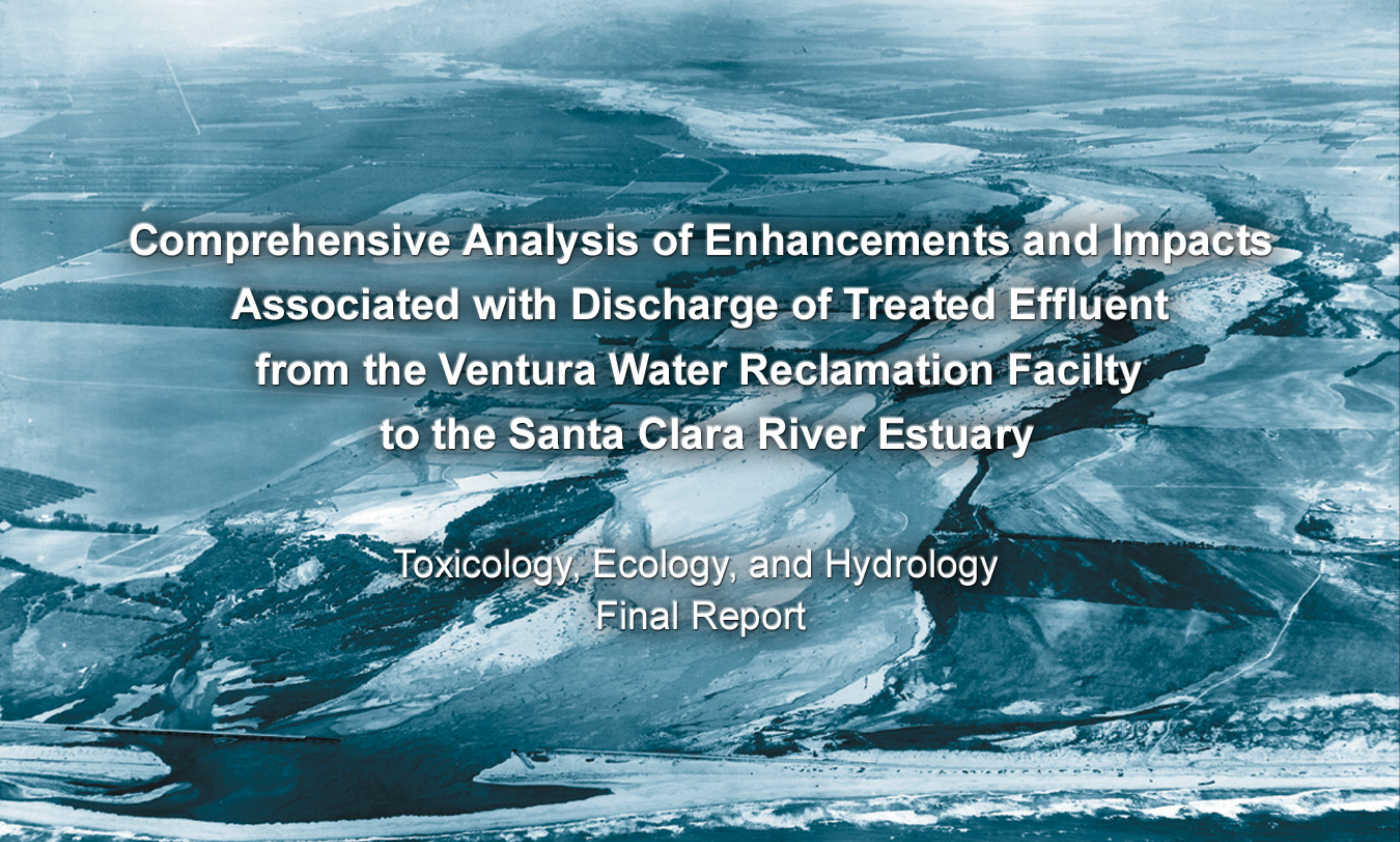
Comprehensive Analysis of Enhancements and Impacts Associated with Discharge of Treated Effluent from the Ventura Water Reclamation Facilty to the Santa Clara River Estuary

Toxicology, Ecology, and Hydrology
Final Report



Prepared for:
City of San Buenaventura
Ventura Water Reclamation Facility

CITY OF SAN BUENAVENTURA
FOUNDED 1782

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COMPREHENSIVE ANALYSIS OF ENHANCEMENTS AND IMPACTS ASSOCIATED WITH DISCHARGE OF TREATED EFFLUENT FROM THE VENTURA WATER RECLAMATION FACILITY TO THE SANTA CLARA RIVER ESTUARY

TOXICOLOGY, ECOLOGY, AND HYDROLOGY

FINAL REPORT

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Note: This document was prepared by Nautilus Environmental for the sole use and benefit of the City of San Buenaventura.

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EXECUTIVE SUMMARY

The City of San Buenaventura (City; also known as Ventura) owns and operates the Ventura Water Reclamation Facility (VWRF) which, over the past 5 years, has discharged an average of 7.2 million gallons per day (mgd) of tertiary-treated wastewater to the Santa Clara River Estuary under waste discharge requirements contained in Order No. 00-143, adopted by the California Regional Water Quality Control Board, Los Angeles Region (Regional Board), on October 12, 2000 (NPDES Permit No. CA0053651). Although the VWRF has been discharging to the Santa Clara River Estuary for approximately 45 years, the discharge is in conflict with the State Water Resources Control Board's Water Quality Control Policy for the Enclosed Bays and Estuaries of California (Resolution No. 74-43, 1974), which mandates that the discharge of municipal and industrial wastewaters to enclosed bays and estuaries be phased out. Exceptions to this policy are limited to circumstances in which a Regional Board finds that the treated wastewater enhances the quality of receiving waters above that which would occur in the absence of the discharge. A previous exemption to this policy was granted in 1977, on the basis that the VWRF discharge enhanced fish and wildlife habitat and non-contact water recreation. However, more recent information regarding the relationship of the discharge to the ecological function of the estuary is lacking. Consequently, this study was initiated at the request of the Regional Board with the specific objective of identifying enhancements to beneficial uses associated with the Santa Clara River Estuary that could be directly attributed to the VWRF discharge.

The results of this study clearly indicate that the discharge enhances beneficial uses associated with the estuary environment. These enhancements are primarily related to improvements in habitat and water quality, which have direct benefits to the aquatic community. Moreover, these benefits to water quality and the aquatic community are likely to result in additional benefits to higher trophic levels (e.g., birds) that rely on the aquatic community for food resources, as well as enhancing recreational uses associated with the estuary.

1. The discharge provides a portion of the freshwater inflow that historically entered the estuary, but is now currently appropriated for other uses by upstream diversions. In fact, the discharge is frequently the only source of freshwater available to the estuary during extended dry weather periods.
2. Effluent from the VWRF is high-quality water compared with urban, agricultural, and groundwater inputs to the lagoon. In the absence of flows from the VWRF, the lagoon would be dominated by inputs from these other sources, lowering the overall water quality of the lagoon.
3. Effluent flow in the discharge channel maintains a continuous source of water during breach outflow events when the lagoon drains, providing an area of habitat stability during periods when most of the lagoon is dry.
4. The discharge channel provides critical side-channel habitat for aquatic organisms, including the endangered tidewater goby, during periods of high river outflows when elevated flow velocities and sediment scouring preclude the use of most of the lagoon by resident organisms.
5. Given that the discharge is responsible for most of the flows entering the estuary during dry weather periods, it is largely responsible for initiating the berm breaches that occur

during the summer months. These breaches allow at least partial draining of the lagoon, improving circulation, flushing and overall water quality.

6. Again, given that the discharge is responsible for most of the freshwater inflows to the lagoon that occur during dry weather periods, it is largely responsible for filling the lagoon following breaching events. As the lagoon fills, it creates hydraulic pressure that directs subsurface flows towards McGrath Lake. Otherwise, these subsurface flows, including groundwater with elevated TDS and seepage from agricultural operations, would flow towards the lagoon, further degrading its water quality.

Overall, these results indicate that the discharge is clearly enhancing beneficial uses associated with the estuary and, therefore, meets the requirement for obtaining an exception to the Enclosed Bays and Estuaries policy. Moreover, the improvements to water quality and habitat attributed to the discharge are consistent with the Regional Board's overall objectives to protect beneficial uses. A more detailed summary of these findings, as well as the background of this study are presented in the following sections of the Executive Summary; the report and associated appendices provide the complete basis for these conclusions.

This investigation was initiated in the fall of 2003. In addition to evaluating enhancements, the study addressed two major issues raised in previous discussions with regulatory agencies:

1) The level and effect, if any, of copper in the effluent stream. This study assessed copper toxicity on both marine and freshwater test species, and analyzed estuary sediments to determine if copper, as well as other contaminants of concern, are accumulating to levels that might result in adverse effects.

2) The effect of the freshwater effluent discharge on the habitat and species in the estuary. Through an assessment of historical hydrological and ecological conditions, and their interactions, this component evaluated the effect of the freshwater effluent on the estuary.

Six sampling events related to water and/or sediment quality were completed, covering both wet and dry periods. In addition, Water Effect Ratio (WER) studies were performed on water samples collected during four events to determine the bioavailability of copper in the samples, as well as develop site-specific water quality criteria for copper. Hydrological and ecological evaluations were also carried out to compare current and historical conditions with respect to variations in flow regimes and habitat quality. This report presents the results of these studies, as well as an integrated analysis of the data obtained.

The results of this analysis identified several areas in which the discharge from the VWRF enhances beneficial uses associated with the Santa Clara River Estuary, particularly as they relate to maintaining suitable habitat and water quality. These parameters are basic requirements for supporting aquatic and terrestrial organisms associated with the estuary, including species requiring special protection. In addition, maintaining a viable estuary environment also enhances recreational uses associated with the estuary.

Specific areas of enhancement include:

Habitat

1. The discharge channel supports freshwater marsh, improving habitat diversity. Marsh is a key habitat component of estuaries that supports both aquatic and terrestrial organisms. Most of the marsh historically associated with the Santa Clara River Estuary

has been lost due to reclamation projects and appropriation of river flows for other uses. Continuous freshwater flows ensure maintenance of plant communities and habitat in the estuary even during dry periods. Without input from the VWRF, such inflows would be largely absent due to upstream diversions of river flows during most of the dry months between June and October.

2. The discharge channel provides side-channel habitat (i.e., refugia) during outflow events. Historically, the estuary was composed of a complex network of channels, sloughs and small ponds, which provided extensive off-channel habitat for aquatic organisms during flood periods when high flows rushed to the ocean. Today, virtually all such historic side-channel habitat has been lost due to extensive levee construction on both sides of the lower river. These levees have constrained the channel, increasing current velocity and scouring during high outflow events. In contrast, the discharge channel provides a stable low-flow environment that remains relatively unaffected by high outflow events, reducing the probability that resident aquatic organisms will be swept out to sea.

3. In addition, the discharge channel maintains a continuous source of water during breach outflow events when the lagoon drains, providing habitat stability. When the lagoon drains during normal breaching events, water remains only in the main river channel and in a few perched ponds trapped in depressions, thus reducing aquatic habitat to <10 percent of what is available during periods when the lagoon is flooded. Organisms in these shallow exposed areas are vulnerable to predation, as well as impacts of elevated temperature. Under these conditions, the discharge channel retains its integrity as desirable habitat. In addition, the edges of the discharge channel are heavily vegetated, providing both cover and food.

4. Current habitat conditions in the lagoon are consistent with the requirements of the tidewater goby, which have been listed by the U.S. Fish and Wildlife Service as "Endangered," due to declines in their distribution and abundance, their existence in semi-isolated population units, their susceptibility to certain types of disturbances, and their limited ability to disperse and colonize new habitats. Poor water quality is one factor that has been identified as an issue limiting goby populations. In this case, the discharge from the VWRF is not only consistent with general water chemistry (e.g., salinity) preferred by the goby, its overall quality is higher than the urban, agricultural, and groundwater inputs that would seasonally dominate in-flows to the lagoon in the absence of the VWRF discharge. Another factor identified as potentially affecting goby populations is being swept from their preferred lagoon habitats during periods of high outflows. As described above, the discharge provides a clear benefit to the gobies in that the side channel and associated habitat provides a refuge from high out-flows during flood events.

Water Quality

1. Effluent from the VWRF is high-quality water in terms of lower total dissolved solids (TDS) and contaminant and nutrient loads, compared with urban, agricultural, and groundwater inputs to the lagoon. In the absence of flows from the VWRF, the lagoon would be dominated by inputs from these other sources, particularly during dry periods. Elevated TDS, contaminants and nutrients all contribute to reductions in overall water

quality. Indeed, elevated nutrients can result in eutrophication that, in the absence of sufficient circulation, can lead to fish kills as oxygen levels in the water decrease to concentrations that no longer support aquatic life. This situation has been noted in a number of lagoons in southern California in which the natural flow regime has become dominated by urban and agricultural inputs.

Hydrology

1. Discharge from the VWRF makes up a portion of water that historically flowed to the estuary, but is now appropriated for uses upstream. Anecdotal evidence indicates that perennial flows existed in lower river, even during dry months, providing water to the estuary and marshes that extended well upstream. However, beginning in the late 1800s, intensive development of water resources in the basin reduced groundwater reserves and altered surface flows in the river. Upstream appropriations of water for agricultural use and managing salt-water intrusion have reduced annual flows to the estuary by as much as 75 percent, depending on the water year, and eliminated surface flows to the estuary during most of the dry weather months. For example, between 1928 and 2001, no natural river flows reached the estuary in approximately 70% of the dry weather months between June and October. Thus, in dry months, flows from the VWRF are clearly an important component of freshwater inputs to the estuary, accounting for up to 100% of fresh water entering the estuary.
2. Under current conditions, the discharge is responsible for berm breaching that occurs during the summer months, improving lagoon circulation and flushing. Many southern California lagoons undergo periods of hypoxia due to elevated nutrients, eutrophication and high temperatures during the summer months. This can result in fish kills, plant die-offs, etc., all of which are indicative of poor water quality conditions and demonstrate reduced ability to support the aquatic community. Indeed, minimizing such adverse conditions are of concern in terms of maintaining viable tidewater goby populations. To the extent that the discharge comprises most of the freshwater flows reaching the estuary during dry months, it provides most of the impetus required to initiate the breaching process.
3. In the process of filling the lagoon, the discharge not only provides water of high quality, it creates a differential in the hydraulic pressure gradient such that subsurface flows are directed towards McGrath Lake. Otherwise, these flows (including groundwater and seepage from agricultural operations) would be towards the lagoon, further degrading water quality in the lagoon.

In addition to identifying enhancements, this study also included a detailed analysis of potential impacts associated with the discharge, as well as an evaluation of historical ecological and hydrological conditions associated with the estuary. This analysis resulted in the following findings:

Water and Sediment Quality

1. Analysis of historical data indicates no relationship between effluent toxicity and copper concentrations.
2. Analysis of species present in the estuary clearly suggests that the community is dominated by a combination of freshwater species and brackish species tolerant of

freshwater. Marine species appear to be present on a transient and opportunistic basis associated with ocean inflows during tidal breaching.

3. Some of the most sensitive taxa used to determine the freshwater copper criterion are found in the estuary, suggesting that copper is not limiting their distribution.
4. Copper and other contaminants of concern (i.e., zinc, nickel and selenium) are not accumulating in sediments in the estuary.
5. Copper concentrations in sediments are below sediment quality guidelines, as were concentrations of other contaminants of concern.
6. The low frequency of toxicity observed in sediment samples further suggests that sediment quality is generally good throughout the lagoon.
7. Intermittent toxicity observed in sediment samples was not related to concentrations of copper or other contaminants measured. Reduced survival of amphipods appeared to be related to the presence of coarse sediments, and the cause of reduced normal development of mussel larvae was not determined.
8. Over 100 toxicity tests were conducted on water samples from the lagoon. Approximately 10 percent of the samples exhibited toxicity, with most of the toxicity occurring during stormwater or dry weather outflow events, suggesting that upstream and groundwater sources are of concern. No toxicity was observed during a dry weather period when the lagoon was full; this condition would correspond with maximum influence of VWRF on water quality in the lagoon.
9. Generally, water samples collected from the lagoon did not exhibit toxicity to freshwater aquatic test organisms, other than what could be attributed to elevated salinity.
10. Generally, no adverse effects were observed with bivalve larvae (*Mytilus* sp.), the most sensitive species used to determine the marine copper water quality criterion.
11. Overall, the frequency and intensity of toxicity was low, with no sampling location consistently eliciting a response.
12. Copper concentrations were generally low in all water samples tested, and no relationships were observed between aquatic toxicity and concentrations of copper or other contaminants of concern.
13. Results from the WER studies indicate that the bioavailability of copper in samples collected from the lagoon is appreciably less than in laboratory seawater. Site-specific marine acute and chronic water quality criteria were calculated as 17.8 micrograms per liter (µg/L) and 11.5 µg/L, respectively.

<u>Ecological Conditions Associated with the Estuary</u>

1. Historical accounts describe the area as rich in biological resources, including marshes, small lakes, side-channels, and riparian woodlands that supported diverse and abundant wildlife.
2. Ecological impacts have been appreciable due to considerable alterations that have occurred over time to the estuary and floodplain originally associated with the Santa

Clara River delta; only approximately 10 percent of the historical area associated with wetlands, floodplain, and estuary remain.

3. Current habitat complexity and extent have been dramatically reduced compared with historical levels, reducing carrying capacity.
4. The estuary is currently dominated by flood scouring and deposition events.
5. The estuary still supports a number of sensitive and endangered species, including birds, reptiles, and fish. The tidewater goby, in particular, is abundant throughout the lagoon, and steelhead are still found in the Santa Clara River.
6. Water chemistry and substrate composition in the lagoon generally match conditions preferred by tidewater goby.
7. The freshwater marsh associated with the discharge channel comprises a significant portion of the remaining habitat diversity found in the estuary.
8. The discharge channel itself is probably the best example of side-channel habitat remaining in the estuary and lower river; therefore, it provides critical off-channel habitat (refugia) for species such as the tidewater goby during periods of high river outflow (i.e., flood events).
9. There is no evidence that freshwater flows from the VWRF have significantly altered the vegetation community associated with the estuary.

<u>Hydrological Conditions Associated with the Estuary</u>

1. Hydrological impacts on the system are extensive and pervasive due to changes in water storage and use, channel modifications, and flow manipulation throughout the system.
2. Historical accounts describe perennial flows in the river, ”throughout the valley.”
3. Appropriation of water for use upstream of the estuary has reduced flow in the river at Montalvo by as much as 74 percent on an annual basis, with the greatest effect occurring in dry years.
4. Water appropriation has also changed flow duration curves, reducing fish passage opportunities for migratory species (e.g., steelhead).
5. Deriving an estimate of natural historical monthly flows is problematic because uncertainties associated with the prediction process become proportionally greater during low-flow periods. In addition, the flow gauge at Montalvo was not installed until 1928; therefore, even the earliest flow data associated with the lower Santa Clara River are available only after development of water resources was already well underway.
6. Based on the period of record (i.e., 1928 – 2001), the effluent discharge replaces a portion of upstream flows that would have contributed to estuary inflows, but have been diverted for other uses. This situation is most clearly apparent during dry rainfall years.
7. Under dry weather conditions, effluent discharge from the VWRF may account for 100 percent of the freshwater entering the estuary.

8. The cycle and duration of lagoon breaching and reconstruction are functions of lagoon capacity, outflow, and sediment delivery to the river mouth, with outflow and capacity having greater importance in terms of triggering a breach, and sediment accumulation affecting the duration of the breach (i.e., speed of barrier beach reconstruction). Under current dry weather conditions, flows from the VWRF dominate inputs to the lagoon, and trigger breaching events when the lagoon water level exceeds the barrier beach height.
9. Levee construction has considerably reduced the floodplain and overall storage capacity of the lagoon.
10. Littoral sand supply to the mouth of the Santa Clara River has been significantly reduced due to trapping behind dams and bypassing of material dredged from the Ventura Harbor. These changes slow barrier beach construction following outflow events.

The results of this, and other studies, suggest that the estuary is currently operating as a viable, if highly modified, ecological unit. Moreover, there is no evidence that discharge from the VWRF is responsible for any negative impacts on the estuary. In fact, the discharge is in a unique position in terms of enhancing beneficial uses, particularly during dry weather periods. Overall, water and sediment quality are generally good, and habitat conditions appear to be relatively stable. Therefore, given the complexity of the system, careful consideration should be applied prior to altering any of the components currently contributing to ecological function.

1.0 INTRODUCTION

The City of San Buenaventura (City; also known as Ventura) owns and operates the Ventura Water Reclamation Facility (VWRF) located at 1400 Spinnaker Drive, Ventura, California, adjacent to the Santa Clara River Estuary. Constructed in 1958, the facility has discharged an average of 7.2 million gallons per day (mgd) of tertiary-treated wastewater to the Santa Clara River Estuary over the past 5 years. The City discharges the effluent under waste discharge requirements contained in Order No. 00-143, adopted by the California Regional Water Quality Control Board, Los Angeles Region (Regional Board), on October 12, 2000. Order No. 00-143 also serves as a permit under the National Pollutant Discharge Elimination System (NPDES Permit No. CA0053651).

In 1974, the State Water Resources Control Board adopted the Water Quality Control Policy for the Enclosed Bays and Estuaries of California (Resolution No. 74-43). This policy states that the discharge of municipal wastewaters and industrial process waters to enclosed bays and estuaries should be phased out at the earliest practicable date. Exceptions to this provision may be granted by a Regional Board only when the Regional Board finds that the wastewater would consistently be treated and discharged in such a manner that it would enhance the quality of receiving waters above that which would occur in the absence of the discharge.

In response, the City filed a facilities plan for effluent utilization in 1976 that included a demonstration of enhancement of the Santa Clara River Estuary due to the plant's freshwater discharge. This plan indicated that some of the beneficial uses of the estuary, such as fish and wildlife habitat and non-contact water recreation, were enhanced by the presence of the discharge. Consequently, Order No. 77-100, adopted by the Regional Board in May 1977, granted the City an exception to the discharge prohibition and allowed discharge of treated municipal wastewater into the Santa Clara River Estuary. The demonstration of enhancement was based on maintaining a minimum daily discharge flow rate of 5.6 mgd.

In 1996, due to concerns over effluent copper concentrations, the City conducted a source control study for copper. This study identified that the major source of copper in the wastewater effluent was from corrosion of the potable water supply system piping.

In 2000, the City received an updated permit from the Regional Board (NPDES Permit CA 0053651). This permit included requirements for copper concentrations based on the California Toxics Rule (CTR), which provides that the most stringent water quality criteria shall be applied in calculating numerical limitations (saltwater criteria in the case of copper) in cases where the discharge is to an estuary that is subject to a combination of freshwater and marine influences. The CTR limit for copper based on a discharge to the marine environment with no dilution is 3.1 micrograms per liter (µg/L). Because the effluent has an average concentration in excess of 10 µg/L copper, the City recognized that it could not meet the CTR saltwater aquatic life criterion for copper and, consequently, asked that the Regional Board staff recommend the application of the freshwater limit for copper, which is 52 µg/L.

Subsequently, the Regional Board issued Time Schedule Order (TSO) No. 00-144 giving the City until October 12, 2002, to achieve compliance with the marine criterion. In the meantime, the TSO required the City to comply with interim limits based on the CTR freshwater aquatic criterion. TSO No. 00-144 further required the City to conduct a translator study to determine the ratio between total and dissolved copper in the estuary, develop a recalculation procedure for the bioavailability of copper in the estuary (Water Effect Ratio), and to conduct a Resident Species Survey to determine if the marine or freshwater criterion was more applicable. In 2001, the Regional Board amended TSO No. 00-144 with TSO No. 01-058, which extended the submittal date for the required studies identified above.

In 2002, the City completed a *Metal Translator Study and Salinity Profile of the Santa Clara River Estuary* and a *Resident Species Study* (City 2002a and b). The *Metal Translator Study* and *Salinity Profile of the Santa Clara River Estuary* determined that metal concentrations entering the study area from upstream closely approximated those found in the treated wastewater. In addition, the City's ability to comply with the copper limits was not significantly improved by incorporating a site-specific translator (ratio of total to dissolved) into the application of the saltwater quality criterion for copper.

