Valley Basin				
	Confined aquifers	1,200	600	150	1.0
	Unconfined aquifers	--	--	--	--
	Gillibrand Basin	900	350	50	1.0
4-10	**Conejo Valley**	800	250	150	1.0
4-11	**Los Angeles Coastal Plain**				
	Central Basin	700	250	150	1.0
	West Coast Basin	800	250	250	1.5
	Hollywood Basin	750	100	100	1.0
	Santa Monica Basin	1,000	250	200	0.5
4-12	**San Fernando Valley**				
	Sylmar Basin	600	150	100	0.5
	Verdugo Basin	600	150	100	0.5
	San Fernando Basin				
	West of Highway 405	800	300	100	1.5
	East of Highway 405 (overall)	700	300	100	1.5
	Sunland-Tugunga area[e]	400	50	50	0.5
	Foothill area[e]	400	100	50	1.0
	Area encompassing RT-Tujunga-Erwin-N. Hollywood-Whithall-LA/Verdugo-Crystal Springs-Headworks-Glendale/Burbank Well Fields	600	250	100	1.5
	Narrows area (below confluence of Verdugo Wash with the LA River)	900	300	150	1.5
	Eagle Rock Basin	800	150	100	0.5
4-13	**San Gabriel Valley**				
	Raymond Basin				
	Monk Hill sub-basin	450	100	100	0.5
	Santa Anita area	450	100	100	0.5
	Pasadena area	450	100	100	0.5
	Main San Gabriel Basin				
	Western area[f]	450	100	100	0.5
	Eastern area[f]	600	100	100	0.5
	Puente Basin	1,000	300	150	1.0
4-14 8-2[g]	**Upper Santa Ana Valley**				
	Live Oak area	450	150	100	0.5
	Claremont Heights area	450	100	50	--
	Pomona area	300	100	50	0.5
	Chino area	450	20	15	--
	Spadra area	550	200	120	1.0
4-15	**Tierra Rejada**	700	250	100	0.5
4-16	**Hidden Valley**	1,000	250	250	1.0
4-17	**Lockwood Valley**	1,000	300	20	2.0
4-18	**Hungry Valley and Peace Valley**	500	150	50	1.0

Table 3-10. Water Quality Objectives for Selected Constituents in Regional Ground Waters[a] (cont.)

DWR Basin No.[b]	BASIN	OBJECTIVES (mg/L)			
		TDS	Sulfate	Chloride	Boron
4-19	Thousand Oaks area	1,400	700	150	1.0
4-20	Russell Valley				
	Russell Valley	1,500	500	250	1.0
	Triunfo Canyon area	2,000	500	500	2.0
	Lindero Canyon area	2,000	500	500	2.0
	Las Virgenes Canyon area	2,000	500	500	2.0
4-21	Conejo-Tierra Rejada Volcanic area [h]	–	–	–	–
	Santa Monica Mountains--southern slopes [i]				
	Camarillo area	1,000	250	250	1.0
	Point Dume area	1,000	250	250	1.0
4-22	Malibu Valley	2,000	500	500	2.0
	Topanga Canyon area	2,000	500	500	2.0
	San Pedro Channel Islands [j]				
	Anacapa Island	–	–	–	–
	San Nicolas Island	1,100	150	350	–
	Santa Catalina Island	1,000	100	250	1.0
	San Clemente Island	–	–	–	–
	Santa Barbara Island	–	–	–	–

a. Objectives for ground waters outside of the major basins listed on this table and outlined in Figure 1-9 have not been specifically listed. However, ground waters outside of the major basins are, in many cases, significant sources of water. Furthermore, ground waters outside of the major basins are either potential or existing sources of water for downgradient basins and, as such, objectives in the downgradient basins shall apply to these areas.

b. Basins are numbered according to Bulletin 118-80 (Department of Water Resources, 1980).

c. Ground waters in the Pitas Point area (between the lower Ventura River and Rincon Point) are not considered to comprise a major basin, and accordingly have not been designated a basin number by the California Department of Water Resources (DWR) or outlined on Figure 1-9.

d. The Santa Clara River Valley (4-4), Pleasant Valley (4-6), Arroyo Santa Rosa Valley (4-7) and Las Posas Valley (4-8) Ground Water Basins have been combined and designated as the Ventura Central Basin (DWR, 1980).

e. The category for the Foothill Wells area in previous Basin Plan incorrectly groups ground water in the Foothill area with ground water in the Sunland-Tujunga area. Accordingly, the new categories, Foothill area and Sunland-Tujunga area, replace the old Foothill Wells area.

f. All of the ground water in the Main San Gabriel Basin is covered by the objectives listed under Main San Gabriel Basin – Eastern area and Western area. Walnut Creek, Big Dalton Wash, and Little Dalton Wash separate the Eastern area from the Western area (see dashed line on Figure 2-17). Any ground water upgradient of these areas is subject to downgradient beneficial uses and objectives, as explained in Footnote a.

g. The border between Regions 4 and 8 crosses the Upper Santa Ana Valley Ground Water Basin.

h. Ground water in the Conejo-Tierra Rejada Volcanic Area occurs primarily in fractured volcanic rocks in the western Santa Monica Mountains and Conejo Mountain areas. These areas have not been delineated on Figure 1-9.

i. With the exception of ground water in Malibu Valley (DWR Basin No. 4-22), ground waters along the southern slopes of the Santa Monica Mountains are not considered to comprise a major basin and accordingly have not been designated a basin number by the California Department of Water Resources (DWR) or outlined on Figure 1-9.

j. DWR has not designated basins for ground waters on the San Pedro Channel Islands.

Statewide Objectives for Ocean Waters

The State Board's *Water Quality Control Plan for Ocean Waters of California* (Ocean Plan) and the *Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays and Estuaries of California* (Thermal Plan) and any revision thereto, shall also apply to all ocean waters of the Region. These plans are described in Chapter 5, Plans and Policies. Copies of these plans can be obtained at the Office of Legislative and Public Affairs (OLPA) in Sacramento or at the Regional Board office.

Site Specific Objectives

While many pollutants are regulated under federal, state or regionally applied water quality standards, the Regional Board supports the idea of developing site-specific objectives (SSOs) in appropriate circumstances. Site-specific, or reach-specific, objectives are already in place for some parameters (i.e., mineral quality). These were established to protect a specific beneficial use or were based on antidegradation policies. The development of site-specific objectives requires complex and resource intensive studies; resources will limit the number of studies that will be performed in any given year. In addition, a Use Attainability Analysis (UAA) study will be necessary if the attainment of designated aquatic life or recreational beneficial uses is in question. UAAs include waterbody surveys and assessments which define existing uses, determine appropriateness of the existing and designated uses, and project potential uses by examining the waterbody's physical, chemical, and biological characteristics. Under certain conditions, a designated use may be changed if attaining that use would result in substantial and widespread economic and social impacts. Uses that have been attained can not be removed under a UAA analysis. If a UAA study is necessary, that study must be completed before a SSO can be determined. Early planning and coordination with Regional Board staff will be critical to the development of a successful plan for developing SSOs.

Site-specific objectives must be based on sound scientific data in order to assure protection of beneficial uses. There may be several acceptable methods for developing site-specific objectives. A detailed workplan will be developed with Regional Board staff and other agencies (if appropriate) based on the specific pollutant and site involved. State Board staff and the USEPA will participate in the development of the studies so that there is agreement on the process from the beginning of the study.

Although each study will be unique, there are several elements that should be addressed in order to justify the need for a site-specific objective. These may include, but are not limited to:

- Demonstration that the site in question has different beneficial uses (e.g., more or less sensitive species) as demonstrated in a UAA or that the site has physical or chemical characteristics that may alter the biological availability or toxicity of the chemical.
- Provide a thorough review of current technology and technology-based limits which can be achieved at the facility(ies) on the study reach.
- Provide a thorough review of historical limits and compliance with these limits at all facilities in the study reach.
- Conduct a detailed economic analysis of compliance with existing, proposed objectives.
- Conduct an analysis of compliance and consistency with all federal, state, and regional plans and policies.

Once it is agreed that a site-specific objective is needed, the studies are performed, and an objective is developed, the following criteria must be addressed in the proposal for the new objective.

- Assurance that aquatic life and terrestrial predators are not currently threatened or impaired from bioaccumulation of the specific pollutant and that the biota will not be threatened or impaired by the proposed site-specific level of this pollutant. Safe tissue concentrations will be determined from the literature and from consultation with the California Department of Fish and Game and the U.S. Fish and Wildlife Service.

  For terrestrial predators, the presence, absence, or threat of harmful bioaccumulated pollutants will be determined through consultation with the

California Department of Fish and Game and the U.S. Fish and Wildlife Service.

- Assurance that human consumers of fish and shellfish are currently protected from bioaccumulation of the study pollutant, and will not be affected from bioaccumulation of this pollutant under the proposed site-specific objective.
- Assurance that aquatic life is currently, and will be protected from chronic toxicity from the proposed site-specific objective.
- Assurance that the integrity of the aquatic ecosystem will be protected under the proposed site-specific objective.
- Assurance that no other beneficial uses will be threatened or impaired by the proposed site-specific objective.

Water Quality Control Plan Los Angeles Region

Chapter: Beneficial Uses

Table 2-1 ~ Table 2-4

Table 2-1. Beneficial Uses of Inland Surface Waters.

Table Page 1

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
VENTURA COUNTY COASTAL STREAMS																									
Los Sauces Creek	401.00	P*	I	I	I	I				I	I			I	I				E			I	I		
Poverty Canyon	401.00	P*	I	I	I	I				I	I			I	I				E			I	I		
Madranio Canyon	401.00	P*	I	I	I	I				I	I			I	I				E			I	I		
Javon Canyon	401.00	P*	I	I	I	I				I	I			I	I				E			I	I		E
Padre Juan Canyon	401.00	P*	I	I	I	I				I	I			I	I				E			I	I		
McGrath Lake c	403.11									Ed	Ed	P					E		E		Ee				E
Big Sycamore Canyon Creek	404.47	P*				I				I	I			I	E				E			P	P		E
Little Sycamore Canyon Creek	404.45	P*								I	I			I					E		E		P		
VENTURA RIVER WATERSHED												E													
Ventura River Estuary c	402.10							E		E	E	E		E			E	E	E		Ee	Ef	Ef	E	E
Ventura River	402.10	P*	E		E	E	E			E	E			E	E				E		E	E	E		E
Ventura River	402.20	E	E	E	E	E	E			E	E			E	E				E		Eg	E	E		E
Cañada Larga	402.10	P*		I	I	I	I			I	I			I	I				E			I	I		
Lake Casitas	402.20	E	E	E	E	P	P		P	Ph	E			E	E				E		E				
Lake Casitas tributaries	402.20	E*			P	E				E	E			E	E				E		P	E	E		E
Coyote Creek below dam	402.20	P*				E				P				E	E				E			E	E		E
San Antonio Creek	402.20	E	E	E	E	E				E	E			E	E				E			E	E		E
San Antonio Creek	402.32	E	E	E	E	E	E			E	E			E	E				E			E	E		E
Lion Creek	402.31	I*	I	I	I					I	I			I	I				E						
Reeves Creek	402.32	I*	I	I	I	I				I	I			I	I				E			I	I		
Mirror Lake	402.20	P*				E				P	E			E					E						E
Ojai Wetland	402.20	P*								P	E			E					E						E
Matilija Creek	402.20	P*				E				E	E				E				E			E	E		E
Murietta Canyon Creek	402.20	P*				E				E	E				E				E			E	E		E
North Fork Matilija Creek	402.20	E*	E	E	E	E				E	E			E	E				E		E	E	E		E
Matilija Reservoir	402.20	E			E	E	E			E	E			E	E				E			E	E		E
SANTA CLARA RIVER WATERSHED																									
Santa Clara River Estuary c	403.11							E		E	E	E					E	E	E		Ee	Ef	Ef		E
Santa Clara River	403.11	P*	E	E	E	E	E			E	E			E	E				E		E	E			E
Santa Clara River	403.21	P*	E	E	E	E	E			Ed	E			E					E		E	E			E
Santa Clara River	403.31	P*	E	E	E	E	E			Ed	E			E					E		E	E			E
Santa Clara River	403.41	P*	E	E	E	E	E			E	E			E					E		E	E			E
Santa Clara River	403.51	P*	E	E	E	E	E			E	E			E					E		E				E
Santa Clara River (Soledad Cyn)	403.55	E*	E	E	E	E	E			E	E			E					E		Ei				E
Santa Paula Creek	403.21	P	E	E	E	E	E			E	E			E	E				E		E	E	E		

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required
* Asterixed MUN designations are designated under SB 88-63 and RB 89-03. Some designations may be considered for exemptions at a later date. (See pages 2-3,4 for more details).

Footnotes are consistent on all beneficial use tables.

a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries. Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.

b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody. Any regulatory action would require a detailed analysis of the area.

c Coastal waterbodies which are also listed in Coastal Features Table (2-3) or in Wetlands Table (2-4).

d Limited public access precludes full utilization.

e One or more rare species utilize all ocean, bays, esturaries, and coastal wetlands for foraging and/or nesting.

f Aquatic organisms utilize all bays, estuaries, lagoons and coastal wetlands, to a certain extent, for spawning and early development. This may include migration into areas which are heavily influenced by freshwater inputs.

g Condor refuge.

h Water contact recreational activities prohibited by Casitas MWD.

i Soledad Canyon is the habitat of the Unarmored Three-Spine Stickleback.

Table 2-1. Beneficial Uses of Inland Surface Waters (Continued).

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
SANTA CLARA RIVER WATERSHED (CONT)																									
Sisar Creek	403.21	P	E	P	E	E				E	E			E	E				E		Eg		E		E
Sisar Creek	403.22	P	E	P	E	E				E	E			E	E				E		Eg		E		E
Sespe Creek	403.31	P	E	E	E	E				E	E			E	E				E	E	E	E	E		E
Sespe Creek	403.32	P	E	P	E	E				E	E			E	E				E	E	Eg	E	E		E
Timber Creek	403.32	P*				E				E	E				E				E	E	E	E	E		E
Bear Canyon	403.32	P*				E				E	E			E	P				E	E	E	E	E		E
Trout Creek	403.32	P*				E				E	E			E	E				E		E	E	E		E
Piedra Blanca Creek	403.32	P*				E				E	E				E				E		E	E	E		E
Lion Canyon	403.32	P*				E				E	E			E	E				E			E	E		E
Rose Valley Creek	403.32	P*				E				E	E			E	E				E				E		E
Howard Creek	403.32	P*				E				E	E				E				E	E	E	E	E		E
Tule Creek	403.32	P*				E				P	E				P				E	E	E	E	E		E
Potrero John Creek	403.32	P*				E				E	E				P				E		E	E	E		E
Hopper Creek	403.41	P*	E		E	E	E			E	E			E	E				E		Eg				E
Piru Creek	403.41	P	E	E	E	E	E			E	E			E	E				E		Eg	E	E		E
Piru Creek	403.42	P	E	E	E	E	E			E	E			E	E				E		Eg		E		E
Lake Piru	403.41	P	E	E	E	E	P			E	E			E	E				E		E		E		
Lake Piru	403.42	P	E	E	E	E	P		P	E	E			E	E				E		E		E		
Pyramid Lake	403.42	E	E	E	E	E	P		E	E	E			E	E				E		E				
Cañada de los Alamos	403.43	I*			I	I	I			I	I			I	I				E		E				
Gorman Creek	403.43	I*			I	I				I	I			I	I				E		P				
Lockwood Creek	403.42	I*			I	I				I	I			I	I				E						
Lockwood Creek	403.44	I*			I	I	I			I	I			I	I				E						
Tapo Canyon	403.41	P*			P					P	E			E					E						
Castaic Creek	403.51	I	I	I	I	I	I			I	E			I					E		E				
Castaic Lagoon	403.51	E*	E	E	E	E	E			E	E			E					E						
Castaic Lake	403.51	E	E	E	E	E	E		E	E	E			E	I				E		E		E		
Elderberry Forebay	403.51	E	E	E	E	E	E		E	Ek	E			E					E		E		E		
Elizabeth Lake Canyon	403.51	I	I	I	I	I	I			I	E			I					E						
San Francisquito Canyon l	403.51	I	I	I	I	I	I			I	I			I					E		E		I		E
South Fork (Santa Clara River)	403.51	I*	I	I	I	I	I			I	I			I					E						
Drinkwater Reservoir	403.51	P*				E				Pk	E			P					E		E				E
Bouquet Canyon	403.51	E I	E I	P I	P I	E	P			Em	E			E	E				E				P		E
Bouquet Canyon	403.52	P	P	P	E	E	P			Em	E			E	E				E		E				E
Dry Canyon Creek	403.51	I	I	I	I	I	I			I	I			I					E						
Dry Canyon Reservoir j	403.51	E	E	E	E	P	P		P	Pk	E			E					E						
Bouquet Reservoir	403.52	E	E	E	E	E	E		P	Pk	E			E					E						

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required
* Asterixed MUN designations are designated under SB 88-63 and RB 89-03. Some designations may be considered for exemptions at a later date. (See pages 2-3,4 for more details).

Footnotes are consistent on all beneficial use tables.

a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries. Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.

b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody. Any regulatory action would require a detailed analysis of the area.

g Condor refuge.

j Out of service.

k Public access to reservoir and its surrounding watershed is prohibited by Los Angeles County Department of Public Works.

l The majority of the reach is intermittent; there is a small area of rising ground water creating perennial flow.

m Access prohibited by Los Angeles County Department of Public Works in the concrete-channelized areas.

Table 2-1. Beneficial Uses of Inland Surface Waters (Continued).

Table Page 3

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
SANTA CLARA RIVER WATERSHED (CONT)																									
Mint Canyon Creek	403.51	I	I	I	I	I	I			Im	I			I					E						
Mint Canyon Creek	403.53	I*	I	I	I	I	I			Im	I			I					E						
Agua Dulce Canyon Creek	403.54	I*	I	I	I	I	I			I	I			I					E		E				
Agua Dulce Canyon Creek	403.55	I*			I	I	I			I	I			I					E						
Aliso Canyon Creek	403.55	P*			P	E				E	E			E					E						E
Lake Hughes	403.51	P	P	P	P	P	P			E	E			E					E						
Munz Lake	403.51	P*	P	P	P	E	P			E	E			E					E						
Lake Elizabeth	403.51	P	P	P	P	P	P			E	E			E					E		E				
CALLEGUAS-CONEJO CREEK WATERSHED																									
Mugu Lagoon c	403.11							E		Pn	E	Ed					E	E	Eo	E	Ee,p	Ef	Ef	Ed	E
Calleguas Creek Estuary c	403.11							P		Pn	E	E					E		E		Ee,p	Ef	Ef		E
Calleguas Creek	403.11	P*			E	E	E			E	E			E	E				E		Ep				E
Calleguas Creek	403.12	P*	E	E	E	E				Eq	E			E					E						
Revolon Slough	403.11	P*	P		E	E				Eq	E			E					E						E
Beardsley Wash	403.61	P*					E			E	E			E					E						
Conejo Creek	403.12	P*	E	E	E	E				Eq	E			E					E						
Conejo Creek	403.63	P*				I	I			I	I			I					E				E		
Arroyo Conejo	403.64	P*				I	I			I	I			I					E		E				
Arroyo Conejo	403.68	P*				I	I			I	I			I					E						
Arroyo Santa Rosa	403.63	P*				I	I			I	I			I					E						
Arroyo Santa Rosa	403.65	P*				I	I			I	I			I					E						
North Fork Arroyo Conejo	403.64	P*			E	E				E	E			E					E				E		
Arroyo Las Posas	403.12	P*	P	P	P	E				E	E			E	P				E						
Arroyo Las Posas	403.62	P*	P	P	P	E	E			E	E			E	P				E						
Arroyo Simi	403.62	P*	I			I	I			I	I			I					E		E				
Arroyo Simi	403.67	I*	I			I	I			I	I			I					E						
Tapo Canyon Creek	403.66	I*		P	P	I				I	I			I					E						
Tapo Canyon Creek	403.67	I*		P	P	I				I	I			I					E						
Gillibrand Canyon Creek	403.66	P*				I	I			I	I			I					E						
Gillibrand Canyon Creek	403.67	P*				I				I	I			I					E						
Lake Bard (Wood Ranch Reservoir)	403.67	E	E	E	E	P				Pr	Er			E					E						
LOS ANGELES COUNTY COASTAL STREAMS																									
Arroyo Sequit	404.44	P*				I				E	E			E	E				E		E	E	E		E
San Nicholas Canyon Creek	404.43	P*								I	I			I					E						

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required
* Asterixed MUN designations are designated under SB 88-63 and RB 89-03. Some designations may be considered for exemptions at a later date. (See pages 2-3,4 for more details).

Footnotes are consistent on all benefical use tables.

a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.

b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody. Any regulatory action would require a detailed analysis of the area.

c Coastal waterbodies which are also listed in Coastal Features Table (2-3) or in Wetlands Table (2-4).

d Limited public access precludes full utiliazation.

e One or more rare species utilize all ocean, bays, esturaries, and coastal wetlands for foraging and/or nesting.

f Aquatic organisms utilize all bays, estuaries, lagoons and coastal wetlands, to a certain extent, for spawning and early development. This may include migration into areas which are heavily influenced by freshwater inputs

m Access prohibited by Los Angeles County DPW in the concrete-channelized areas.

n Area is currently under control of the Navy: swimming is prohibited.

o Marine habitats of the Channel Islands and Mugu Lagoon serve as pinneped haul-out areas for one or more species (i.e., sea lions).

p Habitat of the Clapper Rail.

q Whenever flow conditions are suitable.

r Public access prohibited by Calleguas MWD.

Table 2-1. Benefical Uses of Inland Surface Waters (Continued).

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
LA COUNTY COASTAL STREAMS (CONT)																									
Los Alisos Canyon Creek	404.42	P*								I	I			I					E		E				
Lachusa Canyon Creek	404.42	P*								I	I			I					E						
Encinal Canyon Creek	404.41	P*								I	I			I					E		E				
Trancas Canyon Creek	404.37	E*								Em	E			E					E		E				
Dume Lagoon c	404.36							E		E	E	E					E		E		Ee	Pf	Pf		E
Dume Creek (Zuma Canyon)	404.36	E*								E	E			E	E				E		E	P	P		
Ramirez Canyon Creek	404.35	I*								I	I			I					E				P		
Escondido Canyon Creek	404.34	I*								I	I			I					E		E				
Latigo Canyon Creek	404.33	I*								I	I			I					E		E				
Solstice Canyon Creek	404.32	E*								E	E			E					E			P	P		
Puerco Canyon Creek	404.31	I*								I	I			I					E						
Corral Canyon Creek	404.31	I*								I	I			I					E						
Carbon Canyon Creek	404.16	P*								I	I			I					E						
Las Flores Canyon Creek	404.15	P*								I	I			I					E						
Piedra Gorda Canyon Creek	404.14	P*								I	I			I					E						
Pena Canyon Creek	404.13	P*								I	I			I	E				E						
Tuna Canyon Creek	404.12	P*								I	I			I					E						
Topanga Lagoon c	404.11							E		E	E	E					E		E		Ee	Ef	Ef		E
Topanga Canyon Creek	404.11	P*								I	I			E	E				E			P	I		
Santa Ynez Canyon	405.13	P*								I	E			I					E		E				
Santa Ynez Lake (Lake Shrine)	405.13	P*								Pk	E			E					E						
Santa Monica Canyon Channel	405.13	P*								Ps	I			P					P						
Rustic Canyon Creek	405.13	P*								I	I			I					E						
Sullivan Canyon Creek	405.13	P*								I	I			I					E						
Mandeville Canyon Creek	405.13	P*								I	I			I					E						
Coastal Streams of Palos Verdes	405.11	P*				I				I	I			I					E		E				
Canyon Streams trib. to Coastal Streams of Palos Verdes	405.12	P*				I				I	I			I					E		Et				
Bixby Slough and Harbor Lake	405.12	P*								E	E			E					E		E				E
Los Cerritos Wetlands c	405.15							E		E	E	E					E		E		Ee	Pf	Pf	E	E
Los Cerritos Channel Estuary c	405.12		E					E		Es	E	E					E	E	E		Ee	Ef	Ef	E	
Sims Pond	405.15	P*								P	E			P					E						E
Los Cerritos Channel to Estuary	405.15	P*								P	I			I					E						
Colorado Lagoon	405.12									E	E	E		P					E					E	
Madrona Marsh	405.12									P	E			P					E						E
Stone Canyon Reservoir	405.13	E*	E	E		P				Pk	E			E					E						
Hollywood Reservoir	405.14	E*	E	E		P				Pk	E			E					E						
Franklin Canyon Reservoir	405.14	E*								Pk,u				Pu											
Upper Franklin Canyon Reservoir	405.14	E*	E	E		P				P	E			E					E						E

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required
* Asterixed MUN designations are designated under SB 88-63 and RB 89-03. Some designations may be considered for exemptions at a later date. (See pages 2-3,4 for more details).

Footnotes are consistent on all benefical use tables.

a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries
Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.

b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody.
Any regulatory action would require a detailed analysis of the area.

c Coastal waterbodies which are also listed in Coastal Features Table (2-3) or in Wetlands Table (2-4).

e One or more rare species utilize all ocean, bays, esturaries, and coastal wetlands for foraging and/or nesting.

f Aquatic organisms utilize all bays, estuaries, lagoons and coastal wetlands, to a certain extent, for spawning and early development.
This may include migration into areas which are heavily influenced by freshwater inputs.

k Public access to reservoir and its surrounding watershed is prohibited by the Los Angeles Department of Water and Power.

m Access prohibited by Los Angeles County DPW in the concrete-channelized areas.

s Access prohibited by Los Angeles County DPW.

t Rare applies only to Agua Magna Canyon & Sepulveda Canyon areas.

u These reservoirs are covered and thus inaccessible.

Table 2-1. Benefical Uses of Inland Surface Waters (Continued).

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
MALIBU CREEK WATERSHED																									
Malibu Lagoon c	404.21							E		E	E						E	E	E		Ee	Ef	Ef		E
Malibu Creek	404.21	P*								E	E			E	E				E		E	E	E		E
Cold Creek	404.21	P*								E	E				P				E		E		P		E
Las Virgenes Creek	404.22	P*								Em	E			E	P				E		E	P	P		E
Century Reservoir	404.21	P*								E	E			E					E						E
Malibou Lake	404.24	P*						E		E	E			E					E		E				E
Medea Creek	404.23	P*				I				Im	I			I	P				E		E				E
Medea Creek	404.24	I*				I				Em	E			E					E						E
Lindero Creek	404.23	P*								I	I			I					E						
Triunfo Creek	404.24	P*								Im	I			I					E						
Triunfo Creek	404.25	P*				I				Im	I			I					E		E				
Westlake Lake	404.25	P*						E		E	E			E					E						
Potrero Valley Creek	404.25	P*				I				I	I			P					E						
Lake Eleanor Creek	404.25	P*				I				I	I			I					E						
Lake Eleanor	404.25	P*				E				E	E			E					E		E				E
Las Virgenes (Westlake) Reservoir	404.25	E	E	E	E					Pk,v	E			P					E						
Hidden Valley Creek	404.26	I*				I				I	I			I					E						
Lake Sherwood	404.26	P*				E		E		E	E			E					E						E
BALLONA CREEK WATERSHED																									
Ballona Creek Estuary c,w	405.13							E		E	E	E					E	E	E		Ee	Ef	Ef	E	
Ballona Lagoon/ Venice Canals c	405.13							E		E	E	E					E	E	E		Ee	Ef	Ef	E	E
Ballona Wetlands c	405.13									E	E						E		E		Ee	Ef	Ef		E
Del Rey Lagoon c	405.13							E		E	E	E					E		E		Ee	Ef	Ef		E
Ballona Creek to Estuary	405.13	P*								Ps	E			P					P						
Ballona Creek	405.15	P*								Ps	E			P					E						
DOMINGUEZ CHANNEL WATERSHED																									
Dominguez Channel Estuary c,w	405.12							P		Es	E	E					E	E	E		Ee	Ef	Ef		
Dominguez Channel to Estuary	405.12	P*								Ps	E			P					P		E				
LOS ANGELES RIVER WATERSHED																									
Los Angeles River Estuary c,w	405.12		E					E		E	E	E					E	E	E		Ee	Ef	Ef	P	E
Los Angeles River to Estuary	405.12	P*	P	P		E				Es	E			E				E	E		E	P	P	Ps	
Los Angeles River	405.15	P*	P			E				Es	E			E					P						
Los Angeles River	405.21	P*	P			E				E	E			E					E						E
Compton Creek	405.15	P*				E				Es	E			E					E						E

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
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* Asterixed MUN designations are designated under SB 88-63 and RB 89-03. Some designations may be considered for exemptions at a later date. (See pages 2-3,4 for more details).

Footnotes are consistent on all beneficial use tables.

a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries. Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.

b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody. Any regulatory action would require a detailed analysis of the area.

c Coastal waterbodies which are also listed in Coastal Features Table (2-3) or in Wetlands Table (2-4).

e One or more rare species utilize all ocean, bays, esturaries, and coastal wetlands for foraging and/or nesting.

f Aquatic organisms utilize all bays, estuaries, lagoons and coastal wetlands, to a certain extent, for spawning and early development. This may include migration into areas which are heavily influenced by freshwater inputs.

k Public access to reservoir and its surrounding watershed is prohibited by LADWP.

m Access prohibited by Los Angeles County DPW in the concrete-channelized areas.

v Public water supply reservoir. Owner prohibits public entry.

w These areas are engineered channels. All references to Tidal Prisms in Regional Board documents are functionally equivalent to estuaries.

s Access prohibited by Los Angeles County DPW.

Table 2-1. Benefical Uses of Inland Surface Waters (Continued).

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
LA RIVER WATERSHED (CONTINUED)																									
Rio Hondo below Spreading Grounds	405.15	P*				I				Pm	E			P					I						
Rio Hondo to Spreading Grounds	405.15	P*				I				Im	E			P					I						
Rio Hondo	405.41	P*				I				Im	E			P					I		E				E
Alhambra Wash	405.41	P*				I				Pm	I			P					P		E				
Rubio Wash	405.41	P*				I				Im	I			I					E		P				
Rubio Canyon	405.31	P*				E				I	I			I					E		E				E
Eaton Wash	405.41	P*				I				I	I			I					E						
Eaton Wash (below dam)	405.31	P*				I				Im	I			I					E						
Eaton Wash (above dam)	405.31	P*				I				I	I			I					E						
Eaton Dam and Reservoir	405.31	P*				I				P	Id			I					E						
Eaton Canyon Creek	405.31	P*				E				E	E			E					E		E		E		E
Arcadia Wash (lower)	405.41	P*				I				Pm	I			P					P						
Arcadia Wash (upper)	405.33	P*				I				Pm	I			P					P						
Santa Anita Wash (lower)	405.41	P*				I				Pm	E			P					P		E				
Santa Anita Wash (upper)	405.33	P*				E				Em	E			E					E		E				
Little Santa Anita Canyon Creek	405.33	P*				I				I	I			I					E						
Big Santa Anita Reservoir	405.33	P*				E				Px	E			E	E				E						
Santa Anita Canyon Creek	405.33	E*				E				E	E			E	E				E		E		E		E
Winter Creek	405.33	P*				I				I	E			I					E						E
East Fork Santa Anita Canyon	405.33	P*				E				E	E			E	E				E				E		E
Sawpit Wash	405.41	I				I				Im	I			I					E						
Sawpit Canyon Creek	405.41	P*				I				I	I			I					E		E				
Sawpit Dam And Reservoir	405.41	P*				I				Px	I			I					E						
Monrovia Canyon Creek	405.41	I				I				I	I			I					E						E
Arroyo Seco S. Of Devil's Gates. (L)	405.15	P*								I	I			P					P						
Arroyo Seco S. Of Devil's Gates (U)	405.31	P*								Im	I			P					P		E				
Devil's Gate Reservoir (lower)	405.31	P*				I				Im	I			I					E						
Devil's Gate Reservoir (upper)	405.32	I*				I				I	I			I					E						
Arroyo Seco	405.32	E	E	E		E				Em	E			E	E				E						E
Millard Canyon Creek	405.32	E*	E	E		E				E	E			E					E		E				E
El Prieto Canyon Creek	405.32	I	I	I		I				I	I			I					E						
Little Bear Canyon Creek	405.32	P*				I				I	I			I	I				E						E
Verdugo Wash	405.24	P*				I				Pm	I			P					P						
Halls Canyon Channel	405.24	P*	I	I		I				Im	I			I					E						
Snover Canyon	405.32	I	I	I		I				Im	I			I					E						
Pickens Canyon	405.24	I*				I				Im	I			I					E						
Shields Canyon	405.24	I	I	I		I				Im	I			I					E						

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required
* Asterixed MUN designations are designated under SB 88-63 and RB 89-03. Some designations may be considered for exemptions at a later date. (See pages 2-3,4 for more details).

Footnotes are consistent on all beneficial use tables.

a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries
Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.

b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody.
Any regulatory action would require a detailed analysis of the area.

m Access prohibited by Los Angeles County DPW in concrete-channelized areas.

x Owner prohibits entry.

Table 2-1. Benefical Uses of Inland Surface Waters (Continued).

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
LA RIVER WATERSHED (CONT)																									
Dunsmore Canyon Creek	405.24	I	I	I		I				I	I			I					E						
Burbank Western Channel	405.21	P*								Pm	I			P					P						
La Tuna Canyon Creek	405.21	P*				I				Im	I			I					E						
Tujunga Wash	405.21	P*				I				Pm	I			P	P				P						
Hansen Flood Control Basin & Lakes	405.23	P*				E				E	E			E	E				E		E				
Lopez Canyon Creek	405.21	P*				I				Im	I			I					E						
Little Tujunga Canyon Creek	405.23	P*				I				I	E			I	I				E		E				
Kagel Canyon Creek	405.23	P*				I				Im	I			I					E						
Big Tujunga Canyon Creek	405.23	P*				E				E	E			E	E				E		E		E		E
Upper Big Tujunga Canyon Creek	405.23	P*				E				E	E			I	P				E						E
Haines Canyon Creek	405.23	P*				I				Im	I			I					E		E				
Vasquez Creek	405.23	P*				E				E	E			P	P				E						E
Clear Creek	405.23	P*				E				E	E			E	E				E						E
Big Tujunga Reservoir	405.23	P*				E				Pk	E			E	P				E				E		
Mill Creek	405.23	P*				E				E	E			E	E				E						E
Pacoima Wash	405.21	P*				E				Pm	E			E					E		E				
Pacoima Reservoir	405.22	P*				E				E	E			E					E						
Pacoima Canyon Creek	405.22	P*				E				E	E			E	E				E		E		E		E
Stetson Canyon Creek	405.22	P*				I				Pm	E			P					P						
Wilson Canyon Creek	405.22	P*				I				Em	E			I					E						
May Canyon Creek	405.22	P*				I				I	E			I					E						
Sepulveda Flood Control Basin	405.21	P*				E				E	E			E					E						E
Bull Creek	405.21	P*				I				Im	I			I					E						
Los Angeles Reservoir	405.21	E	E	E		P				Pk	E			E					E		E				
Lower Van Norman Reservoir	405.21	E*	E	E		E				E	E			E					E		E				
Solano Reservoir	405.21	E*								Pk,u				Pu					E						
Caballero Creek	405.21	P*				I				Im	I			I					E						
Aliso Canyon Wash and Creek	405.21	P*				I				Im	I			I					E						
Limekiln Canyon Wash	405.21	P*				I				Im	I			I					E						
Browns Canyon Wash and Creek	405.21	P*				I				Im	I			I					E						
Arroyo Calabasas	405.21	P*								Pm	I			P					P						
McCoy Canyon Creek	405.21	P*				I				I	I			I					E						
Dry Canyon Creek	405.21	P*				I				Im	I			I					E						
Bell Creek	405.21	P*				I				Im	I			I					E						
Chatsworth Reservoir y	405.21	E	E	E						P	E			E					E						
Dayton Canyon Creek	405.21	P*				I				I	I			I					E						

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P: Potential beneficial use
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Footnotes are consistent on all beneficial use tables.
a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries
Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.
b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody.
Any regulatory action would require a detailed analysis of the area.
k Public access to reservoir and its surrounding watershed is prohibited by Los Angeles Department of Water and Power.
m Access prohibited by Los Angeles County DPW in concrete-channelized areas.
u This reservoir is covered and thus inaccessible.
y Currently dry and no plans for restoration.

Table 2-1. Benefical Uses of Inland Surface Waters (Continued).

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
LOS ANGELES RIVER WATERSHED (CONT)																									
ISOLATED LAKES AND RESERVOIRS:																									
Eagle Rock Reservoir	405.25	E*								Pk,u				Pu											
Echo Lake	405.15	P*								P	E			P					E						
El Dorado Lakes	405.15	P*								E	E			P					E						E
Elysian Reservoir	405.15	E*	E	E						Pk	E			P					E						
Encino Reservoir	405.21	E*	E	E						Pk	E			P					E						
Ivanhoe Reservoir	405.15	E*	E	E						Pk	E			P					E						
Lincoln Park Lake	405.15	P*								P	E			P					E						
Silver Lake Reservoir	405.15	E*	E	E						Pk	E			P					E						
Toluca Lake	405.21	P*								Pk	E			P					E						
SAN GABRIEL RIVER WATERSHED																									
San Gabriel River Estuary c,w	405.15		E					E		E	E	E					E	E	E		Ee	Ef	Ef	P	
San Gabriel River: Firestone Blvd-Esutary	405.15	P*								Em	E			P					P						
San Gabriel River: Whittier N-Firestone	405.15	P*	P	P		I				Em	E			I					E		E				
San Gabriel River	405.41	P*				I				Im	I			I					E						
San Gabriel River	405.42	E	E	E	E	E				E	E			E	E				E		E				
San Gabriel River: Main Stem z	405.43	E	E	E	E	E				E	E			E	E				E				E		
North Fork San Gabriel River	405.43	For uses please see UPPER SAN GABRIEL TRIBUTARIES below																							
West Fork San Gabriel River	405.43	For uses please see UPPER SAN GABRIEL TRIBUTARIES below																							
East Fork San Gabriel River	405.43	For uses please see UPPER SAN GABRIEL TRIBUTARIES below																							
Coyote Creek to Estuary	405.15	P*	P	P						Pm	I			P					P		E				
Whittier Narrows Flood Control Basin	405.41	P*				E				E	E			E					E		P				
Legg Lake	405.41	P*				E				E	E			E	E				E						E
San Jose Creek	405.41	P*				I				Pm	I			I					E						
San Jose Creek	405.51	P*				I				Pm	I			I					E						
Puente Creek	405.41	P*				I				P	I			P					P						
Thompson Wash	405.52	P*				I				Im	I			I					E						
Thompson Creek	405.53	P*				I				I	I			I					E		E				
Thompson Creek Dam & Reservoir	405.53	P*				I				Px	I			I					E		E				
Walnut Creek Wash	405.41	P*				I				Im	I			I					E						E
Big Dalton Wash	405.41	P*				I				Pm	I			P					P						
Big Dalton Canyon Creek	405.41	P*				I				I	I			I					E						E
Mystic Canyon	405.41	P*				I				I	I			I					E						
Big Dalton Dam & Reservoir	405.41	P*				E				Px	E			E					E						

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P: Potential beneficial use
I: Intermittent beneficial use
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Footnotes are consistent on all beneficial use tables.

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c Coastal waterbodies which are also listed in Coastal Features Table (2-3) or in Wetlands Table (2-4).

e One or more rare species utilize all ocean, bays, esturaries, and coastal wetlands for foraging and/or nesting.

f Aquatic organisms utilize all bays, estuaries, lagoons and coastal wetlands, to a certain extent, for spawning and early development. This may include migration into areas which are heavily influenced by freshwater inputs.

k Public access to reservoir and its surrounding watershed is prohibited by the Los Angeles Department of Water and Power.

w These areas are engineered channels. All references to Tidal Prisms in Regional Board documents are functionally equivalent to estuaries.

m Access prohibited by Los Angeles County DPW in concrete-channelized areas.

x Owner prohibits entry.

u This reservoir is covered and thus inaccessible.

z Listed twice in this table (see next page).

Table 2-1. Benefical Uses of Inland Surface Waters (Continued).

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
SAN GABRIEL RIVER WATERSHED (CONT)																									
Bell Canyon Creek	405.41	P*				I				I	I			I					E						
Little Dalton Wash	405.41	P*				I				Pm	I			P					P						
Little Dalton Canyon Creek	405.41	P*				I				I	I			I					E						E
San Dimas Wash (lower)	405.41	P*				I				Im	I			I					E		E				
San Dimas Wash (upper)	405.44	P*				E				Im	I			I					E						
San Dimas Dam and Reservoir	405.44	E*				E				Px	E			E	E				E						
San Dimas Canyon Creek	405.44	E*				E				E	E			E	E				E						E
West Fork San Dimas Canyon	405.44	E*				E				E	E			E	P				E						E
Wolfskill Canyon	405.44	E*				E				E	E			E	P				E		E				E
Puddingstone Dam and Reservoir	405.52	E*			E	E				E	E			E	E				E		E				
Puddingstone Wash	405.41	E*				I				Im	I			I					E						
Marshall Creek and Wash	405.41	E*				I				Im	I			I					E						
Marshall Creek and Wash	405.53	E*				I	I			Im	I			I					E		E				E
Live Oak Wash	406.52	E*				I	I			I	I			I					E						
Live Oak Creek And Wash	405.53	E*				I	I			I	I			I					E						
Live Oak Dam and Reservoir	405.53	E*				E	E			E	E			E					E						
Emerald Creek And Wash	405.53	E*				I	I			Im	I			I					E						
Santa Fe Flood Control Basin	405.41	P*				I				P	I			I					E						E
Bradbury Canyon Creek	405.41	P*				I				I	I			I					E						
Spinks Canyon Creek	405.41	P*				I				I	I			I					E						
Maddock Canyon Creek	405.43	P*				I				I	I			I					E						
Van Tassel Canyon	405.43	P*				I				I	I			I					E		E				
Fish Canyon Creek	405.43	P*	I			E				E	E			E					E		E		E		E
Roberts Canyon Creek	405.43	P*				I				I	I			I					E		E				E
Morris Reservoir	405.43	E	E	E	E	E			E	P	E			E	E				E				E		
San Gabriel Reservoir	405.43	E	E	E	E	E			E	E	E			E	E				E						
UPPER SAN GABRIEL RIVER TRIBUTARIES																									
San Gabriel River: Main Stem z	405.43	E	E	E	E	E				E	E			E	E				E						E
Cattle Canyon Creek	405.43	P*				E				E	E			E	E				E		E		E		E
Coldwater Canyon Creek	405.43	P*				E				E	E			E	E				E		E		E		E
Cow Canyon Creek	405.43	P*				E				E	E			E	E				E		E		E		E
East Fork San Gabriel River	405.43	P*				E				E	E			E	E				E		E		E		E
Allison Gulch	405.43	P*				E				E	E			E	E				E				E		E
Fish Fork	405.43	P*				E				E	E			E	E				E				E		E

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required
* Asterixed MUN designations are designated under SB 88-63 and RB 89-03. Some designations may be considered for exemptions at a later date. (See pages 2-3,4 for more details).

Footnotes are consistent on all benefical use tables.
a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries
Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.
b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody.
Any regulatory action would require a detailed analysis of the area.
m Access prohibited by Los Angeles County DPW in concrete channelized areas.
x Owner prohibits entry.
z Also listed on previous page.

Table 2-1. Benefical Uses of Inland Surface Waters (Continued).

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
SAN GABRIEL RIVER WATERSHED (CONT)																									
North Fork San Gabriel River	405.43	P*				E				E	E			E	E				E		E		E		E
Bichota Canyon	405.43	P*				E				E	E			E	E				E		P		E		
Coldbrook Creek	405.43	P*				I				I	I			I					E				E		
Cedar Creek	405.43	P*				E				E	E			E	E				E		E		E		E
Crystal Lake	405.43	P*								E	E			E	E				E				E		
Soldier Creek	405.43	P*				I				I	I			I					E				E		
West Fork San Gabriel River	405.43	P*				E				E	E			E	E				E		E		E		E
Bear Creek	405.43	P*				E				E	E			E	E				E		E		E		E
Cogswell Reservoir	405.43	P*				E				E	E			E	E				E				E		
Devils Canyon Creek	405.43	P*				E				E	E			E	E				E				E		E
ISLAND WATERCOURSES																									
Anacapa Island	406.10	P*								P				P					E		E				
San Nicolas Island	406.20	P*								P				P					E		Eaa				
Santa Barbara Island	406.30	P*								E	E			P					E		E				
Santa Catalina Island	406.40	E*				E				E	E			E					E		E				
Middle Ranch System	406.40	P*				E				E	E			E					E		E				
San Clemente Island	406.50	E*				E				E	E			E					E		E				
SAN ANTONIO CREEK WATERSHED ab																									
San Antonio Dam And Reservoir	481.23	E*				E				E	E			E					E						
San Antonio Canyon Creek	481.23	E		E	E	E			E	E	E			E	E				E				E		

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required
* Asterixed MUN designations are designated under SB 88-63 and RB 89-03. Some designations may be considered for exemptions at a later date. (See pages 2-3,4 for more details).

Footnotes are consistent on all benefical use tables.

[a] Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries. Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.

[b] Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody. Any regulatory action would require a detailed analysis of the area.

[aa] Habitat of the Channel Island Fox.

[ab] This watershed is also in Region 8 (801.23).

Table 2-2. Beneficial Uses of Ground Waters.[ac]

DWR Basin No.[ad]	BASIN	MUN	IND	PROC	AGR	AQUA
	PITAS POINT AREA ae	E	E	P	E	
4-1	OJAI VALLEY					
	Upper Ojai Valley					
	West of Sulfur Mountain Road	E	E	E	E	
	Central area	E	E	E	E	
	Sisar area	E	E	E	E	
4-2	Lower Ojai Valley					
	West of San Antonio--Senior Canyon Creeks	E	E	E	E	
	East of San Antonio--Senior Canyon Creeks	E	E	E	E	
4-3	VENTURA RIVER VALLEY					
	Upper Ventura	E	E	E	E	
	San Antonio Creek area	E	E	E	E	
	Lower Ventura	P	E	P	E	
	VENTURA CENTRAL af					
4-4	Santa Clara--Piru Creek area					
	Upper area (above Lake Piru)	P	E	E	E	
	Lower area east of Piru Creek	E	E	E	E	
	Lower area west of Piru Creek	E	E	E	E	
	Santa Clara--Sespe Creek area					
	Topa Topa (upper Sespe) area	P	E	P	E	
	Fillmore area					
	Pole Creek Fan area	E	E	E	E	
	South side of Santa Clara River	E	E	E	E	
	Remaining Fillmore area	E	E	E	E	E
	Santa Clara-Santa Paula area					
	East of Peck Road	E	E	E	E	
	West of Peck Road	E	E	E	E	
	Oxnard Plain					
	Oxnard Forebay	E	E	E	E	
	Confined aquifers	E	E	E	E	
	Unconfined and perched aquifers	E	P		E	
	VENTURA CENTRAL (CONT.)					
4-6	Pleasant Valley					
	Confined aquifers	E	E	E	E	
	Unconfined and perched aquifers	P	E	E	E	
4-7	Arroyo Santa Rosa	E	E	E	E	
4-8	Las Posas Valley					
	South Las Posas area					
	NW of Grimes Cyn Rd. and LA Ave. & Somis Rd.	E	E	E	E	
	E of Grimes Cyn Rd and Hitch Blvd.	E	E	E	E	
	S of LA Ave between Somis Rd and Hitch Blvd.	E	E	E	E	
	Grimes Canyon Rd. and Broadway area	E	E	E	E	
	North Las Posas area	E	E	E	E	
4-5	UPPER SANTA CLARA					
	Acton Valley	E	E	E	E	
	Sierra Pelona Valley (Agua Dulce)	E	E		E	
	Upper Mint Canyon	E	E	E	E	
	Upper Bouquet Canyon	E	P	P	E	
	Green Valley	E	P	P	E	
	Lake Elizabeth-Lake Hughes area	E	P	P	E	
4-4.07	EASTERN SANTA CLARA					
	Santa Clara-Mint Canyon	E	E	E	E	
	South Fork	E	E	E	E	
	Placerita Canyon	E	E	E	E	
	Santa Clara-Bouquet and San Francisquito Canyons	E	E	E	E	
	Castaic Valley	E	E	E	E	
	Saugus Aquifer	E				
4-9	SIMI VALLEY					
	Simi Valley Basin					
	Confined aquifers	E	E	E	E	
	Unconfined aquifers	E	E	E	E	
	Gillibrand Basin	E	E	P	E	
4-10	CONEJO VALLEY	E	E	E	E	

E: Existing beneficial use
P: Potential beneficial use
See pages 2-1 to 2-3 for descriptions of beneficial uses.

Footnotes are consistent for all beneficial use tables.

[ac] Beneficial uses for ground waters outside of the major basins listed on this table and outlined in Fig. 1-9 have not been specifically listed. However, ground waters outside of the major basins are, in many cases, significant sources of water. Furthermore, ground waters outside of the major basins are either potential or exisitng sources of water for downgradient basins, and as such, beneficial uses in the downgradient basins shall apply to these areas.

[ad] Basins are numbered according to California Department of Water Resources (DWR) Bulletin No. 118-80 (DWR, 1980).

[ae] Ground waters in the Pitas Point area (between the lower Ventura River and Rincon Point) are not considered to comprise a major basin and, accordingly, have not been designated a basin number by the DWR or outlined on Fig. 1-9.

[af] The Santa Clara River Valley (4-4), Pleasant Valley (4-6), Arroyo Santa Rosa Valley (4-7), and Las Posas Valley (4-8) Ground Water Basins have been combined and designated as the Ventura Central Basin (DWR, 1980).

Table 2-2. Beneficial Uses of Ground Waters (Continued). [ac]

Table Page 2

DWR Basin No. [ad]	BASIN	MUN	IND	PROC	AGR	AQUA
4-11	LOS ANGELES COASTAL PLAIN					
	Central Basin	E	E	E	E	
	West Coast Basin	E	E	E	E	
	Hollywood Basin	E	E	E	E	
	Santa Monica Basin	E	E	E	E	
4-12	SAN FERNANDO VALLEY					
	Sylmar Basin	E	E	E	E	
	Verdugo Basin	E	E	E	E	
	San Fernando Basin					
	West of Highgway 405	E	E	E	E	
	East of Highway 405 (overall)	E	E	E	E	
	Sunland-Tujunga area ag	Eah	E	E	E	
	Foothill area ag	E	E	E	E	
	Area encompassing RT-Tujunga-Erwin-N. Hollywood-Whithall-LA/Verdugo-Crystal Springs-Headworks-Glendale/Burbank Well Fields	E	E	E	E	
	Narrows area (below confluence of Verdugo Wash with the Los Angeles River)	E	E	E	E	
	Eagle Rock Basin	E	E	E	E	
4-13	SAN GABRIEL VALLEY					
	Raymond Basin					
	Monk Hill sub-basin	E	E	E	E	
	Santa Anita area	E	E	E	E	
	Pasadena area	E	E	E	E	
	Main San Gabriel Basin					
	Western area ai	E	E	E	E	
	Eastern area ai	E	E	E	E	
	Puente Basin	E	E	E	E	
4-14	UPPER SANTA ANA VALLEY					
8-2aj	Live Oak area	E	E	E	E	
	Claremont Heights area	E	E	E	E	
	Pomona area	E	E	E	E	
	Chino area	E	E	E	E	
	Spadra area	E	E	E	E	
4-15	TIERRA REJADA	E	P	P	E	
4-16	HIDDEN VALLEY	E	P		E	
4-17	LOCKWOOD VALLEY	E	E		E	
4-18	HUNGRY VALLEY AND PEACE VALLEY	E	P	E	E	
4-19	THOUSAND OAKS AREA	E	E	E	E	
4-20	RUSSELL VALLEY					
	Russell Valley	E	P		E	
	Triunfo Canyon area	P	P		E	
	Lindero Canyon area	P	P		E	
	Las Virgenes Canyon area	P	P		E	
4-21	CONEJO-TIERRA REJADA VOLCANIC AREA ak	E			E	
	SANTA MONICA MOUNTAINS-SOUTHERN SLOPES al					
	Camarillo area	E	P		E	
	Point Dume area	E	P		E	
4-22	Malibu Valley	P	P		E	
	Topanga Canyon area	P	P		E	
	SAN PEDRO CHANNEL ISLANDS am					
	Anacapa Island	P	P			
	San Nicolas Island	E	P			
	Santa Catalina Island	E	P		E	
	San Clemente Island	P	P			
	Santa Barbara Island	P	P			

E: Existing beneficial use
P: Potential beneficial use
See pages 2-1 to 2-3 for descriptions of beneficial uses.

Footnotes are consistent for all beneficial use tables.

[ac] Beneficial uses for ground waters outside of the major basins listed on this table and outlined in Fig. 1-9 have not been specifically listed. However, ground waters outside of the major basins are, in many cases, significant sources of water. Furthermore, ground waters outside of the major basins are either potential or exisitng sources of water for downgradient basins, and as such, beneficial uses in the downgradient basins shall apply to these areas.

[ad] Basins are numbered according to DWR Bulletin No. 118-80 (DWR, 1980).

[ag] The category for the Foothill Wells area in the old Basin Plan incorrectly grouped ground water in the Foothill area with ground water in the Sunland-Tujunga area. Accordingly, the new categories, Foothill area and Sunland-Tujunga area, replace the Foothill Wells area.

[ah] Nitrite pollution in the groundwater of the Sunland-Tujunga area currently precludes direct MUN uses. Since the ground water in this area can be treated or blended (or both), it retains the MUN designation.

[ai] All of the ground water in the Main San Gabriel Basin is covered by the beneficial uses listed under Main San Gabriel Basin-eastern area and western area. Walnut Creek, Big Dalton Wash and Little Dalton Wash separate the eastern area from the western area (see dashed line on Fig. 2-17). Any ground water upgradient of these areas is subject to downgradient beneficial uses and objectives, as explained in Footnote ac

[aj] The border between Regions 4 and 8 crosses the Upper Santa Ana Valley Ground Water Basin.

[ak] Ground water in the Conejo-Tierra Rejada Volcanic Area occurs primarily in fractured vocanic rocks in the western Santa Monica Mountains and Conejo Mountain areas. These areas have not been delineated on Fig. 1-9.

[al] With the exception of ground water in Malibu Valley (DWR Basin No. 4-22), ground waters along the southern slopes of the Santa Monica Mountains are not considered to comprise a major basin and accordingly have not been designated a basin number by DWR or outlined on Fig. 1-9.

[am] DWR has not designated basins for ground waters on the San Pedro Channel Islands.

Table 2-3. Benefical Uses of Coastal Features.

Table Page 1

COASTAL FEATURE [a]	Hydro. Unit No.	MUN	IND	PROC	NAV	POW	REC1	REC2	COMM	WARM	COLD	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
VENTURA COUNTY COASTAL																				
Nearshore +			E		E		E	E	E				E	E	Ean	Ee	Ef	Ef	E	
Offhore Zone					E		E	E	E				E	E		Ee	Ef	Ef	E	
Rincon Beach	401.00				E		E	E	E				E	E			E		E	
Ventura River Estuary c	402.10				E	*	E	E	E	E		E	E	E		Ee	Ef	Ef	E	E
Ventura Keys (Marina)	403.11				E		E	E	E				E	E						
Ventura Marina	403.11		E		E		E	E	E				E	E					E	
Santa Clara River Estuary c	403.11				E		E	E	E			E	E	E		Ee	Ef	Ef		E
Mandalay Beach	403.11				E		E	E	E				E	E		Ee			E	
McGrath Lake c	403.11						Ed	Ed	P			E		E		Ee				E
Edison Canal Estuary	403.11		E				Eao	E					E	E		Ee				
Channel Islands Harbor	403.11		E		E		Eap	E	E				E	E						
Mandalay Bay (Marina)	403.11		E		E		Eaq	E					E	E						
Port Hueneme (Harbor)	403.11			E	E		E	E	E				E	E						
Ormond Beach	403.11		E		E	E	E	E	E				E	E		Ee		P	E	
Ormond Beach Wetlands c	403.11						E	E				E		E		Ee				E
Mugu Lagoon c	403.11				E		Pn	E	Ed			E	E	Eo	E	Ee,p	Ef	Ef	Ed	E
Calleguas Creek Estuary c	403.11				P		Pn	E	E			E		E		Ee,p	Ef	Ef		E
LOS ANGELES COUNTY COASTAL																				
Nearshore Zone +			E		E		E	E	E				E	E	Ean	Ee	Ef	Ef	Ear	
Offshore Zone			E		E		E	E	E				E	E		Ee	Ef	Ef	E	
Nicholas Canyon Beach	404.43				E		E	E	E				E	E				P	E	
Trancas Beach	404.37				E		E	E	E				E	E				P	E	
Zuma County (Westward)Beach	404.36				E		E	E	E				E	E				P	Ear	
Dume State Beach	404.36				E		E	E	E				E	E				P	E	
Dume Lagoon c	404.36				E		E	E	E			E		E		Ee	Pf	Pf		E
Escondido Beach	404.34				E		E	E	E				E	E				P	E	
Dan Blocker Memorial (Corral) Beach	404.31				E		E	E	E				E	E				P	E	

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required
\+ Nearshore is defined as the zone bounded by the shoreline and a line 1000 feet from the shoreline or the 30-foot depth contours, whichever is further from the shore line. Longshore extent is from Rincon Creek to the San Gabriel River Estuary.

Footnotes are consistent for all beneficial use tables.

a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries. Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.
b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody. Any regulatory action would require a detailed analysis of the area.
c Coastal waterbodies which are also listed in Inland Surface Waters Table (2-1) or in Wetlands Table (2-4).
d Limited public access precludes full utilization.
e One or more rare species utilize all ocean, bays, esturaries, and coastal wetlands for foraging and/or nesting.
f Aquatic organisms utilize all bays, estuaries, lagoons and coastal wetlands, to a certain extent, for spawning and early development. This may include migration into areas which are heavily influenced by freshwater inputs.
n Area is currently under control of the Navy: swimming is prohibited.
o Marine Habitats of the Channel Islands and Mugu Lagoon serve as pinniped haul-out areas for one or more species (i.e., sea lions).
p Habitat of the Clapper Rail.
an Areas of Special Biological Significance (along coast from Latigo Point to Laguna Point) and Big Sycamore Canyon and Abalone Cove Ecological Reserves and Point Fermin Marine Life Refuge.
ao Water contact recreation activites are prohibited by the Southern California Edison Co.
ap Water contact recreational activities are limited to the beach area at the harbor by Marina Authorities.
aq Water contact recreational activities are limited by City of Oxnard to within the easement area of each home.
ar Areas exhibiting large shellfish populations include Malibu, Point Dume, Point Fermin, White Point and Zuma Beach.

Table 2-3. Benefical Uses of Coastal Features (Continued).

COASTAL FEATURE [a]	Hydro. Unit No.	MUN	IND	PROC	NAV	POW	REC1	REC2	COMM	WARM	COLD	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET [b]
LOS ANGELES COUNTY COASTAL (CONT)																				
Puerco Beach	404.31				E		E	E	E				E	E				P	E	
Amarillo Beach	404.21				E		E	E	E				E	E				P	E	
Malibu Beach	404.21				E		E	E	E				E	E			E	Eas	Ear	
Malibu Lagoon c	404.21				E		E	E				E	E	E		Ee	Ef	Ef		E
Carbon Beach	404.16				E		E	E	E				E	E				P	E	
La Costa Beach	404.16				E		E	E	E				E	E				P	E	
Las Flores Beach	404.15				E		E	E	E				E	E				P	E	
Las Tunas Beach	404.12				E		E	E	E				E	E				P	E	
Topanga Beach	404.11				E		E	E	E				E	E				P	E	
Topanga Lagoon c	405.11				E		E	E	E			E		E		Ee	Ef	Ef		E
Will Rogers State Beach	405.13				E		E	E	E				E	E				P	E	
Santa Monica Beach	405.13				E		E	E	E				E	E			E	Eas	E	
Venice Beach	405.13				E		E	E	E				E	E		E	E	Eas	E	
Marina Del Rey							E													
Harbor	405.13				E		E	E	E				E	E					E	
Public Beach Areas	405.13				E		E	E	E				E	E		E				
All other Areas	405.13				E		P	E	E				E	E		E			E	
Entrance Channel	405.13				E		E	E	E				E	E		E			E	
Ballona Creek Estuary c,w	405.13				E		E	E	E			E	E	E		Ee	Ef	Ef	E	
Ballona Lagoon/Venice Canals c	405.13				E		E	E	E			E	E	E		Ee	Ef	Ef	E	E
Ballona Wetlands c	405.13						E	E				E		E		Ee	Ef	Ef		E
Del Rey Lagoon c	405.13				E		E	E	E			E		E		Ee	Ef	Ef		E
Dockweiler Beach	405.12		E		E		E	E	E				E	E				P		
Manhattan Beach	405.12				E		E	E	E				E	E				P	E	
Hermosa Beach	405.12				E		E	E	E				E	E				Eas	E	
King Harbor	405.12		E		E		E	E	E				E	E		E				
Redondo Beach	405.12		E		E		E	E	E				E	E		E	E	Eas	E	
Torrance Beach	405.12				E		E	E	E				E	E			E	Eas	E	
Point Vicente Beach	405.11				E		E	E	E				E	E				P	E	
Royal Palms Beach	405.11				E		E	E	E				E	E				P	E	

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required

Footnotes are consistent for all beneficial use tables.

a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries
Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.

b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody.
Any regulatory action would require a detailed analysis of the area.

c Coastal waterbodies which are also listed in Inland Surface Waters Table (2-1) or in Wetlands Table (2-4).

e One or more rare species utilize all ocean, bays, esturaries, and coastal wetlands for foraging and/or nesting.

f Aquatic organisms utilize all bays, estuaries, lagoons and coastal wetlands, to a certain extent, for spawning and early development.
This may include migration into areas which are heavily influenced by freshwater inputs.

ar Areas exhibiting large shellfish populations include Malibu, Point Dume, Point Fermin, White Point and Zuma Beach

as Most frequently used grunion spawning beaches. Other beaches may be used as well.

w These areas are engineered channels. All references to Tidal Prisms in Regional Board documents are functionally equivalant to estuaries.

Table 2-3. Benefical Uses of Coastal Features (Continued).

COASTAL FEATURE [a]	Hydro. Unit No.	MUN	IND	PROC	NAV	POW	REC1	REC2	COMM	WARM	COLD	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
LOS ANGELES COUNTY COASTAL (CONT)																				
Whites Point County Beach	405.11				E		E	E	E				E	E				P	E	
Cabrillo Beach	405.12				E		E	E	E				E	E			E	Eas	E	
Los Angeles-Long Beach Harbor																				
Outer Harbor	405.12				E		E	E	E				E			E			P	
Marinas	405.12		E		E		E	E	E				E			E			P	
Public Beach Areas	405.12				E		E	E	E				E	E		E		P	E	
All Other Inner Areas	405.12		E		E		P	E	E				E			Ee			P	
Dominguez Channel Estuary c,w	405.12				P		E	E	E			E	E	E		Ee	Ef	Ef		
Los Angeles River Estuary c,w	405.12		E		E		E	E	E			E	E	E		Ee	Ef	Ef	P	E
Alamitos Bay	405.12		E		E		E	E	E			E	E	E		E			E	E
Los Cerritos Wetlands c	405.15				E		E	E	E			E		E		Ee	Pf	Pf	E	E
Los Cerritos Channel Estuary c	405.12		E		E		E	E	E			E	E	E		Ee	Ef	Ef	E	
San Gabriel River Estuary c,w	405.15		E		E		E	E	E			E	E	E		Ee	Ef	Ef	P	
Long Beach Marina	405.12						P	E	E				E			E			E	
Public Beach Areas	405.12				E		E	E	E				E			E		P		
All other Areas	405.12						P	E	E				E			E			P	
Marine Stadium	405.12						P	E	E				E			E			E	
Long Beach	405.12				E		E	E	E				E	E			E	Eas	E	
ISLANDS: NEARSHORE ZONES+																				
Anacapa Island	406.10				E		E	E	E				E	Eo	Eat	E		P	E	
San Nicolas Island	406.20				E		E	E	E				E	Eo	Eat	E		P	E	
Begg Rock Nearshore Zone	406.20						E	E	E				E	Eo	Eat	E		P	E	
Santa Barbara Island	406.30				E		E	E	E				E	Eo	Eat	E		P	E	
Santa Catalina Island	406.40	P*			E		E	E	E				E	Eo	Eat	E		P	E	
San Clemente Island	406.50				E		E	E	E				E	Eo	Eat	E		P	E	

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required
* Asterixed MUN designations are designated under SB 88-63 and RB-03 Some designations may be considered for exemptions at a later date (See pages 2-3 and 2-4 for more details).
+ Nearshore is defined as the zone bounded by the shoreline and a line 1000 feet from the shoreline or the 30-foot depth contours, whichever is further from the shore line.

Footnotes are consistent for all beneficial use tables.

a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries. Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.

b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody. Any regulatory action would require a detailed analysis of the area.

c Coastal waterbodies which are also listed in Inland Surface Waters Table (2-1) or in Wetlands Table (2-4).

e One or more rare species utilize all ocean, bays, esturaries, and coastal wetlands for foraging and/or nesting.

f Aquatic organisms utilize all bays, estuaries, lagoons and coastal wetlands, to a certain extent, for spawning and early development. This may include migration into areas which are heavily influenced by freshwater inputs.

o Marine Habitats of the Channel Islands and Mugu Lagoon serve as pinniped haul-out areas for one or more species (i.e., sea lions).

w These areas are engineered channels. All references to Tidal Prisms in Regional Board documents are functionally equivalant to estuaries.

as Most frequently used grunion spawning beaches. Other beaches may be used as well.

at Areas of Special Biological Significance or ecological reserves.

Table 2-4. Beneficial Uses of Significant Coastal Wetlands *.

WATERSHED[a]	Hydro. Unit No.	MUN	IND	PROC	AGR	GWR	FRSH	NAV	POW	REC1	REC2	COMM	AQUA	WARM	COLD	SAL	EST	MAR	WILD	BIOL	RARE	MIGR	SPWN	SHELL	WET[b]
Ventura River Estuary c	402.10							E		E	E	E		E			E	E	E		Ee	Ef	Ef	E	E
Santa Clara River Estuary c	403.11							E		E	E	E					E	E	E		Ee	Ef	Ef		E
McGrath Lake c	403.11									Ed	Ed	P					E		E		Ee				E
Ormond Beach Wetlands c	403.11									E	E						E		E		Ee				E
Mugu Lagoon c	403.11							E		Pn	E	Ed					E	E	Eo	E	Ee,p	Ef	Ef	Ed	E
Dume Lagoon c	403.36							E		E	E	E					E		E		Ee	Pf	Pf		E
Malibu Lagoon c	404.21							E		E	E						E	E	E		Ee	Ef	Ef		E
Topanga Lagoon c	404.11							E		E	E	E					E		E		Ee	Ef	Ef		E
Ballona Lagoon/Venice Canals c	405.13							E		E	E	E					E	E	E		Ee	Ef	Ef	E	E
Ballona Wetlands c	405.13									E	E						E		E		Ee	Ef	Ef		E
Del Rey Lagoon c	405.12							E		E	E	E					E		E		Ee	Ef	Ef		E
Los Cerritos Wetlands c	405.15							E		E	E	E					E		E		Ee	Pf	Pf	E	E

* This list may not be all inclusive. More areas may be added as information becomes available.

E: Existing beneficial use
P: Potential beneficial use
I: Intermittent beneficial use
E, P, and I shall be protected as required

Footnotes are consistent for all beneficial use tables.

a Waterbodies are listed multiple times if they cross hydrologic area or subarea boundaries.
Beneficial use designations apply to all tributaries to the indicated waterbody, if not listed separately.
b Waterbodies designated as WET may have wetlands habitat associated with only a portion of the waterbody.
Any regulatory action would require a detailed analysis of the area.
c Coastal waterbodies which are also listed in Inland Surface Waters Table (2-1) or in Coastal Features Table (2-3).
d Limited public access precludes full utilization.
e One or more rare species utilize all ocean, bays, esturaries, and coastal wetlands for foraging and/or nesting.
f Aquatic organisms utilize all bays, estuaries, lagoons and coastal wetlands, to a certain extent, for spawning and early development.
This may include migration into areas which are heavily influenced by freshwater inputs.
n Area is currently under control of the Navy: swimming is prohibited.
o Marine Habitats of the Channel Islands and Mugu Lagoon
serve as pinniped haul-out areas for one or more species (i.e., sea lions).
p Habitat of the Clapper Rail.

UNIVERSITY OF CALIFORNIA

SANTA CRUZ

IMPORTANCE OF ESTUARINE REARING TO CENTRAL CALIFORNIA STEELHEAD (*ONCORHYNCHUS MYKISS*) GROWTH AND MARINE SURVIVAL

A thesis submitted in partial satisfaction
of the requirements for the degree of

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in

ECOLOGY AND EVOLUTIONARY BIOLOGY

by

Morgan H. Bond

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The Thesis of Morgan H. Bond
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

IMPORTANCE OF ESTUARINE HABITAT TO CENTRAL CALIFORNIA STEELHEAD (*ONCORHYNCHUS MYKISS*) GROWTH AND MARINE SURVIVAL

Morgan H. Bond

ABSTRACT

Estuaries are important rearing areas for many juvenile fishes and invertebrates. Often viewed as nursery habitats, estuaries are productive waters affording high growth potential and protection from predation. Juvenile anadromous salmonids move through estuarine waters during their annual migration from stream habitats to ocean waters where maturation occurs. In central California, near the southern extent of the steelhead (*Oncorhynchus mykiss*) range, estuaries often form seasonal freshwater lagoons, primarily during summer low flow conditions. To investigate the role that estuaries play in southern steelhead survival, I monitored juvenile size and growth and size at ocean entry of returning adults in Scott Creek, a representative central California coastal stream. During the annual spring emigration, the largest smolts (>150 mm fork length) move directly to sea, while some of the smaller smolts remain in the estuary until sandbar formation creates a closed freshwater lagoon. They remain in estuarine habitat at least until bar breakage during winter storms. High growth rates in the estuarine lagoon throughout the summer result in a doubling of fork length from the time of estuary entry (mean FL of spring migrants-112 mm, mean FL of fall lagoon resident-206 mm). Morphological analysis of returning adult steelhead scales indicates that there is strong size-dependent mortality at sea. Based

upon tagged recaptures and scale samples, estuary-reared steelhead show a large survival advantage and comprise 85% of the returning adult population despite being between 8% and 48% of the juvenile population. Although the Scott Creek estuary comprises less than 5% of the watershed area, it is critical nursery habitat, as estuary-reared juveniles make a disproportionate contribution to the spawning adult pool.

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INTRODUCTION:

Pacific salmon, including both semelparous salmon and iteroparous steelhead, are born in freshwater rivers and streams, and eventually move to the ocean to grow and mature before returning as adults. Because of their anadromous nature, salmonids inherently encounter several distinctly different habitats throughout their life-history. The effects of differential habitat use on growth and survival of individuals may play large roles in their recruitment to the adult population, and has been the focus of extensive study (Reimers 1973; Mitro and Zale 2002; Harvey et al. 2005).

During their seaward migration salmon may enter estuarine habitats, which vary widely in their physical characteristics (Healey 1991). Estuaries are of particular interest because they have been found to be nursery habitats for many species of fishes and invertebrates (Sogard 1992; Yamashita et al. 2000; Epifanio et al. 2003; Le Pape et al. 2003; Brown 2006). These nurseries provide a productive area that allows juveniles who use them to recruit disproportionately to the adult population compared to those from other habitats, because of the increased growth and survival nurseries afford (Beck et al. 2001). Salmon utilizing estuarine habitats have been well documented for rivers from British Columbia to central California (Reimers 1973; Levy and Northcote 1982; Dawley et al. 1986; McCabe et al. 1986; MacFarlane and Norton 2002). However, the time spent in an estuary, and the benefits received from that habitat may vary widely among species and watersheds. Some salmon move through estuaries in days, while others remain for months (Reimers 1973; Myers and

Horton 1982; MacFarlane and Norton 2002; Miller and Sadro 2003; Bottom et al. 2005).