This study also concluded that the salinity in the estuary was predominantly below the saltwater threshold of 10 parts per thousand, but exceeded the freshwater threshold of 1 part per thousand 95 percent of the time, according to the definition in 40 CFR Part 131 (California Toxics Rule). However, salinity levels fluctuate considerably, approaching freshwater levels during periods when the mouth of the estuary lagoon is closed, but increasing to 10 parts per thousand or higher when the lagoon is open to ocean water influence. The *Resident Species Study* concluded that most of the organisms present were either freshwater taxa, or euryhaline species tolerant of low salinity conditions.

The preamble to the CTR provides that the most stringent water quality criteria shall be applied in calculating numerical limitations. However, it also provides for the use of alternative criteria (in this case, the freshwater criterion for copper) in situations where such an application is scientifically defensible. Thus, based on the results of the above studies, the City requested that the Regional Board apply the freshwater criterion, rather than the saltwater criterion, to establish effluent limitations for copper in the facility discharge. If this request were to be approved, the discharge would be in compliance with site-specific discharge limits for copper of 18 µg/L and 52 µg/L for monthly average and daily maximum, respectively.

In late 2002 and early 2003, Regional Board staff invited representatives from the U.S. Fish and Wildlife Service, California Department of Parks and Recreation, California Department of Fish and Game, and National Marine Fisheries Service to attend two meetings to discuss "Water Quality Criteria Applied on Santa Clara Estuary for Ventura Water Reclamation Plant" and "Impact of Continued Effluent Discharge by Ventura Water Reclamation Plant."

The meetings resulted in a series of conclusions and recommendations.

- Baseline information regarding salinity profiles and descriptions of the biota in the estuary prior to the facility's first discharge in 1958 is unavailable, making it difficult to evaluate the impact of the facility's freshwater discharge on the estuary.

- The facility has been discharging wastewater to the Santa Clara River Estuary for more than 45 years. Thus, it is possible that the ecosystem could have shifted from an estuarine community to one dominated primarily by freshwater organisms, as indicated in the *Resident Species Study* (City 2002b).
- Wildlife habitat might be improved through a return to a more natural flow regime, particularly with respect to preservation of rare and endangered species.
- The City's demonstration of enhancement of the Santa Clara River Estuary due to the facility's freshwater discharge should be reevaluated and verified for the current discharge conditions.
- The City should conduct toxicity tests on the effluent using non-freshwater species.
- The City should analyze copper accumulation in the sediments of the estuary.
- The freshwater quality criteria of the CTR are inappropriate for the Santa Clara River Estuary due to the presence of marine and estuarine species.
- In addition to addressing non-compliance with the copper limits, the fundamental question of whether the VWRF should be allowed to continue discharging into the estuary should be evaluated.

The meeting attendees also discussed possible alternatives that would eliminate the facility's discharge to the estuary. These included the following:

- Ocean discharge. This would be very expensive and may not be feasible.
- A new outfall located upstream of the estuary. A new outfall may provide a solution to the copper issue; however, this alternative does not resolve the impact of the extra freshwater in the estuary.
- Reduction of treated wastewater discharge. The allowable quantity of discharge should not be greater than the water withdrawn from the Santa Clara River. The remainder of the treated wastewater should be recycled.
- Recycling 100 percent of treated wastewater. The City would need to conduct a feasibility study.
- Zero discharge during the dry weather season.

Based in part upon these recommendations, Regional Board staff required a reevaluation of the 1976 demonstration of enhancement of the Santa Clara River Estuary due to the facility's discharge. As a first step, the City was directed to submit a work plan to the Regional Board by February 28, 2003, outlining a scope of work that would demonstrate enhancement and a time schedule for submittal of the final report. Subsequently, the City has undertaken an environmental study of the Santa Clara River Estuary to verify the impacts of the VWRF effluent disposal into the estuary. This study addresses the two primary issues raised by the Regional Board:

1) <u>The level and effect, if any, of copper in the effluent stream</u>. This study assesses copper toxicity effects of the effluent on both marine and freshwater test species and analyzes estuary sediments to determine if copper is accumulating to levels that might result in adverse effects; and

2) <u>The effect of the freshwater effluent discharge on the habitat and species in the estuary</u>. Through an assessment of historic hydrologic and ecological conditions, and their interactions, this study assesses the effect of the

freshwater effluent on the estuary. As part of this analysis, positive benefits of the discharge that enhance the quality of the receiving environment are identified.

This investigation was initiated in the fall of 2003, and included six sampling events. The first sampling event, conducted in October 2003, was characterized as a “dry weather” event. The beach berm was intact and the estuary inundated with water. Water quality measurements were taken at this time, as well as sediment samples. The sediment samples were measured for grain size; total organic carbon; toxicity; and copper, zinc, selenium, and nickel concentrations. The November 2003 event was characterized as “wet weather,” the berm was breached, and the lagoon was flowing into the ocean. Only water quality measurements were taken during the November sampling event to support the hydrological component of the overall investigation. The third sampling event was conducted in March 2004. This event was also characterized as a “wet weather event” with the berm open. In addition to sediment samples, which were subjected to the same analyses described above, water samples were taken for evaluation of toxicity and for analysis of concentrations of contaminants of interest. In addition, Water-Effect Ratio (WER) studies were carried out on the water samples to determine the bioavailability of copper in the samples.

Additional water sampling events that characterized toxicity, contaminant concentrations, and WERs were carried out in the July 2004 (dry weather, berm closed), September 2004 (dry weather, berm open), and January 2005 (wet weather, berm open). Hydrological and ecological evaluations were also carried out to compare current and historical conditions with respect to variations in flow regimes and habitat quality. The ecological evaluation involved review of historical literature for the region, analysis of aerial photographs and historic maps, mapping of vegetation communities, and identification of sensitive species. This effort was aimed at identifying (1) the historical baseline condition of the estuary; (2) the extent of changes that have occurred over time, and any impacts that the discharge from the VWRF may have had on the estuary, as determined by changes in the biological community. The hydrological component evaluated flow and diversion data, historical records, and relationships between rainfall and flow to develop models that would facilitate prediction of historical conditions, as well as identify the relative contribution of the VWRF to overall flows. In addition, hydrodynamics in the lagoon were monitored in an effort to determine the effect of the VWRF discharge on the frequency of breaching the berm at the mouth of the lagoon.

This report provides a description of methods and findings of studies that have been completed. It also includes the results that were previously submitted to the City in an earlier Progress Report (May 2004). Ultimately, the findings are discussed in terms of impacts and benefits associated with the discharge from the VWRF.

2.0 Evaluation of Toxicity Associated with the Ventura Water Reclamation Facility and Associated Contaminants of Concern

This component of the study contained a number of different elements designed to provide a comprehensive basis for examining the extent to which discharge from the VWRF may impact the beneficial uses of the estuary in terms of toxicity or elevated concentrations of contaminants. Specifically, historical data on effluent toxicity and copper concentrations were evaluated to determine any relationships between copper and adverse effects. In addition, the general literature on copper toxicity was evaluated to identify sensitive species and compare these species to those found in the lagoon. The objective of these two tasks was to determine if elevated concentrations of copper were associated with toxicity in laboratory tests, and to determine if copper might be having a long-term effect on organisms in the receiving environment in terms of eliminating sensitive taxa from the suite of species potentially present in the lagoon.

Because contaminants may accumulate in sediments over time, this study also incorporated a sediment sampling program to identify whether toxicity was present, and whether concentrations of selected contaminants exceeded their respective sediment quality guidelines. The toxicity tests were conducted with bivalve larvae and amphipods using standard protocols, and sediment concentrations of copper, zinc, nickel, and selenium were determined analytically and compared to both the results of the toxicity tests and to the appropriate sediment quality guidelines. Samples for this component were collected at two different points in time, one representing a dry weather berm-closed condition, and one representing a wet weather berm-open condition.

Water quality in the lagoon, including toxicity tests and sampling for selected chemical parameters, was determined in four discrete sampling events. The original objective was to sample when the berm was opened and closed under both dry and wet weather conditions. However, overall time constraints and weather patterns made it impossible to collect a sample during a wet weather, berm-closed condition. Consequently, both wet weather samples were collected during periods when the berm was breached.

Water quality monitoring entailed taking measurements of basic water quality parameters (i.e., temperature, DO, pH, and conductivity/salinity) at different locations throughout the lagoon. Measurements were taken at different depths if the lagoon was full; otherwise, one sample was generally taken at each site if the depth was shallow enough to be considered fully mixed. In addition, samples were taken for toxicity testing with both marine and freshwater species, as well as for measurement of selected contaminant concentrations (i.e., copper, nickel, zinc, selenium, and cyanide).

Because of concerns regarding the appropriateness of applying the current marine water quality criterion for copper to the lagoon, WER studies were also conducted on samples collected for toxicity tests. These studies compared the relative toxicity of copper in samples collected from the lagoon to the toxicity observed in clean seawater to develop a ratio for adjusting the current copper criterion to reflect site-specific characteristics that reduce the bioavailability of copper in water samples from the lagoon. The WER was determined using the test organisms with the greatest sensitivity to copper (i.e., mussel larvae) and reflects samples collected from sites distributed throughout the lagoon, and collected at four separate times during the year.

2.1 Review of Historical Toxicity Data and Measured Copper Concentrations

2.1.1 Methods

Historical records of toxicity and measured copper concentrations associated with the effluent were obtained from the City for the period between 1999 and 2003 and entered into a spreadsheet. The records for toxicity and copper concentrations were then screened to eliminate records for which sampling for chemistry and toxicity did not occur on the same day. Next, regressions were performed between copper concentrations and the various endpoints obtained from the toxicity tests to determine any relationships between copper concentrations and toxicity. The data were further evaluated to determine if there was an apparent threshold for copper toxicity and what concentration ranges were tolerated by the test species.

2.1.2 Results

Copper concentrations in effluent samples tested for toxicity in the period between 1999 and 2003 were evaluated to determine if they were related to any observed effects. During this period, data are available from eleven 7-day *Ceriodaphnia dubia* survival and reproduction toxicity tests. No adverse effects on survival were noted in any of the tests, although reproduction was reduced in two of the tests. Copper concentrations associated with all of tests ranged up to 40.1 µg/L, with a median of 11.4 µg/L. There was no relationship between the concentrations of copper present and the reproductive response ($R^2 = 0.046$). These data are shown in Figure 2-1.

Data from 34 fathead minnow tests were associated with measured copper values, which reached as high as 160 µg/L, with a median of 8.6 µg/L. Of these 34 samples, only two resulted in reduced survival and growth. Again, there was no evidence of a relationship between copper concentrations and toxicity ($R^2 \leq 0.02$). These data are shown in Figure 2-2.

Selenastrum (green algae) tests were conducted on 33 samples for which there were measured copper concentrations. Only three of these tests resulted in reduced cell numbers. Copper concentrations were as high as 48.6 µg/L, with a median of 7.7 µg/L. There was no relationship between copper concentrations in the samples and toxicity ($R^2 = 0.000$). These data are shown in Figure 2-3.

In addition to copper concentrations appearing completely unrelated to toxicity in the samples tested, these data also indicate that the overall incidence and degree of toxicity associated with the discharge are quite low. Moreover, comparing the actual copper concentrations found in the effluent with long-term laboratory (AMEC/Nautilus) reference toxicant average EC_{50} values for each of the species tested suggests that, for the most part, copper concentrations in the effluent are well-below actual toxicity thresholds for these species. In fact, over the entire dataset, only three concentrations exceeded “effects thresholds.” The fact that these samples, which were tested with fathead minnow, did not exhibit toxicity, suggests that the copper present was less bioavailable in the samples than in clean laboratory dilution water.

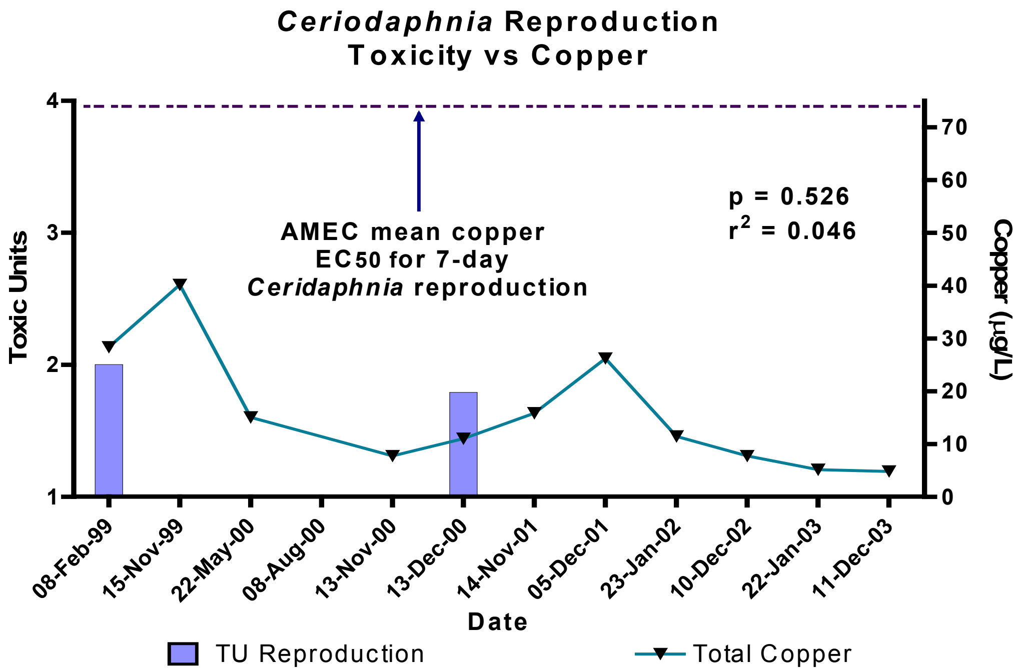
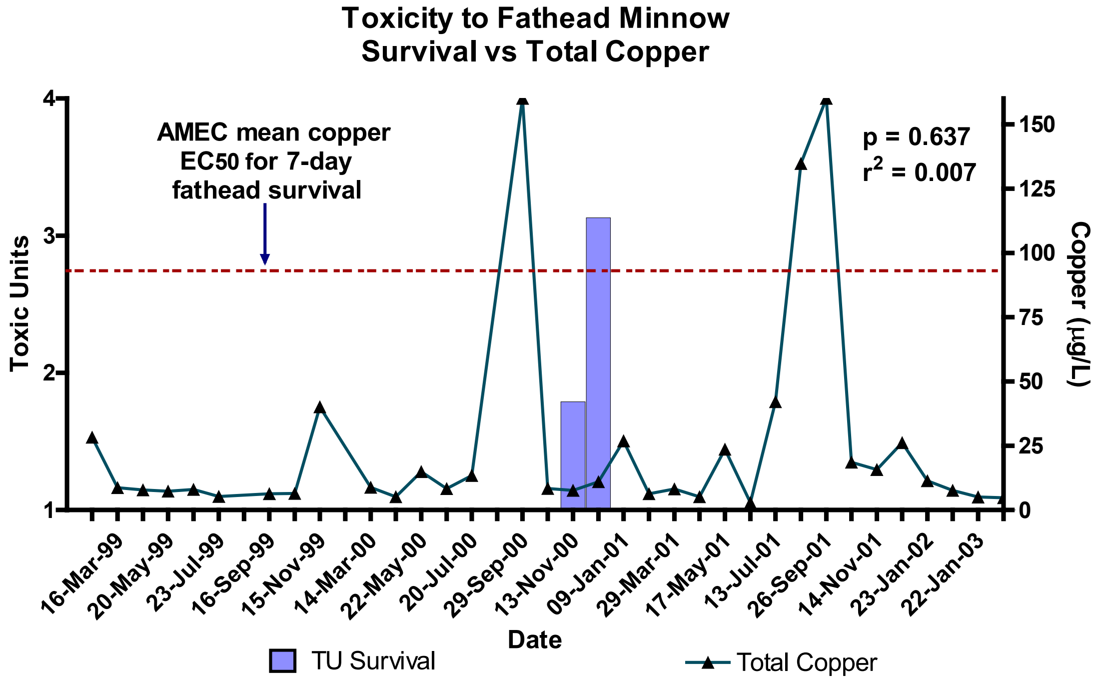


Figure 2-1. Relationship between historical (1999 – 2003) copper data and concurrent toxicity to *Ceriodaphnia* 7-day reproduction. No samples were toxic to survival.



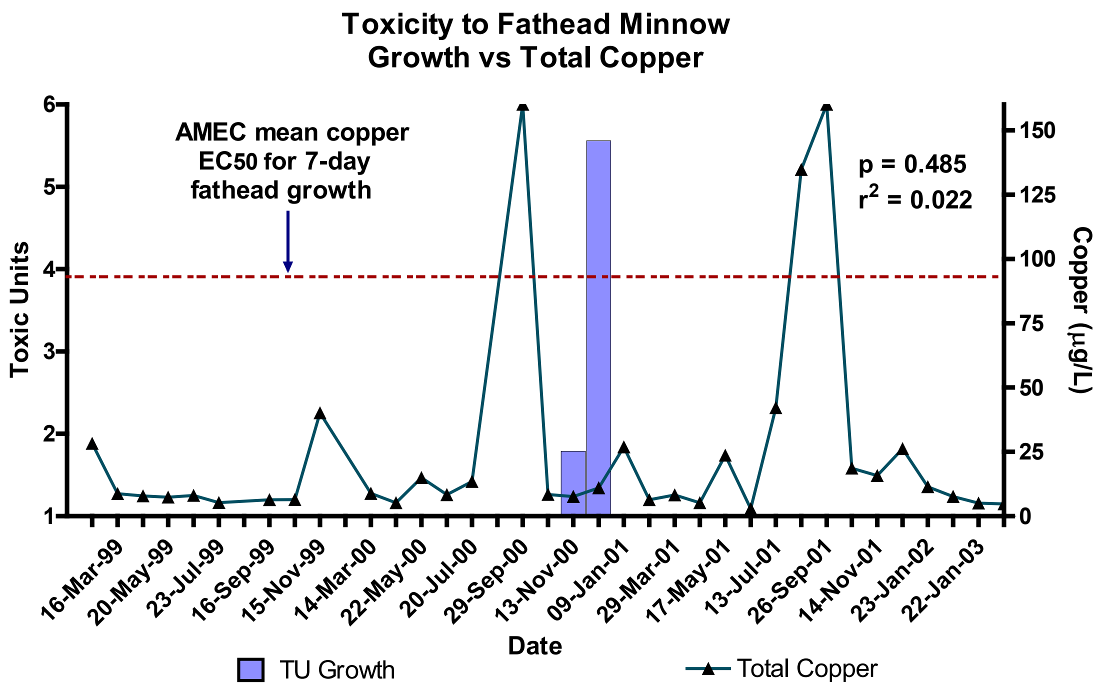


Figure 2-2. Relationships between historical copper data (2000 – 2003) and concurrent toxicity to fathead minnow chronic survival and growth.

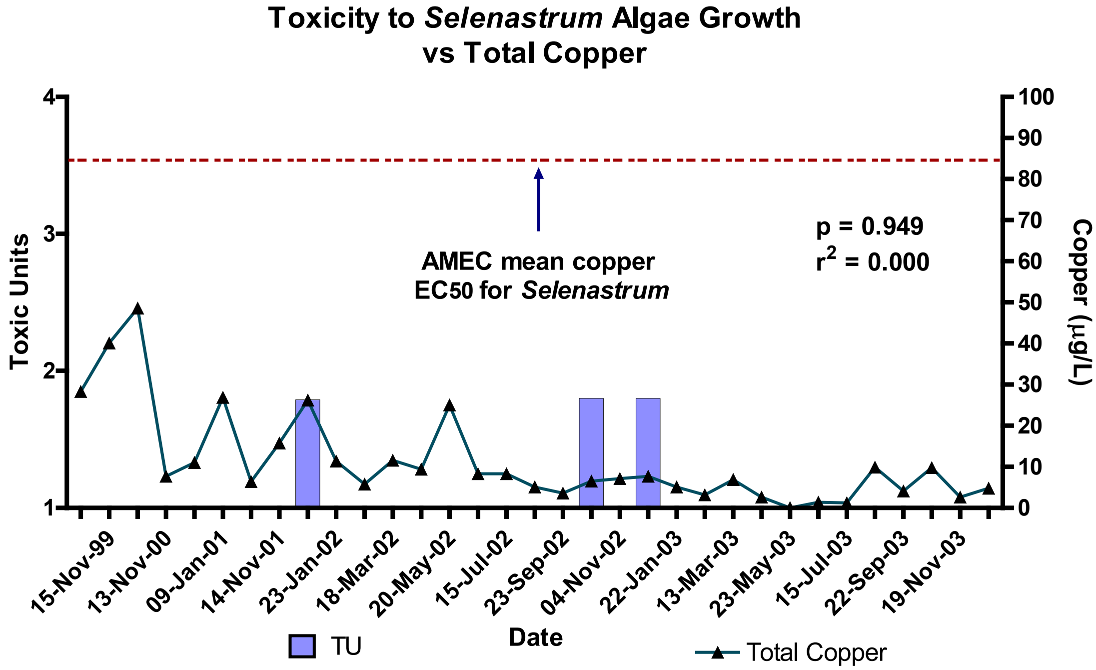


Figure 2-3. Relationship between historical copper data (1999 – 2003) and concurrent toxicity to *Selenastrum* algae growth.

2.2 Comparison of Sensitive Species with Those Found in the Estuary

2.2.1 Methods

Copper toxicity data from the AQUIRE acute and chronic aquatic toxicity database and the database used for the U.S. Environmental Protection Agency (USEPA) water quality criterion for copper were downloaded into a spreadsheet, including species, test type, duration, and endpoint. Invertebrate and fish species identified as being present in the estuary in the *Resident Species Report* (City 2002b) were also entered into a database; characterized as freshwater, marine, or estuarine; and compared against the toxicity database to evaluate their sensitivity to copper. If a match could not be made at the species level, the comparison was made to genus or, if necessary, to family. For example, if data were not available for green sunfish (*Lepomis cyanellus*), data for the closely related bluegill (*L. macrochirus*) were used instead. Copper data were used only if reported as "copper," and not as a copper salt.

These data were used to evaluate two issues: (1) which of the criteria (i.e., marine or freshwater) is more representative of the organisms actually present in the estuary; and (2) whether species present in the estuary belong to taxa that are considered sensitive to copper. With respect to the first issue, the biological community present in the estuary should determine the most appropriate application of the criteria values which, by definition, are intended to protect the most sensitive species present. However, since the estuary has received discharge containing elevated copper concentrations from the treatment plant for an extended period of time, it could be argued that the species assemblage has been shaped by the presence of copper and that sensitive species have been extirpated. Consequently, the second issue addresses whether sensitive taxa remain in the estuary; their presence would support the argument that copper toxicity is not a defining variable with respect to community structure.

2.2.2 Results

Approximately 20 aquatic species have been reported from the estuary. Most of the resident species would be characterized as freshwater. Some are euryhaline with a range of salinity tolerances, and a few are stenohaline marine species that appear to enter the estuary on an opportunistic basis when the berm is breached and saltwater enters the lagoon on high tide.

Benthic invertebrate community structure is often used to characterize both condition and quality of a given habitat because the relative lack of mobility of these organisms ties them to a particular environment. Conversely, more mobile organisms may use habitat on an opportunistic and transient basis, even though it may not provide suitable conditions for long-term occupancy. Comparison of the invertebrate species found in the estuary with those for which copper toxicity data are available found no matches among taxa used to develop the marine criterion, even at the family level. Conversely, four matches were found with taxa used to develop the freshwater criterion. With respect to fish, three species matches were found with the freshwater database and two euryhaline taxonomic matches were found in the marine database.

Of all taxa for which matches were found in the databases, the freshwater taxa exhibited the greatest sensitivity. The two most sensitive taxa were *Daphnia* sp., and *Hyalella azteca*. Both of these taxa are commonly used in tests that evaluate and regulate water quality; the presence of these organisms in the estuary suggests that water quality is typically reasonably good and that copper is not limiting their distribution.

2.3 Sediment Quality

2.3.1 Methods

A total of 11 sediment samples were collected on 17 October 2003 from the Santa Clara River Estuary. The sampling period was considered a “dry weather” sampling event; the estuary was closed to the sea by a sandbar and the lagoon area inundated with water. Samples were generally collected across three north-south transects corresponding to the upper, middle, and lower portions of the lagoon. Three samples were collected along each transect. In addition, one sample was collected upstream of the bridge and another from the effluent discharge channel. The sampling locations are shown in Figure 2-4 (note that the lagoon shown in this figure represents an outflow condition and is not inundated as was the case during the 17 October sampling event) and identified using Global Positioning System (GPS) equipment (Garman Model 76). Samples were collected in a 10 x 10 centimeter (cm) stainless steel Van Veen grab; a total of 4 liters (L) of sediment was collected at each station. All samples were stored in coolers with blue ice and transported to the laboratory on the day of collection. At the laboratory, they were stored at 4 degrees Celsius (°C) until use. Sediments were tested for toxicity within 8 days of collection.

All of the sediment samples were analyzed by Cal-Science Environmental Laboratories (Garden Grove, CA) for copper, nickel, zinc, and selenium concentrations by ICP-MS (USEPA Method 3050B/6020), and total organic carbon (TOC) (USEPA Method 9060). These results were reported on a dry-weight basis. Grain size was determined at AMEC/Nautilus (San Diego, CA). Concentrations of the trace elements were compared with commonly applied threshold values for evaluating sediment quality (Long et al. 1995). With the exception of the sample collected from upstream of the bridge (D-1), the samples were also tested for toxicity using the 10-day amphipod test (survival) and the 48-hour larval bivalve test (survival and shell development). The toxicity tests were performed according to methods presented in USEPA (1994a) and PSEP (1995) for the amphipod and mussel tests, respectively.

Eleven sediment samples were again collected on 16 March 2004. This sampling event was considered representative of “wet weather” conditions; runoff from recent rains had breached the sandbar; the lagoon freely drained to the ocean on outgoing tides and filled on incoming tides. Sampling was undertaken during an outflow period, with the lagoon partially or completely drained and water confined to main channel areas and to isolated perched pools. Samples were collected for toxicity and chemistry from the same sites previously sampled (Figure 2-4), using the methods described above. Detailed test methods are presented in the appendices.

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Sediment Sampling Locations
Santa Clara River Estuary, City of San Buenaventura
(Collected 17 October 2003, Photo Taken 1 June 2002)

FIGURE **2-4**

Graphics2/3164/Santa Clara River/SantaClaraSedSampLocs.fh8

2.3.2 Results

2.3.2.1 October 2003 (Dry Weather: Berm Closed)

Sediment quality

Copper concentrations were relatively low at all sites, generally between 2.3 and 4.2 milligrams per kilogram (mg/kg), except at Sites A-1 and B-4 where they reached 16.9 and 19.3 mg/kg, respectively. These two sites were also associated with the highest concentrations of organic carbon, with TOCs of 10,920 and 16,950 mg/kg, respectively. TOC at the other sites ranged from 1,590 to 7,070 mg/kg. These data are shown in Table 2-1, which also includes selenium, nickel, and zinc concentrations in the different samples. Concentrations of nickel ranged between 0.6 and 20.4 mg/kg, with no apparent trend across sites. Selenium concentrations were below the detection limit of 0.5 mg/kg at most sites; the highest concentration was 0.9 mg/kg. Concentrations of zinc were somewhat more variable and ranged from below detection to 63.1 mg/kg across the sites; however, there was no apparent relationship between zinc concentrations and the location of the site sampled.

To determine if these metals concentrations are likely to cause adverse effects on the benthic community, these concentrations were compared with the "effects range-low" (ERL) values proposed for marine and brackish waters by Long et al. (1995). These values correspond to the 10th percentile concentration at which biological effects were reported in a large dataset compiled by these investigators. All measured concentrations were below their respective ERL values (no value is available for selenium). However, the two highest concentrations of nickel were slightly over 20 mg/kg; the ERL for nickel is 20.9 mg/kg (see Table 2-5 in Section 2.4).

Sediment grain size

The distribution of sediment grain sizes is summarized in Table 2-2. Virtually all of the sites contained relatively coarse-grained sediments, predominantly composed of sand. Percent fines ranged between 1.3 and 5.4 percent, except for Sites A-1 and B-4, which exhibited 47.9 and 60.8 percent fines, respectively. These two sites were also associated with the highest concentrations of TOC, and copper.

Toxicity

The results of the toxicity tests are summarized in Figures 2-5 and 2-6. Amphipods (*Eohaustorius estuarius*) provided no indication of adverse effects associated with the sediments collected; survival averaged 90 percent in the controls, compared with a range of 82 to 91 percent across the test samples (Figure 2-5). None of the samples were statistically different from the control. Furthermore, there were no statistically significant relationships between the observed responses, grain size (i.e., % fines), TOC, or metal concentrations.

The mussel (*Mytilus galloprovincialis*) data were more variable; recovery of larvae with normal shell development averaged approximately 89 percent in the sediment controls and ranged from 23 to 99 percent in the test samples (Figure 2-6). The lowest recovery (23%) was associated with a sample from B-1, located near the discharge point. Sites B-

3, A-1, and B-4 exhibited intermediate levels of response (58, 72, and 77 percent recovery, respectively); of these three samples, only B-3 was significantly different from the control ($p<0.05$). There were no apparent relationships between the observed responses and TOC, % fines, or metals concentrations; R^2 values associated with these relationships were <0.05.

Table 2-1. Sediment Metals and TOC Measurements
17 October 2003 - Dry Weather Sampling Event

Site	Copper (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)	TOC (mg/kg)
A-1	16.9	0.7	ND	ND	10920
A-2	3.4	3.1	ND	9.1	7070
A-3	2.3	20.2	1.9	63.1	2730
B-1	3.1	4.3	ND	12.1	4900
B-2	4.2	6.0	ND	18.1	4680
B-3	3.0	4.2	ND	9.5	3040
B-4	19.3	20.4	0.9	61.4	16950
C-1	3.8	3.3	ND	8.2	1590
C-2	2.7	3.4	ND	18.4	2750
C-3	2.8	3.8	ND	6.9	3360
D-1	2.9	4.2	ND	7.9	2010

All values reported as dry weight.

Table 2-2. Summary of Grain Size Results
17 October 2003 - Dry Weather Sampling Event

Site	% Gravel	% Sand	% Silt	% Clay	% Fines Silt+Clay
A-1	1.1	51.0	32.9	15.0	47.9
A-2	16.2	81.2	1.3	1.3	2.6
A-3	0.2	98.5	1.3	0.0	1.3
B-1	2.3	95.1	1.3	1.3	2.6
B-2	1.9	92.7	2.7	2.7	5.4
B-3	2.2	95.2	1.3	1.3	2.6
B-4	0.0	39.2	42.4	18.4	60.8
C-1	0.2	98.5	1.3	0.0	1.3
C-2	7.6	91.1	0.0	1.3	1.3
C-3	13.2	84.2	1.3	1.3	2.6
D-1	30.0	68.8	0.0	1.3	1.3

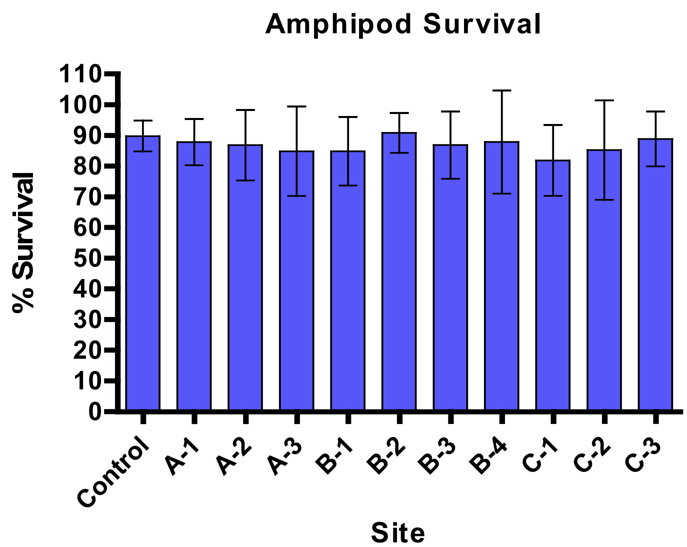


Figure 2-5. Summary of sediment toxicity test results for amphipod 10-day survival. Santa Clara River Estuary samples were collected 17 October 2003. Mean (±1 SD) values are displayed. No significant decreases relative to the control were observed.

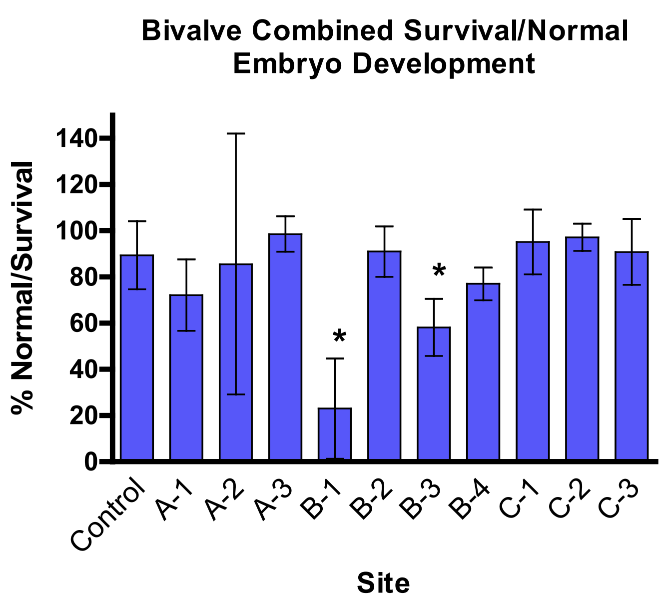


Figure 2-6. Summary of sediment toxicity test results for bivalve embryo development. Santa Clara River Estuary samples were collected 17 October 2003. Mean (±1 SD) are displayed. A significant reduction in survival/normal embryo development was observed for samples B-1 and B-3.

2.3.2.2 March 2004 (Wet Weather: Berm Open)

Sediment quality

Sediment metals concentrations and TOC are summarized for the different sites in Table 2-3. Selenium concentrations were below the detection limit of 0.5 mg/kg at all sites. Copper concentrations were relatively low at all sites, generally between 2.69 and 4.1 mg/kg. Nickel concentrations ranged between 3.8 and 6.4 mg/kg, with no particular trend across sites. Zinc concentrations were also relatively uniform across sites, and ranged between 11.5 and 16.2 mg/kg. Sediment metal concentrations were all well below their respective ERL sediment quality guidelines (Long et al. 1995). TOC concentrations ranged between 1,400 and 8,100 mg/kg, with no indication of any trends across sites.

Sediment grain size

The distribution of sediment grain sizes is summarized in Table 2-4. Virtually all of the sites contained relatively coarse-grained sediments, predominantly composed of sand or a mixture of gravel and sand. Percent fines ranged between 1.0 and 7.8 percent.

Toxicity

The results of the toxicity tests are summarized in Figures 2-7 and 2-8. With respect to the amphipods (*Eohaustorius estuarius*), control survival exceeded 95 percent, compared with a range of 76 to 95 percent across the test sediments (Figure 2-7). Survival in samples from A-1, B-3, C-2, and C-3 ranged between 76 and 85 percent; survival in sediments from these sites were all significantly less than the controls. However, there appeared to be no statistically significant relationships between the observed responses and % fines, TOC, or metals concentrations. Conversely, % gravel was inversely related to survival, suggesting that a predominance of coarse grain size adversely affected survival.

Recovery of mussel (*Mytilus galloprovincialis*) larvae with normal shell development averaged approximately 68 percent in the sediment controls and ranged from 51 to 98 percent in the test samples (Figure 2-8). The lowest recovery (51%) was associated with the sample from B-1, located near the discharge point. This sample was retested to confirm these results and again exhibited reduced recovery of normal larvae compared with the sediment controls (61% vs 88%, normal larvae, respectively). There were no apparent relationships between the observed responses and TOC, % fines, % gravel, or concentrations of the selected metals; R^2 values associated with all of these relationships were <0.10.

**Table 2-3. Sediment Metals and TOC Measurements
16 March 2004 - Wet Weather Sampling Event**

Site	Copper (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)	TOC (mg/kg)
A-1	3.3	3.8	ND	12.1	2400
A-2	4.1	5.5	ND	16.2	4000
A-3	2.7	6.5	ND	11.5	3300
B-1	3.8	4.8	ND	15.7	2400
B-2	3.1	4.4	ND	12.4	2500
B-3	3.2	4.4	ND	12.5	3900
B-4	4.1	5.2	ND	15.4	3800
C-1	2.9	4.1	ND	11.5	1700
C-2	3.0	4.4	ND	12.1	6700
C-3	2.9	4.3	ND	11.5	1400
D-1	3.8	5.4	ND	13.7	8100

All results reported on a dry weight basis.

**Table 2-4. Summary of Grain Size Results
16 March 2004 - Wet Weather Sampling Event**

Site	% Gravel	% Sand	% Silt	% Clay	% Fines (Silt+Clay)
A-1	12.1	84.2	1.2	2.5	3.7
A-2	1.7	95.8	1.3	1.3	2.5
A-3	0.4	91.9	3.9	3.9	7.7
B-1	1.7	97.0	0.0	1.3	1.3
B-2	5.1	93.8	1.1	0.0	1.1
B-3	9.2	88.4	1.2	1.2	2.5
B-4	0.1	92.1	5.2	2.6	7.8
C-1	11.0	87.9	0.0	1.0	1.0
C-2	14.4	83.2	1.2	1.2	2.4
C-3	29.0	69.8	0.0	1.2	1.2
D-1	17.4	81.3	0.0	1.2	1.2

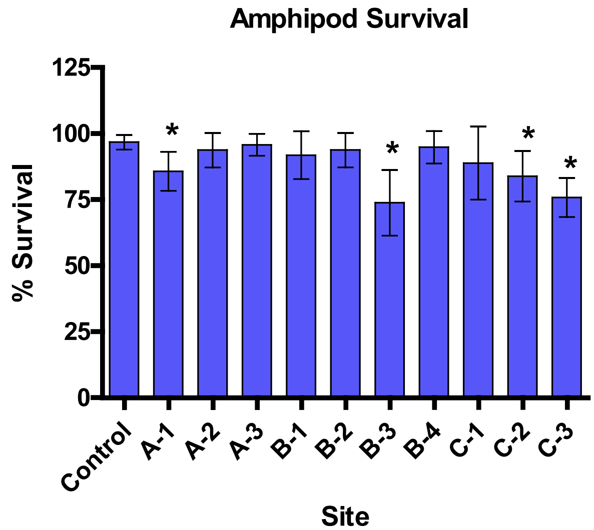


Figure 2-7. Summary of sediment toxicity test results for amphipod 10-day survival. Santa Clara River Estuary samples were collected 16 March 2004. Mean (±1 SD) values are displayed. A significant reduction in survival was observed for samples A-1, B-3, C-2, and C-3.

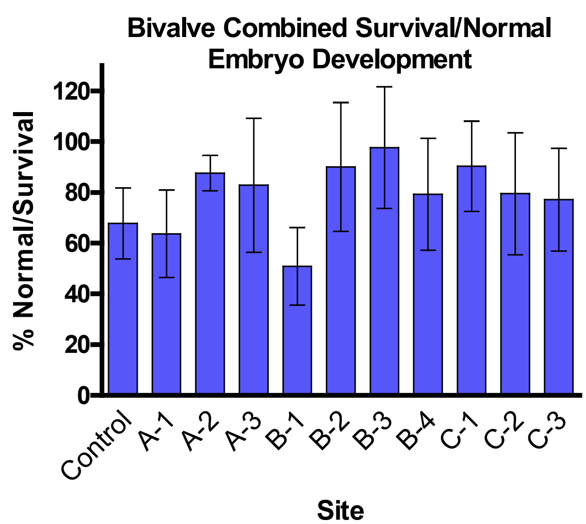


Figure 2-8. Summary of sediment toxicity test results for bivalve embryo development. Santa Clara River Estuary samples were collected 16 March 2004. Mean (±1 SD) values are displayed. No significant decreases relative to the control were observed.

2.3.3 Potential Impacts of Disposal of Dredged Sediments

During February 2004, it was brought to AMEC/Nautilus' attention that sediments dredged from the Ventura Harbor were being disposed offshore of the beach to the south of the mouth of the Santa Clara River. Since this coincided with a beach break condition (river mouth open and the estuary subject to saltwater incursions on an incoming tide), there was concern about the potential for suspended sediments to be carried into the lagoon and deposited on high tides. Depending on the level of contaminants present, this scenario could affect not only the results of the toxicity tests, but also any correlations between contaminants and toxicity. Furthermore, it was possible that such relationships might be erroneously attributed to contaminants present in the effluent discharge. Consequently, we requested data on the contaminant concentrations in the sediments to determine the extent they might affect the results of the study.

Interestingly, while the Ventura Harbor is dredged on an annual basis, concentrations of potential sediment contaminants are measured less frequently. Consequently, we were able to evaluate only the most recent data. In 2002, Applied Environmental Technologies, Inc. (AET), measured physical and chemical parameters associated with sediments from dredging sites in the harbor. Chemical parameters included polynuclear aromatic hydrocarbons (PAHs), phthalates, pesticides, polychlorinated biphenyls (PCBs), phenols, oil and grease, total recoverable petroleum hydrocarbons, sulfides, and various metals. On the basis of the analytical results, AET concluded that (1) chemical concentrations measured in sediments from these sites were not environmentally significant; and (2) no significant impacts would result from disposal of these sediments offshore of the Santa Clara River (AET 2002 a and b).

Of particular interest to this study are the concentrations of copper, zinc, nickel, and selenium. These data are summarized in Table 2-5 and compared with their associated toxicity threshold values (Long et al. 1995). In general, copper concentrations ranged from slightly less to slightly greater than the threshold for adverse effects (ERL), and well under the median value for adverse effects ("effects range-median" [ERM]). Zinc concentrations were all below the ERL; whereas, nickel concentrations all exceeded the ERL but were less than the ERM. No threshold values are available for selenium. Given that some of the copper and all of the nickel concentrations exceeded their respective threshold effects concentrations, it is not possible to eliminate the possibility of adverse effects associated with these sediments. However, assuming that the amount of sediment entering the estuary from this disposal operation is likely to be quite small relative to sediments deposited from upstream sources during recent storm events, it is likely that the impact of metals from Ventura Harbor sediments on sediment chemistry in the estuary will be minimal.

Table 2-5. Comparison of Concentrations of Selected Contaminants in Ventura Harbor Sediments to Sediment Quality Criterion

Metal	ERL	ERM	Connecting Channel	Ventura Harbor
Copper	34	270	33.8	18.4 – 49.7
Zinc	150	410	112	82.3 – 137
Selenium	na[1]	na	1.81	0.27 – 0.44
Nickel	20.9	51.6	34.8	22.5 – 33.7

[1]No value provided (Long et al. 1995).

All concentrations are in mg/kg.

ERL – Effects range low (corresponds to 10th percentile).

ERM – Effects range median (corresponds to 50th percentile).

2.4 Field Water Quality Evaluation

2.4.1 Methods

Water quality measurements, including depth, were generally taken in the field at the time sediment and water samples were collected. Measurements were typically collected across three north-south transects corresponding to the upper, middle, and lower portions of the lagoon. Three samples were collected along each transect. In addition, one sample was collected upstream of the bridge and another from the effluent discharge channel. The sampling locations are shown in Figure 2-4 (note that the lagoon shown in this figure represents an outflow condition). Where possible, temperature, conductivity, and salinity were measured at the surface, mid-depth and bottom; pH was measured at the surface only; and DO was measured at the surface and mid-depth. However, some sampling events occurred when the berm was open and the lagoon at least partially drained. Under these circumstances, water at some locations was either absent or too shallow to sample at multiple depths. Instrumentation included YSI Model 55 (DO), and Orion Models 250A and 130 (pH/temperature and conductivity/salinity, respectively).

2.4.2 Results

2.4.2.1 October 2003 (Dry Weather: Berm Closed)

Water depths ranged between 3.0 and 7.0 feet, depending upon location. The deepest points were associated with the lower portion of the main river channel (Sites A-2 and B-3). There was little indication of temperature stratification; temperatures across all sites and depths ranged between 20.7 and 22.2°C. pH was highest above the bridge (9.2) and lowest at the effluent discharge point (7.1). Otherwise, pH at all sites ranged between 8.6 and 8.9. Salinity and conductivity exhibited similar patterns, with most sites averaging between 2.0 and 2.4 parts per thousand (ppt), regardless of depth. Exceptions included Sites A-2 and B-3, which exhibited noticeably higher salinities (11 - 12 ppt) at the bottom depth compared with the surface and mid-water sampling points, which averaged 2.3 ppt. Site A-1 exhibited a modest increase in salinity at the bottom, compared with mid-water and surface measurements; this site was located in the discharge channel. The lowest salinity (1.5 ppt) was observed at the surface at the effluent discharge point and increased with increasing depth to a maximum of 2.9 ppt at this site. Dissolved oxygen was supersaturated at all sites, except at the discharge point, which was 7.5 milligrams per liter (mg/L). These data are presented in Table 2-6.

2.4.2.2 November 2003 (Wet Weather: Berm Open)

This sampling event was conducted during an extreme low tide 2 days after the berm had been breached. In contrast to the inundated condition of the estuary observed 3 weeks earlier, the lagoon was essentially drained and flowing freely to the ocean at the time of sampling. Aside from a few localized ponds located along the southern margin of the estuary, the flows were restricted to the channels associated with the Santa Clara River and the effluent discharge. Field measurements for this event were taken by

Kamman Hydrology & Engineering, Inc. (KHE) and do not correspond to any sediment or water sample collections.

Water quality measurements were taken at a total of 11 locations within the channels, as well as from 2 of the "perched" ponds located adjacent to the river channel along the southern edge of the estuary. In general, sampling locations were distributed along upstream:downstream gradients; three sites were measured in the discharge channel, six sites were measured in the Santa Clara River channel between the Harbor Boulevard Bridge and the breach in the sand berm, and two sites were measured at the junction of the two channels. The locations of the sampling sites for this event are shown in Figure 2-9.

Because water depths did not exceed 1.5 feet, and the flowing conditions suggested that there was complete mixing throughout the water column, only single measurements were made at each site. Parameters measured included temperature, conductivity, pH, and DO. All measurements were performed with a handheld YSI 556 multi-probe system that was calibrated the day prior to monitoring. All measurements were stored in the unit's internal memory and downloaded directly into a personal computer to avoid transcription errors.

Maximum water depth was 1.5 feet. Temperature ranged between 19.0 and 21.6°C across all sites. pH ranged between 7.42 and 7.76 across sites. Salinity exhibited somewhat higher variability; the highest values (11.6 – 13.7 ppt) were observed in the isolated ponds located south of the main channel (Sites 67 and 69) and likely represent residual conditions associated with saltwater inflows to the estuary during the previous high tide. Salinities associated with the main river channel upstream of the confluence with the discharge channel (Sites 66, 68, and 70 – 72) ranged from 1.6 ppt at the upstream end to 4.4 ppt at the downstream end. Sites in the discharge channel ranged between 1.3 and 1.7 ppt. Salinities at the junction of the two channels were 1.9 and 8.6 ppt and, just prior to entering the ocean, the salinity was 6.5 ppt. Dissolved oxygen was supersaturated at all sites, particularly in the discharge channel where values as high as 322 mg/L were measured. These concentrations decreased rapidly to between 47 and 66 mg/L at the confluence of the two channels. Values associated with the main river channel were between 10 and 31 mg/L. The elevated DO concentrations reported for this event should be considered qualitative, as they were not verified with a Winkler titration, and may reflect calibration error or damaged probe membrane. These water quality data are presented in Table 2-7.