Several theories have been proposed to explain why salmon may choose to remain in estuarine waters, postponing their eventual ocean migration. Estuaries can be extremely productive and may provide excellent opportunities for growth due to a complex invertebrate prey community and warmer water temperatures that cannot be found in freshwater tributaries (Boehlert and Yoklavich 1983; Macdonald et al. 1987; Shreffler et al. 1992). Estuaries may also provide a habitat where young salmon can avoid predation because visual predators may be limited by the potentially turbid nature of estuarine waters (Simenstad et al. 1982; Gregory 1993; Thorpe 1994)). Finally, because the physiological adaptation from a freshwater to a marine environment can be energetically costly, the estuary may provide a transition zone where fish can acclimate to increasing salinity before entering the ocean (Iwata and Komatsu 1984).

Estuaries of smaller coastal watersheds in the southern margin of North American Pacific salmon and steelhead distributions commonly form ephemeral freshwater lagoons. These lagoons are the products of low summer flow regimes that cannot displace ocean sand deposition at the estuary mouth. Eventual formation of a sandbar effectively blocks surface connectivity with the ocean, and reduces the tidal influence on the system, creating a warm, mostly freshwater, slow moving body of deep water. Summer temperatures in these systems can be substantially greater than temperatures in upstream tributaries, and may at times be near the thermal tolerance limit of steelhead (~25° C) (Myrick and Cech 2004). Lagoon conditions are generally present until the first winter freshet[1] increases stream flow and removes the sandbar, opening the estuary to the ocean. The development of lagoon conditions and their effects on salmonids is not well understood, although a recent study has shown a lagoon[2] environment to be beneficial to the growth of steelhead in central California (Hayes, unpublished data). Steelhead hatch in upstream waters and tributaries of creeks and spend some portion of time there before migrating toward the ocean. Many move quickly through estuary and enter the ocean, while others remain in the estuary habitat for an additional 6-9 months before ocean entry.

Throughout much of their range, steelhead populations continue to decline despite a federal Endangered Species Act (ESA) listing. This loss has been attributed to habitat loss, water loss and poor land management (Nehlsen et al. 1991; Busby et al. 1996). Still, the factors effecting steelhead population dynamics are not well understood, and few studies have looked at juvenile rearing habitats and their effect on survival for these threatened populations. Ward and Slaney (1989) found a strong size-dependent ocean survival in British Columbia's Keogh River steelhead, with the largest smolts exhibiting a higher survival than the smaller migrants. In their landmark study of central California coastal steelhead, Shapovalov and Taft (1954) suspected the Waddell Creek estuary as potential beneficial rearing habitat:

---

[1] A freshet refers to the sudden large increase in stream flow resulting from locally heavy rains.

[2] To avoid confusion, further reference to the physical space that forms either an open estuary in the winter and spring, or closed lagoon in the summer and fall is referred to as estuary habitat regardless of its condition.

“It is possible that the fish of the age 1 group have a strong tendency to stay in the lower stream and lagoon in order to make use of the extremely favorable living conditions there, while the fish of the age 2 group have reached a size where they can most favorably make use of the growing conditions found in the ocean.”

However, neither Ward and Slaney (1989), nor Shapovalov and Taft (1954) were able to attribute survival of returning adults to a particular juvenile rearing habitat. Although young steelhead have been observed in estuaries (Dawley et al. 1985; Quinones and Mulligan 2005), the effects of that habitat on juvenile-to-adult survival has not been evaluated. Higher ocean survival of estuary-reared steelhead would implicate the estuary as an important nursery habitat despite its small proportion of all freshwater habitats. In light of population declines it is necessary to make the link between individuals that recruit to the reproductive population, and the factors that may have lead to their survival.

In this thesis, I address several questions to determine whether coastal California estuaries may serve as juvenile steelhead nursery habitats: *Do steelhead from Scott Creek exhibit evidence of size-selective survival at sea*? *Are emigrating steelhead from estuarine and upstream habitats different sizes upon ocean entry? Do juvenile steelhead experience differential growth between upstream and estuarine habitats?* and *Do estuarine reared steelhead have a disproportionately higher ocean survival than those from exclusively upstream habitats?* To investigate these questions, I have quantified the size distribution and abundance of downstream migrants and estuary-reared juvenile steelhead. I compared those data to the juvenile characteristics of surviving adults using scale morphologies to determine what contribution estuary-reared steelhead made to the adult population. In addition, I used passive integrated transponder (PIT) tags to monitor juvenile-to-adult survival rates of individuals from both estuarine and upstream habitats.

METHODS

Study System:

Scott Creek is a small coastal California watershed draining approximately 75km^2. It empties into the Pacific Ocean 80km south of San Francisco (37° 02' 28" N and 122° 13' 50" W) (Figure 1). Large waterfalls form impassable barriers on each of the main tributaries, thereby restricting access by anadromous fish to just 23 km of stream. Flow in Scott Creek is highly variable with peak winter flows reaching 28 m^3 s^{-1} (Hayes, unpublished data). Summer and autumn flows, however, may be reduced to 0.08 m^3 s^{-1} during an average year, and during extreme droughts the stream may run dry in the lower reaches. Substratum throughout the watershed is mudstone cobble with the exception of the Big Creek tributary, which is partially granitic cobble. The upper portion of the watershed is comprised of a high gradient stream dominated by a thick coastal redwood (*Sequoia sempervirens*) canopy. The lower gradient main stem of the creek has a lower density overstory cover primarily produced by alders (*Alnus sp.*), with understory dominated by willows (*Salix sp.*). An area of low-lying stream near the ocean forms a small estuary, which is subject to periods of high salinity during large tidal and swell events. The estuary is surrounded by a bullrush (*Scirpus californicus*) marsh. Like many coastal California streams, a sandbar forms each summer or fall, which causes the estuary to become a freshwater lagoon with infrequent saltwater input from ocean surges.

Native fishes of Scott Creek include steelhead, coho salmon (*Oncorhynchus kisutch*), threespine stickleback (*Gasterosteus aculeatus*), prickly sculpin (*Cottus asper*), coastrange sculpin (*Cottus aleuticus*), and tidewater goby (*Eucyclogobius newberryi*). Juvenile starry flounder (*Platichthys stellatus*), and Pacific staghorn sculpin (*Leptocottus armatus*) are infrequently observed in the estuary. A small conservation hatchery has been operated continuously on Scott Creek since 1982, spawning a small number of steelhead and coho salmon each spring that are at least one generation removed from the hatchery (Hayes et al. 2004). Like many southern populations, steelhead in Scott Creek are listed as threatened by the ESA because of low population numbers, despite a relatively unaltered watershed.

Species:

Steelhead, *Oncorhynchus mykiss,* also known as the sea-run rainbow trout, is an anadromous fish endemic to much of the western coast of North America. Although it shares the *Oncorhynchus* genus with seven species of Pacific salmon, all salmon are semelparous, whereas steelhead have the potential to be iteroparous and will return to the ocean after spawning if possible. Like salmon, steelhead have the ability to move between fresh and saltwater through a series of physiological changes that alter the function of their osmoregulatory system. Adult steelhead in central California return from the ocean and begin entering the stream in the winter, following the first freshet (usually late December or early January), with the numbers of returning adults peaking in February or March, and continuing through late April (Shapovalov and Taft 1954; Hayes et al. 2004). Adults spawn in loose gravel in the main stem and tributaries, and superimposition of redds (nests) may occur as preferred spawning habitat is used multiple times. Egg development time depends on water temperature, but juveniles are generally observed emerging from the gravel four to six weeks after spawning (Shapovalov and Taft 1954) (Figure 2). Upon emergence, juveniles begin exogenous feeding and may remain in the stream from one to four years as parr before beginning the downstream migration (Shapovalov and Taft 1954). Downstream migration of juvenile steelhead begins in the late winter and early spring as a response to lengthening days triggers some parr to undergo physiological, morphological and behavioral changes in preparation for ocean life, thus becoming smolts (Zaugg and Wagner 1973; Hoar 1976; Handeland and Stefansson 2001). The seaward migration of smolts generally peaks in late April or May. During migration, smolts encounter estuarine water just prior to ocean entry, and some percentage of the migrants remain in that habitat. Fish remaining in the estuary may continue to occupy that habitat for an additional 6-9 months before entering the ocean. Steelhead generally remain at sea for 1-2 years before returning to spawn, although a small percentage of spawners have spent three years in the ocean. It is generally unknown what ocean habitats are utilized by central California steelhead, but through limited ocean captures it is safe to assume that at least some adults move far offshore during their ocean migration (Burgner et al. 1992).

Methods Overview

To effectively demonstrate what influence the estuary has on the survival rate of steelhead at sea, it is important to sample both the juvenile and adult populations. Initially, I measured the strength of size-dependent ocean survival with a population of marked hatchery-reared smolts. Then, I monitored growth rates of wild fish in both upstream and estuary waters to examine the potential benefits of each habitat type. Additionally, I evaluated the abundance and size distribution of downstream migrating juveniles (smolts), and those fish that remained in the estuary area throughout the summer and fall. Some of the wild individuals were tagged for later identification to measure individual growth and survival rates. Finally, scale samples were taken from returning adults to identify the size at initial ocean entry and classify the juvenile rearing habitat (i.e., upstream or estuary) through scale morphology.

Estimation of the strength of size selective mortality at sea

In order to determine whether processes of size-selective ocean survival could be driving differential return rates of estuarine and upstream reared fish, I utilized a population of hatchery smolts released in the spring of 2003. I measured the fork length (FL) of 562 hatchery-raised smolts from a pool of 6880 individuals, one week prior to release from the hatchery. Hatchery fish in Scott Creek enter the ocean soon after release (Hayes et al. 2004), therefore I assume that the size distribution of hatchery fish prior to release closely resembled the distribution that entered the ocean. All fish released from the hatchery were adipose fin clipped to permanently mark their origin as hatchery-reared. Hatchery fish from the 2003 cohort that returned from the ocean as adults in the winter and spring of 2004 and 2005 as 1-and 2-year ocean fish were sampled to determine the size at ocean entry of surviving adults, and the extent of size-dependent survival. Initial size at ocean entry was back-calculated from scale samples using a method described below. The size at release of hatchery smolts was compared to the size at ocean entry of returning hatchery adults with a two-sample T-test to determine whether processes of size-dependent ocean survival were having a strong effect on the resulting adult population.

Sampling of Returning Adult Steelhead

To determine the strength of size-dependent mortality, adults that returned from the ocean in the winter and spring of 2004 and 2005 to spawn were sampled with a floating resistance panel weir, operated daily during the spawning run (Tobin 1994). The weir had a trap box with a one-way door to capture all steelhead moving upstream. The weir operated in stream flows up to 7 m^3 sec^{-1}, beyond which the resistance panels fold flat and allow water and debris to flow over the top. Although the successful operation of the weir was flow dependent, 60-80% of the returning adult population were successfully sampled during normal years, as determined by a mark-and-recapture estimate (Hayes, unpublished data). Upon capture each fish was identified as either hatchery or wild origin, measured to the nearest 0.5 cm FL, and weighed to the nearest 0.1 kg. A sample of 10-15 scales was taken from a standard area, just above the lateral line on a diagonal between the posterior attachment of the dorsal fin and the anal fin (Maher and Larkin 1954). All scale samples were positioned onto waxed weighing paper, which was placed in a labeled envelope and dried for preservation.

Scale Analysis

I used the relationship between fish size and scale size to determine the size at ocean entry of surviving hatchery adult steelhead from the 2003 smolt class. To prepare scale samples for analysis, each wax paper containing dried scales was removed from its envelope and placed under a dissection microscope. All scales were scanned to find the most original, uniform scale available. Original scales (compared to regenerated scales) have complete circuli forming concentric rings from the edge to the core, or focus, of the scale. Scales are also judged for uniformity of shape. Scales that are symmetrical and not overly oblique are preferred for analysis. Up to six of the most original and uniform scales were placed on slides, and flattened with a cover slip. Cover slips were fixed into place with transparent tape. Scales that were original and uniform, but too dirty to be accurately read, were placed into 1ml microcentrifuge tubes with de-ionized water. The tubes were then floated in an ultrasonic bath for 5 minutes at 37º C. Upon removal from the tubes, clean scales were dried on Kim-Wipes®, and quickly flattened on the slide with a cover slip and allowed to dry flat. Scales were photographed using a microscope mounted Nikon® digital camera (DXM1200 3840 x 3072 pixels). The most original, uniform scale from each slide was photographed and saved as an uncompressed TIFF file.

Once each scale had been photographed, OPTIMAS® software (Media Cybernetics, Inc., Silver Spring, MD) and a custom macro were used to analyze for: total scale radius (SR, the distance from the focus to the edge of the scale), radius at ocean entry (OER, the distance from the focus to the ocean entry check), number and spacing of each freshwater and ocean circulus, and number of ocean annuli (Figure 3). For ease of reading, all measurements were made 20º off of the longest axis. A qualitative score for each analysis was noted on a scale of 1-3, with a score of 1 being a very original, normally shaped scale with a high reading confidence. Only scales with a score of 1 or 2 were used in further analyses.

There is a strong relationship between fish size and scale size, therefore fish size can be back-calculated from scale size (Ricker 1992). The FL at initial ocean entry was back-calculated on scales from adult steelhead using a regression of FL on SR. The regression was created with original scales from 1251 juvenile and adult steelhead representing the complete range of sizes available. The relationship between SR and FL (Figure 4) is described by:

$$\text{(Eqn. 1)} \qquad \text{FL (mm)} = 0.1686 \text{ SR (microns)} + 34.872$$

$(R^2=0.97)$

An intercept of 34 mm agrees with other published values of FL at initial scale formation for *O. mykiss* (Snyder 1938; Kesner and Barnhart 1972; Hoplain 1998). There is some discussion in the literature as to the most appropriate method for back-calculation of size (Francis 1990; Panfili and Troadec 2002). However, the Fraser-Lee method is widely used, and recent studies have empirically demonstrated its reliability in several fish species, including *O. mykiss* (Davies and Sloane 1986; Klumb et al. 1999). I employed the Fraser-Lee method (Fraser 1916; Lee 1920) in all back-calculations using the formula:

(Eqn. 2) $$L_{oe}=((L_c-c)(R_{oe}/R_c)+c)$$

where

L_{oe} = fork length at ocean entry of juvenile in mm

R_{oe} = Scale radius at ocean entry of juvenile in microns

L_c = fork length of adult at capture in mm

R_c = Scale radius of adult at capture in microns

c = intercept from (FL) on scale radius (SR) regression (Eqn. 1)

Size at ocean entry of upstream and estuarine reared juveniles

To determine whether juvenile steelhead from both upstream habitats and the estuary entered the ocean at different sizes and numbers, I trapped spring downstream migrants (smolts) each winter and spring (Jan.-June) and sampled the estuary population each fall (Oct.-Dec.). To determine both the number and size of downstream migrants, I placed a fyke net across the stream approximately 50m upstream of the estuary (Figure 1). The fyke net consists of a series of 91cm diameter steel hoops, covered in 6.4 mm (¼”) nylon mesh that are separated by mesh cones that allowed fish to enter but prohibit their escape. The net has two 1.2m tall seine type wings, which were affixed in the stream to produce a "V" shape and help collect downstream-moving fish in the net. The net was generally run three days per week; however, storm events periodically prohibited the net from being operated. To estimate the number of downstream migrants (N_m), I first calculated net efficiency (E) by releasing a known number of hatchery fish, which are assumed to move rapidly toward the ocean (Hayes et al. 2004) upstream of the net, and count the number captured (Table 2). Net efficiency was estimated as the percentage of hatchery fish caught, and used to estimate the number of wild downstream migrants with the following equation:

$$N_m=(C_m*365)/E \qquad \text{(Eqn 3)}$$

Where

N_m = Estimated number of downstream migrants

C_m = Mean daily catch

E= Trap efficiency (Number of hatchery fish caught/number of hatchery released)

Steelhead captured in the fyke net were placed in aerated buckets until sampling was complete. Each fish was measured to the nearest mm FL, and mass was measured to the nearest 0.01 gram. A sample of 10-15 scales was taken by running the blade of a pair of scissors in the posterior to anterior direction lightly along the side of the fish. Scales were routinely taken from the left side of each fish, but if there was damage to that area scales would be taken from the opposing side. All scales were placed on waxed weighing paper and dried for later analysis. Finally, each fish ≥65 mm FL was scanned for a Passive Integrated Transponder (PIT) tag, using a handheld tag reader (Allflex USA, Dallas Fort Worth Airport, TX.). If no tag was found, then one would be injected using a sterile 12 gauge needle. PIT tags carry a unique identification code so that each fish can be identified later for measurements of individual growth and survival. After sampling, fish were returned to an aerated black bucket to recover for a minimum of 10 minutes before release into the stream. All data was recorded on a Palm® handheld computer in the field, and was uploaded to a Microsoft Access® database daily.

The estuary habitat was sampled each summer and fall to determine both the population size and the size distribution of estuary juveniles just prior to ocean entry. The estuary habitat, which I define as the area from the beach at the mouth of Scott Creek to approximately 800 m upstream (Figure 1), was sampled monthly using a modified 30 m x 2 m nylon beach seine. A large 2 m x 2 m, 6.4 mm (¼”) mesh bag was sewn into the center of the seine to help collect fish in the deeper portions of the estuary where pulling the net onto land was not possible. The entire estuary was seined as thoroughly as possible in 50 m sections each month, with the exception of the upper 200 m. Extremely dense plant cover dominated the upper estuary and seining was impossible. All fish were placed into mesh containers in the estuary until all seining was complete, so that fish could not be collected twice. Estuary steelhead were sampled using the same protocol as trap captured downstream migrants.

However, the estimation of size at ocean entry required adjusting the size distribution of the last sampling each fall to account for growth occurring between the last sampling and sandbar breakage. To do this, growth rates from the last sampling event (see: Differential growth of estuary and upstream fish, below), and the number of days between the last sampling and bar breakage were calculated and added to the final fall size distribution. Because the size distributions of spring downstream migrants and estuary fish could not be compared statistically between years due to the change in sampling technique and varying trap effectiveness, all fish were grouped into only two distributions; spring downstream migrants, and fall estuary fish. These two distributions were compared with a two-sample T-test.

To estimate the population size in the estuary each fall, PIT tags were employed in a simple mark and recapture using the Petersen method (Roff 1973). After sandbar closure, I tagged a subset of the fish caught in the newly formed lagoon. In the month following the initial tagging, a new seining effort was performed to assess the number of tagged individuals present and estimate the population size. This process was repeated every month until winter rains made seining of the estuary impossible. The following equations were employed to estimate the estuary population size and variance:

(Eqn 4) $N_e=C_eM_e/R_e$

(Eqn 5) $V(N_e) = (M_e^2C_e(C_e-R_e)) / R_e^3$

Where

N_e= Estimated estuary population size

M_e= Number of individuals marked in the first seining

C_e= Number of individuals captured in the 2nd seining

R_e= Number of individuals from the 2nd seining that are marked

$V(N_e)$= Variance of population estimate

Because there are few predators of steelhead in the estuary, mortality is assumed to be negligible in the time between the first and second seining efforts. A mark and recapture was not conducted prior to sandbar closure because of the possibility of individuals entering the ocean and leaving the population during that time. In addition, the number of downstream migrants entering the estuary drops rapidly after June, and I assumed new input to be negligible (Hayes et al. 2004).

In addition to determining the number of fish from the upstream and estuary habitats, it is important to determine how both size class, and date of estuary entry affect the resulting estuary population. To do this, I compared the size distribution of all downstream migrants with the size distribution at downstream migration of those PIT tagged individuals that stayed in the estuary after sand bar closure. Data were organized into 15 mm FL bins from 85 mm to 145 mm, with all fish greater than 145 mm being grouped into the last bin of >145 mm, and a Chi-squared test was used to compare the two distributions.

Sandbar closure often occurs in midsummer, late July or early August during years with normal rainfall. However, downstream migration of juvenile steelhead is usually complete by early July. The individuals that remain in the estuary throughout the summer are therefore not simply fish that began their migration too late, and were forced to remain in the estuary until sandbar breakage in the winter. To determine what effect timing of downstream migration had in determining what individuals remained in the estuary after sand bar closure, I compared the number of fish per day captured at the downstream migrant trap to the initial capture date for those PIT tagged individuals that remained in the estuary. The two resulting frequency-date distributions were compared with a two-sample T-test.

Differential growth between estuary and upstream habitats

To determine whether differential growth rates between the estuary and upstream habitats may be driving differences in size at emigration for the two populations I sampled fish in each habitat monthly. Upper watershed samples were collected at six sites in the upper watershed that were characteristic of the area and where juvenile steelhead were abundant (Figure 1). All sites were pool habitats that could be sampled effectively during low summer and fall stream flows, and are collectively referred to as upstream habitat, with no distinction between any of the sites. Fish were collected using a 3.2 mm (⅛") mesh, 4 m x 1 m seine net, or hook and line. For both methods, all collected fish were placed in aerated buckets with fresh stream water until processing, and were sampled with identical methods to downstream migrants and estuary residents.

During regular monthly juvenile sampling at each of the six upstream sites and the estuary, all fish were scanned for PIT tags as an indication of previous handling. Fish with PIT tags were measured, and specific individual growth rates were calculated using the following equation:

$$\text{(Eqn. 6)} \qquad SPGR=100 \times [\ln(L_2/ L_1)]/(D_2-D_1)$$

where

L_1 = FL at initial capture in mm

L_2 = FL at next successive capture in mm

D_1 = date of initial capture

D_2 = date of next successive capture

SPGR = specific growth rate (% change in FL/day)

A mean date of growth was assigned to each growth rate calculation as the midpoint between two fish measurement dates. Growth rates from fish at all upstream sampling locations were pooled, and mean growth rates for upstream fish and estuary fish were generated for each year. Growth rates for both 2003 and 2004 were grouped for each habitat, and were compared with a two sample T-test to look for differences in growth by habitat.

Finally, I investigated the relationship between mean fish growth and mean population density in the estuary after sandbar closure in 2003-2005 to explain potential differences between growth each year. To do this, I generated a regression of mean annual specific growth rate on mean annual estuary population size for each year from 2003-2005. Because the lagoon created by sandbar closure in the estuary each year is of similar size, I assume population size to be a good proxy for density.

Do estuary reared fish recruit disproportionately to the adult population compared to upstream reared individuals?

Size at ocean entry of returning adults

I used four methods to determine whether estuary fish were returning disproportionately to the returning adult population. In the first, I calculated the size at ocean entry of returning adults and compared that distribution with the sizes at ocean entry of emigrating juveniles. The second method involved the classification of returning adults to either upstream or estuary juvenile rearing habitat using a discriminant function analysis and measures of scale morphology. Additionally, I calculated return rates of adult steelhead that were PIT tagged as juveniles at one of the two habitats to determine relative survival rates for each habitat type. Finally, I analyzed scale microchemistry to determine whether elemental scale composition varied between scale growth in each of the two habitats, and whether that variation could be utilized to classify returning adults to freshwater habitat of origin.

I back-calculated the size at ocean entry of wild returning adult steelhead utilizing the same scale measurement technique that was employed in the calculation of size at ocean entry for returning hatchery fish. Scale samples were collected from 439 wild adults from spring of 2002 through spring of 2005. Although some 1-year ocean fish were captured and assigned to the 2004 ocean entry group, these samples were omitted from this analysis because of the potential bias of using only “early” returning fish to classify the entire 2004 cohort. After removals, 364 original, uniform, scale samples that received a score of 2 or better during reading were used for the final analysis. Because of the difficulties of identifying freshwater annuli in adult scales, especially in estuary residents, returning adult steelhead were not assigned to a particular downstream migrant cohort for comparison. Instead, all returning adults were grouped together as one class, and compared to grouped estuary fish and downstream migrants from all years. Analysis of variance (ANOVA) was conducted to evaluate the relationship between fish FL and fish type. The independent variable, fish type, had three categories: spring downstream migrant, fall estuary, and FL at ocean entry of returning adults. Fork lengths for each group were data for all sampling years combined. Fork length was the dependent variable.

Scale morphology DFA

In addition to size, I used circuli spacing and spacing variance to distinguish between adults reared as juveniles in the estuary and those reared upstream. Circuli spacing in scales is correlated with growth in both coho (*Oncorhynchus kisutch*) (Fisher and Pearcy 1990; Fisher and Pearcy 2005), and sockeye salmon (*Oncorhynchus nerka*) (Fukuwaka and Kaeriyama 1997), therefore it is reasonable to assume that the relationship holds true for steelhead as well. The origin of fish in mixed stocks of hatchery and wild steelhead has been determined successfully by differences in scale morphology attributable to different growth regimes in the hatchery and the wild (Maher and Larkin 1954; Bernard and Myers 1996; Tattam et al. 2003). To provide an indication of estuary-derived growth, I calculated the mean circuli spacing and variance for the last 18 circuli of juvenile fish of all size classes from the upper watershed and estuary. Although many combinations of circuli were tested in a stepwise fashion, the mean of the last 18 circuli was most effective at discriminating between prior habitat use, while simultaneously removing problems of non-independence in sampling. Upstream samples were collected throughout the year, but because individuals only use estuary habitat after a prior stay in the upper watershed, estuary samples were taken in the late fall when the estuary growth signature has been maximized. To separate upstream and estuary-reared juveniles, mean circuli spacing and the variance of circuli spacing were used in a discriminant function analysis (DFA). The mean spacing and variance of the last 18 freshwater circuli of scales from returning adults were then included in the DFA to classify the freshwater life-history path returning adults had utilized as juveniles.

Ocean survival of PIT tagged juveniles

In order to calculate the ocean survival of juvenile steelhead, I placed PIT tags in 640 steelhead at both the downstream migrant trap and the estuary in the spring and summer of 2003. Through mark and recapture, I was able to estimate the number of tagged fish that remained in the estuary after sandbar closure. Some returning adults in the winter and spring 2005 were carrying PIT tags from the 2003 deployment (Adults returning in 2004 were checked, but no tags were found.). I used estimates of the number of juvenile PIT tagged fish from each habitat, and the number of returning adults from each habitat to calculate the survival rate of fish from each habitat. In addition, scale morphology was analyzed for each returning adult to determine whether the number of ocean years expressed on each scale matched with expected time of ocean entry based on measured juvenile habitat use from PIT tag recaptures.

Scale microchemistry

In addition to patterns of morphology, I explored scale microchemistry to identify periods of estuary residence. Because fish live in an aqueous environment, they obtain the raw materials for growth from both their diet, and the surrounding water. As calcified tissues are formed, fish incorporate many elements present in the water in the proportion they are found in the environment. It is fortuitous that the abundance of these elements varies in different water masses. Scales, comprised of a calcium phosphate matrix, have successfully been used as a historical record of habitat use where water chemistry varies between discreet regions (Wells et al. 2003).

To test whether estuarine residence was recorded in scales as an area of mixing between fresh and oceanic water, I used scales collected from juvenile steelhead that were sampled just prior to their entrance into the estuary and compared these to scales collected from the same individuals after at least one month of estuarine residence. Scales were cleaned under a laminar flow hood by placing them in a microcentrifuge tube with 2mL of Millipore® Milli-Q ultrapure water. The microcentrifuge tubes were placed in an ultrasonic bath for 10 minutes to remove any surface material. Scales were removed from the microcentrifuge tubes and placed in a second, empty tube to dry. Dried scales were then mounted on petrographic slides with double sided tape (3M® 665 permanent-linerless double coated tape). Scale chemistry was analyzed with a VG Excel quadrupole inductively-coupled plasma mass spectrometer (ICP-MS) coupled with a 193 nm Excimer laser. Scales were pre-ablated with the laser to remove any possible surface contamination by running a laser transect from the focus to the edge along the same 20° offset that was used to measure scale morphology (travel rate: 60μm sec^{-1}, spot size: 70μm, firing rate:1Hz). The scale sample was collected for introduction to the ICP-MS immediately following pre-ablation by running a second transect along the original transect (travel rate: 5μm sec^{-1}, spot size:10μm, firing rate: 10Hz). Thirteen elements were targeted for analysis with the ICP-MS: ^{7}Li, ^{24}Mg, ^{43}Ca, ^{55}Mn, ^{65}Cu, ^{66}Zn, ^{88}Sr, ^{137}Ba, ^{138}Ba, ^{139}La, ^{140}Ce, ^{208}Pb, ^{238}U. Data were binned to generate a mean value for each five micron interval, and each element was converted to an elemental ratio with respect to calcium to account for differences in the amount of material introduced into the ICP-MS. Transects from multiple scales taken from the same individuals over time were compared to ascertain how stable the chemical signal of each habitat was, and whether those signals were strong enough to identify juvenile habitat use in returning adult steelhead.

RESULTS

Estimation of the strength of size selective mortality at sea

Hatchery smolts released in April of 2003 encountered strong size selective mortality at sea. Smolts measured just prior to release had a mean FL of 158 mm (SD=35). Few hatchery fish were observed in the stream two weeks after the release date, and hatchery fish were not found to use the estuary habitat (Hayes et al. 2004)

Original scales were obtained from hatchery fish returning as adults in the winter/spring of 2004 and 2005 as 1-and 2-ocean year fish, respectively. Back-calculation of FL at ocean entry indicated that the surviving adult population had a mean FL at ocean entry of 181.2 mm (SD=28.9), which was significantly larger upon ocean entry than the initial population of fish released from the hatchery (t(592)=4.47 p<0.001, Figure 5).

Size at ocean entry of upstream and estuarine reared juveniles

The mean FL of downstream migrating smolts in 2002 and 2003 was 110 mm. The mean FL of 2004 downstream migrants was 92 mm, however, net mesh size was changed from 9.5 mm (⅜”) to 6.4 mm (¼”) and the net became more effective at catching the smaller individuals that were not sampled in 2002 and 2003. Additionally, high flows in the spring of 2005 prevented net operation until late in the season, and early migrants were not sampled. Because of these discrepancies in sampling, I did not compare downstream migrant size distributions between years. The total number of downstream migrating steelhead is estimated for 2003 and 2004 (Table 1). No population size is estimated for 2002 or 2005 because of the lack of early season samples due to excessive stream flow.

The size distribution of the estuary population upon bar breakage each winter varied by year, mean FL upon winter sandbar breakage was largest in 2003 at 213 mm (SD=32), and smallest in 2004 at 182 mm (SD=26), but estuary fish from all years (2002-2005) were significantly larger than spring downstream migrating juveniles in the same years (t(455.4)=45.76 p<0.001, Table 2). The estuary population varied by year, but was between 8 (2004) and 48 (2003) percent of the downstream migrant population where estuary mortality is assumed to be low (Table 1).

Stay in estuary or go to sea?

Of the 298 fish I measured and PIT tagged at the downstream migrant trap in spring of 2003, 61 fish were recaptured in the estuary after sandbar formation in the fall. The initial FL at estuary entry was compared between the two groups of fish to determine what sizes of fish remained in the estuary. A Chi-Square test was used to compare the two distributions and a significant difference was found, indicating that the initial size of downstream migrants was larger than the initial size of those individuals that remained in the estuary $\chi^2(5, N=359)=15.36$ $p=0.009$. No fish with an initial estuary entry FL larger than 150 mm was observed after sandbar closure, indicating that those fish move to the ocean before bar formation (Figure 6). The mean downstream trap tagging date for all tagged fish and those that stayed in the estuary was not significantly different ($t(227)=0.490$, $p=0.625$) indicating that the timing of downstream migration did not have an effect on the resulting downstream migrant population, and fish from throughout the entire run inhabited the estuary after sandbar closure.

Differential Growth Between Estuary and Upstream Habitats

Specific growth in the estuary was significantly greater than upstream habitats for 2003 and 2004 ($t(501)=22.7$, $p<0.001$, Figure 7). Mean growth in the estuary for 2003 and 2004 was 0.36% increase in FL per day, while mean upstream growth was

0.06% increase in FL per day for the same period. A strong negative relationship between growth rate and population size among the three years sampled (R^2=0.99), suggests that estuary growth rate among years is at least partially explained by differences in steelhead density among years (Figure 8).

Do estuary reared fish recruit disproportionately to the adult population compared to upstream reared individuals?

Size at ocean entry

To determine whether returning adults were recruiting disproportionately from one of the two general habitats, I compared the size at ocean entry of the two juvenile groups from 2002-2005 with the size at ocean entry of returning adults from the same years (Figure 9). For all sampling years combined, FL at ocean entry differed significantly among the spring downstream migrants, fall estuary residents, and back-calculated returning adults (ANOVA: F(2, 1802)=2192.9, $p<0.001$). Post-hoc comparisons using the Tukey test indicated that there were significant differences among all three groups. However, the mean FL of spring downstream moving smolts for all years was 106 mm (SD=26, n=1108), while fall estuary fish was 198 mm (SD=33, n=331), and ocean entry FL of returning adults was 208 mm (SD=38, n=364).

Habitat Classification by Circuli Spacing

In order to provide another independent measure of juvenile freshwater rearing habitat of returning adult steelhead, I used measures of scale spacing as a proxy for juvenile growth, with large spacing indicating faster growth and estuary residence, and smaller spacing indicating lower growth and upstream residence. Mean circuli spacing of the last 18 circuli of scales from estuary (n=96) and upstream juveniles (n=92) were log transformed. Spacing was significantly different between upstream and estuary fish (t(186)=13.95 p<0.001, Figure 10). A discriminant function analysis (DFA) using mean spacing and variance of spacing of the last 18 freshwater circuli as predictors was performed to assign juveniles to their respective rearing habitat. The DFA jackknifed classification indicated an 86% correct assignment (83% for estuary, 90% for upstream) to either habitat. Scales from all adult fish with a reading score of two or better (n=406) were analyzed to determine the mean spacing and variance for the last 18 circuli prior to ocean entry. Spacing was significantly wider than either the estuary or upstream individuals F(2, 593)=151.8, p<0.001, Tukey post-hoc test. The DFA was then used to assign returning adult steelhead to one of the two juvenile rearing habitats (Upstream or Estuary) based upon the same parameters used to in the juvenile habitat assignment (mean spacing of the last 18 circuli, variance of spacing). Of the 406 adults analyzed, the DFA jackknifed classification matrix assigned 61 ±9 (15%) returning adults to upstream juvenile habitat, while 344 ±48 (85%) were assigned to estuary juvenile rearing habitat.

Pit Tag Recaptures and Survival

I estimated through mark and recapture that 1 in 10 steelhead in the estuary was carrying a PIT tag by December of 2003. In winter and spring of 2005, 142 returning adult steelhead were sampled. Thirteen adults (7 males, 6 females) were carrying PIT tags implanted when they were juveniles. All 13 individuals were observed in the estuary in 2003. Scale analysis indicated that all of the tag-carrying adults had only one year of growth in the ocean, indicating that they had not entered the ocean until spring of 2004. In addition, the PIT tagged adults maintained nearly the same tag ratio (1:10.9) in the returning adult population that I observed in the estuary in 2003, indicating that it is probable that many of the returning adults not carrying tags were also products of the estuary juvenile rearing environment.

Ocean survival of all Scott Creek steelhead from 2003 was estimated from the percentage of PIT tag recaptures from adults captured in winter of 2005 and 2006 (no 2003 tagged steelhead were captured in 2004). Thirteen tags were recovered in 2005, however, only 78% of returning steelhead were sampled (Hayes, unpublished data), which indicates that approximately 17 tagged steelhead returned that year. In addition, 4 tags were recovered in 2006, however, since the 2006 adult return season has not yet ended, there is no sampling efficiency currently available for 2006. A total of 640 juveniles were tagged at both the downstream migrant trap and the estuary in 2003, which indicates a population-wide smolt-to-adult survival rate of at least 3.3%. However, all tags recovered were from estuary-reared fish, as revealed by tagging histories and scale analysis. I estimate that there were 254 tagged fish utilizing the estuary habitat in the fall of 2003 from the population size (2540) and the ratio of tagged to untagged fish (1:10). This indicates an 8.3% survival of the estuary-reared population.

Scale Microchemistry

Ratios of each elements or isotope to calcium along scale focus-to-margin transects were plotted for each fish to compare before and after estuarine growth samples. Most elements showed no significant change in ratio upon estuary entrance. However, the Mn:Ca and ^{138}Ba:Ca ratios showed changes in their elemental ratios after estuary entrance (Figure 11). Unfortunately, these data also indicate that there is only partial stability between the samples, and previous signatures had been altered in the time between when each sample was taken. Given the short time between the first and second scale samples from each individual and the relative instability of chemical content, I can conclude that the chemical composition is likely not stable enough to retain signatures of estuary residence throughout the entire ocean phase.

DISCUSSION

This study provides evidence for the importance of estuarine habitat to central California steelhead populations. A strong size-dependent ocean survival coupled with a large dichotomy in sizes between estuary and upstream-reared smolts, has led to a large survival advantage for the larger estuary-reared individuals. These patterns are driven by the difference in growth rates between productive estuary waters and the relatively oligotrophic upstream habitat.

Estimation of the strength of size selective mortality at sea

Although evidence of size selective survival is not new (Sogard 1997), the strength of size selective survival coupled with an extreme dichotomy in sizes of ocean entry between the two general rearing habitats (upstream tributaries and estuary) could lead to size selective survival being the largest determinant in driving which individuals ultimately return to the adult population. Back-calculated size at ocean entry for 2003 hatchery juveniles as adults returning in 2004 and 2005 indicated that small hatchery smolts (≤150 mm FL) were underrepresented in the returning adult population, and larger smolts (>200 mm) were overrepresented. These data support the size-biased survival proposed by Ward and Slaney (1989) for a northern stock of steelhead. Because few hatchery fish were observed in the upper watershed or estuary after planting, I assume that fish of all sizes completed the ocean migration and the resulting ocean-entry size distribution of returning adults was created through size-dependent selection in the marine environment. It has been shown that hatchery-reared salmon may experience lower overall survival in the marine environment (Jonsson et al. 2003). Although this inherent difference in smolt quality could be driving the size-biased survival in the resulting returns, I would argue that although hatchery fish may suffer a lower overall survival, the processes shaping the size distribution of surviving fish (i.e., predation, foraging success) should act similarly on both hatchery and wild populations. This would suggest that wild Scott Creek smolts should also experience a strong size-biased survival.

Size at ocean entry of upstream and estuary reared juveniles

Downstream migration

Spring downstream migrants enter the Scott Creek estuary at a relatively small size compared to smolting steelhead in more northern populations (Ward and Slaney

1988) (Figure 9). This is consistent with the relatively low growth rates observed in upstream habitats of Scott Creek (Hayes et al. 2006, unpubl. data), and what was observed by Shapovalov and Taft (1954) in nearby Waddell Creek. While the estimated number and mean size of downstream migrants differed annually (due to both a change in net mesh size and differences in flow affecting the number of days the net could be operated each year), these differences are minimal and still indicate that the vast majority of Scott Creek steelhead move downstream at a very small size.

Estuary Residence

The estuary population of steelhead is comprised of juveniles that emigrated from the upper watershed in the spring and summer. The largest downstream migrants (>150 mm FL) move through the estuary and are not observed again as juveniles, indicating that they are large enough to move directly to sea without additional growth. It is certainly possible that young steelhead in Scott Creek are migrating at a small size specifically to take advantage of the favorable estuary growth potential. The estuary population each fall varied between 8 and 48% of the estimated total number of downstream migrants (in 2004 and 2003, respectively). However, 48% estuary utilization in 2003 is probably an overestimate, because a large mesh size was used in the downstream migrant trap that year, effectively underestimating the number of downstream migrants. Timing of sandbar formation does appear to impact the overall number of downstream migrants that will reside there. In years when high flow prevents early season sandbar formation, productive deep water is not found until the late summer and may harbor fewer fish. On the other hand, early sandbar formation during low flow years leads to productive habitat being available during peak downstream migration, and may cause more fish to remain in the estuary throughout the summer.

Differential growth between estuary and upstream habitats

Growth rates in the estuary are extremely high, nearly 10 times what is observed in the upper watershed for some portions of the year (Figure 7). This leads to average downstream migrants doubling their FL with only a few months of estuary residence. High growth is probably due to the abundance of gammarid amphipods (*Gammarus* sp.) in the estuary, which are a preferred food source of steelhead inhabiting coastal estuaries (Needham 1939). Although only qualitative surveys were performed, gammarids were not observed upstream of the lagoon. Incidentally, fall estuary fish were similar in size to smolts found in more northerly populations (Ward and Slaney 1988; Lohr and Bryant 1999). This may indicate that estuaries in central California are filling a role that upstream waters have in the northern part of the steelhead range.

Although growth rates in the estuary were always higher than the upper watershed, growth in the estuary appears to be density-dependent, with growth rates decreasing as the number of fish utilizing the estuary increases. However, the decrease in growth rates with increasing fish density had little effect on the eventual size of fall estuary fish. This is probably due to annual flow regimes altering the number of days that productive lagoon conditions were available to young steelhead. Therefore, during low flow years when deep-water conditions formed earlier, the population was larger and growth rates were lower, but each fish had a longer period of time to experience that habitat before winter bar breakage allows fish to move to sea. Because of this dynamic, fall estuary fish were very similar in size regardless of sandbar formation date and population size. It is important to note however, that the estuary is currently quite small and the sandbar formation dynamics may be very different since coastal development in the 1930's restricted the Scott Creek estuary to a fraction of its historic size[3]. In fact, the severe alteration of the estuary is probably the largest anthropogenic change to the watershed, as much of the upper watershed remains in an undeveloped state.

Juvenile steelhead growth in the estuary is relatively unaffected by competition for prey by other fish species. Coho salmon are abundant during some years in Scott Creek, but are rarely observed in the estuary, and do not appear to reside there for more than a few weeks. Threespine sticklebacks are often found in abundance in the estuary, although it is unclear how much competition for resources exists between these species.

It is likely that estuary mortality is low in Scott Creek because there appear to be few predators. Unlike many estuaries, no marine mammals have been observed in the Scott Creek estuary. Prickly sculpin have been observed feeding on smaller steelhead in the upper watershed, however most steelhead entering the estuarine water were probably large enough to avoid predation by prickly sculpin. Avian predators

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[3] California Highway 1, constructed in the late 1930's along the California coast potentially altered the size and seasonal dynamics of estuaries in many watersheds, Scott Creek included, as indicated by historic aerial photographs.

are an important source of mortality for estuarine salmonids, particularly steelhead in the Columbia River estuary, with birds consuming greater than 10% of the steelhead previously detected moving into the estuary (Ryan et al. 2003). Avian predators, while often present, are found in low numbers in the Scott Creek estuary. To a limited extent mergansers have been observed, but they appear to utilize upstream areas with riparian cover more readily than the open estuary habitat. In fact, the deeper estuarine water may provide a refuge from the avian predators (e.g., mergansers, *Mergus* sp.; kingfishers, *Ceryle alcyon*; great blue herons, *Ardea herodias*) that readily feed on steelhead in the shallower upstream waters. Further study is required to determine what effect predation has on the distribution and density of steelhead in the estuary. It is certainly possible though, that steelhead utilize the Scott Creek estuary specifically because of the excellent growth opportunity it provides, and the relatively low predation pressure compared to marine environments. Additionally, small coastal estuaries in central and southern California streams appear to function much differently than larger estuaries (e.g., Columbia River mouth, San Francisco Bay). Many of the larger estuaries have extensive populations of large piscivorous fish (e.g., cutthroat trout, *Oncorhynchus clarki*; striped bass, *Morone saxatilis*), and potentially vast communities of competitors (e.g., other salmonids, *Oncorhynchus* sp.; perch, Percidae; shad, *alosa sapidissima*; smelt, Osmeridae; sole, Soleidae) and extended residence in these areas may not offer the same advantages that smaller estuaries, with few other fish species may provide.

Do estuary reared fish recruit disproportionately to the adult population compared to upstream reared individuals

Scale chemistry

Scale microchemistry indicated that there may be compelling trends in the chemical signatures imparted in calcified structures as an indicator of habitat use. However, there appears to be instability issues in the chemical composition of scales, with potential overwriting of previous chemistry (Figure 11). This may be due to the physiological changes associated with smoltification. Fish do have the capacity to draw upon scales when calcium is needed, and chemical signatures may be lost during that process (Persson et al. 1998; Persson et al. 1999; Kacem et al. 2000). In addition, when estuary sandbar formation occurs, the estuary often becomes mostly freshwater, which may be nearly identical in chemistry to the upstream tributaries. What few pockets of salinity remain during this time become hypoxic, reduced environments over time and are easily avoided by inhabiting steelhead. Although chemical analysis of scales indicated some patterns of interest, more work is needed to establish the potential for long-term stability in anadromous fish.

Size at ocean entry

Back-calculation of size at ocean entry from the morphological characteristics of scales from returning adults indicates that surviving adults were quite large as juveniles at ocean entry. In fact, the vast majority of survivors were so large at ocean entry that the upstream waters alone could not have produced them, as indicated by the size of downstream migrants (Figure 9). Only one returning adult had an ocean entry size (90 mm FL) near the average downstream migrant size (106 mm FL). Fewer than 15% of downstream migrants were above the size threshold (140 mm FL) where the vast majority of returning adults originally went to sea. Additionally, only a small fraction of downstream migrants (<0.01%) captured over 4 years (2002-2005) were larger than 200 mm FL, yet the majority (56%) of returning adults were at least that size upon ocean entry as juveniles. Size-dependent survival in both wild and hatchery fish indicates that small fish are less likely to survive in the marine environment, and estuary-reared juveniles comprise most of the returning adult population.

Scale morphology

Although the relationship between somatic growth and rate of circuli deposition may be somewhat weak, I was able to use the spacing and variance of the spacing to successfully discriminate between estuarine and upstream-reared individuals with 86% accuracy because growth rates are very different in the two habitats. I was then able to assign each returning adult to a freshwater rearing habitat. The vast majority of adult steelhead (~85%) were assigned to rearing in estuary habitat, regardless of their year of return, or year of ocean entry. Habitat assignment by circuli spacing and size at ocean entry give two independent measures of habitat use that both implicate the estuary as having been used by most surviving adult steelhead as juveniles.

PIT tag returns

Some adults returning in the winter and spring of 2004/2005 carried PIT tags from juvenile implantation. Because these fish returned in nearly the same ratio in which estuary fish were tagged (1:10.9 vs. 1:10 respectively) there was probably a large number of untagged estuary-reared fish, which returned as well, which is indicated by the scale circuli spacing data. Because estuary fish were tagged randomly, there is no reason to believe that there was any bias in the return of tagged fish over untagged individuals. Every adult that returned with a PIT tag was either tagged or observed in the estuary during the summer and fall. This is further evidence that migrating steelhead that did not use the estuary experienced very poor survival at sea. I estimated survival rates of estuary-reared juveniles to be 8.3 percent from the 2003 estuary cohort, as compared to the 3.3 percent of the total population from the 2003 cohort. However, no fish tagged at the spring migrant trap that were not observed in the estuary in the summer and fall of 2003 were recaptured as adults, further indicating a weak ocean survival of the 2003 smolt class that did not utilize the estuarine habitat.

CONCLUSIONS

The results of this study support the contention of size-dependent ocean mortality of central California coastal steelhead. Further, these data strongly suggest the estuary as being important nursery habitat for producing large steelhead with increased ocean survival. Estuarine waters in Scott Creek comprise less than 3% of the habitat available to steelhead, yet the vast majority of the adult population may be products of that environment. This indicates that coastal estuaries may be more important to steelhead persistence in the southern portion of their range than previously thought, and their degradation could have drastic implications for steelhead populations already listed as threatened or endangered. Indeed, restoration of coastal estuaries may be an effective method of returning steelhead to their historic population levels in these watersheds. Finally, more work is needed to determine what strategies steelhead take in watersheds without estuaries, to achieve a size large enough to survive at sea without the additional growth these habitats afford. In addition, the strength of size-selective mortality in the ocean appears to be strong enough that the very small size at ocean entry observed in Scott Creek should not persist in the population. More work is needed to determine what conditions may favor the small size at ocean entry and why it is maintained in the face of strong selection against small smolts.

Table 1. Proportion of downstream migrating juvenile steelhead utilizing the estuary in 2003 and 2004.

Year	**# of hatchery fish released**	**# of hatchery fish captured**	**Estimated % of hatchery fish captured**	**# of wild downstream migrants captured**	**Estimated total # of wild downstream migrants**	**Estuary population ±SD**	**% of downstream migrants utilizing the estuary**
2003	7500	827	11.02	581*	5272*	2540 ±479.4	48
2004	3770	470	12.46	2287	18354	1489 ±381.9	8

* 2003 is assumed to be an underestimate because of the large mesh size of the net used to capture downstream migrants.

Table 2. Mean FL of downstream migrants and late summer estuary residents.

	Downstream Migrants			Estuary Residents	
Year	**Trapping Dates**	**n**	**Mean Fork Length (mm) ±SD**	**Estuary Population ±SD**	**Mean Fork Length at Ocean Entry ± SD**
2002	April-July	370	110.2 ±25	N/A	196.2 ±21
2003	Jan.-July	386	110.0 ±29	2540 ±479	213.6 ±32
2004	Jan.-July	306	92.6 ±24	1489 ±381	182.5 ±26
2005	March-July	113	96.0 ±25	540 ±93	191.1 ±33
All Years		1175	102.2 ±26	1523 ±317	195.8 ±28

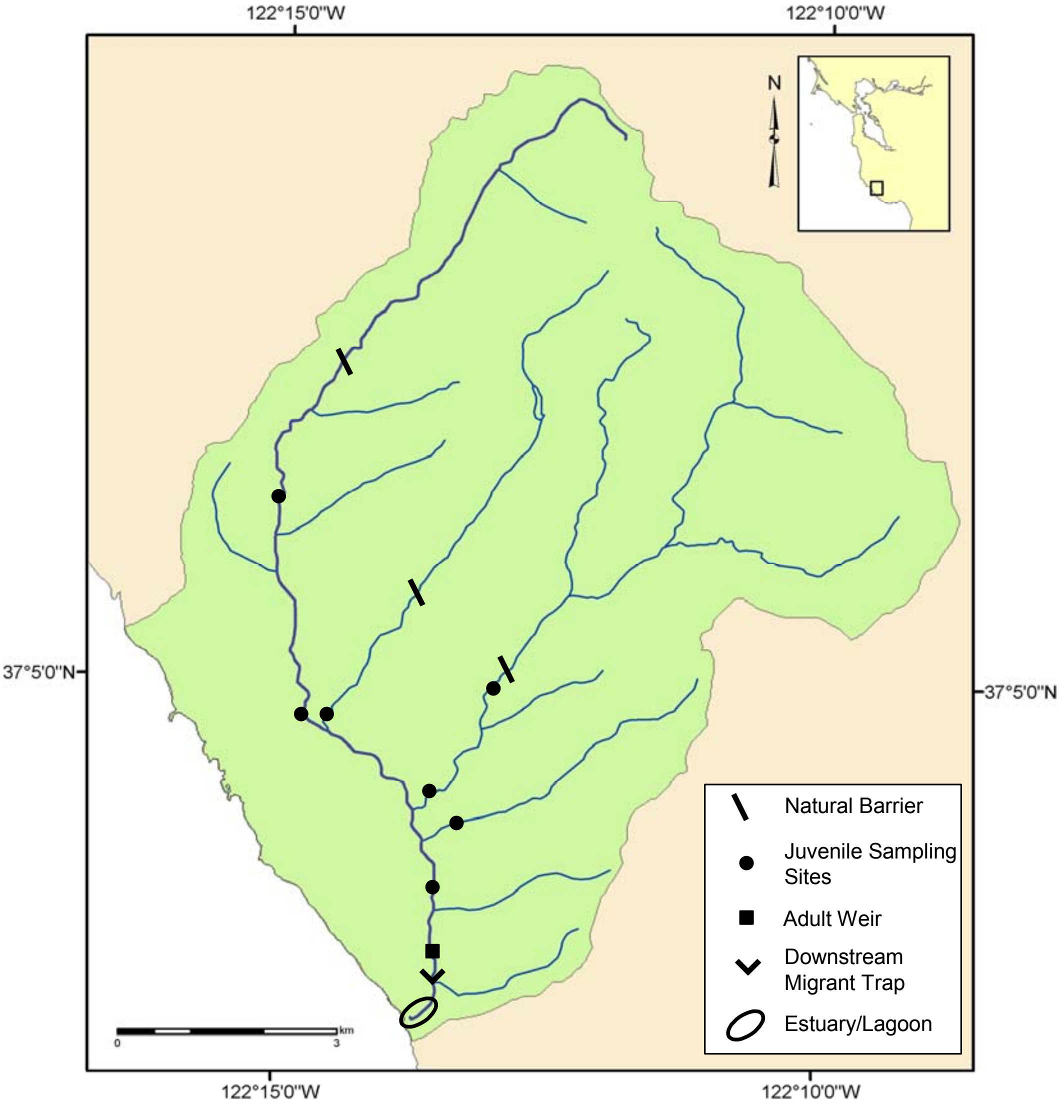

Figure 1. Scott Creek Watershed

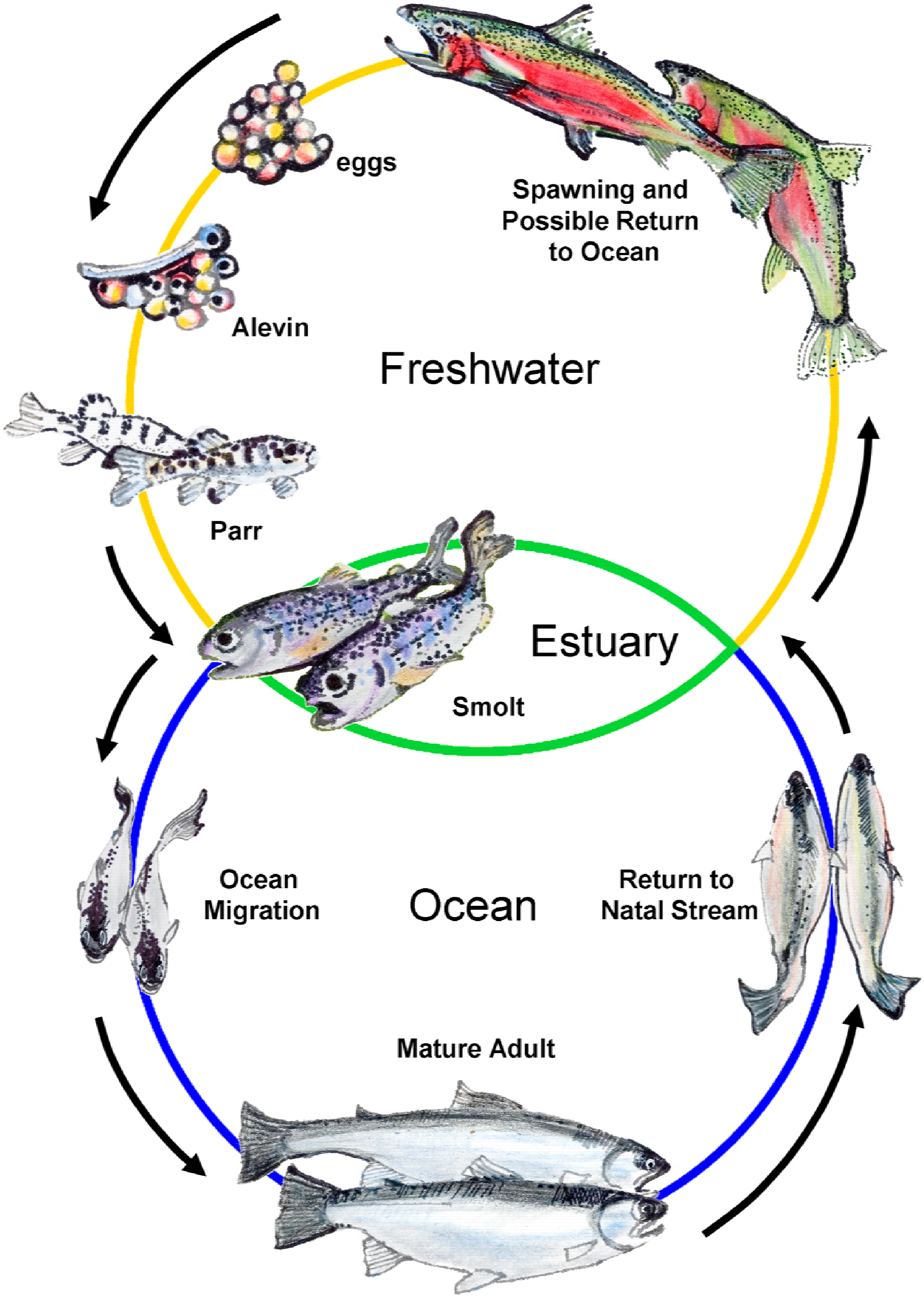

Figure 2. Steelhead Life-Cycle (Drawings by Susan Turner)

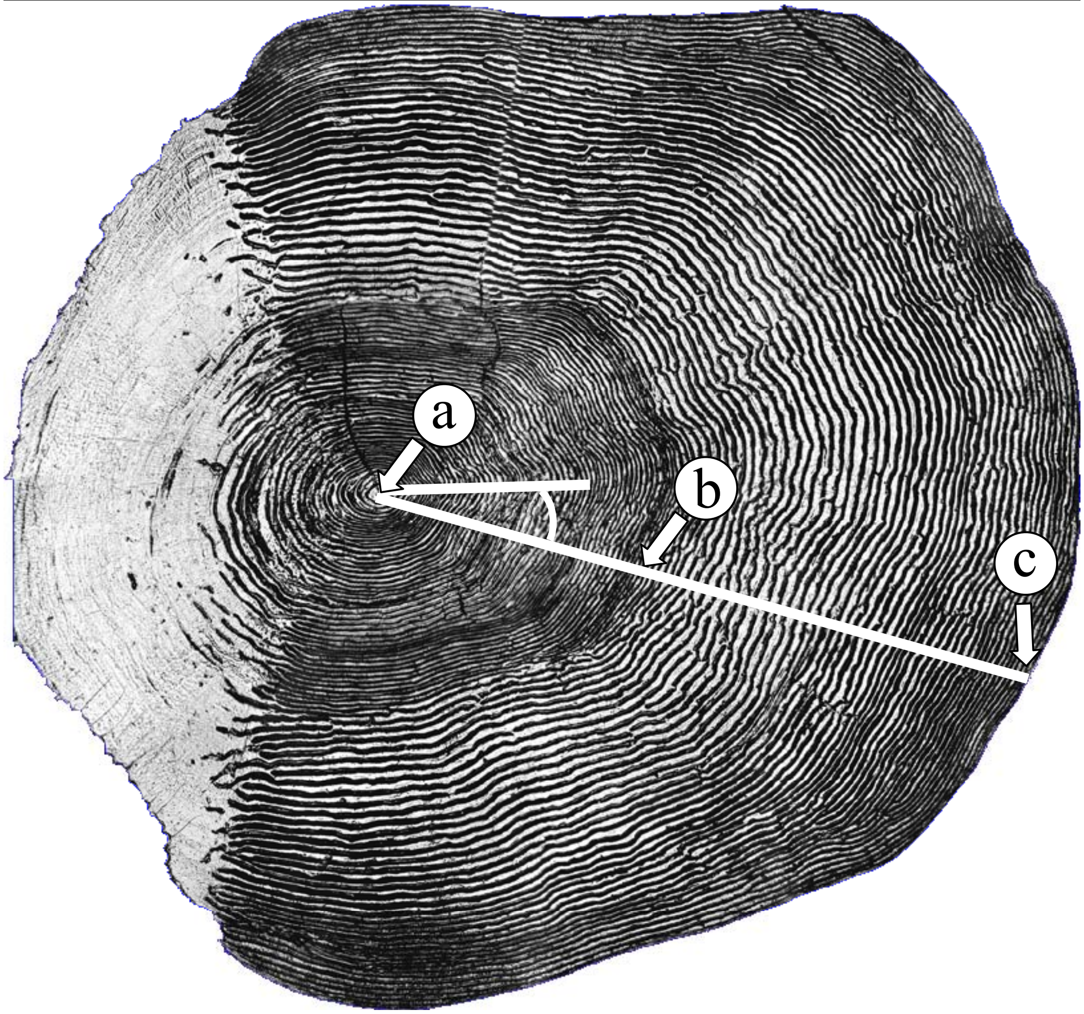

Figure 3. Photograph of scale indicating; a, focus of scale, b, ocean entry radius (OER) and c, scale radius (SR) and the 20° offset from the center axis used to make measurements.

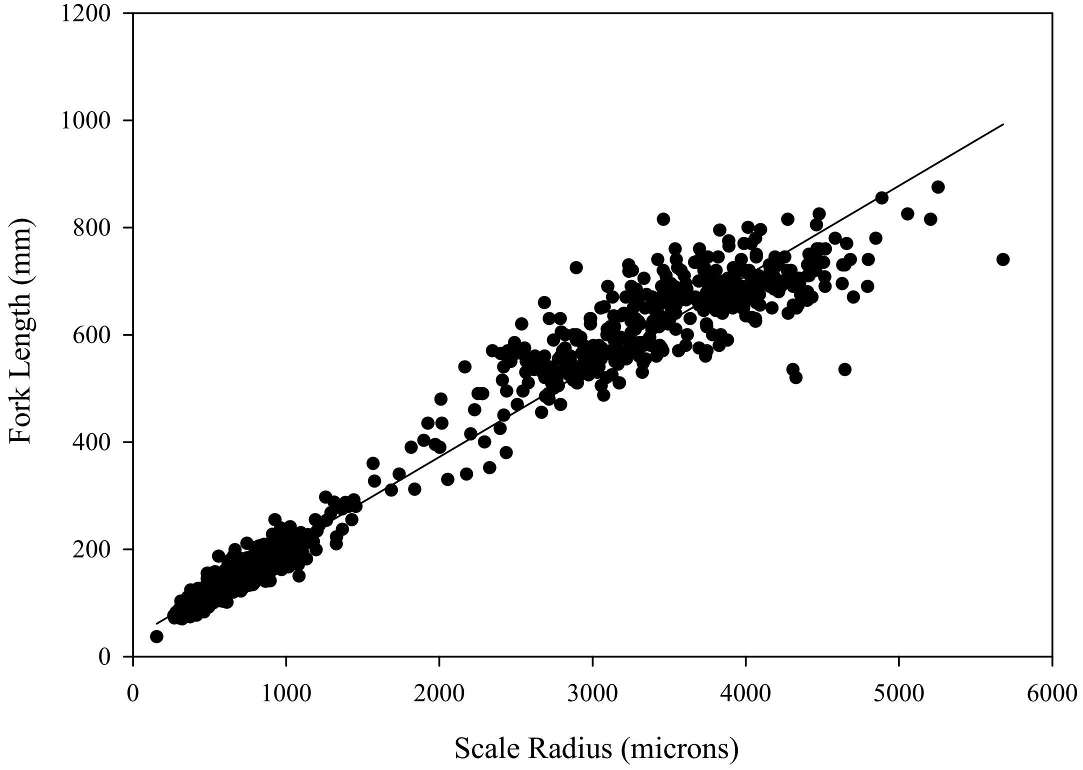

Figure 4. Relationship between fork length and scale radius based on scales from juvenile and adult steelhead collected throughout the watershed n=1250 (2002-2005). FL=0.1686(SR)+34.87 R^2=0.97

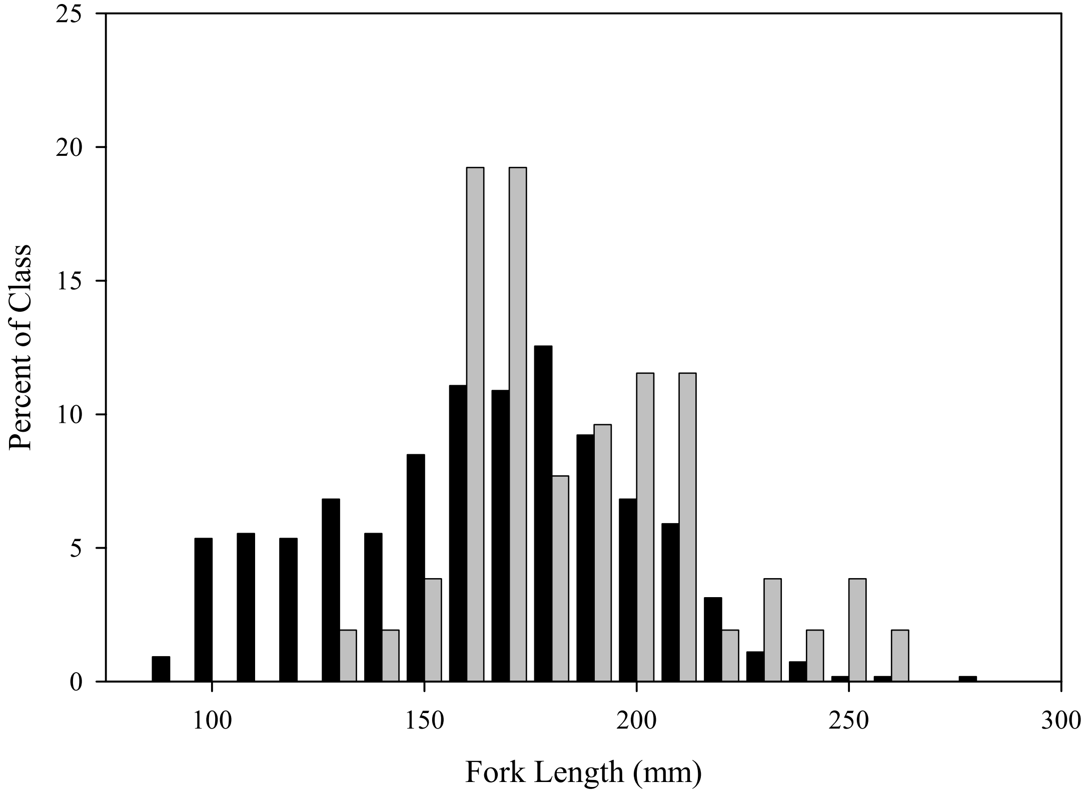

Figure 5. Size distributions of juvenile hatchery smolts (n=542, black bars) sampled immediately preceding release, and the back-calculated size at ocean entry of surviving adults from the same cohort (n=52, grey bars).

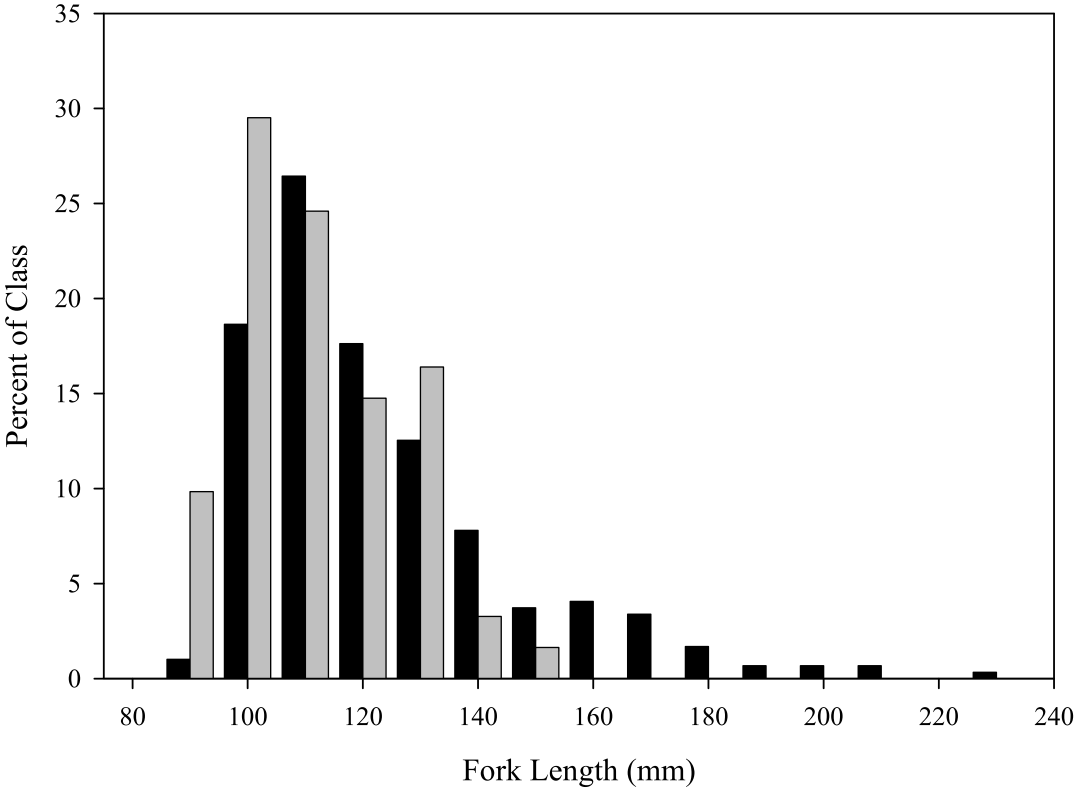

Figure 6. Size distribution of spring downstream migrants PIT tagged prior to estuary entry (n=298, black bars), and the size at initial estuary entry of tagged fish recaptured in the estuary after sandbar closure (n=61, grey bars).

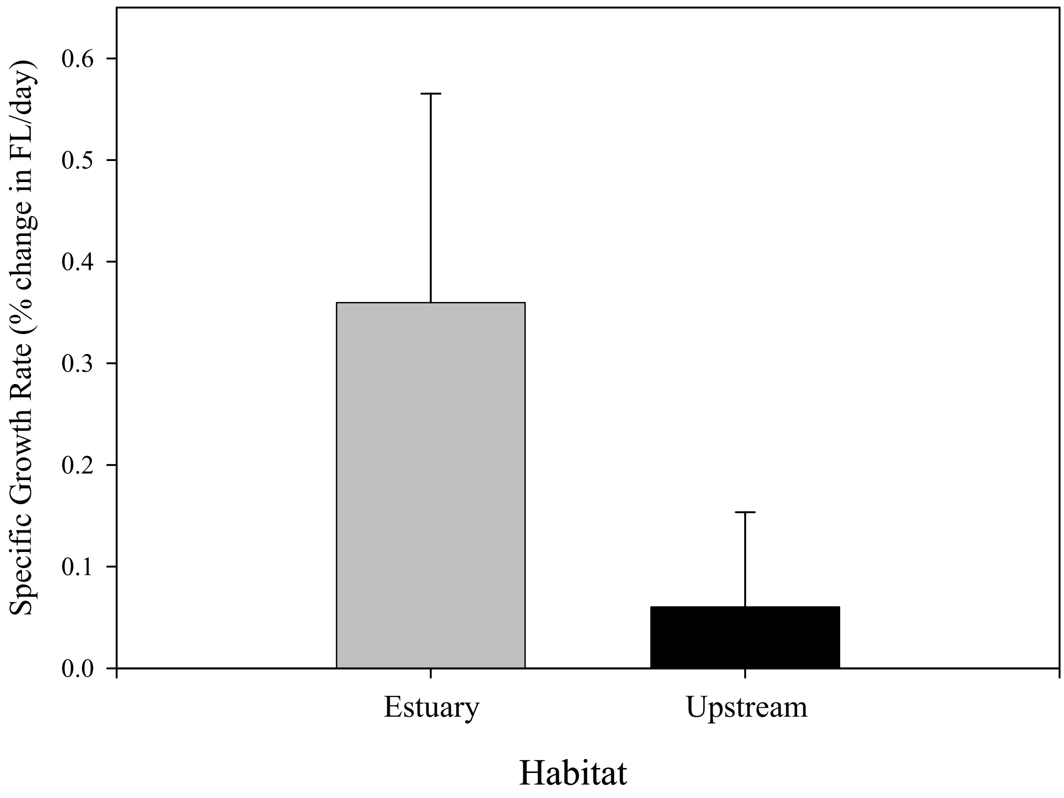

Figure 7. Specific mean (+1 SD) daily growth rates of estuary-reared (grey bar) and upstream (black bar) juvenile steelhead for 2003 and 2004.