2.4.2.3 March 2004 (Wet Weather: Berm Open)

Water samples were collected on 16 March 2004. This was a "wet weather" sampling event; runoff from recent rains had breached the sandbar, and the lagoon freely drained to the ocean on outgoing tides and filled on incoming tides. Sampling was undertaken during an outflow period, with the lagoon partially or completely drained, with water confined to main channel areas and to isolated perched pools. No overlying water was present at Sites B-2, C-1, and C-2. Water depths ranged between 0.3 and 2.5 feet, depending upon location. The deepest point was associated with the lower portion of the main river channel (Site A-3). There was little indication of temperature stratification, which was expected, given the relatively shallow water depths across sites. However, temperatures were noticeably lower in upstream sites located near the Harbor Boulevard Bridge (C-3 and D-1), compared with the temperatures associated with the rest of the sites. Temperatures in the vicinity of the bridge ranged from 15.2ºC to 16.4ºC, compared with a range of 18.5 to 20.5ºC across the remaining sites. pH ranged between 7.44 and 8.64, with no particular relationship between sites. The salinity of water entering the estuary was approximately 1.5 ppt; similar values were also found at Sites A-1 and B-1. The site closest to the mouth of the estuary (A-3) exhibited strong stratification; although it was only 2.5 feet deep, salinity at the surface was 6.3 ppt, compared with 30 ppt at the bottom. Salinity at the remaining sites ranged from 3.1 ppt (A-2) to between 12.7 and 14.4 ppt (Sites B-4 and B-3, respectively). Dissolved oxygen ranged between 8.7 and 13.0 mg/L, with no particular pattern across sites. These data are presented in Table 2-8.

2.4.2.4 July 2004 (Dry Weather: Berm Closed)

Water depths ranged between 2.0 and 5.5 feet, depending upon location. The deepest points were associated with the lower portion of the main river channel (sites A-2 and B-3). Temperatures across all sites and depths ranged between 24.4 and 27.1°C. Site B-1 exhibited an inverse temperature gradient with the warmest water (27.0 °C) at the bottom, and cooler water (25.1 and 25.9 °C, respectively) measured at the middle and surface depths. pH was highest below the bridge (9.84 at A-3) and lowest above the bridge (8.97), with the exception of the surface measurement taken at site B-1 (7.69). Otherwise, pH at all sites ranged between 9.04 and 9.77. Salinity and conductivity exhibited similar patterns, with most sites averaging between 2.6 and 3.2 ppt, regardless of depth. Exceptions included sites C-3, A-2, and B-3, which exhibited noticeably higher salinities (7.5, 7.7, and 9.5 ppt, respectively) at the bottom depth, compared with the surface and mid-water sampling points. Sites A-1 and A-3 exhibited a modest increase in salinity at the bottom, compared with mid-water and surface measurements; these sites were located in the discharge channel. The lowest salinity (1.3 ppt) was observed at the surface at the effluent discharge point, and increased with increasing depth to a maximum of 4.0 ppt at this site. Dissolved oxygen was supersaturated at all sites, except at the discharge point which was 5.0 mg/L at the surface and 4.0 mg/L at mid-depth. These data are presented in Table 2-9.

2.4.2.5 September 2004 (Dry Weather: Berm Open)

Water depths ranged between 0.3 and 4.3 feet. Three of the 11 sites (B-2, C-1, and C-2) were dry because the berm was open and the lagoon only partially full. Water quality sampling at sites B-1, C-3, and D-1 was restricted to the middle of the water column due to the shallow depth of the water. Water temperatures during this sampling event ranged from 18.1 to 25.7 °C, depending upon location and depth. Salinity measurements ranged between 3.3 and 34.5 ppt, with most measurements falling between 22.6 and 33.2 ppt. Salinity at site B-1, which is located nearest to the VWRF outfall, was 3.3 ppt. Salinity at sites C-3 and D-1 were 4.6 and 4.1 ppt, respectively. pH ranged from 7.74 to 8.43, with higher pH at sites with higher salinity. Dissolved oxygen ranged from 7.6 to 17 mg/L. Site B-1 exhibited the lowest DO, while the highest DO was measured at mid-water at site B-3. These data are presented in Table 2-10.

2.4.2.6 January 2005 (Wet Weather: Berm Open)

Water depths ranged between 1.0 and 3.0 feet. Water temperature ranged from 12.9 to 18.7 °C, depending upon location and depth of measurement. Salinity was noticeably lower during this event than previous events, most likely due to the large volume of freshwater input from the river from the large storm event that occurred during January. Salinity ranged from 0.6 to 2.7 ppt, with the exception of site A-3, which exhibited a salinity of 9.5 ppt. pH ranged from 7.46 to 8.75. Dissolved oxygen ranged between 6.1 and 11.8 mg/L, with the lowest measurements at sites C-3 and B-4 (6.1 and 6.2 mg/L, respectively). The highest DO value was measured at site D-1. These data are presented in Table 2-11.

amec

Sediment Sampling Locations
Santa Clara River Estuary, City of San Buenaventura
(Collected 06 November 2003, Photo Taken 1 June 2002)
Wet Weather

FIGURE

2-9

Graphics2/3164/Santa Clara River/SantaClaraSedSampLocs_wet.fh8

Table 2-6. Dry Weather Field Water Quality Measurements Sampled on 17 October 2003 (berm closed).

Sample ID	Depth (ft)	Temperature (ºC)	Salinity (ppt)	Conductivity (umhos/cm)	pH	DO (mg/L)
A-1	0	21.5	2.3	4360	8.74	16.7
	2.5	21.6	2.4	4440	nr	16.7
	5.0	21.7	4.3	7840	nr	nr
A-2	0	21.3	2.3	4400	8.72	16.5
	3.5	21.3	2.3	4400	nr	16.7
	7.0	22.0	11.9	19930	nr	nr
A-3	0	21.0	2.0	4220	8.90	15.2
	2.3	20.8	2.2	4210	nr	15.5
	4.6	20.7	2.2	4210	nr	nr
B-1	0	21.9	1.5	2780	7.10	7.5
	2.4	21.4	1.5	3110	nr	7.6
	4.7	21.8	2.9	5400	nr	nr
B-2	0	22.2	2.3	4350	8.83	>20.0
	1.5	22.2	2.3	4350	nr	>20.0
	3.0	22.2	2.3	4350	nr	nr
B-3	0	21.7	2.3	4340	8.65	18.9
	3.2	21.7	2.3	4340	nr	19.1
	6.3	22.1	10.6	18650	nr	nr
B-4	0	21.7	2.3	4420	8.55	19.1
	2.6	21.7	2.3	4430	nr	18.2
	5.1	21.7	2.3	4430	nr	nr
C-1	0	21.9	2.1	3930	8.77	>20.0
	1.6	21.9	2.1	3910	nr	>20.0
	3.1	21.9	2.1	4040	nr	nr
C-2	0	21.9	2.2	4200	8.92	>20.0
	1.6	21.9	2.2	4200	nr	>20.0
	3.1	21.9	2.2	4220	nr	nr
C-3	0	22.0	2.2	4200	8.92	>20.0
	2.3	22.0	2.2	4200	nr	>20.0
	4.6	22.0	2.2	4250	nr	nr
D-1	0	21.8	2.2	4230	9.15	>20.0
	1.7	21.8	2.2	4230	nr	>20.0
	3.4	21.8	2.2	4240	nr	nr

nr - not recorded

Table 2-7. Wet Weather Field Water Quality Measurements Sampled on 6 November 2003[a] (berm open).

Sample ID	Depth (ft)	Temperature (ºC)	Salinity (ppt)	Conductivity (umhos/cm)	pH	DO (mg/L)
60	nr	20.1	1.3	2502	7.61	322.4
61	nr	20.5	1.6	3030	7.45	163.7
62	nr	20.5	1.7	3301	7.44	78.1
72	nr	19.0	1.6	3032	7.71	10.1
71	nr	19.9	2.3	4274	7.63	10.6
70	nr	20.1	2.7	5035	7.71	14.6
68	nr	21.0	3.2	5871	7.76	16.8
66	nr	21.1	4.4	7944	7.76	24.0
63	nr	20.3	1.9	3590	7.42	65.9
64	nr	21.6	8.6	14769	7.62	47.7
65	nr	21.6	6.5	11417	7.67	30.6
69	nr	20.3	11.6	19498	7.55	14.6
67	nr	21.2	13.7	22615	7.71	22.6

[a] Measurements taken by KHE. Depth not recorded.

nr - not recorded

Table 2-8. Wet Weather Field Water Quality Measurements Sampled on 16 March 2004 (berm open).

Sample ID	Depth (ft)	Temperature (ºC)	Salinity (ppt)	Conductivity (umhos/cm)	pH	DO (mg/L)
A-1	0.3	20.4	1.5	nr	7.58	9.3
A-2	1.0	20.5	3.1	nr	7.79	10.5
A-3	0.3 2.5	18.5 18.5	6.3 30.0	nr nr	8.17 8.52	11.6 13.0
B-1	1.0	19.8	1.4	nr	7.46	8.7
B-2	nw					
B-3	0.3	20.2	14.4	nr	8.64	12.0
B-4	0.3	19.0	12.7	nr	7.44	11.3
C-1	nw					
C-2	nw					
C-3	1.0	15.2	1.7	nr	7.62	10.9
D-1	0.3	16.4	1.5	nr	8.05	10.9

nr - not recorded
nw - no water present

Table 2-9. Dry Weather Field Water Quality Measurements Sampled on 20 July 2004 (berm closed).

Sample ID	Depth (ft)	Temperature (ºC)	Salinity (ppt)	Conductivity (umhos/cm)	pH	DO (mg/L)
A-1	Surface	26.8	3.1	5830	9.73	>20
	Middle	26.7	3.2	5840	9.73	>20
	3.7	26.0	4.6	8230	nr	nr
A-2	Surface	26.6	3.0	5620	9.77	>20
	Middle	26.6	3.0	5660	9.75	>20
	5.5	26.1	7.7	14570	nr	nr
A-3	Surface	27.1	3.1	5790	9.84	>20
	Middle	27.0	3.1	5850	9.83	>20
	4.3	25.8	4.0	7700	nr	nr
B-1	Surface	25.9	1.3	2500	7.69	5.0
	Middle	25.1	1.3	2570	9.04	4.0
	4.3	27.0	4.7	8890	nr	nr
B-2	Surface	26.4	2.6	4770	9.27	>20
	Middle	nr	nr	nr	nr	nr
	2.0	26.4	2.7	4840	9.54	>20
B-3	Surface	25.4	2.8	5250	9.52	>20
	Middle	25.4	2.9	5320	9.54	>20
	5.3	25.8	9.5	9340	nr	nr
B-4	Surface	26.0	3.0	5640	9.72	>20
	Middle	25.9	3.0	5640	9.69	>20
	4.0	24.4	3.2	5890	nr	nr
C-1	Surface	25.2	3.0	5540	9.47	>20
	Middle	25.2	3.0	5550	9.47	>20
	2.5	25.2	3.0	5540	9.44	>20
C-2	Surface	25.3	2.9	5460	9.53	>20
	Middle	25.2	2.9	5440	9.40	>20
	3.3	25.1	2.9	5340	nr	nr
C-3	Surface	25.1	2.9	5390	9.52	>20
	Middle	25.1	2.9	5400	9.29	>20
	4.7	25.0	7.5	13320	nr	nr
D-1	Surface	25.1	2.7	5110	8.97	>20
	Middle	24.9	2.7	5170	8.97	>20
	3.3	24.9	2.8	5210	nr	nr

Note: Site B-2 was only 0.6 meters deep; therefore, only surface and bottom values were measured. Due to limitations of cord length on pH and DO meters, only sites B-2 and C-1 have recorded measurements at depth for these parameters.

nr - not recorded

Table 2-10. Dry Weather Field Water Quality Measurements Sampled on 28 September 2004 (berm open).

Sample ID	Depth (ft)	Temperature (ºC)	Salinity (ppt)	Conductivity (umhos/cm)	pH	DO (mg/L)
A-1	0.1	20.1	4.0	nr	8.11	9.6
	0.3	18.8	31.1	nr	8.15	9.9
	0.9	18.1	32.1	nr	8.13	9.8
A-2	Surface	18.3	22.6 to 31.3	nr	8.15	8.5
	Middle	18.2	33.2	nr	8.20	8.8
	2.5	18.1	33.2	nr	8.21	8.9
A-3	Surface	18.6	32.7	nr	8.26	10
	Middle	18.2	34.4	nr	8.29	11
	4.3	18.2	34.5	nr	nr	nr
B-1	Middle	22.5	3.3	2470	7.74	7.6
	1.0- 2.0					
B-2	nw					
B-3	Surface	20.3	24.7	nr	8.06	9.8
	Middle	19.9	31.6	nr	8.43	17
	1.2	19.9	31.6	nr	nr	nr
B-4	Middle	20.8	28.3	nr	8.15	10
	1.2					
C-1	nw					
C-2	nw					
C-3	Middle	25.3	4.6	4880	7.89	15
	0.3-0.5					
D-1	Middle	25.7	4.1	4020	7.85	14
	0.5-0.7					

Note: When depths were shallow, water quality measurements were taken in the middle of the water column only.

nr - not recorded

nw - no water present

Table 2-11. Wet Weather Field Water Quality Measurements Sampled on 31 January 2005 (berm open).

Sample ID	Depth (ft)	Temperature (ºC)	Salinity (ppt)	Conductivity (umhos/cm)	pH	DO (mg/L)
A-1	Middle 0.5-1.0	18.7	2.1	3660	8.03	10.3
A-2	Surface <1.0	18.1	2.5	4380	8.34	9.5
A-3	Surface 1.0	17.7	9.5	nr	8.27	8.9
B-1	Surface	18.3	1.2	2160	7.89	9.3
	1.5	18.3	1.2	2160	7.90	9.4
	3.0	18.3	1.2	2160	7.92	9.5
B-2	Middle 1.0	14.6	0.7	1310	8.33	10.2
B-3	Middle 1.0- 2.0	13.4	0.6	1142	8.44	10.7
B-4	Middle 2.5	14.2	2.7	4300	7.46	6.2
C-1	Surface 1.5	12.9	0.6	1135	8.75	11.1
C-2	nw					
C-3	Surface <1.0	16.4	1.9	3330	7.92	6.1
D-1	Surface 1.0	13.2	0.7	1178	8.45	11.8

Note: Water quality measurements were taken at the surface or in the middle of the water column only at sites with shallow depths

nr - not recorded

2.5 Water-Column Toxicity Tests

2.5.1 Methods

A total of four samples were collected for toxicity tests during each of the four sampling events. One sample was collected from the effluent outfall channel, one from the main channel upstream of the junction between the outfall channel and the main river channel through the estuary, one at the confluence of the river and outfall channels, and one just upstream of where the main channel cut through the sandbar at the mouth of the estuary.

When the berm was open, and water depths were shallow, samples were collected with a 4-L polyethylene beaker and transferred into 20-L polyethylene buckets for a total of approximately 40 L per site. Sampling containers were pre-rinsed with site water prior to filling. When the berm was closed, and water depths were deep, samples were collected using a plastic hand pump and transferred into 20-L polyethylene buckets for a total of approximately 40 L per site. When the berm was open, samples were collected on an outgoing tide, such that net flows were clearly downstream, thus eliminating the possibility of “short-circuiting” between the outfall channel and the main river channel upstream of its junction with the outfall channel. This study design was selected because it involved an upstream reference site, the discharge, and a mixture of the main flow and discharge. Thus, if any toxicity was observed it would be possible to separate upstream sources from the discharge, as well as identify any interactions between them. Samples were collected at the same locations when the berm was closed; however, under these conditions, there was no clear circulation pattern in the lagoon. The sampling site codes correspond to the sampling sites shown in Figure 2-4.

All samples were stored in coolers packed with wet ice and transported to the laboratory on the day of collection. At the laboratory, they were stored at 4°C until used. Toxicity tests were generally initiated on water samples within 36 hours of collection.

Toxicity tests were conducted on all water samples using a comprehensive suite of freshwater and marine testing protocols. Test organisms included representative freshwater (fathead minnows, *Ceriodaphnia dubia*, and *Selenastrum capricornutum*) and marine (mysids, topsmelt, giant kelp, and mussels) species. Test procedures followed those described in the appropriate marine and freshwater testing manuals (USEPA 1995, 2002a, 2002b; ASTM 1993). Note that an abbreviated dilution series was performed with the freshwater species since the effluent and receiving environment is already being tested with freshwater species as part of the City’s routine monitoring program. Full dilution series were used with the marine species since previous information on their sensitivity to samples of the effluent and receiving environment was not available. Detailed test methods are presented in the appendices.

Performing toxicity tests with freshwater organisms on samples from the estuary was complicated because the salinity of the samples varied between sites and could pose variable levels of stress on the test organisms. Consequently, each sample was tested with a concurrent salinity control. To separate salinity effects from other constituents present in the sample, statistical comparisons were made between the test concentration and the appropriate salinity controls.

Similar issues were associated with tests conducted with the marine organisms in which the salinities of the samples needed to be increased in order to achieve the salinity required by the test protocols. In these cases, salinity was increased by the use of artificial dried sea salts, or by addition of hypersaline brine. Addition of dried sea salts meant that the samples could be tested at full-strength; whereas, addition of brine resulted in modest dilutions of the samples. Regardless, statistical comparisons were made against the appropriate controls to identify the presence of any adverse effects.

Sub-samples were also taken and submitted to CRG (Torrance, CA) or Cal-Science for analysis of total copper, nickel, selenium, and zinc. Concentrations of these analytes were determined using ICP-MS (USEPA Methods 1640 and 6020/200.8, respectively).

2.5.2 Results

2.5.2.1 March 2004 (Wet Weather: Berm Open)

Freshwater species

Survival of fathead minnow larvae exceeded 80 percent in samples from Sites A-2, B-1, and C-3. Conversely, only 20 percent survival was observed in sample B-3; since this site exhibited a salinity of 14.4 ppt and no larvae survived in the corresponding salinity control sample, reduced survival in this sample was attributed to elevated salinity. Growth results in the remaining samples were similar to those observed for survival; no adverse effects occurred; in fact, average dry weights of larvae exposed to the samples exceeded those of their corresponding salinity controls. Overall, these results suggested that there were no adverse effects in samples beyond what could be attributed to the salinities of the samples, and that the response was limited to one sample in which the salinity reached 14.4 ppt. Conversely, the salinities of the remaining samples ranged between 1.4 and 3.1 ppt. These data are summarized in Figure 2-10.

Survival of *C. dubia* exposed to samples from the lagoon was also influenced primarily by salinity. Survival in the laboratory control was 80 percent, compared with a range of 0 to 100 percent across the sampling sites. Two of the Sites, A-2 and B-3, exhibited survivals of 50 and 0 percent, respectively. However, these values were similar to their corresponding salinity controls and, therefore, these responses were attributed to salinity. Similarly, reproductive output appeared to be strongly influenced by the salinity of the samples, with no apparent evidence for any additional effects. These data are summarized in Figure 2-11.

The results of the *Selenastrum* (green algae) tests are more difficult to interpret. Clearly, the elevated salinity associated with the sample from Site B-3 was likely responsible for the reduced cell numbers observed in this sample. However, cell numbers in the other three samples were all significantly less than their corresponding salinity controls, which may imply that other constituents present in the samples were responsible for the reduced growth (Figure 2-12). Interestingly, field blanks (site water not inoculated with *Selenastrum*, but with nutrients) incubated concurrently with the exposure flasks also exhibited elevated chlorophyll concentrations as measured by fluorescence. Thus, it is possible that algae already present in the samples sequestered the added nutrients and prevented the *Selenastrum* from reaching their optimum cell density. Alternatively, organic material present in the samples may also have bound some of the micronutrients added to the flasks and reduced the amount available for growth by the introduced *Selenastrum*.

Marine species

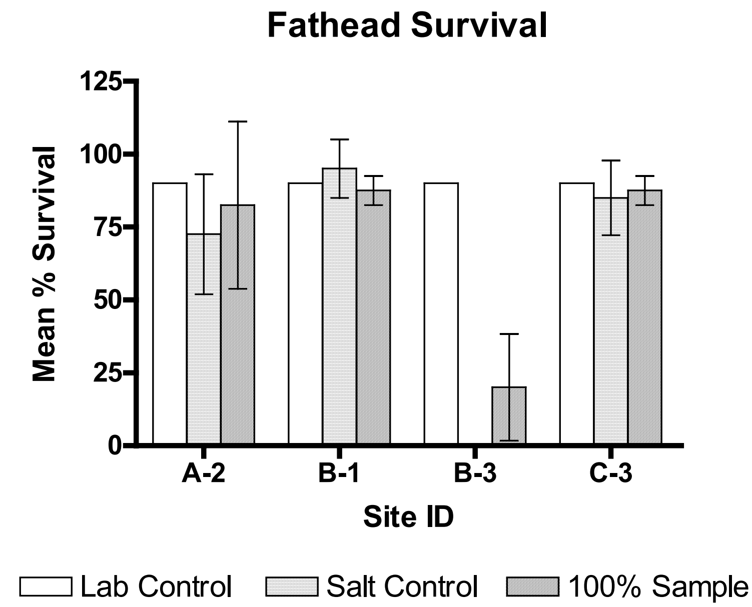
Marine toxicity tests included bivalve larvae (*Mytilus* sp.), topsmelt, giant kelp, and mysids. The samples were tested up to full strength with topsmelt and mysids, since addition of dried sea salts did not dilute the samples. Conversely, because the salinity of the samples was increased with hypersaline brine in tests with *Mytilus* and giant kelp, modest dilutions of the samples occurred. Consequently, the highest concentrations tested with bivalve larvae were 66 (C-3 and B-1), 67 (A-2) and 75 percent (B-3). Similarly, the highest concentrations tested with giant kelp were 60 (A-2), 58 (B-1), 68 (B-3), and 59 (C-3) percent.

Survival of topsmelt ranged between 88 and 100 percent, depending upon the sample tested. Although the reduction in survival was relatively small, it was statistically significant in the sample collected at C-3. Growth was significantly reduced in the highest concentrations of all samples tested when compared with the salt control. The level of reduction ranged from approximately 18 to 37 percent of the dry weight observed in the controls. The greatest reduction was associated with the sample collected farthest upstream (i.e., C-3). These data are summarized in Figure 2-13.

Survival of mysids averaged between 95 and 100 percent across all four samples, indicating that exposure to the samples did not increase mortality. No adverse effects were observed with the growth endpoint, as well (Figure 2-14).

No adverse effects were observed with bivalve larvae, even at the highest concentrations tested. These data are shown in Figure 2-15.

No adverse effects on the germination of giant kelp spores were observed. By way of comparison, percent germination averaged between 78 and 90 percent in the highest concentrations of all the samples tested, compared with a range of 83 to 89 percent in the brine controls, and 76 to 82 percent in the laboratory controls. Growth averaged higher in each of the test samples than in the controls. These data are presented in Figure 2-16.



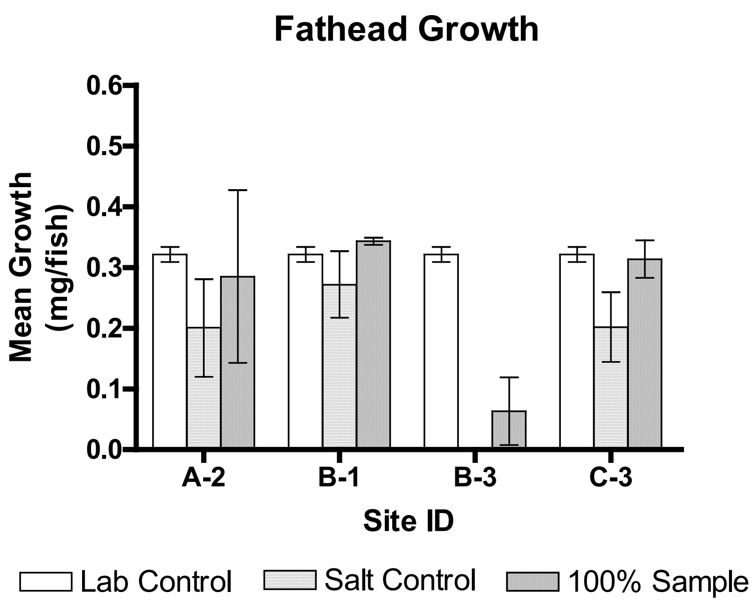
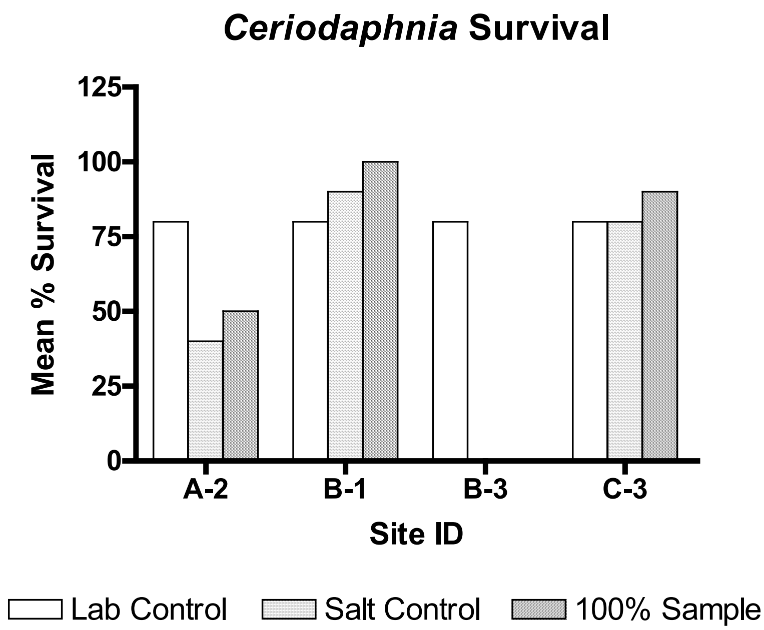


Figure 2-10. Summary of toxicity test results (March 2004) for fathead minnow 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. No statistically significant decreases were observed compared to concurrent salinity controls.



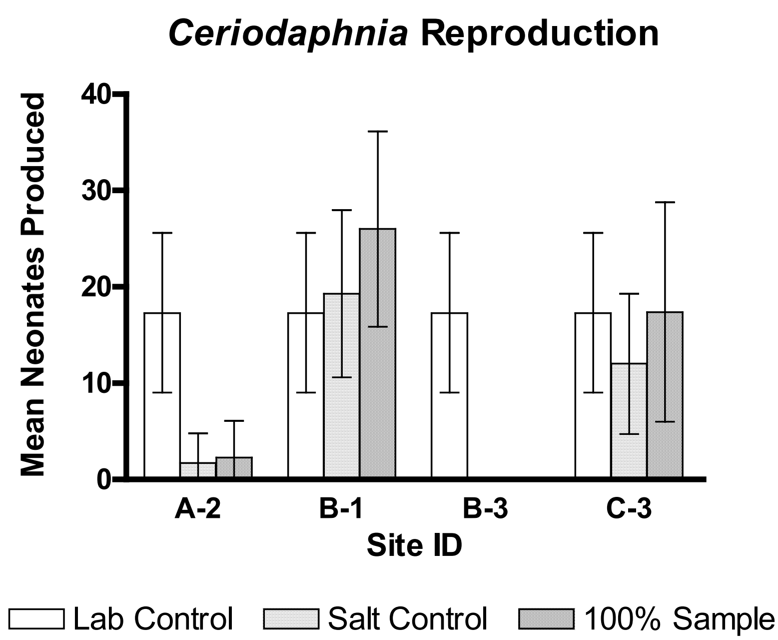


Figure 2-11. Summary of toxicity test results (March 2004) for water flea 7-day survival and reproduction. Mean (±1SD) values in 100-percent sample are displayed. No statistically significant decreases were observed compared to concurrent salinity controls.

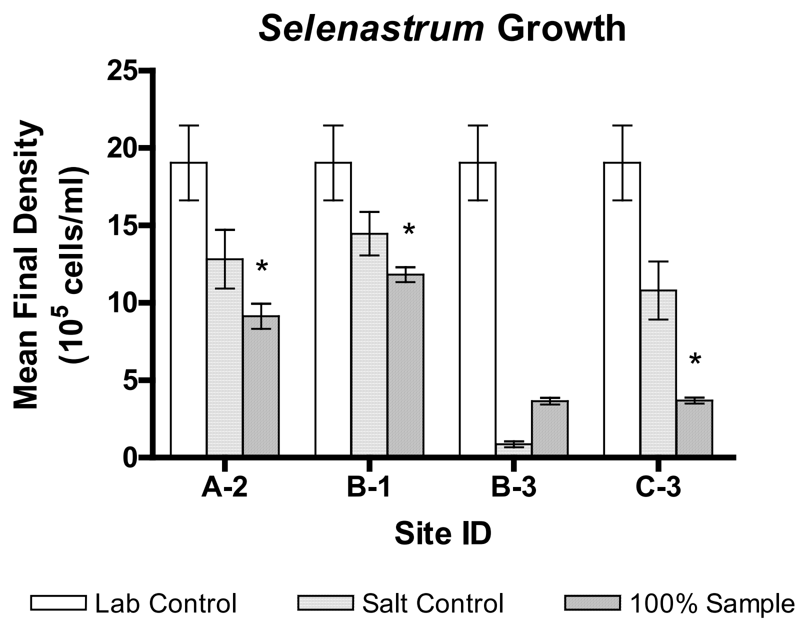
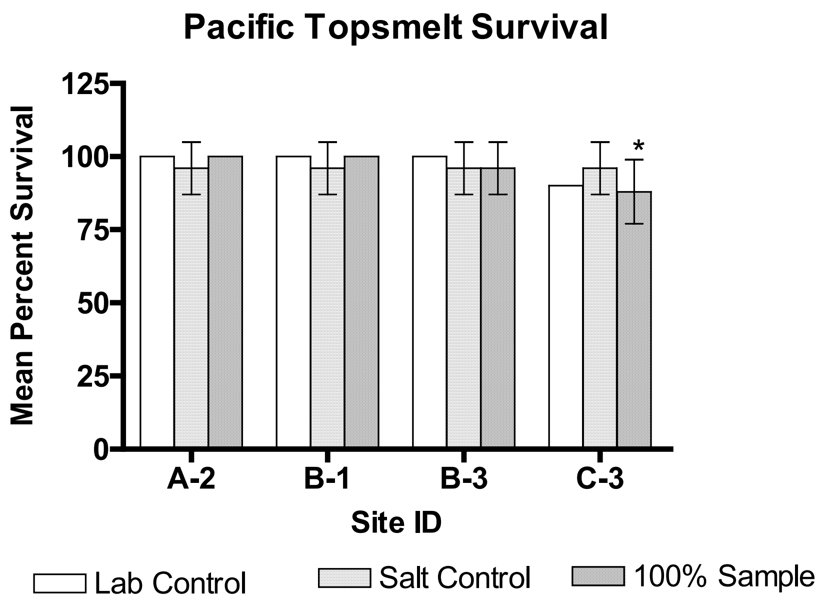


Figure 2-12. Summary of toxicity test results (March 2004) for algal growth inhibition. Mean (±1SD) values in 100-percent sample are displayed. A significant reduction in growth was observed for samples A-2, B-1, and C-3, relative to the salt control.



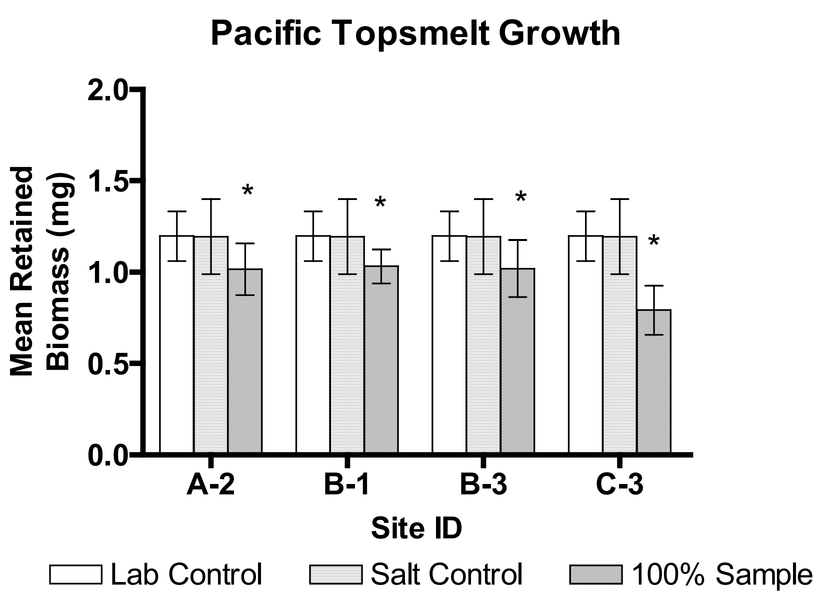
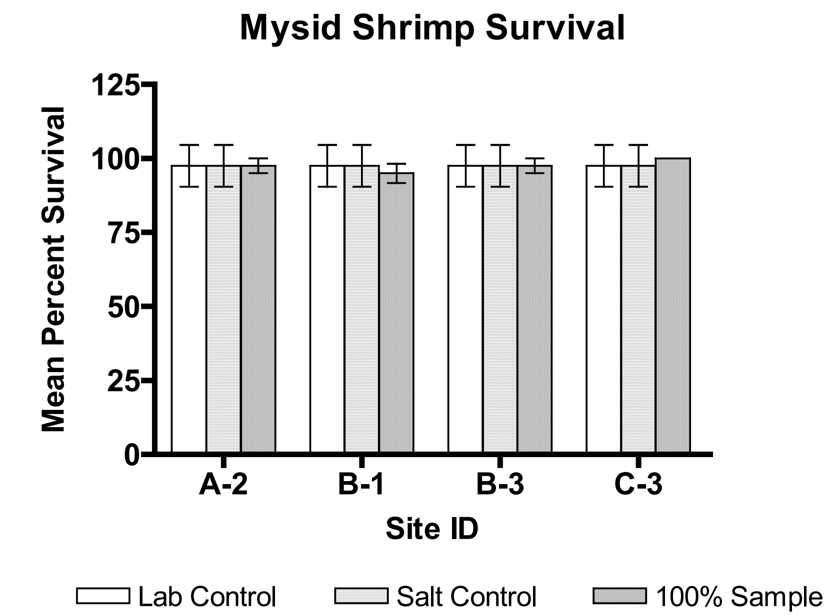


Figure 2-13. Summary of toxicity test results (March 2004) for Pacific topsmelt 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. A significant reduction in survival was observed for sample C-3, and a significant decrease in growth was observed for samples A-2, B-1, B-3, and C-3, relative to the salt control.



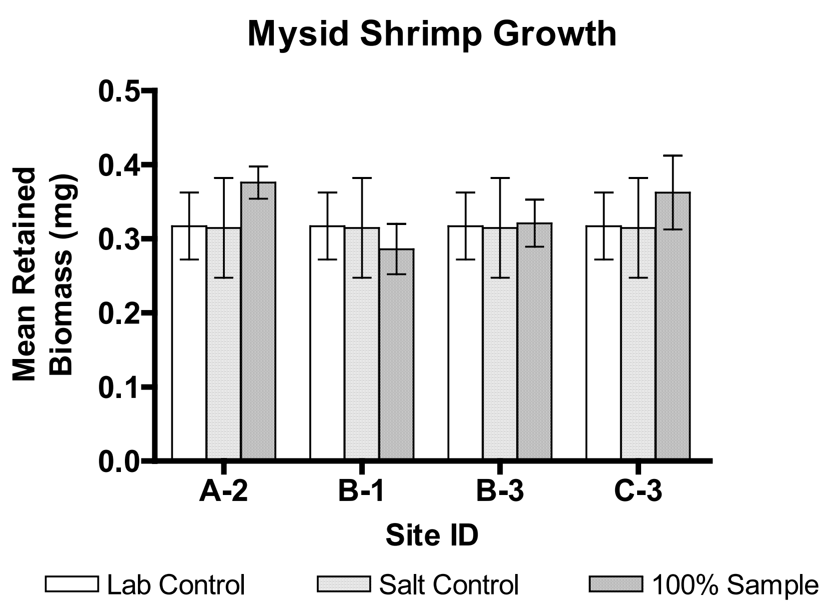


Figure 2-14. Summary of toxicity test results (March 2004) for mysid 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. No statistically significant decreases were observed compared to concurrent salt controls.

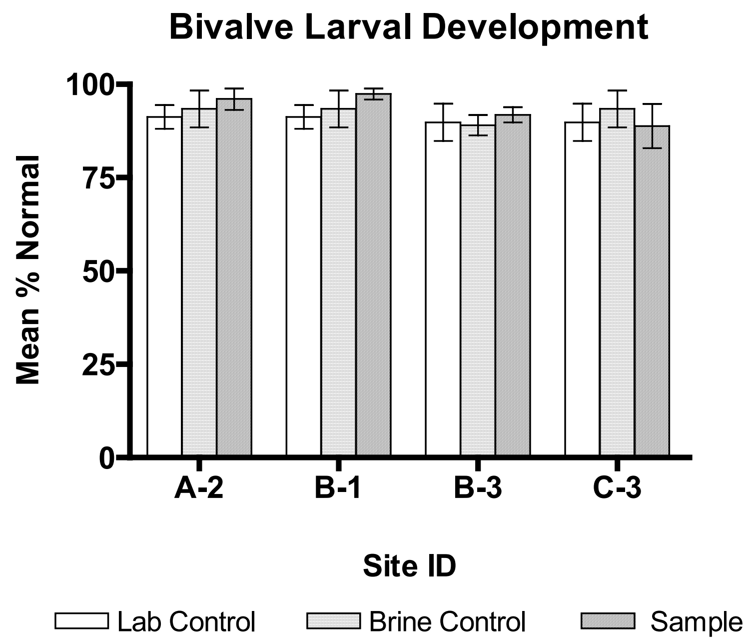


Figure 2-15. Summary of toxicity test results (March 2004) for bivalve 48-hour embryo development using *Mytilus galloprovincialis*. Mean (±1SD) values are displayed (see text for highest concentrations tested). No statistically significant decreases were observed compared to concurrent brine controls.

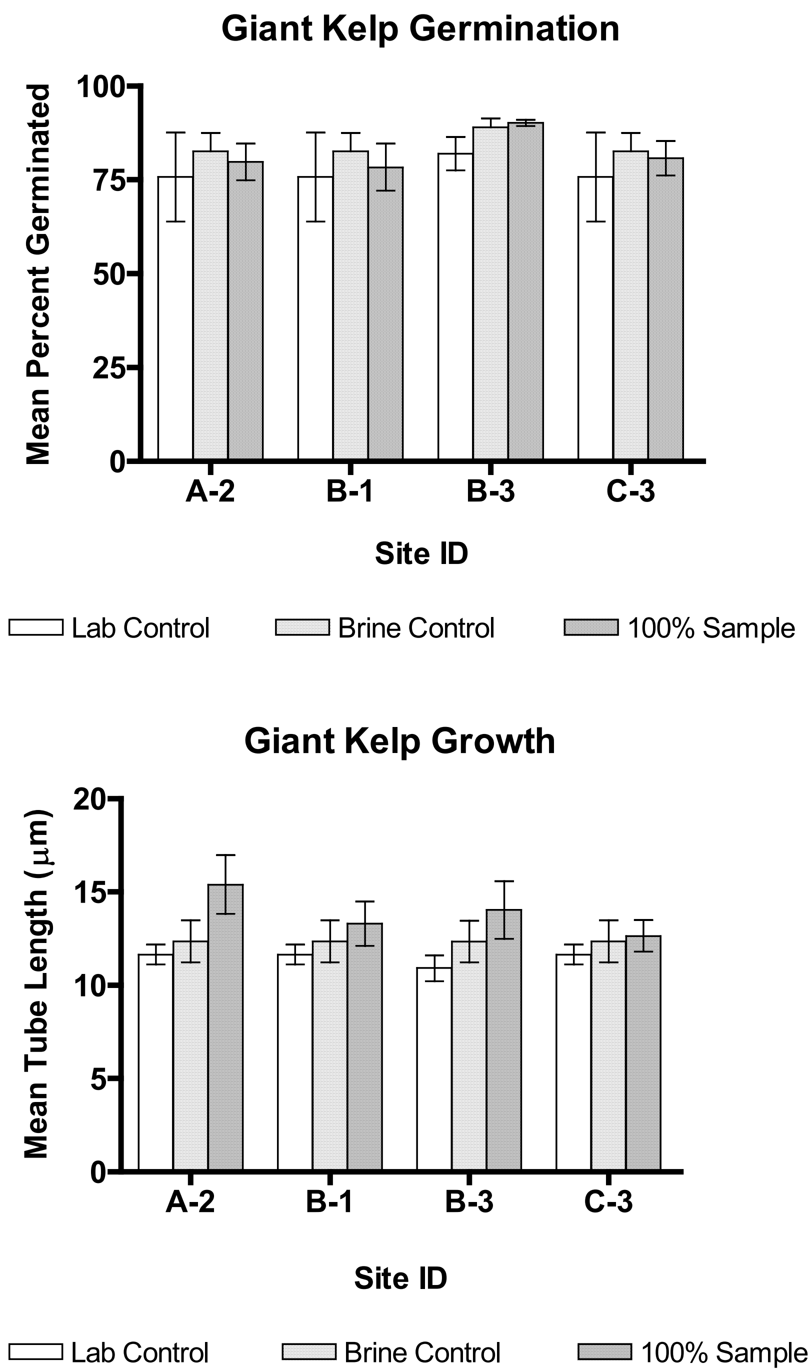


Figure 2-16. Summary of toxicity test results (March 2004) for kelp spore germination and growth. Mean (±1SD) values are displayed (see text for highest concentrations tested). No statistically significant decreases were observed compared to concurrent brine controls.

2.5.2.2 July 2004 (Dry Weather: Berm Closed)

Freshwater species

In addition to the salinity controls, three of the samples had a pH above 9.00, which exceeds the range specified in the USEPA protocols. Consequently, the samples were tested with concurrent salinity and pH controls. To separate salinity and pH effects from other constituents present in the samples, statistical comparisons were made between each full-strength sample and the appropriate salinity control for site B-1, and the salinity-adjusted pH controls for sites A-2, B-2, and C-2.

Survival of fathead minnow larvae was 90 percent or greater in all samples. Growth results were similar to those for survival; no adverse effects were observed. In fact, average dry weights of larvae exposed to the samples exceeded those of their corresponding salinity controls. The mean dry weight of fish exposed to the samples ranged from 0.41 to 0.53 milligrams per fish (mg/fish); whereas, the weights of the fish in the salinity controls ranged from only 0.36 to 0.38 mg/fish. These data are shown in Figure 2-17.

Due to unforeseen health problems with the *C. dubia* culture, 7-day results for survival and reproduction were poor in all controls and treatments. Therefore, the results reported here are only for 96-hour survival and should be used for qualitative purposes only. Mean survival was 100 percent for site B-1, which was the site with the lowest salinity. The remaining sites exhibited lower survival, with mean values of 30, 40, and 50 percent survival for sites A-2, B-3, and C-2, respectively. However, none of these data were significantly different compared to the appropriate pH or salinity controls. This suggests that the reduced survival observed in samples A-2, B-3, and C-2 can likely be attributed to elevated salinity or pH, rather than the presence of toxic constituents. These data are shown in Figure 2-18.

The results of the *Selenastrum* (green algae) tests were slightly affected by salinity, based on the differences between the lab control (0 ppt) and the salinity controls (1.1 to 3.1 ppt). The mean cell density of both lab controls exceeded 2.0 x 10^6 cells per milliliter (cells/ml), while the salinity and pH controls exhibited growth in the range of 0.9 to 1.8 x 10^6 cells/ml. Conversely, algae exposed to filtered ambient water from sites A-2, B-3, and C-2 exhibited greater increases in mean cell density than the corresponding salinity or pH controls, with cell numbers ranging from 1.4 to 2.0 x 10^6 cells/ml. On the other hand, unfiltered samples tested concurrently exhibited low growth, with means ranging from 0.20 to 0.33 x 10^6 cells/ml; nearly an order of magnitude lower than the filtered samples, or the salinity controls. Thus, it is likely that native algal species and/or particulate debris in the samples sequestered the added nutrients and prevented the *Selenastrum* from reaching their optimum cell density. These data are presented in Figure 2-19.

Marine species

Increasing the salinity of the samples with hypersaline brine in tests with the blue mussel and giant kelp resulted in highest test concentrations of 67 and 65 percent, for the mussel larvae and giant kelp, respectively. These two species were also tested up to full strength with the addition of artificial sea salts. All of the salinity adjustments for the Pacific topsmelt and mysid shrimp were performed with artificial salts; these species were tested up to full strength.

Neither survival nor growth of topsmelt larvae was adversely affected by exposure to the samples. Mean survival ranged between 92 and 96 percent, and mean biomass ranged from 1.2 to 1.6 milligrams (mg) among all samples tested. Notably, biomass was greater in all four samples tested at full strength, compared with the corresponding salt controls. These data are shown in Figure 2-20.

Survival of mysids averaged between 95 and 100 percent across sites, indicating that exposure to the samples did not cause mortality. In addition, no adverse effects were observed for growth, with the mean biomass ranging from 0.26 to 0.49 mg. These data are shown in Figure 2-21.

Mussel larvae were tested up to 67 percent sample with the addition of hypersaline brine, and up to full-strength sample with the addition of dried sea salts to increase salinity. No adverse effects were observed, even at the highest concentrations tested. Mean normal development for the embryos exposed to undiluted samples ranged from 84 to 89 percent; these values were not statistically different from the artificial salt control (see Figure 2-22).

Increasing the salinity of the samples with hypersaline brine in tests with the giant kelp resulted in a high test concentration of 65 percent. This species was also tested up to full strength with the addition of artificial sea salts. No adverse effects on the germination or growth of giant kelp spores were observed, compared with the appropriate controls. Percent germination averaged between 66 and 73 percent in the highest concentrations of all the samples tested. Growth averaged between 11.3 and 16.6 micrometers (μm). These data are shown in Figure 2-23.