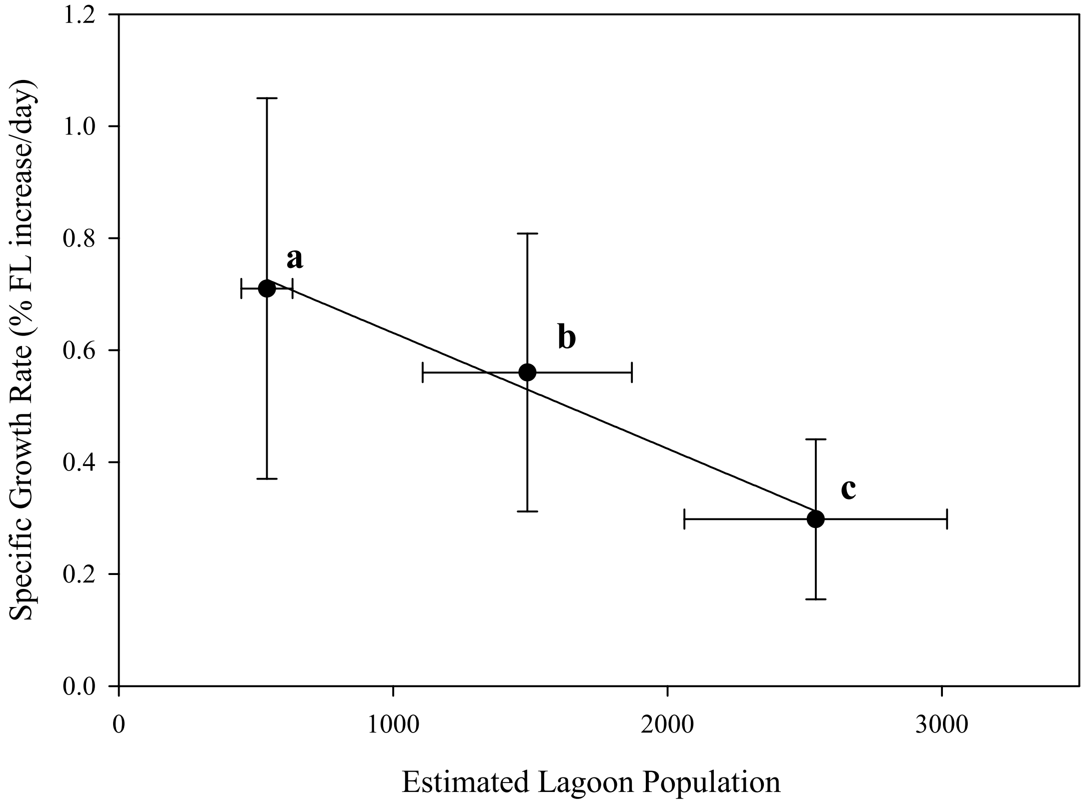

Figure 8. Estimated post-closure estuary population sizes and growth rates from (**a**) 2005, (**b**) 2004, (**c**) 2003. All data are means ±SD. SPGR=-0.000206(Population Size)+0.837 R^2=0.98

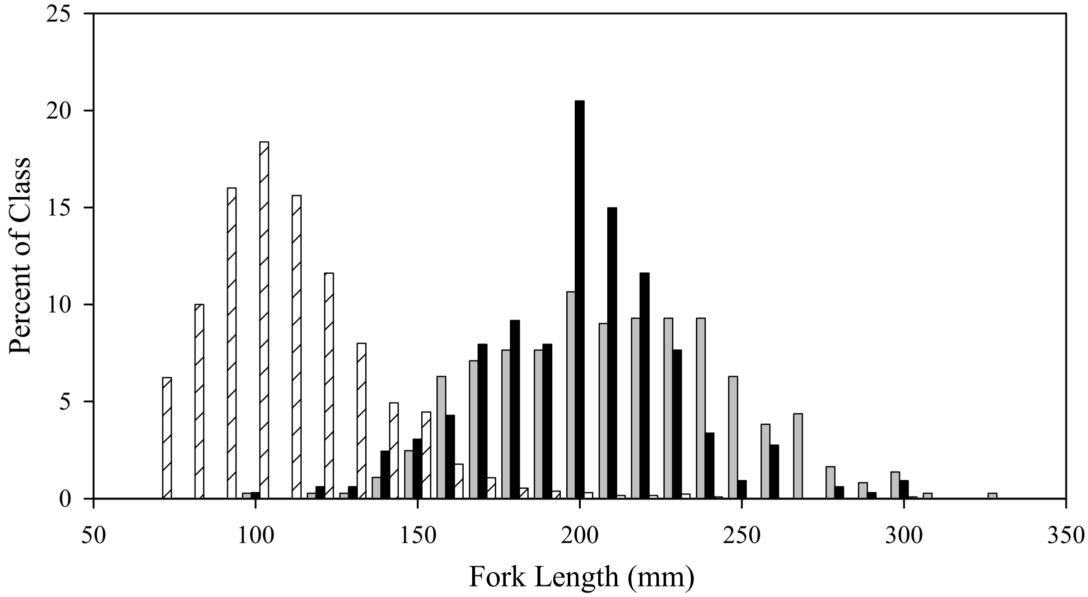

Figure 9. Summed size distribution of all downstream migrants 2002-2004, (n=1300, hashed bars), late fall estuary residents 2002-2005, (n=327, black bars), and back-calculated size at ocean entry of adults returning in 2002-2005, (n=364, grey bars).

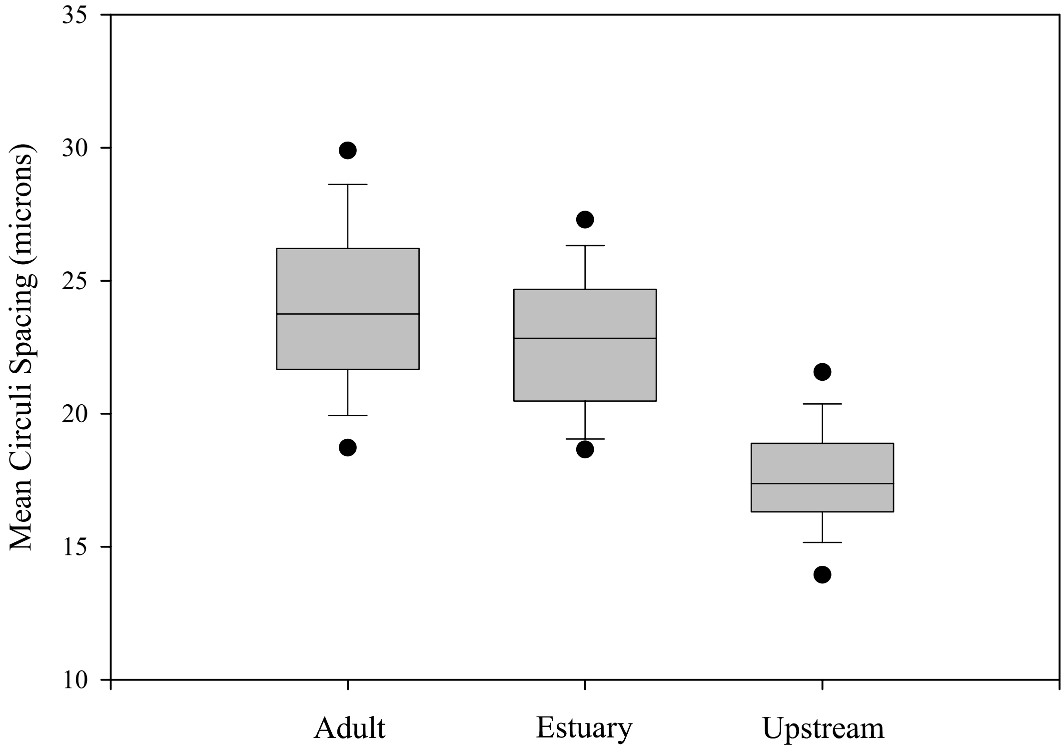

Figure 10. Boxplot depicting the distribution of the mean circuli spacing for the last 18 freshwater circuli for: The freshwater portion of returning adult scales, fall estuary juveniles, and upstream juveniles. Centerline indicates median spacing, while the outer edge of the box indicates the 25th and 75th percentiles. Whiskers indicate 10th and 90th percentiles, and dots indicate 5th and 95th percentiles.

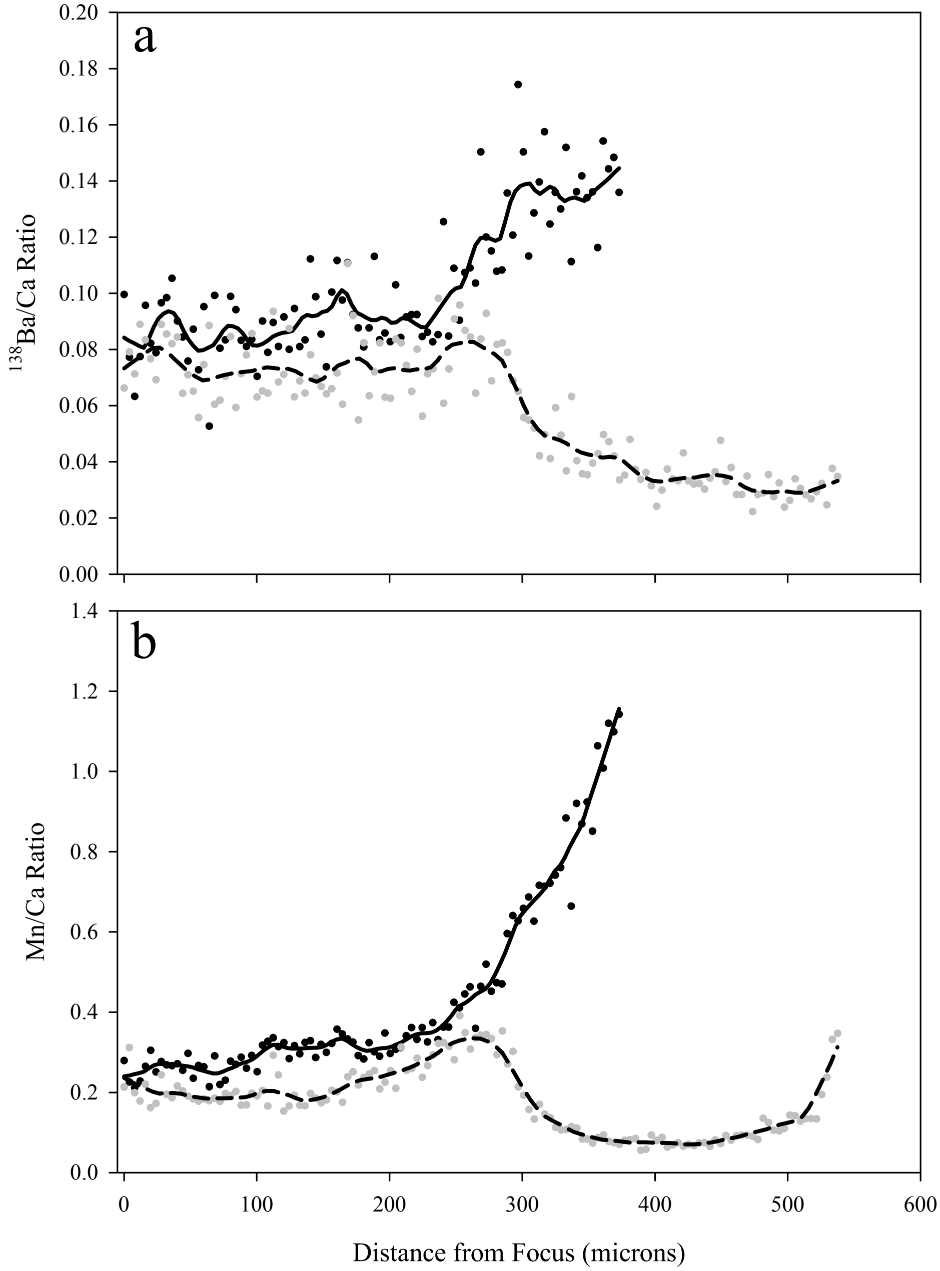

Figure 11. Graphs depicting loess smoothed **(a)** ^{138}Ba:Ca, and **(b)** Mn:Ca ratios from the focus to the margin on a scale from a juvenile steelhead captured at the downstream migrant trap on 6/22/2004 at 78 mm FL (solid black line), and 78 days later in the estuary at 135 mm FL (dashed line). These data are typical of multiple scales analyzed from pre-and post-estuary entrance.

Appendix A. Numbers of hatchery and wild produced steelhead sampled (i.e. measured, tagged or scales taken) over the course of the study.

Year	**Upstream Juveniles Tagged and Sampled**		**Downstream Migrants Sampled**		**Lagoon Juveniles Sampled**		**Adults Sampled**	
	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery
2002	0	0	455	21	650	8	39	17
2003	270	2	621	10	695	13	51	42
2004	381	2	953	11	473	0	256	104
2005	57	0	235	3	605	3	141	90

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Attachment B

Pharmaceuticals in the Environment

The Secure Medicine Return Bill (HB 1165 / SB 5279) will create a producer-provided medicine return program that is convenient, safe and secure for residents throughout the state. Prescription and over-the-counter medicines will be collected and disposed using the safest technology currently available to help prevent accidental poisonings, drug misuse, and environmental contamination. This background document provides brief summaries and references about detection of pharmaceuticals in our environment and potential impacts on aquatic species and ecosystems.

How Pharmaceuticals get into the Environment

Medicines have been found in small amounts in our streams, groundwater and marine waterways. Medicines enter our environment in two ways:
1. Excretion from our bodies: Humans and animals pass drugs or drug metabolites through their bodies and then these chemicals pass through septic systems or wastewater treatment plants.
2. Direct disposal to sewers or landfills: Medicines can enter the environment when flushed down toilets or sinks or thrown into the garbage. They can pass through septic systems and through wastewater treatment plants.

No one knows exactly how much of the medicines in our environment come from each of these two pathways. We do know that a significant amount of medicines go unused. Unwanted waste medicines can be prevented from entering the environment through collection and safe disposal provided by pharmaceutical take-back-programs. Preventative programs are far more economical than wastewater treatment or cleanup.

Detection of Pharmaceuticals in the Environment

Numerous environmental studies document the presence of pharmaceuticals in surface water, ground water, soils, sediments, and marine waters. These studies predominantly conclude that pharmaceuticals are present wherever wastewater has been discharged. Conventional wastewater treatment systems do not do a good job of removing or destroying pharmaceuticals. No single treatment process will completely remove all of the thousands of different pharmaceutical compounds. The presence of pharmaceuticals in the environment depends upon their individual chemical structure and the frequency of their use. Some sampling studies are listed below.

- A water quality assessment of the Columbia River in 2004-2005 detected a number of pharmaceutical compounds including: acetaminophen, diphenhydramine (a widely used antihistamine), and trimethoprim (an antibiotic).
  Morace, J.L. 2006. Water-Quality Data, Columbia River Estuary, 2004-05. Data Series. U.S. Department of the Interior, U.S. Geological Survey
  http://pubs.usgs.gov/ds/2006/213/pdf/lcrep_data.pdf
- A recent study of sediment contaminants in the lower Columbia Basin conducted by USGS detected a number of pharmaceutical compounds including: trimethoprim, thiabendazole, diphenhydramine, diltiazem, venlafaxine, fluoxetine, citalopram and carbamazapine at

> "There's no doubt about it, pharmaceuticals are being detected in the environment and there is genuine concern that these compounds, in the small concentrations that they're at, could be causing impacts to human health or to aquatic organisms."
>
> **Mary Buzby, director of environmental technology for Merck & Co. Inc**, *in USA Today, March 10, 2008. "AP: Drugs found in drinking water". Online at:* *http://www.usatoday.com/news/nation/2008-03-10-drugs-tap-water_N.htm*

concentrations ranging from 2 to 150 ng/g sediment. Additionally, codeine, dehydronifedipine, miconazole, azithromycin and cimetidine were detected at or below the level of the lowest standard (~0.4 and 28 ng/g sediment). The highest frequency of detection for these compounds was found in the tributaries.

Nilsen, E., R. Rosenbauer, E. Furlong,M. Burkhardt, S. Werner, L. Greaser, M. Noriega. USGS. 2007. Pharmaceuticals and personal care products detected in streambed sediments of the lower Columbia River and selected tributaries. http://www.csc.noaa.gov/cz/2007/Coastal_Zone_07_Proceedings/PDFs/Tuesday_Abstracts/0000.Nilsen.pdf and http://or.water.usgs.gov/proj/Emerging_contaminants/PPCP_Poster2.pdf

- A 2004 study in the Sequim-Dungeness region of the Olympic Peninsula detected medicines in effluent from tertiary wastewater treatment plants, including: acetaminophen, codeine, metformin (a diabetes medicine), sulfamethoxazole (an antibiotic), salbutamol (albuterol), carbamazepine (anticonvulsant and bipolar disorder treatment), ranitidine (Zantac), estrone (hormone replacement therapy), trimethoprim (antibiotic), and ketoprofen (NSAID). Metformin was also found in groundwater and wells.

  Johnson, A, B Carey, and S Golding, 2004, *Results of a Screening Analysis for Pharmaceuticals in Wastewater Treatment Plant Effluents, Wells and Creeks in the Sequim-Dungeness Area.* http://www.ecy.wa.gov/biblio/0403051.html, accessed 12/30/08.

- A King County study that evaluated select endocrine disrupting compounds in surface waters detected the hormones ethynylestradiol (birth control pills) and estradiol (a natural estrogen also used in hormone replacement therapy) in some lakes and streams in King County. At some sites, measured levels of these compounds were detected within the range of levels found to cause effects on aquatic species from laboratory studies.

  King County. 2007. *Survey of Endocrine Disruptors in King County Surface Waters. Prepared by Richard Jack and Deb Lester*. Water and Land Resources Division. Seattle; WA. http://your.kingcounty.gov/dnrp/library/2007/kcr1976.pdf, accessed 01/19/09.

- A nationwide survey conducted by the USGS in 1999 studied 139 streams in 30 states for 95 organic wastewater compounds, including some pharmaceuticals. At least 1 medicine was detected in 80% of the sites surveyed. Acetaminophen was found in 23.8% of streams tested, the antibiotic trimethoprim was found in 27.4% of streams tested, codeine was found in 10.6% of streams tested. Concentrations of pharmaceuticals were generally low.

  Kolpin, D.W., et al., 2002, *Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000*, Environ. Sci. Technol. 36:1202-1211. Abstract available online at: http://pubs.acs.org/cgi-bin/abstract.cgi/esthag/2002/36/i06/abs/es011055j.html, accessed 08/25/08. *See also:* http://toxics.usgs.gov/regional/emc/streams.html

- In a 2006 USGS study, scientists detected 12 of the 22 pharmaceuticals evaluated in a Colorado watershed including: diltiazem, cotinine, and sulfamethoxazole, ranitidine, codeine, diltiazem.

  Barber LB, Murphy SF, Verplanck PL, Sanstrom MW, Taylor HE, and Furlong ET. 2006. *Chemical Loading into Surface Water along a Hydrological, Biogeochemical, and Land Use Gradient: A Holistic Watershed Approach*. Environ. Sci. Tech.. 40(2): 475-486

- A study conducted by NOAA in the Chesapeake Bay detected a number of pharmaceutical compounds and associated metabolites in surface waters including: carbamazepine, erythromycin-HO (an antibiotic degradate), trimethoprim (antibiotic), sulfamethoxazole, diltiazem (antianginal medication), fluoxetine (antidepressant) and acetaminophen.

  Pait, S, R Warner, SI Hartwell, JO Nelson, PA Pacheco, and AL Mason. 2006. Human Use Pharmaceuticals in the Estuarine Environment: A Survey of the Chesapeake Bay, Biscayne Bay and Gulf of the Farallones. NOAA Technical Memorandum NOS NCCOS 7. http://www.ccma.nos.noaa.gov/publications/HumanUsePharma.pdf

- Ground water samples from a landfill site in Oklahoma were analyzed by USGS for pharmaceuticals and other organic waste water contaminants (OWCs). Five sites, four of which are located downgradient of the landfill, were sampled and analyzed for 76 OWCs. OWCs were detected in water samples from all of the sites sampled, with 22 of the 76 OWCs being detected at least once including an antibiotic and a nonprescription drug. Because the landfill was established in the 1920s and closed in 1985, many compounds detected in the leachate plume were likely disposed of decades ago. These results indicate the potential for long-term persistence and transport of some OWCs in ground water.

Barnes, K.K., Christenson, S.C., Kolpin, D.W., Focazio, M.J., Furlong, E.T., Zaugg, S.D., Meyer, M.T., and Barber, L.B. (2004). "Pharmaceuticals and other organic waste water contaminants within a leachate plume downgradient of a municipal landfill." Groundwater Monitoring & Remediation 24(2): 119-126.

- A Florida landfill received waste in 1968 and 1969 from two large naval aviation bases. Although permitted to accept only solid waste, physical evidence suggested it could have received waste from a local hospital. Samples taken from groundwater and drinking water wells located 300 meters from the landfill in 1991 confirmed pentobarbital contamination at 1 ppb. Finding trace amounts of pentobarbital 21 years after the landfill closed and 300 meters from the landfill site, demonstrates the persistence of the pharmaceutical.

  Eckel, William, et al. (1993) Pentobarbital found in Ground Water, Ground Water, Vol. 31, Issue 5, pp 801-804.
- Robinson *et al*. provide a useful overview of the detection of pharmaceuticals in the environment, emerging information on impacts, and potential mitigation methods – which they suggest include consumer take-back programs for medicines.

  Robinson, I, Junqua, G, Van Coillie, R, Thomas, O. 2007. *Trends in the detection of pharmaceutical products, and their impact and mitigation in water and wastewater in North America.* Anal. Bioanal. Chem. 387:1143-1151.

Detection of Pharmaceuticals in Drinking Water

Public drinking water supplies are not commonly tested for pharmaceuticals. Sampling in other states has found widespread presence in public drinking water at very low levels. Conventional wastewater treatment systems cannot remove or destroy all pharmaceuticals, so water supplies which are downstream of wastewater treatment discharges from other municipalities may be impacted.

- A 2008 Associated Press story published the results of a nationwide study that found medicines in the drinking water of 24 major metropolitan areas serving 41 million Americans. Some frequently detected compounds were atenolol (heart medication), carbamazepine (mood-stabilizer), gemfibrozil (anti-cholesterol), meprobamate (tranquilizer), naproxen (pain-killer), phenytoin (anti-seizure medication), sulfamethoxazole and trimethoprinm (antibiotics).
- Seattle's drinking water supply tested negative for pharmaceuticals because it is drawn from an uninhabited, pristine watershed. This result is expected for any water supply which is protected from human activities.

  "*AP Probe Finds Drugs in Drinking Water*", Seattle Times, March 12, 2008. Available online at: http://seattletimes.nwsource.com/html/nationworld/2004271213_appharmawateri.html, accessed 08/25/08.
  "*AP: Drugs found in drinking water*", USA Today, March 10, 2008. Available online at: http://www.usatoday.com/news/nation/2008-03-10-drugs-tap-water_N.htm, accessed 11/30/08.
  "*Report: Drugs in drinking water of more Americans*:, USA Today, September 12, 2008. Available online at: http://www.usatoday.com/news/health/2008-09-12-drugs-water_N.htm, accessed 11/30/08.
  JAMA review article**:** *Traces of Drugs Found in Drinking Water: Health Effects Unknown, Safer Disposal Urged*. Bridget M. Kuehn *JAMA*. 2008;299 (17):2011-2013 (doi:10.1001/jama.299.17.2011)

Detection of Pharmaceuticals in Fish Tissue

Pharmaceuticals are also being detected in tissue of fish collected from streams.

- EPA completed the first phase of a pilot study to evaluate pharmaceuticals and personal care products (PPCPs) in fish tissue in 2008. Sampling locations were in AZ, FL, IL, NM, PA, and TX. Seven of the 24 pharmaceuticals analyzed were detected in fish tissue and included diphenylhydramine, norfluoxetine sertraline, fluoxetine (antidepressants), carbamazepine, diltiazem and gemfibrozil.

  EPA Pilot Study of PPCPs in Fish Tissue. 2008. http://www.epa.gov/waterscience/ppcp/files/fish-pilot.pdf
- Antidepressants and their associated metabolites were found in fish in Texas streams. Fluoxetine and sertraline and the SSRI metabolites norfluoxetine and desmethylsertraline were detected at levels greater than 0.1 ng/g in all tissues examined.

  Brooks BW, Chambliss CK, Stanley JK, Ramirez A, Banks KE, Johnson RD, Lewis RJ. 2005. Determination of select antidepressants in fish from an effluent dominated stream. Environ. Toxicol. Chem. 24:464-469.

Studies on Environmental Impacts of Pharmaceuticals

The environmental concentrations of pharmaceuticals are typically low; less than the recommended therapeutic doses for humans. Studies are emerging that suggest exposure to some medicines, or combinations of medicines, in surface waters are sufficient to impact aquatic organisms or ecosystems. Some studies are listed below.

- In a Boulder, Colorado study, the sex ratios of fish upstream from a wastewater treatment plant were 47% female to 53% male, while the ratios of those downstream from the plant were 83 % female to 17 % male. Researchers speculate this disturbance could be associated with endocrine-disrupting compounds, including a synthetic estrogen, found in the treatment plant effluent.

  Woodling, J. D, EM Lopez, TA Maldonado, DO Norris and AM Vajda. 2006, *Intersex and other reproductive disruption of fish in wastewater effluent dominated Colorado streams*, Comp. Biochem. Physiol.. Part C 144 (2006) 10 – 15.
- In another study, researchers exposed western mosquitofish to fluoxetine, the active ingredient in Prozac, at concentrations similar to those detected in surface waters. They observed increased lethargy enough to indicate behavior changes.

  Henry, TB, Black, MC, 2008, *Acute and Chronic Toxicity of Fluoxetine (Selective Serotonin Reuptake Inhibitor) in Western Mosquitofish.* Arch Environ. Contam. Toxicol 43:325-330. Available online at DOI 10.1007/s00244-007.9018-0.
- Another study found potential reduction in aquatic plant growth due to antibiotic exposure. Members of the fluoroquinolone, sulfonamide, and tetracycline classes of antibiotics displayed significant phytotoxicity.

  Brain, RA, DJ Johnson, SM Richards, H Sanderson, PK Sibley, KR Solomon. 2004. Effects of 25 pharmaceutical compounds to *Lemna gibba* using a seven-day static-renewal test. Environ. Toxicol. Chem.. 23(2): 371-82.
- Outdoor aquatic microcosms were exposed for 35 days to combinations of ibuprofen, fluoxetine, and ciprofloxacin at (6, 10, and 10 µg/L, respectively (low treatment [LT]); 60, 100, and 100 µg/L, respectively (medium treatment [MT]); and 600, 1,000, and 1,000 µg/L, respectively (high treatment [HT]). Few responses were observed in the LT; however, effects were observed in the MT and HT. All responses were observed at concentrations well below the equivalent pharmacologically active concentrations in mammals. Fish mortality occurred in the

MT and HT. Phytoplankton increased in abundance and decreased in diversity (number of taxa) in the HT, with consistent trends being observed in the MT and LT. Zooplankton showed increased abundance and decreases in diversity in the HT, with consistent trends being observed in the MT. Duckweed (*Lemna gibba)* and water milfoil (*Myriophyllum*) showed mortality in the HT; growth of *L. gibba* was also reduced in the MT. Although the present data do not suggest that ibuprofen, fluoxetine, and ciprofloxacin are individually causing adverse effects in surface-water environments, questions remain about additive responses from mixtures.

  Richards, SM, CJ Wilson, DJ Johnson, DM Castle, M Lam, SA Mabury, PK Sibley, and KR Solomon. 2004. Effects of Pharmaceutical Mixtures in Aquatic Microcosms. Environ. Toxicol. Chem. 23:1035–1042.

- Short-term exposure to 17α-ethinylestradiol¸ the active component in oral contraceptive pills at environmentally relevant levels was found to alter aggression, and shift individual social status and reproductive success in male zebrafish.

  Coleman, JR., D Baldwin, LL Johnson and NL Scholz. 2009. Effects of the synthetic estrogen, 17α-ethinylestradiol, on aggression and courtship behavior in male zebrafish (*Danio rerio*)Aquatic Toxicology. in press. Available online 7 December 2008.

- English sole from Puget Sound were surveyed for evidence of xenoestrogen (an estrogen compound or mimic) exposure, using vitellogenin (VTG) production in males as an indicator. VTG is a yolk protein produced by the liver in response to estrogens which normally occurs only in sexually mature females with developing eggs. However, males can produce VTG when exposed to environmental estrogens, making abnormal production of VTG in male animals a useful biomarker of exposure. Significant levels of VTG were found in male fish from several urban sites, especially in Elliott Bay, along the Seattle Waterfront. In addition, the timing of spawning in both male and female fish at the Elliott Bay sites appeared altered. These data suggest that English sole in some areas of Puget Sound are exposed to estrogen compounds that may be causing biological effects.

  Johnson, LL, DP Lomaxa, MS Myers, OP Olsona, SY Sola, S M O'Neill, J West and TK Collier 2008. Xenoestrogen exposure and effects in English sole (Parophrys vetulus) from Puget Sound, WA. Aquat. Toxicol. 88:29-38

- Changes in reproductive behavior have been found in male bluehead wrasse exposed to fluoxetine, the active ingredient in Prozac. Exposed fish were not able to compete as effectively as those not exposed.

  Perreault, H, K Semsar, J Godwin. 2003. *Fluoxetine treatment decreases territorial aggression in a coral reef fish.* Physiol. Behav. 79:719-724.

- Brown trout (*Salmo trutta* f. *fario*) were exposed to 0.5, 5 and 50 µg/L diclofenac (an NSAID used for arthritis or pain) for 7, 14 and 21 days (the lowest concentration is comparable with concentrations found in the aquatic environment). Fish exposed to diclofenac displayed significantly reduced haematocrit after 7 and 14 days of exposure. After 21 days, trout were examined for histopathological and immunohistological alterations and indicated damage to the liver, gills, and kidney. In general, the study suggests exposure of brown trout to diclofenac at environmentally relevant concentrations can result in adverse effects to various organs and may compromise the health of affected fish populations.

  Hoeger, B, B Köllner, DR Dietrich and B Hitzfeld. 2005. Water-borne diclofenac affects kidney and gill integrity and selected immune parameters in brown trout (*Salmo trutta* f. *fario*). Aquat. Toxicol. 75(1):53-64

- Effects of three pharmaceuticals - fluoxetine, ibuprofen and carbamazepine - were examined on the activity of the benthic invertebrate *Gammarus pulex.* Exposure to low concentrations (10–100 ng/L) of fluoxetine and ibuprofen resulted in a significant decrease in activity; however, activity at higher concentrations (1 µg/L–1 mg/L) was similar to the control. Response to carbamazepine showed a similar pattern, however, differences were not significant. These behavioral effect concentrations were 10^4 to 10^7 times lower than previously reported Lowest Observed Effect Concentrations and in the range of environmentally occurring concentrations.

De Lange H.J, W Noordoven, AJ Murk, M Lürling and ETHM Peeters. 2006. Behavioural responses of *Gammarus pulex* (Crustacea, Amphipoda) to low concentrations of pharmaceuticals Aquat. Toxicol.. 78(3): 209-216

- Effect of the lipid regulatory drug gemfibrozil (GEM) was examined in goldfish over 96 hours by measuring GEM in blood plasma. A decrease in plasma testosterone by over 50% in fish from all treatments was observed. Results demonstrate that exposure to environmental levels of GEM leads to bioconcentration of the drug in plasma and the potential for endocrine disruption in fish.

  Mimeault C, Woodhouse AJ, Miao XS, Metcalfe CD, Moon TW, Trudeau VL. (2005). "The human lipid regulator, gemfibrozil bioconcentrates and reduces testosterone in the goldfish, *Carassius auratus*." Aquat. Toxicol. 73: 44-54.

- This study evaluated the toxicity of clotrimazole (a fungicide widely used in human and veterinary medicine) on marine microalgae, which are primary producers for the ecosystem. Exposure resulted in a decrease in primary productivity which may in turn have adverse effects on community structure.

  Porsbring, T, H Blanck, H Tjellström and T Backhaus. 2008. Toxicity of the pharmaceutical clotrimazole to marine microalgal communities. Aquatic Toxicology 2008 Nov 12. [Epub ahead of print]

- A 7-year, whole lake experiment at the Experimental Lakes Area in northwestern Ontario, Canada showed that chronic exposure of fathead minnow (Pimephales promelas) to low concentrations (5–6 ng/L) of the potent 17-ethynylestradiol led to feminization of males, impacts on gonadal development as evidenced by intersex in males and altered oogenesis in females, and, ultimately, a near extinction of this species from the lake. These observations demonstrate that the concentrations of estrogens and their mimics observed in freshwaters can impact the sustainability of wild fish populations.

  Kidd KA, Blanchfield PJ, Mills KH, Palace VP, Evans RE, Lazorchak JM, Flick RW.2007..Collapse of a fish population after exposure to a synthetic estrogen. Proc. Nat. Acad. Sci. 104: 8897-8901.

Potential Human Health Impacts

Scientists do not yet know the full extent and magnitude of the effects of these chemical compounds on human health. The concentrations of pharmaceuticals in the environment are low and are not likely to be an immediate human health threat. There is limited information available about the potential long-term health effects. Most pharmaceuticals degrade in the environment, but have a quality of pseudo-persistence due to the continual release of these contaminants via use, excretion, and disposal.

- One study found some cause for concern about the exposure of pregnant women and their fetuses to drinking water containing very small amounts of chemotherapy drugs.

  Johnson, A.C. T Ternes, RJ Williams, and JP Sumpterl. 2008. *Do cytotoxic chemotherapy drugs discharged into rivers pose a risk to the environment and human health? An overview and UK case study*. Jrnl. Hydrol. 348:167-175.

- Another study looked at the effect of environmentally relevant levels of a mixture of 13 drugs on human cell function. Human embryonic cells were exposed to a mixture of atenolol, bezafibrate, carbamazepine, cyclophosphamide, ciprofloxacin, furosemide, hydrochlorothiazide, ibuprofen, lincomycin, ofloxacin, ranitidine, salbutamol, and sulfamethoxazole. The drug mix inhibited the growth of human embryonic cells, with the highest effect observed as a 30% decrease in cell proliferation compared to controls. Results suggest that a mixture of drugs at ng/L levels can inhibit cell proliferation by affecting their physiology and morphology. This also suggests that water-borne pharmaceuticals can be potential effectors on aquatic life.

Pomati, F, S Castiglioni, E Zuccato, R Fanelli, D Vigetti, C Rossetti and D Calamari. 2006. Effects of a Complex Mixture of Therapeutic Drugs at Environmental Levels on Human Embryonic Cells. Environ. Sci. Technol. 40:2442-2447.

Pharmaceuticals and Puget Sound

- The Puget Sound Partnership's Action Agenda, December 2008, calls for **implementation of pharmaceutical take-back programs** under its strategy "C.1 Prevent pollutants from being introduced into the Puget Sound ecosystem to decrease the loadings from toxics, nutrients, and pathogens."

  See page 49 of the Action Agenda, December 2008, http://www.psp.wa.gov/downloads/ACTION_AGENDA_2008/Action_Agenda.pdf.
- The Puget Sound Partnership's Water Quality Discussion Paper also states "We know enough from the research conducted with English sole to have concerns about the potential for unintended consequences associated with the levels of EDCs [endocrine disrupting compounds] in wastewater and nonpoint pathways to the Sound. Efforts to reduce EDCs and other pharmaceuticals may have the potential for significant pollutant reduction prior to more costly investments in enhanced wastewater treatment systems."

  Original study: Johnson. LL DP Lomaxa, MS Myers, OP Olsona, SY Sola, S M O'Neill, J West and TK Collier 2008. . Xenoestrogen exposure and effects in English sole (*Parophrys vetulus*) from Puget Sound,WA. Aquat. Toxicol. 88:29-38
- The Washington State Department of Ecology also states on its web site: "In addition, pharmaceutical use in the general population is growing, so more unwanted drugs are generated creating increased environmental concerns." and "The treatment methods that most POTWs use fail to remove these pharmaceutical compounds from either the wastewater or the biosolids. Therefore pharmaceutical compounds pass through the treatment plant into the receiving waters or remain in the biosolids that are land applied across the state, which has a potential impact on human health and the environment."

  http://www.ecy.wa.gov/programs/hwtr/pharmaceuticals/pages/faqs.html

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Compiled 2/1/09 from literature research conducted by members of the Medicine Return Project in Washington www.medicinereturn.com, and by researchers at King County's Department of Natural Resources & Parks and Washington State Department of Ecology's Environmental Assessment Program.

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Attachment D

The Economics of Low-Impact Development: A Literature Review

November 2007

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ECONorthwest specializes in the economic and financial analysis of public policy. ECO has analyzed the economics of resource-management, land-use development, and growth-management issues for municipalities, state and federal agencies, and private clients for more than 30 years.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Low-impact development (LID) methods can cost less to install, have lower operations and maintenance (O&M) costs, and provide more cost-effective stormwater management and water-quality services than conventional stormwater controls. LID also provides ecosystem services and associated economic benefits that conventional stormwater controls do not.

The available economic research on some of these conclusions is preliminary or limited in scope. For example, most economic studies of LID describe the costs of installing LID, or compare the costs of installing LID with the costs of installing conventional controls. Few reports quantify the economic benefits that LID can provide in addition to managing stormwater. Fewer researchers report results of studies that measure at least some costs *and* at least some benefits of LID vs. conventional controls.

The costs and benefits of LID controls can be site specific and will vary depending on the LID technology (e.g., green roof vs. bioswale), and local biophysical conditions such as topography, soil types, and precipitation. Including developers, engineers, architects and landscape architects early in the design process can help minimize the LID-specific construction costs.

Despite the fact the LID technologies have been promoted and studied since the early 1990s, for many stormwater managers and developers, LID is still a new and emerging technology. As with most new technologies, installation and other costs of LID are highest during the early phases of development and adoption. Over time, as practitioners learn more about the technology, as the number of suppliers of inputs expands, and as regulations adapt to the new technology, costs will likely decline.

Combined sewer overflows (CSO), and the resulting biophysical and economic consequences, are major concerns for municipal stormwater managers. LID can help minimize the number of CSO events and the volume of contaminated flows by managing more stormwater on site and keeping flows out of combined sewer pipes. Some preliminary evidence exists that LID can help control CSO volumes at lower cost than conventional controls.

Many municipalities have zoning and building-inspection standards in place that were adopted many years ago, long before LID was an option. Municipalities with outdated stormwater regulations typically require that builders file variances if they want to use LID controls. This can increase a builder's design and regulatory costs, which delays construction and can increase a builder's financing costs. Updating building regulations to accommodate LID can help reduce the regulatory risk and expense that builders face.

The large majority of the economic studies on LID focus on the costs of including LID in new construction. Replacing curbs, gutters and stormwater pipes with bioswales, pervious pavers and other LID controls can reduce construction costs. Protecting a site's existing drainage patterns can reduce the need for pipe infrastructure and a developer may be able to do away with surface stormwater ponds, which also increases the number of developable lots. Some researchers report that developments that emphasize LID controls and protected natural grass and forest drainage areas cost less to develop and sell for more than traditionally-developed lots with conventional stormwater controls.

Few studies considered the economic outcomes of including LID in urban redevelopment projects. Some evidence exists that LID controls cost more than conventional controls under these conditions, however, these studies excluded O&M costs of the two alternatives and the economic benefits that the LID controls can provide.

I. INTRODUCTION

Conventional stormwater controls collect stormwater from impervious surfaces, including roads, parking lots and rooftops, and transport the flow off site through buried pipes to treatment facilities or directly to receiving bodies of water. This approach efficiently collects and transports stormwater, but also can create high-velocity flows polluted with urban contaminants, including sediment, oil, fertilizers, heavy metals, and pet wastes. Such flows can erode stream banks and natural channels, and deposit pollutants that pose ecosystem and public health risks (Kloss and Calarusse 2006).The resulting ecosystem and public health consequences can create significant economic costs.

A study of the biophysical and public health damages and associated economic costs of stormwater runoff in the Puget Sound estimates these costs at over $1 billion during the next decade (Booth et al. 2006). These costs include flood-related property damage and financial losses, capital costs of new stormwater infrastructure, cleaning up stormwater-polluted water resources, and habitat restoration and protection efforts. The Natural Resources Defense Council (Kloss and Calarusse 2006) describes similar impacts attributed to conventional controls across the U.S.: stormwater sewers collect and discharge untreated stormwater to water bodies, while combined sewer and stormwater systems overflow during heavy rains, discharging both untreated sewage and stormwater into the nation's rivers and lakes. Both contribute to impaired water quality, flooding, habitat degradation, and stream bank erosion. The U.S. Environmental Protection Agency (EPA) estimates the costs of controlling combined sewer overflows (CSO) throughout the U.S. at approximately $56 billion. Developing and implementing stormwater-management programs and urban-runoff controls will cost an additional $11 to $22 billion (Kloss and Calarusse 2006).

In contrast to conventional stormwater controls, low-impact development (LID) techniques emphasize on-site treatment and infiltration of stormwater. The term low-impact development encompasses a variety of stormwater-management techniques. Examples include bioswales, rain gardens, green streets, and pervious pavers (U.S. EPA 2000). The name LID came into use around the late 1990s, however stormwater managers employed LID techniques prior to this. Technicians in Prince George's County, Maryland were some of the first to install what eventually became known as LID techniques in the early 1990s as an alternative to conventional stormwater controls. Soon after, a few communities in the Chesapeake Bay area followed, experimenting with a number of LID demonstration projects. Over time, interest in LID as an alternative or complement to conventional controls grew, and so did the number of LID demonstration projects and case studies across the United States. The EPA reviewed the early literature on LID and described their assessment of this literature in a report released in 2000 (U.S. EPA and Low Impact Development Center 2000). Their review assessed the availability and reliability of data on LID projects and the effectiveness of LID at managing stormwater. While this report focused primarily on the potential stormwater-management benefits of LID, it concluded that LID controls can be more cost effective and have lower maintenance costs than conventional stormwater controls. In December of the following year, the Center for Watershed Protection published one of the earliest studies that focused primarily on the economic aspects of "better site design," which included many LID principles (Center for Watershed Protection 2001).

The amount of information available on the economics of managing stormwater using LID has grown since the publication of these first reports. Most studies describe the costs of installing LID, or compare the costs of installing LID with the costs of installing conventional controls. Other reports focus on the economic benefits that LID can provide in addition to managing stormwater. These benefits include mitigating flooding, improving water-quality, and providing amenity values for properties adjacent to LID, such as green streets. A few—very few—researchers report results of studies that attempt to characterize at least some costs *and* at least some benefits of LID vs. conventional controls in a *single* study. In this report we summarize our review of the literature on the economic costs and benefits of managing stormwater by LID.

This literature review has three objectives. First, to describe briefly, and in plain language, the methods economists use when measuring the costs and benefits of LID and conventional stormwater controls. This information provides the reader with a context for the economic descriptions of costs and benefits that follow. Second, to summarize the literature that identifies and measures the economic costs and benefits of managing stormwater using LID, or that compares costs or benefits, or both, between LID and conventional controls. Third, to organize and present this information in a way that non-economist municipal officials, stormwater managers, ratepayer stakeholders and others can use as they consider and deliberate stormwater-management plans.

This literature review differs from literature reviews that accompany academic studies. Typically, academic literature reviews provide an introduction and a context for an analysis of a specific economic issue, e.g., a new analytical technique that measures economic benefits. In this case, the literature review is a stand-alone document that summarizes information on the broad issue of economic costs and benefits of LID. Academic literature reviews also target academic and professional economists. This literature review targets non-economist readers.

The technical effectiveness of LID stormwater controls is outside the scope of our review. Our analysis assumes that the LID techniques described in the economic studies that we reviewed provide the necessary or expected stormwater controls. As we understand, there is a growing body of literature on LID effectiveness, and we include some of these references in the Appendix to this report. Also, the more general topic of the economic values of ecosystem services, while somewhat related, was outside the scope of our review. Our analysis focused on the values of ecosystem services as affected by LID techniques.

We began our search for relevant literature by developing a list of key words with which to find reports or articles that contained relevant information. After a cursory search of LID literature, we identified LID- and economics-related key words that researchers and practitioners use when describing LID projects and analyses. The list includes words often used synonymously with LID (i.e., source control, natural drainage systems, sustainable stormwater management), or that describe a set of conservation-design strategies that include LID techniques (i.e., green infrastructure and conservation development). We also searched the literature using economics-related terms (i.e., costs, benefits, and savings). Table 1-1 lists the LID- and economics-related search terms we used in our search of the literature.

Using the terms listed in Table 1-1, we searched databases that contained the widest-possible range of sources including academic literature, reports produced by government agencies and non-profit organizations, news coverage, and articles in the popular press. These databases include information published in peer-reviewed articles, books, reports, conference papers and presentations, and web pages. Table 1-2 lists the databases included in our search.

Table 1-1: Search Terms

LID-Related Search Terms	Economics-Related Search Terms
Low-impact development	Economics
Source control	Benefits, economic benefits
Green infrastructure	Costs, economic costs
Natural drainage systems	Cost comparison
Sustainable stormwater management	Savings
Conservation development	Benefit cost analysis, cost benefit analysis
Alternative stormwater management	Cost effectiveness
Better site design	
Low-impact urban design and development	

Source: ECONorthwest

Table 1-2: Databases

Database	Description
Academic Search Premier	Index of 8,000 academic journals in the social sciences, humanities, and general science, back to 1965.
Article First	Index of 16,000 journal titles in business, humanities, popular culture, science, social science, and technology, back to 1990.
Econlit	American Economic Association's index of economic research, back to 1969.
Environmental Protection Agency (EPA) website	Database of studies, reports, educational material, and newsletters authored or supported by the EPA.
Environmental Valuation Reference Inventory (EVRI)	Database of empirical studies conducted internationally on the economic values of ecosystem services.
Google	Source for non-peer reviewed reports, articles, websites and other publications.
Journal Storage (JSTOR)	Index of over 100 major research journals in a variety of academic disciplines, some back to 1870.
Web of Science	Index of science and social science journals, back to 1975.
WorldCat	Index of bibliographic records of books, journals, manuscripts, etc. archived in university, public and private library catalogs around the world.

Source: ECONorthwest

We reviewed potential sources for relevance. If a source contained LID-related cost or benefit information, we indexed it in our own database, summarized the information on costs or benefits, and reviewed its bibliography for additional sources of information.

This report of our review of the literature is organized as follows. The next two sections provide background information to the discussion of the economic costs and benefits of managing stormwater. This background information provides a context or economic frame-of-reference that will help the reader consider the descriptions of costs and benefits that follow.

In **Section II** we list the range of benefits associated with LID, as identified in the LID literature, along with illustrations of the values of these benefits as reported in the economic literature. We found that many more reports simply list these benefits rather than quantify them.

In **Section III** we describe two of the more common methods of measuring the economic costs and benefits of stormwater controls: the cost-effectiveness and benefit-cost methods. As the names imply, cost-effectiveness studies compare alternatives looking exclusively at the alternatives' costs. This method assumes away benefits or holds them constant across alternatives. A benefit-cost analysis considers the range of costs and benefits for each alternative. The benefit-cost method has greater data demands and can be more expensive than the cost-effectiveness approach—primarily because it adds benefits into the analysis—but it can also yield a more accurate economic picture of the full range of economic consequences of implementing the alternatives.

In **Section IV** we summarize the literature that considers the costs and benefits of LID. The large majority of these studies focus exclusively on the costs of installing LID, or compare the costs of installing LID with the costs of installing conventional controls. Some studies look beyond installation costs to include operations and maintenance costs. Few studies consider both the costs and benefits of LID or compare costs and benefits of LID with conventional controls.[1] When the literature allowed, we described the economic aspects of adopting LID from the perspective of municipal decisionmakers, ratepayer stakeholders, and private developers.

In **Section V** we describe LID from the perspective of property developers. As with other new technologies, adopting LID includes opportunities and risks. We describe the risks and challenges that developers face when they include LID controls in their projects and the successes developers have had adopting LID.

In **Section VI** we discuss areas of future research that would increase our understanding of the economics of LID. For example, limited information exists on the life-cycle costs of LID, the economic benefits of LID beyond stormwater control, and the economic impacts of installing LID in urban-redevelopment settings.

The **Bibliography** lists the references we cite in this report. During our search for information on the economic aspects of LID, we encountered non-economic information that supports the use of LID. We list this information in the **Appendix** to this report.

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[1] We list the reported dollar amounts of costs and benefits without converting to current, 2007-year, dollars because in most cases, the available information prevented such a conversion.

II. ECOSYSTEM SERVICES PROVIDED OR ENHANCED BY LOW-IMPACT DEVELOPMENT

Conventional controls and LID techniques both manage stormwater flows. By promoting stormwater management on site using a variety of techniques, LID controls can provide a range of ecosystem services beyond stormwater management. Braden and Johnston (2004), Coffman (2002), and the Natural Resources Defense Council (Lehner et al. 2001) list and describe the kinds of ecosystem services that LID can provide or enhance. Taken together, these researchers describe the following ecosystem services: reduced flooding, improved water quality, increased groundwater recharge, reduced public expenditures on stormwater infrastructure, reduced ambient air temperatures and reduced energy demand, improved air quality, and enhanced aesthetics and property values. We briefly describe each of these services below.

Reduced Flooding

Braden and Johnston (2004) studied the flood-mitigation benefits of managing stormwater on site, including reduced frequency, area, and impact of flooding events. In a follow-up study, Johnston, Braden, and Price (2006) focus on the downstream benefits accrued from flood reduction accomplished by greater upstream on-site retention of stormwater. These benefits include reduce expenditures on bridges, culverts and other water-related infrastructure.

Improved Water Quality

Brown and Schueler (1997), Center for Watershed Protection (1998), U.S. EPA and Low Impact Development Center (2000), and Braden and Johnston (2004) describe the water-quality benefits that LID stormwater controls can provide. These benefits include effectively capturing oil and sediment, animal waste, landscaping chemicals, and other common urban pollutants that typically wash into sewers and receiving water bodies during storm events. Plumb and Seggos (2007) report that LID controls that include vegetation and soil infiltration, e.g., bioswales, can prevent more stormwater pollutants from entering New York City's harbor than conventional controls.

Increased Ground Water Recharge

On-site infiltration of stormwater helps recharge groundwater aquifers. According to a report by American Rivers, the Natural Resources Defense Council, and Smart Growth America (Otto et al. 2002), areas of impervious cover can significantly reduce ground water recharge and associated water supplies. The study found that impervious surfaces in Atlanta reduced groundwater infiltration by up to 132 billion gallons each year—enough water to serve the household needs of up to 3.6 million people per year.

Braden and Johnston (2004) distinguish between two services associated with increased groundwater recharge: the increased volume of water available for withdrawal and consumption, and maintaining a higher water table, which reduces pumping costs and increases well pressure.

Reduced Public Expenditures on Stormwater Infrastructure

The Center for Watershed Protection (1998), Lehner et al. (2001), and U.S. EPA (2005) report that LID techniques, such as bioswales, rain gardens, and permeable surfaces, can help reduce the demand for conventional stormwater controls, such as curb-and-gutter, and pipe-and-pond infrastructure. Braden and Johnston (2004) report that retaining stormwater runoff on site reduces the size requirements for downstream pipes and culverts, and reduces the need to protect stream channels against erosion.

Two recent studies by the Natural Resources Defense Council (Kloss and Calarusse 2006) and Riverkeeper (Plumb and Seggos 2007) report that by managing stormwater on site, LID techniques can help reduce combined sewer overflows. Combined sewer systems transport both sewage and stormwater flows. Depending on the capacity of the pipes and the amount of rainfall, the volume of combined sewer and stormwater flows can exceed the capacity of the pipes when it rains. When this happens, overflows of sewage and stormwater go directly to receiving bodies of water untreated. LID helps to keep stormwater out of the combined system, which reduces CSO events. Thurston (2003) found that decentralized stormwater controls, such as LID, can control CSO events at a lower cost than conventional controls.

Reduced Energy Use

LID techniques, such as green roofs and shade trees incorporated into bioswales and other controls can provide natural temperature regulation, which can help reduce energy demand and costs in urban areas. Plumb and Seggos (2007) estimate that covering a significant amount of the roof area in New York City with green roofs could lower ambient air temperatures in summer by an estimated 1.4 degrees Fahrenheit. The U.S. EPA and Low Impact Development Center (2000) report that the insulation properties of vegetated roof covers can help reduce a building's energy demand, and notes that green roofs in Europe have successfully reduced energy use in buildings.

Improved Air Quality

Trees and vegetation incorporated into LID help improve air quality by sequestering pollutants from the air, including nitrogen dioxide, sulfur dioxide, ozone, carbon monoxide, and particulate matter (American Forests 2000-2006). In a study by Trees New York and Trees New Jersey, Bisco Werner et al. (2001) report similar air-quality benefits of trees and vegetation in urban areas. Plumb and Seggos (2007) cite one study that found that a single tree can remove 0.44 pounds of air pollution per year.

Enhanced Aesthetics and Property Values

Several studies including Lacy (1990), Mohamed (2006), U.S. Department of Defense (2004), and Bisco Werner et al. (2001) report that the natural features and vegetative cover of LID can enhance an area's aesthetics, and increase adjacent property values. The U.S. Department of Defense (2004) highlights how LID can improve the aesthetics of the landscape and increase adjacent property values by providing architectural interest to otherwise open spaces. On commercial sites, Bisco Werner et al. (2001) found that LID on commercial sites provided amenities for people living and working in the area and complemented the site's economic vitality, which improved its competitive advantage over similar establishments for customers and tenants.

III. ECONOMIC FRAMEWORK: MEASURING COSTS AND BENEFITS OF LOW-IMPACT DEVELOPMENT

Researchers and practitioners assess the economic aspects of LID using several methodologies. These methodologies range from rough cost evaluations, that compare a subset of costs of LID against the same costs for conventional management techniques, to benefit-cost analyses, that compare a range of costs and benefits of LID to the same for conventional stormwater controls. This section examines the differences in these methodologies.

Most economic evaluations of LID reported in the literature emphasize costs. The overwhelming majority of these studies confined their analyses to measuring installation costs. Evaluators prefer this method perhaps because from a developer's perspective, installation cost is one of the most important considerations when choosing between LID or conventional controls. LID can compare favorably with conventional controls in a side-by-side analysis of installation costs (*see for example* Foss 2005; Conservation Research Institute 2005; U.S. EPA 2005; Zickler 2004), however, focusing on installation costs misses other relevant economic information. For example, such a focus excludes operation and maintenance (O & M) costs, differences in the effectiveness of LID versus conventional systems, and the environmental and economic benefits that LID can provide, but which conventional controls cannot.

Evaluating projects based on installation costs has advantages of costing less than studies that include other economic factors, e.g., O & M costs, taking less time than more extensive analyses, and relying on readily available construction-cost data. The tradeoff for stormwater managers is an incomplete and possibly biased description of economic consequences, especially over the long term.

Some researchers look beyond comparisons of installation costs and evaluate LID and conventional controls using a method know as a life-cycle cost analysis (LCCA) (Powell et al. 2005; Sample et al. 2003; Vesely et al. 2005). This approach considers a comprehensive range of stormwater-management costs including planning and design costs, installation costs, O & M costs, and end-of-life decommissioning costs. An LCCA method requires more data than a comparison of installation costs, and this data, particularly data on lifetime O & M costs, may not exist or is difficult and costly to obtain. The tradeoff for policy makers is more accurate information on the cost implications of alternative stormwater-management options. However, LCCA, like more limited cost comparisons, excludes measures of economic benefits.

Another limitation of cost comparisons is that they ignore differences in effectiveness between LID and conventional controls. For this reason, researchers recommend that LCCA should compare projects that provide the similar levels of services (Powell et al. 2005). Brewer and Fisher (2004), Horner, Lim, and Burges (2004), and Zielinski (2000) found, however, that LID approaches can manage stormwater quantity and quality more effectively than the conventional approaches, either controlling more flow, or filtering more pollutants, or both. In these cases, an LCCA study could conclude that an LID option costs more than the conventional control, without accounting for the fact that the LID option can manage a larger volume of stormwater.

The benefit-cost approach overcomes the limitations of simple cost comparisons or LCCA by considering the full range of costs and benefits of alternative management options. The tradeoff is that the benefit-cost approach requires more data than cost comparison, which increases the time and costs of conducting the economic analysis.

The benefit-cost approach evaluates the net economic benefits of a project, or compares outcomes among projects, by comparing relevant costs with relevant economic benefits (Boardman et al. 2005; Field and Field 2006; Gramlich 1990; Kolstad 2000). Economic researchers in academic, business, and public-policy sectors have for many years conducted benefit-cost analyses in a wide variety of applications. Since at least the middle of the twentieth century, economic evaluations of large-scale public projects included some type of benefit-cost analysis, and since 1981, the federal government required that new programs and regulations include a benefit cost analysis (Freeman 2003). The U.S. Office of Management and Budget (OMB) considers the benefit-cost method the “recommended” technique when conducting formal economic analyses of government programs or projects (U.S. OMB 1992). Over the years, the technique has grown more sophisticated, especially with respect to measuring and incorporating non-market goods and services, such as the values of ecosystem services (Croote 1999).

The economic literature on benefit-cost analysis is voluminous and growing, but the basic process can be broken into four steps (Field and Field 2006).[2]

1. The first step defines the scope of the analysis, including the population that will experience the benefits and costs, and the elements of the project, including location, timing, and characteristics of the work to be done.

2. The second step determines a project’s full range of inputs and effects, from the planning and design phase through the end of the project’s lifespan.

3. The third step identifies and, where possible, quantifies the costs and benefits resulting from the project’s inputs and effects. Where quantification is not possible, qualitatively describe the cost or benefit in as much detail as possible, including degree of uncertainty and expected timing of impacts (long-term or short-term).

4. The final step compares the benefits and costs of the project, either in terms of net benefits (the total benefits minus the total costs) or in terms of a benefit-cost ratio (the amount of benefits produced per unit of cost). If relevant, compare results among alternative projects.

We found few benefit-cost evaluations of LID projects. The large majority of studies estimate installation costs, a few consider additional costs, such as O & M costs, and a handful compared some measures of costs against some measures of benefits. The reported benefit-cost studies of LID include Bachand (2002) and Fine (2002),[3] Devinny

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[2] For a more complete discussion of benefit-cost analysis, see Field and Field (2006), Gramlich (1990) and Harberger and Jenkins (2002).

[3] We reviewed summaries of Bachand (2002) and Fine (2002) because we were unable to acquire copies of the full articles.

et al. (2005), and Doran and Cannon (2006). Data limitations may explain part of the reason for the limited number of benefit-cost analyses of LID. This is especially true for lifetime O & M costs and the economic importance of LID benefits. Sample et al. (2003), Powell et al. (2005), Johnston, Braden, and Price (2006), and Conservation Research Institute (2005), among others, describe the need for more research quantifying the benefits of LID practices.

Another reason may be that economic benefits or lifetime O & M costs have no relevance to a given economic study. For example, property developers pay installation costs of stormwater controls, but not lifetime O & M costs. Nor do they benefit directly from the ecosystem services that LID can enhance or provide. Economic results reported by developers will therefore likely focus exclusively on installation costs of LID or compare installation costs for LID and conventional controls.

Using the benefit-cost approach has challenges that the other analytical methods do not. However, benefit-cost analysis has advantages in that it can provide decisionmakers, ratepayers and other stakeholders with a more complete picture of the economic consequences of stormwater-management alternatives than other analytical methods. This is especially true for costs and benefits of alternatives over the long term. In situations in which time, budget, or other information constraints limit quantifying economic benefits or costs, the next best alternative is identifying the range of costs and benefits, quantifying what can be measured and describing the remaining impacts qualitatively. The federal government takes this approach in that the OMB recommends that when benefits and costs cannot be quantified, agencies should provide qualitative descriptions of the benefits and costs. These qualitative descriptions should include the nature, timing, likelihood, location, and distribution of the unquantified benefits and costs (U.S. OMB 2000).

IV. COSTS AND BENEFITS OF LOW-IMPACT DEVELOPMENT

The large majority of literature that describe economic assessments of LID focus on the costs of installing the technology. Most studies report the costs of building LID stormwater controls, or compare the costs of installing LID to the costs of conventional controls. The organization of this section reflects this emphasis in the literature. We begin by summarizing studies that list the costs of installing various LID techniques. Most of these reports describe the outcomes of case studies of LID installed as new or developing stormwater-management technologies. We then discuss studies that compare the costs of building LID controls with the costs of building conventional controls.

A number of researchers looked beyond installation costs and considered the impacts that operations and maintenance costs can have on economic evaluations of LID. Analysts sometimes refer to these as life-cycle studies because they consider the relevant costs throughout the useful life of a technology. We summarize three studies that took this approach with LID evaluations.

Combined sewer overflows, and the resulting biophysical and economic consequences, are major concerns for municipal stormwater managers. LID can help minimize the number of CSO events and the volume of contaminated flows by managing more stormwater on site and keeping flows out of combined sewer pipes. We summarize five studies that evaluated the costs of managing CSO events using LID.

A relatively small percentage of the economic evaluations of LID reported in the literature include assessments of the economic benefits of the technology. We summarize a number of these reports at the end of this section.

A. Cost of Low-Impact Development

Brown and Schueler (1997) surveyed construction costs for different methods of managing stormwater in urban areas. Their survey emphasized conventional controls but also included a number of LID techniques. At the time of their study, LID techniques were considered “next generation” best-management practices (BMPs). The report lists construction costs for sixty-four BMPs including wet and dry stormwater ponds, bioretention areas, sand filters and infiltration trenches. The authors’ major conclusion is that a BMP’s construction cost increases with the volume of stormwater the BMP stores. The report’s construction costs may be out-of-date, however they provide insights into relative cost differences between LID and other controls listed in the report.

In a more recent study, Tilley (2003) reports construction costs for LID case studies implemented in Puget Sound and Vancouver, B.C. The report describes a range of case studies from small-scale projects implemented by homeowners to large installations completed by universities, developers and municipal governments. The LID techniques studied include rain gardens, permeable pavement and green roofs. The amount of cost information varies by case study. In some cases the report lists per-unit costs to install an LID, e.g., a pervious concrete project cost $1.50 per square foot for materials (excluding labor). Other descriptions report costs generally, but not costs specific to the case study described, e.g., the cost for pervious concrete is typically $6 to $9 per square foot. Some descriptions have no cost information, and others list total construction costs without a detailed breakdown of cost components.

The U.S. Department of Defense (DoD) (2004) developed a manual of design guidelines to incorporate LID into DoD facilities. The manual describes 13 stormwater-management techniques and their most appropriate uses, maintenance issues, and cost information. The list of LID techniques includes bioretention, grassed swales, and permeable pavers. The manual describes costs in some detail but also notes the site-specific nature of construction costs and factors that can influence construction costs for certain LIDs.

Liptan and Brown (1996) describe one of the earliest comparisons of construction costs for LID with that for conventional controls.[4] They focus on two projects in Portland, Oregon, which they refer to as the OMSI and FlexAlloy projects, and the Village Homes development in Davis, California. In all cases, the LID option cost less. The LID design implemented at the OMSI project saved the developer $78,000 in construction costs by reducing manholes, piping, trenching, and catch basins. At the FlexAlloy site, the City of Portland conducted a retrospective study of LID vs. conventional development, after the builder installed conventional controls. The City calculated that the developer could have saved $10,000 by implementing the LID option. The description of the FlexAlloy case study includes a detailed comparison of construction costs for the two options. The Village Homes case study concluded that by using vegetated swales, narrow streets, and a cluster layout of building lots, the developer saved $800 per lot, or $192,000 for the development. The Village Homes description includes no additional details on construction costs for the two options. The report also includes brief descriptions of other LID case studies, some with cost comparisons for LID vs. conventional controls. The authors conclude that involving developers, engineers, architects and landscape architects early in the design of a development that includes LID can help minimizing the LID-specific construction costs.

Hume and Comfort (2004) compared the costs of constructing conventional roads and stormwater controls with the costs of building LID options, such as bioretention cells and pervious pavement. The researchers added complexity to some of their comparisons by paring the same conventional and LID controls, e.g., infiltration trench (conventional) vs. bioretention cell (LID) on a different soil types and with different sources of stormwater runoff (e.g., driveway vs. roof top) to see how this affected construction costs. In some comparisons the LID option cost more than the conventional option, in other cases the results were opposite. These comparisons illustrate the site-specific nature of LID construction costs. Local conditions, e.g., less pervious soils, can influence the costs of LID controls.

In some cases, LID can help lower construction costs by making use of a site's existing or undisturbed drainage conditions in ways that conventional controls cannot. Planners of a 44-acre, 80-lot residential development in Florida took advantage of the site's natural drainage patters to help lower stormwater-management costs (PATH 2005). The site's low-lying areas convey the large majority of stormwater runoff to forested basins. The developer minimized disturbing natural drainage patterns by clustering building sites and connecting sites with narrow roads. Relying on natural infiltration and drainage patterns help the developer save $40,000 in construction costs by avoiding the costs of constructing stormwater ponds.

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[4] In this Section we describe some of the developments associated with costs comparisons reported in the LID literature. The next Section focuses on LID from the perspective of property developers and contractors. In that Section we list results for a larger number of cost comparisons

Comparing construction costs between LID and conventional options, while informative, provides no information on the relationship between the cost and effectiveness. For example, in cases where the LID option costs more to build, it may also control a larger volume of stormwater relative to the conventional option. LID that keeps stormwater out of pipes and treatment facilities help lower operations and maintenance (O & M) costs, and help extend the useful life of the infrastructure, which can reduce future construction costs. The relative importance of construction or O & M costs depends on who pays for them. Builders likely focus exclusively on construction costs, however, cost and effectiveness information would help stormwater managers better evaluate control options and plan for future demands on stormwater infrastructure.

Brewer and Fisher (2004) report the results of four case studies that compared the cost and effectiveness of LID to that of conventional controls. The case studies modeled stormwater costs and conditions on four developments: high- and medium-density residential, an elementary school, and a commercial development. In both residential developments LID controls cost less than conventional controls. LID cost more for the school and commercial development. However, in all four cases, the LID option managed a larger volume of stormwater than the conventional option. We reproduce Brewer and Fisher's results in Table 4-1.

Table 4-1: Comparison of Runoff Controlled and Cost Savings for Conventional and LID Design.

Site Example	Runoff Storage (acre-feet)		LID Net Cost or Savings
	Conventional	LID	
Medium Density Residential	1.3	2.5	$476,406
Elementary School	0.6	1.6	$(48,478)
High Density Residential	0.25	0.45	$25,094
Commercial	0.98	2.9	$(9,772)

Source: Brewer and Fisher 2004

We calculated the economic value of the additional storage provided by the LID designs reported in Brewer and Fisher (2004), using data on the national average of construction costs as reported by American Forests. American Forests' CITYgreen analyses calculate the national-average cost of storing 1 acre-foot of runoff at $87,120.[5] American Forests uses a value of $2.00 per cubic foot of storage, obtained from national estimates of stormwater construction costs. This amount represents the avoided costs of not building stormwater detention ponds. This value may vary, depending on a project's location. In some of its analyses, American Forests uses local estimates of construction costs, which can be lower or higher than the national average. For example, American Forests uses

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[5] *See, for example,* American Forests. 2003. *Urban Ecosystem Analysis: San Diego, California*. July. Retrieved August 2, 2007, from http://www.americanforests.org/downloads/rea/AF_SanDiego.pdf, American Forests. 2003. *Urban Ecosystem Analysis: Buffalo-Lackawanna Area, Erie County, New York*. June. Retrieved August 2, 2007, from http://www.americanforests.org/downloads/rea/AF_Buffalo.pdf.

$0.66 per cubic foot of storage in Houston, TX,[6] $5.00 per cubic foot of storage in the Washington D.C. Metro Area,[7] and $6.00 per cubic foot of storage in Portland, OR.[8] Table 4-2 shows the results of our calculation.

Table 4-2: Value of the Difference in Runoff Storage Provided by LID Designs.

Site Example	Runoff Storage (acre-feet)			Runoff Storage Difference (cubic-feet)[a]	Value of Difference in Runoff Storage ($2/cf)
	Conventional	LID	Difference		
Medium Density Residential	1.3	2.5	1.2	52,272	$104,544
Elementary School	0.6	1.6	1	43,560	$87,120
High Density Residential	0.25	0.45	0.2	8,712	$17,424
Commercial	0.98	2.9	1.92	83,635	$167,270

Source: ECONorthwest

Notes: [a] To convert from an acre foot to cubic feet, multiply by 43,560 (the number of cubic feet in an acre-foot).

Based on the results reported in Table 4-1, and taking the perspective of a builder, LID is the higher-cost alternative for the school and commercial development. Including the results from Table 4-2, and taking the perspective of a municipal stormwater manager—that is, considering construction costs and the cost savings associated with reductions in stormwater volume in our example calculation above—the LID option dominates the conventional choice in all four cases. The LID options control a larger volume of stormwater, which helps avoid municipal expenditures on stormwater management.

Doran and Cannon (2006) studied the relationship between construction costs of LID and conventional controls and effectiveness as measured by improvements in water quality. They studied the impacts of incorporating LID into a downtown redevelopment project in Caldwell, Idaho. The analysis modeled construction costs and improvements to water quality as measured by reduced concentrations of sediment and phosphorus in stormwater runoff. The LID techniques used in the project included permeable pavers, bioretention swales, riparian wetlands, and plantings of restored native vegetation. The study evaluated the LID and conventional controls using the cost of a 1-percent reduction in sediment and phosphorus concentrations. Conventional stormwater controls had lower

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[6] American Forests. 2000. *Urban Ecosystem Analysis for the Houston Gulf Coast Region*. December. Retrieved August 2, 2007, from http://www.americanforests.org/downloads/rea/AF_Houston.pdf.

[7] American Forests. 2002. *Urban Ecosystem Analysis: The District of Columbia*. February. Retrieved August 2, 2007, from http://www.americanforests.org/downloads/rea/AF_WashingtonDC2.pdf.

[8] American Forests. 2001. *Regional Ecosystem Analysis for the Willamette/Lower Columbia Region of Northwestern Oregon and Southwestern Washington State*. October. Retrieved August 2, 2007, from http://www.americanforests.org/downloads/rea/AF_Portland.pdf.

installation costs, but also had a lesser impact on water quality. Conventional controls cost $8,500 and reduced sediment and phosphorus concentrations by 5 percent, or $1,700 per percent reduction. LID stormwater controls cost more, $20,648, but had a greater impact on water quality, reducing sediment by 32 percent and phosphorus by 30 percent. The authors calculated a cost of $645 per percent reduction for the LID option. The LID option produced a better return on initial investment, as measured by improvements to water quality, than did investments in conventional controls.

As the previous two studies illustrate, comparing LID and conventional controls based on costs may bias the assessment against the most effective management option, and the option that yields the greatest return on investment. LID may cost more to build, but from an investment perspective, it may also control more stormwater and better improve water quality. The studies above considered separately LID effectiveness as measured by volume of stormwater managed and improvements in water quality of stormwater runoff. A more complete and accurate assessment of effectiveness and costs would consider the impacts on both in a single study. That is, compare LID and conventional controls based on costs and effectiveness as measured by volume of stormwater *and* water quality. We found no such studies in the literature.

Looking beyond construction costs to O & M and other costs gives a more complete description of the economic consequences of adopting LID or conventional controls. Sample et al. (2003) promotes evaluating stormwater BMPs using life-cycle-cost (LCC) analysis. LCC analysis includes the initial capital expenditures for construction, planning, etc., and the present value of lifetime O & M costs, and the salvage value at the end of the BMP's useful life. In addition, the authors suggest including the opportunity cost of land in the cost analysis. BMPs that occupy more land area have a higher opportunity cost valued at the next-best use for the land, e.g., residential value.

Vesely et al. (2005) compared the LCC for LID controls in the Glencourt Place residential development in Auckland, New Zealand with LCC results for conventional controls. The LID option had the added benefit of reusing stormwater collected on site as grey water for laundry, flushing toilets and irrigation. The LID option had LCCs that were 4 to 8 percent higher than the conventional option, depending on the discount rate and number of years in the analysis. These results do not account for the value of recycled stormwater. Including the avoided cost associated with water saved by recycling stormwater as household gray water, the LCC for the LID option were 0 to 6 percent higher, again, depending on the discount rate and number of future years in the analysis. The authors conclude that accounting for the value of water saved, the LID option was cost competitive with the conventional approach, as measured by the LCC method.

Data constraints on this study included difficulty estimating current and future maintenance costs and future decommissioning costs. Accounting for the opportunity cost of land also proved challenging give the available data. Data limitations also prevented the authors from considering the economic aspects of environmental externalities associated with the LID and conventional options.

LCC evaluations are an improvement over comparisons of construction costs in that they provide a more comprehensive assessment of relevant costs. On the other hand, LCC analyses require more data and results are sensitive to the discount rate applied to future values and the number of years of the analysis. Powell et al. (2005) underscore these advantages and challenges associated with LCC analysis. They recommend a checklist of factors to consider when conducting a LCC for LID and conventional controls. The checklist includes *quantitative* assessments of the components of LCC costs including acquisition, construction, O & M, and salvage value. Also included are *qualitative* assessments of the effectiveness of managing stormwater and the benefits attributed to the management option. The authors note that effectively and accurately implementing LCC analyses for LID will require more research into the costs of LID design, construction and O & M. Further research is also need in assessing the monetary benefits of LID controls.