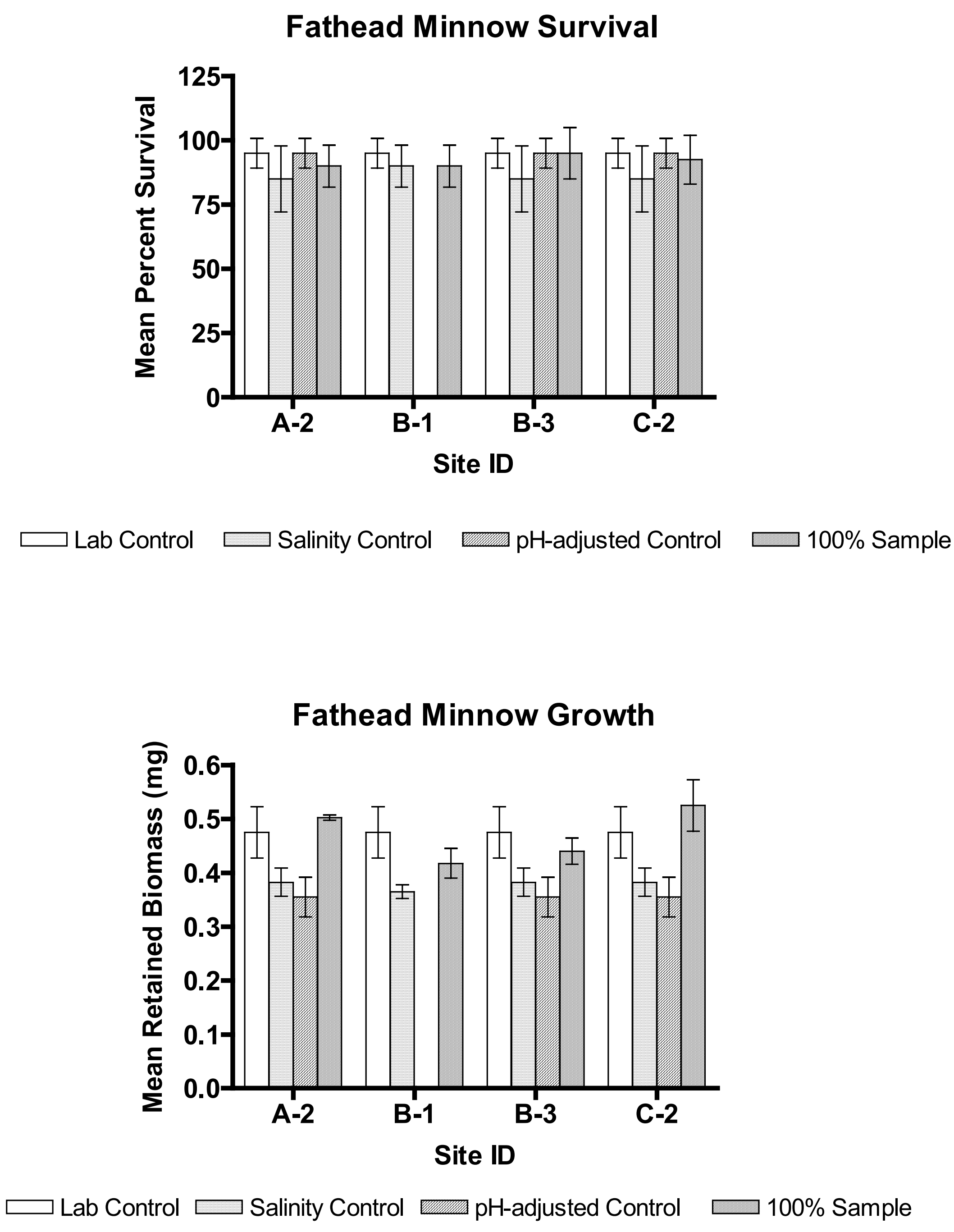


Figure 2-17. Summary of toxicity test results (July 2004) for fathead minnow 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. No statistically significant decreases were observed compared to concurrent salinity control (Site B-1) and pH control (Sites A-2, B-3, and C-2).

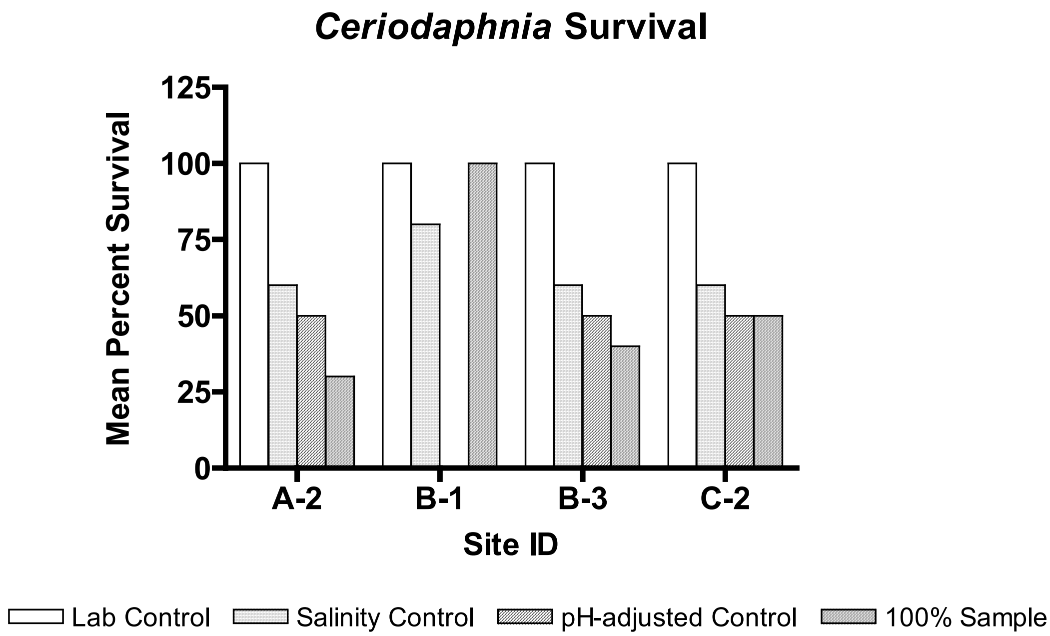


Figure 2-18. Summary of toxicity test results (July 2004) for water flea 96-hour survival. Mean values in 100-percent sample are displayed. No statistically significant decreases were observed compared to concurrent salinity control (Site B-1) and pH control (Sites A-2, B-3, and C-2).

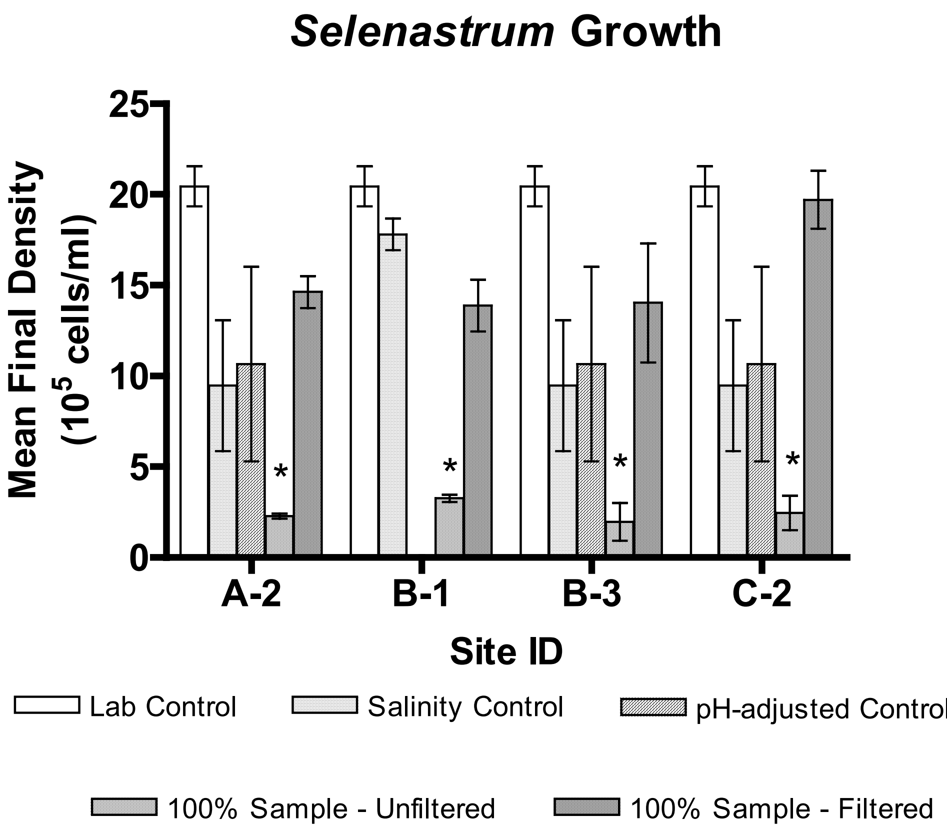


Figure 2-19. Summary of toxicity test results (July 2004) for algal growth inhibition. Mean (±1SD) values in 100-percent sample are displayed. All unfiltered samples showed a significant decrease relative to the salinity control (t-test, $p < 0.05$, n=4).

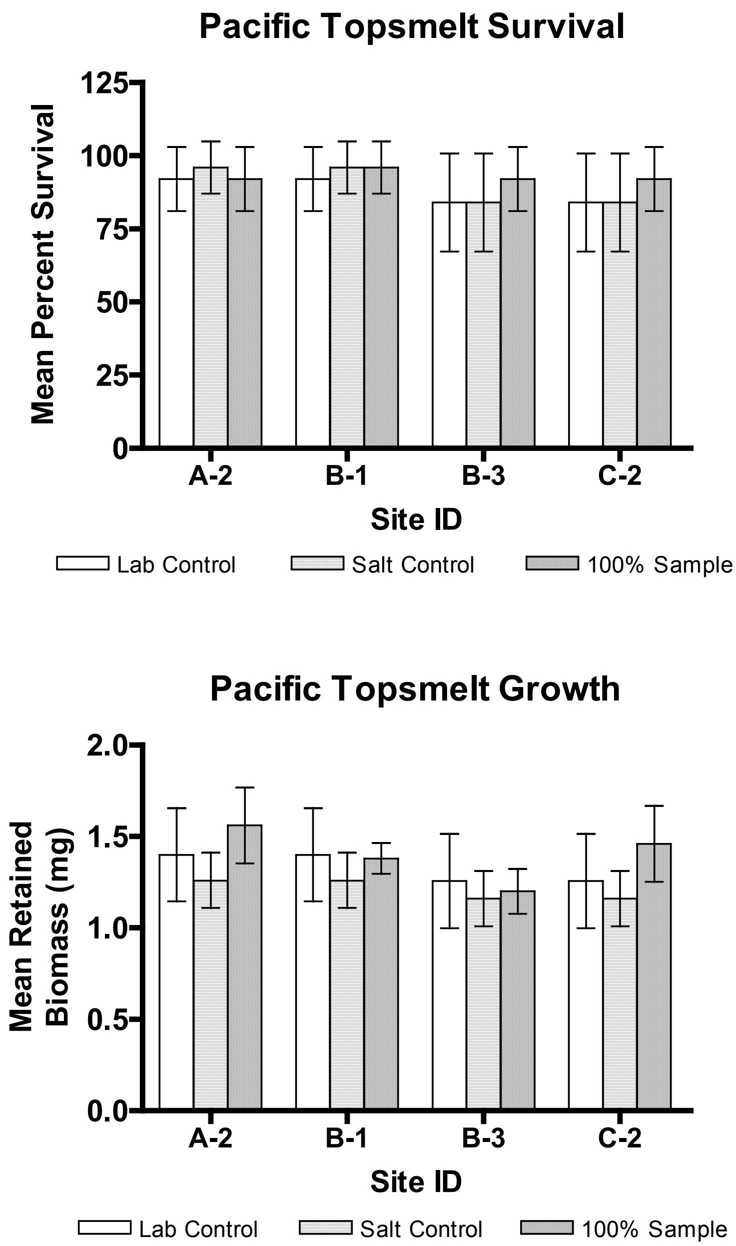


Figure 2-20. Summary of toxicity test results (July 2004) for pacific topsmelt 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. No statistically significant decreases were observed compared to the salt control.

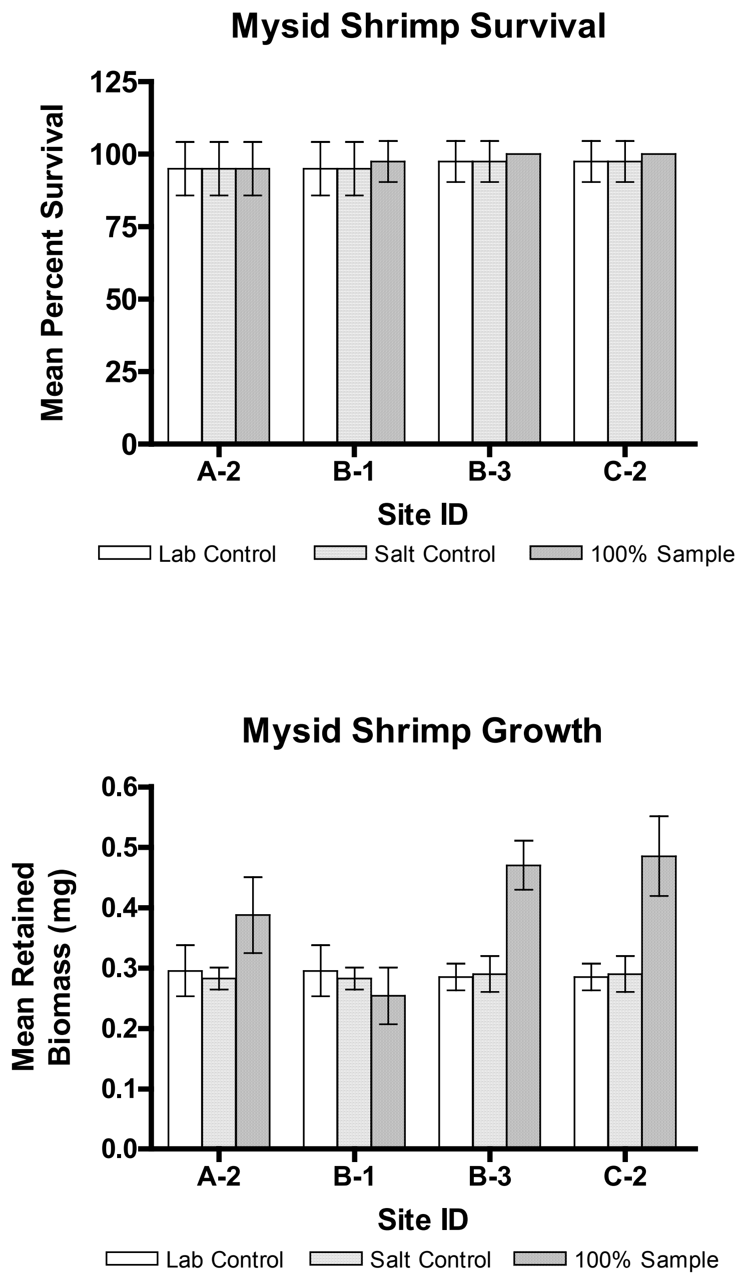


Figure 2-21. Summary of toxicity test results (July 2004) for mysid 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. No statistically significant decreases were observed compared to concurrent salt controls.

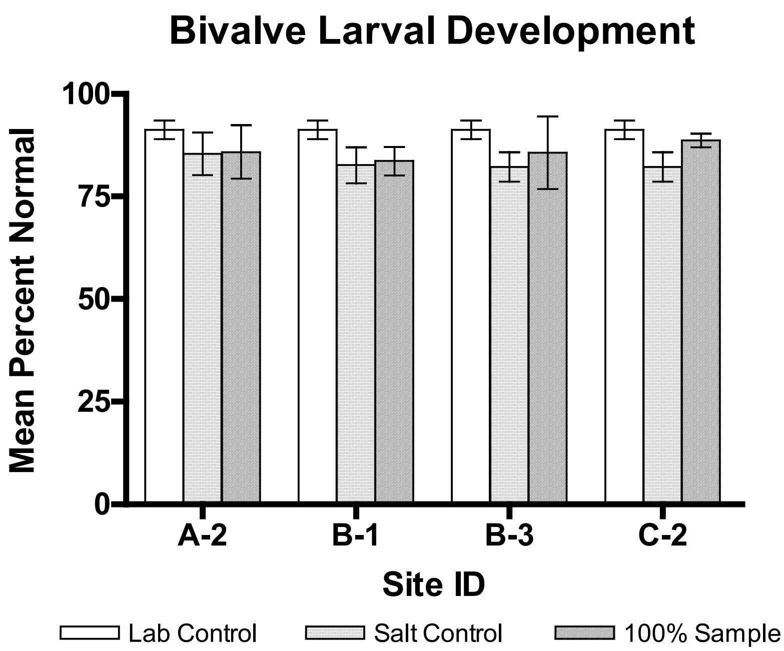
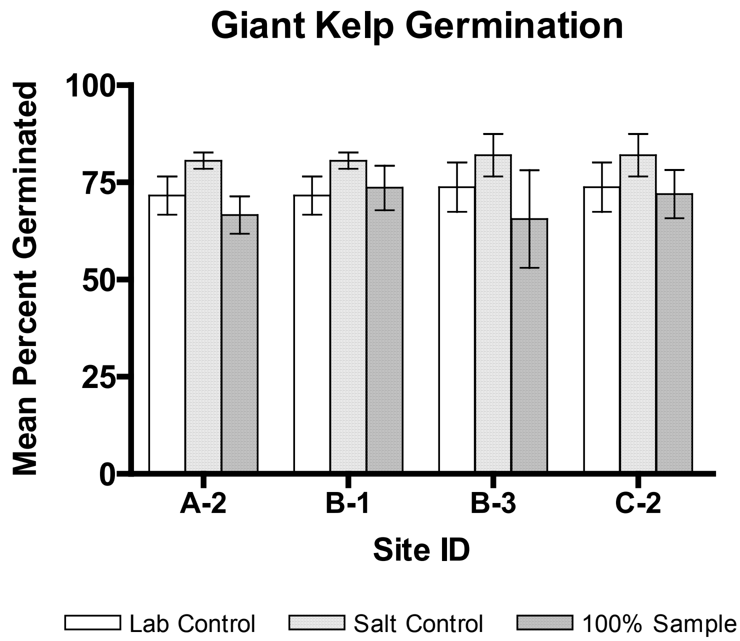


Figure 2-22. Summary of toxicity test results (July 2004) for bivalve 48-hour embryo development using *Mytilus galloprovincialis*. Mean (±1SD) values in the 100-percent sample are displayed. No statistically significant decreases were observed compared to concurrent artificial salt controls.



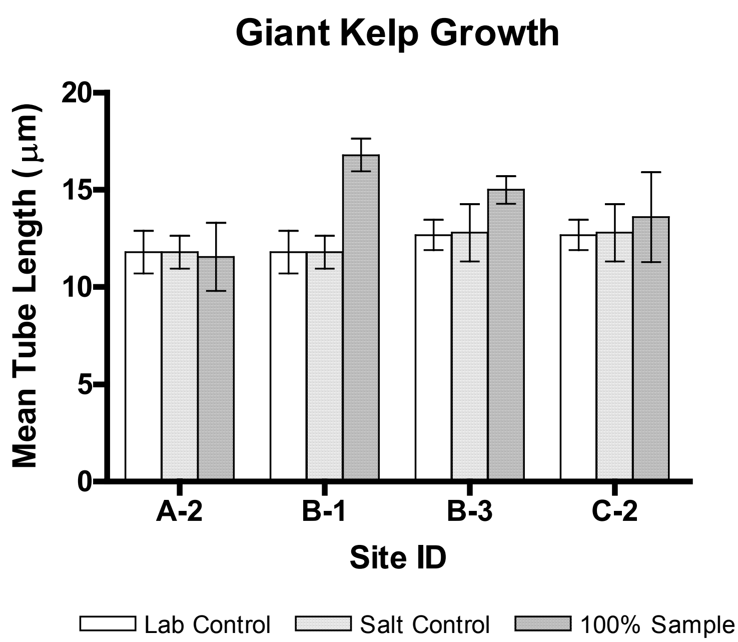


Figure 2-23. Summary of toxicity test results (July 2004) for kelp spore germination and growth. Mean (±1SD) values in 100% sample for each site are displayed. No statistically significant decreases were observed compared with the concurrent artificial salt controls.

2.5.2.3 September 2004 (Dry Weather: Berm Open)

Freshwater species

In this sampling event, tests were conducted with freshwater organisms only on samples collected from B-1 and C-3. The salinities in samples from the remaining sites approached those found in seawater and therefore exceeded the survival thresholds for the freshwater test species.

Survival of fathead minnow larvae was 98 percent in sample B-1 and 83 percent in sample C-3. Salinity did appear to have a slight effect on fathead minnow survival; survival in the B-1 salinity control (1.1 ppt) was close to that observed in the laboratory dilution water control (90 percent), and survival in the C-3 salinity control (3.0 ppt) was only 80 percent. Because of the close correspondence in survival between sample C-3 and its salinity control, the reduction in survival appears to be related to salinity, rather than the presence of toxic constituents. No adverse effects on larval growth were observed. The mean dry biomass of fish exposed to the samples and their corresponding salinity controls ranged from 0.32 to 0.39 mg (Figure 2-24).

As with fathead minnows, salinity also affected survival of *Ceriodaphnia*. Mean survival in the B-1 and C-3 salinity controls was 90 and 40 percent, respectively. However, this effect did not translate directly to the lagoon samples as it did with fathead minnows; survival of *C. dubia* was 80 percent in both samples (Figure 2-25).

With respect to reproduction, no adverse effect was observed with *C. dubia* for sample B-1 or its salinity control. However, sample C-3 did exhibit reduced reproduction but was not significantly reduced compared to the salinity control (Figure 2-25). This result suggests that the reduced reproduction was caused by the sample salinity, rather than other toxic components.

In the tests with *Selenastrum*, cell growth in the salinity controls was reduced compared to the lab control, but both the B-1 and C-3 salinity controls met the test acceptability criteria. Adverse effects were present in both the B-1 and C-3 samples, as reduced cell numbers were observed in both filtered and unfiltered samples compared with the appropriate salinity controls. However, cell density in the unfiltered samples was lower than that in the filtered samples, suggesting that native algae or other particulate material in the samples interfered with cell growth to some extent (Figure 2-26).

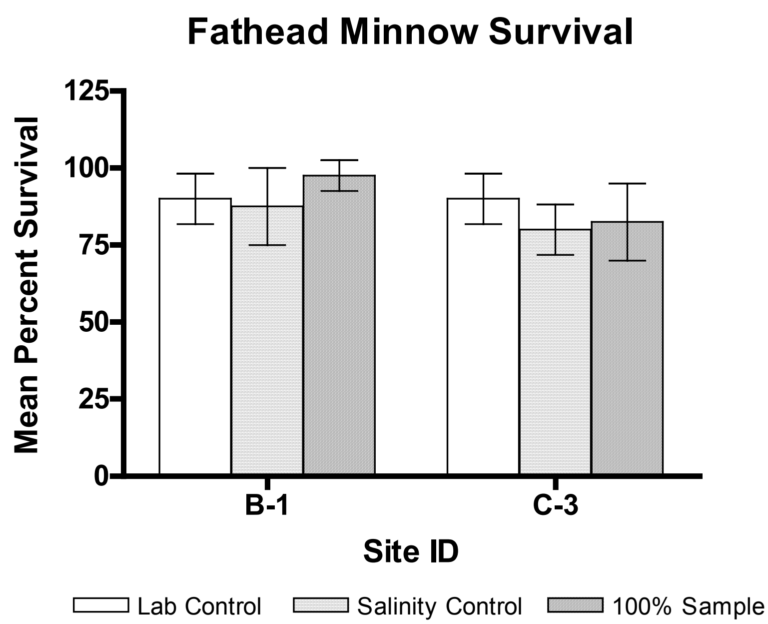
Marine species

Survival of topsmelt larvae was high across all test concentrations and samples, ranging from 92 to 100 percent. A significant reduction in growth was observed relative to the control for site A-2 only. Mean biomass in 100-percent sample from this site was 1.3 mg compared to 1.6 mg in the control. However, this finding was most likely related to atypically high biomass obtained in the control for A-2, rather than the presence of toxicants in the sample itself, since the biomass obtained in A-2 was consistent with that found in the other controls and samples that were tested concurrently. For comparison, mean biomass in the remaining controls and undiluted samples ranged between 1.2 and 1.3 mg (Figure 2-27).

No adverse effects were observed on survival for mysids. Mean survival ranged from 93 to 100 percent. However, reductions in growth were observed for sites A-2, B-1, and B-3 relative to the artificial salt control. For site A-2, mean biomass in the undiluted sample was 0.32 mg compared with 0.42 mg in the control. Growth in samples B-1 and B-3 were more strongly affected; mean biomass was 0.14 and 0.24 mg, respectively (Figure 2-28).

Mussel embryo development was not impacted by exposure to any of the samples tested. Normal development was high in samples amended with hypersaline brine, as well as with artificial sea salts. Mean normal development ranged from 87 to 94 percent among test concentrations and sample sites (Figure 2-29).

No significant reductions were observed in the germination success of giant kelp spores (Figure 2-30). However, spores exposed to samples from sites A-2 and B-1 exhibited small, but statistically significant reductions in germ tube length in undiluted sample compared with the appropriate controls. Mean tube length was 13 µm for site A-2, and 15 µm for site B-1, compared with approximately 15 µm and 17 µm in their respective controls.