Despite the fact that LID technologies have been promoted and studied since the early 1990s, in many ways, and to many stormwater managers, LID is still a new and emerging technology (Coffman 2002). As with most new technologies, installation and other costs for LID are highest during the early phases of development and adoption. Over time, as practitioners learn more about the technology, as the number of suppliers of inputs increases, and as regulations adapt to the new technology, costs will likely decline.

Foss (2005) describes this relationship between a learning curve and construction costs for greenstreet technology in Seattle. The city spent $850,000 implementing a greenstreet pilot project, known as the "Street Edge Alternative" (SEA) street. The City's street planners expect that based on their experience with the pilot project, building greenstreets in the future will cost substantially less. Foss quotes the manager of the City's surface water program on this point:

> *"You could take $200,000 off the price just from what we didn't know. … The pilot phases that we are currently in are more expensive, but as the project becomes institutionalized, all the costs will come down. Even still, these projects are less expensive than standard projects." (p. 7)*

B. Costs of Managing Combined Sewer Overflows By Low-Impact Development

One of the earliest studies of the economic aspects of managing combined sewer overflows by LID evaluated a project that disconnected downspouts as a means of reducing the number of CSO events and costs (Kaufman and Wurtz 1997). In 1994, the Beecher Water District (BWD) near Flint, Michigan, provided free downspout diversions from home sites to sanitary-sewer pipes for the 6,020 residential customers in their service area. The purpose of the program was to reduce the volume of sewer flows from the BWD to the City of Flint's stormwater facility—and reduce the fees that BWD paid the city to manage these flows—and reduce the number and volume of CSO events in the BWD.

The program was a success on many levels and is an example of a small-scale and inexpensive approach that effectively managed CSO events. Disconnecting downspouts cost the BWD just over $15,000. After the diversions, the mean volume of sewer flows measured across all precipitation events decreased 26 percent. The program saved the BWD over $8,000 per month in reduced fees to the City of Flint's stormwater facility, and in reduced costs of managing CSO events. The program paid for itself in two months. Other benefits included reduced CSO-related customer complaints, improved recharge of groundwater and reduced pollution of the Great Lakes, the receiving waters for CSO from the District.

In another study looking at controlling CSO events on a smaller scale, Thurston et al. (2003) modeled the costs of CSO controls for a small watershed in Cincinnati, Ohio. The modeling exercise was part of a study that evaluated the theoretical considerations of developing a market for tradable stormwater credits as a means of reducing CSO events and costs. One part of the study compared the construction costs of controlling CSO events by building tunnels and storage vaults with the costs of building LID controls on each of the 420 mostly-residential lots in the study area.

They calculated that building the tunnel and vault option would cost between $8.93 to $11.90 per cubic foot of storage capacity. Building LID controls on individual lots would cost $5.40 per cubic foot of capacity. Based on these results the researchers suggest that the costs of managing CSOs by implementing LID throughout the watershed would cost less than building a large centralized tunnel and vault system to store excess flows. They also note, however that their analysis does not include the opportunity cost of land that the LID controls would occupy, and so the cost of the LID option would be higher than they report. Their analysis also excludes O & M costs for both options, as well as the costs of education and outreach to property owners, and managing the construction of a large number of dispersed LID projects as components of the LID option. The project also excludes the economic benefits of the LID option.

Kloss and Calarusse (2006) developed a set of policy guidelines for decisionmakers interested in implement LID controls as a means of reducing CSO events in their jurisdictions. Regarding the costs of LID controls, the authors distinguish between new and retrofit construction projects. In new developments, they conclude, LID typically cost less than conventional stormwater controls. They note, however, that retrofit developments in urban areas that include LID typically cost more than conventional controls. This is especially true for individual, small-scale retrofit projects. The relative costs of LID controls can be reduced when they are incorporated into larger-scale redevelopment projects. The report provides conclusions with limited details on cost information. The report also describes the experiences of nine municipalities across the country that include LID in their policies to control CSO events and related costs.

Montalto et al. (2007) described the relationship between public agencies tasked with controlling CSO events, and private land owners on whose property the large majority of LID controls would be sited. The public agencies benefit from the reduced stormwater flows and CSO events that LID provides. The land owner, however, pays the LID installation and O & M costs, but may see little benefit beyond reduced stormwater fees or increased property values from LID such as greenstreets. These benefits may not outweigh the costs to the land owner, and so they may choose not to install LID controls. Given this disconnect, the authors note the benefits of public policies, incentives and subsidies to promote LID adoptions by private-property owners.

In an effort, in part, to measure the amount of subsidy that may be required, the authors developed a model to assess the cost-effectiveness of mitigating CSO events in urban areas using LID. They applied their model to a case study in the Gowanus Canal area of Brooklyn, NY. The case study compared the costs of installing porous pavement, green roofs, wetland developments and other LID throughout the study area to the costs of installing storage tanks to catch excess stormwater flows. As part of their analysis they collected and report installation and O & M costs for a range of LID techniques.

They conclude that under a range of cost and performance assumptions, LID installed throughout the study area could potentially reduce the number of CSO events and volume at a cost that would be competitive or less than the costs of the conventional storage-tank option. They note that they could improve the performance of their model if more data were available on LID performance, costs and public acceptance.

Plumb and Seggos (2007) studied the impacts of diverting monies currently designated to building storage tanks and other conventional CSO controls for New York City to building LID controls throughout the city. They compared the effectiveness of storage tanks and LID controls based on gallons of stormwater managed per $1,000 invested. We reproduce their results in Table 4-3 below. Except for greenroofs, the LID options control more stormwater per $1,000 invested than the conventional storage-tank option.

Table 4-3: Gallons of Stormwater Managed per $1,000 Invested.

Stormwater Control	Gallons per $1,000 Invested
Conventional Storage Tanks	2,400
Greenstreet	14,800
Street Trees	13,170
Greenroof	810
Rain Barrel	9,000

Source: Plumb and Seggos 2007

They describe their analysis as a simple and preliminary cost comparison and conclude that their results demonstrate that LID controls can be cost competitive with conventional controls, if not more so. The authors recommended further detailed study of the issue. Their analysis focused on the costs of LID vs. conventional controls and did not consider economic benefits of the LID techniques.

C. Economic Benefits of Low-Impact Development

Many reports and articles describe the potential benefits that LID stormwater controls can provide—benefits that conventional controls can not offer.[9] Very few studies, however, quantify these benefits, either in biophysical measures or in dollar amounts. A study by CH2MHill (2001) is a typical example. The analysis compared the costs and benefits of managing stormwater in two residential developments using LID or conventional controls. The cost analysis included detailed information for the LID and conventional controls. In this case, results of the cost analysis were mixed. In one development the LID option cost less to build and in the other development the conventional control cost less. In both cases the LID option had higher maintenance costs but homeowners would benefit from lower stormwater and water fees.

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[9] We list a number of these sources in Section II of this report.

The analysis of benefits included much less detailed information. The study lists the benefits that the LID option would provide, benefits that the conventional approach would not. These benefits include reduced auto traffic, increased open space, improved downstream water quality, and increased groundwater recharge. However, the benefits were not quantified in dollar amounts.

In another example, Bachand (2002) studied the costs and benefits of developing wetlands as a stormwater management option. The analysis described the construction and O & M costs associated with the wetlands option, and the benefits including adding new recreational opportunities, increased wildlife habitat and increase property values for near-by homeowners. However, they did not measure the benefits in economic terms. An accompanying study by Fine (2002) quantified some of the recreational benefits that derive from wildlife watching in the wetlands, but left unquantified the benefits of other direct uses of the wetlands, as well as the value of habitat improvements and other non-use benefits.[10]

When researchers cite the needs for further research into LID-related topics, quantifying benefits and measuring their economic importance invariably makes the list. For example, Sample et al. (2003) cites the need for more research into measuring the technical and economic benefits of LID, including benefits to downstream receiving waters. Powell et al. (2005) note the need for more research into monetary measures of the benefits of LID, e.g., the impact that a greenstreet can have on adjacent property values. Vesely et al. (2005) state that future studies should include not only the economic benefits of LID but also the negative economic impacts of conventional controls. Failing to do so will continue biasing management decisions in favor of conventional controls:

> *"Exclusive reliance on profitability and market value will favour [sic] the conventional approach to stormwater management by disregarding both the negative environmental externalities associated with this approach, and the positive environmental externalities associated with the low impact approach." (page 12)*

A number of studies do measure some of the economic benefits of on-site stormwater controls. For example, Braden and Johnson (2004) studied the economic benefits that on-site stormwater management could have on properties downstream. The researchers first estimated the impacts that on-site stormwater controls could have on the frequency and extent of downstream flooding. Using information reported in the literature on the extent to which property markets discount the value of properties in a floodplain, they approximated the economic value of reduced flooding attributed to on-site management of stormwater. They then calculated the value of avoided flood damage as a percentage of property values. They estimate that a marginal reduction in flooding would increase property values 0 to 5 percent for properties in a floodplain, depending on the extent to which the on-site controls reduce stormwater runoff.

They then took a similar approach to valuing improvements in water quality. Based on values reported in the literature, they estimate that the benefits of improved water quality could reach 15 percent of market value for properties that border the water body at issue

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[10] We were unable to obtain a copy of the full report. We base our description on a summary of the analysis.

if water quality improves significantly. The increase is much less for smaller improvements in water quality, for undeveloped properties, and for properties not adjacent to the water body.

They conclude with a best-guess estimate of a 2 to 5 percent increase in property values for properties in a floodplain from on-site management of stormwater. Other benefits that could not be quantified or valued given available information include reduced infrastructure expenditures for culverts, bridges and other drainage infrastructure.

In a follow-up case study, Johnston, Braden, and Price (2006) applied the analytical method developed in the previous study to properties in the one-hundred-year floodplain portion of a watershed in the Chicago area. They estimate the economic benefit of avoided flooding two ways and extend the analysis to approximate reduced municipal expenditures on culverts.

Applying the 0 to 5 percent impact on property values calculated in the previous study to properties in the case study, the researchers estimated an economic benefit of $0 to $7,800 per acre of increased property value attributed to reduced flooding. They also calculated the economic benefit of reduced flooding based on the avoided flood damage to structures and contents for properties in the floodplain. This analytical method included data compiled by the U.S. Army Corps of Engineers on the relationship between flooding and damages to properties in floodplains. This approach yields an economic benefit of avoided flooding of $6,700 to $9,700 per acre for properties in the floodplain.

The researchers approximate that for the case-study portion of the watershed, conservation-design practices such as LID techniques that retain more stormwater on site and reduce flooding could generate $3.3 million in avoided costs for road culverts.

The estimated economic benefit of increased on-site management of stormwater for properties in the case study for both avoided flooding and reduced municipal expenditures on culverts is $380 to $590 per acre.

A series of analyses by American Forests (2000-2006) report the economic benefits of stormwater services provided by trees in various cities and regions throughout the United States. These reports describe results from American Forests' CITYgreen model, which calculates the volume of stormwater absorbed by existing tree canopies and estimates the avoided costs in stormwater management that the trees provide. The model includes city-specific per-unit stormwater-management costs when available. The model substitutes national per-unit costs when city-specific data are not available. In Table 4-4 below we report the results for some of American Forests' city and regional analyses. The dollar amounts represent the costs of expanding stormwater infrastructure to manage the stormwater that existing trees otherwise absorb and transpire.

Table 4-4: Avoided stormwater-construction costs attributed to trees, as measured by the American Forests' CITYgreen model.

Urban Area	Amount that trees save in one-time stormwater-construction costs
Houston, Texas	$1.33 billion
Atlanta, Georgia	$2.36 billion
Vancouver, Washington/ Portland-Eugene, Oregon	$20.2 billion
Washington D.C. Metro Area	$4.74 billion
New Orleans, Louisiana	$0.74 billion
San Antonio, Texas	$1.35 billion
San Diego, California	$0.16 billion
Puget Sound Metro Area, Washington	$5.90 billion
Detroit, Michigan	$0.38 billion
Chesapeake Bay Region	$1.08 billion

Source: American Forests 2000-2006

The Bisco Werner et al. (2001) analysis of the economic benefits of trees attributed to stormwater management also employed the CITYgreen model. Researchers applied the CITYgreen model to a case study that included the commercial corridor along a major highway through central New Jersey. The analysis modeled the change in tree canopy between 1975 and 1995, and calculated the value of lost stormwater services. During this time, the value of services declined from $1.1 million to $896,000, a 19-percent reduction. If existing trends continue, the expected value in 2015 will be $715,000, a 35-percent reduction relative to the value of services available in 1975. As services supplied by street trees declines, demand on municipal stormwater controls, and associated costs, increase.

The researchers extended their study to include the economic benefits of tree cover attributed to removing air pollutants. This portion of their analysis studied the tree cover at a number of commercial properties in the New York and New Jersey area. In this case the CITYgreen model calculated avoided stormwater-construction costs associated with stormwater services provided by trees on site and, using values reported in the literature, the amounts of air pollutants absorbed by trees, and the per-unit value for each pollutant.

In one case study of a shopping mall, the analysis estimated that the trees currently on the site manage approximately 53,000 cubic feet of stormwater. The CITYgreen model estimated the value of the associated avoided infrastructure costs at just over $33,000. The value of air-pollutant removed is estimated at $1,441 per year. The report lists results for fifteen such case studies.

Wetlands that absorb stormwater runoff can help minimize stormwater-related management and infrastructure costs. Depending on their location and makeup, wetlands may provide other benefits, such as wildlife habitat and recreational opportunities. Fine (2002)[11] studied the recreational benefits provided by wetlands proposed as part of the Treasure Island redevelopment in San Francisco Bay. The analysis assumes that the wetlands will attract visitors year round, with the winter months providing the best opportunity to view migratory birds. Based on recreational expenditures for similar sites in the San Francisco Bay area, Fine calculates that area visitors will spend $4 to $8 million annually. Other benefits that Fine was unable to quantify and value include fisheries enhancement and water-quality services.

Devinny et al. (2005) developed a first-approximation of a benefit-cost analysis of complying with water-quality requirements throughout Los Angeles County using LID and other stormwater BMPs. They present their analysis as an alternative to the approach described by Gordon et al. (2002), which relies on collecting and treating the county's stormwater using conventional controls. The Devinny et al. approach assumes widespread adoption of LID and other on-site stormwater BMPs.

The Devinny et al. analysis accounts for the fact that the density of existing development will limit the extent to which LID and other BMPs can be retrofitted into developments. As an alternative they propose a combination of LID and BMPs along with directing stormwater to regional wetlands and other infiltration systems. As the density of development increases, so does the size and costs of developing regional wetlands.

This study differs from other benefit-cost analyses of stormwater-management options in that the researchers quantify a range of potential benefits associated with the approach that emphasizes on-site treatment of stormwater. They estimate the cost of their approach at $2.8 billion if disbursed LID and other on-site BMPs sufficiently control stormwater quality. Costs increase to $5.7 to $7.4 billion if regional wetlands and other infiltration systems are needed. This approach costs less than the estimated cost of $44 billion to implement the option that emphasizes conventional controls (California Department of Transportation 2005).

The estimated value of the economic benefits of implementing LID, other on-site BMPs and regional wetlands range from $5.6 to $18 billion. Benefits include the economic aspects of reduced flood control, increased property values adjacent to new greenspaces and wetlands, additional groundwater supplies, improved beach tourism, and reduced sedimentation of area harbors. The conventional approach would provide none of these economic benefits.

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[11] We were unable to obtain a copy of the full report. We base our description on a summary of the analysis.

V. DEVELOPERS' EXPERIENCES WITH LOW-IMPACT DEVELOPMENT

Baring regulations that mandate LID controls, developers adopt LID because they help reduce construction costs, increase sales, boost profits, or some combination of the three. These deliberations focus primarily on the extent to which local property markets account for the direct costs and benefits that LID can provide. Typically these deliberations do not include indirect costs and benefits and the potential non-market impacts of LID that may be important to others such as municipal stormwater managers and area residents. These non-market impacts may include reduced downstream flooding, improved water quality and habitat of water bodies that receive stormwater, reduced CSO events, or impacts on the costs of operating municipal-stormwater infrastructure.

In this section we summarize developers' experiences installing LID. As with other new technologies, adopting LID includes opportunities and risks. We begin by describing the risks and challenges that developers face by including LID in their projects. These risks include uncertain construction delays as the developer applies for variances to local zoning codes because the codes do not explicitly recognize LID as an accepted stormwater control.

Next, we describe some of the efforts by municipal governments to reduce the developers' regulatory risk and uncertainty of using LID. Finally, we list some of the successes developers have had adopting LID and the resulting impacts on construction costs, sales, and profits.

A. Challenges Developers Face Using LID

Much of the general public is still unaware of LID attributes, the benefits they can provide, or their O & M costs. As such, they may not understand or appreciate why a developer included LID in a project. This may give developers pause because they supply products that they believe their customers—homebuyers—want and will purchase. Potential buyers may shy away from homes that include an unfamiliar technology.

A general lack of understanding of LID may concern developers in part because including on-site treatment of stormwater will also require on-site management of stormwater facilities, the LID technologies. Homeowners unfamiliar with LID likely will have no understanding of their maintenance requirements (Lewis 2006; England 2002; Foss 2005). For example, a bioswale clogged with sediment may not control stormwater volume or quality, which could negatively reflect on the builder. Another concern has to do with the lack of understanding as to the life-expectancy of LID controls (Lewis 2006). A builder may be concerned that an untimely failure of stormwater controls could negatively affect their reputation.

Similar to the public's general lack of understanding of LID, many builders are also unfamiliar with the technology. A builder may not be able to identify the most effective and least-cost LID technology for a given development from the wide variety of possible LID controls (Foss 2005; Lewis 2006). A related point is that construction costs for LID technologies are site specific. For example, not all soils can support LID technologies that emphasize stormwater infiltration. Assessing a site and designing LID technologies that will function on the site may also increase a builder's design costs (Coffman 2002; Strassler et al. 1999).

A much-mentioned impediment to builders' adoption of LID is building codes that do not account for LID as stormwater controls. Many municipalities have zoning and building-inspection standards in place that were adopted many years ago, long before LID was an option (Coffman 2002; NAHB Research Center Inc. 2003; Foss 2005; Lewis 2006). These standards emphasize conventional stormwater controls that collect stormwater and transport it off site to a receiving body of water or to a treatment facility. Municipalities with outdated stormwater regulations typically require that builders file variances if they want to use LID controls. Filing variances for LID increases design and regulatory costs, which delays construction and can increase a builder's financing costs (Clar 2004; Coffman 2002; Lewis 2006; NAHB Research Center Inc. 2003).

A related constraint in some jurisdictions with outdated regulations is a lack of technical expertise or understanding by regulators regarding LID stormwater controls. In some cases, regulators unfamiliar with LID technology must be convinced of their effectiveness, which also increases a builder's design and regulatory costs (Coffman 2002; NAHB 2003; Lewis 2006).

B. Municipal Actions To Increase LID Adoption On Private Developments

Some jurisdictions help promote LID adoption on private lands and take steps that reduce the regulatory uncertainty and risk that builders face when including LID in private developments. These jurisdictions may have CSO problems, or are trying to extend the useful life of their stormwater infrastructure in the face of increasing population and economic activity. In any case, they recognize the importance of managing as much stormwater on site as possible and keeping it out of the jurisdiction's stormwater pipes.

One way that jurisdictions promote LID adoption on private lands is by updating their zoning codes and building-inspection standards to explicitly address LID stormwater controls (Coffman 2002; NAHB Research Center Inc. 2003; Foss 2005; Lewis 2006). This helps reduce a builder's regulatory risk because it eliminates the need to file variances. Rather than spending time convincing regulators as to the desirable stormwater attributes or effectiveness of LID controls, builders can instead proceed with their development.

Granting density bonuses for developments that install LID stormwater controls is another way jurisdictions encourage the proliferation of LID techniques. In this case, the jurisdiction grants the developer a greater number of individual building lots than would have been allowed if the development relied on conventional stormwater controls (Coffman 2002; NAHB Research Center Inc. 2003). This type of incentive not only reduces a builder's regulatory risk, and associated costs, but also increases the number of lots that can be sold, which can increase the builder's revenue and profits. Jurisdictions also promote LID installation on private lands by reducing development-related fees, such as inspection fees (Coffman 2002; NAHB Research Center Inc. 2003).

C. Benefits To Developers of Including LID Controls in Their Projects

Developers who accept the regulatory uncertainty and other challenges of adopting LID do so with the expectation that controlling stormwater on site can have economic advantages. These advantages include increasing the number of developable lots and reducing expenditures associated with stormwater infrastructure. Managing stormwater on site using LID controls can mean doing away with stormwater ponds, thus increasing a site's developable area (Coffman 2002; NAHB Research Center Inc. 2003). Selling additional lots can increase a builder's revenues and profits. Replacing curbs, gutters and stormwater pipes with bioswales, pervious pavers and other LID controls reduces construction costs for some developers (Coffman 2002; NAHB Research Center Inc. 2003; Center for Watershed Protection 2001).

An analysis of a development in Prince George's County, Maryland, documented the impacts that controlling stormwater on site with LID can have on the site's buildable area and construction costs. The Somerset Community development installed rain gardens, grass swales along streets, and other LID controls. Substituting LID for conventional controls saved the developer approximately $900,000. Doing away with the site's stormwater ponds gave the developer six additional lots (Foss 2005).

A study of the Pembroke Woods Subdivision in Frederick County, Maryland found similar results (Clar 2004). The developer substituted LID for conventional controls, doing away with curbs, gutters, sidewalks, and eliminated two stormwater ponds. Eliminating the curbs and gutters saved the developer $60,000. Installing narrower streets eliminated impervious area and reduced paving costs by 17 percent. Excluding the stormwater ponds saved $200,000 in construction costs and added two developable lots, valued at $45,000 each. Other economic benefits to the developer include reduced costs of clearing land for development of $160,000, and adding 2.5 additional acres of open space, which reduced the developer's wetland-mitigation requirements.

Conservation subdivisions take a comprehensive approach to stormwater management by combining LID controls with a site design that takes advantage of existing drainage patterns. Narrow streets and clustered building lots make maximum use of natural stormwater controls, thus reducing construction costs (Center for Watershed Protection 2001). A study of ten subdivisions found that conservation subdivisions that emphasized LID and protected natural drainage patterns cost, on average, thirty-six percent less than subdivisions that relied on conventional stormwater controls (Conservation Research Institute 2005).

Researchers note that some conservation subdivisions have an additional benefit in that there's greater demand for lots in these subdivisions compared with the demand for lots in conventional subdivisions. Greater demand for lots means the developer can charge more for the lot and lots may sell faster (Center for Watershed Protection 2001).

A case study of conservation and conventional subdivisions in South Kingstown, Rhode Island quantified the market benefits of conservation developments. The study compared the costs of developing the lots and the market value of the lots (Mohamed 2006). Results show that conservation lots cost less to develop and sell for a higher price. On average, conservation lots cost $7,400 less to produce than lots in conventional subdivisions, and sold for 12 to 16 percent more, per acre, than conventional lots. Lots in the conservation subdivision also sold in approximately half the time as lots in conventional subdivisions.

Another study of cluster developments in New England found that houses in these types of developments appreciate faster than houses in conventional developments (Lacy 1990). Lacy identified developments in Concord and Amherst, Massachusetts that were characterized by smaller individual lots surrounded by natural open space, limited lot clearing, and narrower streets. He compared these with nearby conventional developments. The Concord cluster development appreciated 26 percent more than conventional developments over an eight-year study period. The Amherst cluster development also yielded a higher rate of return on investment over a 21-year study period, compared to nearby conventional development.

In Tables 5-1 and 5-2 below we summarize the results of studies that compared construction costs using LID vs. conventional stormwater controls for residential and commercial developments (respectively). We included information in the tables if a study described the source of the cost difference, e.g., substituting a bioswale for curbs and gutters saved $Z. We excluded studies that reported a cost difference, but did not describe the details of the cost comparison. We found many studies in the literature that did not provide details of cost comparisons.

We distinguish between study results for built developments from results for proposed or modeled developments. In some cases the studies report total cost savings for a development but not savings per lot in the development. In these cases we calculated the per-lot cost savings. We recognize that the cost savings values reported below are in dollars from different years, and so comparisons of cost savings between examples may not be appropriate. We found insufficient data in most case studies to convert all values to the same-year dollars.

The large majority of studies listed in Tables 5-1 and 5-2 describe LID installed or proposed to be installed in new developments. We found very few studies that measured the economic outcomes of including LID stormwater controls in urban, redevelopment projects. We identified these studies as “retrofits” in the tables.

Table 5-1: Cost savings attributed to installing LID stormwater controls in residential developments.

Location	Description	LID Cost Savings[a]
Meadow on the Hylebos Residential Subdivision Pierce County, WA	9-acre development reduced street width, added swale drainage system, rain gardens, and a sloped bio-terrace to slowly release stormwater to a creek. Stormwater pond reduced by 2/3, compared to conventional plan. (Zickler 2004)	LID cost 9% less than conventional
Somerset Community Residential Subdivision Prince George's Co., MD	80-acre development included rain gardens on each lot and a swale drainage system. Eliminated a stormwater pond and gained six extra lots. (NAHB Research Center Inc. 2003)	$916,382 $4,604 per lot
Pembroke Woods Residential Subdivision Frederick County, MD	43-acre, 70-lot development reduced street width, eliminated sidewalks, curb and gutter, and 2 stormwater ponds, and added swale drainage system, natural buffers, and filter strips. (Clar 2004; Lehner et al. 2001)	$420,000 $6,000 per lot[b]
Madera Community Residential Subdivision Gainesville, FL	44-acre, 80-lot development used natural drainage depressions in forested areas for infiltration instead of new stormwater ponds. (PATH 2005)	$40,000 $500 per lot[b]
Prairie Crossing Residential Subdivision Grayslake, IL	667-acre, 362-lot development clustered houses reducing infrastructure needs, and eliminated the need for a conventional stormwater system by building a natural drainage system using swales, constructed wetlands, and a central lake. (Lehner et al. 2001; Conservation Research Institute 2005)	$1,375,000-$2,700,000 $3,798-$7,458 per lot[b]
SEA Street Retrofit Residential street retrofit Seattle, WA	1-block retrofit narrowed street width, installed swales and rain gardens. (Tilley 2003)	$40,000
Gap Creek Residential Subdivision Sherwood, AK	130-acre, 72-lot development reduced street width, and preserved natural topography and drainage networks. (U.S. EPA 2005; Lehner et al. 2001; NAHB Research Center Inc. 2003)	$200,021 $4,819 per lot
Poplar Street Apartments Residential complex Aberdeen, NC	270-unit apartment complex eliminated curb and gutter stormwater system, replacing it with bioretention areas and swales. (U.S. EPA 2005)	$175,000
Kensington Estates* Residential Subdivision Pierce County, WA	24-acre, 103-lot hypothetical development reduced street width, used porous pavement, vegetated depressions on each lot, reduced stormwater pond size. (CH2MHill 2001; U.S. EPA 2005)	$86,800 $843 per lot[b]
Garden Valley* Residential Subdivision Pierce County, WA	10-acre, 34-lot hypothetical development reduced street width, used porous paving techniques, added swales between lots, and a central infiltration depression. (CH2MHill 2001)	$60,000 $1,765 per lot[b]
Circle C Ranch Residential Subdivision Austin, TX	Development employed filter strips and bioretention strips to slow and filter runoff before it reached a natural stream. (EPA 2005)	$185,000 $1,250 per lot

Location	Description	LID Cost Savings[a]
Woodland Reserve* Residential Development Lexana, KS	Reduced land clearing, reduced impervious surfaces, and added native plantings. (Beezhold 2006)	$118,420
The Trails* Multi-Family Residential Lexana, KS	Reduced land clearing, reduced impervious surfaces, and added native plantings. (Beezhold 2006)	$89,043
Medium Density Residential* Stafford County, VA	45-acre, 108-lot clustered development, reduced curb and gutter, storm sewer, paving, and stormwater pond size. (Center for Watershed Protection 1998b)	$300,547 $2,783 per lot[b]
Low Density Residential* Wicomico County, MD	24-acre, 8-lot development eliminated curb and gutter, reduced paving, storm drain, and reforestation needs. Eliminated stormwater pond and replaced with bioretention and bioswales. (Center for Watershed Protection 1998b)	$17,123 $2,140 per lot[b]

Source: ECONorthwest, with data from listed sources.
Notes: * indicates hypothetical or modeled project, not actually constructed.
[a] Dollar amounts as reported at the time of study.
[b] Per-lot cost savings calculated by ECONorthwest.

Table 5-2: Cost savings attributed to installing LID stormwater controls in commercial developments.

Location	Description	LID Cost Savings[a]
Parking Lot Retrofit Largo, MD	One-half acre of impervious surface. Stormwater directed to central bioretention island. (U.S. EPA 2005)	$10,500-$15,000
Old Farm Shopping Center* Frederick, MD	9.3-acre site redesigned to reduce impervious surfaces, added bioretention islands, filter strips, and infiltration trenches. (Zielinski 2000)	$36,230 $3,986 per acre[b]
270 Corporate Office Park* Germantown, MD	12.8-acre site redesigned to eliminate pipe and pond stormwater system, reduce impervious surface, added bioretention islands, swales, and grid pavers. (Zielinski 2000)	$27,900 $2,180 per acre[b]
OMSI Parking Lot Portland, OR	6-acre parking lot incorporated bioswales into the design, and reduced piping and catch basin infrastructure. (Liptan and Brown 1996)	$78,000 $13,000 per acre[b]
Light Industrial Parking Lot* Portland, OR	2-acre site incorporated bioswales into the design, and reduced piping and catch basin infrastructure. (Liptan and Brown 1996)	$11,247 $5,623 per acre[b]
Point West Shopping Center* Lexana, KS	Reduced curb and gutter, reduced storm sewer and inlets, reduced grading, and reduced land cost used porous pavers, added bioretention cells, and native plantings. (Beezhold 2006)	$168,898
Office Warehouse* Lexana, KS	Reduced impervious surfaces, reduced storm sewer and catch basins, reduced land cost, added bioswales and native plantings. (Beezhold 2006)	$317,483
Retail Shopping Center*	9-acre shopping development reduced parking lot area, added porous pavers, clustered retail spaces, added infiltration trench, bioretention and a sand filter, reduced curb and gutter and stormwater system, and eliminated infiltration basin. (Center for Watershed Protection 1998b)	$36,182 $4,020 per acre[b]
Commercial Office Park*	13-acre development reduced impervious surfaces, reduced stormwater ponds and added bioretention and swales. (Center for Watershed Protection 1998b)	$160,468 $12,344 per acre[b]
Tellabs Corporate Campus Naperville, IL	55-acre site developed into office space minimized site grading and preserved natural topography, eliminated storm sewer pipe and added bioswales. (Conservation Research Institute 2005)	$564,473 $10,263 per acre[b]
Vancouver Island Technology Park Redevelopment Saanich, British Columbia	Constructed wetlands, grassy swales and open channels, rather than piping to control stormwater. Also used amended soils, native plantings, shallow stormwater ponds within forested areas, and permeable surfaces on parking lots. (Tilley 2003)	$530,000

Source: ECONorthwest, with data from listed sources.
Notes: * indicates hypothetical or modeled project, not actually constructed.
[a] Dollar amounts as reported at the time of study.
[b] Per-acre cost savings calculated by ECONorthwest.

VI. DIRECTIONS FOR FUTURE RESEARCH

Despite the increasing use of LID stormwater controls, and the growing number of economic studies of this technique, our literature review found areas for further research. These areas include:

- Additional research that quantifies the costs and benefits of stormwater management. This includes economic research on the lifetime O & M costs for LID and conventional controls, as well as, studies that quantify the economic benefits of LID methods.
- More detailed information on costs associated with LID. Specifically, information on the factors that contribute to cost savings or cost increases of LID relative to conventional controls.
- Economic studies of LID and conventional methods that control for the effectiveness of the techniques regarding managing stormwater volumes and improving water quality. Comparing LID techniques that cost more to install than conventional methods, but control larger amounts of stormwater, is an apples-to-oranges comparison.
- The large majority of economic studies of LID methods apply to new construction. More research is needed on the economic outcomes of including LID methods in urban redevelopment projects.
- Some preliminary evidence exists that LID can help control CSO volumes at a lower cost than conventional controls. Stormwater managers and public-policy decisionmakers would benefit from additional economic research on this topic.
- Economic studies that model theoretical LID and conventional controls, while informative, may be less convincing to some stormwater managers, decisionmakers and ratepayer stakeholders than retrospective studies of installed controls.

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APPENDIX: ADDITIONAL LOW-IMPACT DEVELOPMENT RESOURCES

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Attachment A

Table 4.4-32 below shows the estimated changes in stormwater runoff volume and mean annual loads for the modeled pollutants of concern for the VCC planning area. **Table 4.4-33** below shows the estimated changes in concentration in stormwater runoff for the VCC planning area.

Table 4.4-32
Estimated Average Annual Runoff Volume and Pollutant Loads for the VCC Project

Parameter	Units	Existing Conditions	Developed Conditions w/out PDFs	Developed Conditions w/ PDFs	Change w/ PDFs
Volume	acre-ft	51	241	192	141
TSS	tons/yr	12.2	21	9.6	-2.6
Total Phosphorus	lbs/yr	68	234	186	118
Nitrate-N + Nitrite-N	lbs/yr	220	411	231	11
Ammonia-N	lbs/yr	81	576	464	383
Total Nitrogen	lbs/yr	564	2,226	1,068	504
Dissolved Copper	lbs/yr	2.0	7.0	3.6	1.6
Total Lead	lbs/yr	1.3	6.1	2.5	1.2
Dissolved Zinc	lbs/yr	26	97	30	4
Total Aluminum	lbs/yr	173	1,181	582	409
Chloride	tons/yr	1	14	11	10

Source: Geosyntec, 2008

Table 4.4-33
Estimated Average Annual Pollutant Concentrations for the VCC Project

Parameter	Units	Existing Conditions	Developed Conditions w/out PDFs	Developed Conditions w/ PDFs	Change w/ PDFs
TSS	mg/L	175	65	37	-138
Total Phosphorus	mg/L	0.49	0.4	0.36	-0.13
Nitrate-N + Nitrite-N	mg/L	1.5	0.6	0.4	-1.1
Ammonia-N	mg/L	0.58	0.9	0.89	0.31
Total Nitrogen	mg/L	4.0	3.4	2.0	-2.0
Dissolved Copper	µg/L	14	11	7	-7
Total Lead	µg/L	9.5	9.3	4.9	-4.6
Dissolved Zinc	µg/L	189	148	57	-132
Total Aluminum	µg/L	1,241	1,804	1,114	-127
Chloride	mg/L	20	43	43	23

Source: Geosyntec, 2008.

Attachment C

Staff Report

Los Angeles Region Integrated Report

Clean Water Act Section 305(b) Report and Section 303(d) List of Impaired Waters

2008 Update

Prepared by
California Regional Water Quality Control Board, Los Angeles Region

Revised July 2009

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

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Regional Board staff appreciate the assistance given by Peter Kozelka of the United States Environmental Protection Agency and the State Water Resources Control Board Integrated Report Staff.

1 Executive Summary

This Integrated Report provides the recommendations of the staff of the California Regional Water Quality Control Board, Los Angeles Region (Los Angeles Water Board) for changes to the Clean Water Act (CWA) Section 303(d) list of impaired waterbodies and provides a draft Clean Water Act Section 305(b) report (Integrated Report). The Integrated Report includes both the list of impaired waterbodies and identified waters which are known to be meeting beneficial uses within the Los Angeles Region.

The Introduction to this Integrated Report provides the context and purpose and an overview of the approach and describes the public process that will be used for adoption of the changes to the 303(d) list and finalization of the Integrated Report. The remainder of the report describes data sources used, the objectives and criteria against which data were compared, the methodology for comparing the available data to the criteria to assess attainment of water quality standards and determine potential 303(d) listings and the methodology used to categorize waterbody segments according to beneficial use support for the 305(b) report. Results are briefly summarized and discussed following descriptions of the methodology.

Recommendations are shown in detail in the appendices. Appendix A shows the public solicitation letters requesting that the public submit any and all available data to support the assessment of water quality in the Region. Appendices B through E provide lists of waterbodies in Integrated Report categories of beneficial use support. Appendix F presents a list of all impairments by waterbody including those waterbodies in Integrated Report categories 4 and 5 (appendices D and E) which is the list referred to as the 303(d) list. Appendix G presents “fact sheets” for each waterbody-pollutant combination that was analyzed for the proposed 303(d) listing decisions. These fact sheets include at least one “Line of Evidence” describing the data and information used as a basis for each proposed decision. Appendix H presents fact sheets for other miscellaneous changes to the 303(d) list. Appendix I provides citations for all of the references used in developing the Integrated Report.

There are 68 proposed new 303(d) listings in 41 waterbodies and 30 proposed de-listings in 19 waterbodies on the Los Angeles Region 303(d) list.

Additions of new impaired waterbodies to the list (‘listings’) or deletions of no longer impaired waterbodies from the list (‘delistings’) were constrained by availability of water quality data. Many waterbodies in the Region are not sampled on a regular basis. In addition, identification of waterbodies which are not impaired by pollutants and meet all beneficial uses has also been driven by availability of data.

Regional Board staff reviewed all data available to determine impairment or the absence of impairment but staff focused on developing listing or delisting decisions and factsheets for the update and did not usually develop do-not-list or do-not-delist decisions and factsheets as these decisions would not alter the final 303(d) list.

The Los Angeles Region Integrated Report and updated 303(d) list included in this staff report is being circulated for public comments. Written comments received before June 17, 2009 will be responded to in writing. The reports and the response to comments will then be brought before the Los Angeles Water Board at a public hearing for potential approval. Public testimony will also be heard at the public hearing. After approval by the Los Angeles Water Board, the Integrated Report, including the updated 303(d) list, will be submitted to the State Water Resources Control Board (State Board) for approval along with the other Region's reports. The full State Integrated Report will then be submitted to the USEPA for approval and will then be final.

2 Introduction

The purpose of this report is to identify those surface waters in the Los Angeles Region which are impaired by pollutants or conditions which prevent them from meeting beneficial uses and to identify those waterbodies which data show are meeting beneficial uses.

An important requirement of the Clean Water Act is to identify those waters which are polluted, not meeting established standards and not supporting the uses expected of those waterbodies. With identification is the recognition of the need for action. Appropriate action after identifying a polluted waterbody is generally the development of a Total Maximum Daily Load (TMDL) but, in some cases, may also include permitting actions or prohibiting discharges to the waterbody, taking cleanup actions, or restoration projects.

2.1 Regulatory Process

The Clean Water Act (CWA) requires each State to assess the status of water quality in the State (Section 305(b)), and provide a list of impaired water bodies (Section 303(d)) to the U.S. Environmental Protection Agency (U.S. EPA) every two years. For water quality limited segments included on the 303(d) list, the state is required to develop a Total Maximum Daily Load (TMDL)or take other action to address the impairment.

The last review and update of the State's 303(d) list occurred in 2006. That review was conducted by the State Water Resources Control Board using the State Board's *Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List* (Listing Policy) (SWRCB 2004) developed in 2004. The 2006 update was the first review and update to use that policy.

For the 2008 update, each Regional Water Board is conducting their own reviews of new and previous water quality data and updating the assessment and list of impaired waterbodies according to the Listing Policy.

This staff report presents this Regional Board's assessment of the current status of water quality in the Los Angeles Region for water bodies with readily available data, and identifies the methods and data used to evaluate the water quality. This report proposes additions, deletions, and changes to the 2006 303(d) list. The water quality assessments also result in the identification of water bodies where water quality standards are met or where not enough information is available to accurately assess water quality.

Certain sections of the Integrated Report require public review and approval by the Regional Board and then approval by the State Board. These sections, or categories, are the lists of water quality limited segments whether being addressed by a TMDL or action other than a TMDL or not yet being addressed (Category lists 4 and 5, the 303(d) list). The other sections of the Integrated Report, which are waters supporting beneficial uses and waters with insufficient data (Categories lists 1, 2, and 3), are provided as information and do not require Board action.

After approval by the Los Angeles Water Board, the Integrated Report will be submitted to the State Water Resources Control Board for approval along with the other Region's reports. The results of the water quality assessments will be compiled with other Regional Board reports into a statewide integrated report referred to as the 303(d)/305(b) Integrated Report by the State Board. The statewide list of all the water quality limited segments will require final approval by the USEPA. The US EPA then compiles these assessments into their biennial "National Water Quality Inventory Report" to Congress.

3 Development of the Integrated Report

3.1 Data solicitation

Federal regulation [(40 CFR § 130.7(b)(5)] states that "Each State shall assemble and evaluate all existing and readily available water quality-related data and information" when developing the 303(d) list. On December 4, 2006, Water Board staff solicited the public to submit any and all water quality data to be considered in preparation of the 2008 303(d) list and 305(b) report. This solicitation established a data submittal deadline of February 28, 2007. On January 30, 2007, staff transmitted a notice clarifying that there were no limits on the type or format of data and information that the public could provide to the Water Boards for their assessment. The notices provided to the public can be found in Appendix A of this report.

The Regional Board received 17 submissions in response to the data solicitation. In addition, staff assembled all other available data. Larger databases considered included:

- National Pollutant Discharge Elimination System (NPDES) permitting data from major NPDES discharges. These data included data collected under the Municipal Separate Storm Sewer System (MS4) NPDES permits.

- Surface Water Ambient Monitoring Program (SWAMP) data. SWAMP is a statewide monitoring effort, administered by the State Water Board, designed to assess the conditions of surface waters throughout the state of California. Monitoring is conducted in SWAMP through the Department of Fish and Game and Regional Boards monitoring contracts.

- Southern California Bight Regional Monitoring (Bight) data. The Southern California Water Research Project (SCCWRP) coordinates the efforts of many participating organization to conduct the Coastal Ecology component of the Bight regional monitoring effort. These surveys seek to determine the spatial extent of contaminant accumulation in marine sediments and assess the effects of this contamination on living marine resources. Coastal Ecology regional monitoring is conducted every five years. More than 60 organizations have participated as partners in the Coastal Ecology portion of SCCWRP's Bight regional monitoring efforts.

3.2 Listing Policy and Evaluation Criteria

The proposed 2008 303(d) list of impaired water bodies in the Los Angeles Region was developed in accordance with the Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List (State Board Listing Policy) and the Functional Equivalent Document, both adopted by the State Water Resources Control Board in September 2004. The Listing Policy establishes a standardized approach for developing California's section 303(d) list. It outlines an approach that provides the rules for making listing decisions based upon different types of data and establishes a systematic framework for statistical analysis of water quality data.

The Listing Policy also establishes requirements for data quality, data quantity, and administration of the listing process. Decision rules for listing and delisting are provided for: chemical-specific water quality standards; bacterial water quality standards; health advisories; bioaccumulation of chemicals in aquatic life tissues; nuisances such as trash, odor, and foam; nutrients; water and sediment toxicity; adverse biological response; and degradation of aquatic life populations and communities. The listing policy specifies the frequency of exceedance of applicable water quality objectives that is necessary to make a determination that the water is impaired.

Listing and delisting decisions were made in accordance with the listing policy, using all applicable narrative and numeric water quality criteria contained in the Los Angeles Region Basin Plan and in the California and National Toxic Rules.

3.3 Standards Used in the Analysis

Beneficial Uses:
The beneficial uses for waters in the Los Angeles Region are identified in the Los Angeles Regional Water Quality Control Plan (Basin Plan). For consistency with other Regions in California and other States, six "core" beneficial uses were assessed. The designated beneficial uses in the Basin Plans fit within these six "core" beneficial uses categories, which are:

1. Aquatic Life Support
2. Drinking Water Supply
3. Fish Consumption
4. Secondary Contact
5. Shell fishing, and
6. Swimming.

Water Quality Objectives, Criteria and Guidelines:
The water quality objectives and criteria used in the assessments were from existing and available State Policy and Plans and included the following:

- Water Quality Control Plan, Los Angeles Region (Basin Plan)
- Statewide Water Quality Control Plans (e.g., the California Ocean Plan)
- California Toxics Rule (40 CFR 131.38)
- Maximum Contaminant Levels in California Code of Regulations, Title 22.

Narrative water quality objectives were evaluated using evaluation guidelines as allowed by the Listing Policy. When evaluating narrative water quality objectives, staff identified evaluation guidelines that represented standards attainment or beneficial use protection. Depending on the beneficial use and narrative standard, the following were used in the selection of evaluation guidelines:

1. Sediment Quality Guidelines for Marine, Estuarine, and Freshwater Sediments: When applying narrative water or sediment quality criteria, staff used guidelines developed by the U.S. EPA and other government agencies together with findings published in the scientific peer-reviewed literature to interpret data and evaluate the water quality conditions. Sediment quality guidelines published in the peer-reviewed literature or developed by state or federal agencies were used. Acceptable guidelines included selected values (e.g., effects range-median, probable effects level, probable effects concentration), and other sediment quality guidelines. Only those sediment guidelines that were predictive of sediment toxicity were used (i.e., those guidelines that have been shown in published studies to be predictive of sediment toxicity in 50 percent or more of the samples analyzed).

2. Evaluation Guidelines for Protection from the Consumption of Fish and Shellfish: Evaluation guidelines published by USEPA or OEHHA were used.

3. Evaluation Guidelines for Protection of Aquatic Life from Bioaccumulation of Toxic Substances: Evaluation values for the protection of aquatic life published by the National Academy of Science were used.

The State Listing Policy and the use of the same water quality objectives criteria and guidelines ensure that all Regions develop listing or delisting decisions in a consistent manner. Below are three pollutant categories which require some Los Angeles Region-specific elaboration

3.3.1 Indicator bacteria

For indicator bacteria listing decisions, the Los Angeles Region followed the State Listing Policy but used a Los Angeles Region-specific exceedance day approach as outlined below.

Previous iterations of the Los Angeles Region's 303(d) list included impairments for "total coliform," "enterococcus," "viruses (enteric)," "coliform," "beach closures," "swimming restrictions," "high coliform count," "bacteria indicators," and "fecal coliform." In this update, Regional Board staff have begun to categorize these impairments all as "indicator bacteria."

"Indicator bacteria" impairments can include impairments due to any sewage or fecal matter bacterial indicator including total coliform, fecal coliform, *E. coli*, and *enterococcus*.

In this update, Regional Board staff have calculated the frequency of exceedances of standards for indicator bacteria using a exceedance day approach.

Basin Plan

The Los Angeles Region Basin Plan lists bacteria water quality objectives to protect the water contact recreation and non-contact water recreation beneficial uses in marine and fresh water. The marine water objectives for bacteria are also mirrored in the State Water Resources Control Board's Water Quality Control Plan for Ocean Waters of California (Ocean Plan).

Regional Board Resolution **2002-022,** effective on July 15, 2003, to the Basin Plan included Implementation Provisions for Water Contact Recreation Bacteria Objectives which allow a reference system approach. In part, below

> *...In the context of a TMDL, the Regional Board may implement the single sample objectives in fresh and marine waters by using a 'reference system/antidegradation approach' or 'natural sources exclusion approach' as discussed below. ...*
>
> *Under the reference system/antidegradation implementation procedure, a certain frequency of exceedance of the single sample objectives above shall be permitted on the basis of the observed exceedance frequency in the selected reference system or the targeted water body, whichever is less. The reference system/anti-degradation approach ensures that bacteriological water quality is at least as good as that of a reference system and that no degradation of existing bacteriological water quality is permitted where existing bacteriological water quality is better than that of the selected reference system.*

Bacterial TMDLs and exceedance days in the Los Angeles Region

All bacterial TMDLs developed in the Los Angeles Region have used the reference system approach and have calculated the number of exceedance days at the reference system to define the reference condition. These TMDLs include the Santa Monica Bay Beaches Dry Weather Bacteria TMDL (effective 2003), the Santa Monica Bay Beaches Wet Weather

Bacteria TMDL (effective 2003), Marina Del Rey Back Basins Bacteria TMDL (effective 2004), Los Angeles Harbor Inner Cabrillo Beach and Main Ship Channel Bacteria TMDL (effective 2005), the Malibu Creek and Lagoon Bacteria TMDL (effective 2006), the Ballona Creek Bacteria TMDL (effective 2007), and the Harbor Beaches of Ventura County (Channel Islands Harbor Beaches) Bacteria TMDL (effective 2008).

With an exceedance day method, all appropriate bacterial indicators (i.e. marine or fresh water indicators) are evaluated in one analysis to determine if the waterbody is impaired as opposed to evaluating each bacterial indicator separately and then considering those two or three evaluations to determine if the waterbody is impaired.

To calculate the number of exceedance days, the number of days during a defined period during which one or more indicator bacteria exceeds the standard is an exceedance day. For example, at a freshwater, REC-1 site, a day in which *E. coli* exceeds the standard is one exceedance day, a day in which Fecal Coliform exceeds the standard is one exceedance day and a day in which *both E. coli* and Fecal Coliform exceeds the standard is also one exceedance day.

Calculating exceedance days for all applicable indicators may be in some instances a more conservative approach (i.e. more likely to find a waterbody to be impaired) than a straight indicator by indicator approach and therefore is more protective of human health.

The Listing Policy has specific listing factors for bacterial data from coastal beaches. Section 3.3 and of the Listing Policy discuss methodology for listing water bodies. For *listing* coastal beaches, "if water quality monitoring was conducted April 1 through October 31 only, a four percent exceedance percentage shall be used" (SWRCB, 2004). The 4% exceedance percentage applies to the null hypothesis for the binomial distribution formula at the bottom of Table 3.2. Section 4.3 of the Listing Policy discuss methodology for *delisting* water bodies and does not specifically describe the use of more stringent exceedance percentage for coastal beach water quality monitoring conducted April 1 through October 31 only, though one is inferred. A 19% exceedance percentage was used for water quality monitoring conducted April 1 through October 31 only when assessing delisting status. The 19% exceedance percentage applies to the null hypothesis for the binomial distribution formula at the bottom of Table 4.2. Therefore, for coastal beach datasets in which both year-round monitoring was conducted following by subsequent monitoring from April 1 to October 31 (e.g., year-round from 2000 to 2002 and April 1 to October 31 from 2003 to 2005), the datasets were evaluated in two parts due to differing exceedance percentages for assessing listing and delisting status.

Regional Board staff followed the Listing Policy methodology and exceedance percentages and calculated exceedance days by both single sample exceedances and geometric mean exceedances.

a. Single Sample

The Basin Plan lists four single sample limits for marine waters and two for fresh water. If samples tested for indicator bacteria exceed any of the indicator bacteria limits, a "single sample exceedance day" for indicator bacteria was designated.

b. Geometric Means

The Basin Plan lists three geometric mean bacteria limits for marine waters and two for fresh water. Receiving water data was evaluated based on these numeric limits and the exceedance day approach in a similar manner to single samples. As such, a calendar month approach as opposed to a rolling 30 day sample approach was used to assess geometric mean to maintain sample independence. Two or more samples were used per calendar month for calculating geometric means.

3.3.2 Invasive species

In this update, Regional Board staff propose new listings for invasive species.

Several other Region's 303 (d) lists include listings for "exotic species," which were made in recent listing updates. In the Los Angeles Region there is one listing for "exotic vegetation," a listing made prior to 1998.

Table 3-1 Listings for exotic species in the State 2006 303(d)

	Region	Number of listings	listing	notes
1	North Coast	1	exotic species	european green crab
2	San Francisco Bay	12	exotic species	ballast water
5	Central Valley	10	exotic species	source unknown
4	Los Angeles	1	exotic vegetation	Ballona Creek

For this listing update, Regional Board staff are proposing listings for "invasive species" as opposed to exotic species" Staff prefer not listing for "exotics" or "non-native" because not all exotic or non-native species are invasive or cause loss of beneficial uses and may even support beneficial uses. For example, the Department of Fish and Game has regulations to protect certain non-native species (e.g. striped bass) and mosquito fish are "non-native" but are used as a biological control by most mosquito abatement districts. In fact, in this listing update, The State Board is re-naming the "exotic species" listings as "invasive species" listings to reflect this.

Invasive species is defined as: an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health. This definition is taken from United States Executive Order 13112 of February 3, 1999 on Invasive Species (USA, 1999).

However, there are still several issues inherent in listing for such a non-traditional pollutant.

> 1) While certain "biological materials" have been considered pollutants, populations of animals have not been traditionally considered "pollutants." Section 502(6) of the Clean Water Act defines "pollutants" to include "biological materials…*discharged into water*". The courts have interpreted the term "biological materials" to include "invasive" species that might be found in ballast water which is discharged. It is not clear that these Clean Water Act definitions and court interpretations would apply equally to invasive or non-native species that are already established (i.e. non-native species whose populations are not sustained or increased by ongoing discharges) as they would to invasive species that are continuing to be discharged.
>
> 2) Standards have not been written explicitly for invasives.
>
> 3) A 303(d) listing would trigger an obligation by the Regional Board to develop a program to address the "invasive" species impairment. It would be a significant challenge to develop the regulatory program to regulate a population of an established invasive species.

In this 2008 update, Regional Board staff have recommended the new listing of Malibu Creek, Medea Creek, Lindero Creek and Las Virgenes Creek in the Malibu Creek watershed and Solstice Canyon Creek in the Santa Monica Bay watershed as impaired for invasive species, specifically the New Zealand mudsnail. Factsheets for these decisions are included in Appendix G.

Cold Creek, and Triunfo Creek also have mudsnails but are not recommended for listing at this time. Factsheets for these decisions are included in Appendix G.

New Zealand mudsnails, *Potamopyrgus antipodarum,* are tiny (3-5 mm), highly invasive aquatic snails. From the Santa Monica Bay Restoration Commission/Santa Monica Baykeeper (2009):

> *In large numbers, these small snails can completely cover a stream bed and wreak havoc on local stream ecosystems. Several studies have documented NZMS [New Zealand Mud Snail] densities in streams at more than 500,000 organisms per square meter. These massive colonies simply outcompete native aquatic invertebrates that the watershed's fish and amphibians rely on for food, disrupting the entire food web. NZMS are easily transported from stream-to-stream by hitchhiking, they attach themselves to shoes (especially waders), equipment (fishing gear, bicycle tires), animals (native and non-native), and even boats. Anything that contacts a stream infested by NZMS will likely become contaminated. New Zealand mudsnails were discovered in Idaho in the mid-1980s, and have since spread to every western state except New Mexico. NZMS were first identified in benthic macroinvertebrate (BMI) samples*

> *collected in the Malibu Creek watershed in May 2005. Unfortunately, the Malibu Creek watershed samples containing NZMS were not identified until May 2006. NZMS pose a significant danger to streams throughout the Santa Monica Mountains and threaten the many efforts at habitat restoration and protection, particularly those to restore populations of the endangered steelhead trout in this region.*

The data available for mudsnails was evaluated by the State Listing Policy, Section 3.10, Trends in Water Quality, using the narrative toxicity standard in the Basin Plan as the criteria. This approach is similar to the approach taken by State Board for listing "exotic species" during the 2006 listing update and is in accordance with the Listing Policy.

For mudsnails in the Los Angeles Region specifically, a waterbody is proposed to be included on the 303(d) list as impaired for invasive species if a negative trend in water quality has been demonstrated and the Aquatic Life Support core beneficial use was not supported. Staff considered a reach to be demonstrating a negative trend in water quality if at least one site in the waterbody exhibited an increase in density of mudsnails (with at least a three years sampled). Staff considered the core beneficial use of Aquatic Life Support not to be supported if at least one site exhibited a medium or high density of mudsnails.

3.3.3 **Biostimulatory Substances- possible future impairment determinations**

In this Integrated Report and 303(d) list update, Regional Board staff have continued to determine impairments and list and de-list decisions for nitrogen compounds as in the past based on Basin Plan nitrogen compound objectives. The Basin Plan contains a specific nitrogen (nitrate nitrite) water quality objective, which is established at 10 mg/L nitrogen as nitrate-nitrogen plus nitrite-nitrogen. This objective is specifically set to protect drinking water beneficial uses and is consistent with the California Department Public Health nitrate drinking water standard.

This nitrogen water quality objective does not protect waterbodies from impairments related to biostimulatory substances and eutrophication. However, Basin Plan also contains a narrative standard for biostimulatory substances and the Regional Board recognizes the need for a clear approach for determinations of impairment under the biostimulatory substances standard in the Basin Plan.

Previous iterations of the Los Angeles Region's 303(d) list have recognized the need to determine impairment based on biostimulatory substances and eutrophication and have included impairments for 'low DO/org. enrichment,' 'algae,' 'nutrient/(algae),' 'odors, scum,' 'Eutroph,' and 'unnatural scum/foam.' In future updates, Regional Board staff is considering categorizing these impairments all as 'biostimulatory substances' using a Los Angeles Region specific, nutrient concentration/biological response method as described below. In this 2008 list update, however, no "biostimulatory substances" impairments have been included.

The biostimulatory substances water quality objective in the Basin Plan addresses water quality impairments related to nutrient enrichment (eutrophication). The Basin Plan identifies biostimulatory substances as ‘nitrogen, phosphorus and other compounds that stimulate growth’. The water quality objective states:

> *Waters shall not contain biostimulatory substances in concentrations that promote aquatic growth to the extent that such growth causes nuisance or adversely affects beneficial uses.*

Eutrophication and nutrient enrichment problems rank as the most widespread water quality problems nationwide; for example, more lake acres are affected by nutrients than any other pollutant or stressor (EPA 2000). Eutrophication is defined by increased nutrient loading to a waterbody and the resulting increased growth of phytoplankton and other aquatic plants. Additionally, other parameters such as decreased dissolved oxygen and water clarity can also indicate eutrophic conditions. Phosphorus and nitrogen are recognized as key nutrients for the growth of phytoplankton, algae, and aquatic plants and are responsible for the eutrophication of surface waters.

A waterbody’s biological response to nutrient loading is often what actually impairs beneficial uses. For example, increased nitrogen and phosphorus loading can lead to harmful algal blooms, which impair the beneficial uses of the waterbody. Therefore, it is useful to evaluate potential biostimulatory substance impairments in terms of both nutrient concentrations and biological response indicators. Key biological response indicators include the following:

Low Dissolved Oxygen (DO)
Dramatic Diurnal Variations in DO
Increased pH
Decreased Water Clarity
Increased Chlorophyll a Concentration
Increase Macro and/or Benthic Algal Biomass
Unpleasant Odors, Taste and/or Aesthetics

By evaluating both nutrient concentrations and biological response indicators together, a more direct linkage is made between water quality conditions and beneficial use impairments. This approach provides a more robust water quality assessment.

The Los Angeles Regional Water Board is considering including waterbodies on the State’s 303(d) list of impaired waterbodies for biostimulatory substances when both nutrient concentrations and one or more biological response indicators are at levels which characterize eutrophic conditions and/or beneficial uses of the waterbody are impaired.

However, there are many nutrient and biological response indicator criteria that may be reviewed and applied for the purposes of placing a waterbody on the State’s 303(d) list. Table 3.1 and 3.2 below present various nutrient concentrations and associated biological response indicator criteria limits. These criteria are being considered by the Regional Board to assess the biostimulatory substances water quality objective. The sources of these criteria include EPA Nutrient Criteria Technical Guidance Manual, EPA Ambient Water Quality Criteria Recommendations Nutrient Ecoregion III, and California Nutrient Numeric Endpoints. The Regional Board intends to solicit stakeholder comments regarding the criteria presented below for development of the guidelines to be used for listing in future updates of the 303(d) list.

Table 3-2 Rivers and Streams: Nutrient Concentration and Biological Response Indicators Criteria Limits

Potential Criteria to assess Biostimulatory Substances Water Quality Objective

Rivers and Streams

Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Benthic Algal Biomass (mg/m^2)	Percent Cover	pH	Dissolved Oxygen (mg/L)	Source
0.65	0.09	150	none	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	EPA National Nutrient Criteria Technical Guidance
0.37	0.022	43.9	none	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	EPA Nutrient Criteria Recommendations Ecoregion III
0.5	0.03	none	none	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	EPA Nutrient Criteria Recommendations Ecoregion III: Sub -Ecoregion 6 - Southern and Central CA
0.06	0.002	150	none	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	Nutrient Numeric Endpoints - Malibu Creek Case Study
0.23	0.02	WARM 150 COLD 100	none	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	Nutrient Numeric Endpoints - SWRCB Nutrient Screening tools for 303(d) Listing
< 0.295 as SIN*	< 0.026 as SRP**	120	Floating 30% Benthic 60%	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	New Zealand Periphyton Guideline. Barry Biggs, June 2000

*Soluble Inorganic Nitrogen (SIN). **Soluble Reactive Phosphorus (SRP)

Basin Plan Water Quality Objectives are applied for pH and dissolved oxygen

Table 3-3 Lakes: Nutrient Concentration and Biological Response Indicators Criteria Limits

Potential Criteria to assess Biostimulatory Substances Water Quality Objective

Lakes

Total Nitrogen (mg/L)	**Total Phosphorus (mg/L)**	**Chlorophyll a (ug/L)**	**Secchi Depth (m)**	**pH**	**Dissolved Oxygen (mg/L)**	**Source**
1	0.1	14	none	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	EPA National Nutrient Criteria Technical Guidance
0.4	0.017	3.5	2.8	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	EPA Nutrient Criteria Recommendations Ecoregion III
0.51	0.172	24.6	1.9	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	EPA Nutrient Criteria Recommendations Ecoregion III: Sub - Ecoregion 6 - Southern and Central CA
0.84	0.05	20	none	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	Nutrient Numeric Endpoints - Malibu Creek Case Study
1.2 (summer mean)	0.1 (summer mean)	WARM 10 COLD 5	none	Shall not be < 6.5 or > 8.5 or change 0.5 units from ambient condition due to waste discharge	WARM ≥5 COLD ≥ 6 COLD & SPWN ≥ 7	Nutrient Numeric Endpoints - SWRCB Nutrient Screening tools for 303(d) Listing

Basin Plan Water Quality Objectives are applied for pH and dissolved oxygen

3.4 Data Analysis

Water Board staff evaluated the submitted data and additional data in accordance with the Listing Policy, taking into account data quality and spatial and temporal representativeness.

LOEs. A determination that a waterbody is impaired by a particular pollutant was dependent on one or more Lines of Evidence (LOE). A Line of Evidence is the specific information for a single pollutant from a single data source in a waterbody. The LOE includes the beneficial use(s) impacted; the pollutant name(s) pertaining to that water segment and data; the water quality objective (WQO), criterion (WQC) or guideline used to assess the data; detailed information specific to that data; how the data was assessed including the type of data, the total number of samples assessed and those samples that exceeded the WQO, WQC or guideline; where and when the data was collected.

Factsheets. The factsheet includes all LOEs developed for a certain pollutant waterbody combination and the resulting listing or delisting decision.

All available data was reviewed by staff. Analyses were documented in Lines of Evidence, factsheets and listing or delisting decisions according to established priorities. All high priority factsheets were completed.

Los Angeles Region Factsheet Development Priorities

1. High Priority

a. factsheets (decision: *list*) for waterbody/pollutant combinations not on the 2006 303(d) list where an examination of the data indicate standards were not met. This factsheet may refer to more than one core beneficial use.

b. factsheets (decision: *de-list*) for waterbody/pollutant combinations on the 2006 303(d) list where an examination of the data indicate standards were met.

c. factsheets (decision: *a core use is being supported*) for waterbody/core use combination where an examination of the data indicate that all standards (for which there are data) are being met for that core use (305(b)). This factsheet may refer to more than one pollutant.

d. factsheets for waterbody/pollutant combinations on the 303(d) list where a TMDL has been completed and approved by EPA (new approved TMDLs since 2006 303(d) list).

2. Medium Priority

a. factsheets (decision *a core use is being supported)* for waterbody/core use combination where a preliminary examination of the data indicate that standards are being met for that core use (305(b)). This factsheet may refer to more than one pollutant. However, there may be a waterbody/pollutant combinations on the list impairing other core uses.

b. factsheets (decision: *clarification*) for waterbody/pollutant combinations where the name of the pollutant has changed (e.g. PAHs to become individual PAHs (e.g. aldrin, fluoranthene)) or it is advisable to make a change in the extent of the waterbody (e.g. one waterbody is broken into two or a the dividing line between two reaches is modified).

c. factsheets (decision: *do not list or do not de-list)* for waterbody/pollutant combinations where there is significant new data (new line of evidence) but a preliminary examination of the data indicate that the list status (listed or not listed) would not change.

3. Low Priority

a. factsheets for waterbody/pollutant combinations where a preliminary examination of the data indicate standards were met (the creation of a "do not list" factsheet where the waterbody is listed for some other waterbody/pollutant combination or a 305(b) supporting factsheet has been completed).

b. factsheets for waterbody/pollutant combinations where the waterbody/pollutant combination is on the 303(d) list for that waterbody/pollutant combination and a preliminary examination of the data indicate standards were not met (the creation of a "do not de-list" factsheet).

c. factsheets for waterbody/pollutant combinations where available data is of insufficient quantity or quality to make assessments.

3.5 Integrated Report Categories

In this report, each assessed waterbody segment was assigned to one of five non-overlapping categories.

First, for each core beneficial use associated with each waterbody segment, a rating of fully supporting, not supporting, or insufficient information was assigned based on the readily available data and the analyses and criteria described, above. Then each assessed water segment was placed into one of five non-overlapping categories of water bodies. These Integrated Report categories are based on the USEPA guidance for states' Integrated Reports, but contain some modifications based on the State Listing Policy. The distribution of waterbodies into these categories may not be representative of the true state of waterbodies in the Los Angles Region due to the availability of water quality data and Regional Board decision development priorities.

Category 1: A water segment that 1) supports a minimum of one Beneficial Use for each Core Beneficial Use that is applicable to the water; and 2) has no other uses impaired. (No appendix to this report has been included for this category since, at this time, the Los Angeles Region has no waterbodies for which data supports that all beneficial uses are being supported.)

Category 2 (Appendix B): A water segment that 1) supports some, but not all, of its beneficial uses; 2) can have other uses that are not assessed or lack sufficient information to be assessed; 3) cannot have uses are which not supported; and 4) in agreement with the USEPA, may be included in this category with a minimum of one pollutant assessed for one use.

Category 3: (Appendix C): A water segment with water quality information that could not be used for an assessment, for reasons such as: monitoring data have poor quality assurance, not enough samples in a dataset, no existing numerical objective or evaluation guideline, the information alone cannot support an assessment, etc. Waters completely lacking water quality information are considered “not assessed”.

Category 4A (Appendix D): A water segment where ALL its 303(d) listings are being addressed; and 2) at least one of those listings is being addressed by a USEPA approved TMDL.

Category 4B: A water segment where ALL its 303(d) listings are being addressed by action(s) other than TMDL(s). (No appendix to this report has been included for this category since, at this time, the Los Angeles Region does not have waterbodies in this category.)

Category 4C: A water segment that is impacted by non-pollutant related cause(s). (No appendix to this report has been included for this category since, at this time, the Los Angeles Region does not have waterbodies in this category.)

Category 5 (Appendix E): A water segment where standards are not met and a TMDL is required, but not yet completed, for at least one of the pollutants being listed for this segment.

3.6 Information Management

All LOEs, factsheets and listing or delisting decisions were entered into the statewide *California Water Quality Assessment (CalWQA) Database.* The CalWQA database stores all LOEs, listing decisions, and beneficial use support ratings for assessed water bodies in California. This database was developed in 2007 for the purpose of storing detailed water quality assessment information. The database is designed so that this information can be easily reevaluated in future assessment updates and can be exported to the USEPA’s Assessment Database at the end of each assessment update.

4 Summary of Assessment Results

A full summary of the Los Angeles Region Integrated Report is included as Table 4-1.

Table 4-1 Integrated Report Summary

Integrated Report Category Number	Integrated Report Category definition	Number of waterbodies
1	Waters Supporting All Beneficial Uses	0
2 (Appendix **B**)	Waters Supporting Some Beneficial Uses	26
3 (Appendix C)	Waters With Insufficient Information	23
4 (Appendix D)	Water Quality Limited Segments Addressed	31
5 (Appendix E)	Water Quality Limited Segments not Fully Addressed	158
Total		*238 assessed waterbodies*
(4 and 5) *(Appendix F)* *303(d) list*	*List of All Waterbody Impairments (the updated 303 (d) list)*	*189 waterbodies on the 303(d) list*

Of the waterbodies included in the Integrated Report, a total of 68 new listings are proposed and 30 de-listings are proposed. In addition, in this update, 113 previous listings are now included in the list as 'being addressed by a TMDL' because a USEPA approved TMDL has been completed. A summary of new additions to the Integrated Report is found in Table 4-2. In this Table, decisions to List are shown in three categories. "List" is the decision to include a waterbody/pollutant combination on the 303(d) list for the first time; "List (being addressed by TMDL)" is the decision to move a waterbody/pollutant combination from the 'requires a TMDL" portion of the list to the "being addressed by a TMDL" portion of the list because a USEPA approved TMDL has been completed since the last update to the 303(d) list in 2006; "List (being addressed by action other than TMDL)" is the decision to move a waterbody/pollutant combination from the 'requires a TMDL" portion of the list to the "being addressed by action other than TMDL" portion of the list because another regulatory action(such as a permitted restoration action) is sufficient to address the impairment. Factsheets for all these decisions are found in Appendix G.

Table 4-2 Integrated Report Summary for NEW decisions in 2008 including *delist*, *do not delist, do not list and list*

New Decision in 2008	Number of waterbodies	Number of waterbody/pollutant combinations
Delist	19	30
Do Not Delist	23	29
Do Not List	50	86
List	41	68
List (being addressed by TMDL)	55	113
List (being addressed by action other than TMDL)	2	3
Total		329

The total number of waterbody/pollutant combinations in the proposed 2008 303(d) list is 829. 448 of these waterbody/pollutant combinations, or 54%, require the completion of a TMDL or other regulatory action to address the impairment. 381 of these waterbody/pollutant combinations, or 46%, are currently being addressed by an EPA approved TMDL or other regulatory action.

This was the first time that the Water Boards have prepared an Integrated 303(d)/305(b) Report under the current Listing Policy and USEPA Integrated Report Guidance and the first time that the Regional Boards have used the CalWQA database. Combining the 303(d) list update with the 305(b) report and using the same database as all other Regions added efficiency and ensured consistency, but provided challenges in terms of workload and project management. While individual assessments for potential 303(d) listings or de-listings provided valuable information for the 305(b) report, creating the overall 305(b) report using 303(d) listing decisions as the primary input also had limitations. Preparing assessment fact sheets at the level of detail required for 303(d) list changes under the Listing Policy limited the amount of data which could be developed in the manner necessary for inclusion in the CalWQA database. In addition, the readily available data are also often biased towards areas with more potential discharges, since these areas are where the bulk of the monitoring activity takes place. For these reasons, the number of waterbody segments in each Integrated Report category is not necessarily a representative sampling of all the waterbodies within the Los Angeles Region. Despite these limitations, this Integrated Report provides the most complete 305(b) report for the Los Angeles Region to date.

5 TMDL Scheduling

As part of its 1996 and 1998 regional water quality assessments, the Regional Board identified over 700 waterbody-pollutant combinations in the Los Angeles Region where TMDLs would be required (LARWQCB, 1996, 1998). A 13-year schedule for development of TMDLs in the Los Angeles Region was established in a consent decree (Heal the Bay Inc., et al. v. Browner, et al. C 98-4825 SBA) (United States District Court, Northern District of California, 1999) approved on March 22, 1999 (USEPA/Heal the Bay Consent Decree).

For the purpose of scheduling TMDL development, the decree combined the over 700 waterbody-pollutant combinations into 92 TMDL analytical units. Proposed de-listings in this report would discharge or partially discharge 12 TMDL analytical units as specified in the USEPA/Heal the Bay Consent Decree between the U.S. EPA and Heal the Bay, Inc. et al. filed on March 22, 1999.

Staff identified the new listings as a low priority, to be started after the USEPA/Heal the Bay Consent Decree commitments are met. A possible exception to this would be if a new listing could be folded into an existing analytical unit without the need for additional resources to develop the resulting TMDL. The assignment of a low priority to these new TMDL analytical units is not a reflection on their importance, but is given because the Regional Board has first prioritized existing USEPA/Heal the Bay Consent Decree commitments before beginning new TMDLs. The maximum time that can elapse between 303(d) listing and TMDL completion is 13 years. Accordingly, staff have assigned all new listings a TMDL completion date of 2021. This does not suggest that all new listings have the same priority, but rather that the factors determining TMDL priorities have not yet been evaluated as part of this listing process.