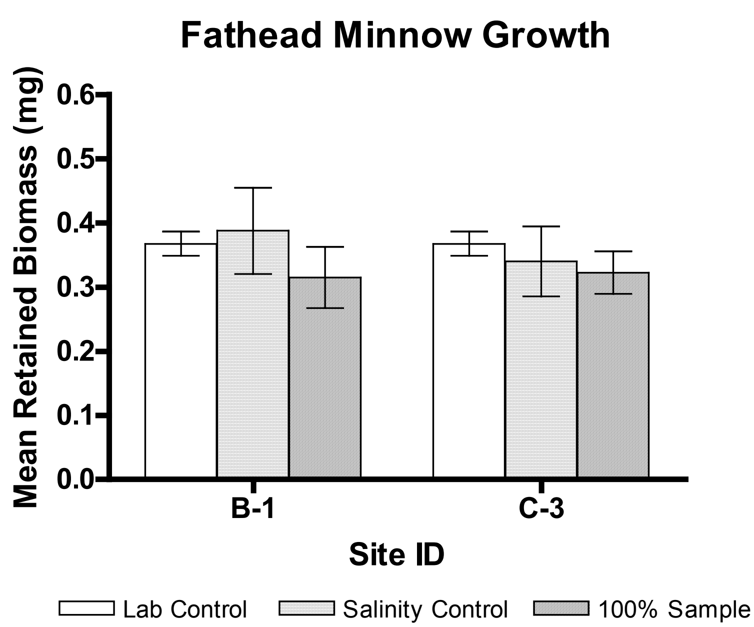
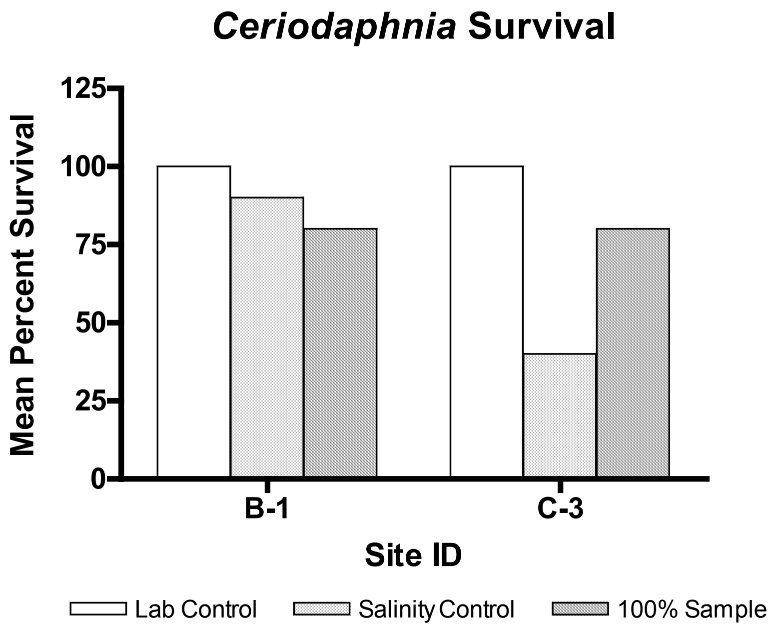


Figure 2-24. Summary of toxicity test results (September 2004) for fathead minnow 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. No statistically significant decreases were observed compared to concurrent salinity controls.



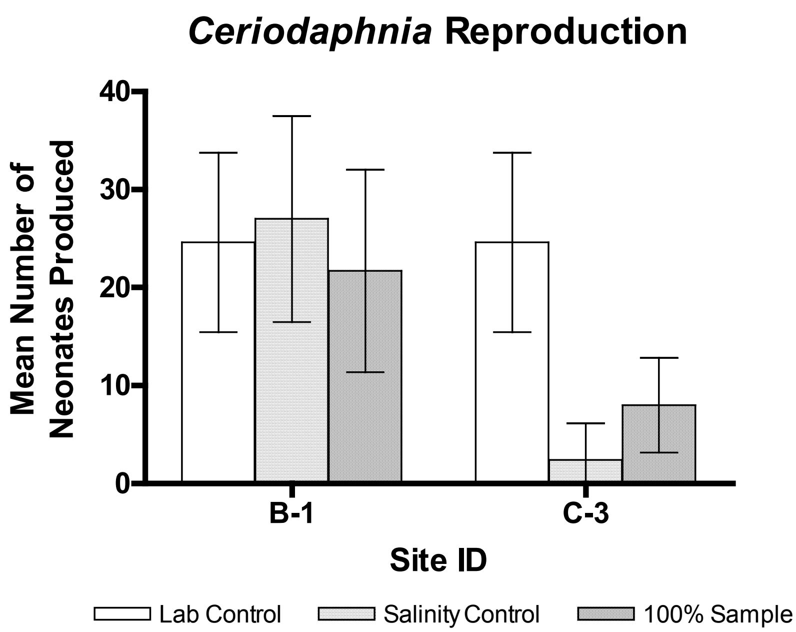


Figure 2-25. Summary of toxicity test results (September 2004) for water flea 7-day survival and reproduction. Mean (±1SD for reproduction) values in 100-percent sample are displayed. No statistically significant decreases were observed relative to the concurrent salinity controls.

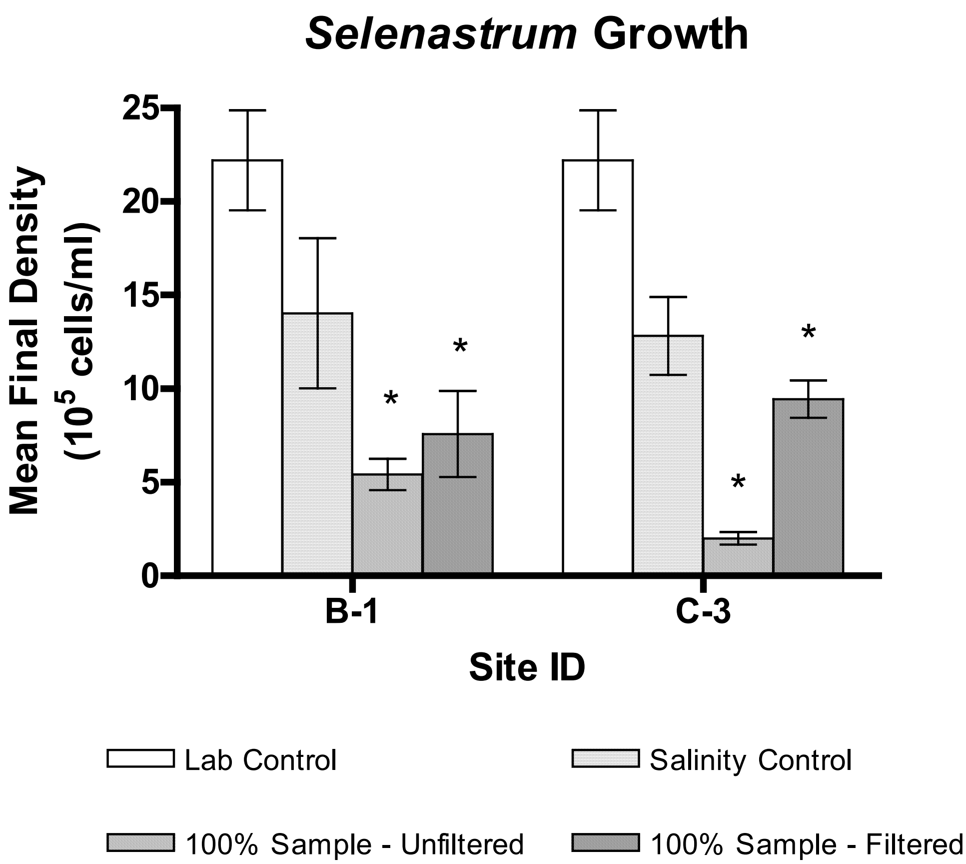
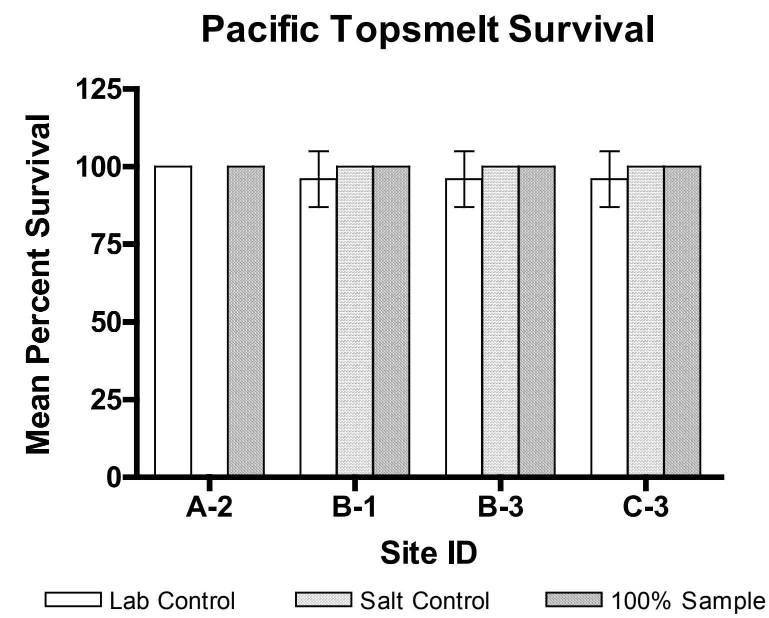


Figure 2-26. Summary of toxicity test results (September 2004) for algal growth inhibition. Mean (±1SD) values in 100-percent sample are displayed. Filtered and unfiltered samples showed a significant decrease relative to the salinity controls.



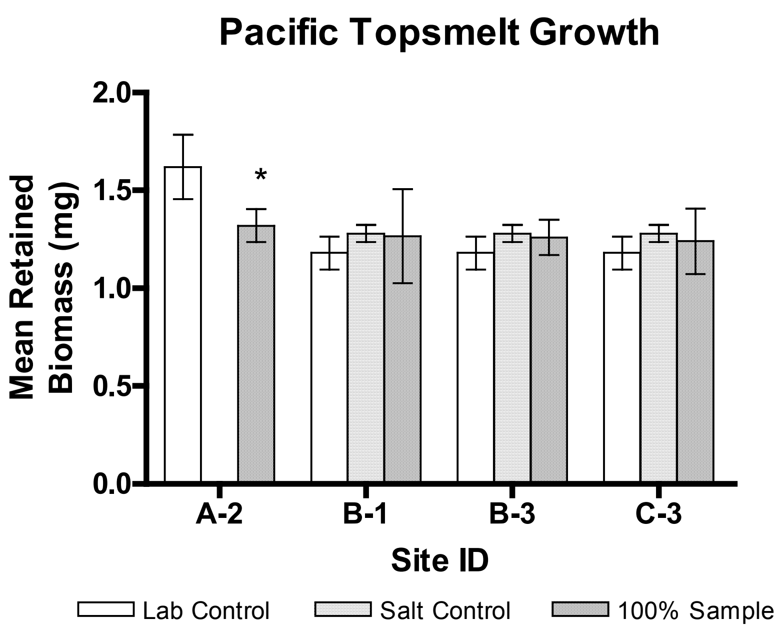
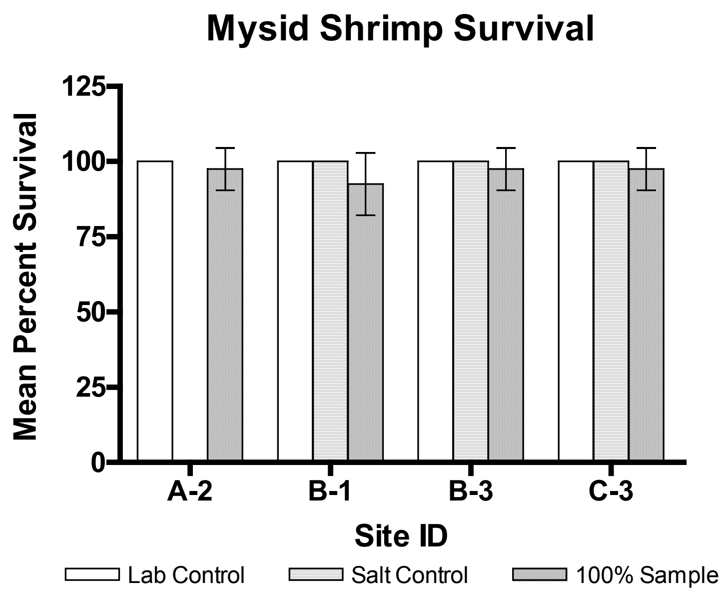


Figure 2-27. Summary of toxicity test results (September 2004) for Pacific topsmelt 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. A significant reduction in growth was observed for sample A-2 relative to the laboratory seawater control; no salinity adjustment was required for this sample (t-test, $p \leq 0.05$, n=5).



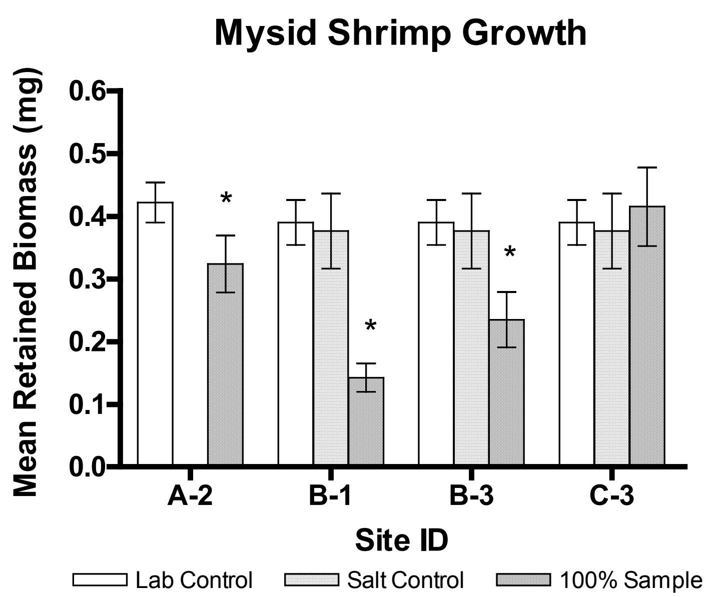


Figure 2-28. Summary of toxicity test results (September 2004) for opossum shrimp 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. Significant decreases in growth were observed for samples A-2, B-1, and B-3 (t-test, $p < 0.05$, $n=8$).

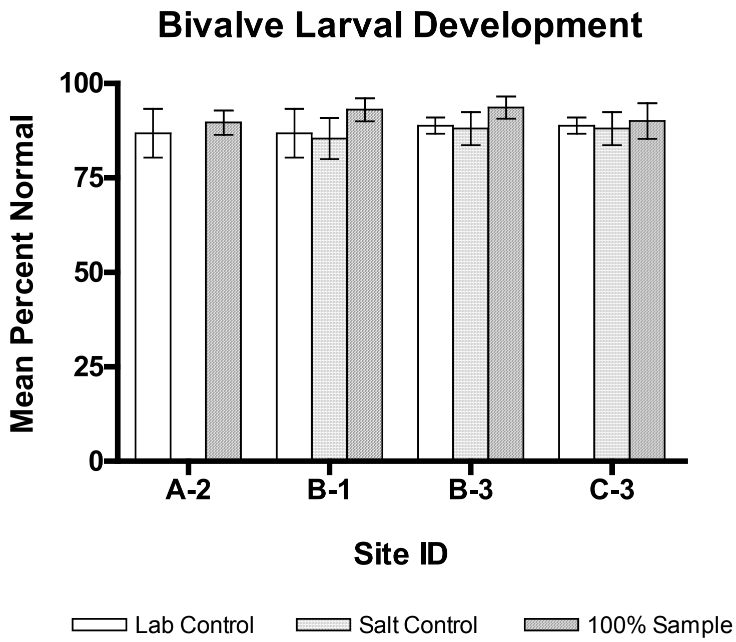
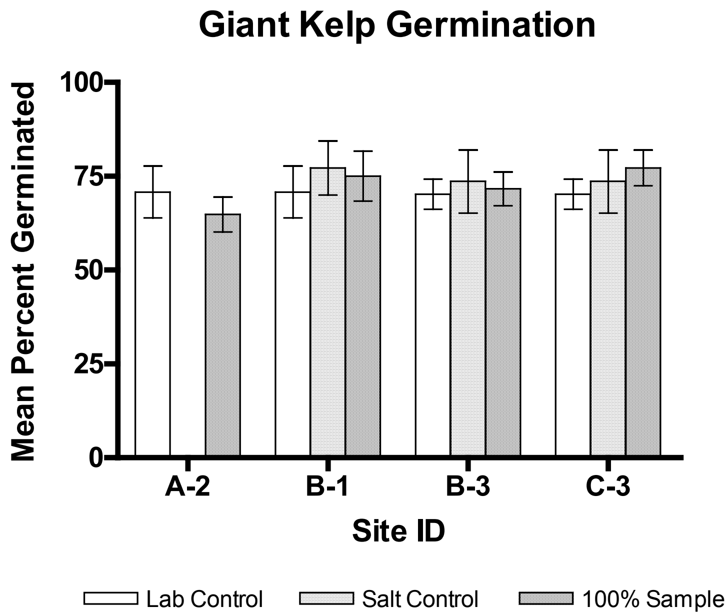


Figure 2-29. Summary of toxicity test results (September 2004) for bivalve 48-hour embryo development using *Mytilus galloprovincialis*. Mean (±1SD) values in the 100-percent sample are displayed. No statistically significant decreases were observed compared to the appropriate concurrent controls.



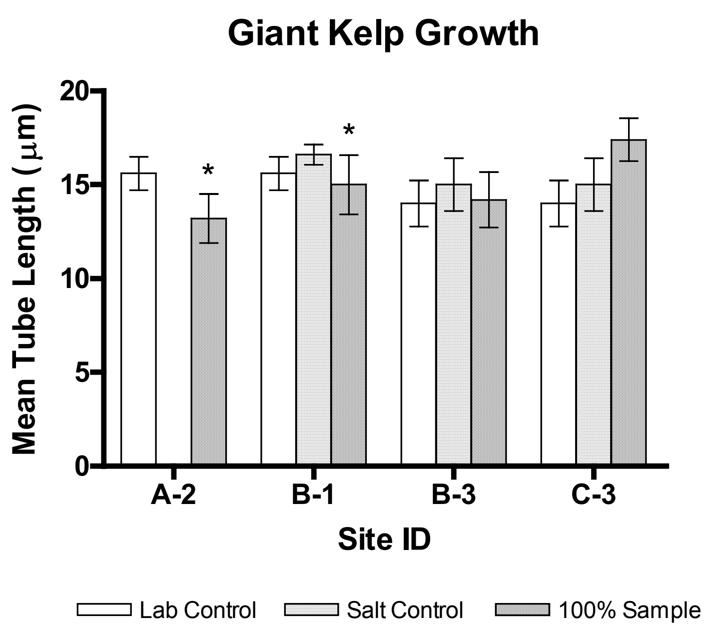


Figure 2-30. Summary of toxicity test results (September 2004) for giant kelp spore germination and growth. Mean (±1SD) values for each site are displayed. No statistically significant decreases in germination were observed compared to appropriate concurrent controls. A significant decrease in growth was observed for samples A-2 and B-1 relative to their respective controls.

2.5.2.4 January 2005 (Wet Weather: Berm Open)

Freshwater species

Survival of fathead minnow larvae in the salinity controls met the test acceptability criterion of 80 percent, with mean values of 85 and 98 percent in the 1.3 and 0.7 ppt controls, respectively. Survival of fathead minnow larvae was high in all test samples, ranging from 95 to 98 percent (Figure 2-31), In addition, no adverse effects on larval growth were observed; the mean dry biomass of fish exposed to the samples, and their corresponding salinity controls, ranged from 0.32 to 0.40 mg (Figure 2-31). These data suggest that salinity, or any other constituents present in the samples, did not adversely affect the test organisms.

Salinity did not affect survival of *Ceriodaphnia*. Mean survival in the 1.3 and 0.7 ppt salinity controls was 90 and 100 percent, respectively. Survival in the lagoon samples ranged from 90 to 100 percent, depending upon the site. With respect to reproduction, no adverse effects were observed for samples A-2, B-1, and C-1, or their corresponding salinity controls. However, sample B-3 exhibited a significant reduction in young produced, with a mean of 17.8 neonates produced in the full-strength sample, compared with a mean of 23.8 neonates in the corresponding salinity control (Figure 2-32).

No toxicity was observed with *Selenastrum* in either the salinity controls or in the filtered samples. However, cell density in the unfiltered samples was lower than that in the filtered samples, suggesting that particulate material or native algae in the samples interfered with cell growth to some extent (Figure 2-33).

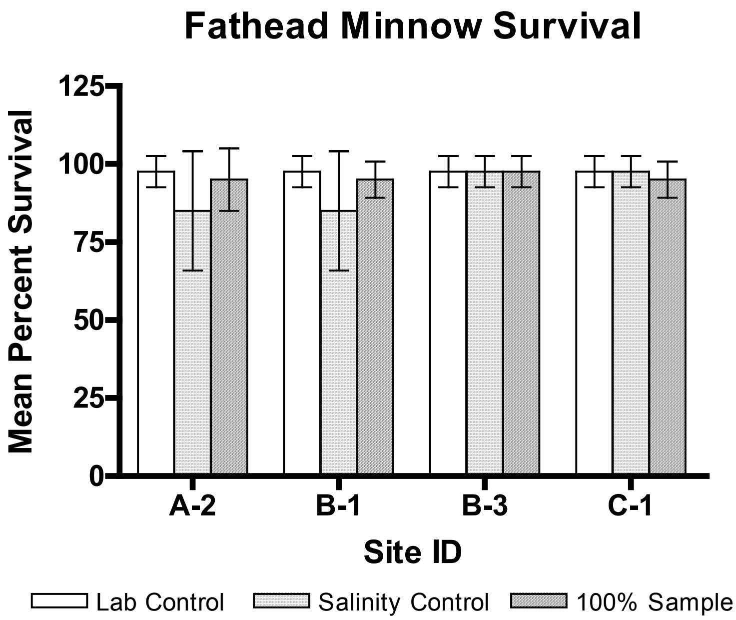
Marine species

Survival of topsmelt larvae was high across all test concentrations and samples, ranging from 88 to 100 percent. Moreover, no reductions in growth were observed relative to the salt controls. Mean biomass in the undiluted samples ranged from 1.1 to 1.4 mg, compared to 1.2 mg in the salt controls. These data are presented in Figure 2-34.

No adverse effects on survival or growth were observed with mysids. Mean survival ranged from 90 to 100 percent across all samples and test concentrations, and mean biomass ranged between 0.20 and 0.26 mg (Figure 2-35).

Mussel embryo development did not appear to be affected by exposure to the test samples. However, this conclusion is based on comparisons with the brine control and treatments, since addition of artificial sea salts resulted in virtually no normal larvae present in either the salt controls or the samples amended with salts. Therefore, these treatments were deemed invalid and are not reported here. Conversely, normal development was high in samples amended with hypersaline brine, and ranged from 83 to 91 percent among test concentrations (up to 71 percent sample) and sample sites (Figure 2-36).

No significant reductions in germination success of giant kelp spore or germ tube length were observed (Figure 2-37). Mean germination ranged from 68 to 88 percent in full-strength samples amended with artificial salts, as well as samples amended with hypersaline brine. Mean tube length ranged from 11 to 13 µm (Figure 2-37). These values were not significantly different from the corresponding brine or artificial salt controls.