NOAA Technical Memorandum NMFS-NWFSC-83

An Overview of Sensory Effects on Juvenile Salmonids Exposed to Dissolved Copper:

Applying a Benchmark Concentration Approach to Evaluate Sublethal Neurobehavioral Toxicity

October 2007

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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This document should be referenced as follows:

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NOAA Technical Memorandum NMFS-NWFSC-83

An Overview of Sensory Effects on Juvenile Salmonids Exposed to Dissolved Copper:

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Table of Contents

List of Figures

List of Tables

Executive Summary

Dissolved copper (dCu) is a ubiquitous surface water pollutant that causes a range of adverse effects in fish as well as in aquatic invertebrates and algae. This technical memorandum is a summary and targeted synthesis regarding sensory effects to juvenile salmonids from low-level exposures to dCu. As such, the material presented here serves to summarize scientific research on dCu and its impacts on salmonid sensory systems. In addition, this document provides a benchmark analysis of empirical data generated in recent National Marine Fisheries Service investigations that have focused on salmon olfactory function. The review section, Appendix A, discusses peer reviewed and gray literature on the effects of dCu on salmonid sensory systems, associated sensory-mediated behaviors, and physiology. It is intended to facilitate understanding of the effects of dCu on sensory system–mediated behaviors that are important to survival, reproduction, and distribution of salmonids. The review does not address the effects of dCu on salmonid habitats, although copper is also highly toxic at low µg/L concentrations to aquatic primary producers and invertebrates (i.e., the aquatic food web). Undoubtedly, new information will become available that enhances our current understanding of copper's effect on threatened and endangered salmonids and their supporting habitats.

A large body of scientific literature has shown that fish behaviors can be disrupted at concentrations of dCu that are at or slightly above ambient concentrations (i.e., background). In this document, background is operationally defined as surface waters with less than 3 µg/L dCu, as experimental water had background dCu concentrations as high as 3 µg/L dCu. Sensory system effects are generally among the more sensitive fish responses and underlie important behaviors involved in growth, reproduction, and (ultimately) survival (i.e., predator avoidance). Recent experiments on the sensory systems and corresponding behavior of juvenile salmonids contribute to more than four decades of research and show that dCu is a neurotoxicant that directly damages the sensory capabilities of salmonids at low concentrations. These effects can manifest over a period of minutes to hours and can persist for weeks.

To estimate toxicological effect thresholds for dCu in surface waters, benchmark concentrations (BMCs) were calculated using a U.S. Environmental Protection Agency methodology. This paper presents examples of BMCs for juvenile salmonid olfactory function based on recent data. BMCs ranged 0.18–2.1 µg/L, corresponding to reductions in predator avoidance behavior of approximately 8–57%. The BMC examples represent the dCu concentration (above background) expected to affect the ability of juvenile salmonids to avoid predators in freshwater. These concentration thresholds for juvenile salmonid sensory and behavioral responses fall within the range of other sublethal endpoints affected by dCu such as behavior, growth, and primary production, which is 0.75–2.5 µg/L.

The paper also discusses the influence of water chemistry on the bioavailability and toxicity of copper to fish sensory systems. Studies exploring behavioral avoidance as well as representative studies of other effects to salmonids are also summarized. Salmon may be able to avoid dCu in environmental situations where distinct gradients occur. However, avoidance of dCu originating from nonpoint sources appears unlikely. Given the large body of literature on copper and responses of aquatic ecosystems, we focused on a subset of fish sensory system studies relevant to anadromous salmonids.

Point and nonpoint source discharges from anthropogenic activities frequently exceed these thresholds by one, two, and sometimes three orders of magnitude, and can occur for hours to days. The U.S. Geological Survey ambient monitoring results for dCu representing 811 sites across the United States detected concentrations ranging 1–51 µg/L, with a median of 1.2 µg/L. Additionally, typical dCu concentrations originating from road runoff from a California study were 3.4–64.5 µg/L, with a mean of 15.8 µg/L. Taken together, the information reviewed and presented herein indicates that impairment of sensory functions important to survival of juvenile salmonids is likely to be widespread in many freshwater aquatic habitats. Impairment of these essential behaviors may manifest within minutes and continue for hours to days depending on concentration and exposure duration. Therefore, dCu has the potential to limit the productivity and intrinsic growth potential of wild salmon populations by reducing the survival and lifetime reproductive success of individual salmonids.

Acknowledgments

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Introduction

Copper, a naturally occurring element, is an essential micronutrient for plants and animals. However, copper is also recognized as a priority pollutant under the U.S. Clean Water Act. Historical and current anthropogenic activities have mobilized significant quantities of copper. Vehicle emissions and brake pad dust (Drapper et al. 2000), pesticides (USEPA 2005), industrial processes, municipal discharges, mining, and rooftops (Good 1993, Thomas and Greene 1993) are a few of the sources of copper in the environment. These various human activities may lead to the unintended and, in some circumstances, intended introduction of copper into aquatic ecosytems (Sansalone and Buchberger 1997, Wheeler et al. 2005). Once in the aquatic environment, copper is detected in multiple forms. It can be dissolved, or bound to organic and inorganic materials either in suspension or in sediment. This so called speciation of copper is dependent on site specific abiotic and biotic factors. As an element, copper will persist and cycle through ecosystems. Copper in its dissolved state is worthy of particular scrutiny as it is highly toxic to a broad range of aquatic species including algae, macrophytes, aquatic invertebrates, and fishes. The latter include anadromous salmon and steelhead within the *Oncorhynchus* and *Salmo* genera that are, in part, managed by the National Marine Fisheries Service.

Currently, anadromous salmonid populations inhabit waters of Alaska, Oregon, Washington, California, Idaho (*Oncorhynchus* spp.), and Maine (Atlantic salmon [*Salmo salar*]). Dissolved copper (referred to as dCu herein) is consistently detected in salmonid habitats including areas important for rearing, migrating, and spawning (Alpers et al. 2000, Soller et al. 2005). Dissolved copper is known to affect a variety of biological endpoints in fish (e.g., survival, growth, behavior, osmoregulation, sensory function, and others, as reviewed in Eisler 1998). More than three decades of experimental results have shown that the sensory systems of salmonids are particularly vulnerable to the neurotoxic effects of dCu. Recent experimental evidence showed that juvenile sensory system–mediated behaviors are also affected by short-term exposures to dCu.

Given the ecological significance of these behaviors to salmonids, it is important to characterize the potential effects from dCu. The growing body of scientific literature indicates that dCu is a potent neurotoxicant that directly damages the sensory capabilities of salmonids at low concentrations (see the Previous Studies on the Effects of Copper section). These concentrations may stem from anthropogenic inputs of dCu to salmonid habitats. Salmonid sensory systems mediate ecologically important behaviors involved in predator avoidance, migration, and reproduction. Impairment of these behaviors can limit an individual salmonid's potential to complete its life cycle and thus may have adverse consequences at the scale of wild populations.

The purpose of this paper is to: (1) summarize information on the effects of dCu to the sensory systems of juvenile salmonids in freshwater (also see Appendix A), (2) conduct a benchmark concentration analysis to generate examples of dCu effect thresholds, and (3) to discuss site-specific considerations for sensory system effects. As such, it focuses on a single contaminant (dCu), two relevant sensory system endpoints (olfaction and alarm response behavior), and a single salmonid life stage (juvenile, <10 months old).

Previous Studies on the Effects of Copper

Examples of copper's effects on a suite of selected biological endpoints from laboratory and field exposures are presented in Table 1. Additionally, Appendix A contains a targeted review and summary of some of the previous studies showing copper's effect on salmonid behavior, including avoidance and migratory disruptions. Appendix B is a supplementary bibliography that provides further information sources on salmonid sensory systems. The following analysis of sensory effects on juvenile salmonids primarily emphasizes recent and ongoing research conducted at the National Marine Fisheries Service's Northwest Fisheries Science Center. However, the phenomenon that copper and some other trace metals can interfere with chemoreception, alter behaviors, and influence the movements of fish was first described at least 40 years ago, and a large body of knowledge on the adverse effects of dCu has subsequently developed (Table 1).

The salmonid olfactory sensory system relies on olfactory receptor neurons (ciliated ORNs) to detect and respond to cues in the aquatic environment. The receptors are in direct contact with the aqueous environment. Olfactory receptors detect chemical cues that are important in finding food, avoiding predators, navigating migratory routes, recognizing kin, reproducing, and avoiding pollution. The architecture of the salmon olfactory system consists of a pair of olfactory rosettes, each positioned within an olfactory chamber near the midline of the fish's rostrum (Figure 1A). Each rosette contains ORNs that respond to dissolved odorants as water passes through the olfactory chamber (Figure 1B) and over the surface of the rosette in which the receptor neurons are embedded (Figure 1C). These chemical cues convey important information about the surrounding aquatic environment.

Direct exposure to dCu can impair and destroy olfactory sensory neurons, although the precise mechanism by which dCu interferes with the normal function of ORNs remains unknown (Hansen et al. 1999b, Baldwin et al. 2003, Sandahl et al. 2006, Sandahl et al. 2007). Impairment of olfaction (i.e., smell) can be measured by an electrophysiological technique called the electro-olfactogram (EOG) (Figure 1) (Scott and Scott-Johnson 2002, Baldwin and Scholz 2005, Sandahl et al. 2006). The EOG measures olfactory response of a population of receptor neurons in fish. Reductions in the EOG amplitude of copper-exposed fish compared to unexposed fish reflect functional losses in sensory capacity. Dissolved copper's toxic effect to olfactory sensory neurons is observable as a reduction in or elimination of the EOG amplitude to a recognizable odor (Figure 1D).

Several recent studies highlight some important aspects of copper olfactory toxicity (Baldwin et al. 2003, Sandahl et al. 2004, 2007). Baldwin et al. (2003) found that the neurotoxic effects of copper in coho salmon (*Oncorhynchus kisutch)* manifest over a timescale of minutes. At 10 minutes, EOG amplitude reductions were observed in juvenile coho exposed to 2, 5, 10, and 20 µg/L dCu above experimental background (3 µg/L). After 30 minutes at 2 µg/L dCu above experimental background, the EOG amplitude from juvenile coho to odors was reduced by approximately 25% compared to controls; in 20 µg/L dCu after 30 minutes by approximately

80%. Sandahl et al. (2004) found similar effects following 7 days of exposure (both in EOG reductions and copper concentrations). This result indicated that the juvenile olfactory system does not appear to be able to adapt or otherwise compensate for continuous copper exposure for durations up to 7 days.

Table 1. Selected examples of adverse effects with copper to salmonids or their prey.[a]

Species (lifestage)	**Effect**	**Effect concentration (µg/L)[b]**	**Effect statistic**	**Hardness (mg/L)[c]**	**Exposure duration**	**Source**
	Sensory and behavioral effects					
Coho salmon (juvenile)	Reduced olfaction and compromised alarm response	0.18–2.1	EC_{10} to EC_{50}	120	3 hours	Sandahl et al. 2007
Chinook salmon (*O. tshawytscha)* (juvenile)	Avoidance in laboratory exposures	0.75	LOEC	25	20 minutes	Hansen et al. 1999a
Rainbow trout (*O, mykiss)* (juvenile)	Avoidance in laboratory exposures	1.6	LOEC	25	20 minutes	Hansen et al. 1999a
Chinook salmon (juvenile)	Loss of avoidance ability	2	LOEC	25	21 days	Hansen et al. 1999a
Atlantic salmon (juvenile)	Avoidance in laboratory exposures	2.4	LOEC	20	20 minutes	Sprague et al. 1965
Atlantic salmon (adult)	Spawning migrations in the wild interrupted	20	LOEC	20	Indefinite	Sprague et al. 1965
Chinook salmon (adult)	Spawning migrations in the wild apparently interrupted	10–25	LOEC	40	Indefinite	Mebane 2000
Coho salmon	Delays and reduced downstream migration of dCu-exposed juveniles	5	LOEC	95	6 days	Lorz and McPherson 1976, 1977
Rainbow trout	Loss of homing ability	22	LOEC	63	40 weeks	Saucier et al. 1991
	Ecosystem effects					
NA[d]	Ecosystem function: Reduced photosynthesis	2.5	LOEC	49	≈ 1 year	Leland and Carter 1985
NA[d]	Ecosystem structure: loss of invertebrate taxa richness in a mountain stream	5	LOEC	49	≈ 1 year	Leland et al. 1989
	Other sublethal effects					
Chinook salmon	Reduced growth (as weight)	1.9	EC_{10}	25	120 days	Chapman 1982
Rainbow trout	Reduced growth (as weight)	2.8	EC_{10}	25	120 days	Marr et al. 1996

Table 1 continued. Selected examples of adverse effects with copper to salmonids or their prey.[a]

Species (lifestage)	Effect	Effect concentration (μg/L)[b]	Effect statistic	Hardness (mg/L)[c]	Exposure duration	Source
	Other sublethal effects (cont.)					
Coho salmon	Reduced growth (as weight)	21–22	NOEC	24–32	60 days	Mudge et al. 1993
Steelhead (*O. mykiss*)	Reduced growth (as weight)	45 to >51	NOEC	24–32	60 days	Mudge et al. 1993
	Direct lethality[e]					
Chinook salmon (fry)	Death	19	LC_{50}	24	96 hours	Chapman 1978
Coho salmon (fry)	Death	28–38	LC_{50}	20–25	96 hours	Lorz and McPherson 1976
Steelhead/rainbow trout (fry)	Death	9–17	LC_{50}	24–25	96 hours	Chapman 1978, Marr et al. 1999
Coho salmon (adult)	Death	46	LC_{50}	20	96 hours	Chapman and Stevens 1978
Steelhead (adult)	Death	57	LC_{50}	42	96 hours	Chapman and Stevens 1978
Coho salmon (juvenile)	Death	21–22	NOEC	24–32	60 days	Mudge et al. 1993
Steelhead (juvenile)	Death	24–28	NOEC	24–32	60 days	Mudge et al. 1993
Steelhead (egg-to-fry)	Death	11.9	EC_{10}	25	120 days	Chapman 1982

[a] Abbreviations: LOEC = Lowest observed adverse effect concentration (and most LOEC values given are not thresholds, but were simply the lowest concentration tested); NOEC = No observed adverse effect concentration; LC_{50} = the concentration that kills 50% of the test population; ECp = effective concentration adversely affecting (p) percent of the test population or percent of measured response, e.g., 10% for an EC10, etc.; and Indefinite = field exposures without defined starting and ending times. NA = not applicable.
[b] Effects and exposure durations stem from laboratory and field experiments, therefore in some experiments multiple routes of exposure may be present (i.e., aqueous and dietary) and water chemistry conditions will likely differ (see reference for details).
[c] Hardness is reported, as it can influence the toxicity of copper.
[d] This study examined ecosystems consisting of a number of species or unidentified species.
[e] Acute sensitivity of salmonids to copper probably varies by life stage, and the swim-up fry stage is probably more sensitive than older juvenile life stages such as parr and smolts or adults.

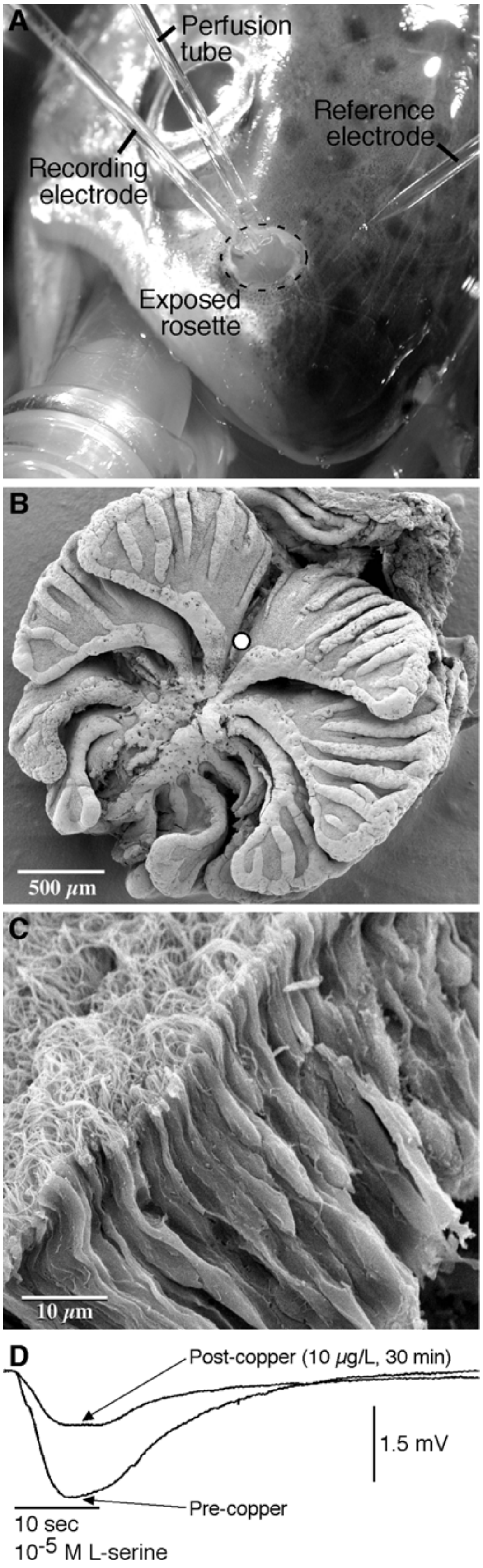

Figure 1. Recording methods and features of the salmon peripheral olfactory system. A) Photograph showing the rostrum of a coho salmon during the recording of electro-olfactograms (EOGs). The mouthpiece provides chilled, anaesthetized water to the gills, while the perfusion tube delivers odor-containing solutions to the olfactory chamber. The recording electrode in the olfactory chamber and reference electrode in the skin monitor the response of the olfactory system to an odor. B) Scanning electron micrograph showing a rosette, located within an olfactory chamber of a juvenile coho salmon. Each rosette consists of lamellae (lobes) covered by an epithelium containing regions of sensory neurons. The open circle denotes the location and approximate size of the tip of the recording microelectrode. C) Scanning electron micrograph showing a cross section from a region of sensory epithelium of a lamella. In the upper left is the apical surface containing the cilia and microvilli of the olfactory receptor neurons (ORNs). The dendrites and somata of the ORNs appear in the center within the epithelium, while the axons of the ORNs emerge from the basal surface at the lower right to produce the olfactory nerve. D) Typical odor-evoked EOGs obtained from a salmon before and after exposure to copper. A 10-second switch to a solution containing 10^{-5} M L-serine is shown with a horizontal bar. The EOG evoked by the odor pulse consists of a negative deflection in the voltage. A 30-minute exposure to copper reduced the amplitude of the EOG evoked in the same fish by 57%. (Photos courtesy of Carla Stehr. Figure adapted from Baldwin and Scholz 2005).

Recently, using EOG measurements in combination with a predator avoidance assay, Sandahl et al. (2007) presented the first evidence that impaired olfaction (smell) resulted in a direct suppression of predator avoidance behavior (alarm response) by juvenile coho salmon at environmentally relevant dCu exposures (≥2.0 µg/L; 3 hr exposure). Unexposed juveniles (control treatment) reduced their swimming speed on average by 74% (alarm response) in response to an alarm odor (conspecific skin extract). A reduction in swimming speed is a typical predator avoidance response for salmonids and many other fish. In unexposed fish, the alarm odor elicited a mean EOG response of 1.2 mV. Juvenile coho salmon exposed to 2-20 µg/L copper exhibited measurable reductions in both EOG (50–92%) and alarm response (47 to >100%) (derived from data in Figure 2 of Sandahl et al. 2007). Juvenile coho exhibited statistically significant decline in antipredator behavior at 5, 10, and 20 µg/L dCu (Figure 2).

Importantly, concentrations of dCu below 2 µg/L were not tested in Sandahl et al. (2007). This is notable because all concentrations tested (between 2 and 20 µg/L) significantly affected olfaction with reductions in EOG ranging ≈50–92%. Because individual juvenile coho were significantly affected at the lowest concentration tested (2 µg/L), uncertainty remains with respect to the precise threshold for olfactory impairment. The results of this last study provide evidence that juvenile salmon exposed to sublethal dCu concentrations at 2 µg/L (resulting in approximately 50% reductions in EOG), and likely even lower, might not recognize and respond to a predation threat, and therefore have an increased risk of being eaten by other fishes or birds (a form of ecological death, Kruzynski and Birtwell 1994).

Typically dCu concentrations in road runoff are well within the range affecting antipredator behavior, for example, 3.4–64.5 µg/L, with a mean of 15.8 µg/L (Soller et al. 2005). A 3 hour exposure is also likely to be environmentally relevant, as stormwater runoff durations from roads typically range from a few minutes to several hours (Sansalone and Buchberger 1997). Fish may regain their capacity to detect odors fairly quickly in some cases; physiological recovery of olfactory neuron function is dose-dependent and occurs within a few hours at low copper concentrations (i.e., <25 µg/L dCu, Baldwin et al. 2003). However, long-term damage to the sensory epithelia has also been documented. Where cell death occurs (i.e., ≥25 µg/l copper, Hansen et al. 1999a, 1999b) recovery is on the order of weeks (Moran et al. 1992) and in some cases months (Evans and Hara 1985).

Interestingly, another fish sensory system, the lateral line, is also a target for the neurotoxic effects of dCu. It is composed of mechanosensory neurons (hair cells) that respond to surface water vibrations, flow, and other types of mechanical cues in the aquatic environment. The lateral line system thereby mediates shoaling, pursuit of prey, predator avoidance, and rheotaxis (orientation to flow). In a recent study, dCu (i.e., ≥20 µg/L; 3 hour exposure) killed 20% of hair cells in zebrafish (*Danio rerio*) (Linbo et al. 2006). As mentioned earlier, juvenile salmon ORNs may also be killed at higher concentrations of dCu, highlighting the similar sensitivity of olfactory and lateral line receptors to this toxic metal. Consequently, dCu may damage or destroy either or both of these important sensory systems. Currently, we are not aware of any research on the effects of dCu to the lateral line of salmonids, although the comparable sensitivity of the olfactory system across species suggests that the salmon lateral line is likely to be vulnerable as well.

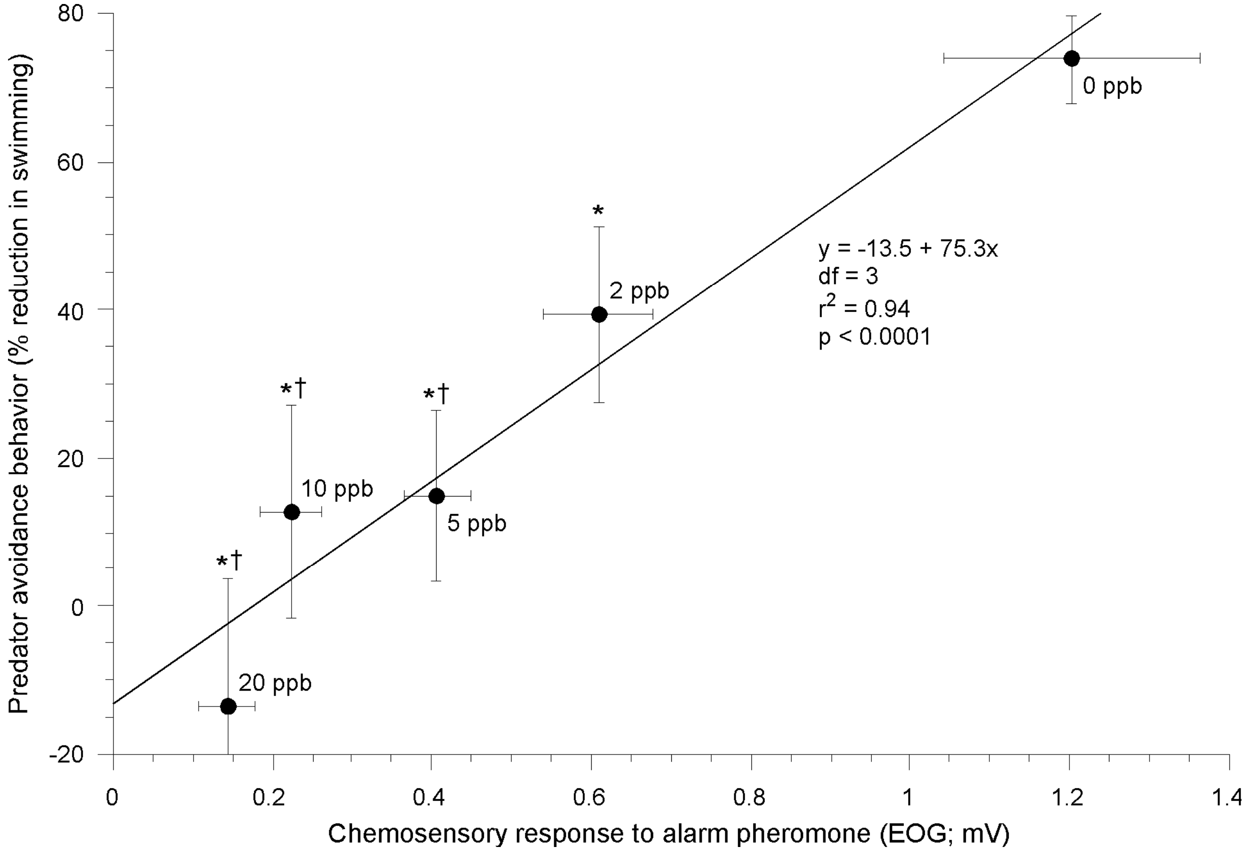

Figure 2. Copper-induced reductions in juvenile salmonid olfactory response and behavior are significantly correlated. Fish exposed to dCu (3 hours) showed reduced olfactory sensitivity and corresponding reduction in predator avoidance behavior. Values represent treatment means (with copper exposure concentration labeled to the right); error bars represent one standard error; n = 8–12 individual coho salmon; asterisk (*) represents a statistically significant difference in olfactory response (EOG data) compared to controls (one-way ANOVA with Dunnett post hoc test, $p < 0.05$); †represents statistically significant difference in behavioral response to skin extract (% reduction in swimming) compared to controls (one-way ANOVA with Dunnett post hoc test, $p < 0.05$). The line represents a statistically significant linear regression based on treatment means ($n = 5$; $p < 0.0001$; $r^2 = 0.94$). 1 ppb = 1 µg/l. (Adapted from Figure 2C in Sandahl et al. 2007.)

In this paper, a benchmark dose (concentration) analysis (USEPA 1995) is applied to recent data from dose-response experiments on juvenile salmonids exposed to dCu (Sandahl et al. 2007) to determine the exposure concentrations that may adversely affect salmonid sensory systems. In previous studies, benchmark concentrations (BMCs) were determined for olfactory responses, however, concomitant behavioral responses were not measured (Baldwin et al. 2003, Sandahl et al. 2004). The BMC analysis conducted herein determined concentrations of dCu that could be expected to affect juvenile salmonid olfaction and, by extension, alarm response behavior involved in predator avoidance.

Application of the Benchmark Concentration Analysis

The BMC, also referred to as a benchmark dose, is a method that has been used since 1995 by agencies such as the U.S. Environmental Protection Agency (EPA) to determine no observable adverse effect level (NOAEL) values. The method statistically fits dose-response data to determine NOAEL values (EPA 1995). This is in contrast to other methods (e.g., using an analysis of variance) that rely on finding a no observable effect concentration (NOEC) and lowest observable effect concentration (LOEC) to establish the NOAEL. Multiple difficulties arising from the traditional approach of selecting a NOAEL from dose-response data were previously identified by the EPA. Specific shortcomings associated with traditional methods included: 1) arbitrary selection of a NOAEL based on scientific judgments; 2) experiments involving fewer animals produced higher NOAELs; 3) dose-response slopes were largely ignored; and 4) the NOAEL was limited to the doses tested experimentally (EPA 1995). These as well as other concerns with selection of a NOAEL led to the development of an alternative approach, the BMC analysis. The BMC approach uses the complete dose-response data set to identify a NOAEL, thereby selecting an exposure concentration that may not have been tested experimentally.

The BMC is statistically defined as the lower confidence limit for a dose that produces a predetermined adverse effect relative to controls. This effect is referred to as the benchmark response (BMR) (EPA 1995). Unlike the traditional method of selecting the NOAEL (e.g., establishing a NOEC), the BMC takes into account the full range of dose-response data by fitting it with an appropriate regression equation. These can be linear, logarithmic, sigmoidal, etc. The BMR is generally set near the lower limit of responses (e.g., an effect concentration of 10%) that can be measured directly in exposed or affected animals.

In the present context, a BMC approach was used to estimate thresholds for dCu’s sublethal effects on the chemosensory physiology and predator avoidance behaviors of juvenile coho salmon (Sandahl et al. 2007). An example of this approach is shown in Figure 3. This methodology has been used previously to determine toxicity thresholds in Pacific salmon (Sandahl and Jenkins 2002, Baldwin et al. 2003, Sandahl et al. 2004). The dose-response relationship for copper’s effect on the EOG was described by fitting the data with a sigmoid logistic model:

$$y = m/[1+(x/k)^n]$$

where m is maximum EOG amplitude (fixed at the control mean of 1.2 mV), y is EOG amplitude, x is copper concentration, k is copper concentration at half-maximum EOG amplitude (EC_{50}), and n is slope.

For this nonlinear regression, the average olfactory response of the control fish to a natural odor was used to constrain the maximum odor evoked EOG (m in the above equation). Consequently, the control fish were not used in the regression other than to set m. The regression incorporated the individual response of each exposed fish (n = 44 total) rather than the average values for each exposure group. As shown in Figure 3, the sigmoid logistic model was a very good fit for both the sensory and behavioral data ($r^2 = 0.94$, $p < 0.0001$). Benchmark concentrations were then determined based on the concentration at which the estimated curve intersected benchmark responses.

Results of the Benchmark Concentration Analysis

Examples of benchmark concentrations and responses are presented in Figure 3 and Table 2. The EPA methodology recommends using the concentration that represents a 10% reduction in response compared to controls when limited biological effects data are available (EPA 1995). This is the BMC_{10} and is synonymous with the concentration producing an effect of 10% (EC_{10}), in this case a 10% reduction in the recorded amplitude of the salmon's chemosensory response (EOG). Since the predicted fish EOG response at the BMC_{10} falls well within the olfactory response of unexposed juveniles, that is, 95% CI (control fish, Figure 3), it is more than likely that this individual response (1.08 mV) at the BMC_{10} (0.18 µg/L) would not be detectable or biologically significant as an adverse response.

Other BMCs were derived using statistical criteria to determine benchmark responses. For example, Table 2 shows two BMCs that were determined using the statistical departure of the lower-bound confidence interval (CI) of the control mean (unexposed fish), 1.2 mV (either the 90 or 95% CI). The selection of different CIs results in different BMCs. The CI-derived BMCs represent a reasonable estimate of when an individual salmonid is likely to have a biologically significant reduction in olfaction and a concomitant reduction in predator avoidance behavior. The relative departures from controls in Table 2 are equivalent to effective concentrations for olfactory inhibition, that is, at the lower-bound 90% CI a BMC of 0.59 µg/L equates to a $BMC_{24.2}$. Put another way, the BMC analysis predicts a substantial 24.2 % reduction in olfaction (i.e., EOG amplitude) at 0.59 µg/L dCu. At the lower-bound 95% CI a 29.2% reduction in olfaction is predicted to occur at 0.79 µg/L.

The BMC_{50} is equivalent to the EC_{50} for olfactory responses (2.1 µg/L) and is very similar to the lowest observable effect concentration (LOEC) of 2 µg/L. Since the EC_{50} approximately equals the LOEC, it is almost certain that effects to juvenile salmonid olfaction will occur at lower concentrations than those measured. Therefore it is appropriate and useful to apply a BMC analysis to these data to predict effects occurring between 0 and 2 µg/L dCu. The predicted effect thresholds for sensory responses in juvenile coho salmon ranged 0.18–2.1 µg/L, which corresponded to reductions in predator avoidance behavior (i.e., reduced alarm response) of 8–57%. Comparatively, the other two studies that conducted a BMC approach with salmon olfaction data sets (e.g., EOG measures) estimated dCu BMCs of 3.6–10.7 µg/L (BMC_{20}–BMC_{50}) (Sandahl et al. 2004) and 2.3–3.0 µg/L (BMC_{25}) (Baldwin et al. 2003).

Together these three studies highlight that different experimental conditions including age of fish, exposure duration, and experimental background of dCu may influence BMCs. Importantly, of the three experiments that derived BMCs for olfactory impairment, the data set used in this technical memorandum from Sandahl et al. (2007) empirically linked impaired olfaction to an ecologically relevant behavior, that is, reduced alarm behavior (Figure 2).

Therefore, we believe that the dCu BMC analysis herein is derived from the most ecologically relevant of the three studies.

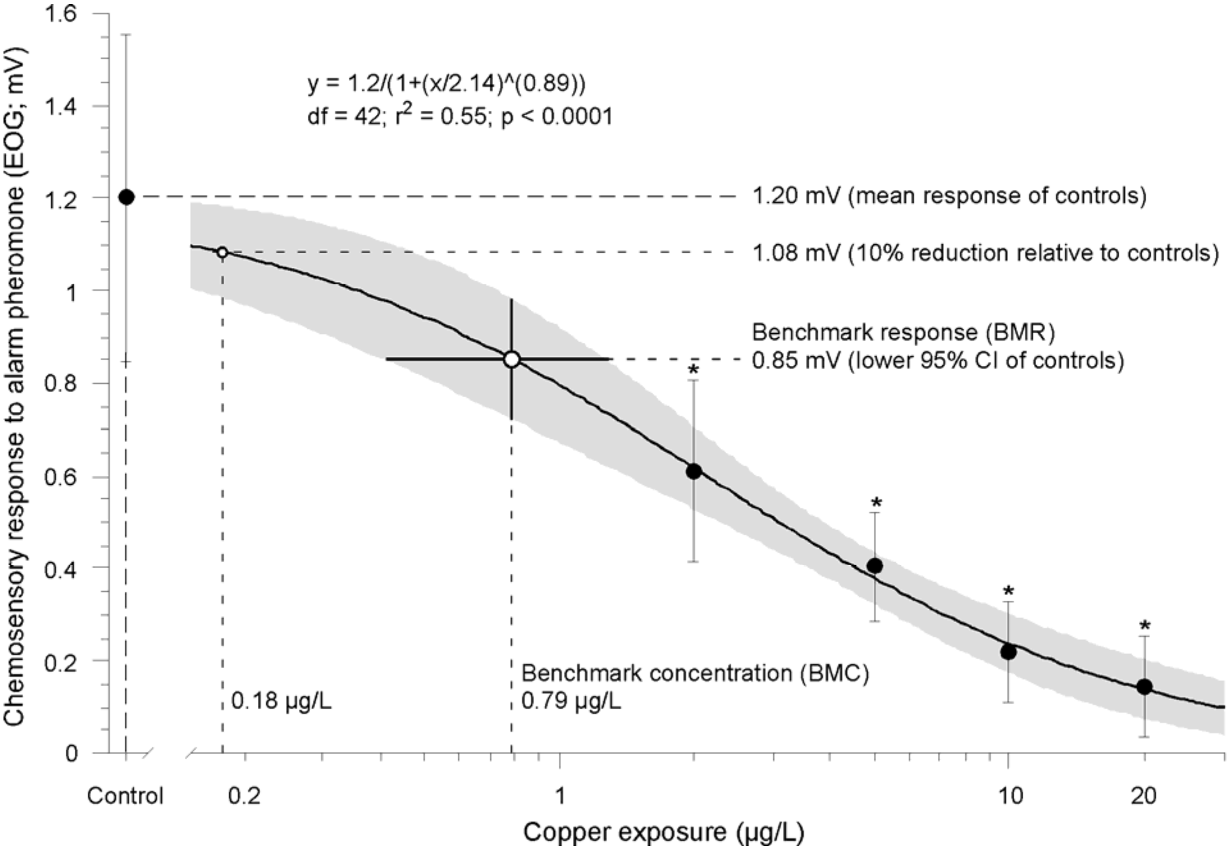

Figure 3. Using a benchmark concentration approach to estimate a threshold for dCu toxicity in the salmonid olfactory system. Filled circles represent treatment means; error bars represent the 95% confidence interval for each mean (n = 8–12 individual coho salmon). An asterisk (*) indicates a statistically significant difference in the size of the olfactory response (EOG data) compared to controls (one-way ANOVA with Dunnett post hoc test, $p < 0.05$). The line represents a statistically significant nonlinear regression based on individual fish (n = 44, $p < 0.0001$, $r^2 = 0.55$). The gray shading shows the 95% confidence band for the nonlinear regression. The regression used a standard sigmoid function with the maximum constrained to the control mean (1.2 mV, indicated by the upper horizontal dashed line). Therefore, the control fish were not included in the nonlinear regression. The lower bound of the 95% confidence interval of the control mean (0.85 mV) is indicated by the lower horizontal dashed line and is an example of a BMR. The large open circle shows where the regression line crosses the BMR and denotes the corresponding BMC, which in this case is a dCu concentration of 0.79 µg/L. Horizontal and vertical lines through the open circle highlight the 95% confidence intervals for the BMC based on the results of the nonlinear regression. The small open circle shows where the regression line crosses the BMR (1.08 mV) and denotes the corresponding BMC_{10} (0.18 µg/L) at which a 10% reduction in olfactory capacity is expected. (Data from Sandahl et al. 2007.)

Table 2. Benchmark responses and benchmark concentrations for juvenile salmon exposed to dCu for 3 hours. Benchmark response values represent a reduction in olfactory response to an alarm pheromone as measured via EOG recordings. Behavioral impairment indicates a predicted decrease in predator recognition and avoidance as indicated by a reduced alarm response. CI = confidence interval; NA = not applicable.

Benchmark responses[a]		**Benchmark concentrations**[b]		**Behavioral impairment (predicted)**[c]
Departure from mean of controls				Departure from mean of controls
Statistical[d] (CI of control mean)	Relative[e] (% reduction in olfactory response)	Value[f] (µg/l)	95% CI[g] (µg/l)	Relative[h] (% reduction in alarm response)
NA	10.0	0.18	0.06–0.52	8.3
Lower 90%	24.2	0.59	0.30–1.16	25.6
Lower 95%	29.2	0.79	0.44–1.42	31.8
NA	50.0	2.10	1.60–2.90	57.2

[a] The predetermined level of altered response or risk at which the benchmark dose (concentration) is calculated (EPA/630/R-94/007, 02/1995).

[b] The dose (concentration) producing a predetermined, altered response for an effect (EPA/630/R-94/007; 02/1995).

[c] Based on the linear regression shown in Figure 2; note behavioral responses were determined by inputting the Benchmark response value (EOG, mV) into the regression equation.

[d] Location of the value with respect to a confidence interval of the mean of the controls.

[e] Amount of reduction in the olfactory response represented by the value relative to the mean of the controls.

[f] Corresponding concentration; see Figure 3 and text for calculation method.

[g] Confidence interval for the value based on the nonlinear regression.

[h] Amount of reduction in alarm response represented by the value relative to the mean of the controls.

Discussion of Site Specific Considerations for Sensory System Effects

Below we identify several issues to consider when using the BMCs to evaluate dCu concentrations under natural conditions.

Impairment from Short-term Increases of dCu

These BMCs reflect expected impairment of chemosensory systems from short-term increases of dCu above ambient concentrations (defined here as < 3 µg/L) (Baldwin et al. 2003, Sandahl et al. 2004, 2007) and are not expected to be alleviated by homeostatic mechanisms. Specifically, the BMCs are predicated on increases of dCu in salmon habitats that result from specific human activities. Effects to juvenile salmonid olfaction are expected following a few minutes of exposure. Salmonids are capable of regulating the amount of internal copper via uptake and elimination processes. These so called homeostatic mechanisms (such as metallothionein induction) can reduce copper's toxic effects and may result in acclimation. Consequently, fish may tolerate certain dCu exposures without showing overt toxicological responses; however, at higher levels these mechanisms could ultimately fail.

Initial evidence indicates that homeostatic mechanisms are not likely to reduce copper toxicity to the olfactory sensory system for pulsed or short-term exposures lasting less than a week (Hansen et al. 1999a) or for chronically exposed fish (McPherson et al. 2004). Moreover, lateral line neurons exposed continuously to dCu for 72 hours showed no signs of acclimation within this exposure interval (Linbo et al. 2006). For other measures of copper toxicity from long-term exposures, evidence suggests that olfactory acclimation may not occur (Table 1, Appendix A). Fish exposed to higher dCu concentrations for longer periods may lose much of their olfactory function. For example, field evidence suggests that wild fish living in heavy metal contaminated lakes where total copper concentrations ranged 9.7–15 µg/L showed reduced olfactory-mediated predator avoidance behavior; that is, homeostatic mechanisms appeared insufficient to alleviate metal toxicity, including copper (McPherson et al. 2004).

Calculating an Acute Criterion Maximum Concentration

The EPA sets acute water quality criteria by calculating an acute criterion maximum concentration (CMC) (Stephan et al. 1985). The CMC is an estimate of the highest concentration of a substance in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect (EPA 2002).We calculated an acute CMC using the Biotic Ligand Model (BLM) (EPA 2007). Interestingly, the estimated acute CMC based on the BLM using measured and estimated water quality parameters from Sandahl et. al. (2007) was 0.63 µg/L with a range from 0.34 to 3.2 µg/L, while the EPA hardness-based acute CMC (EPA 2002) was 6.7 µg/L. Because the BLM-based acute criterion is sensitive to pH and

DOC, the range of measured test pH values (6.5–7.1) and the range of estimated DOC values (0.3–1.5 mg/L) produced this range of BLM-based acute criterion values. It is also interesting that the acute CMC range (0.34–3.2 µg/L) overlapped with the olfactory-based BMC range (0.18–2.1 µg/L).

Salmonids Are Typically Exposed to Multiple Stressors

These BMCs are specifically focused on the impact of dissolved copper alone on olfaction and predator avoidance behavior. Salmonids are rarely exposed to dCu only under natural conditions. In fact, exposure to complex environmental mixtures of other toxic compounds (e.g., metals, pesticides, PAHs, etc.) in conjunction with other stressors (e.g., elevated temperatures, low dissolved oxygen, etc.,) is the norm for many salmonid-bearing habitats. Equally important are exposure routes other than the water column, such as consumption of contaminated prey items (dietary) or direct contact with contaminated sediments. Threshold examples (BMCs) presented here are based solely on juvenile salmonids exposed to dCu. Presently, these thresholds do not take into account multiple routes of exposure or the potential impacts of complex mixtures of contaminants on olfaction. That said, several studies have shown a greater than expected toxicity (i.e., nonadditive) to other fish endpoints from mixtures of metals (Sprague et al. 1965, Norwood et al. 2003). For example, mixtures containing zinc and copper were found to have greater than additive toxicity to a wide variety of aquatic organisms including freshwater fish (Eisler 1998). Other metal mixtures also yielded greater than additive toxic effects at low dissolved concentrations (Playle 2004). The toxic effects of metals to salmonids may also be exacerbated by other types of contaminants such as pesticides (Forget et al. 1999). While interactions among multiple stressors, including contaminant mixtures, are beyond the scope of this document, they warrant careful consideration in site-specific assessments.

Bioavailability of dCu

These BMCs were derived from experiments using a single freshwater source (dechlorinated, soft municipal water). Hardness, alkalinity, and dissolved organic carbon (DOC) are known to alter the bioavailability of dissolved copper in surface waters to ligands in the fish gill. These water chemistry parameters can therefore influence the potential for dCu exposure in the field to cause an acute fish kill. Acute copper lethality mediated via the gill route of exposure is typically estimated using the Biotic Ligand Model (BLM; reviewed by Niyogi and Wood 2004). However, recent unpublished research by McIntyre et al. (in press) suggest that these parameters may have less of an influence on salmonid olfactory function across environmentally realistic ranges of hardness, alkalinity, and DOC.

To date, the U.S. Geological Survey (USGS) has monitored hardness, alkalinity, and DOC for more than 10 years in many West Coast river basins including the Willamette River basin, Puget Sound basin, Yakima River basin, and the Sacramento-San Joaquin River basin (USGS no date). Several at-risk species of anadromous salmonids inhabit these basins. The monitoring data indicate that surface waters within these basins typically have very low hardness and alkalinity and seasonally affected DOC concentrations. Hardness, alkalinity, and DOC levels found in most freshwater habitats occupied by Pacific salmonids would be unlikely to confer substantial protection against dCu olfactory toxicity (Winberg et al. 1992, Bjerselius et al. 1993, Baldwin et al. 2003, McIntyre et al. in press).

Recent experimental results suggest that significant amelioration of olfactory toxicity due to hardness is unlikely in typical Pacific salmonid freshwater habitats. The experiment showed that hardness at 20, 120, and 240 mg/L Ca (experimentally introduced as $CaCl_2$) did not significantly protect juvenile coho salmon from olfactory toxicity following 30 minute laboratory exposures to 10 µg dCu/L above an experimental background of 3 µg/L (Baldwin et al. 2003). In another experiment, a 20 µg dCu/L exposure (30 minutes) in water with low hardness and alkalinity and no DOC produced an 82% inhibition in juvenile coho olfactory function (McIntyre et al. in press). A hardness of ≥82 mg/L Ca was needed to reduce the level of olfactory inhibition to ≤50% at 20 µg/L dCu (McIntyre et al. in press). However, 82 mg/L was never exceeded in any of the surface water samples from USGS-sampled NAWQA basins (McIntyre et al. in press).

Typical alkalinity values from Pacific Northwest and California freshwater surface waters are also unlikely to protect salmonids from olfactory toxicity (USGS no date). Some reduction in dCu olfactory toxicity was observed in a recent study (McIntyre et al. in press). However, only 0.4% of stream samples contained alkalinity levels sufficient to reduce olfactory toxicity of dCu by half (McIntyre et al. in press). Bjerselius et al. (1993) and Winberg et al. (1992) also found that hardness and alkalinity provided limited amelioration of olfactory responses in juvenile Atlantic salmon exposed to dCu.

Increases in DOC showed greater protection to dCu compared to increases in alkalinity and hardness. Twenty-nine percent of USGS surface water samples from West Coast basins had a DOC concentration sufficient to limit olfactory impairment to 50% or less at 20 µg dCu /L (McIntyre et al. in press). Only a small fraction (6%) of all samples contained DOC levels (greater or equal to 6 mg/L) sufficient to completely protect the olfactory responses of juvenile coho salmon from the toxic effect of 20 µg dCu /L (McIntyre et al. in press). This information underscores the importance of evaluating site-specific DOC data to address the potential influence of this water quality parameter on olfactory toxicity.

Because the typical range of hardness, alkalinity, and DOC concentrations are unlikely to confer substantial protection against dCu toxicity, we expect that the BMC thresholds presented in this document will be applicable for most of the freshwater environments that provide migrating, spawning, and rearing habitats for salmonids.

Olfactory Toxicity in Saltwater

Dissolved copper's effect on salmonid olfaction in saltwater environments remains a recognized data gap and it is presently uncertain whether the BMC thresholds derived in this document apply to salt water environments. Estuarine and nearshore salt water environments, despite their higher salinity (in part due to increased cation concentrations) and hardness may or may not confer protection against dCu-induced olfactory toxicity. One source of this uncertainty is whether or not free copper (Cu^{2+}) is the sole species of copper responsible for olfactory toxicity. In freshwater, evidence suggests that Cu^{2+} is not the only toxic species that adversely affects olfaction in fish (McIntyre et al. in press) as well as more conventional endpoints such as mortality (Niyogi and Wood 2004). Other copper species (e.g., CuOH; Cu^{1+}) will also bind to the gill, thereby causing toxicity (Niyogi and Wood 2004). While the physiological basis for salmonid olfaction is well characterized, the transition to saltwater may involve important changes in olfactory receptor neuron function that ultimately influence the expression of the as yet unidentified ligands for dCu.

Avoiding Short-term Increases in dCu

Salmonids may or may not avoid short-term increases in dCu. Salmonids will actively avoid water containing dCu if they can detect it. As a consequence, fish may not use otherwise high quality rearing and spawning habitats. In addition, the presence of dCu may affect migratory routes of juveniles and adults. Smith and Bailey (1990) and Mebane (2000) derived regulatory “zones of passage” around wastewater discharges that were based on salmonid avoidance responses. However, in areas with diffuse, nonpoint source pollution, or multiple point source discharges, it may be difficult to apply “zones of passage”, and in some cases available zones of passage may not exist. Despite a fish’s preference to avoid dCu, circumstances may force migrating juveniles and adults to be exposed. For dCu contaminated, high quality rearing habitats, juveniles could either remain and be exposed or move to lower quality habitats. Juveniles could therefore suffer either reduced predator avoidance or reduced growth. For contaminated spawning habitats, adult salmon may either remain and be exposed as well as their offspring or move to lower quality habitats. Both of these scenarios result in potential reductions in reproductive success.

Coho Salmon–derived BMCs Should Apply to Other Salmonids

These BMCs were derived using data from juvenile coho salmon, but should apply to other fish species. The examples of BMC thresholds were derived from data based on juvenile coho salmon (4–5 month old, mean of 0.9 grams wet weight). However, we expect these BMC examples to be generally applicable to other species of salmon, trout, and steelhead in freshwater habitats. For example, 3 hour exposures of 4-month-old steelhead to a similar range of dCu produced comparable olfactory toxicity to that reported for 4-month-old coho salmon (Baldwin et al. in prep.). Studies on 10-month-old juvenile coho had similar reductions in olfaction compared to 4-month-old fish (Baldwin et al. 2003, Sandahl et al. 2004). Juvenile chum salmon (*O. keta)* (2–3 month old) also showed a dose dependent reduction in EOG amplitude following exposure to dCu (3–58 µg/L) (Sandahl et al. 2006). Taken together these findings suggest that the BMC threshold derived herein should be applicable to juvenile life stages of coho, Chinook, sockeye (*O. nerka)*, and pink salmon (*O. gorbuscha*) as well as steelhead, bull trout (*Salvelinus confluentus*), and other members of the family Salmonidae. As noted earlier, the toxicity of dCu to other life stages (particularly marine phases of life) remains to be determined.

Conclusions

Dissolved copper (dCu) is a ubiquitous, bioavailable pollutant that can directly interfere with fish sensory systems and by extension important behaviors that underlie predator avoidance, juvenile growth, and migratory success (see Appendix A). Recent research shows that dCu not only impairs sensory neurons in a salmonid's nose, but also impairs juvenile salmonids' ability to detect and respond to predation cues. A juvenile salmonid with disrupted predator avoidance behaviors stands a greater risk of mortality and by extension a reduction in the likelihood of surviving to reproduce. The degree to which effects on individual behavior and survival impact a given population will depend in part on the number of the individuals affected and the status of the population (numbers, distribution, growth rate, etc.).

In this report, BMCs were calculated using an EPA methodology to provide examples of effect thresholds of dCu's impacts on salmonid sensory biology and behavior. The BMC examples represent increases in the dCu concentration above background or ambient levels (where background is less than or equal to 3 µg/L) expected to affect juvenile salmonid ability to avoid predators in fresh water. Benchmark concentrations ranged 0.18–2.1 µg/L, corresponding to reductions in predator avoidance behavior (alarm reaction) that ranged approximately 8–57%. Taking into account the olfactory responses of unexposed fish, a more biologically relevant range of BMCs is 0.59–2.1 µg/L (Table 2). This second range of BMC thresholds is similar to or slightly less than documented effects to other copper-affected sublethal endpoints such as behavior and growth that range 0.75–2.5 µg/L (see Table 1).

The primary objective of this report was to present examples of threshold concentrations for effects of dCu on a critical aspect of salmonid biology: olfaction. A secondary objective of this paper was to summarize a selection of recent and historical information related to the effects of dCu on salmonid sensory systems. This document is based on the current state of the science. Importantly, this overview is not a comprehensive summary of the myriad effects of copper to anadromous salmonids. As such, new information will undoubtedly become available that enhances our understanding of copper's effect on salmonid populations and their supporting habitats. The information reviewed and presented herein indicates that significant impairment of sensory functions important to survival of threatened and endangered juvenile salmonids is likely to be widespread in many freshwater aquatic habitats. Impairment of these essential behaviors may occur following 10 minutes of exposure and continue for hours to weeks depending on concentration and duration.

Glossary

Acute exposure. Short-term continuous exposure usually lasting 96 hours or less.

BLM. Biotic Ligand Model

Chronic exposure. Longer-term continuous or pulsed exposures generally lasting greater than 96 hours.

Confidence interval (CI). A random interval constructed from data in such a way that the probability that the interval contains the true value can be specified before the data are collected.

dCu. dissolved copper.

DOC. dissolved organic carbon.

EC_p. Effective concentration adversely affecting (p) percent of the test population or percent of measured response, for example, 10% for an EC_{10} and so forth.

EOG. electro-olfactogram.

LC_{50}. The aqueous concentration of a substance that kills 50% of the test population.

Lower-bound 90% confidence interval. The lower half of the 90% confidence interval of the mean.

Lower-bound 95% confidence interval. The lower half of the 95% confidence interval of the mean.

LOEC. lowest observable effect concentration.

Mean. The average of the response values in a treatment population. Numerically the mean represents the sum of the individual response values divided by the number of individuals in a treatment.

mV. millivolts.

NOAEL. no observable adverse effect level.

NOEC. no observable effect concentration.

ORN. olfactory receptor neuron.

ppb. part(s) per billion, equivalent to µg/L.

Relative departure from control response. A user selected level of response compared to control response; for example, a 10% reduction from the control response (unexposed individuals).

Statistical departure from control response. Uses statistical methods to select a response based on the distribution of responses seen in unexposed individuals. For example, the 95% lower bound confidence interval of the mean response from controls (unexposed individuals).

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Appendix A:
Other Salmonid Sensory Effects of dCu

In this appendix, results are highlighted from several studies that we thought were particularly relevant, including comparing the concentrations that have caused sensory effects to concentrations causing lethality or growth reductions in field and laboratory experiments. As such, the following review is not an exhaustive summary of copper's adverse effects to anadromous salmonids. We emphasize studies that were conducted in waters with low alkalinity and hardness (<50 mg/L as calcium carbonate), and if reported, low concentrations of dissolved organic material. These conditions were emphasized since we believe these are the most relevant water quality conditions for an area of particular concern to us—freshwater habitats used by juvenile salmonids in the Pacific Northwest and California.

Migratory Disruption

Laboratory and field experiments with salmonids have shown avoidance of low concentrations of copper, disruption of downstream migration by juvenile salmonids, loss of homing ability, and loss of avoidance response to even acutely lethal concentrations of copper following long-term habituation to low level copper exposure. Saucier et al. (1991) examined the impact of a long-term sublethal copper exposure (22 µg/L, 37–41 weeks in duration) on the olfactory discrimination performance in rainbow trout (*Oncorhynchus mykiss*). When controls were given a choice between their own rearing water or other waters, they significantly preferred their own rearing water, whereas both copper-exposed groups showed no preference. They concluded that their results demonstrate that a long-term sublethal exposure to copper, as it commonly occurs under "natural" conditions, may result in olfactory dysfunction with potential impacts on fish survival and reproduction.

Field studies have reported that copper impairs both upstream spawning migration of salmonids and downstream outmigration of juveniles. Avoidance of copper in the wild has been demonstrated to delay upstream passage of Atlantic salmon (*Salmo salar*) moving past copper-contaminated reaches of the river to their upstream spawning grounds, cause unnatural downstream movement by adults away from the spawning grounds, and increase straying from their contaminated home stream into uncontaminated tributaries. Avoidance thresholds in the wild of 0.35 to 0.43 toxic units were about seven times higher than laboratory avoidance thresholds (0.05 toxic units), perhaps because the laboratory tests used juvenile fish rather than more motivated spawning adults. For this study 1.0 toxic unit was defined as an incipient lethal level (ILL, essentially a time independent LC_{50}), of 48 µg/L in soft water (Sprague et al. 1965, Saunders and Sprague 1967). Studies of home water selection with returning adult salmon showed that addition of 44 µg/L copper to their home water reduced the selection of their home stream by 90% (Sutterlin and Gray 1973). Releases of about 20 µg/L from a mine drainage into a salmon spawning river resulted in 10–22% repulsion of ascending salmon during four consecutive years compared to 1–2% prior to mining (Sutterlin and Gray 1973). The upstream spawning migration of Chinook salmon (*O. tshawytscha*) in Panther Creek, Idaho, may have been interrupted during the 1980s and early 1990s when the fish encountered dCu concentrations of 10–25 µg/L. In Panther Creek, the majority of spawning habitat and historical locations of Chinook salmon spawning were high in the watershed, upstream of copper discharges. However, Chinook salmon were only observed spawning below the first major diluting tributary, a point above which copper concentrations averaged about 10–25 µg/L during the times of the spawning observations (Mebane 1994, 2000).

Sublethal copper exposure has been shown to interfere with the downstream migration to the ocean of yearling coho salmon (*O. kisutch*). Lorz and McPherson (1976, 1977) and Lorz et al. (1978) evaluated the effects of copper exposure on salmon smolts' downstream migration success in a series of 14 field experiments. Lorz and McPherson (1976, 1977) exposed yearling coho salmon for six to 165 days to nominal copper concentrations varying from 0–30 µg/L. They then marked and released the fish during the normal coho salmon migration period and monitored downstream migration success. The fish were released simultaneously, allowing for evaluation of both copper exposure concentrations and exposure duration on migration success. All dCu exposures resulted in reduction of migration compared with unexposed control fish. Migration success decreased with both increasing copper concentrations and increased exposure time for each respective concentration. Exposure to 30 µg/L dCu for as little as 72 hours caused a considerable reduction in migration (≈60%) compared to control fish. The reductions in migration following short-term exposures to dCu are illustrated in Figure A-1. Following exposure to 30 µg/L dCu, 80% of coho did not reach the migratory point in 49 days. These concentrations (5-20 µg/L) were one-tenth to one-third the 96-hour LC_{50} for the same stock of juvenile coho salmon in the same water. Lorz et al. (1978) further tested downstream migration with yearling coho salmon previously exposed to copper, cadmium, copper-cadmium mixtures, zinc, and copper-zinc mixtures. Copper concentrations in all tests were held at 10 µg/L. In all cases, the copper exposed fish again had poorer migratory success than did controls. The other metals did not show the dose-dependent result found for copper. These studies suggest that exposure to copper concentrations at levels found in streams subject to nonpoint copper pollution may impair downstream migration, a result of direct and indirect effects to salmon smolts, including reproductive success.

Laboratory Avoidance Studies

Studies have shown that salmonids can detect and avoid copper at low concentrations when tested in troughs or streams that allow them to choose between concentration gradients. To our knowledge, the lowest copper concentration reported to cause avoidance in laboratory conditions was 0.1 µg/L (Folmar 1976). However, these results may have low applicability to ambient conditions because copper exposure concentrations were not analytically verified. Avoidance thresholds of 2 µg/L copper have been reported for Atlantic salmon (*Salmo salar*), concentrations that are less than one-tenth of acute LC_{50} values (Saunders and Sprague 1967). Giattina et al. (1982) reported that rainbow trout appeared to detect copper concentrations down to 1.4–2.7 µg/L, because declines in residence time started to occur at these lower concentrations. However, the responses were only statistically significant at 4.4 to 6.4 µg/L depending on whether fish were exposed to a gradually increasing or abruptly increasing concentration gradient respectively. At exposure to extremely high dCu levels, for example,

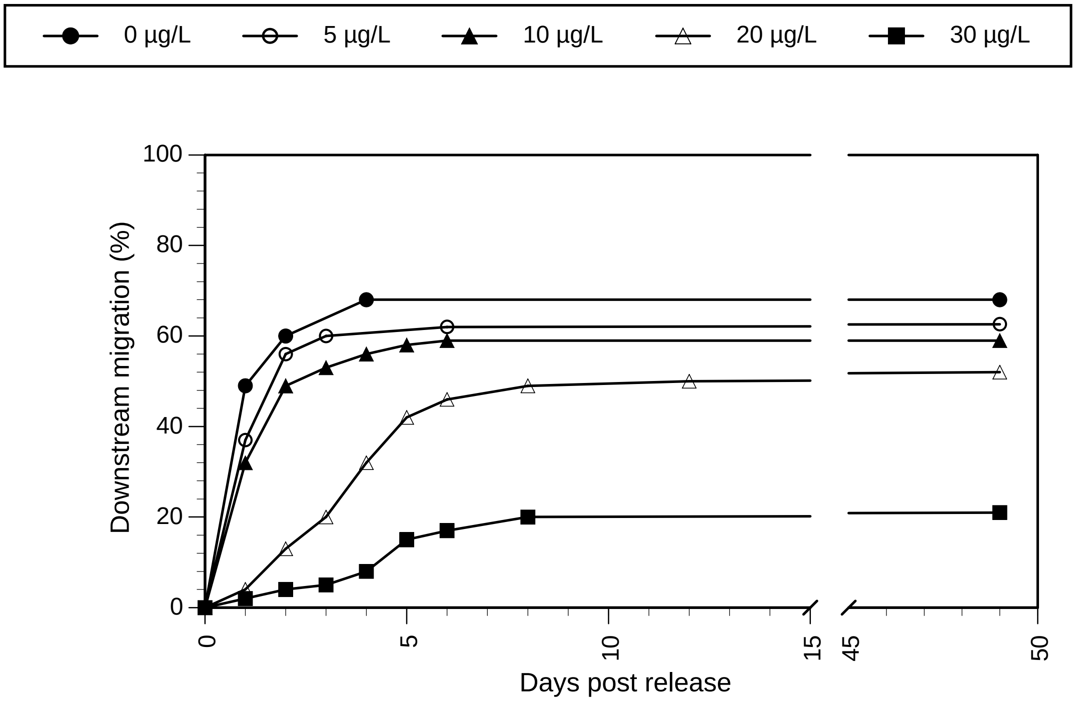

Figure A-1. Reduction in downstream migration of yearling coho salmon following 6 days of exposure to copper at various concentrations. (Redrawn from Lorz and McPherson 1977, their Figure 19.)

330–390 µg/L, trout showed diminished avoidance and sometimes attraction to acutely lethal concentrations (Giattina et al. 1982, Hansen et al. 1999a, Chapman unpubl. data).

Chapman (unpubl. data) reported that long-term sublethal copper exposures had impaired the avoidance performance of salmonids. Steelhead (*O. mykiss*), acclimated to low copper levels by surviving about 3 months early life stage toxicity testing, subsequently failed to avoid much higher, acutely lethal concentrations. Following about 3 month continuous exposure to 9 µg/L copper (from fertilization to about 1 month after swim up) the copper-acclimated fish and control fish with no previous copper exposure were exposed to a range of copper concentrations from 10 to 80 µg/L in avoidance-preference testing. The tests used the same counter flow avoidance-preference test chambers described by Giattina et al. (1982). The acclimated steelhead failed to avoid even the highest copper concentrations while most of the unexposed fish avoided all concentrations.

Hansen et al. (1999a) and Marr et al. (1995) conducted a variety of behavioral and other toxicity studies with Chinook salmon and rainbow trout exposed to copper. In these studies they used well water that was diluted with deionized water and spiked with copper to obtain a hardness, alkalinity, and pH that simulated those in Panther Creek, a mine-affected stream in Idaho. The avoidance response of the Chinook salmon was statistically significant for 0.8 and 2.8–22.5 µg/L copper but was not significant for a 1.6 µg/L copper treatment. Since the avoidance responses (percent time spent in test water) were similar between the 0.8, 1.6, and 3 µg/L treatments, but the 1.6 µg/L treatment had fewer replicates than the other treatments (10 vs. 20), the lack of statistical significance for the 1.6 µg/L treatment was probably an artifact of the different sample sizes rather than a true lack of response. Rainbow trout consistently avoided copper at concentrations of 1.6 µg/L and above. To simulate avoidance responses that might result on exposing fish to background levels of copper, Hansen et al. (1999a) acclimated both Chinook salmon and rainbow trout to 2 µg/L copper for 25 days, and repeated the avoidance experiments. They observed that the avoidance response of Chinook salmon was greatly dampened such that no copper treatments resulted in statistically significant responses. In contrast, the avoidance response of rainbow trout was unaffected by the acclimation. This dramatic difference between Chinook salmon and rainbow trout avoidance was so unexpected that Hansen et al. (1999a) ran a second set of experiments that yielded the same results. Background dCu concentrations (<4 µg/L) are commonly observed in natural waterways, yet Chinook salmon failed to avoid any higher dCu concentrations following an acclimation to a nominal 2 µg dCu/L. Importantly, if Chinook salmon will not avoid any dCu concentrations following acclimation to low dCu concentrations, the behavioral defense against chronic and acute exposures to dCu is lost, and high mortality or chronic physiological effects are probable if subsequent higher levels of dCu exposure occur. Unlike Chinook salmon, dCu-acclimated rainbow trout preferred clean water and avoided higher dCu concentrations. Other differences between Chinook salmon and rainbow trout avoidance responses to copper were that addition of 4 and 8 mg/L dissolved organic carbon (DOC) did not appreciably affect the avoidance response of Chinook salmon to copper, nor did altering pH across a range of 6.5 to 8.5. In contrast, the addition of DOC (4 and 8 mg/L) did reduce the avoidance response of rainbow trout to copper. Although variable, avoidance responses of rainbow trout were slightly stronger at pH 7.5 and 8.5 than at 6.5 (Marr et al. 1995).

A further repeated finding from these laboratory avoidance tests was that although rainbow trout, steelhead, and Chinook salmon avoided low concentrations of dCu, they were apparently intoxicated and sometimes attracted to very high concentrations (Giattina et al. 1982, Hansen et al. 1999a, Chapman unpubl. data). The direct relevance of laboratory avoidance studies to the behaviors of fish in the wild is debatable since in natural waters fish likely select and move among habitats based on myriad reasons such as access to prey, shelter from predators, shade, velocity, temperature, and interactions with other fish. In contrast, laboratory preference/avoidance tests are commonly conducted under simple, highly artificial conditions to eliminate or minimize confounding variables other than the water characteristic of interest. Laboratory tests may overestimate the actual protection this behavior provides fish in heterogeneous, natural environments (Hartwell et al. 1987, Korver and Sprague 1989, Scherer and McNoil 1998).

However, at least one study suggested that experimental avoidance responses observed with salmonids are relevant to fish behaviors in the wild. From 1980 to 1982, sublethal levels of a contaminant (fluoride) from an aluminum mill at the John Day Dam on the Columbia River were associated with a significant delay in salmon passage and decreased survival (Damkaer and Dey 1989). Salmon took an average of 36 hours to pass up the fish ladder at the Bonneville and McNary dams compared to 157 hours delay at the John Day Dam. Greater than 50% mortality occurred between the Bonneville and McNary dams (above and below the John Day dam), compared to about 2% mortality associated with the other dams. Damkaer and Dey (1989) introduced similar levels of the contaminant in streamside test flumes alongside a salmon spawning stream (Big Beef Creek, Washington). Significant numbers of adult Chinook salmon failed to move out of their holding area and continue upstream; those that did move upstream chose the noncontaminated side of the flume. By adjusting the dose, Damkaer and Dey (1989) predicted a threshold detection limit for avoidance by salmon. The mill subsequently reduced its release of the contaminant to below these experimental threshold levels, which did not show a response in the streamside tests. Afterwards, fish passage delays and salmon mortality between the dams decreased to 28 hours and <5%, respectively (Damkaer and Dey 1989). This study suggested that the delay due to avoidance of a chemical affected the spawning success of migrating adult salmonids. These results are also consistent with the field studies of salmon migration in copper-contaminated streams and from laboratory avoidance/preference testing. Experimental avoidance/preference testing thus appears to be relevant to fish behavior in nature.

Other Adverse Effects

The focus of this literature synthesis is sensory effects of copper on juvenile salmonids. However, other adverse effects of copper to salmonids reported in the literature include weakened immune function and disease resistance, increased susceptibility to stress, liver damage, reduced growth, impaired swimming performance, weakened eggshells, and direct mortality (McKim and Benoit 1971, Stevens 1977, Schreck and Lorz 1978, Waiwood and Beamish 1978a, 1978b, Chapman 1982, Farag et al. 1994, Marr et al. 1996, Farag et al. 2003). While a comprehensive review of other adverse effects of copper on fish is beyond the scope of this synthesis, we discuss several studies of interest below.

Stevens (1977) reported that preexposure to sublethal levels of dCu interfered with the immune response and reduced the disease resistance in yearling coho salmon. Juvenile coho salmon were vaccinated with the bacterial pathogen *Vibrio anguillarum* prior to copper exposure to investigate the effects of copper upon the immune response and survival. Following copper exposure (9.6–40 µg/L), surviving juveniles were challenged under natural conditions to *V. anguillarum*, the causative agent of vibriosis in fish. Vibriosis is a disease commonly found in wild and captive fish from marine environments and has caused deaths of coho and Chinook salmon. Coho salmon were exposed to constant concentrations of dCu for about one month at levels that covered the range from no effect to causing 100% mortality, 9.6–40 µg/L. The antibody titer level against *V. anguillarum* was significantly reduced in fish exposed to 13.9 µg/L of dCu when compared to that developed in control fish. The survivors of the dCu bioassays were then exposed in saltwater holding ponds for an additional 24 days to the *V. anguillarum* pathogen. The unvaccinated, non-dCu exposed control fish had 100% mortality and the vaccinated, non-dCu exposed fish had the lowest mortality. The vaccinated, dCu-exposed fish had increasing mortality corresponding to the lower antibody titer levels which in turn corresponded to the increasing dCu exposure levels. Therefore, dCu exposure can significantly reduce a fish's immune function and disease resistance at concentrations as low as 13.9 µg/L following 30 days of exposure (Stevens 1977).

Schreck and Lorz (1978) studied the effects of copper exposure to stress resistance in yearling coho salmon. Fish that were exposed for 7 days to 15 µg/L dCu and unexposed control fish were subjected to severe handling and confinement stress. Copper-exposed fish survived this additional stress for a median of 12–15 hours while control fish experienced no mortality at 36 hours. Schreck and Lorz (1978) concluded that exposure to copper placed a sublethal stress on the fish which made them more vulnerable to handling and saltwater adaptation. Further, they hypothesized that dCu exposure may make salmonids more vulnerable to secondary stresses such as disease and pursuit by predators.

Exposure of brook trout (*Salvelinus fontinalis*) eggs to 17.4 µg dCu/L for 90 days resulted in weakened chorions (eggshells) and embryo deformities. After hatching, poor yolk utilization and reduced growth were demonstrated. These overall weakened conditions may reduce survival chances in the wild (McKim and Benoit 1971, McKim 1985). Copper accumulation in the liver of rainbow trout caused degeneration of liver hepatocytes, which resulted in reduced ability to metabolize food, reduced growth, or eventual death (Leland and Carter 1985, Farag et al. 1994, Meyer 2005). Waiwood and Beamish (1978a), Chapman (1982), Seim et al. (1984), McKim and Benoit (1971), and Marr (1996) have also observed reduced growth of salmonids in response to chronic copper exposures as low as 1.9 µg/L. Waiwood and Beamish (1978b) reported that rainbow trout exposed to copper levels had reduced swimming performance (10, 15, 20, 30 µg/L dCu) and reduced oxygen consumption (25, 40 µg/L dCu) apparently due to gill damage and decreased efficiency of gas exchange.

In sum, there is a large body of literature showing that behavior of salmonids and other fishes can be disrupted at concentrations of dCu that are only slightly elevated above background concentrations. Further, dCu stress has been shown to increase the cost of maintenance to fish and to limit oxygen consumption and food metabolism. Reduced growth may result in increased susceptibility to predation, and impaired swimming ability may result in reduced escape reaction and prey hunting, with a possible consequence of reduced survival at the population level. We summarize selected examples of effect concentrations reported with copper for several different types of effects in Table 1 of this technical memorandum. In general, typical copper exposures probably do not kill juvenile salmonids directly until concentrations greater than about 10 times that of sensory thresholds, and then only if the concentrations are sustained for at least several hours. In selecting these examples, we sought to list representative effects and concentrations rather than extreme values that could be gleaned from the literature. However, the selected examples do not constitute an exhaustive review of the effects of copper to fish; more general reviews of effects of copper to fish and other aquatic organisms are available elsewhere (Leland and Carter 1985, Sorensen 1991, Eisler 1998, USEPA 2007).

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State of California
California Regional Water Quality Control Board, Los Angeles Region

RESOLUTION NO. R08-006
May 1, 2008

Amendment to the *Water Quality Control Plan for the Los Angeles Region* to Incorporate a Total Maximum Daily Load for Eutrophic, Algae, Ammonia, and Odors (Nutrient) for Machado Lake

WHEREAS, the California Regional Water Quality Control Board, Los Angeles Region, finds that:

1. The Federal Clean Water Act (CWA) requires the California Regional Water Quality Control Board, Los Angles Region (Regional Board) to establish water quality standards for each water body within its region. Water quality standards include beneficial uses, water quality objectives that are established at levels sufficient to protect those beneficial uses, and an antidegradation policy to prevent degrading waters. Water bodies that do not meet water quality standards are considered impaired.

2. CWA section 303(d)(1) requires each state to identify the waters within its boundaries that do not meet water quality standards. Those waters are placed on the state's "303(d) List" or "Impaired Waters List". For each listed water, the state is required to establish the Total Maximum Daily Load (TMDL) of each pollutant impairing the water quality standards in that waterbody. Both the identification of impaired waters and TMDLs established for those water must be submitted to the United States Environmental Protection Agency (U.S. EPA) for approval pursuant to CWA section 303(d)(2). For all waters that are not identified as impaired, the states are nevertheless required to create TMDLs pursuant to CWA section 303(d)(3).

3. A consent decree between U.S. EPA, Heal the Bay, Inc. and BayKeeper, Inc. was approved on March 22, 1999, which resolved litigation between those parties relating to the pace of TMDL development. The court order directs the U.S. EPA to ensure that TMDLs for all 1998-listed impaired waters be established within 13 years of the consent decree. The consent decree combined water body pollutant combinations in the Los Angeles Region into 92 TMDL analytical units. In accordance with the consent decree, the Machado Lake Eutrophic, Alage, Ammonia, and Odors (Nutrient) TMDL addresses the waterbody with eutrophic, algae, ammonia, and odor listings in analytical unit 76. Based on the consent decree schedule, TMDLs must be approved or established by U.S.EPA by March 2012.

4. The elements of a TMDL are described in 40 CFR 130.2 and 130.7 and section 303(d)(1)(C) and (D) of the CWA, as well as in U.S. EPA guidance documents (Report No. EPA/440/4-91/001). A TMDL is defined as the sum of the individual waste load allocations for point sources, load allocations for nonpoint sources and natural background (40 CFR 130.2). TMDLs must be set at levels necessary to attain and maintain the applicable narrative and numeric water quality

standards with seasonal variations and a margin of safety that takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality (40 CFR 130.7(c)(1)). 40 CFR 130.7 also dictates that TMDLs shall take into account critical conditions for stream flow, loading and water quality parameters. TMDLs typically include one or more numeric "targets", i.e., numerical translations of the existing water quality standards, which represent attainment of those standards, contemplating the TMDL elements described above. Since a TMDL must represent the "total" load, TMDLs must account for all sources of the relevant pollutants, irrespective of whether the pollutant is discharged to impaired or unimpaired upstream reaches.

5. Neither TMDLs nor their targets or other components are water quality objectives, and thus their establishment does not implicate California Water Code section 13241. Rather, under California Law, TMDLs are programs to implement existing standards (including objectives), and are thus established pursuant to Water Code section 13242. Moreover, they do not create new bases for direct enforcement against dischargers apart from the existing water quality standards they translate. The targets merely establish the bases through which load allocations (LAs) and waste load allocations (WLAs) are calculated. WLAs are only enforced for a discharger's own discharges, and then only in the context of the discharger's National Pollutant Discharge Elimination System (NPDES) permit (or other permit, waiver, or prohibition), which must contain effluent limits consistent with the assumptions and requirements of the WLAs (40 C.F.R. 122.44(d)(vii)(B)). The Regional Board will develop permit requirements through subsequent permit actions that will allow all interested persons, including but not limited to municipal storm water dischargers, to provide comments on how the WLAs should be translated into permit requirements.

6. As envisioned by Water Code section 13242, the TMDL contains a "description of surveillance to be undertaken to determine compliance with objectives." The Compliance Monitoring and Special Studies elements of the TMDL recognize that monitoring will be necessary to assess the on-going condition of Machado Lake and to assess the on-going effectiveness of efforts by dischargers to reduce nutrient loading to Machado Lake. Special studies may also be appropriate to provide further information about new data, new or alternative sources, and revised scientific assumptions. The TMDL does not establish the requirements for these monitoring programs or reports, although it does recognize the type of information that will be necessary to secure. The Regional Board's Executive Officer will issue orders to appropriate entities to develop and to submit monitoring programs and technical reports. The Executive Officer will determine the scope of these programs and reports, taking into account any legal requirements, and issue the orders to the appropriate entities.

7. Upon establishment of TMDLs by the State or U.S. EPA, the State is required to incorporate the TMDLs into the State Water Quality Management Plan (40 CFR 130.6(c)(1), 130.7). This Water Quality Control Plan for the Los Angeles Region (Basin Plan) and applicable statewide plans serve as the State Water Quality Management Plans governing the watersheds under the jurisdiction of the Regional Board. Attachment A to this resolution contains the Basin Planning language for this TMDL.

8. Machado Lake is located in the Ken Malloy Harbor Regional Park (KMHRP), which is a 231 acre Los Angeles City Park serving the Wilmington and Harbor City areas. The Park is located west of the Harbor freeway (110) and east of Vermont Street between the Tosco Refinery on the south and the Pacific Coast Highway on the North. The Machado Lake area is approximately 103.5 acres in total size. The upper portion, which includes the open water area, is approximately 40 acres and the lower wetland portion is about 63.5 acres. This TMDL will address the 40 acre open water lake. Machado Lake is located within the Machado Lake Sub-watershed which is approximately 20 square miles and positioned within the larger 110 square mile Dominguez Channel Watershed. The dominant land use in the Machado Lake Watershed is high density single family residential accounting for approximately 45 % of the land use. Industrial, vacant, retail/commercial, multi-family residential, transportation, and educational institutions each account for 5-7 % of the land use while "all other" accounts for the remaining 23 %. Machado Lake is a receiving body of urban and stormwater runoff from a network of storm drains throughout the watershed. Machado Lake is identified on the 1998, 2002, and 2006 Clean Water Act 303(d) list of impaired water bodies as impaired due to eutrophic conditions, algae, ammonia, and odors. The proposed TMDL addresses impairments of water quality caused by these constituents and the Implementation Plan is developed to achieve water quality objectives for biostimulatory substances in Machado Lake.

9. Eutrophication is increased nutrient loading to a waterbody and the resulting increased growth of biota, phytoplankton and other aquatic plants. Phosphorus and nitrogen are key nutrients for phytoplankton growth in lakes and are often responsible for the eutrophication of surface waters. The increased nutrient loading is generally from two sources, external loading (discharges into the lake) and internal loading (recycling of nutrients within the lake). There are many biological responses to nutrients (nitrogen and phosphorus) in lakes. The biologically available nutrients and light will stimulate phytoplankton and or macrophyte growth. As these plants grow they provide food and habitat for other organisms such as zooplankton and fish. When the aquatic plants die they will release nutrients (ammonia and phosphorus) back into the water through decomposition. The decomposing of plant material consumes oxygen from the water column; in addition the recycled nutrients are available to stimulate additional plant growth. Physical properties such as light, temperature and wind mixing also play integral roles throughout the pathways described.

10. Excessive nutrient loading, from either external or internal process, will lead to excessive phytoplankton and macrophyte growth, which are often considered the primary problems associated with increased nutrient concentrations in lakes. This excessive plant biomass may cause increased turbidity, altered planktonic food chains, algal blooms, reduced dissolved oxygen concentrations, and increased nutrient recycling. These changes can lead to a cascade of biological responses culminating in impaired beneficial uses. Plant growth can lead to increased pH in the lake due to rapid consumption of carbon dioxide. The elevated pH creates a harmful environment for organisms and can increase the concentration of ammonia potentially leading to direct toxicity of fish and other organisms. As these large phytoplankton populations and macrophytes die or break apart the decomposition process will consume oxygen and reduce the

oxygen levels found in the lake. Low dissolved oxygen levels can be stressful for fish and other organisms and may in fact lead to fish kills.

11. Numeric targets for the TMDL are based on the specific narrative and numeric water quality objectives (WQOs) provided in the Basin Plan.

12. The Regional Board's goal in establishing the TMDL for eutrophic, algae, ammonia, and odors in Machado Lake is to protect the REC 1, REC 2, aquatic life (WARM, WILD, RARE, WET) and water supply (MUN) beneficial uses of Machado Lake and to achieve the numeric and narrative water quality objectives set to protect those uses.

13. Regional Board Staff have prepared a detailed technical document that analyzes and describes the specific necessity and rationale for the development of this TMDL. The technical document entitled "Machado Lake Eutrophic, Algae, Ammonia, and Odors (Nutrient) TMDL" is an integral part of this Regional Board action and was reviewed, considered, and accepted by the Regional Board before acting. Further, the technical document provides the detailed factual basis and analysis supporting the problem statement, numeric targets (interpretation of the narrative and numeric water quality objectives, used to calculate the load allocations), source analysis, linkage analysis, waste load allocations (for point sources), load allocations (for nonpoint sources), margin of safety, and seasonal variations and critical conditions of this TMDL.

14. On November 2, 2004, City of Los Angeles voters approved Proposition O, a ballot initiative to implement water quality improvement projects within the City of Los Angeles. As part of Proposition O, concept reports have been developed for the Machado Lake Ecosystem Rehabilitation Project and the Wilmington Drain Multi-use project. Many of the proposed actions under these Proposition O projects, such as sediment removal and storm drain inlet upgrades, will improve water quality in Machado Lake. Therefore, the Implementation Plan for the Machado Lake TMDL was designed to coordinate with these Proposition O projects in order to realize the best use of public funds. However, the Proposition O projects, currently in the concept stage, may need to be augmented to achieve TMDL numeric targets and eliminate negative eutrophic conditions in Machado Lake. In recognition of the potential need to expand on Proposition O projects, the TMDL Implementation Schedule provides adequate time for design and implementation of projects so that they attain TMDL requirements and achieve water quality standards.

15. On May 1, 2008, prior to the Board's action on this resolution, public hearings were conducted on the Machado Lake Eutrophic, Algae, Ammonia, and Odors (Nutirent) TMDL. Notice of the hearing for the Machado Lake Nutrient TMDL was published in accordance with the requirements of Water Code Section 13244. This notice was published in the Los Angeles Times on February 7, 2008.

16. The public has had a reasonable opportunity to participate in the review of the amendment to the Basin Plan. Public Stakeholder meetings were held on March 14, 2006, February 21, 2007, July 16, 2007, September 12, 2007, and November 26, 2007. A draft of the TMDL was released for public comment on February 7,

2008; a Notice of Hearing and Notice of Filing were published and circulated 45 days preceding Board action; Regional Board staff responded to oral and written comments received from the public; and the Regional Board held a public hearing on May 1, 2008 to consider adoption of the TMDL.

17. In amending the Basin Plan to establish this TMDL, the Regional Board considered the requirements set forth in Sections 13240 and 13242 of the California Water Code.

18. Because the TMDL implements existing narrative and numeric water quality objectives (i.e., numeric water quality objectives in the Basin Plan), the Regional Board (along with the State Water Resources Control Board) have determined that adopting a TMDL does not require the water boards to consider the factors of Water Code section 13241. The consideration of the Water Code section 13241 factors, by section 13241's express terms, only applies "in establishing water quality objectives." Here the Regional Board is not establishing water quality objectives, but as required by section 303(d)(1)(C) of the Clean Water Act is adopting a TMDL that will implement the previously established objectives that have not been achieved. In making this determination, the Regional Board has considered and relied upon a legal memorandum from the Office of Chief Counsel to the State Water Board's basin planning staff detailing why TMDLs cannot be considered water quality objectives. (See Memorandum from the Staff Counsel Michael J. Levy, Office of Chief Counsel, to Ken Harris and Paul Lillebo, Division of Water Quality: *The Distinction Between A TMDL's Numeric Targets and Water Quality Standards*, dated June 12, 2002.)

19. While the Regional Board is not required to consider the factors of Water Code section 13241, it nonetheless has developed and received significant information pertaining to the Water Code section 13241 factors and has considered that information in developing and adopting this TMDL. The past, present, and probable future beneficial uses of water have been considered in that Machado Lakeis designated for a multitude of beneficial uses in the Basin Plan. The beneficial uses for Machado Lake include aquatic life habitat uses, water contact and non-contact water recreation, and water supply. The environmental characteristics of Machado Lake are spelled out at length in the Basin Plan and in the technical documents supporting this Basin Plan amendment, and have been considered in developing this TMDL. Water quality conditions that reasonably could be achieved through the coordinated control of all factors which affect water quality in the area have been considered. This TMDL provides several compliance options, including lake management strategies/lake treatment options that could be implemented directly at the lake and watershed strategies for stormwater runoff throughout the watershed to treat and reduce nutrient loading to the lake. These options provide flexibility for responsible jurisdictions to reduce internal and external nutrient loading to Machado Lake. Establishing a plan that will ensure Machado Lake attains and continues to maintain water quality standards is a reasonable water quality condition. However, to the extent that there would be any conflict between the consideration of the factor in Water Code section 13241, subdivision (c), if the consideration were required, and the Clean Water Act, the Clean Water Act would prevail. Economic considerations were considered throughout the development of the TMDL. Some of these economic considerations arise in the

context of Public Resources Code section 21159 and are equally applicable here. The implementation program for this TMDL recognizes the economic limitations on achieving immediate compliance and allows a flexible implementation schedule of 8.5 years. The need for housing within the region has been considered, but this TMDL is unlikely to affect housing needs. Whatever housing impacts could materialize are ameliorated by the flexible nature of this TMDL and the 8.5 year implementation schedule.

20. The amendment is consistent with the State Antidegradation Policy (State Board Resolution No. 68-16), in that the changes to water quality objectives (i) consider maximum benefits to the people of the state, (ii) will not unreasonably affect present and anticipated beneficial use of waters, and (iii) will not result in water quality less than that prescribed in policies. Likewise, the amendment is consistent with the federal Antidegradation Policy (40 CFR 131.12).

21. Pursuant to Public Resources Code section 21080.5, the Resources Agency has approved the Regional Water Boards' basin planning process as a "certified regulatory program" that adequately satisfies the California Environmental Quality Act (CEQA) (Public Resources Code, § 21000 et seq.) requirements for preparing environmental documents (14 Cal. Code Regs. § 15251(g); 23 Cal. Code Regs. § 3782.) The Regional Water Board staff has prepared "substitute environmental documents" for this project that contains the required environmental documentation under the State Water Board's CEQA regulations. (23 Cal. Code Regs. § 3777.) The substitute environmental documents include the TMDL staff report entitled "Machado Lake Eutrophic Algae, Ammonia, and Odors (Nutrient) TMDL", the environmental checklist, the comments and responses to comments, the basin plan amendment language, and this resolution. The project itself is the establishment of a TMDL for eutrophic, algae, ammonia, and odors in Machado Lake. While the Regional Board has no discretion to not establish a TMDL (the TMDL is required by federal law), the Board does exercise discretion in assigning waste load allocations and load allocations, determining the program of implementation, and setting various milestones in achieving the water quality standards. The CEQA checklist and other portions of the substitute environmental documents contain significant analysis and numerous findings related to impacts and mitigation measures.

22. A CEQA Scoping hearing was conducted on September 12, 2007 at the Regional Board's office – 320 West 4th Street, Suite 200, Los Angeles, California. A notice of the CEQA Scoping hearing was sent to interested parties including cities and/or counties with jurisdiction in or bordering the watershed. The notice of CEQA Scoping hearing was also published in the Los Angeles Daily News on August 1, 2007.

23. In preparing the substitute environmental documents, the Regional Board has considered the requirements of Public Resources Code section 21159 and California Code of Regulations, title 14, section 15187, and intends those documents to serve as a tier 1 environmental review. This analysis is not intended to be an exhaustive analysis of every conceivable impact, but an analysis of the reasonably foreseeable consequences of the adoption of this regulation, from a programmatic perspective. Many compliance obligations will be undertaken directly by public agencies that will have their own obligations

under CEQA. In addition, public agencies including but not limited to County of Los Angeles, Los Angeles County Flood Control District, Cities of Carson, Lomita, Los Angeles, Palos Verdes Estates, Rancho Palos Verdes, Redondo Beach, Rolling Hills, Rolling Hills Estates, and Torrance are foreseeably expected to facilitate compliance obligations. The "Lead" agencies for such tier 2 projects, will assure compliance with project-level CEQA analysis of this programmatic project. Project level impacts will need to be considered in any subsequent environmental analysis performed by other public agencies, pursuant to Public Resources Code section 21159.2.

24. The foreseeable methods of compliance for this TMDL entail construction and operation of stormwater management practices such as filter systems, alum injection system, swales, and bioretention areas. Foreseeable methods of compliance also include lake management practices, such as hydraulic dredging, aeration systems, alum treatment, and fisheries management.

25. Consistent with the Regional Board's substantive obligations under CEQA, the substitute environmental documents do not engage in speculation or conjecture, and only consider the reasonably foreseeable environmental impacts, including those relating to the methods of compliance, reasonably foreseeable feasible mitigation measures to reduce those impacts, and the reasonably foreseeable alternative means of compliance, which would avoid or reduce the identified impacts.

26. The proposed amendment could have a potentially significant adverse effect on the environment. However, there are feasible alternatives, feasible mitigation measures, or both, that if employed, would substantially lessen the potentially significant adverse impacts identified in the substitute environmental documents; however such alternatives or mitigation measures are within the responsibility and jurisdiction of other public agencies, and not the Regional Board. Water Code section 13360 precludes the Regional Board from dictating the manner in which responsible agencies comply with any of the Regional Board's regulations or orders. When the agencies responsible for implementing this TMDL determine how they will proceed, the agencies responsible for those parts of the project can and should incorporate such alternatives and mitigation into any subsequent projects or project approvals. These feasible alternatives and mitigation measures are described in more detail in the substitute environmental documents. (14 Cal. Code Regs. § 15091(a)(2).)

27. From a program-level perspective, incorporation of the alternatives and mitigation measures outlined in the substitute environmental documents may not forseeably reduce impacts to less than significant levels.

28. The substitute documents for this TMDL, and in particular the Environmental Checklist and staff's responses to comments, identify broad mitigation approaches that should be considered at the project level.

29. To the extent significant adverse environmental effects could occur, the Regional Board has balanced the economic, legal, social, technological, and other benefits of the TMDL against the unavoidable environmental risks and finds that specific economic, legal, social, technological, and other benefits of the TMDL outweigh

the unavoidable adverse environmental effects, such that those effects are considered acceptable. The basis for this finding is more fully set forth in the substitute environmental documents. (14 Cal. Code Regs. § 15093.)

30. Health and Safety Code section 57004 requires external scientific peer review for certain water quality control policies. Prior to public notice of the draft TMDL, the Regional Board submitted the scientific basis and scientific portions of the Machado Lake Nutrient TMDL to Dr. Rakesh Gelda and Dr. Paul McGinley for external scientific peer review. The peer review comment reports were received by the Regional Board on January 7, 2008 and January 15, 2008. The peer review found that the proposed TMDL data, modeling analyses, and pollutant allocations were presented in a scientifically credible manner. Minor modifications were made to the scientific portions of the TMDL to address comments identified during the peer review process.

31. The regulatory action meets the "Necessity" standard of the Administrative Procedures Act, Government Code, section 11353, subdivision (b). As specified above, Federal law and regulations require that TMDLs be incorporated into the water quality management plan. The Regional Board's Basin Plan is the Regional Board's component of the water quality management plan, and the Basin Plan is how the Regional Board takes quasi-legislative, planning actions. Moreover, the TMDL is a program of implementation for existing water quality objectives, and is, therefore, appropriately a component of the Basin Plan under Water Code section 13242. The necessity of developing a TMDL is established in the TMDL staff report, the section 303(d) list, and the data contained in the administrative record documenting the eutrophic, algae, ammonia, and odors impairments of Machado Lake.

32. The Basin Plan amendment incorporating a TMDL for eutrophic, algae, ammonia, and odors for Machado Lake must be submitted for review and approval by the State Water Resources Control Board (State Board), the State Office of Administrative Law (OAL), and the U.S. EPA. The Basin Plan amendment will become effective upon approval by OAL and U.S. EPA. A Notice of Decision will be filed with the Resources Agency.

33. If during the State Board's approval process Regional Board staff, the SWRCB or State Board staff, or OAL determines that minor, non-substantive modifications to the language of the amendment are needed for clarity or consistency, the Executive Officer should make such changes consistent with the Regional Board's intent in adopting this TMDL, and should inform the Board of any such changes.

34. Considering the record as a whole, this Basin Plan amendment will result in no effect, either individually or cumulatively, on wildlife resources.

THEREFORE, be it resolved that pursuant to sections 13240 and 13242 of the Water Code, the Regional Board hereby amends the Basin Plan as follows:

1. The Regional Board hereby approves and adopts the CEQA substitute environmental documentation, which was prepared in accordance with Public Resources Code section 21159 and California Code of Regulations, title 14, section 15187, and directs the Executive Officer to sign the environmental checklist.

2. Pursuant to Sections 13240 and 13242 of the California Water Code, the Regional Board, after considering the entire record, including oral testimony at the hearing, hereby adopts the amendments to Chapter 7 of the Water Quality Control Plan for the Los Angeles Region, as set forth in Attachment A hereto, to incorporate the elements of the Machado Lake Eutrophic, Algae, Ammonia, and Odors (Nutrient) TMDL.

3. The Executive Officer is directed to forward copies of the Basin Plan amendment to the State Board in accordance with the requirements of section 13245 of the California Water Code.

4. The Regional Board requests that the State Board approve the Basin Plan amendment in accordance with the requirements of sections 13245 and 13246 of the California Water Code and forward it to OAL and the U.S. EPA.

5. If during the State Board's approval process, Regional Board staff, the State Board or OAL determines that minor, non-substantive modifications to the language of the amendment are needed for clarity or consistency, the Executive Officer may make such changes, and shall inform the Board of any such changes.

6. The Executive Officer is authorized to request a "No Effect Determination" from the Department of Fish and Game, or transmit payment of the applicable fee as may be required to the Department of Fish and Game.

I, Tracy J. Egoscue, Executive Officer, do hereby certify that the foregoing is a full, true, and correct copy of a resolution adopted by the California Regional Water Quality Control Board, Los Angeles Region, on May 1, 2008.

Tracy J. Egoscue
Executive Officer

5/29/08
Date

ABCL (Aquatic Bioassay & Consulting Laboratories), "2007 Annual Bioassessment Monitoring of the Santa Clara River at Newhall Ranch" (March 2008)

GEOSYNTEC CONSULTANTS
SANTA CLARA RIVER AT NEWHALL RANCH

2007 ANNUAL BIOASSESSMENT MONITORING OF THE SANTA CLARA RIVER AT NEWHALL RANCH

Prepared by:

Aquatic Bioassay & Consulting Laboratories

29 N. Olive St
Ventura, CA 93001
805 643 5621

March 2008

AQUATIC
BIOASSAY &
CONSULTING
LABORATORIES, INC.

February 25th, 2008

Mr. Brandon Steets
Geosyntec Consultants
924 Anacapa St. Suite 4A
Santa Barbara, CA 93101

Dear Mr. Steets:

In accordance with the agreement between Geosyntec Consultants and Aquatic Bioassay and Consulting Laboratories, Inc., we are pleased to present the 2007 Bioassessment Monitoring Report for the pre-discharge monitoring requirements for the Newhall Wastewater Reclamation Plant on the Santa Clara River.

Yours very truly,

Scott C. Johnson

Scott C. Johnson
Director of Environmental Programs
Aquatic Bioassay & Consulting Laboratories
29 N. Olive St.
Ventura, CA 93001

Newhall Wastewater Reclamation Plant Spring & Fall 2007 Bioassessment Monitoring Report

Submitted to:

Geosyntec Consultants
924 Anacapa St., Suite 4A
Santa Barbara, CA 93101

Submitted by:

Aquatic Bioassay and Consulting Laboratories
29 N Olive Street
Ventura, CA 93001

March 2008

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This report is submitted to Geosyntec as part of the pre-discharge monitoring requirements for the Newhall Wastewater Reclamation Plant (WRP). This study included bioassessment monitoring on the Santa Clara River east of the City of Piru, at the Los Angeles and Ventura County Line using protocols specified by in the State of California, Surface Water Ambient Monitoring Program (SWAMP 2007). Aquatic Bioassay and Consulting Laboratory scientists conducted sampling on July 27th and October 31st, 2007. The goals of the bioassessment study were to:

1. Provide a comparison of the benthic macroinvertebrate (BMI) assemblages present in the Santa Clara River upstream and downstream of the future Newhall WRP discharge site.
2. Evaluate the physical/habitat condition of these sampling sites.

This report includes all of the physical, chemical and biological data collected during the spring and fall surveys. These include photographic documentation of each site, QA/QC procedures and documentation, followed by a presentation of the calculated metrics specified in the SWAMP protocols, the Southern California IBI and interpretation of the results. In addition, this report includes a summary of BMI data collected since 2004.

BACKGROUND

Major issues facing streams and rivers in California include modification of in-stream and riparian structure, contaminated water and increases in impervious surfaces which have led to the increased frequency of flooding. There have been many studies and reports showing the deleterious effects of land-use activities to macroinvertebrate and fish communities (Jones and Clark 1987; Lenat and Crawford 1994; Weaver and Garman 1994; and Karr 1998).

During the past 150 years, direct measurements of biological communities including plants, invertebrates, fish, and microbial life have been used as indicators of degraded water quality. In addition, biological assessments (bioassessments) can be used as a watershed management tool for surveillance and compliance of land-use best management practices. Combined with measurements of watershed characteristics, land-use practices, in-stream habitat, and water chemistry, bioassessment can be a cost-effective tool for long-term trend monitoring of watershed conditions (Davis and Simons 1996).

Biological communities act to integrate the effects of water quality conditions in a stream by responding with changes in their population abundances and species composition over time. These populations are sensitive to multiple aspects of water and habitat quality and provide the public with more familiar expressions of ecological health than the results of chemical and toxicity tests (Gibson 1996). Furthermore, biological assessments when integrated with physical and chemical assessments better define the effects of point-source discharges of contaminants and provide a more appropriate means for evaluating discharges of non-chemical substances (e.g. nutrients and sediment).

Benthic macroinvertebrates (BMIs) are ubiquitous, relatively stationary and their diversity provides a spectrum of responses to environmental stresses (Rosenberg and Resh 1993). Individual species of BMIs reside in the aquatic environment for a period of months to several years and are sensitive, in varying degrees, to temperature, dissolved oxygen, sedimentation, scouring, nutrient enrichment and chemical and organic pollution (Resh and Jackson 1993). Finally, BMIs represent a significant food source for aquatic and terrestrial animals and provide a wealth of ecological and bio-geographical information (Erman 1996).

In the United States the evaluation of biotic conditions from BMI community data uses a combination of multimetric and multivariate techniques. In multimetric techniques, a set of biological measurements (“metrics”), each representing a different aspect of the community data, is calculated for each site. An overall site score is calculated as the sum of individual metric scores. Sites are then ranked according to their scores and classified into groups with “good”, “fair” and “poor” water quality. This system of scoring and ranking sites is referred to as an Index of Biotic Integrity (IBI) and is the end point of a multi-metric analytical approach recommended by the EPA for development of biocriteria (Davis and Simon 1995). The original IBI was created for assessment of fish communities (Karr 1981), but was subsequently adapted for BMI communities (Kerans and Karr 1994).

The first demonstration of a California regional IBI was applied to the Russian River watershed in 1999 (DFG 1998). As the Russian River IBI was being developed, the California Department of Fish and Game (CADFG) began a much larger project for the San Diego Regional Board. After a pilot project conducted on the San Diego River in 1995 and 1996, the San Diego Regional Board incorporated bioassessment into their ambient water quality monitoring program. Finally, between 2000 and 2003, bioassessment data were collected from the Mexican border to the south, Monterey County to the north and to the eastern extent of the coastal mountain range. These data were used to create an IBI that is applicable to southern California and is applied to the data in this report (Ode et al. 2005). While many low gradient reference sites were included in the development of the IBI, it has become apparent that the further work may be necessary to make the IBI applicable to low gradient systems in southern California.

MATERIALS AND METHODS

Sampling Site Descriptions

Two sampling locations (NR1 upstream and NR3 downstream) were visited in the Santa Clara River on July 27th and October 31st, 2007 (Table 1, Figure 1). Photographs of each site are displayed in Figure 2. These sites were selected so that the biological communities at the future discharge location for the Newhall WRP could be evaluated. It is important that these sites are similar to one another in terms of physical habitat. If they are not, future comparisons between the BMI communities residing at sites upstream and downstream of the WRP could be confounded by habitat differences.

During dry weather this section of the Santa Clara River sustains a low flow of water which is fed to it by several upstream waste treatment facilities. This is not a typical condition during the dry summer months in southern California where even large rivers such as the Santa Clara are historically dry. The land surrounding the river at both the upstream and downstream sites have been used during the past century for agriculture. As a result there are dirt roads, irrigation ditches and heavy machinery present throughout the area.

The Station NR1 was located 300 feet upstream of the Los Angeles/Ventura County Line, at an elevation of 835 feet. This site will be the location of the new waste discharge from the treatment facility. The River is located in a relatively natural southern California river habitat with a sand, cobble and gravel streambed. The channel with flowing water is normally small in comparison to the entire width of the Santa Clara River which is dry during most of the year except during rain storms. Station NR3 was located 2.74 miles downstream of the Los Angeles/Ventura County Line, at an elevation of 724 feet. Here the river filled more than 75% of the streambed and was bordered on each side by thick vegetation. This site was situated just upstream of a bridge and was composed of sand, cobble and gravel.

Table 1. Sampling locations and descriptions for 2 sites on the Santa Clara River.

Sta.ID	Description and Comments	Latitude	Longitude	Elev. (ft)
NR1 Upstream	Located 300 ft. upstream of the Los Angeles/Ventura County Line.	34° 24.193' N	118° 41.391' W	835
NR3 Downstream	Located 2.74 mi. downstream of the Los Angeles/Ventura County Line	34° 24.232' N	118° 44.363' W	724

Figure 1. BMI sampling locations for the two sites on Santa Clara River.

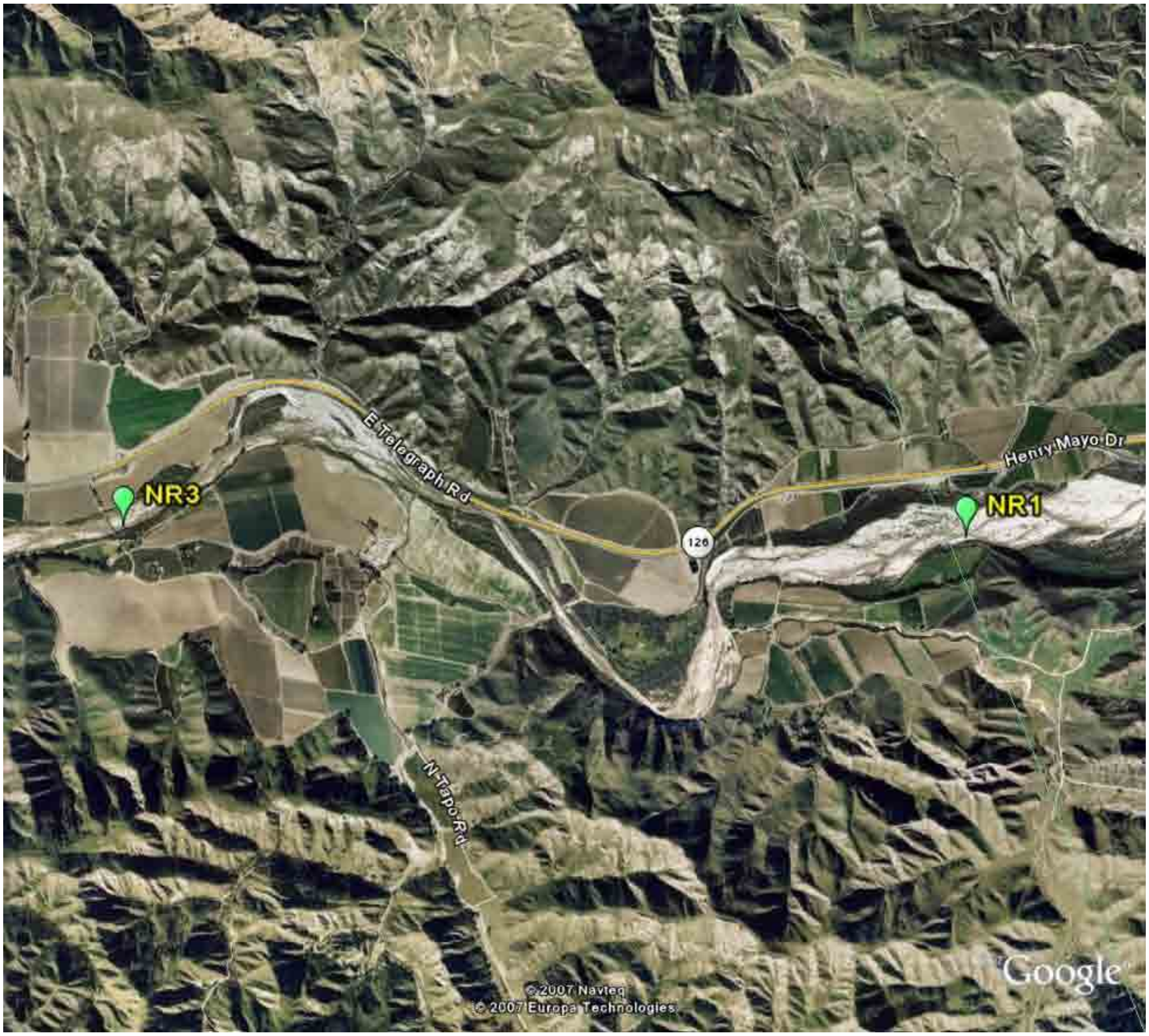


Figure 2: Sampling location photos of upstream Station NR1 and downstream Station NR3 in the Santa Clara River.

NR1 - Spring | NR1 - Spring | NR1 - Fall | NR1 - Fall

NR3 - Spring | NR3 - Spring | NR3 - Fall | NR3 - Fall

Collection of Benthic Macroinvertebrates

Wadeable Streams Protocols

The field protocols and assessment procedures followed the draft Surface Water Ambient Monitoring Program (SWAMP) protocols which were taken from existing California Department of Fish and Game protocols (CDFG 2003) and the United States Environmental Protection Agencies (USEPA) Western Environmental Monitoring Assessment Program (EMAP). These protocols have since been promulgated and will be used throughout the State of California in coming years (SWAMP 2007).

Benthic macroinvertebrate (BMI) samples were collected in strict adherence to the SWAMP in terms of both sampling methodology and QC procedures. At each station, a 150 m reach was measured and 11 transects were established equidistance apart from the downstream to upstream end of the reach. If access to the full 150 m reach was not possible due to obstacles (i.e. heavy vegetation), the total reach length was divided by 11 and transects were established as above. At each site the SWAMP Worksheet was used to collect all of the necessary station information and physical habitat data.

BMI samples were collected starting with the downstream transect and working upstream. Since the percent streambed gradient was <1%, the Reach Wide Benthos (RWB) sampling protocol was used:

- At the most downstream transect a single location was sampled 25% of the distance from the right wetted width. On the second upstream transect a sample was collected 50% of the distance from the right wetted width and, on the third transect, 75% of the distance from the right wetted width. This process was repeated until each of the eleven transects had been sampled.

All samples of the benthos were collected within a 1 ft^2 area upstream of a 1 ft wide, 0.5 mm mesh D-frame kick-net at each transect. Sampling of the benthos was performed manually by rubbing cobble and boulder substrates in front of the net, followed by “kicking” the upper layers of substrate to dislodge any remaining invertebrates. The duration of sampling ranged from 60-120 seconds, depending on the amount of boulder and cobble-sized substrate that required rubbing by hand; more and larger substrates required more time to process.

Each of the 11 samples was combined into a single composite sample that represented an 11 ft^2 area of the total reach. The composite sample was transferred into a 1/2 gallon wide-mouth plastic jar containing approximately 300 ml of 95% ethanol. Chain of Custody (COC) sheets were completed for samples as each station was completed.

Physical/Habitat Quality Assessment and Water Quality

Bioassessment sampling included a measure of the instream physical habitat conditions using a method originally developed by the USEPA and modified by SWAMP (2007) for use in California. This method focuses on the habitat conditions found in the streambed and banks. The team collected the physical/habitat measurements at each station according to the Basic method outlined in the SWAMP manual and recorded the information on the SWAMP worksheets. To maintain a historical record of physical habitat quality, both reaches were also assessed using the California Stream Bioassessment Procedure (CSBP, 1999) Visual-Based Habitat Assessment method developed by USEPA for its Rapid Bioassessment Procedures (RBP; Barbour et al 1999).

These measurements are summarized as follows:

1. Water temperature, specific conductance, pH and dissolved oxygen were measured using a hand held YSI 85 water quality meter that was pre-calibrated in the laboratory. A water sample was collected for alkalinity and analyzed by titration in the lab.
2. Wetted width was measured in meters using a stadia rod or measuring tape at each transect.
3. Velocity was measured in the spring and discharge was measured in the fall on a single transect using a hand held flow meter.
4. A densitometer was used to measure % canopy cover.
5. Stream gradient was measured using either an auto leve, and sinuosity was measured using a compass working downstream from the most upstream transect.

Sample Analysis/Taxonomic Identification of Benthic Macroinvertebrates (BMIs)

Sample sorting and taxonomy were conducted by Aquatic Bioassay and Consulting Laboratories. Sorting and taxonomice identifications were conducted at the Aquatic Bioassay laboratory in Ventura, CA and taxonomic identifications were conducted by Craig Pernot. Identifications were made using standard taxonomic keys (Literature Cited, Taxonomic References). In most cases taxa for this study were identified to the species level in adherence with Professional Taxonomic Effort Level 2 specified by the Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT). All taxa identifications were rolled up to the appropriate taxonomic level for the calculation of biological metrics and the Southern California IBI. Samples entering the lab were processed as follows:

A maximum number of 500 organisms were sub-sampled from the composite sample using a divided tray, and then sorted into major taxonomic groups. All remnants were stored for future reference. The 500 organisms were identified to the genus level for most insects and order or class for non-insects. As new species to the survey area were identified, examples of each were added to the voucher collection. The voucher collection includes at least one individual of each species collected and ensures that naming conventions can be maintained and changed as necessary into the future.

The taxonomic quality control (QC) procedures followed for this survey included:

- Sorting efficiencies were checked on all samples. The leftover material from each sample was inspected by the laboratory supervisor. Minimum required sorting efficiency was 95%, i.e. no more than 5% of the total number of organisms sorted from the grids could be left in the remnants. Sorting efficiency results were documented on each station’s sample tracking sheet.
- Once identification work was completed, 10% of all samples were sent to the Department of Fish and Game (DF&G) offices in Rancho Cordova for a QC check. Samples were sorted by species into individual vials that included an internal label. Any discrepancies in counts or identification found by the DF&G taxonomists were discussed, and then resolved. All data sheets were corrected and, when necessary, bioassessment metrics were updated.

Data Development and Analysis

As species were identified, they were included in an Excel data sheet, checked for errors and then imported into the Aquatic Bioassay BMI database system. All biological metrics, figures and tables were then automatically generated. These bioassessment metrics were then used to assess the spatial and temporal distributions of the BMI community or were used to calculate the southern California IBI (Ode et al. 2005). The following metrics were calculated and their responses to impaired conditions are listed in Table 2:

1. Richness measures: taxa richness, cumulative taxa, EPT taxa, cumulative EPT taxa, Coleopteran taxa.
2. Composition measures: EPT index, sensitive EPT index, Shannon diversity.
3. Tolerance/intolerance measures: mean tolerance value, intolerant organisms (%), tolerant organisms (%),tolerant taxa (%), dominant taxa (%), Chironomidae (%), non-insect taxa (%).
4. Functional feeding group: collectors (%), filterers (%), grazers (%), predators (%), shredders (%).

Table 2. Bioassessment metrics used to describe characteristics of the BMI community results.

BMI Metric	Description	Response to Impairment
Richness Measures		
Taxa Richness	Total number of individual taxa	decrease
EPT Taxa	Number of taxa in the Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) insect orders	decrease
Ephemeroptera Taxa	Number of taxa in the insect order Ephemeroptera (mayflies)	decrease
Plecoptera Taxa	Number of taxa in the insect order Plecoptera (stoneflies)	decrease
Trichoptera Taxa	Number of taxa in the insect order Trichoptera (caddisflies)	decrease
Composition Measures		
EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae	decrease
Sensitive EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae with tolerance values between 0 and 3	decrease
Shannon Diversity	General measure of sample diversity that incorporates richness and evenness (Shannon and Weaver 1963)	decrease
Tolerance / Intolerance Measures		
Tolerance Value	Value between 0 and 10 weighted for abundance of individuals designated as pollution tolerant (higher values) or intolerant (lower values)	increase
Percent Intolerant Organisms	Percent of organisms in sample that are highly intolerant to impairment as indicated by a tolerance value of 0, 1 or 2	decrease
Percent Tolerant Organisms	Percent of organisms in sample that are highly tolerant to impairment as indicated by a tolerance value of 8, 9 or 10	increase
Percent Dominant Taxa	Percent composition of the single most abundant taxon	increase
Percent Hydropsychidae	Percent of organisms in the caddisfly family Hydropsychidae	increase
Percent Baetidae	Percent of organisms in the mayfly family Baetidae	increase
Functional Feeding Groups (FFG)		
Percent Collectors	Percent of macrobenthos that collect or gather fine particulate matter	increase
Percent Filterers	Percent of macrobenthos that filter fine particulate matter	increase
Percent Grazers	Percent of macrobenthos that graze upon periphyton	variable
Percent Predators	Percent of macrobenthos that feed on other organisms	variable
Percent Shredders	Percent of macrobenthos that shreds coarse particulate matter	decrease
Estimated Abundance	Estimated number of BMIs in sample calculated by extrapolating from the proportion of organisms counted in the subsample	variable

Parametric Testing

Replicate biological metric data were used to statistically test for differences among stations using analysis of variance (ANOVA). When assumptions of parametric statistics could not be met (such as non-normality or excessive variability), the tests were replaced with nonparametric analogues (Kruskal-Wallis One-Way ANOVA on Ranks and Kruskal-Wallace Rank Test, respectively). Significance was noted when $p \le 0.05$ and marginal significance was noted when $0.05 < p \le 0.10$).

Southern California IBI

The seven biological metric values used to compute the Southern California Index of Biological Integrity (So CA IBI) are presented in Table 3 (Ode et al. 2005). The So CA IBI is based on the calculation of biological metrics from a group of 500 organisms from a composite sample collected at each stream reach. Since 900 organisms were identified from each sample for this survey (3 replicates, 300 organisms each), Monte Carlo randomization was used to select 500 organisms from the 900 collected at each station before the IBI metrics were calculated. This procedure was validated by Ode et al. (2005).

The IBI calculation for data collected for this program from spring 2005 to fall 2006 inadvertently used % non-insect individuals and % tolerant individuals, instead of % non-insect taxa and % tolerant taxa. The re-computed index scores and ranks for each sampling event are presented in Appendix B (Table 10, Figure 10).

Table 3. Scoring ranges for the seven metrics included in the southern California IBI and the IBI values.

Metric Scoring Ranges for the Southern California IBI

Metric Score	Coleoptera Taxa	EPT Taxa		Predator Taxa	% Collector Individuals		% Intolerant Individuals		% Non-Insect Taxa	% Tolerant Taxa
	All Sites	6	8	All Sites	6	8	6	8	All Sites	All Sites
10	>5	>17	>18	>12	0-59	0-39	25-100	42-100	0-8	0-4
9		16-17	17-18	12	60-63	40-46	23-24	37-41	9-12	5-8
8	5	15	16	11	64-67	47-52	21-22	32-36	13-17	9-12
7	4	13-14	14-15	10	68-71	53-58	19-20	27-31	18-21	13-16
6		11-12	13	9	72-75	59-64	16-18	23-26	22-25	17-19
5	3	9-10	11-12	8	76-80	65-70	13-15	19-22	26-29	20-22
4	2	7-8	10	7	81-84	71-76	10-12	14-18	30-34	23-25
3		5-6	8-9	6	85-88	77-82	7-9	10-13	35-38	26-29
2	1	4	7	5	89-92	83-88	4-6	6-9	39-42	30-33
1		2-3	5-6	4	93-96	89-94	1-3	2-5	43-46	34-37
0	0	0-1	0-4	0-3	97-100	95-100	0	0-1	47-100	38-100

Cumulative IBI Scores

Very Poor	Poor	Fair	Good	Very Good
0-19	**20-39**	**40-59**	**60-79**	**80-100**

RESULTS

Habitat Characteristics and Water Quality

The physical characteristics of the transects sampled at Stations NR1 (upstream) and NR3 (downstream) in the Santa Clara River were low gradient (<1%) (Table 4). Average wetted width was similar at both sites and depth was greater at Station NR1 during both seasons. Bank stability was 100% at Station NR1 during both seasons owing to dense vegetation along both banks. Station NR3 had banks that were 100% vulnerable to erosion in the spring and 50% eroded by the fall survey. Vegetative canopy cover was greatest at Station NR3 during both seasons. The dominate flow habitat found at the two sites were runs during both seasons, except at Station NR1 in the spring where riffles dominated the reach.

Water quality measurements for each parameter were within normal ranges at both sites. Temperatures were warmest in the spring and cooler in the fall. Each of the other parameters were similar at both sites, during each season, except at Station NR1 in the spring when pH and dissolved oxygen were greater compared to NR3.

***Physical/Habitat Scores*:** Assessment of the physical/habitat conditions of a stream reach is necessary to determine its quality as a habitat for BMIs. In many cases organisms may not be exposed to chemical contaminants, yet their populations indicate that impairment has occurred. These population shifts can be the result of degraded stream bed and bank habitat. Excess sediment is the leading pollutant in streams and rivers of the United States (Harrington and Born 2000). Sediments fill pools and interstitial areas of the stream substrate where fish spawn and invertebrates live, causing their populations to decline or to be altered.

Out of a total possible score of 200, the physical/habitat score for Station NR3 was in the marginal range and NR1 was in the sub-optimal range during both seasons (Table 5 and Figure 3). Better physical habitat conditions at Station NR1, when compared to NR3, could be attributed to slightly less sediment deposition and channel alteration, coupled with better bank stability, vegetative canopy cover and riparian zone width. Scores were similar between seasons.

Table 4. Physical habitat measurements for 2 reaches in the Santa Clara River. Measurements are specified in by SWAMP (2007).

Parameter	NR3		NR1	
	Spring	Fall	Spring	Fall
Habitat Characteristics				
Reach Length (m)	150	150	150	150
Average Wetted Width (m)	7.6	9.4	5.4	5.0
Average Depth (cm)	28	23	36	32
Velocity (m/sec)	0.67	NR	0.55	NR
Discharge (m^3)	NR	0.70	NR	0.86
Bank Stability				
% Stable	0	50	100	100
% Vulnerable	100	0	0	0
% Eroded	0	50	0	0
Vegetative Canopy Cover (%)	11.9	26.9	1.1	3.2
Flow Habitats (%)				
Cascade/Fall	0	0	0	0
Rapid	0	0	0	0
Riffle	0	0	76	0
Run	89.5	100	18.5	100
Glide	10.5	0	5.5	0
Pool	0	0	0	0
Dry	0	0	0	0
Percent Gradient (%)	0.1		0.2	
Chemical Characteristics				
Water Temperature (C°)	20.17	16.75	23.52	19.27
pH	7.78	7.67	8.02	7.87
Alkalinity	240	245	238	230
DO	7.99	8.20	10.03	7.82
Specific Conductance (S/cm at 25EC)	1336	1201	1290	1186
Salinity (ppt)	0.74	0.72	0.66	0.67

Table 5. Physical habitat assessment for the two sampling sites in the Santa Clara River.

Habitat Parameter	**NR3**		**NR1**	
	Spring	**Fall**	**Spring**	**Fall**
1. Instream Cover	6	10	11	10
2. Embeddedness	5	6	9	7
3. Velocity / Depth Regime	10	15	12	15
4. Sediment Deposition	6	8	11	11
5. Channel Flow	6	10	8	7
6. Channel Alteration	13	11	16	19
7. Riffle Frequency	6	6	10	6
8. Bank Stability	8	7	14	18
9. Vegetative Protection	8	10	14	14
10. Riparian Vegetative Zone Width	14	8	18	18
Reach Total	**82**	**91**	**123**	**125**
Condition Category	**Marginal**	**Marginal**	**Suboptimal**	**Suboptimal**

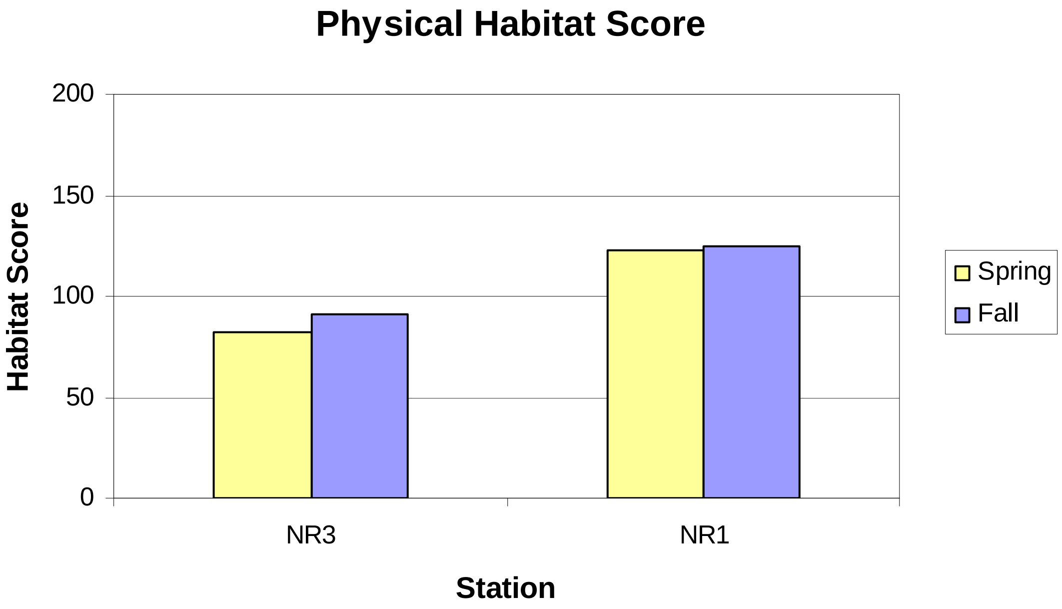


Figure 3. Physical/Habitat quality scores by season.

BMI Community Structure

The BMIs identified from each site are listed in order of ranked abundance in Table 6. The biological metrics calculated from each BMI sample are listed in Table 7 and Figures 4 thru 7. The Southern California IBI scores for each site and season are presented in Table 8 and Figure 8, and averaged by site for each survey since 2004 in Figure 9. Raw BMI abundances, tolerance values and feeding groups are presented in the Appendix, Tables 9a and 9b.

A total of 3,620 BMIs were identified from the samples collected during the spring and fall at the two sampling sites. During the spring seed shrimp (Ostracoda) represented 23% and 37% of the population at Stations NR3 and NR1, respectively (Table 6). Other relatively abundant species at both stations included oligochaete worms (15%), midge flies (Chrionomidae), and the mayfly, *Fallceon quilleri*. During the fall survey the most abundant species at Stations NR1 and NR3 were nematodes, midge flies, flatworms (Turbellaria), and mayflies (*Fallceon quilleri* and *Tricorythodes sp*.).

Biological Metrics

Each of the biological metrics listed in Table 2 above, was calculated for this survey and is presented in Table 7. Each metric is depicted graphically by community measure in Figures 4 to 7.

***Community Richness Measures*:** Taxa richness is a measure of the total number of species found at a site. This relatively simple index can provide much information about the integrity of the community. Few taxa at a site indicate that some species are being excluded, while a large number of species indicate a more healthy community. EPT taxa are the number of all of the mayflies (Ephemeroptera), caddisflies (Trichoptera), and stoneflies (Plecoptera) present at a location. These families are generally sensitive to impairment and, when present, are usually indicative of a healthier community than if any or all are absent. Metrics for Coleopteran and Predator taxa are included since they are used to calculate the So CA IBI.

Each of the community richness measures was similar between stations and seasons, and there were no significant differences among sites by ANOVA (Table 7 and Figure 4). Taxonomic richness ranged from 18 to 20, and EPT taxa ranged from 3 to 5. Numbers of Coleoptera were low during both seasons. Predator taxa ranged from 5 to 7.

***Composition Measures*:** The percent EPT taxa, sensitive EPT, percent non-insect taxa and the Shannon Diversity Index are all measures of community composition. Species diversity indices are similar to numbers of species; however they contain an evenness component as well. For example, two samples may have the same numbers of species and the same numbers of individuals. However, one station may have most of its numbers concentrated into only a few species while a second station may have its numbers evenly distributed among its species. The diversity index would be higher for the latter station. Percent EPT taxa are the proportion of the abundance at a site that is comprised of mayflies, stoneflies and caddisflies. Percent Sensitive EPT taxa are similar except it includes only those EPT taxa whose tolerance values range from 0 to 3. These taxa are very sensitive to impairment and, when present, can be indicative of better water quality conditions. Percent non-insect taxa is a measure of all other phyla represented at a site and, when elevated, generally indicate poorer water quality conditions.

The percentage of EPT taxa were somewhat greater at both Stations NR1 and NR3 during the spring compared to the fall (Table 7 and Figure 5). No sensitive EPT taxa were collected from the survey area. Shannon Diversity and non-insect individuals were nearly the same at each station, during both seasons. There were significantly greater numbers of non-insect taxa at Station NR3 in the fall compared to at Station NR1.

Tolerance Measures**:** The Southern California IBI uses both the percent intolerant individuals and percent tolerant taxa to evaluate the overall sensitivity of organisms to pollution and habitat impairment. Each species is assigned a tolerance value from 0 (highly intolerant) to 10 (highly tolerant). The percent intolerance individuals for a site is calculated by multiplying the tolerance value of each species with a tolerance value ranging from 0 to 2, by its abundance, then dividing by the total abundance for the site. The percent tolerant taxa are similar except that only species with tolerance values ranging from 8 to 10 are included and total numbers of taxa, instead of individuals is used to derive the proportion. A site with many tolerant organisms present is considered to be less pristine or more impacted by human disturbance than one that has few tolerant species. The tolerance values for each species were developed in different parts of the United States and can therefore be region specific. Also, different organisms can be tolerant to one type of disturbance, but highly sensitive to another. For example, an organism that is highly sensitive to sediment deposition may be very insensitive to organic pollution. With these drawbacks in mind, the Tolerance measures generally depict disturbances in a stream that, when coupled with other metrics, can provide good water quality information regarding a stream reach.

Percent dominance reflects the proportion of the total abundance at a site represented by the most abundant species. For example, if 100 organisms are collected at a site and species A is the most abundant with 30 individuals, the percent dominance index score for the site is 30%. The benthic environment tends to be healthier when the dominance index is low, which indicates that more than just a few taxa make up the majority of the community.

The tolerance metrics reported for this survey indicated that Mean tolerance values were moderate (5 to 6) at both sites, during both seasons (Table 7 and Figure 6). Percent dominance and percent tolerant taxa were also similar during both seasons, at both sites. There were no intolerant organisms found in the survey area during either season. The percentage of Baetid mayflies was slightly greater in the fall and there were a significantly greater number of Baetid mayflies at Station NR3 during the fall, compared to Station NR1.

Functional Feeding Groups**:** These indices provide information regarding the balance of feeding strategies represented in an aquatic assemblage. The combined feeding strategies of the organisms in a reach provide information regarding the form and transfer of energy in the habitat. When the feeding strategy of a stream system is out of balance it can be inferred that the habitat is stressed. For the purposes of this study, species were grouped by feeding strategy as percent collector-gatherers, collector-filterers, grazers, predators and shredders. The Southern California IBI uses the numbers of predators and percent collectors (gatherers + filterers) at a site to calculate the index.

Species using collecting and filtering, grazing and predation as their feeding strategy were the most common organisms collected during both seasons (Table 7). Collectors and filterers were dominant in the spring, followed by grazers and predators, at both stations. In the fall collectors and filterers were again dominant at Station NR3, but predators were dominant at Station NR1, followed by collectors and filterers. These differences among stations were significant. The increased numbers of predators at NR1 in the fall was due to large abundances of dragonflies (Odonata) and flatworms (Turbellaria).

***IBI Scores*:** Work conducted in the 1990's by the San Diego Regional Board and the California Department of Fish and Game, established an Index of Biotic Integrity (IBI) for the San Diego region and its watersheds (Ode and Harrington 2002). The index was recently expanded to include all of southern California (Ode et. al. 2005) and is used in this section.

The IBI is a multi-metric technique that employs seven biological metrics that were each found to respond to a habitat and/or water quality impairment at sites from Monterey, California to the Mexican boarder. Each of the seven biological metrics measured at a site are converted to an IBI score then summed. These cumulative scores can then be ranked according to very good (80-100), good (60-79), fair (40-59), poor (20-39) and very poor (0-19) habitat conditions. The threshold limit for this scoring index is 39. Despite the fact that rankings can be identified as "fair", sites with scores above 39 are within two standard deviations of the mean reference site conditions in southern California and are not considered to be impaired. Sites with scores below 39 are considered to have impaired conditions. The metric scoring ranges established for the Southern California IBI survey are listed in Table 4 and were used to classify the sites in this study.

2007

The Southern California IBI scores for 2007 ranged from 23 to 46, with each station ranking in the "poor" range, except Station NR1 in the fall which ranked as "fair" (Table 8 and Figure 8). Except for Station NR1 in the fall, the BMI communities at each of these sites were impaired when compared to conditions found at reference site locations throughout southern California. These impaired conditions appear to be due to habitat disruptions based on the low physical habitat scores measured at these sites (Table 5, Figure 3). Lower scores across sites and seasons were mostly due to the lack of EPT taxa and intolerant taxa and large abundances of relatively tolerant taxa. The improved IBI scores at NR1 in the fall were due to large numbers of predator organisms (predominately dragonflies), the presence of two species of beetle taxa (Coleoptera) and fewer collector taxa.

2004 to 2007

To assess the condition of BMI communities at Stations NR1 and NR3 over time, IBI scores were averaged (± 95% CI) by station and season for all surveys conducted between the spring of 2004 and the fall of 2007 (Figure 9). The average IBI scores at each site were in the poor range for the four year period. This shows that BMI habitat conditions upstream and downstream of the Newhall WRP were similar during this four year period. Importantly, the scores were similar between locations so that future comparisons between sites upstream and downstream of the discharge point will be possible.

DISCUSSION

The Santa Clara River watershed is the longest free-flowing natural river in southern California. Its 70 mile length provides drainage to a 1,600 mi^2 watershed. Before reaching the Pacific Ocean in Ventura, it passes through the Santa Clarita Valley where a large urban development project is planned. A part of this project includes the construction of a Water Reclamation Plant (WRP) that will service the residences and commercial businesses that are included in this project. The future discharge site for the treatment plant is located on Newhall Ranch property in Los Angeles County just upstream of the border with Ventura County. The Newhall Ranch property, which borders both sides of the Santa Clara River, has been used historically for agriculture, ranching oil drilling operations.

For the most part, the Santa Clara River has been allowed to follow its natural course through the valley. The water flow in the river varies widely between wet weather, when the river typically reaches 100,000 cubic feet per second (cfs), and the summer and fall when the river bed can be nearly dry (Swanson et al. 1990). Presently, the combination of natural river flow, urban runoff and the discharge from upstream waste treatment facilities maintain a relatively constant low flow of water in the River, even during the driest summer months.

The goal of this project was to assess the baseline conditions of the benthic macro-invertebrate community in the Santa Clara River at sites located at the discharge point for the future WRP and downstream of it. These data will allow managers to assess if changes are occurring to the benthic community after the treatment plant is completed and discharge to the river has begun. Bioassessment samples were collected, and physical habitat assessments were made on July 27th and October 31st, 2007 at two locations in the Santa Clara River near the Los Angeles/Ventura County line. Site NR1 was located at the future discharge point for the WRP, while NR3 was located 2.7 miles downstream.

All samples and physical habitat surveys were collected and analyzed according to the protocols established in the recently promulgated State of California, Stormwater Ambient Monitoring Program (SWAMP 2007). These protocols were based on the California Stream Bioassessment Protocols (CSBP 2003) and the EPA’s Environmental Monitoring and Assessment Program (EMAP). The results of BMI community metrics collected by each of these protocols were found to be comparable (Rehn et al. 2006). This means that BMI data collected by the CSBP method before 2007 are comparable. The quality assurance criteria specified in the SWAMP protocol were met for both the physical habitat and taxonomic portions of the program.

The Visual-Based Habitat (VBH, Barbour et al. 1999) physical/habitat assessment scores for both the upstream and downstream stations (NR1 and NR3, respectively) were marginal to sub-optimal, with the best conditions found at NR1 during both the spring and fall. The river beds at both stations were of relatively low gradient and composed of mostly sandy particles, with no cobble, boulders, undercut banks or branch fall. Combined, these habitat conditions do not provide for the types of complex habitat that will support a wide diversity of BMIs. Comparing the two sites, the better physical habitat conditions at Station NR1 were mostly associated with less channel alteration, better bank stability, vegetative cover and riparian zone width. The lower scores at Station NR3 were, for the most part, due to large amounts of sedimentation and channel alteration, poor bank stability, and less vegetative canopy cover and riparian zone.

The VBH scoring system used in the CSBP (2003) protocols were originally developed in the mid-west and eastern United States by the USEPA. As a result, the appropriateness of it’s application to low gradient river wash systems such as the Santa Clara River have been questioned. However, since the VBH has been used since the inception of the BMI program in 2004, its use in 2007 was intended to help provide historical context for the physical habitat attributes found during the survey and to determine if any large scale changes to the streambed system had occurred at either site in the previous year. The new Basic SWAMP (2007) physical habitat assessment was also conducted in 2007 at each site. While useful, the scoring system for this protocol has not been completed, which makes judgment of habitat quality difficult.

The Santa Clara River is a large drainage for the Transverse Ranges of southern California and has ephemeral discharge due to winter rainfall and dry summers (Inman and Jenkins 1999). It is the largest contributor of sediment to the coastal ocean waters of the southern California bight due to its steep landscape, weak sedimentary rocks and intense seasonal rainfall (Schwalbach and Gorsline 1985, Scott and Williams 1978, Warrick 2002). Therefore, the large amounts of sediment present in the Santa Clara River bed at Stations NR1 and NR3 may be the result of naturally occurring processes. During a study of the Santa Clara River in 2001, Ambrose (et. al. 2003) also found that sites located at Newhall Ranch were characterized by sandy sediments.

The BMI population metrics measured at both NR1 and NR3 during 2007 was similar in terms of richness, composition, and tolerance measures. Several metrics were significantly different among stations by ANOVA, with the majority of these being community feeding group measures in the fall. These differences were mostly explained by the dominance of collectors and filterers at Station NR3 and a corresponding dominance of predators at Station NR1. The increase in predators at NR1 was due to the presence of large abundances of dragonflies (Odonata) and flatworms (Turbellaria).

The BMI population in this reach of the Santa Clara River is characterized by the absence of intolerant species (sensitive species) and sensitive EPT taxa. Intolerant organisms are those that have been assigned a tolerance value from zero to two. Sensitive EPT taxa are mayflies, stoneflies and caddisflies whose tolerance values range from 0 to 3. Each of these taxa groups are very sensitive to impairment and, when present, can be indicative of more natural conditions. During a 2001 watershed-wide survey conducted by Ambrose (et. al. 2003), investigators found similar BMI communities at sites near those used during the current study.

The IBI scores at both NR1 and NR3 indicated that the condition of the biological communities found there were impaired when compared to the conditions at reference sites in southern California. The exception to the low IBI scores was Station NR1 in the fall when the IBI score was in the fair range. It is possible that the physical habitat condition of this site, which was somewhat better than at Station NR3, is playing a role in this improvement. The increased IBI score at NR1 in the fall was due to large numbers of predator organisms (predominately dragonflies), the presence of two species of beetle taxa (Coleoptera) and fewer collector taxa. It should be noted that while low gradient reference sites were included in the development of the southern California IBI (Ode et al 2005), work is currently underway to determine if the index accurately characterizes large river wash systems such as the Santa Clara River. This work is being conducted by the Stormwater Monitoring Coalition (SMC), which is a consortium of watershed and stormwater agencies that are tasked with assessing the condition of southern California watersheds.

To assess the condition of BMI communities at Stations NR1 and NR3 over time, IBI scores were averaged (± 95% CI) by station and season for all surveys conducted between the spring of 2004 and the fall of 2007. The average IBI score at each site were in the poor range for the four year period. This shows that BMI habitat conditions upstream and downstream of the proposed Newhall WRP outfall location were similar during this four year period.

In prior reports (Aquatic Bioassay 2005 to 2007), the IBI scores were inadvertently miscalculated using % non-insect individuals and % tolerant individuals, instead of % non-insect taxa and % tolerant taxa. The IBI scores in this year's report are corrected. In addition, the IBI scores for the previous reports were recomputed and are presented in Appendix B. While the scores vary between old and new computations, the overall ranking of poor for both sites across each sampling event was unchanged.

The results of the 2007 survey on the Santa Clara River in the vicinity of the future WRP in the Santa Clarita Valley indicated that the river habitat is typical of a southern California river wash located in a heavily developed land use area. As a result, the BMI communities residing there are impaired. One likely disturbance is the high amount of sediments in the river bed and, therefore, the lack of complex habitat. This sedimentation may be the result of the natural geomorphic composition and ephemeral nature of the surrounding watershed and/or human activities.

Table 6. Average species ranked by abundance for each site and season for the Santa Clara River bioassessment survey.

Spring				Fall			
NR3		NR1		NR3		NR1	
Species	% of Total Abund	Species	% of Total Abund	Species	% of Total Abund	Species	% of Total Abund
Ostracoda	23.7	Ostracoda	37	Nematoda	21.8	Turbellaria	27
Oligochaeta	15.6	Oligochaeta	12.1	Chironomidae	19.2	Nematoda	16.1
Chironomidae	15.2	Fallceon quilleri	12	Fallceon quilleri	15.3	Tricorythodes sp	8.9
Hydroptila sp	13.8	Turbellaria	9.2	Oligochaeta	8.9	Chironomidae	7.3
Hydroptilidae	6.1	Hydroptila sp	6.8	Ostracoda	8.3	Simulium sp	6.7
Nematoda	5.9	Tricorythodes sp	6.6	Turbellaria	7.6	Hetaerina sp	6.4
Fallceon quilleri	4.5	Chironomidae	3.2	Simulium sp	5.9	Argia sp	5.8
Hemerodromia sp	4.5	Simulium sp	3.1	Tricorythodes sp	5.4	Physa sp	5.7
Simulium sp	3.3	Caloparyphus/Euparyphus sp	1.9	Sperchon sp	1.6	Fallceon quilleri	5.4
Turbellaria	2	Hydroptilidae	1.7	Baetis sp	1.6	Coenagrionidae	3
Physa sp	1.4	Baetis sp	1.1	Physa sp	0.8	Ostracoda	2.1
Caloparyphus/Euparyphus sp	0.8	Caloparyphus sp	1.1	Copepoda	0.8	Oligochaeta	1.4
Sperchon sp	0.7	Physa sp	0.9	Coenagrionidae	0.7	Chrysomelidae	0.8
Pericoma/Telmatoscopus sp	0.4	Bezzia/Palpomyia sp	0.6	Ephydridae	0.4	Zoniagrion exclamationis	0.4
Baetis sp	0.2	Nematoda	0.6	Hemerodromia sp	0.4	Caloparyphus/Euparyphus sp	0.3
Euparyphus sp	0.2	Sperchon sp	0.5	Hydroptilidae	0.2	Postelichus sp	0.3
Zoniagrion exclamationis	0.2	Zoniagrion exclamationis	0.4	Hydrozetidae	0.2	Hemerodromia sp	0.3
Anisoptera	0.1	Culicoides sp	0.3	Hetaerina americana	0.2	Pericoma/Telmatoscopus sp	0.2
Atractides sp	0.1	Hemerodromia sp	0.3	Argia sp	0.1	Brechmorhoga mendax	0.2
Bezzia/Palpomyia sp	0.1	Coenagrionidae	0.2	Culicoides sp	0.1	Hydropsyche sp	0.2
Coenagrionidae	0.1	Euparyphus sp	0.2	Cladocera	0.1	Optioservus sp	0.2
Culicoides sp	0.1	Helochares sp	0.1	Ceratopogonidae	0.1	Libellulidae	0.1
Ephydridae	0.1			Caloparyphus/Euparyphus sp	0.1	Bezzia/Palpomyia sp	0.1
Helochares sp	0.1			Nemotelus sp	0.1	Ceratopogon sp	0.1
Heteroceridae	0.1					Baetis sp	0.1
Libellulidae	0.1					Ephydridae	0.1
Peltodytes sp	0.1					Libellula sp	0.1
Tropisternus sp	0.1					Petrophila sp	0.1
						Psychodidae	0.1
						Tyrrellia sp	0.1
						Hydrozetidae	0.1
TOTAL	100		100		100		100

Table 7. Comparison of averaged biological metrics (± SD, CV & 95% CI) for each site by season, evaluated using ANOVA. Grayed F scores significant at p ≤ 0.05.

		Spring					Fall				
		Station			Comparison		Station			Comparison	
Metric		**NR3**	**NR1**	**Avg**	**F-Ratio**	**p**	**NR3**	**NR1**	**Avg**	**F-Ratio**	**p**
Community Richness Measures											
Taxonomic richness	**mean**	18	18	18	0.03	0.87	18	20	19	3.77	0.12
	st. dev.	3.1	1.7	2.4			1	2	1		
	cv	17.3	9.6	13.4			3	10	7		
	95% CI	3.5	2	2.8			1	2	2		
EPT taxa	**mean**	4	5	4	4.50	0.10	3	3	3	2.00	0.23
	st. dev.	0.6	0.6	0.6			1	1	1		
	cv	15.7	12.4	14			17	22	20		
	95% CI	0.7	0.7	0.7			1	1	1		
Cumulative EPT Taxa	**mean**	4	3	4	N/A		4	4	4	N/A	
Coleoptera Taxa	**mean**	1	0	1	1.80	0.25	0	2	1	**3.85**[1.]	**0.05**
	st. dev.	1	1	0.9			0.0	0.0	0		
	cv	87	173	129.9			-	0.0	0		
	95% CI	1	1	1			0.0	0.0	0		
Predator Taxa	**mean**	6	5	6	0.45	0.53	6	7	7	0.96	0.38
	st. dev.	3	1	2			2	3	2		
	cv	40	11	25			27	34	31		
	95% CI	3	1	2			2	3	2		
Community Composition Measures											
EPT Index (%)	**mean**	24.6	28.0	26.3	0.19	0.68	22.5	14.6	18.6	2.13	0.22
	st. dev.	0.7	13.3	7.0			6.3	6.9	6.6		
	cv	2.7	47.5	25.1			27.8	47.4	37.6		
	95% CI	0.8	15.1	8			7.1	7.8	7.4		
Sensitive EPT Index (%)	**mean**	0	0	0.0	N/A		0.0	0.0	0.0	N/A	
	st. dev.	0	0	0.0			0.0	0.0	0.0		
	cv	-	-	-							
	95% CI	0	0	0			0.0	0.0	0.0		
Shannon Diversity	**mean**	2.2	2.0	2.1	2.03	0.23	2.2	2.2	2	0.06	0.82
	st. dev.	0.0	0.2	0.1			0.1	0.3	0		
	cv	1.7	12.1	6.9			3.1	12.3	8		
	95% CI	0.0	0.3	0			0.1	0.3	0		
Percent Non-Insect Individuals	**mean**	50.1	60.5	55.3	1.91	0.24	50.1	52.6	51	0.76	0.43
	st. dev.	4.0	12.5	8.2			1.8	4.6	3		
	cv	8.0	20.7	14.4			3.6	8.7	6		
	95% CI	4.5	14.1	9			2.1	5.2	4		
Percent Non-Insect Taxa	**mean**	34.2	33.2	33.7	0.30	0.62	45.3	27.0	36	**29.97**	**0.01**
	st. dev.	5.4	6.9	6.1			1.6	7.3	4		
	cv	15.7	20.6	18.1			3.4	17.6	11		
	95% CI	6.1	7.8	7			1.8	8.3	5		
Community Tolerance Measures											
Mean Tolerance Value	**mean**	6.1	6.1	6.1	0.00	1.00	5.4	5.3	5	0.64	0.47
	st. dev.	0.3	0.7	0.5			0.2	0.2	0		
	cv	4.9	11.5	8.2			2.8	2.9	3		
	95% CI	0.3	0.8	1			0.2	0.2	0		
% dominant taxa	**mean**	24.1	39.8	31.9	3.19	0.14	23.2	31.3	27.2	1.02	0.36
	st. dev.	4.1	14.7	9.4			6.0	12.5	9.2		
	cv	17.1	36.9	27.0			26.1	40.0	33.0		
	95% CI	4.7	16.6	11			6.8	14.1	10.4		
Percent Tolerant Taxa	**mean**	30.6	29.7	30.1	0.03	0.87	37.3	26.3	31.8	2.10	0.22
	st. dev.	8.2	3.0	5.6			9.0	9.5	9.2		
	cv	26.9	9.9	18.4			24.2	36.0	30.1		
	95% CI	9.3	3.3	6			10.2	10.7	10.5		

Table 7. (continued)

Metric		Spring					Fall				
		Station			Comparison		Station			Comparison	
		NR3	NR1	Avg	F-Ratio	p	NR3	NR1	Avg	F-Ratio	p
Community Tolerance Measures (continued)											
Percent Tolerant Individuals (8-10)	**mean**	28.9	41.8	35.3	1.10	0.35	12.6	12.1	12.3	0.08	0.79
	st. dev.	7.3	20.0	13.6			1.8	2.2	2.0		
	cv	25.2	47.8	36.5			14.4	17.9	16.2		
	95% CI	8.2	22.6	15			2.0	2.4	2.2		
Percent Intolerant Individuals (0-2)	**mean**	0.0	0.0	0.0	N/A		0.0	0.0	0.0	N/A	
	st. dev.	0.0	0.0	0.0			0.0	0.0	0.0		
	cv	-	-	-			-	-	-		
	95% CI	0.0	0.0	0.0			0.0	0.0	0.0		
Percent Hydropsychidae	**mean**	0.0	0.0	0.0	N/A		0.0	0.2	0.1	1.00	0.37
	st. dev.	0.0	0.0	0.0			0.0	0.4	0.2		
	cv	-	-	-				173.2	173.2		
	95% CI	0.0	0.0	0.0			0.0	0.5	0.2		
Percent Baetidae	**mean**	4.5	13.0	8.8	1.60	0.27	17.0	5.6	11.3	**10.00**	**0.03**
	st. dev.	2.5	11.3	6.9			5.2	3.4	4.3		
	cv	56.1	87.0	71.6			30.8	60.4	45.6		
	95% CI	2.9	12.8	8			5.9	3.8	4.8		
Community Feeding Group Measures											
Percent Collectors & Filterers	**mean**	64.0	78.8	71.4	**6.52**	**0.06**	66.2	33.0	49.6	**24.86**	**0.01**
	st. dev.	3.4	9.4	6.4			11.4	1.7	6.6		
	cv	5.4	12.0	8.7			17.2	5.0	11.1		
	95% CI	3.9	10.7	7.3			12.9	1.9	7.4		
Percent Collectors	**mean**	61.1	75.7	68.4	**6.28**	**0.06**	60.2	26.1	43.1	**27.16**	**0.01**
	st. dev.	1.4	10.0	5.7			10.4	4.5	7.4		
	cv	2.3	13.2	7.8			17.3	17.3	17.3		
	95% CI	1.6	11.3	6			11.8	5.1	8.4		
Percent Filterers	**mean**	2.9	3.1	3.0	0.01	0.91	6.0	6.9	6.5	0.08	0.79
	st. dev.	2.9	1.7	2.3			3.7	4.2	4.0		
	cv	101.1	53.7	77.4			61.2	60.9	61.0		
	95% CI	3.3	1.9	3			4.2	4.8	4.5		
Percent Grazers	**mean**	22.1	9.3	15.7	**14.90**	**0.02**	1.0	6.0	3.5	**34.34**	**<0.01**
	st. dev.	3.8	4.3	4.0			0.3	1.5	0.9		
	cv	17.2	45.9	31.6			30.0	24.2	27.1		
	95% CI	4.3	4.8	5			0.3	1.6	1.0		
Percent Predators	**mean**	13.8	11.9	12.8	0.30	0.61	32.8	60.2	46.5	**17.94**	**0.01**
	st. dev.	2.4	5.7	4.0			11.2	0.0	5.6		
	cv	17.4	48.1	32.8			34.1	0.0	17.0		
	95% CI	2.7	6.5	5			12.7	0.0	6.4		
Percent Shredders	**mean**	0.0	0.0	0.0	N/A		0.0	0.8	0.4	**64.00**	**0.00**
	st. dev.	0.0	0.0	0.0			0.0	0.2	0.1		
	cv	-	-	-				21.7	21.7		
	95% CI	0.0	0.0	0.0			0.0	0.2	0.1		
Percent Chironomidae	**mean**	15.2	3.2	9.2	**61.39**	**<0.01**	19.2	7.3	13	**16.49**	**0.01**
	st. dev.	2.4	1.2	1.8			3.8	3.4	4		
	cv	15.6	37.7	26.6			19.7	45.7	33		
	95% CI	2.7	1.4	2			4.3	3.8	4		

[1] Variences not equal, ANOVA by Kruskall-Wallis one way ANOVA on ranks and multiple comparison by Kruskall-Wallis Z-test

Marginally Significant	(0.05 < p < 0.10), difference generally not large enough for multiple comparisons to detect.
Significant	(p <0.05)

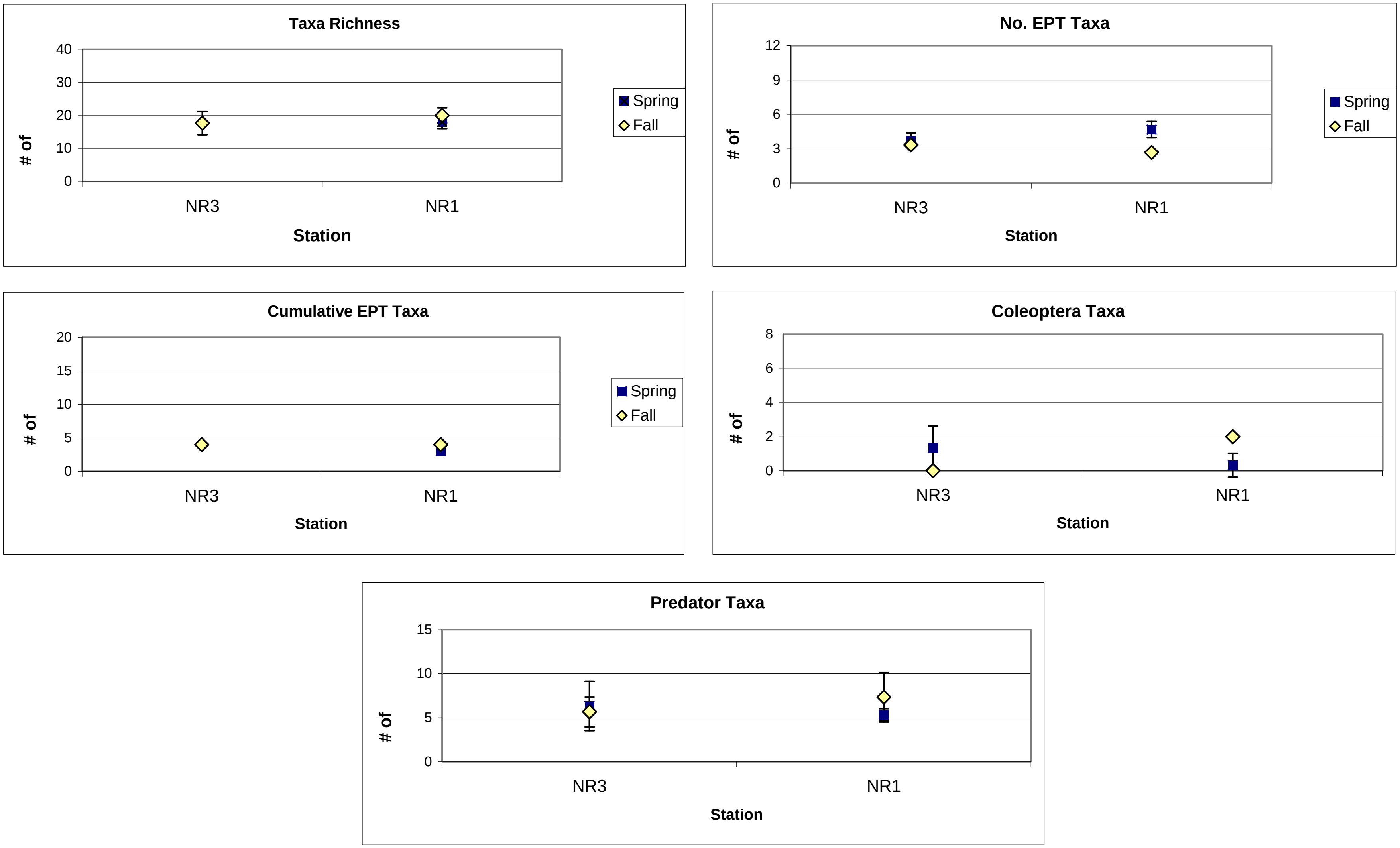


Figure 4. Averaged community richness metrics (± 95% CI) by season for each site.

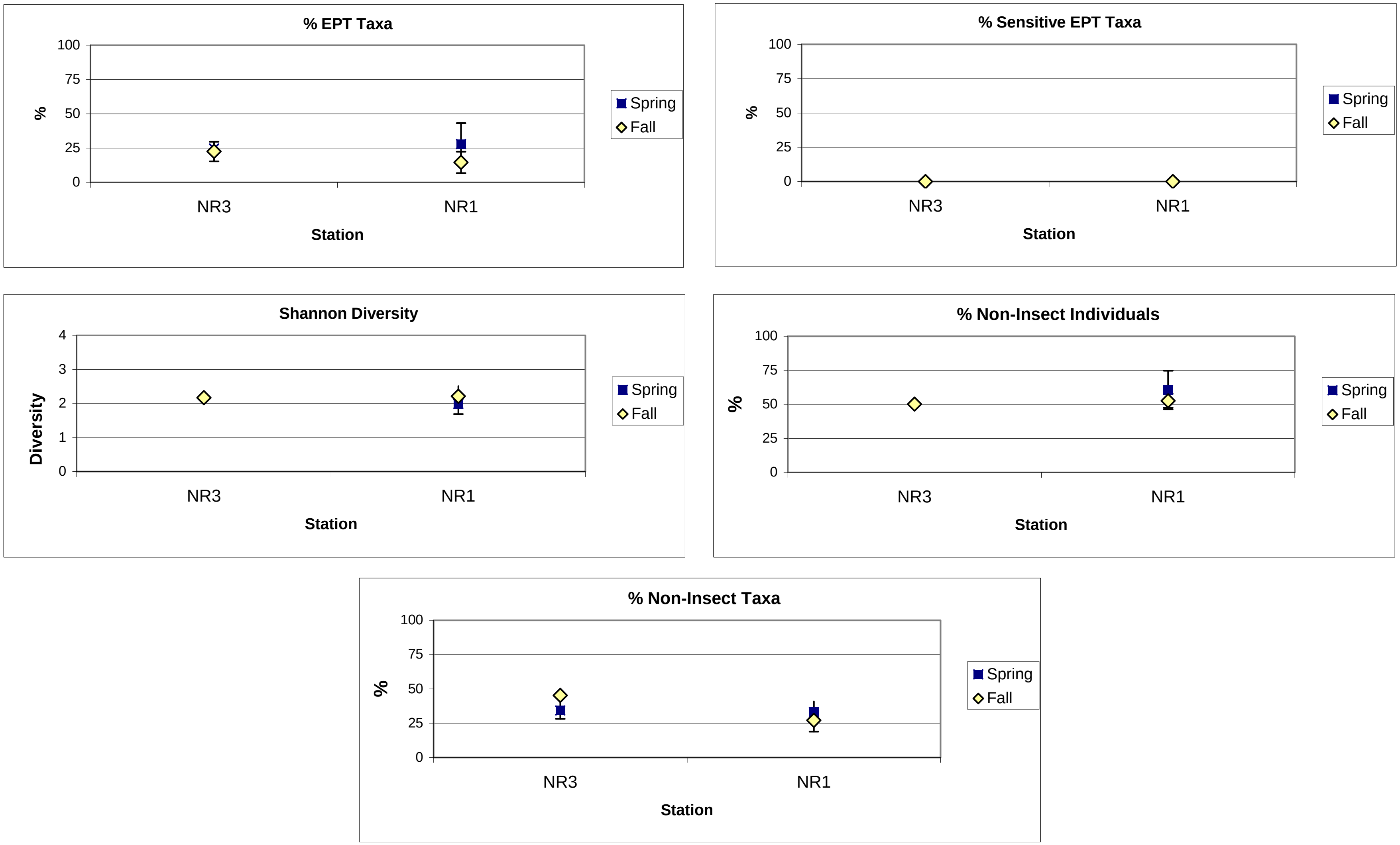


Figure 5. Averaged community composition metrics (± 95% CI) by season for each site.

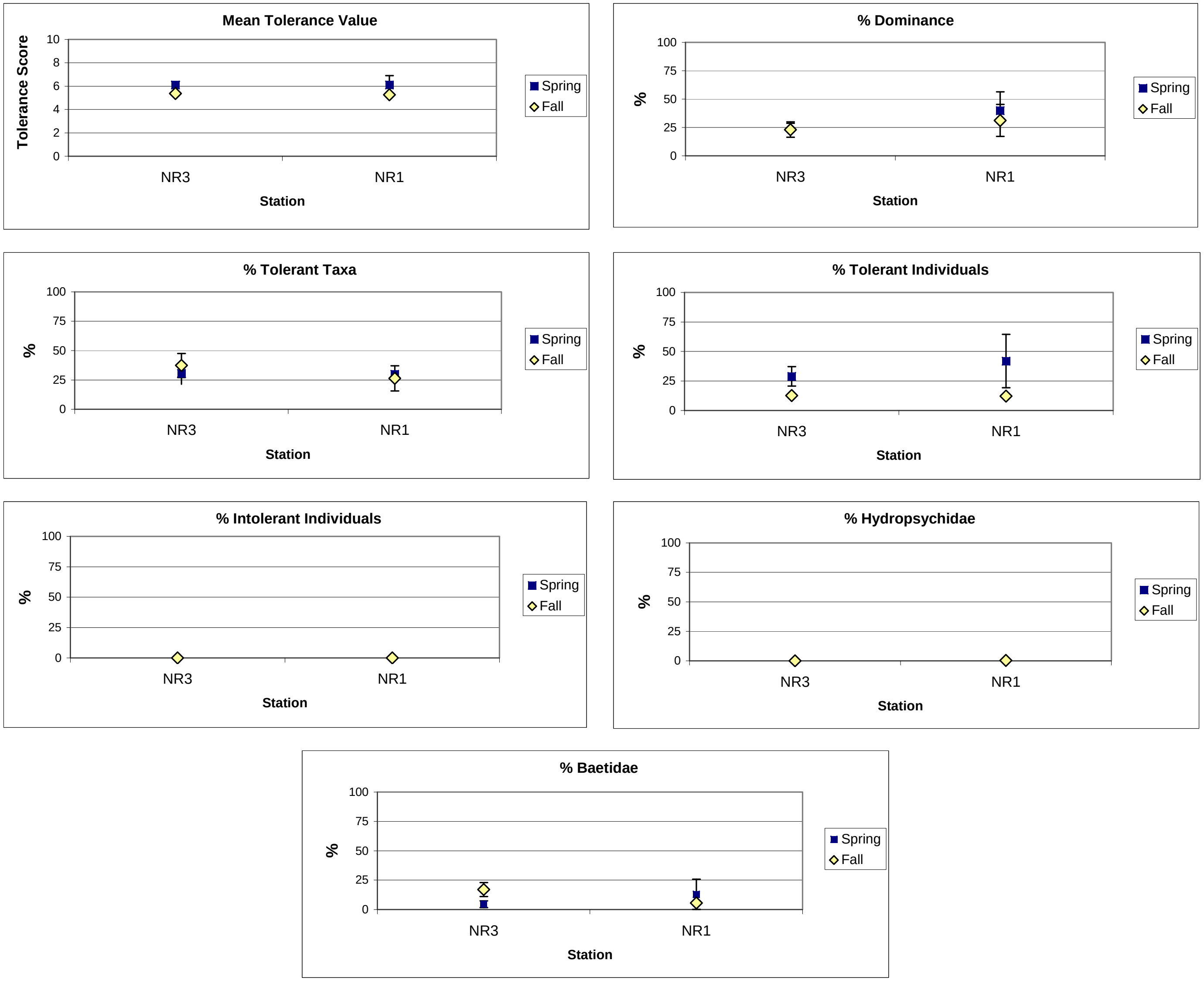


Figure 6. Averaged community tolerance metrics (± 95% CI) by season for each site.

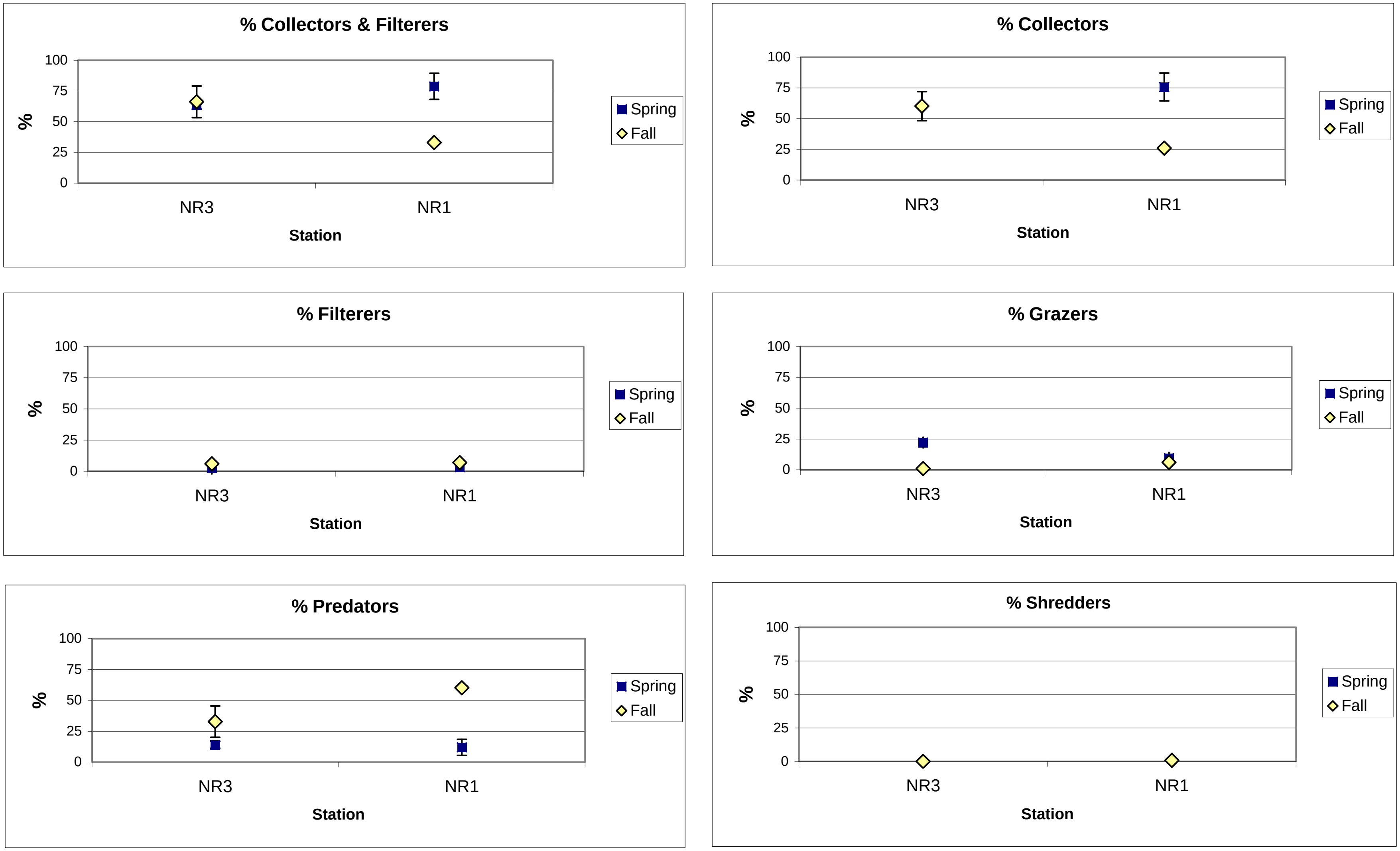
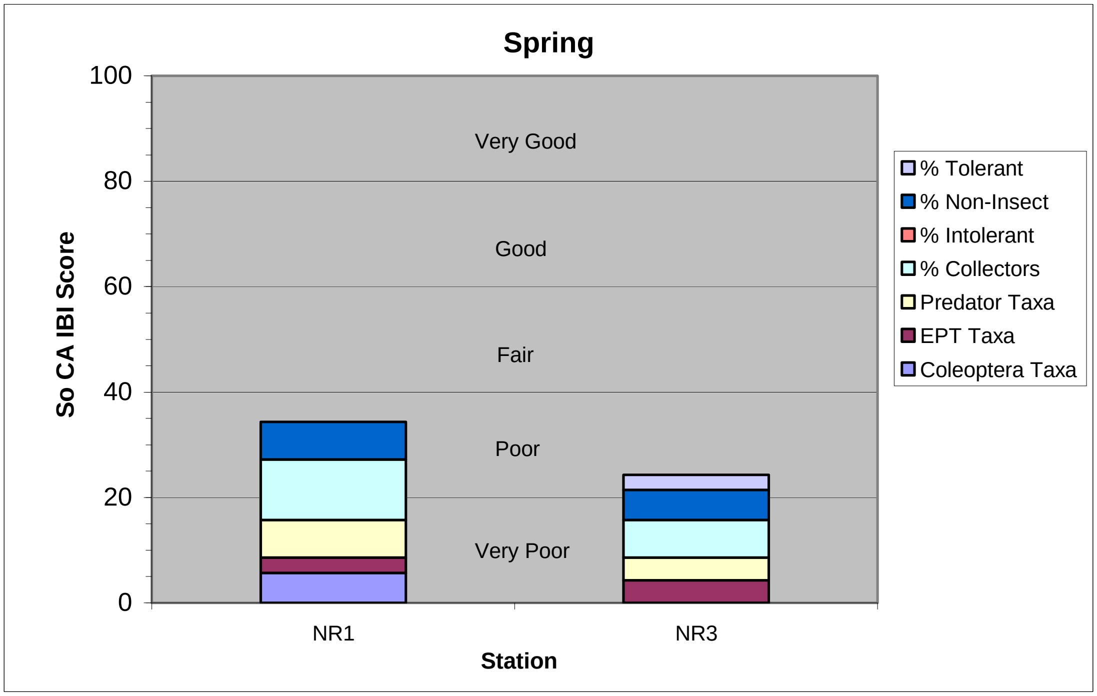


Figure 7. Averaged community feeding metrics (± 95% CI) by season for each site.

Table 8. Southern California IBI calculations for each of the Santa Clara River locations by season.

Station Metric	NR3		NR1	
	Spring	Fall	Spring	Fall
EPT Taxa	2	1	3	2
Predator Taxa	5	4	3	6
Coleoptera Taxa	4	0	0	5
% Non-Insect	5	3	4	6
% Intolerant Taxa	0	0	0	0
% Tolerant	0	0	2	3
% Collector Taxa	8	8	5	10
Total	**24**	**16**	**17**	**32**
Adjusted Score (1.43)	**34**	**23**	**24**	**46**
So. Cal. IBI Rating	**Poor**	**Poor**	**Poor**	**Fair**



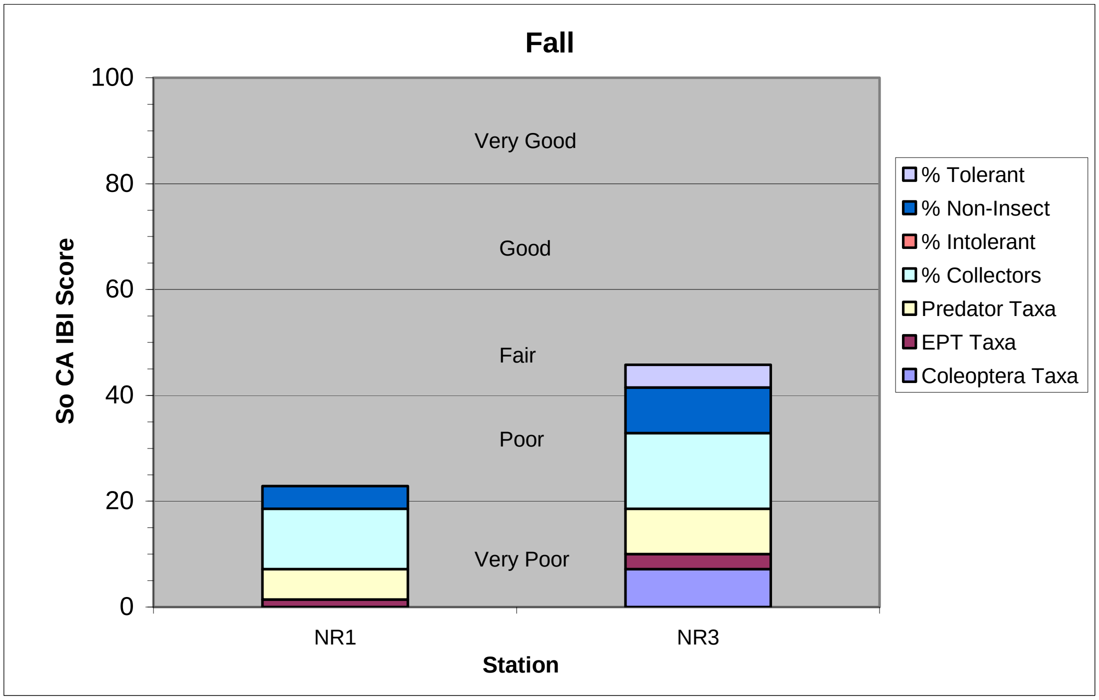


Figure 8. Southern California IBI Scores for sites that were sampled in the Santa Clara River.

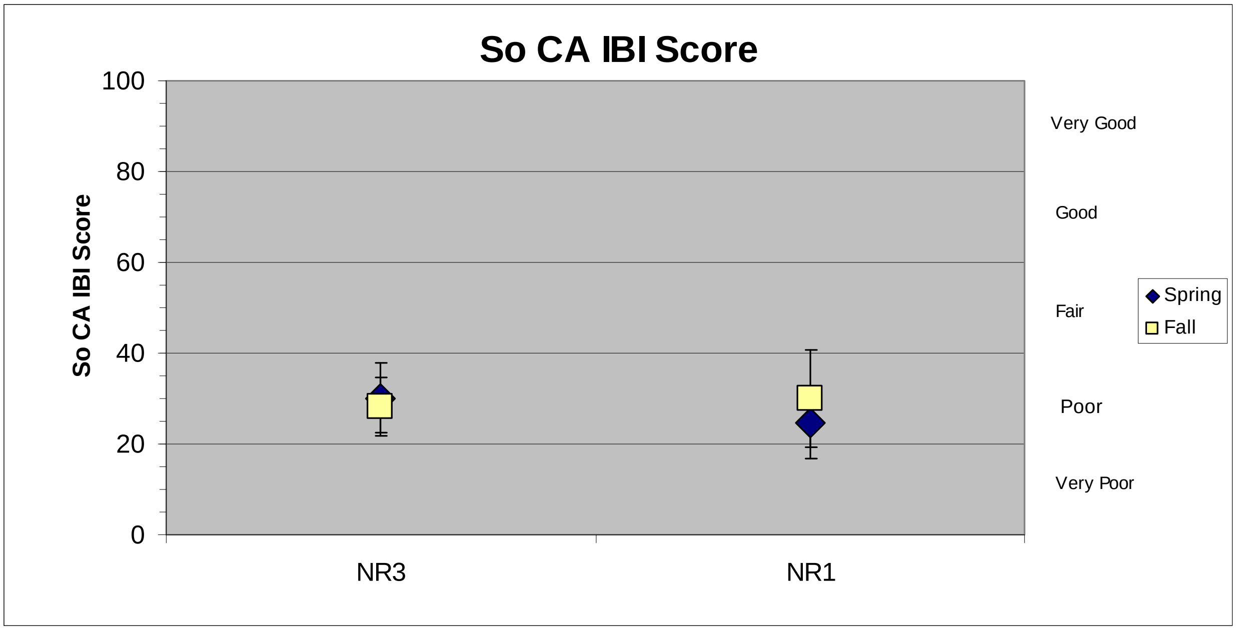


Figure 9. Average Southern California IBI Scores (± 95% CI) for sites that were sampled in the Santa Clara River from the spring of 2004 to the fall of 2007 (n = 4 for each site during each season).

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APPENDIX A – BENTHIC MACROINVERTEBRATE DATA

Table 9a. Spring infauna abundances by station at each site in the Santa Clara River.

Identified Taxa	Tol Val (TV)	Func Feed Grp	NR3			NR1		
			1	2	3	1	2	3
Insecta Taxa								
Ephemeroptera								
Baetis sp	5	cg		1	1	7		4
Fallceon quilleri	4	cg	7	24	7	76	35	5
Tricorythodes sp	4	cg				19	35	10
Odonata								
Anisoptera			1					
Coenagrionidae	9	p			1			2
Libellulidae	9	p			1			
Zoniagrion exclamationis	9	p			2		4	
Trichoptera								
Hydroptila sp	6	sc	38	41	38	36	8	22
Hydroptilidae	4	sc	28	21	3	2	4	10
Coleoptera								
Helochares sp	5	p	1			1		
Heteroceridae					1			
Peltodytes sp	5	mh	1					
Tropisternus sp	5	p			1			
Diptera								
Bezzia/Palpomyia sp	6	p	1			1		5
Caloparyphus sp	7	cg				4	6	1
Caloparyphus/Euparyphus sp	8	cg		3	4	4	1	13
Chironomidae	6	cg	54	47	28	15	7	9
Culicoides sp	8	cg	1			3		
Ephydridae	6				1			
Euparyphus sp	8	cg	2			1		1
Hemerodromia sp	6	p	21	14	3	1	1	1
Pericoma/Telmatoscopus sp	4	cg		3				
Simulium sp	6	cf	6	21	1	8	6	16
Non-Insecta Taxa								
Nematoda	5	p	14	27	9	4	1	1
Oligochaeta	5	cg	32	67	33	42	32	43
Ostracoda	8	cg	83	67	51	52	159	148
Turbellaria	4	p	9	4	4	53	13	23
Basommatophora								
Physa sp	8	sc		1	11	2	2	5
Trombidformes								
Atractides sp	8	p			1			
Sperchon sp	8	p	3	2	1		3	2
TOTAL			**302**	**343**	**202**	**331**	**317**	**321**

Table 9b. Fall infauna abundances by station at each site in the Santa Clara River.

Identified Taxa	Tol Val (TV)	Func Feed Grp	NR3			NR1		
			1	2	3	1	2	3
Insecta Taxa								
Ephemeroptera								
Baetis sp	5	cg	5	5	4			1
Fallceon quilleri	4	cg	33	63	42	5	23	21
Tricorythodes sp	4	cg	13	20	16	13	36	31
Odonata								
Argia sp	7	p			1	16	17	19
Brechmorhoga mendax	9	p					2	
Coenagrionidae	9	p	3	2	1		15	12
Hetaerina americana	6	p	2					
Hetaerina sp	5	p				25	21	12
Libellula sp	9	p					1	
Libellulidae	9	p					1	
Zoniagrion exclamationis	9	p					4	
Trichoptera								
Hydropsyche sp	4	cf				2		
Hydroptilidae	4	sc			2			
Coleoptera								
Chrysomelidae	5	sh				2	2	3
Optioservus sp	4	sc				2		
Postelichus sp	5						2	1
Diptera								
Bezzia/Palpomyia sp	6	p						1
Caloparyphus/Euparyphus sp	8	cg		1		1	1	1
Ceratopogon sp	6	p					1	
Ceratopogonidae	6	p	1					
Chironomidae	6	cg	70	55	48	32	22	12
Culicoides sp	8	cg	1					
Ephydridae	6			2	2		1	
Hemerodromia sp	6	p	2		2	1		2
Nemotelus sp	8	cg		1				
Pericoma/Telmatoscopus sp	4	cg					1	1
Psychodidae	10	cg						1
Simulium sp	6	cf	16	7	30	32	9	19
Lepidoptera								
Petrophila sp	5	sc				1		
Non-Insecta Taxa								
Copepoda	8	cg	1	2	4			
Nematoda	5	p	90	51	56		72	73
Oligochaeta	5	cg	5	28	47	1	7	5
Ostracoda	8	cg	16	24	35	15	3	1
Turbellaria	4	p	30	31	8	137	46	61
Acariformes								
Hydrozetidae			1		1	1		
Basommatophora								
Physa sp	8	sc	4	2	1	13	15	23
Diplostraca								
Cladocera	8	cf		1				
Trombidformes								
Sperchon sp	8	p	7	5	2			
Tyrrellia sp	5	p				1		
TOTAL			**300**	**300**	**302**	**300**	**302**	**300**

APPENDIX B – RE-COMPUTED SOUTHERN CALIFORNIA IBI SCORES

Table 10. Comparison of original and re-computed Southern California IBI scores and their ranks for BMI data collected from 2004 to 2006. 2007 scores are also included.

Station	Year	Season	Old IBI Score	Old Rank	New IBI Score	New Rank
NR1	2004	Spring	35.75	Poor	17.16	Very Poor
NR3	2004	Spring	32.89	Poor	21.45	Poor
NR1	2004	Fall	30.03	Poor	24.31	Poor
NR3	2004	Fall	37.18	Poor	31.46	Poor
NR1	2005	Spring	34.32	Poor	35.75	Poor
NR3	2005	Spring	30.03	Poor	25.74	Poor
NR1	2005	Fall	41.47	Fair	28.6	Poor
NR3	2005	Fall	30.03	Poor	22.88	Poor
NR1	2006	Spring	22.88	Poor	21.45	Poor
NR3	2006	Spring	27.17	Poor	38.61	Poor
NR1	2006	Fall	41.47	Fair	21.45	Poor
NR3	2006	Fall	38.61	Poor	35.75	Poor
NR1	2007	Spring	-	-	24.31	Poor
NR3	2007	Spring	-	-	34.3	Poor
NR1	2007	Fall	-	-	46	Fair
NR3	2007	Fall	-	-	23	Poor

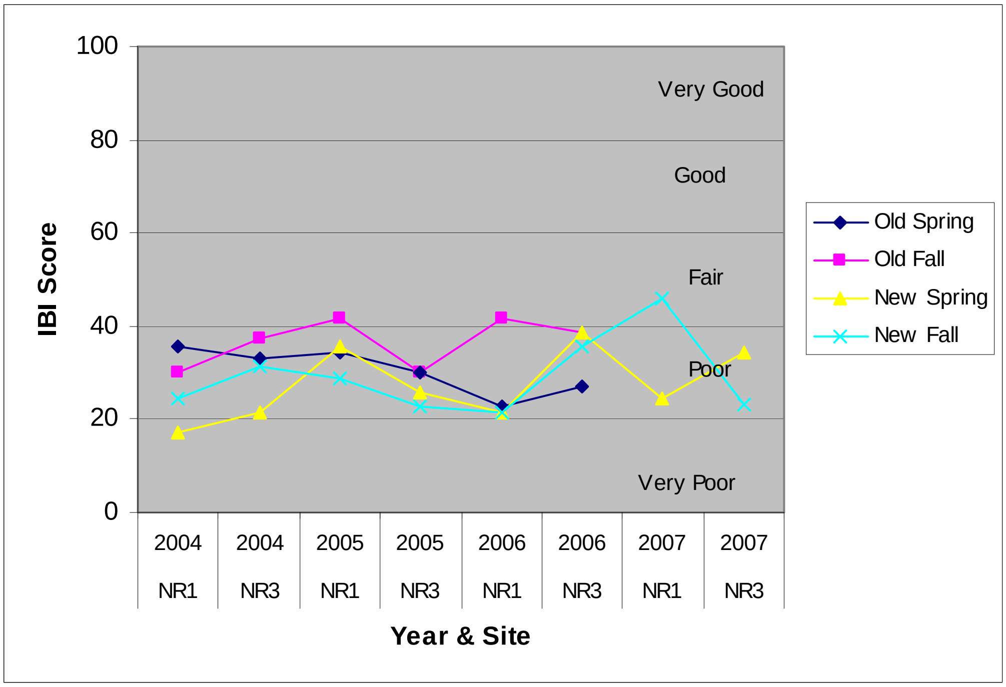

Figure 10. Original (old) vs. new IBI (recomputed) IBI scores for Santa Clara River sites from 2004 to 2007.

Copper:

Effects on Freshwater Food Chains and Salmon

A literature review

25 Aug. 2007

Dr. Carol Ann Woody
Fisheries Research and Consulting

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INTRODUCTION

Copper (Cu) is an element which is essential to healthy metabolism and growth of all living organisms, including fish, although fatal Cu deficiencies remain undocumented for any aquatic species (Sorensen 1991,Carbonell and Tarazona 1994, Eisler 2000). Cu is highly toxic to aquatic organisms and may cause irreversible harm at concentrations just over that required for growth and reproduction (Hall et al. 1988, Eisler 2000, Baldwin et al. 2003). The U.S. Environmental Protection Agency (1980) and a recent review by Eisler (2000) indicates toxicity of Cu to fish and their food chains depends on many factors including:

- Cu species and concentration;
- water quality including: pH, temperature, hardness, salinity, suspended solids, and organics;
- Cu interactions with other local elements;
- Organisms, age, size and species of affected fish and prior Cu exposure

Recent large scale industrialized mining proposals in Alaska’s pristine salmon-rich watersheds instigated this review. Here, highlights of published scientific literature are presented with an emphasis on potential effects of increasing bioavailable Cu to salmon and their freshwater food chains. In Alaska, the state Cu water quality standard for protection of freshwater species is 9 parts per billion (ppb) calculated on 100 mg/L hardness ($CaCO_3$) while the standard for drinking water is 1,300 ppb (Alaska Department of Environmental Conservation 18 AAC 2006).

Sublethal effects to fish and the aquatic food chain can occur at less than 9 ppb Cu (Eisler 2000) and data to accurately assess ecosystem impacts from increased Cu loads are lacking. The following facts are important to consider relative to developments that will increase bioavailability of Cu to freshwaters:

1. Toxicity tests to determine lethal levels and sublethal effects of Cu and other heavy metals are lacking for most Alaskan fish species, all of which are used for subsistence.
2. Many species of freshwater plants and animals die within 96 hours at waterborne concentrations of 5.0 to 9.8 ppb and sensitive species of mollusks, crustaceans and fish die at 0.23 to 0.91 ppb within 96 hr (Eisler 2000)
3. There is a lack of information on how multispecies aquatic food chains are affected by Cu and how aquatic organisms cycle Cu through aquatic ecosystems.
4. Numerous elements in addition to Cu, such as zinc, cadmium, mercury, iron, lead, aluminum, and selenium are released at hard rock mining sites in a unique “cocktail”; such effects of multiple element releases are not well studied nor understood and effects may be additive, synergistic, or antagonistic. Federal and State water quality limits for metals *do not* take these effects into account.
5. The numerous parameters affecting Cu toxicity dictate site and species specific studies to determine acceptable exposure levels in the specific ecosystems of interest.

Sources of Copper

Copper occurs naturally at low levels in air, soil and water (Table 1). Activities such as mining and smelting of copper, industrial emissions, se wage, municipal wastes, fertilizers, and pesticides have increased copper levels in our biosphere (Nriagu 1979a, Eisler 2000). Atmospheric Cu originates primarily from human activities (73%) such as Cu production (e.g. mining) and combustion of fossil fuel (coal, gas), the rest is from natural sources (Nriagu 1979a). Precipitation of atmospheric fallout is a significant source of Cu to the aquatic environment in mining and industrial areas and deposition patterns vary relative to prevailing winds and intensity of industrial activity (Nriagu 1979a, USEPA 1980, Eisler 2000). For example, in lakes near Sudbury, Ontario, an active copper and nickel mining region, total Cu concentrations decreased with distance from the mining site (Stokes et al. 1973).

Table 1. Mean concentration of copper in air, water, and soil from a range of areas. MAX = maximum concentration recorded; µg/m^3=microgram per cubic meter; ppb = parts per billion which is equivalent to µg/L = micrograms per liter. Modified from Eisler (2000).

Material and Concentration	Observed Concentration	Reference
AIR µg/m^3		
Remote areas	Usually < 0.001; MAX= 0.012	Nriagu 1979a
Urban areas	0.15–0.18; MAX = 1.6	Nriagu 1979a
Near copper smelters	1-2; MAX = 5.0	ATSDR 1990 USEPA 1980
FRESHWATERs ppb		
Canada	1-8	ATSDR 1990
Uncontaminated waters	1-7	Schroeder et al. 1966
Contaminated waters	50-100	Schroeder et al. 1966
Lake Sediments		
Lake sediments 3-5 km from smelter; Sweden	707-2531	Johnson et al. 1992
Lake sediments 50-80 km from smelter; Sweden	37-54	Johnson et al. 1992
Glaciers, µg/kg fresh weight	0.2	Veleminsky et al. 1990
Coal, µg/kg dry weight	17,000	Nriagu 1979a
SOILs mg/kg dry weight		
Global	2-250	ATSDR 1990, Aaseth and Norseth 1986
Near copper production facility	7000	ATSDR 1990
Rocks, crustal and sedimentary	24-45	Schroeder et al. 1966 Nriagu 1979a

Copper and the Freshwater Food Chain

Cu affects salmonid ecosystems, from the bottom of the food chain to top predators and hundreds of studies document both sublethal and lethal effects in aquatic systems (see reviews by Hodson et al. 1979, Sorenson 1991, Eisler 2000). Increases in dissolved Cu above normal background levels can reduce productivity of key links in aquatic food chains including algae, zooplankton, insects and fish (Table 2). For example, at the bottom of the food chain, one study showed growth of green algae (*Chlorella* spp.) declined at just 1.0 part per billion (ppb) Cu and photosynthesis was inhibited at 6.3 ppb Cu; photosynthesis in a mixed algae culture declined at 5.0 ppb (USEPA 1980).

Zooplankton feed on algae and their growth and reproduction are affected by food availability; declines in algae production cause declines in zooplankton production (Urabe 1991, Müller-Navarra and Lampert 1996) which translates to less food for species that feed on zooplankton, such as sockeye salmon (*Oncorhynchus nerka*).

Table 2. Copper effects on species representative of the freshwater salmonid food chain. ppb = parts per billion which is = to µg/L or micrograms per liter; hr = hours; d = days; wk = week; MATC = Maximum acceptable toxicant concentration: low value is highest concentration tested with no measurable effect with chronic exposure, higher value is lowest concentration tested producing a measurable effect.

Freshwater Organism, Cu Concentration and notes	**Effects**	**References**
Algae		
Chlamydomonas spp.		
18 ppb 24 hr	Reduction in flagella	Winner and Owen 1991
21 ppb 7 d	Growth normal	Schafer et al. 1994
32 ppb 7 d	50% decline in growth	Schafer et al. 1994
Chlorella spp.		
1.0 ppb	Reduced growth	USEPA 1980
6.3 ppb	Photosynthesis inhibited	
Mixed culture		
5.0 ppb	Photosynthesis reduced	USEPA 1980
Diatom		
Nitzschia spp.; 5.0 ppb	100% inhibition of growth	USEPA 1980
Rotifers		
Brachionus spp.		
2.0 – 5.0 ppb	MATC	Janssen et al. 1994
14 ppb 5 hr	50% impairment of swimming	Janssen et al. 1994
25 ppb 5 hr	100% immobilized	Janssen et al. 1994
26 ppb 24 hr	50% mortality	Janssen et al. 1994 and Ferrando et al. 1993
Molluscs		
Freshwater mussel; *Anodonta* spp.		
2.1 ppb 72 hr	Glochidial valve closure inhibited by 50%; reduced host infection	Huebner and Pynnonen 1992
5.3 ppb for 48 hr	50% decline in valve closure rate	
Villosa iris		
27-29 ppb for 24 hr	Valve closure reduced 50%	Jacobson et al. 1993
Freshwater snail; *Biomphalaria* spp.		
60 ppb 60 hr	Lethal	Cheng 1979
Gammarus pseudolimnaeus		
<4.6 ppb for 15 wk (2 generations)	No adverse effect	Arthur and Leonard 1970
4.6 – 8 ppb	MATC @ 45 mg CaCO3/L	USEPA 1980
6.2 – 12.9 ppb 5 wk	Decreased survival	Arthur and Leonard 1970
20 ppb 4 d	LC50	Arthur and Leonard 1970

Table 2. Continued.

Freshwater Organism, Cu Concentration and notes	**Effects**	**References**
Daphnids		
Daphnia pulex		
0.003-0,3 ppb for 21d	Increased reproduction	Roux et al. 1993
3 ppb 3 wk	Impaired reproduction	Roux et al. 1993
5 ppb 70 d	No change in reproduction; decreased survival on day 58	Ingersoll and Winner 1982
20-37 for 2d	LC50	Ingersoll and Winner 1982 Roux et al. 1993 and Dobbs et al. 1994
Daphnia pulicaria		
7.2-11.4 ppb 4 d	LC50@44-48 mg CaCO3/L	USEPA 1980
17.8-27.3 ppb 4d	LC50 @ 95-245 mg CaCO3/L	USEPA 1980
Daphnia magna		
5.9 ppb 3 wks	Reduced growth (10%)	Enserink et al. 1991
10 ppb 4 d	LC50@ 45 mg CaCO3/L	USEPA 1980
10 ppb life cycle	Inhibited reproduction	USEPA 1980
Macroinvertebrate Communities 11.3 ppb for 10 d	75% decline in abundance of Lab specimens; field streams 44% decline; 56% decline in number of taxa in lab vs. 10% in field sites.	Clements et al. 1990
Aquatic Insects		
Midge, Tanytarsus dissimillis; 16.3 ppb 10 d	LC50	USEPA 1980
Chironomus spp; 10, 20, 100, 150, or 200 ppb for 3 wk @50 mg CaCO3/L	Significant concentration dependent decline in salivary gland gene activity≥ 20ppb	Aziz et al. 1991
Species mix: 25 ppb 10 d in outside experimental channels	Caddisflies declined by 16-30% Chironomids: 80% decline Mayflies:67-100% decline in abundance	Clements et al. 1992
Arctic Grayling (Thymallus arcticus)		
2.65 ppb for 96 hours; swimup	LC50	Buhl and Hamilton 1990
9.6 ppb; fry	LC50	Buhl and Hamilton 1990
White sucker *Catostomus commersoni*		
12.9 -33.8 ppb	MATC @ 45 mg CaCO3/L	USEPA 1980
Northern Pike; *Esox lucias*		
34.9 – 104.4 ppb	MATC @ 45 mg CaCO3/L	USEPA 1980

Zooplankton, a preferred food of sockeye salmon, are directly affected by Cu; *Daphnia pulex,* the common water flea, increased reproductive rates when cultured for 21 days at 0.003 – 0.3 ppb Cu, but impaired reproduction was observed when held at 3.0 ppb Cu for 15 days (Roux et al. 1993). The concentration where 50% of a Daphnia culture died (LC50) occurred at 20-37 ppb Cu for 48 hours (Roux et al. 1993, Dobbs et al. 1994, Ingersoll and Winner 1982). *Bosmina longirostris,* another food of sockeye salmon, were 50% immobilized when held for 48 hours at 1.4 ppb Cu without food, and at 3.7 ppb Cu with food (Koivisto et al. 1992). Their growth declined when held for 15 days at 16 ppb and survival declined at 18 ppb Cu (Koivisto and Ketola 1995). Aquatic insects, an important fish food, are sensitive to dissolved Cu, in an experimental stream treated with 25 ppb Cu for 10 days, mayflies suffered 67-100% mortality, chironomids 80%, and caddisflies 16-30% (Clements et al. 1992). Note that adverse impacts to the salmonid food chain may occur below the criterion for aquatic life in Alaska (9 ppb), and lethal levels are well below the human drinking water standard, which in Alaska is 1,300 ppb (Table 2).

Sublethal Effects of Copper on Salmon

Copper can harm fish at levels below that which cause mortality (Table 3), and at concentrations below the accepted criterion for aquatic life in Alaska (< 9 ppb) Cu can:

a. Impair their sense of smell (olfaction)
b. Interfere with normal migration.
c. Impair their ability to fight disease (immune response).
d. Make breathing difficult
e. Disrupt osmoregulation
f. Impair their ability to sense vibrations via their lateral line canals (a sensory system that can help fish avoid predators)
g. Impair brain function
h. Change their enzyme activity, blood chemistry and metabolism
i. Can delay or accelerate natural hatch rates (Sorenson 1991).

Copper Impairs Olfaction

Copper can impair or destroy a fish's ability to smell (olfaction), which can be fatal. Salmon use their keen sense of smell to identify predators, prey, kin, and mates - mixing up any of these relationships could be detrimental or fatal (Hasler and Schlotz 1983, Groot et al. 1986, Stabell 1987, Olsen 1998, Brown and Smith 1997, Hirovan et al. 2000, Quinn and Busack 1985, Moore and Waring 1996). One study showed an increase of just 2.3 to 3.0 ppb of dissolved Cu above background levels was enough to interfere with behaviors tied to olfaction in juvenile coho salmon; from 1.0 to 20.0 ppb affected their sense of smell within10 minutes and water hardness did not influence the study outcome (Baldwin et al. 2003). Rainbow trout olfaction was impaired when exposed to 8.0 ppb for 2 hours (Hara et al. 1977).

Copper Interferes with Migration

Anadromous salmon memorize or "imprint" a complex map of chemical smells as they migrate from natal freshwaters to saltwater. When they to return to natal habitats to spawn, they follow their nose using this memorized map (Hasler and Schlotz 1983). This behavior is called "homing" and because it isolates small breeding populations in space and time, genetic divergence and population specific adaptations may evolve among local populations (Foerester 1968, Taylor 1991, Woody et al. 2000, Hilborn et al. 2003). If salmon cannot smell, or if the chemical signature of a salmon's natal stream changes, then fish will likely stray to and spawn in non-natal habitats, potentially reducing spawning success. Alteration of natural adaptive behaviors such as homing, migration and spawning due to water pollution can reduce wild salmon survival and change basic population structure.

Population structure is positively associated with genetic diversity and resilience to disturbance such that large, highly structured populations have high genetic diversity and probability of persistence (Giesel 1974, Altukhov 1981). In contrast, small, panmictic populations are vulnerable to inbreeding, demographic stochasticity, genetic drift and thus, reduced evolutionary potential, and increased probability of extinction (Cornuet and Luikart 1996; Luikart *et al.* 1998; Soulé and Mills 1998). Potential changes in population structure due to increased salmon straying rates, has huge implications for sustainable fisheries whose probability of persistence is determined, in part, by the genetic integrity and biodiversity of stocks (Hilborn 2003).

Studies show salmonids avoid waters with low levels of dissolved Cu contamination disrupting their normal migration patterns. For example, coho salmon yearlings held in 5 – 30 ppb Cu for as little as 6 days showed altered downstream migration patterns

(Lorz and McPherson 1977). Chinook avoided at least 0.7 ppb Cu whereas rainbow trout avoided at least 1.6 ppb dissolved Cu (Hansen et al. 1998). Laboratory avoidance of Cu by rainbow trout was observed at 0.1, 1.0 and 10 ppb Cu (Folmar 1976). Oddly, Birge et al. (1993) and others demonstrated that salmon and other fish are attracted to very high concentrations of dissolved Cu (4,560 ppb) which is lethal (Table 3).

Copper Impairs Fish Immune Response

Fish, like humans, tend to become ill when stressed; and Cu is a stress agent that increases both infection and death rates (Rougier et al. 1994). Steelhead trout exposed to 7 and 10 ppb Cu for 96 hours had a higher death rate from a bacterial disease called “redmouth” (*Yersinia* spp.) than non-exposed control fish (Knittel, 1981). Chinook and rainbow trout showed reduced resistance to a wide array of bacterial infections after exposure to 6.4, 16.0, and 29.0 ppm Cu after 3, 7,14, and 21 days (Baker et al. 1983). Rainbow trout stressed by dissolved Cu required half the number of pathogens to induce a fatal infection than non-exposed fish (Baker et al.1983). Fish mortalities caused by long term, low level exposure to stress agents, such as Cu, are difficult to detect compared to mass mortalities caused by a single acute event, such as a single contaminant spill. Because aquatic species that comprise the aquatic food chain will suffer delayed mortality and adverse effects from sublethal Cu exposure, many populations could decline unnoticed.

Table 3. Effects of copper on salmonids. LC10 indicates that 10% of tested fish died after the indicated time period and LC50 indicates 50% of tested fish died after the indicated time period.

Species , Cu concentration	**Effects**	**References**
Chinook salmon		
10-38 ppb for 96 hours	LC50 in soft water	EPA 1980
19 ppb for 200 hours: swimup stage	LC50	EPA 1980
20 ppb for 200 hours; alevins	LC50	EPA 1980
26 ppb for 200 hours; smolts	LC50	EPA 1980
30 ppb for 200h; parr	LC50	EPA 1980
54-60 ppb for for 96 hours; fry	LC50	Hamilton and Buhl 1990
78-145 ppb for 24 hours; fry	LC50	Hamilton and Buhl 1990
85-130 ppb for 96 hours	LC50 in hardwater	EPA 1980

Table 3. Continued.

Species , Cu concentration	Effects	References
Coho salmon		
5-30 ppb for up to 72 days; yearlings	Altered downstream migration patterns, reduced gill function, reduced survival. Appetite depressed at >20 ppb	Lorz & MCPherson 1977
15.1-31.9 ppb for 96 hours; juveniles	LC50	Buhl and Hamilton 1990
18.2 ppb for 31 then put in seawater	Reduced survival	Stevens 1977
24.6 ppb for 31 days; fingerlings	Reduced survival; survivors did not adapt to seawater	Stevens 1977
26 ppb for 96 hours; alevins	LC50 at 25 mg $CaCO_3$/L	EPA 1980
46 ppb for 96 hours; adults	LC50 at 20 mg $CaCO_3$/L	EPA 1980
60 ppb for 96 hours; smolts	LC50 at 95 mg $CaCO_3$/L	EPA 1980
60-74 ppb for 96 hours; yearlings	LC50 at 95 mg $CaCO_3$/L	EPA 1980
Rainbow Trout		
0.1 ppb for 1 hour	Avoidance by fry	EPA 1980
7.0 ppb for 200 hours; smolts	Depressed olfactory response	Hara et al. 1977
9.0 ppb for 200 hours; swimup	LC10	EPA 1980
13.8 for 96 hours; juveniles	LC50	Buhl and Hamilton 1990

Copper Interacts with Other Elements

Areas near hard rock and coal mines, smelters, coal-fired generators, and urban areas commonly release multiple metals such as zinc (Zn), cadmium (Ca), lead (Pb), aluminum (Al), mercury (Hg), selenium (Se), molybdenum (Mo), magnesium (Mg), nickel (Ni) and iron (Fe). Few studies exist on the effects that multiple metal “cocktails” have on fish and aquatic foodchains, but those that do show complex chemical interactions and reactions. Such mixtures, combined with site specific water chemistries and species diversity, make comparisons among sites extremely difficult. Dethloff et al. (1999) investigated changes in the blood, brain biochemistry, and immune system of rainbow trout caused by exposure to sublethal concentrations of Cu and Zn, two metals frequently found together in freshwater systems (Finlayson and Ashuckian, 1979; Roch and McCarter,1984b; Woodward *et al*. 1995). They found fish exposed to Cu, and a low Cu+low Zn and a Cu+high Zn treatment exhibited consistently depressed percentages of lymphocytes and elevated neutrophils; both white blood cell types that play a key role in immune function.

Interactions between Cu and Zn can be more than additive with mixtures of the two metals causing higher rates of mortality in fish than expected based on each element alone (Sprague and Ramsey 1965, Sorenson 1991, Eisler 2000). Once inside an organism, elements exist in a specific form and ratio to other elements and will interact directly or indirectly based on a multitude of parameters (Sandstead 1976, Sorenson 1991). For example, survival from egg to hatch of a catfish (Ictalurus spp.) treated with a 1:1 ratio of Cu:Zn declined predictably under an additive model up to a concentration of ~1 ppm, then mortality rates increased at higher that predicted rates for a synergistic effect (Birge and Black 1979).

Summary

Copper occurs naturally in the environment at low levels; high levels are recorded for regions where hard rock and coal mining, smelting and refining occur and in areas near industrial and municipal waste sites (Eisler 2000). Contamination levels in the aquatic environment generally decline with increasing distance from industrial activity, and are also dependent on prevailing winds, and precipitation patterns (USEPA 1980, Nriagu 1979a).

Copper is highly toxic to aquatic organisms and interacts with numerous inorganic and organic compounds which affect its bioavailability and toxicity to aquatic biota. Toxicity depends on environmental factors that change through time and space (e.g. temperature and water quality). Heavy metal contamination sites generally release more than a single element, such that each site presents a complex and unique suite of metals, environmental conditions, aquatic species, which, when combined with the multitude of factors already mentioned, makes development of accurate predictive models for receiving waters difficult if not impossible. The Alaska Department of Environmental Conservation uses a hardness based formula to calculate acceptable pollution levels for Cu (e.g., $e_{0.8545(\ln \text{hardness}) - 1.702}$) which does not take into account the above mentioned parameters that influence Cu toxicity.

Sublethal effects of dissolved Cu are documented for all levels of the aquatic food chain, from algae to top predators (Tables 2 and 3), and adverse effects to the food chain and salmon occur at levels below the Alaska water quality criterion for protection of aquatic species (9 ppb or 9 µg/L calculated on 100 mg/L CaCO3). Significant effects on olfaction, migration, and immune response, occur at levels below the Alaska criterion for protection of aquatic species and toxicity tests are lacking for most Alaskan species, all of which are used for subsistence and support significant commercial and sport fisheries.

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Authors Note

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GEOSYNTEC CONSULTANTS
SANTA CLARA RIVER AT NEWHALL RANCH

2007 ANNUAL BIOASSESSMENT MONITORING OF THE SANTA CLARA RIVER AT NEWHALL RANCH

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March 2008

AQUATIC
BIOASSAY &
CONSULTING
LABORATORIES, INC.

February 25th, 2008

Mr. Brandon Steets
Geosyntec Consultants
924 Anacapa St. Suite 4A
Santa Barbara, CA 93101

Dear Mr. Steets:

In accordance with the agreement between Geosyntec Consultants and Aquatic Bioassay and Consulting Laboratories, Inc., we are pleased to present the 2007 Bioassessment Monitoring Report for the pre-discharge monitoring requirements for the Newhall Wastewater Reclamation Plant on the Santa Clara River.

Yours very truly,

Scott C. Johnson

Scott C. Johnson
Director of Environmental Programs
Aquatic Bioassay & Consulting Laboratories
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Newhall Wastewater Reclamation Plant Spring & Fall 2007 Bioassessment Monitoring Report

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March 2008

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This report is submitted to Geosyntec as part of the pre-discharge monitoring requirements for the Newhall Wastewater Reclamation Plant (WRP). This study included bioassessment monitoring on the Santa Clara River east of the City of Piru, at the Los Angeles and Ventura County Line using protocols specified by in the State of California, Surface Water Ambient Monitoring Program (SWAMP 2007). Aquatic Bioassay and Consulting Laboratory scientists conducted sampling on July 27th and October 31st, 2007. The goals of the bioassessment study were to:

1. Provide a comparison of the benthic macroinvertebrate (BMI) assemblages present in the Santa Clara River upstream and downstream of the future Newhall WRP discharge site.
2. Evaluate the physical/habitat condition of these sampling sites.

This report includes all of the physical, chemical and biological data collected during the spring and fall surveys. These include photographic documentation of each site, QA/QC procedures and documentation, followed by a presentation of the calculated metrics specified in the SWAMP protocols, the Southern California IBI and interpretation of the results. In addition, this report includes a summary of BMI data collected since 2004.

BACKGROUND

Major issues facing streams and rivers in California include modification of in-stream and riparian structure, contaminated water and increases in impervious surfaces which have led to the increased frequency of flooding. There have been many studies and reports showing the deleterious effects of land-use activities to macroinvertebrate and fish communities (Jones and Clark 1987; Lenat and Crawford 1994; Weaver and Garman 1994; and Karr 1998).

During the past 150 years, direct measurements of biological communities including plants, invertebrates, fish, and microbial life have been used as indicators of degraded water quality. In addition, biological assessments (bioassessments) can be used as a watershed management tool for surveillance and compliance of land-use best management practices. Combined with measurements of watershed characteristics, land-use practices, in-stream habitat, and water chemistry, bioassessment can be a cost-effective tool for long-term trend monitoring of watershed conditions (Davis and Simons 1996).

Biological communities act to integrate the effects of water quality conditions in a stream by responding with changes in their population abundances and species composition over time. These populations are sensitive to multiple aspects of water and habitat quality and provide the public with more familiar expressions of ecological health than the results of chemical and toxicity tests (Gibson 1996). Furthermore, biological assessments when integrated with physical and chemical assessments better define the effects of point-source discharges of contaminants and provide a more appropriate means for evaluating discharges of non-chemical substances (e.g. nutrients and sediment).

Benthic macroinvertebrates (BMIs) are ubiquitous, relatively stationary and their diversity provides a spectrum of responses to environmental stresses (Rosenberg and Resh 1993). Individual species of BMIs reside in the aquatic environment for a period of months to several years and are sensitive, in varying degrees, to temperature, dissolved oxygen, sedimentation, scouring, nutrient enrichment and chemical and organic pollution (Resh and Jackson 1993). Finally, BMIs represent a significant food source for aquatic and terrestrial animals and provide a wealth of ecological and bio-geographical information (Erman 1996).

In the United States the evaluation of biotic conditions from BMI community data uses a combination of multimetric and multivariate techniques. In multimetric techniques, a set of biological measurements ("metrics"), each representing a different aspect of the community data, is calculated for each site. An overall site score is calculated as the sum of individual metric scores. Sites are then ranked according to their scores and classified into groups with "good", "fair" and "poor" water quality. This system of scoring and ranking sites is referred to as an Index of Biotic Integrity (IBI) and is the end point of a multi-metric analytical approach recommended by the EPA for development of biocriteria (Davis and Simon 1995). The original IBI was created for assessment of fish communities (Karr 1981), but was subsequently adapted for BMI communities (Kerans and Karr 1994).

The first demonstration of a California regional IBI was applied to the Russian River watershed in 1999 (DFG 1998). As the Russian River IBI was being developed, the California Department of Fish and Game (CADFG) began a much larger project for the San Diego Regional Board. After a pilot project conducted on the San Diego River in 1995 and 1996, the San Diego Regional Board incorporated bioassessment into their ambient water quality monitoring program. Finally, between 2000 and 2003, bioassessment data were collected from the Mexican border to the south, Monterey County to the north and to the eastern extent of the coastal mountain range. These data were used to create an IBI that is applicable to southern California and is applied to the data in this report (Ode et al. 2005). While many low gradient reference sites were included in the development of the IBI, it has become apparent that the further work may be necessary to make the IBI applicable to low gradient systems in southern California.

MATERIALS AND METHODS

Sampling Site Descriptions

Two sampling locations (NR1 upstream and NR3 downstream) were visited in the Santa Clara River on July 27th and October 31st, 2007 (Table 1, Figure 1). Photographs of each site are displayed in Figure 2. These sites were selected so that the biological communities at the future discharge location for the Newhall WRP could be evaluated. It is important that these sites are similar to one another in terms of physical habitat. If they are not, future comparisons between the BMI communities residing at sites upstream and downstream of the WRP could be confounded by habitat differences.

During dry weather this section of the Santa Clara River sustains a low flow of water which is fed to it by several upstream waste treatment facilities. This is not a typical condition during the dry summer months in southern California where even large rivers such as the Santa Clara are historically dry. The land surrounding the river at both the upstream and downstream sites have been used during the past century for agriculture. As a result there are dirt roads, irrigation ditches and heavy machinery present throughout the area.

The Station NR1 was located 300 feet upstream of the Los Angeles/Ventura County Line, at an elevation of 835 feet. This site will be the location of the new waste discharge from the treatment facility. The River is located in a relatively natural southern California river habitat with a sand, cobble and gravel streambed. The channel with flowing water is normally small in comparison to the entire width of the Santa Clara River which is dry during most of the year except during rain storms. Station NR3 was located 2.74 miles downstream of the Los Angeles/Ventura County Line, at an elevation of 724 feet. Here the river filled more than 75% of the streambed and was bordered on each side by thick vegetation. This site was situated just upstream of a bridge and was composed of sand, cobble and gravel.

Table 1. Sampling locations and descriptions for 2 sites on the Santa Clara River.

Sta.ID	Description and Comments	Latitude	Longitude	Elev. (ft)
NR1 Upstream	Located 300 ft. upstream of the Los Angeles/Ventura County Line.	34° 24.193' N	118° 41.391' W	835
NR3 Downstream	Located 2.74 mi. downstream of the Los Angeles/Ventura County Line	34° 24.232' N	118° 44.363' W	724

Figure 1. BMI sampling locations for the two sites on Santa Clara River.

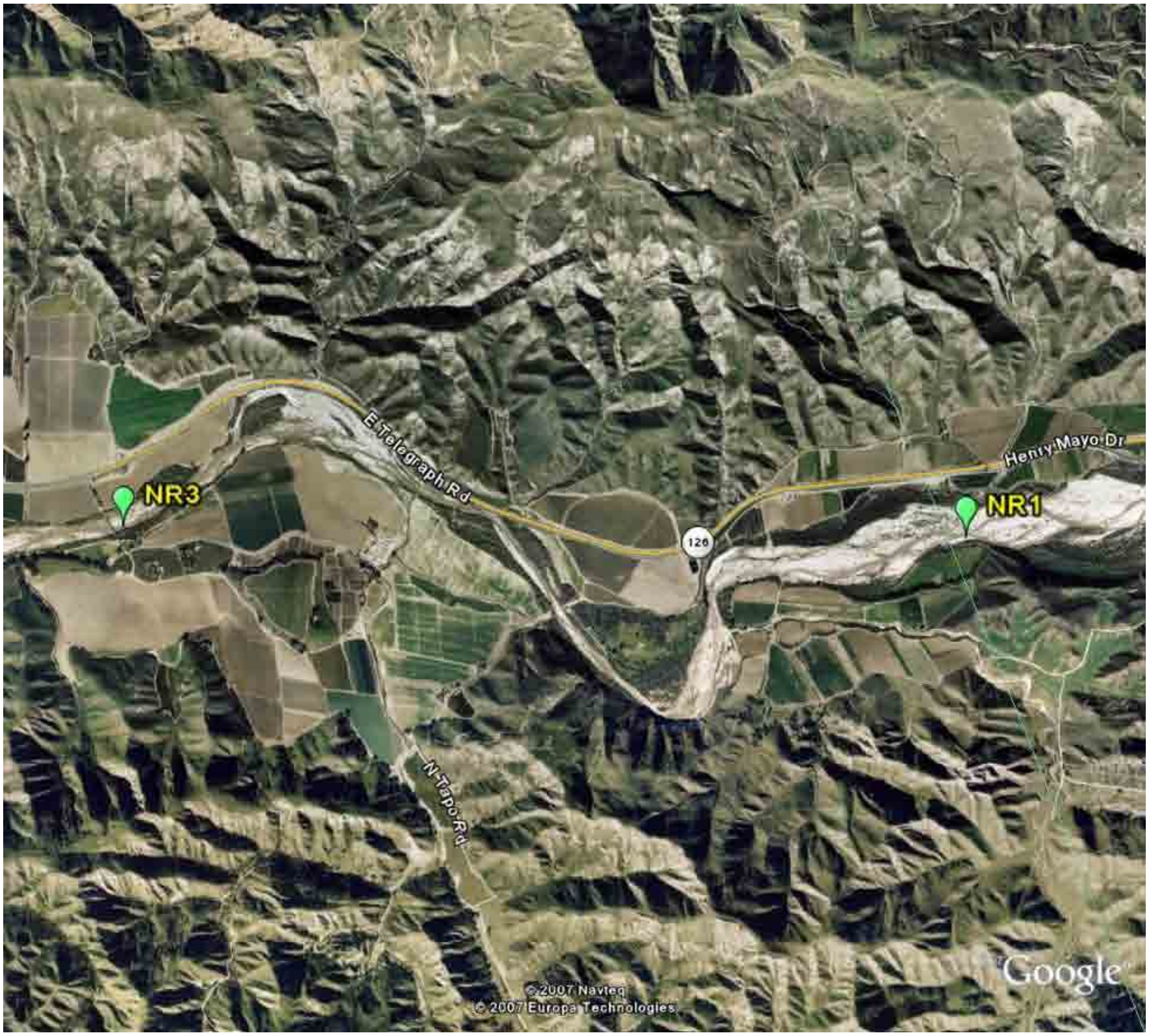


Figure 2: Sampling location photos of upstream Station NR1 and downstream Station NR3 in the Santa Clara River.

NR1 - Spring

NR1 - Spring

NR1 - Fall

NR1 - Fall

NR3 - Spring

NR3 - Spring

NR3 - Fall

NR3 - Fall

Collection of Benthic Macroinvertebrates

Wadeable Streams Protocols

The field protocols and assessment procedures followed the draft Surface Water Ambient Monitoring Program (SWAMP) protocols which were taken from existing California Department of Fish and Game protocols (CDFG 2003) and the United States Environmental Protection Agencies (USEPA) Western Environmental Monitoring Assessment Program (EMAP). These protocols have since been promulgated and will be used throughout the State of California in coming years (SWAMP 2007).

Benthic macroinvertebrate (BMI) samples were collected in strict adherence to the SWAMP in terms of both sampling methodology and QC procedures. At each station, a 150 m reach was measured and 11 transects were established equidistance apart from the downstream to upstream end of the reach. If access to the full 150 m reach was not possible due to obstacles (i.e. heavy vegetation), the total reach length was divided by 11 and transects were established as above. At each site the SWAMP Worksheet was used to collect all of the necessary station information and physical habitat data.

BMI samples were collected starting with the downstream transect and working upstream. Since the percent streambed gradient was <1%, the Reach Wide Benthos (RWB) sampling protocol was used:

- At the most downstream transect a single location was sampled 25% of the distance from the right wetted width. On the second upstream transect a sample was collected 50% of the distance from the right wetted width and, on the third transect, 75% of the distance from the right wetted width. This process was repeated until each of the eleven transects had been sampled.

All samples of the benthos were collected within a 1 ft^2 area upstream of a 1 ft wide, 0.5 mm mesh D-frame kick-net at each transect. Sampling of the benthos was performed manually by rubbing cobble and boulder substrates in front of the net, followed by “kicking” the upper layers of substrate to dislodge any remaining invertebrates. The duration of sampling ranged from 60-120 seconds, depending on the amount of boulder and cobble-sized substrate that required rubbing by hand; more and larger substrates required more time to process.

Each of the 11 samples was combined into a single composite sample that represented an 11 ft^2 area of the total reach. The composite sample was transferred into a 1/2 gallon wide-mouth plastic jar containing approximately 300 ml of 95% ethanol. Chain of Custody (COC) sheets were completed for samples as each station was completed.

Physical / Habitat Quality Assessment and Water Quality

Bioassessment sampling included a measure of the instream physical habitat conditions using a method originally developed by the USEPA and modified by SWAMP (2007) for use in California. This method focuses on the habitat conditions found in the streambed and banks. The team collected the physical/habitat measurements at each station according to the Basic method outlined in the SWAMP manual and recorded the information on the SWAMP worksheets. To maintain a historical record of physical habitat quality, both reaches were also assessed using the California Stream Bioassessment Procedure (CSBP, 1999) Visual-Based Habitat Assessment method developed by USEPA for its Rapid Bioassessment Procedures (RBP; Barbour et al 1999).

These measurements are summarized as follows:

1. Water temperature, specific conductance, pH and dissolved oxygen were measured using a hand held YSI 85 water quality meter that was pre-calibrated in the laboratory. A water sample was collected for alkalinity and analyzed by titration in the lab.
2. Wetted width was measured in meters using a stadia rod or measuring tape at each transect.
3. Velocity was measured in the spring and discharge was measured in the fall on a single transect using a hand held flow meter.
4. A densitometer was used to measure % canopy cover.
5. Stream gradient was measured using either an auto leve, and sinuosity was measured using a compass working downstream from the most upstream transect.

Sample Analysis/Taxonomic Identification of Benthic Macroinvertebrates (BMIs)

Sample sorting and taxonomy were conducted by Aquatic Bioassay and Consulting Laboratories. Sorting and taxonomice identifications were conducted at the Aquatic Bioassay laboratory in Ventura, CA and taxonomic identifications were conducted by Craig Pernot. Identifications were made using standard taxonomic keys (Literature Cited, Taxonomic References). In most cases taxa for this study were identified to the species level in adherence with Professional Taxonomic Effort Level 2 specified by the Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT). All taxa identifications were rolled up to the appropriate taxonomic level for the calculation of biological metrics and the Southern California IBI. Samples entering the lab were processed as follows:

A maximum number of 500 organisms were sub-sampled from the composite sample using a divided tray, and then sorted into major taxonomic groups. All remnants were stored for future reference. The 500 organisms were identified to the genus level for most insects and order or class for non-insects. As new species to the survey area were identified, examples of each were added to the voucher collection. The voucher collection includes at least one individual of each species collected and ensures that naming conventions can be maintained and changed as necessary into the future.

The taxonomic quality control (QC) procedures followed for this survey included:

- Sorting efficiencies were checked on all samples. The leftover material from each sample was inspected by the laboratory supervisor. Minimum required sorting efficiency was 95%, i.e. no more than 5% of the total number of organisms sorted from the grids could be left in the remnants. Sorting efficiency results were documented on each station’s sample tracking sheet.
- Once identification work was completed, 10% of all samples were sent to the Department of Fish and Game (DF&G) offices in Rancho Cordova for a QC check. Samples were sorted by species into individual vials that included an internal label. Any discrepancies in counts or identification found by the DF&G taxonomists were discussed, and then resolved. All data sheets were corrected and, when necessary, bioassessment metrics were updated.

Data Development and Analysis

As species were identified, they were included in an Excel data sheet, checked for errors and then imported into the Aquatic Bioassay BMI database system. All biological metrics, figures and tables were then automatically generated. These bioassessment metrics were then used to assess the spatial and temporal distributions of the BMI community or were used to calculate the southern California IBI (Ode et al. 2005). The following metrics were calculated and their responses to impaired conditions are listed in Table 2:

1. Richness measures: taxa richness, cumulative taxa, EPT taxa, cumulative EPT taxa, Coleopteran taxa.
2. Composition measures: EPT index, sensitive EPT index, Shannon diversity.
3. Tolerance/intolerance measures: mean tolerance value, intolerant organisms (%), tolerant organisms (%),tolerant taxa (%), dominant taxa (%), Chironomidae (%), non-insect taxa (%).
4. Functional feeding group: collectors (%), filterers (%), grazers (%), predators (%), shredders (%).

Table 2. Bioassessment metrics used to describe characteristics of the BMI community results.

BMI Metric	**Description**	**Response to Impairment**
Richness Measures		
Taxa Richness	Total number of individual taxa	decrease
EPT Taxa	Number of taxa in the Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) insect orders	decrease
Ephemeroptera Taxa	Number of taxa in the insect order Ephemeroptera (mayflies)	decrease
Plecoptera Taxa	Number of taxa in the insect order Plecoptera (stoneflies)	decrease
Trichoptera Taxa	Number of taxa in the insect order Trichoptera (caddisflies)	decrease
Composition Measures		
EPT Index Sensitive EPT Index	Percent composition of mayfly, stonefly and caddisfly larvae Percent composition of mayfly, stonefly and caddisfly larvae with tolerance values between 0 and 3	decrease decrease
Shannon Diversity	General measure of sample diversity that incorporates richness and evenness (Shannon and Weaver 1963)	decrease
Tolerance/Intolerance Measures		
Tolerance Value	Value between 0 and 10 weighted for abundance of individuals designated as pollution tolerant (higher values) or intolerant (lower values)	increase
Percent Intolerant Organisms	Percent of organisms in sample that are highly intolerant to impairment as indicated by a tolerance value of 0, 1 or 2	decrease
Percent Tolerant Organisms	Percent of organisms in sample that are highly tolerant to impairment as indicated by a tolerance value of 8, 9 or 10	increase
Percent Dominant Taxa	Percent composition of the single most abundant taxon	increase
Percent Hydropsychidae	Percent of organisms in the caddisfly family Hydropsychidae	increase
Percent Baetidae	Percent of organisms in the mayfly family Baetidae	increase
Functional Feeding Groups (FFG)		
Percent Collectors	Percent of macrobenthos that collect or gather fine particulate matter	increase
Percent Filterers	Percent of macrobenthos that filter fine particulate matter	increase
Percent Grazers	Percent of macrobenthos that graze upon periphyton	variable
Percent Predators	Percent of macrobenthos that feed on other organisms	variable
Percent Shredders	Percent of macrobenthos that shreds coarse particulate matter	decrease
Estimated Abundance	Estimated number of BMIs in sample calculated by extrapolating from the proportion of organisms counted in the subsample	variable

Parametric Testing

Replicate biological metric data were used to statistically test for differences among stations using analysis of variance (ANOVA). When assumptions of parametric statistics could not be met (such as non-normality or excessive variability), the tests were replaced with nonparametric analogues (Kruskal-Wallis One-Way ANOVA on Ranks and Kruskal-Wallace Rank Test, respectively). Significance was noted when $p \leq 0.05$ and marginal significance was noted when $0.05 < p \leq 0.10$).

Southern California IBI

The seven biological metric values used to compute the Southern California Index of Biological Integrity (So CA IBI) are presented in Table 3 (Ode et al. 2005). The So CA IBI is based on the calculation of biological metrics from a group of 500 organisms from a composite sample collected at each stream reach. Since 900 organisms were identified from each sample for this survey (3 replicates, 300 organisms each), Monte Carlo randomization was used to select 500 organisms from the 900 collected at each station before the IBI metrics were calculated. This procedure was validated by Ode et al. (2005).

The IBI calculation for data collected for this program from spring 2005 to fall 2006 inadvertently used % non-insect individuals and % tolerant individuals, instead of % non-insect taxa and % tolerant taxa. The re-computed index scores and ranks for each sampling event are presented in Appendix B (Table 10, Figure 10).

Table 3. Scoring ranges for the seven metrics included in the southern California IBI and the IBI values.

Metric Scoring Ranges for the Southern California IBI

Metric Score	Coleoptera Taxa	EPT Taxa		Predator Taxa	% Collector Individuals		% Intolerant Individuals		% Non-Insect Taxa	% Tolerant Taxa
	All Sites	6	8	All Sites	6	8	6	8	All Sites	All Sites
10	>5	>17	>18	>12	0-59	0-39	25-100	42-100	0-8	0-4
9		16-17	17-18	12	60-63	40-46	23-24	37-41	9-12	5-8
8	5	15	16	11	64-67	47-52	21-22	32-36	13-17	9-12
7	4	13-14	14-15	10	68-71	53-58	19-20	27-31	18-21	13-16
6		11-12	13	9	72-75	59-64	16-18	23-26	22-25	17-19
5	3	9-10	11-12	8	76-80	65-70	13-15	19-22	26-29	20-22
4	2	7-8	10	7	81-84	71-76	10-12	14-18	30-34	23-25
3		5-6	8-9	6	85-88	77-82	7-9	10-13	35-38	26-29
2	1	4	7	5	89-92	83-88	4-6	6-9	39-42	30-33
1		2-3	5-6	4	93-96	89-94	1-3	2-5	43-46	34-37
0	0	0-1	0-4	0-3	97-100	95-100	0	0-1	47-100	38-100

Cumulative IBI Scores

Very Poor	Poor	Fair	Good	Very Good
0-19	20-39	40-59	60-79	80-100

RESULTS

Habitat Characteristics and Water Quality

The physical characteristics of the transects sampled at Stations NR1 (upstream) and NR3 (downstream) in the Santa Clara River were low gradient (<1%) (Table 4). Average wetted width was similar at both sites and depth was greater at Station NR1 during both seasons. Bank stability was 100% at Station NR1 during both seasons owing to dense vegetation along both banks. Station NR3 had banks that were 100% vulnerable to erosion in the spring and 50% eroded by the fall survey. Vegetative canopy cover was greatest at Station NR3 during both seasons. The dominate flow habitat found at the two sites were runs during both seasons, except at Station NR1 in the spring where riffles dominated the reach.

Water quality measurements for each parameter were within normal ranges at both sites. Temperatures were warmest in the spring and cooler in the fall. Each of the other parameters were similar at both sites, during each season, except at Station NR1 in the spring when pH and dissolved oxygen were greater compared to NR3.

***Physical/Habitat Scores*:** Assessment of the physical/habitat conditions of a stream reach is necessary to determine its quality as a habitat for BMIs. In many cases organisms may not be exposed to chemical contaminants, yet their populations indicate that impairment has occurred. These population shifts can be the result of degraded stream bed and bank habitat. Excess sediment is the leading pollutant in streams and rivers of the United States (Harrington and Born 2000). Sediments fill pools and interstitial areas of the stream substrate where fish spawn and invertebrates live, causing their populations to decline or to be altered.

Out of a total possible score of 200, the physical/habitat score for Station NR3 was in the marginal range and NR1 was in the sub-optimal range during both seasons (Table 5 and Figure 3). Better physical habitat conditions at Station NR1, when compared to NR3, could be attributed to slightly less sediment deposition and channel alteration, coupled with better bank stability, vegetative canopy cover and riparian zone width. Scores were similar between seasons.

Table 4. Physical habitat measurements for 2 reaches in the Santa Clara River. Measurements are specified in by SWAMP (2007).

Parameter	**NR3**		**NR1**	
	Spring	**Fall**	**Spring**	**Fall**
<u>Habitat Characteristics</u>				
Reach Length (m)	150	150	150	150
Average Wetted Width (m)	7.6	9.4	5.4	5.0
Average Depth (cm)	28	23	36	32
Velocity (m/sec)	0.67	NR	0.55	NR
Discharge (m^3)	NR	0.70	NR	0.86
Bank Stability				
% Stable	0	50	100	100
% Vulnerable	100	0	0	0
% Eroded	0	50	0	0
Vegetative Canopy Cover (%)	11.9	26.9	1.1	3.2
Flow Habitats (%)				
Cascade/Fall	0	0	0	0
Rapid	0	0	0	0
Riffle	0	0	76	0
Run	89.5	100	18.5	100
Glide	10.5	0	5.5	0
Pool	0	0	0	0
Dry	0	0	0	0
Percent Gradient (%)	0.1		0.2	
<u>Chemical Characteristics</u>				
Water Temperature (C°)	20.17	16.75	23.52	19.27
pH	7.78	7.67	8.02	7.87
Alkalinity	240	245	238	230
DO	7.99	8.20	10.03	7.82
Specific Conductance (S/cm at 25EC)	1336	1201	1290	1186
Salinity (ppt)	0.74	0.72	0.66	0.67

Table 5. Physical habitat assessment for the two sampling sites in the Santa Clara River.

Habitat Parameter	**NR3**		**NR1**	
	Spring	**Fall**	**Spring**	**Fall**
1. Instream Cover	6	10	11	10
2. Embeddedness	5	6	9	7
3. Velocity / Depth Regime	10	15	12	15
4. Sediment Deposition	6	8	11	11
5. Channel Flow	6	10	8	7
6. Channel Alteration	13	11	16	19
7. Riffle Frequency	6	6	10	6
8. Bank Stability	8	7	14	18
9. Vegetative Protection	8	10	14	14
10. Riparian Vegetative Zone Width	14	8	18	18
Reach Total ***Condition Category***	**82** **Marginal**	**91** **Marginal**	**123** **Suboptimal**	**125** **Suboptimal**

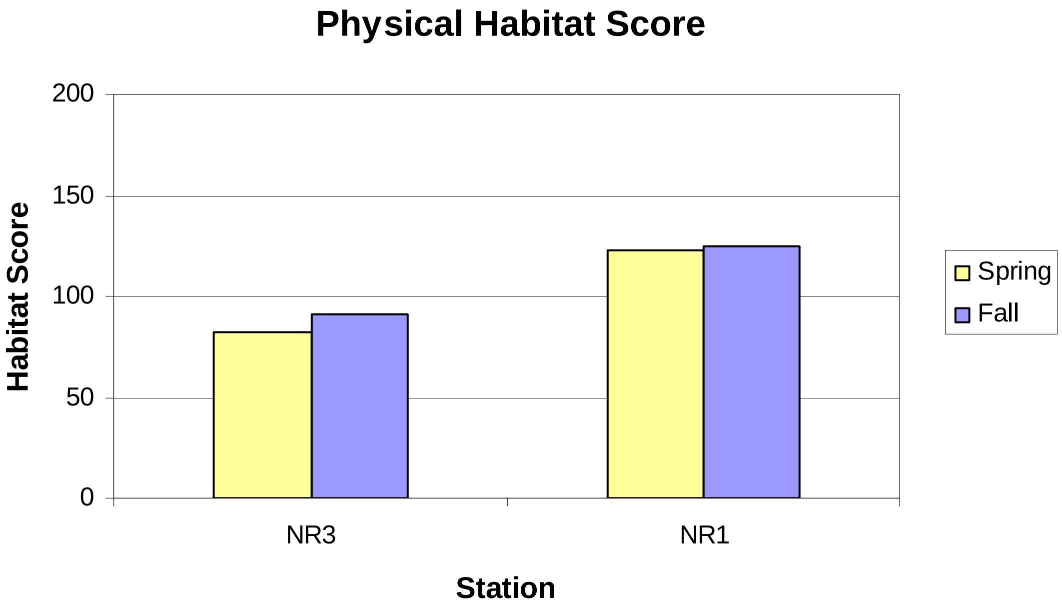


Figure 3. Physical/Habitat quality scores by season.

BMI Community Structure

The BMIs identified from each site are listed in order of ranked abundance in Table 6. The biological metrics calculated from each BMI sample are listed in Table 7 and Figures 4 thru 7. The Southern California IBI scores for each site and season are presented in Table 8 and Figure 8, and averaged by site for each survey since 2004 in Figure 9. Raw BMI abundances, tolerance values and feeding groups are presented in the Appendix, Tables 9a and 9b.

A total of 3,620 BMIs were identified from the samples collected during the spring and fall at the two sampling sites. During the spring seed shrimp (Ostracoda) represented 23% and 37% of the population at Stations NR3 and NR1, respectively (Table 6). Other relatively abundant species at both stations included oligochaete worms (15%), midge flies (Chrionomidae), and the mayfly, *Fallceon quilleri*. During the fall survey the most abundant species at Stations NR1 and NR3 were nematodes, midge flies, flatworms (Turbellaria), and mayflies (*Fallceon quilleri* and *Tricorythodes sp*.).

Biological Metrics

Each of the biological metrics listed in Table 2 above, was calculated for this survey and is presented in Table 7. Each metric is depicted graphically by community measure in Figures 4 to 7.

***Community Richness Measures*:** Taxa richness is a measure of the total number of species found at a site. This relatively simple index can provide much information about the integrity of the community. Few taxa at a site indicate that some species are being excluded, while a large number of species indicate a more healthy community. EPT taxa are the number of all of the mayflies (Ephemeroptera), caddisflies (Trichoptera), and stoneflies (Plecoptera) present at a location. These families are generally sensitive to impairment and, when present, are usually indicative of a healthier community than if any or all are absent. Metrics for Coleopteran and Predator taxa are included since they are used to calculate the So CA IBI.

Each of the community richness measures was similar between stations and seasons, and there were no significant differences among sites by ANOVA (Table 7 and Figure 4). Taxonomic richness ranged from 18 to 20, and EPT taxa ranged from 3 to 5. Numbers of Coleoptera were low during both seasons. Predator taxa ranged from 5 to 7.

***Composition Measures*:** The percent EPT taxa, sensitive EPT, percent non-insect taxa and the Shannon Diversity Index are all measures of community composition. Species diversity indices are similar to numbers of species; however they contain an evenness component as well. For example, two samples may have the same numbers of species and the same numbers of individuals. However, one station may have most of its numbers concentrated into only a few species while a second station may have its numbers evenly distributed among its species. The diversity index would be higher for the latter station. Percent EPT taxa are the proportion of the abundance at a site that is comprised of mayflies, stoneflies and caddisflies. Percent Sensitive EPT taxa are similar except it includes only those EPT taxa whose tolerance values range from 0 to 3. These taxa are very sensitive to impairment and, when present, can be indicative of better water quality conditions. Percent non-insect taxa is a measure of all other phyla represented at a site and, when elevated, generally indicate poorer water quality conditions.

The percentage of EPT taxa were somewhat greater at both Stations NR1 and NR3 during the spring compared to the fall (Table 7 and Figure 5). No sensitive EPT taxa were collected from the survey area. Shannon Diversity and non-insect individuals were nearly the same at each station, during both seasons. There were significantly greater numbers of non-insect taxa at Station NR3 in the fall compared to at Station NR1.

***Tolerance Measures*:** The Southern California IBI uses both the percent intolerant individuals and percent tolerant taxa to evaluate the overall sensitivity of organisms to pollution and habitat impairment. Each species is assigned a tolerance value from 0 (highly intolerant) to 10 (highly tolerant). The percent intolerance individuals for a site is calculated by multiplying the tolerance value of each species with a tolerance value ranging from 0 to 2, by its abundance, then dividing by the total abundance for the site. The percent tolerant taxa are similar except that only species with tolerance values ranging from 8 to 10 are included and total numbers of taxa, instead of individuals is used to derive the proportion. A site with many tolerant organisms present is considered to be less pristine or more impacted by human disturbance than one that has few tolerant species. The tolerance values for each species were developed in different parts of the United States and can therefore be region specific. Also, different organisms can be tolerant to one type of disturbance, but highly sensitive to another. For example, an organism that is highly sensitive to sediment deposition may be very insensitive to organic pollution. With these drawbacks in mind, the Tolerance measures generally depict disturbances in a stream that, when coupled with other metrics, can provide good water quality information regarding a stream reach.

Percent dominance reflects the proportion of the total abundance at a site represented by the most abundant species. For example, if 100 organisms are collected at a site and species A is the most abundant with 30 individuals, the percent dominance index score for the site is 30%. The benthic environment tends to be healthier when the dominance index is low, which indicates that more than just a few taxa make up the majority of the community.

The tolerance metrics reported for this survey indicated that Mean tolerance values were moderate (5 to 6) at both sites, during both seasons (Table 7 and Figure 6). Percent dominance and percent tolerant taxa were also similar during both seasons, at both sites. There were no intolerant organisms found in the survey area during either season. The percentage of Baetid mayflies was slightly greater in the fall and there were a significantly greater number of Baetid mayflies at Station NR3 during the fall, compared to Station NR1.

***Functional Feeding Groups*:** These indices provide information regarding the balance of feeding strategies represented in an aquatic assemblage. The combined feeding strategies of the organisms in a reach provide information regarding the form and transfer of energy in the habitat. When the feeding strategy of a stream system is out of balance it can be inferred that the habitat is stressed. For the purposes of this study, species were grouped by feeding strategy as percent collector-gatherers, collector-filterers, grazers, predators and shredders. The Southern California IBI uses the numbers of predators and percent collectors (gatherers + filterers) at a site to calculate the index.

Species using collecting and filtering, grazing and predation as their feeding strategy were the most common organisms collected during both seasons (Table 7). Collectors and filterers were dominant in the spring, followed by grazers and predators, at both stations. In the fall collectors and filterers were again dominant at Station NR3, but predators were dominant at Station NR1, followed by collectors and filterers. These differences among stations were significant. The increased numbers of predators at NR1 in the fall was due to large abundances of dragonflies (Odonata) and flatworms (Turbellaria).

***IBI Scores*:** Work conducted in the 1990's by the San Diego Regional Board and the California Department of Fish and Game, established an Index of Biotic Integrity (IBI) for the San Diego region and its watersheds (Ode and Harrington 2002). The index was recently expanded to include all of southern California (Ode et. al. 2005) and is used in this section.

The IBI is a multi-metric technique that employs seven biological metrics that were each found to respond to a habitat and/or water quality impairment at sites from Monterey, California to the Mexican boarder. Each of the seven biological metrics measured at a site are converted to an IBI score then summed. These cumulative scores can then be ranked according to very good (80-100), good (60-79), fair (40-59), poor (20-39) and very poor (0-19) habitat conditions. The threshold limit for this scoring index is 39. Despite the fact that rankings can be identified as "fair", sites with scores above 39 are within two standard deviations of the mean reference site conditions in southern California and are not considered to be impaired. Sites with scores below 39 are considered to have impaired conditions. The metric scoring ranges established for the Southern California IBI survey are listed in Table 4 and were used to classify the sites in this study.

2007

The Southern California IBI scores for 2007 ranged from 23 to 46, with each station ranking in the "poor" range, except Station NR1 in the fall which ranked as "fair" (Table 8 and Figure 8). Except for Station NR1 in the fall, the BMI communities at each of these sites were impaired when compared to conditions found at reference site locations throughout southern California. These impaired conditions appear to be due to habitat disruptions based on the low physical habitat scores measured at these sites (Table 5, Figure 3). Lower scores across sites and seasons were mostly due to the lack of EPT taxa and intolerant taxa and large abundances of relatively tolerant taxa. The improved IBI scores at NR1 in the fall were due to large numbers of predator organisms (predominately dragonflies), the presence of two species of beetle taxa (Coleoptera) and fewer collector taxa.

2004 to 2007

To assess the condition of BMI communities at Stations NR1 and NR3 over time, IBI scores were averaged (± 95% CI) by station and season for all surveys conducted between the spring of 2004 and the fall of 2007 (Figure 9). The average IBI scores at each site were in the poor range for the four year period. This shows that BMI habitat conditions upstream and downstream of the Newhall WRP were similar during this four year period. Importantly, the scores were similar between locations so that future comparisons between sites upstream and downstream of the discharge point will be possible.

DISCUSSION

The Santa Clara River watershed is the longest free-flowing natural river in southern California. Its 70 mile length provides drainage to a 1,600 mi^2 watershed. Before reaching the Pacific Ocean in Ventura, it passes through the Santa Clarita Valley where a large urban development project is planned. A part of this project includes the construction of a Water Reclamation Plant (WRP) that will service the residences and commercial businesses that are included in this project. The future discharge site for the treatment plant is located on Newhall Ranch property in Los Angeles County just upstream of the border with Ventura County. The Newhall Ranch property, which borders both sides of the Santa Clara River, has been used historically for agriculture, ranching oil drilling operations.

For the most part, the Santa Clara River has been allowed to follow its natural course through the valley. The water flow in the river varies widely between wet weather, when the river typically reaches 100,000 cubic feet per second (cfs), and the summer and fall when the river bed can be nearly dry (Swanson et al. 1990). Presently, the combination of natural river flow, urban runoff and the discharge from upstream waste treatment facilities maintain a relatively constant low flow of water in the River, even during the driest summer months.

The goal of this project was to assess the baseline conditions of the benthic macro-invertebrate community in the Santa Clara River at sites located at the discharge point for the future WRP and downstream of it. These data will allow managers to assess if changes are occurring to the benthic community after the treatment plant is completed and discharge to the river has begun. Bioassessment samples were collected, and physical habitat assessments were made on July 27th and October 31st, 2007 at two locations in the Santa Clara River near the Los Angeles/Ventura County line. Site NR1 was located at the future discharge point for the WRP, while NR3 was located 2.7 miles downstream.

All samples and physical habitat surveys were collected and analyzed according to the protocols established in the recently promulgated State of California, Stormwater Ambient Monitoring Program (SWAMP 2007). These protocols were based on the California Stream Bioassessment Protocols (CSBP 2003) and the EPA’s Environmental Monitoring and Assessment Program (EMAP). The results of BMI community metrics collected by each of these protocols were found to be comparable (Rehn et al. 2006). This means that BMI data collected by the CSBP method before 2007 are comparable. The quality assurance criteria specified in the SWAMP protocol were met for both the physical habitat and taxonomic portions of the program.

The Visual-Based Habitat (VBH, Barbour et al. 1999) physical/habitat assessment scores for both the upstream and downstream stations (NR1 and NR3, respectively) were marginal to sub-optimal, with the best conditions found at NR1 during both the spring and fall. The river beds at both stations were of relatively low gradient and composed of mostly sandy particles, with no cobble, boulders, undercut banks or branch fall. Combined, these habitat conditions do not provide for the types of complex habitat that will support a wide diversity of BMIs. Comparing the two sites, the better physical habitat conditions at Station NR1 were mostly associated with less channel alteration, better bank stability, vegetative cover and riparian zone width. The lower scores at Station NR3 were, for the most part, due to large amounts of sedimentation and channel alteration, poor bank stability, and less vegetative canopy cover and riparian zone.

The VBH scoring system used in the CSBP (2003) protocols were originally developed in the mid-west and eastern United States by the USEPA. As a result, the appropriateness of it’s application to low gradient river wash systems such as the Santa Clara River have been questioned. However, since the VBH has been used since the inception of the BMI program in 2004, its use in 2007 was intended to help provide historical context for the physical habitat attributes found during the survey and to determine if any large scale changes to the streambed system had occurred at either site in the previous year. The new Basic SWAMP (2007) physical habitat assessment was also conducted in 2007 at each site. While useful, the scoring system for this protocol has not been completed, which makes judgment of habitat quality difficult.

The Santa Clara River is a large drainage for the Transverse Ranges of southern California and has ephemeral discharge due to winter rainfall and dry summers (Inman and Jenkins 1999). It is the largest contributor of sediment to the coastal ocean waters of the southern California bight due to its steep landscape, weak sedimentary rocks and intense seasonal rainfall (Schwalbach and Gorsline 1985, Scott and Williams 1978, Warrick 2002). Therefore, the large amounts of sediment present in the Santa Clara River bed at Stations NR1 and NR3 may be the result of naturally occurring processes. During a study of the Santa Clara River in 2001, Ambrose (et. al. 2003) also found that sites located at Newhall Ranch were characterized by sandy sediments.

The BMI population metrics measured at both NR1 and NR3 during 2007 was similar in terms of richness, composition, and tolerance measures. Several metrics were significantly different among stations by ANOVA, with the majority of these being community feeding group measures in the fall. These differences were mostly explained by the dominance of collectors and filterers at Station NR3 and a corresponding dominance of predators at Station NR1. The increase in predators at NR1 was due to the presence of large abundances of dragonflies (Odonata) and flatworms (Turbellaria).

The BMI population in this reach of the Santa Clara River is characterized by the absence of intolerant species (sensitive species) and sensitive EPT taxa. Intolerant organisms are those that have been assigned a tolerance value from zero to two. Sensitive EPT taxa are mayflies, stoneflies and caddisflies whose tolerance values range from 0 to 3. Each of these taxa groups are very sensitive to impairment and, when present, can be indicative of more natural conditions. During a 2001 watershed-wide survey conducted by Ambrose (et. al. 2003), investigators found similar BMI communities at sites near those used during the current study.

The IBI scores at both NR1 and NR3 indicated that the condition of the biological communities found there were impaired when compared to the conditions at reference sites in southern California. The exception to the low IBI scores was Station NR1 in the fall when the IBI score was in the fair range. It is possible that the physical habitat condition of this site, which was somewhat better than at Station NR3, is playing a role in this improvement. The increased IBI score at NR1 in the fall was due to large numbers of predator organisms (predominately dragonflies), the presence of two species of beetle taxa (Coleoptera) and fewer collector taxa. It should be noted that while low gradient reference sites were included in the development of the southern California IBI (Ode et al 2005), work is currently underway to determine if the index accurately characterizes large river wash systems such as the Santa Clara River. This work is being conducted by the Stormwater Monitoring Coalition (SMC), which is a consortium of watershed and stormwater agencies that are tasked with assessing the condition of southern California watersheds.

To assess the condition of BMI communities at Stations NR1 and NR3 over time, IBI scores were averaged (± 95% CI) by station and season for all surveys conducted between the spring of 2004 and the fall of 2007. The average IBI score at each site were in the poor range for the four year period. This shows that BMI habitat conditions upstream and downstream of the proposed Newhall WRP outfall location were similar during this four year period.

In prior reports (Aquatic Bioassay 2005 to 2007), the IBI scores were inadvertently miscalculated using % non-insect individuals and % tolerant individuals, instead of % non-insect taxa and % tolerant taxa. The IBI scores in this year's report are corrected. In addition, the IBI scores for the previous reports were recomputed and are presented in Appendix B. While the scores vary between old and new computations, the overall ranking of poor for both sites across each sampling event was unchanged.

The results of the 2007 survey on the Santa Clara River in the vicinity of the future WRP in the Santa Clarita Valley indicated that the river habitat is typical of a southern California river wash located in a heavily developed land use area. As a result, the BMI communities residing there are impaired. One likely disturbance is the high amount of sediments in the river bed and, therefore, the lack of complex habitat. This sedimentation may be the result of the natural geomorphic composition and ephemeral nature of the surrounding watershed and/or human activities.

Table 6. Average species ranked by abundance for each site and season for the Santa Clara River bioassessment survey.

Spring				Fall			
NR3		NR1		NR3		NR1	
Species	% of Total Abund	Species	% of Total Abund	Species	% of Total Abund	Species	% of Total Abund
Ostracoda	23.7	Ostracoda	37	Nematoda	21.8	Turbellaria	27
Oligochaeta	15.6	Oligochaeta	12.1	Chironomidae	19.2	Nematoda	16.1
Chironomidae	15.2	Fallceon quilleri	12	Fallceon quilleri	15.3	Tricorythodes sp	8.9
Hydroptila sp	13.8	Turbellaria	9.2	Oligochaeta	8.9	Chironomidae	7.3
Hydroptilidae	6.1	Hydroptila sp	6.8	Ostracoda	8.3	Simulium sp	6.7
Nematoda	5.9	Tricorythodes sp	6.6	Turbellaria	7.6	Hetaerina sp	6.4
Fallceon quilleri	4.5	Chironomidae	3.2	Simulium sp	5.9	Argia sp	5.8
Hemerodromia sp	4.5	Simulium sp	3.1	Tricorythodes sp	5.4	Physa sp	5.7
Simulium sp	3.3	Caloparyphus/Euparyphus sp	1.9	Sperchon sp	1.6	Fallceon quilleri	5.4
Turbellaria	2	Hydroptilidae	1.7	Baetis sp	1.6	Coenagrionidae	3
Physa sp	1.4	Baetis sp	1.1	Physa sp	0.8	Ostracoda	2.1
Caloparyphus/Euparyphus sp	0.8	Caloparyphus sp	1.1	Copepoda	0.8	Oligochaeta	1.4
Sperchon sp	0.7	Physa sp	0.9	Coenagrionidae	0.7	Chrysomelidae	0.8
Pericoma/Telmatoscopus sp	0.4	Bezzia/Palpomyia sp	0.6	Ephydridae	0.4	Zoniagrion exclamationis	0.4
Baetis sp	0.2	Nematoda	0.6	Hemerodromia sp	0.4	Caloparyphus/Euparyphus sp	0.3
Euparyphus sp	0.2	Sperchon sp	0.5	Hydroptilidae	0.2	Postelichus sp	0.3
Zoniagrion exclamationis	0.2	Zoniagrion exclamationis	0.4	Hydrozetidae	0.2	Hemerodromia sp	0.3
Anisoptera	0.1	Culicoides sp	0.3	Hetaerina americana	0.2	Pericoma/Telmatoscopus sp	0.2
Atractides sp	0.1	Hemerodromia sp	0.3	Argia sp	0.1	Brechmorhoga mendax	0.2
Bezzia/Palpomyia sp	0.1	Coenagrionidae	0.2	Culicoides sp	0.1	Hydropsyche sp	0.2
Coenagrionidae	0.1	Euparyphus sp	0.2	Cladocera	0.1	Optioservus sp	0.2
Culicoides sp	0.1	Helochares sp	0.1	Ceratopogonidae	0.1	Libellulidae	0.1
Ephydridae	0.1			Caloparyphus/Euparyphus sp	0.1	Bezzia/Palpomyia sp	0.1
Helochares sp	0.1			Nemotelus sp	0.1	Ceratopogon sp	0.1
Heteroceridae	0.1					Baetis sp	0.1
Libellulidae	0.1					Ephydridae	0.1
Peltodytes sp	0.1					Libellula sp	0.1
Tropisternus sp	0.1					Petrophila sp	0.1
						Psychodidae	0.1
						Tyrrellia sp	0.1
						Hydrozetidae	0.1
TOTAL	100		100		100		100

Table 7. Comparison of averaged biological metrics (± SD, CV & 95% CI) for each site by season, evaluated using ANOVA. Grayed F scores significant at $p \leq 0.05$.

		Spring					**Fall**				
		Station			**Comparison**		**Station**			**Comparison**	
Metric		**NR3**	**NR1**	**Avg**	**F-Ratio**	**p**	**NR3**	**NR1**	**Avg**	**F-Ratio**	**p**
Community Richness Measures											
Taxonomic richness	**mean**	18	18	18	0.03	0.87	18	20	19	3.77	0.12
	st. dev.	3.1	1.7	2.4			1	2	1		
	cv	17.3	9.6	13.4			3	10	7		
	95% CI	3.5	2	2.8			1	2	2		
EPT taxa	**mean**	4	5	4	4.50	0.10	3	3	3	2.00	0.23
	st. dev.	0.6	0.6	0.6			1	1	1		
	cv	15.7	12.4	14			17	22	20		
	95% CI	0.7	0.7	0.7			1	1	1		
Cumulative EPT Taxa	**mean**	4	3	4	N/A		4	4	4	N/A	
Coleoptera Taxa	**mean**	1	0	1	1.80	0.25	0	2	1	**3.85**[1.]	**0.05**
	st. dev.	1	1	0.9			0.0	0.0	0		
	cv	87	173	129.9			-	0.0	0		
	95% CI	1	1	1			0.0	0.0	0		
Predator Taxa	**mean**	6	5	6	0.45	0.53	6	7	7	0.96	0.38
	st. dev.	3	1	2			2	3	2		
	cv	40	11	25			27	34	31		
	95% CI	3	1	2			2	3	2		
Community Composition Measures											
EPT Index (%)	**mean**	24.6	28.0	26.3	0.19	0.68	22.5	14.6	18.6	2.13	0.22
	st. dev.	0.7	13.3	7.0			6.3	6.9	6.6		
	cv	2.7	47.5	25.1			27.8	47.4	37.6		
	95% CI	0.8	15.1	8			7.1	7.8	7.4		
Sensitive EPT Index (%)	**mean**	0	0	0.0	N/A		0.0	0.0	0.0	N/A	
	st. dev.	0	0	0.0			0.0	0.0	0.0		
	cv	-	-	-							
	95% CI	0	0	0			0.0	0.0	0.0		
Shannon Diversity	**mean**	2.2	2.0	2.1	2.03	0.23	2.2	2.2	2	0.06	0.82
	st. dev.	0.0	0.2	0.1			0.1	0.3	0		
	cv	1.7	12.1	6.9			3.1	12.3	8		
	95% CI	0.0	0.3	0			0.1	0.3	0		
Percent Non-Insect Individuals	**mean**	50.1	60.5	55.3	1.91	0.24	50.1	52.6	51	0.76	0.43
	st. dev.	4.0	12.5	8.2			1.8	4.6	3		
	cv	8.0	20.7	14.4			3.6	8.7	6		
	95% CI	4.5	14.1	9			2.1	5.2	4		
Percent Non-Insect Taxa	**mean**	34.2	33.2	33.7	0.30	0.62	45.3	27.0	36	**29.97**	**0.01**
	st. dev.	5.4	6.9	6.1			1.6	7.3	4		
	cv	15.7	20.6	18.1			3.4	17.6	11		
	95% CI	6.1	7.8	7			1.8	8.3	5		
Community Tolerance Measures											
Mean Tolerance Value	**mean**	6.1	6.1	6.1	0.00	1.00	5.4	5.3	5	0.64	0.47
	st. dev.	0.3	0.7	0.5			0.2	0.2	0		
	cv	4.9	11.5	8.2			2.8	2.9	3		
	95% CI	0.3	0.8	1			0.2	0.2	0		
% dominant taxa	**mean**	24.1	39.8	31.9	3.19	0.14	23.2	31.3	27.2	1.02	0.36
	st. dev.	4.1	14.7	9.4			6.0	12.5	9.2		
	cv	17.1	36.9	27.0			26.1	40.0	33.0		
	95% CI	4.7	16.6	11			6.8	14.1	10.4		
Percent Tolerant Taxa	**mean**	30.6	29.7	30.1	0.03	0.87	37.3	26.3	31.8	2.10	0.22
	st. dev.	8.2	3.0	5.6			9.0	9.5	9.2		
	cv	26.9	9.9	18.4			24.2	36.0	30.1		
	95% CI	9.3	3.3	6			10.2	10.7	10.5		

Table 7. (continued)

		Spring					Fall				
		Station			Comparison		Station			Comparison	
Metric		**NR3**	**NR1**	**Avg**	**F-Ratio**	**p**	**NR3**	**NR1**	**Avg**	**F-Ratio**	**p**
Community Tolerance Measures (continued)											
Percent Tolerant Individuals (8-10)	**mean**	28.9	41.8	35.3	1.10	0.35	12.6	12.1	12.3	0.08	0.79
	st. dev.	7.3	20.0	13.6			1.8	2.2	2.0		
	cv	25.2	47.8	36.5			14.4	17.9	16.2		
	95% CI	8.2	22.6	15			2.0	2.4	2.2		
Percent Intolerant Individuals (0-2)	**mean**	0.0	0.0	0.0	N/A		0.0	0.0	0.0	N/A	
	st. dev.	0.0	0.0	0.0			0.0	0.0	0.0		
	cv	-	-	-			-	-	-		
	95% CI	0.0	0.0	0.0			0.0	0.0	0.0		
Percent Hydropsychidae	**mean**	0.0	0.0	0.0	N/A		0.0	0.2	0.1	1.00	0.37
	st. dev.	0.0	0.0	0.0			0.0	0.4	0.2		
	cv	-	-	-				173.2	173.2		
	95% CI	0.0	0.0	0.0			0.0	0.5	0.2		
Percent Baetidae	**mean**	4.5	13.0	8.8	1.60	0.27	17.0	5.6	11.3	**10.00**	**0.03**
	st. dev.	2.5	11.3	6.9			5.2	3.4	4.3		
	cv	56.1	87.0	71.6			30.8	60.4	45.6		
	95% CI	2.9	12.8	8			5.9	3.8	4.8		
Community Feeding Group Measures											
Percent Collectors & Filterers	**mean**	64.0	78.8	71.4	**6.52**	**0.06**	66.2	33.0	49.6	**24.86**	**0.01**
	st. dev.	3.4	9.4	6.4			11.4	1.7	6.6		
	cv	5.4	12.0	8.7			17.2	5.0	11.1		
	95% CI	3.9	10.7	7.3			12.9	1.9	7.4		
Percent Collectors	**mean**	61.1	75.7	68.4	**6.28**	**0.06**	60.2	26.1	43.1	**27.16**	**0.01**
	st. dev.	1.4	10.0	5.7			10.4	4.5	7.4		
	cv	2.3	13.2	7.8			17.3	17.3	17.3		
	95% CI	1.6	11.3	6			11.8	5.1	8.4		
Percent Filterers	**mean**	2.9	3.1	3.0	0.01	0.91	6.0	6.9	6.5	0.08	0.79
	st. dev.	2.9	1.7	2.3			3.7	4.2	4.0		
	cv	101.1	53.7	77.4			61.2	60.9	61.0		
	95% CI	3.3	1.9	3			4.2	4.8	4.5		
Percent Grazers	**mean**	22.1	9.3	15.7	**14.90**	**0.02**	1.0	6.0	3.5	**34.34**	**<0.01**
	st. dev.	3.8	4.3	4.0			0.3	1.5	0.9		
	cv	17.2	45.9	31.6			30.0	24.2	27.1		
	95% CI	4.3	4.8	5			0.3	1.6	1.0		
Percent Predators	**mean**	13.8	11.9	12.8	0.30	0.61	32.8	60.2	46.5	**17.94**	**0.01**
	st. dev.	2.4	5.7	4.0			11.2	0.0	5.6		
	cv	17.4	48.1	32.8			34.1	0.0	17.0		
	95% CI	2.7	6.5	5			12.7	0.0	6.4		
Percent Shredders	**mean**	0.0	0.0	0.0	N/A		0.0	0.8	0.4	**64.00**	**0.00**
	st. dev.	0.0	0.0	0.0			0.0	0.2	0.1		
	cv	-	-	-				21.7	21.7		
	95% CI	0.0	0.0	0.0			0.0	0.2	0.1		
Percent Chironomidae	**mean**	15.2	3.2	9.2	**61.39**	**<0.01**	19.2	7.3	13	**16.49**	**0.01**
	st. dev.	2.4	1.2	1.8			3.8	3.4	4		
	cv	15.6	37.7	26.6			19.7	45.7	33		
	95% CI	2.7	1.4	2			4.3	3.8	4		

[1] Variences not equal, ANOVA by Kruskall-Wallis one way ANOVA on ranks and multiple comparison by Kruskall-Wallis Z-test

Marginally Significant	(0.05 < p < 0.10), difference generally not large enough for multiple comparisons to detect.
Significant	(p <0.05)

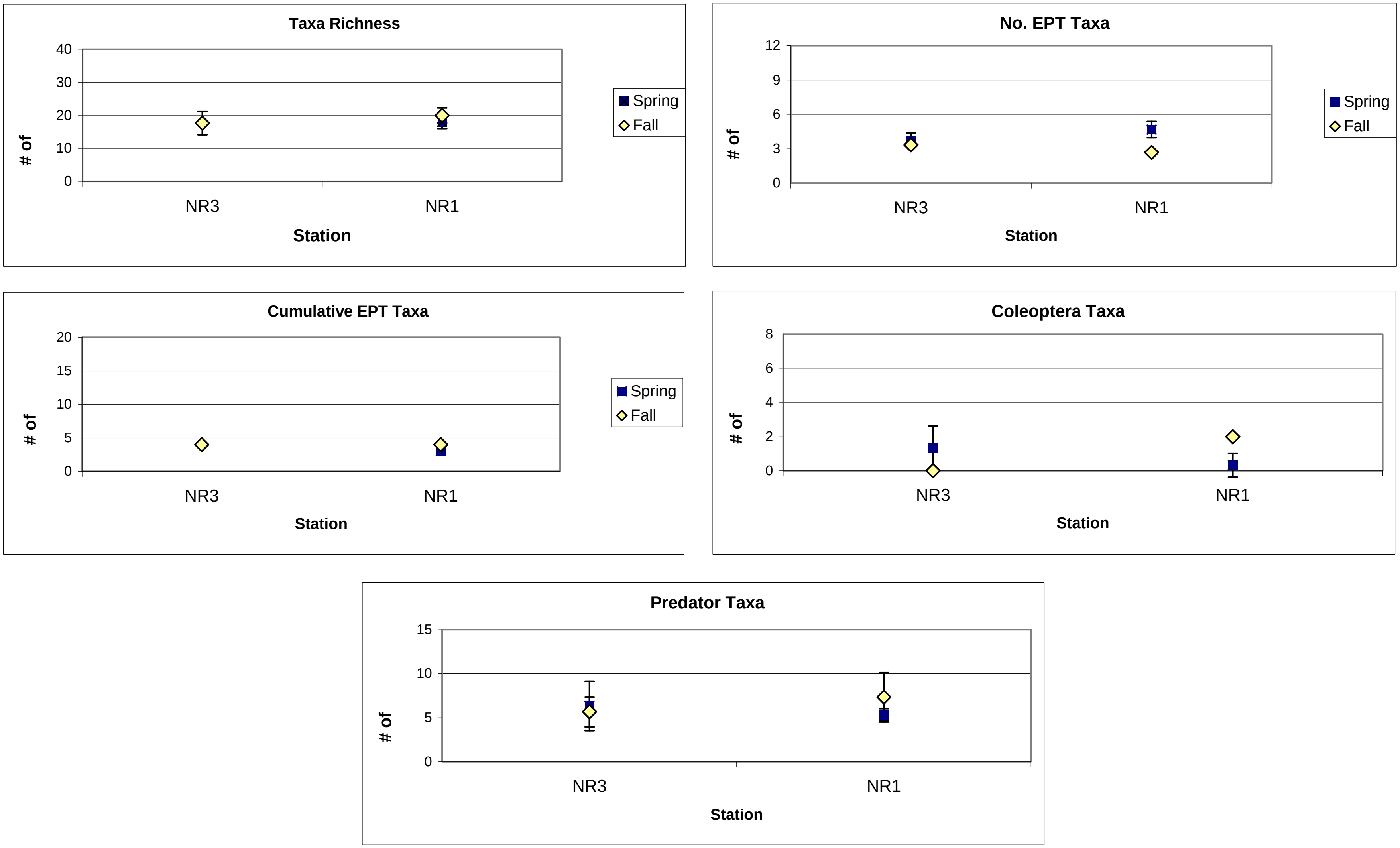


Figure 4. Averaged community richness metrics (± 95% CI) by season for each site.

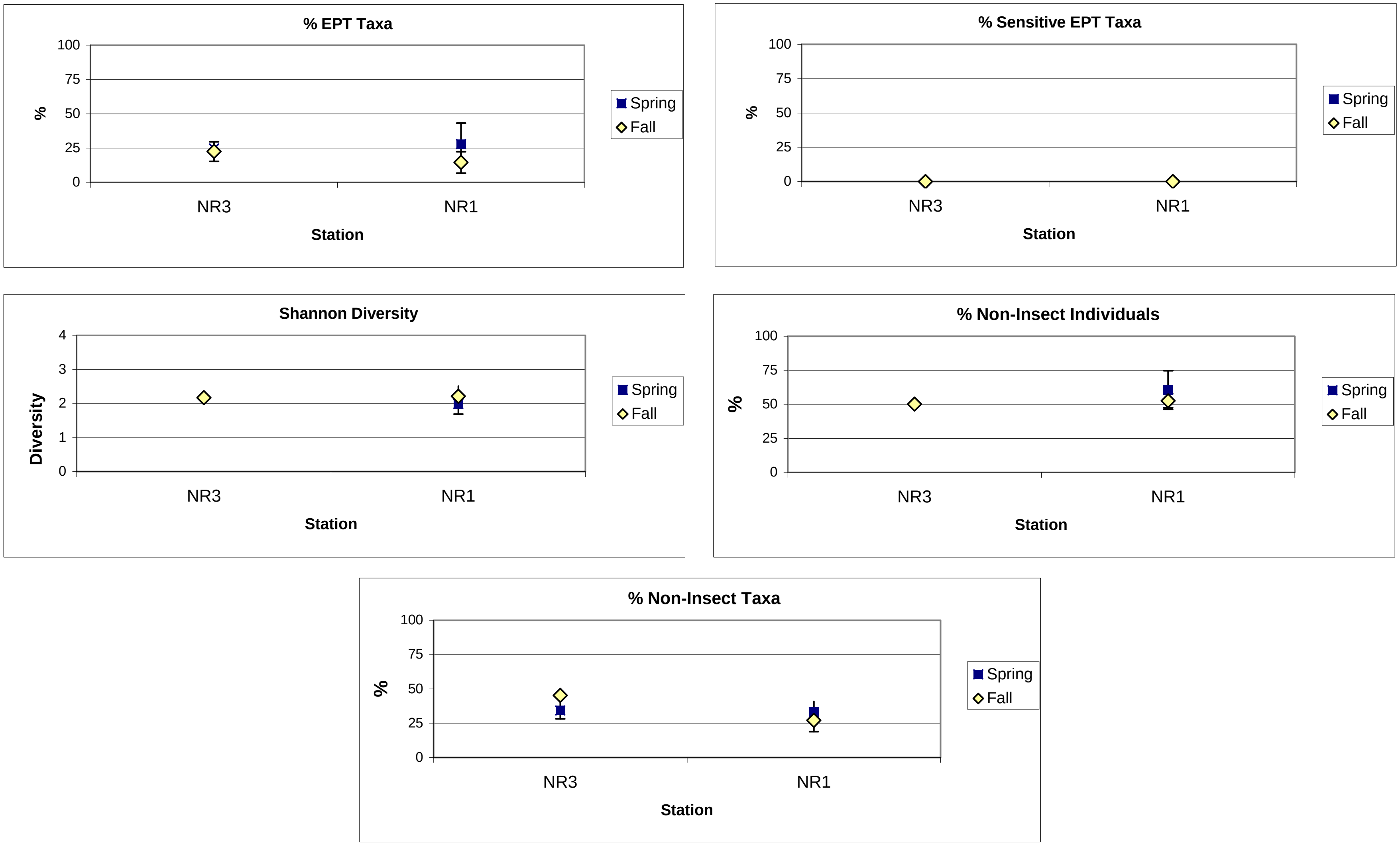


Figure 5. Averaged community composition metrics (± 95% CI) by season for each site.

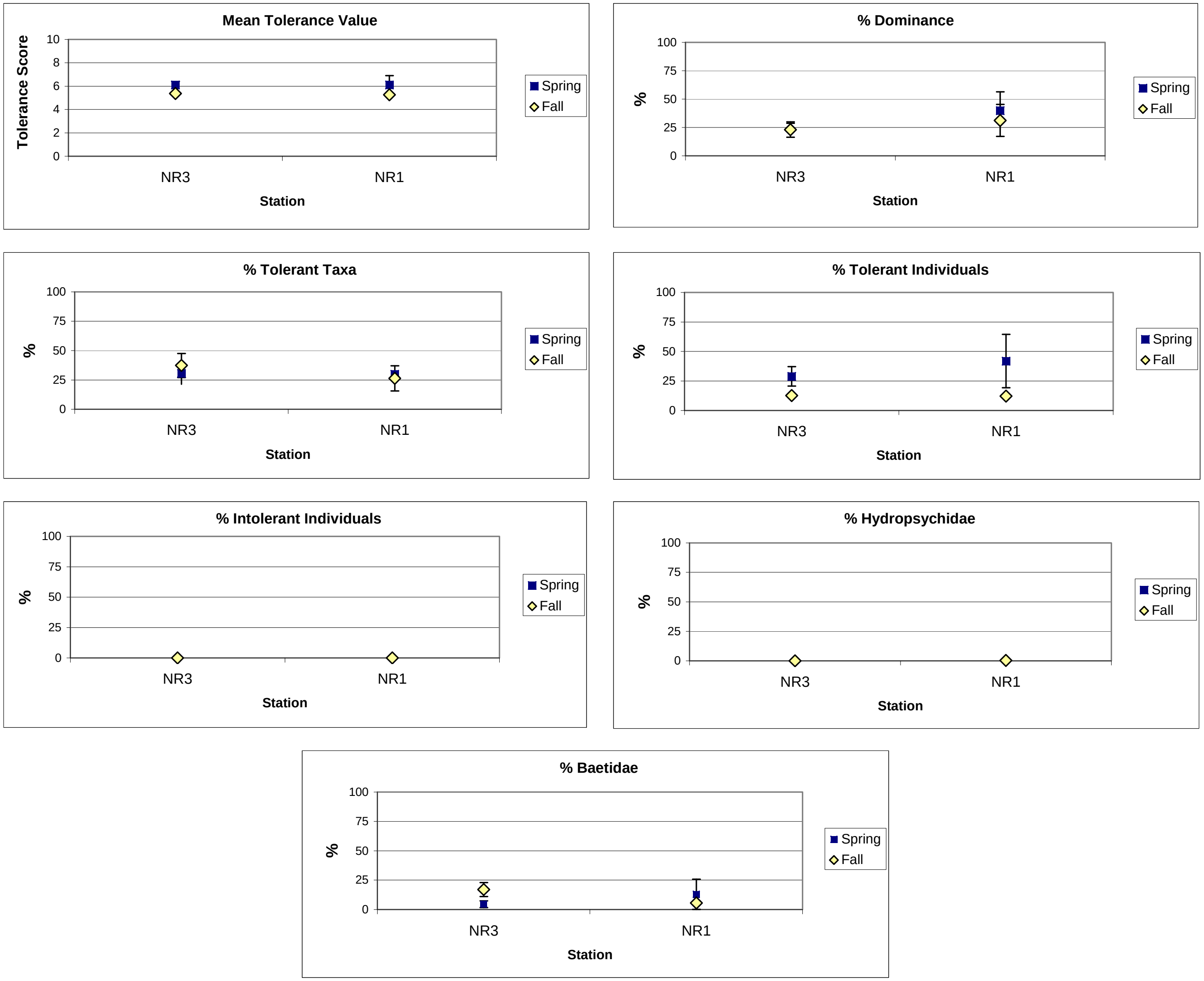


Figure 6. Averaged community tolerance metrics (± 95% CI) by season for each site.

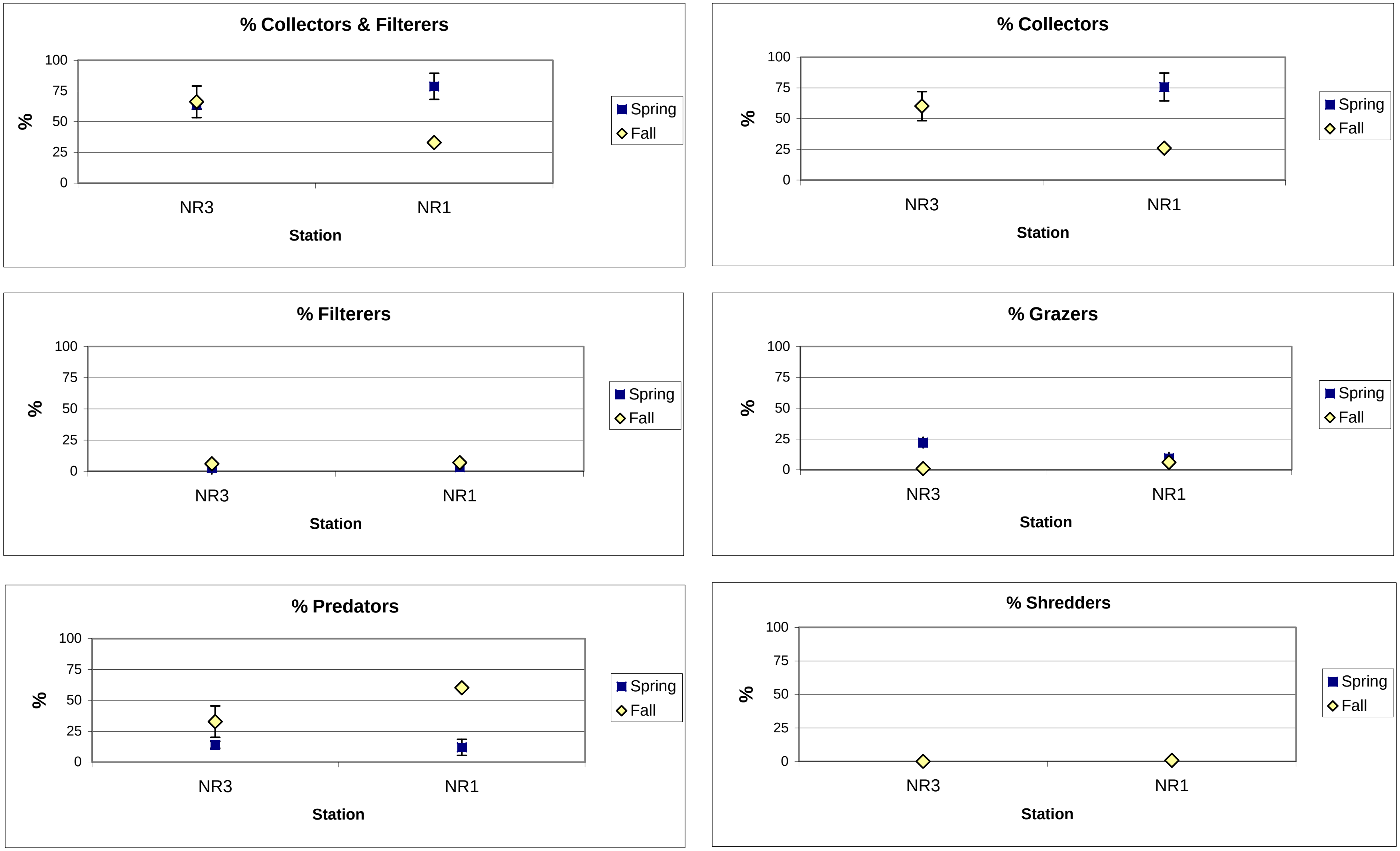
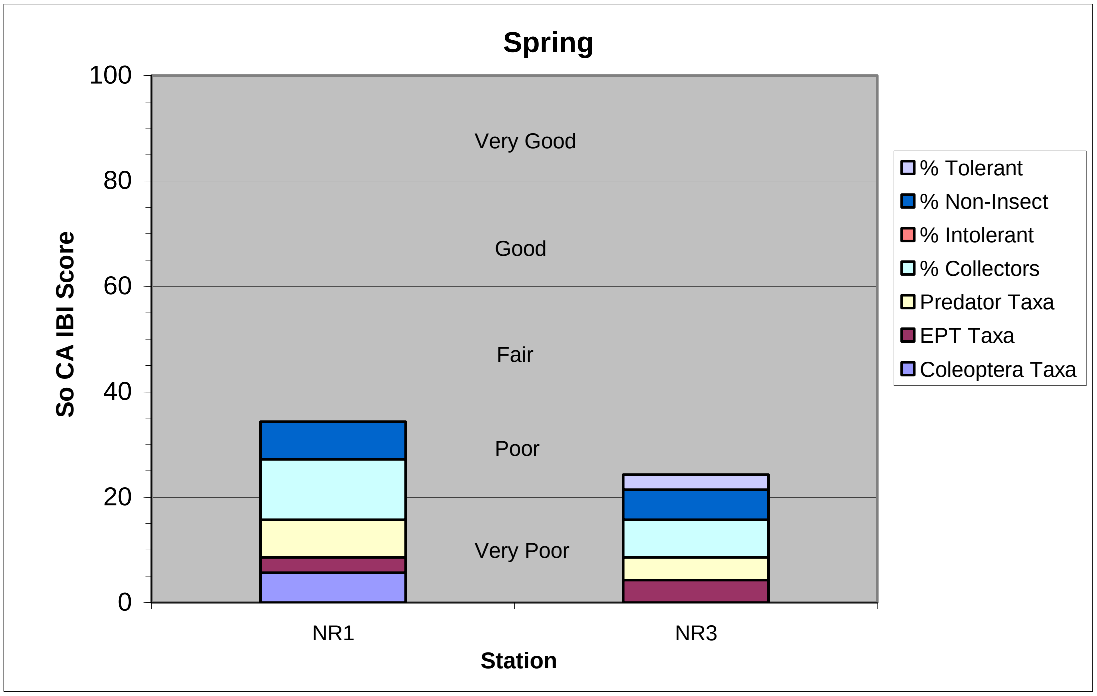


Figure 7. Averaged community feeding metrics (± 95% CI) by season for each site.

Table 8. Southern California IBI calculations for each of the Santa Clara River locations by season.

Station Metric	NR3		NR1	
	Spring	**Fall**	**Spring**	**Fall**
EPT Taxa	2	1	3	2
Predator Taxa	5	4	3	6
Coleoptera Taxa	4	0	0	5
% Non-Insect	5	3	4	6
% Intolerant Taxa	0	0	0	0
% Tolerant	0	0	2	3
% Collector Taxa	8	8	5	10
Total	**24**	**16**	**17**	**32**
Adjusted Score (1.43)	**34**	**23**	**24**	**46**
So. Cal. IBI Rating	**Poor**	**Poor**	**Poor**	**Fair**



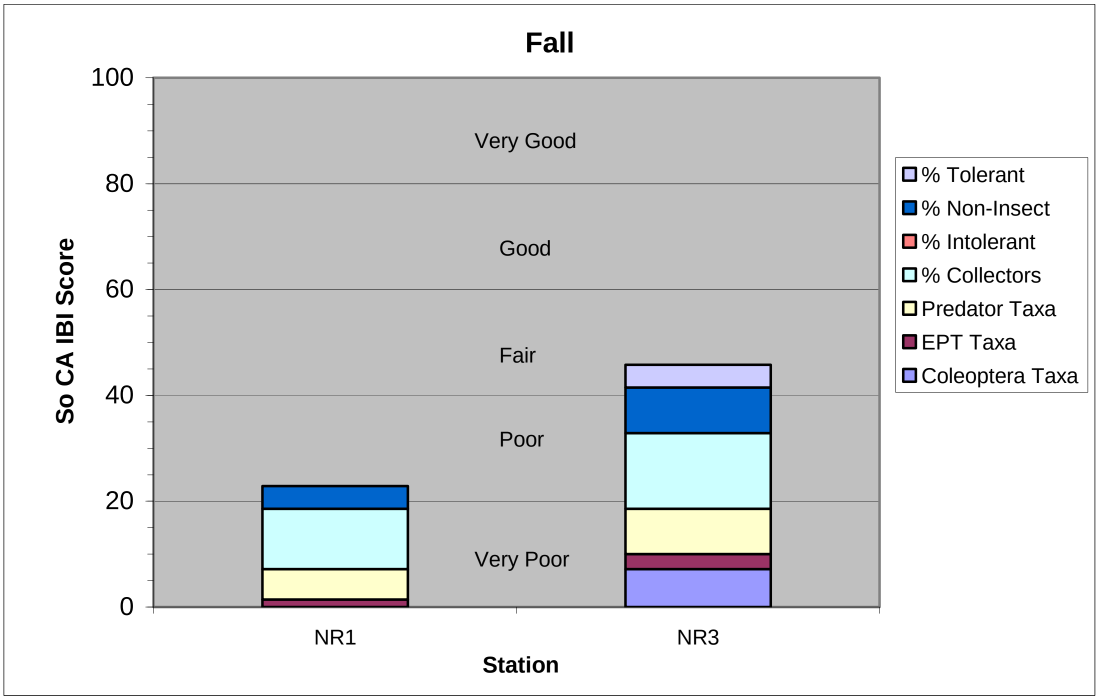


Figure 8. Southern California IBI Scores for sites that were sampled in the Santa Clara River.

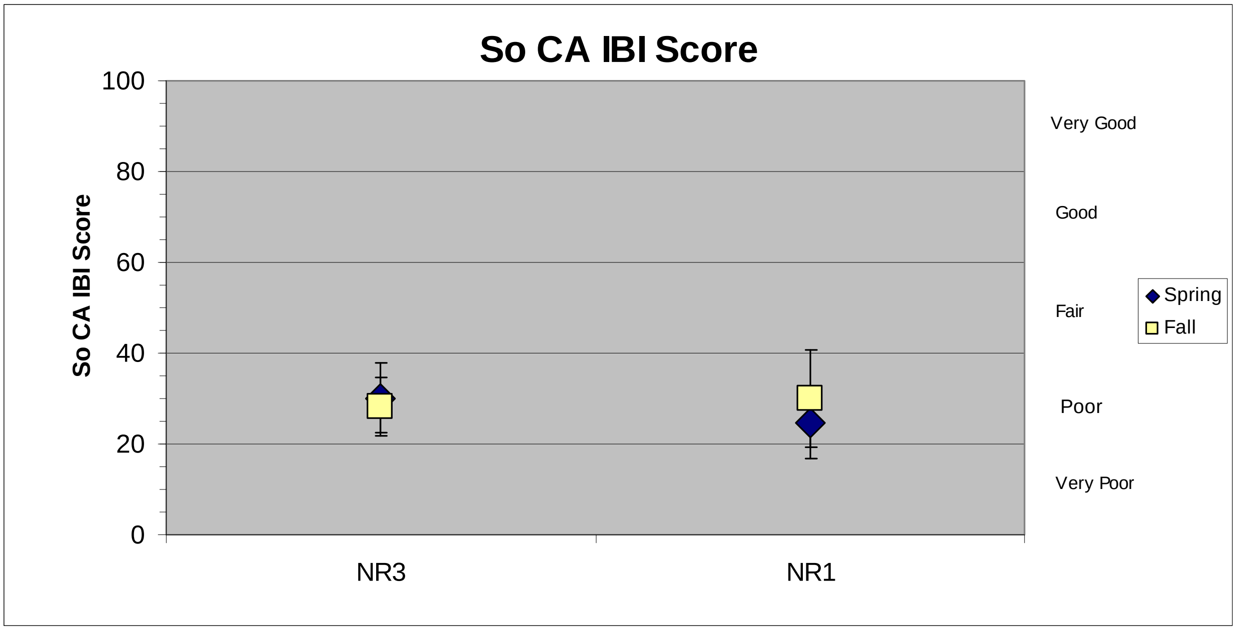


Figure 9. Average Southern California IBI Scores (± 95% CI) for sites that were sampled in the Santa Clara River from the spring of 2004 to the fall of 2007 (n = 4 for each site during each season).

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APPENDIX A – BENTHIC MACROINVERTEBRATE DATA

Table 9a. Spring infauna abundances by station at each site in the Santa Clara River.

Identified Taxa	Tol Val (TV)	Func Feed Grp	NR3			NR1		
			1	2	3	1	2	3
Insecta Taxa								
Ephemeroptera								
Baetis sp	5	cg		1	1	7		4
Fallceon quilleri	4	cg	7	24	7	76	35	5
Tricorythodes sp	4	cg				19	35	10
Odonata								
Anisoptera			1					
Coenagrionidae	9	p			1			2
Libellulidae	9	p			1			
Zoniagrion exclamationis	9	p			2		4	
Trichoptera								
Hydroptila sp	6	sc	38	41	38	36	8	22
Hydroptilidae	4	sc	28	21	3	2	4	10
Coleoptera								
Helochares sp	5	p	1			1		
Heteroceridae					1			
Peltodytes sp	5	mh	1					
Tropisternus sp	5	p			1			
Diptera								
Bezzia/Palpomyia sp	6	p	1			1		5
Caloparyphus sp	7	cg				4	6	1
Caloparyphus/Euparyphus sp	8	cg		3	4	4	1	13
Chironomidae	6	cg	54	47	28	15	7	9
Culicoides sp	8	cg	1			3		
Ephydridae	6				1			
Euparyphus sp	8	cg	2			1		1
Hemerodromia sp	6	p	21	14	3	1	1	1
Pericoma/Telmatoscopus sp	4	cg		3				
Simulium sp	6	cf	6	21	1	8	6	16
Non-Insecta Taxa								
Nematoda	5	p	14	27	9	4	1	1
Oligochaeta	5	cg	32	67	33	42	32	43
Ostracoda	8	cg	83	67	51	52	159	148
Turbellaria	4	p	9	4	4	53	13	23
Basommatophora								
Physa sp	8	sc		1	11	2	2	5
Trombidformes								
Atractides sp	8	p			1			
Sperchon sp	8	p	3	2	1		3	2
TOTAL			**302**	**343**	**202**	**331**	**317**	**321**

Table 9b. Fall infauna abundances by station at each site in the Santa Clara River.

Identified Taxa	Tol Val (TV)	Func Feed Grp	NR3 1	 2	 3	NR1 1	 2	 3
Insecta Taxa								
Ephemeroptera								
Baetis sp	5	cg	5	5	4			1
Fallceon quilleri	4	cg	33	63	42	5	23	21
Tricorythodes sp	4	cg	13	20	16	13	36	31
Odonata								
Argia sp	7	p			1	16	17	19
Brechmorhoga mendax	9	p					2	
Coenagrionidae	9	p	3	2	1		15	12
Hetaerina americana	6	p	2					
Hetaerina sp	5	p				25	21	12
Libellula sp	9	p					1	
Libellulidae	9	p					1	
Zoniagrion exclamationis	9	p					4	
Trichoptera								
Hydropsyche sp	4	cf				2		
Hydroptilidae	4	sc			2			
Coleoptera								
Chrysomelidae	5	sh				2	2	3
Optioservus sp	4	sc				2		
Postelichus sp	5						2	1
Diptera								
Bezzia/Palpomyia sp	6	p						1
Caloparyphus/Euparyphus sp	8	cg		1		1	1	1
Ceratopogon sp	6	p					1	
Ceratopogonidae	6	p	1					
Chironomidae	6	cg	70	55	48	32	22	12
Culicoides sp	8	cg	1					
Ephydridae	6			2	2		1	
Hemerodromia sp	6	p	2		2	1		2
Nemotelus sp	8	cg		1				
Pericoma/Telmatoscopus sp	4	cg					1	1
Psychodidae	10	cg						1
Simulium sp	6	cf	16	7	30	32	9	19
Lepidoptera								
Petrophila sp	5	sc				1		
Non-Insecta Taxa								
Copepoda	8	cg	1	2	4			
Nematoda	5	p	90	51	56		72	73
Oligochaeta	5	cg	5	28	47	1	7	5
Ostracoda	8	cg	16	24	35	15	3	1
Turbellaria	4	p	30	31	8	137	46	61
Acariformes								
Hydrozetidae			1		1	1		
Basommatophora								
Physa sp	8	sc	4	2	1	13	15	23
Diplostraca								
Cladocera	8	cf		1				
Trombidformes								
Sperchon sp	8	p	7	5	2			
Tyrrellia sp	5	p				1		
TOTAL			**300**	**300**	**302**	**300**	**302**	**300**

APPENDIX B – RE-COMPUTED SOUTHERN CALIFORNIA IBI SCORES

Table 10. Comparison of original and re-computed Southern California IBI scores and their ranks for BMI data collected from 2004 to 2006. 2007 scores are also included.

Station	Year	Season	Old IBI Score	Old Rank	New IBI Score	New Rank
NR1	2004	Spring	35.75	Poor	17.16	Very Poor
NR3	2004	Spring	32.89	Poor	21.45	Poor
NR1	2004	Fall	30.03	Poor	24.31	Poor
NR3	2004	Fall	37.18	Poor	31.46	Poor
NR1	2005	Spring	34.32	Poor	35.75	Poor
NR3	2005	Spring	30.03	Poor	25.74	Poor
NR1	2005	Fall	41.47	Fair	28.6	Poor
NR3	2005	Fall	30.03	Poor	22.88	Poor
NR1	2006	Spring	22.88	Poor	21.45	Poor
NR3	2006	Spring	27.17	Poor	38.61	Poor
NR1	2006	Fall	41.47	Fair	21.45	Poor
NR3	2006	Fall	38.61	Poor	35.75	Poor
NR1	2007	Spring	-	-	24.31	Poor
NR3	2007	Spring	-	-	34.3	Poor
NR1	2007	Fall	-	-	46	Fair
NR3	2007	Fall	-	-	23	Poor

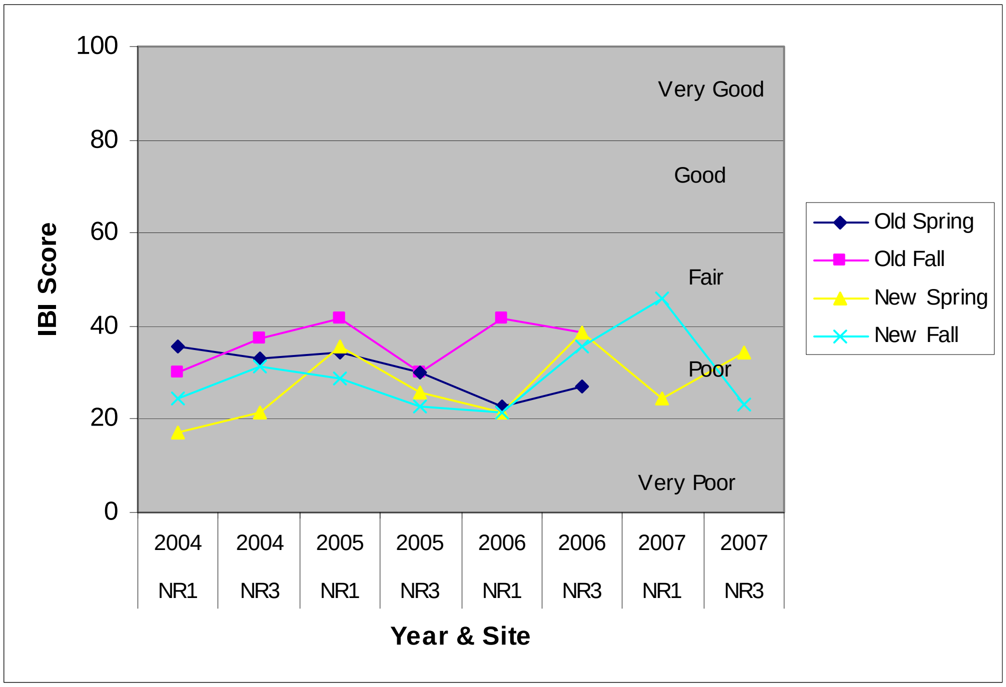

Figure 10. Original (old) vs. new IBI (recomputed) IBI scores for Santa Clara River sites from 2004 to 2007.