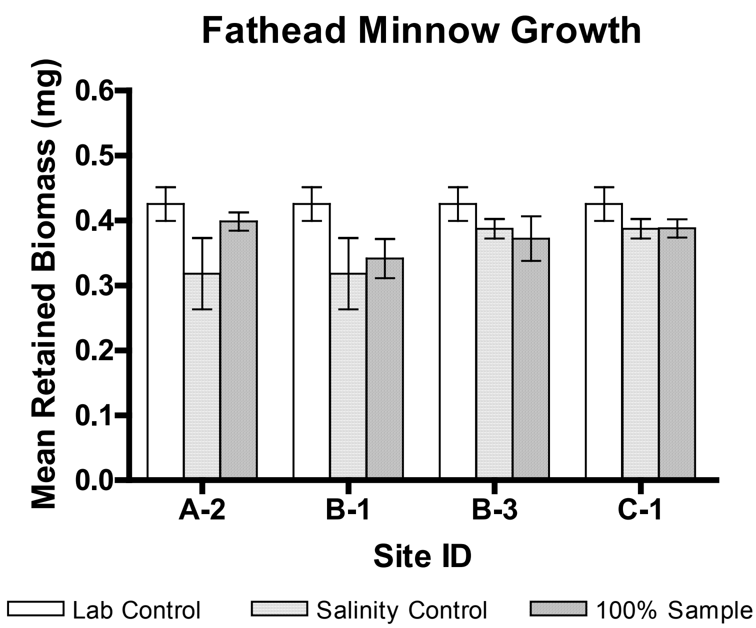
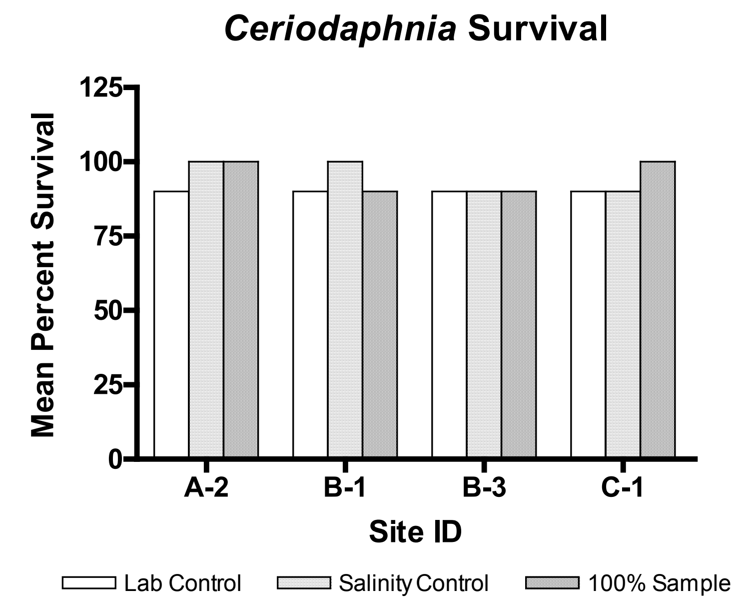


Figure 2-31. Summary of toxicity test results (January 2005) for fathead minnow 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. No statistically significant decreases were observed compared to concurrent salinity controls.



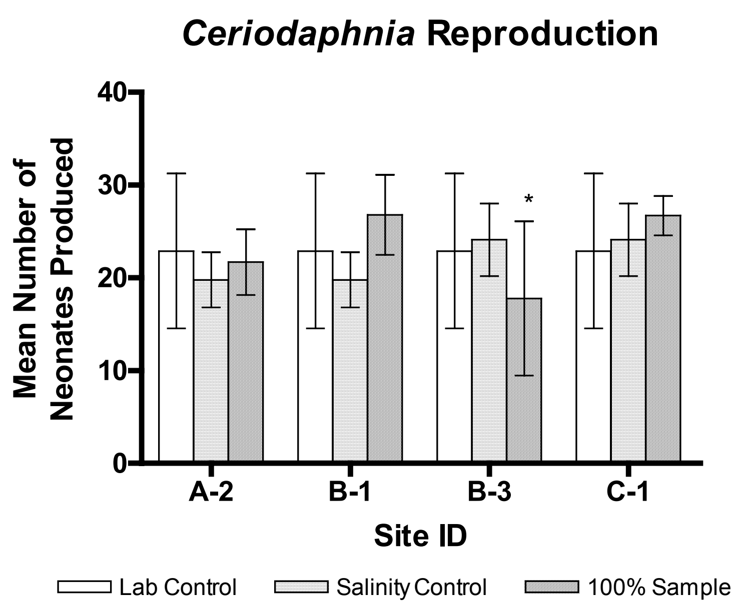


Figure 2-32. Summary of toxicity test results (January 2005) for water flea 7-day survival and reproduction. Mean (±1SD for reproduction) values in 100-percent sample are displayed. Reproduction in sample B-3 was reduced compared to the salinity control ($p<0.05$).

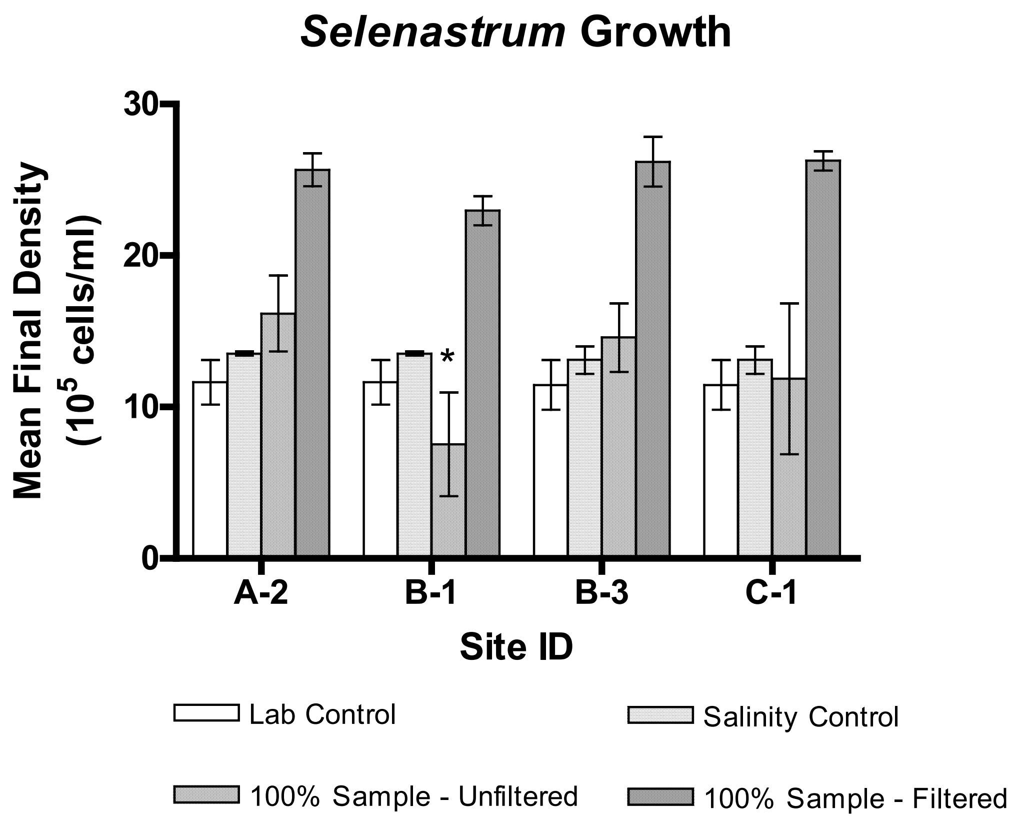
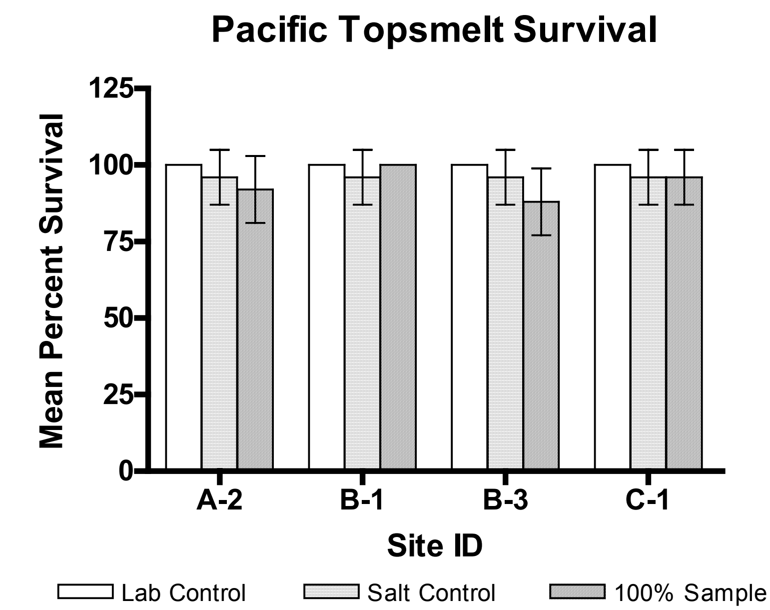


Figure 2-33. Summary of toxicity test results (January 2005) for algal growth inhibition. Mean (±1SD) values in 100-percent sample are displayed. A significant decrease in growth was observed in the B-1 unfiltered sample relative to its salinity control (t-test, $p < 0.05$, $n=4$).



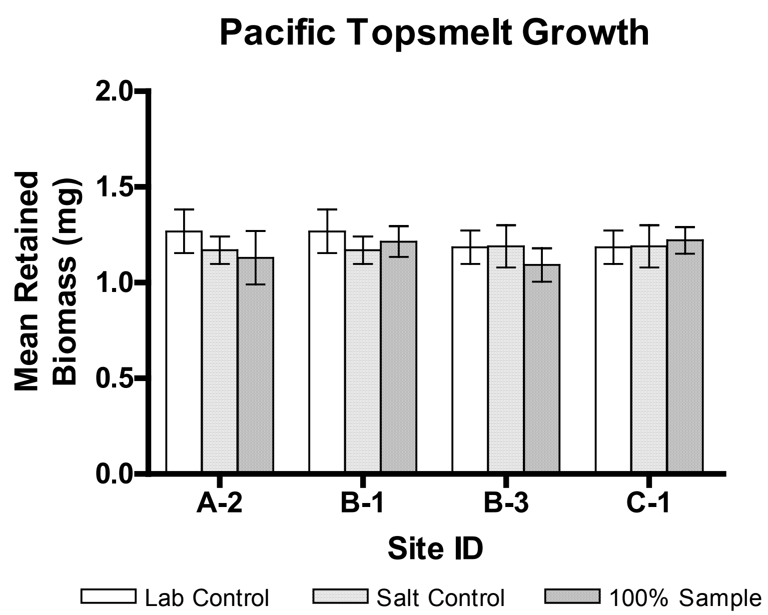
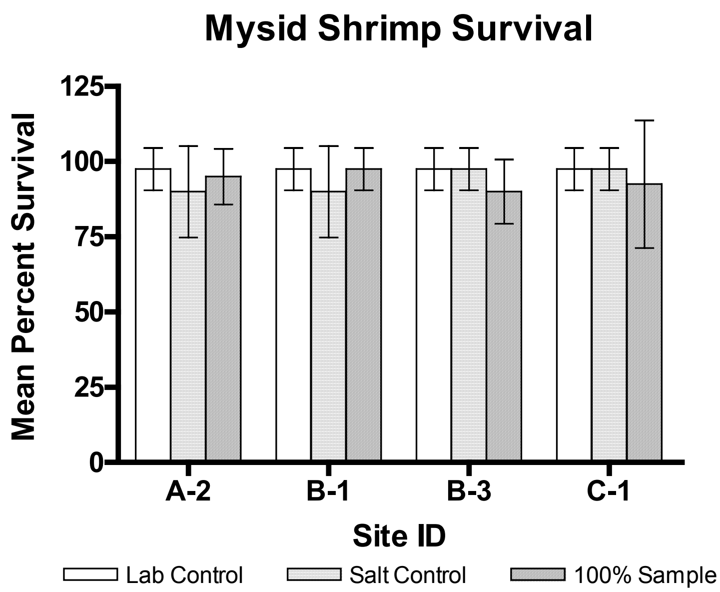


Figure 2-34. Summary of toxicity test results (January 2005) for Pacific topsmelt 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. No statistically significant decreases were observed compared to the appropriate concurrent controls.



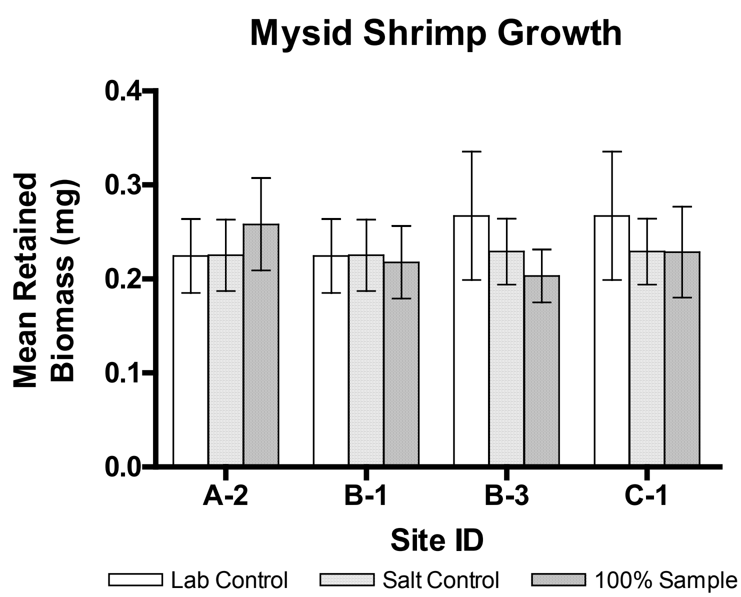


Figure 2-35. Summary of toxicity test results (January 2005) for opossum shrimp 7-day survival and growth. Mean (±1SD) values in 100-percent sample are displayed. No statistically significant decreases in survival were observed compared to concurrent salt controls. No significant decreases in growth were observed compared to concurrent salt controls.

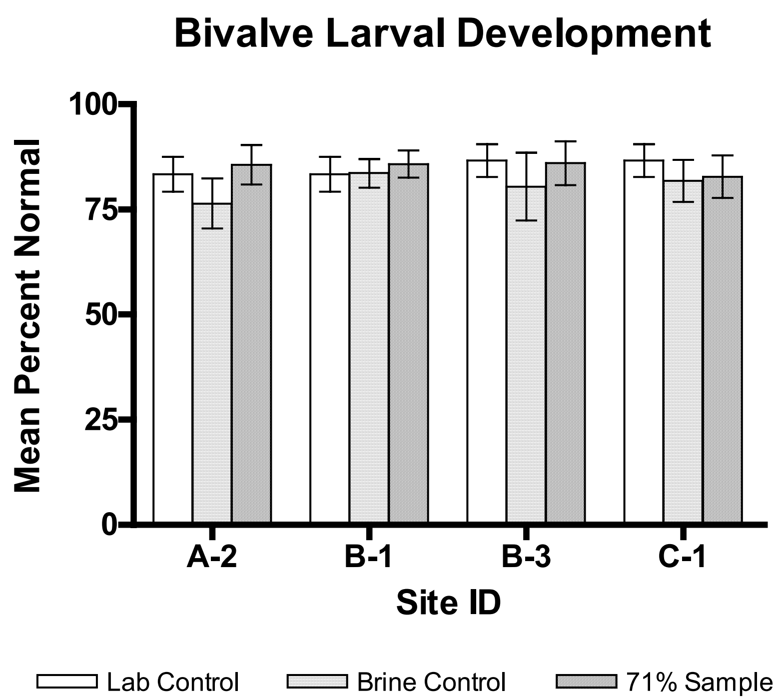
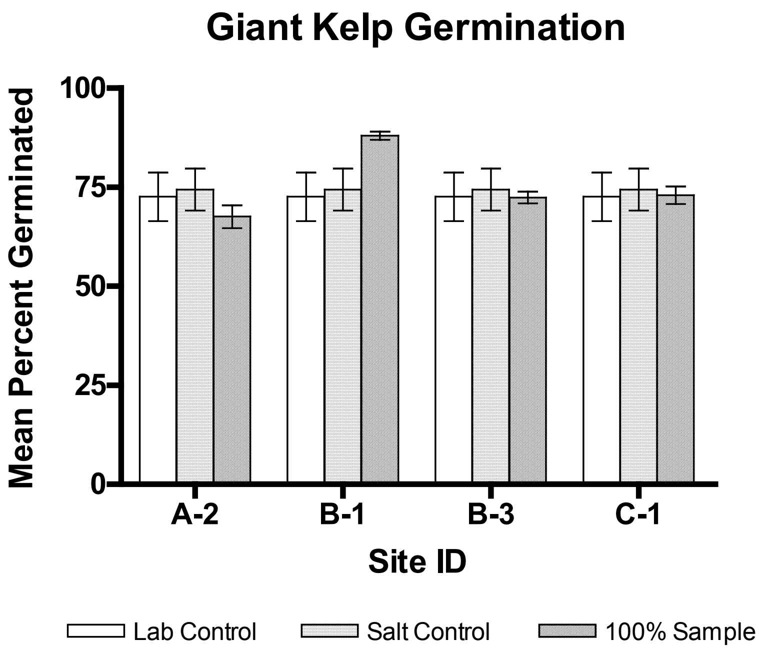


Figure 2-36. Summary of toxicity test results (January 2005) for bivalve 48-hour embryo development using *Mytilus galloprovincialis*. Mean (±1SD) values in the highest testable concentration (71-percent sample) is displayed (see text). No statistically significant decreases were observed compared to the brine controls.



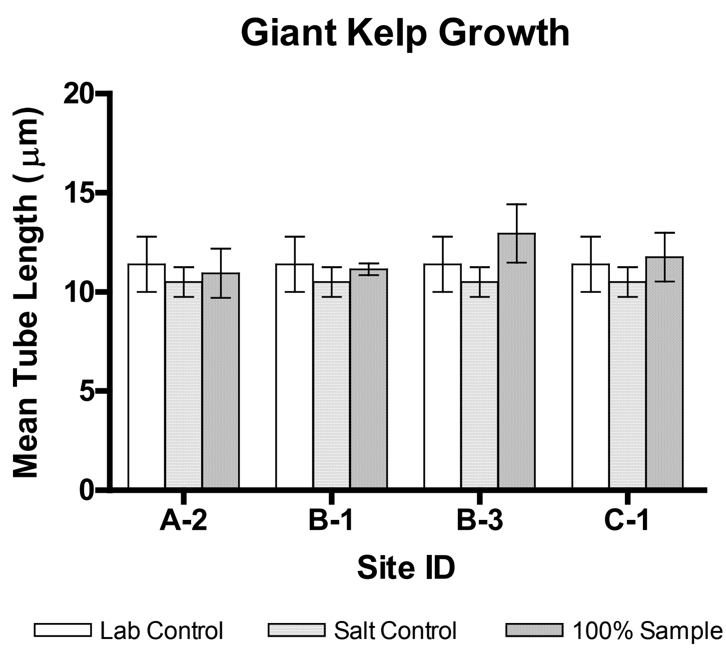


Figure 2-37. Summary of toxicity test results (January 2005) for giant kelp spore germination and growth. Mean (±1SD) values for each site are displayed. No statistically significant decreases in germination were observed compared to the concurrent controls. No significant decreases in growth were observed compared to appropriate concurrent controls.

2.6 Concentrations of Selected Contaminants in Lagoon Samples

2.6.1 Methods

Concentrations of selected contaminants were measured in water samples collected from the lagoon and compared with freshwater and marine water quality criteria to determine whether they might pose a risk to aquatic organisms in the receiving environment. The contaminants were selected on the basis of discussions with the Regional Board and initially included copper, zinc, nickel, and selenium; cyanide was subsequently added to the list in the July 2004 testing event.

2.6.2 Results

Marine and freshwater water quality criteria values for copper, zinc, nickel, selenium, and free cyanide are presented in Table 2-12, based on values reported in *National Recommended Water Quality Criteria* (USEPA 2002c). Analytical results for the different sampling events are described below.

2.6.2.1 March 2004

Dissolved copper concentrations in these samples ranged between 1.83 and 3.10 µg/L. None of these concentrations exceeded the copper criteria values shown in Table 2-12. Moreover, concentrations of nickel, selenium, and zinc were relatively low, and all were below their respective water quality guidelines, suggesting that these contaminants were unlikely to be associated with toxicity. These data are summarized in Table 2-13.

2.6.2.2 July 2004

Dissolved copper concentrations in these samples ranged between 3.03 and 3.44 µg/L (Table 2-14). The dissolved copper concentration at site C-2 was below all of USEPA's water quality criteria for the protection of aquatic life (Table 2-12), while copper concentrations at sites A-2, B-1 and B-3 slightly exceeded USEPA's marine chronic criterion (Table 2-12). Moreover, concentrations of nickel, selenium, and zinc were below their respective water quality guidelines (Table 2-14). This suggests that these contaminants were unlikely to be associated with toxicity. Measurements for cyanide were less than the detection limit of 50 µg/L total cyanide.

2.6.2.3 September 2004

Dissolved and total copper concentrations in samples A-2, B-3, and C-3 were all below the method detection limit of 5.00 µg/L. Dissolved copper in sample B-1 was reported as 8.38 µg/L. However, the total copper concentration reported for this sample was below the method detection limit, suggesting that preparation of the sample for measuring dissolved copper may have added a small amount of copper. It is also important to note that the method detection limit for copper in these samples was above the USEPA acute and chronic water quality criterion for marine species of 4.8 and 3.1 µg/L, respectively. However, this value was determined using the 48-hour bivalve embryo development test, which showed no toxicity in these samples. Moreover, concentrations of nickel, selenium, and zinc were all below their respective water quality guidelines. This suggests that these contaminants were unlikely to be associated with toxicity (Table 2-15). Measurements for total cyanide were less than the detection limit of 50 µg/L.

2.6.2.4 January 2005

Dissolved copper in sample B-1 was reported as 4.87 µg/L, which exceeded USEPA's marine chronic water quality criterion for the protection of aquatic life (USEPA 2002c) (Table 2-12). However, this value was determined using the 48-hour bivalve embryo development test, which showed no toxicity in these samples. In addition, concentrations of nickel, selenium, and zinc were relatively low, and all below their respective water quality guidelines (Table 2-16). This suggests that these contaminants were unlikely to be associated with toxicity. Measurements for cyanide are included in Table 2-16. Measurements for total cyanide were all less than the detection limit of 50 µg/L.

Table 2-12. USEPA Water Quality Criteria for the Protection of Aquatic Life[a]

Criterion	Concentration (μg/L)				
	Cyanide [b]	Copper	Nickel	Selenium	Zinc
USEPA Marine Acute CMC	1	4.8	74	290	90
USEPA Marine Chronic CCC	1	3.1	8.2	71	81
USEPA Freshwater Acute CMC [c]	22	13	470	13-186 [d]	120
USEPA Freshwater Chronic CCC [c]	5.2	9.0	52	5	120

[a] Values expressed as a dissolved fraction excluding the USEPA freshwater CCC value for selenium
[b] Values expressed in terms of free cyanide (e.g., μg HCN/L)
[c] Values for metals are hardness dependent and based in this table on a hardness of 100 mg/L $CaCO_3$
[d] Freshwater CMC depends on ratio of selenite to selenate.
CMC - Criterion Maximum Concentration
CCC - Criterion Continuous Concentration

Table 2-13. Summary of Total and Dissolved Trace Constituent Concentrations Measured in Santa Clara River Estuary Samples Collected 16 March 2004

		Concentration (μg/L)			
Site	**Form**	**Copper**	**Nickel**	**Selenium**	**Zinc**
A-2	Dissolved	3.10	3.26	2.10*	17.7
	Total	4.49	4.18	1.73	22.3
B-1	Dissolved	2.93	1.31	0.57	22.0
	Total	3.75	3.26	0.61	22.5
B-3	Dissolved	2.19	4.11	3.82	3.19
	Total	3.00	5.04	4.54	3.98
C-3	Dissolved	1.83	6.12	2.58	2.39
	Total	1.95	6.26	2.51	2.43

*In these cases the dissolved concentration exceeds the total. However, both sets of results (i.e., total and dissolved) met analytical laboratory quality assurance and reporting criteria. In addition, true differences in concentrations are difficult to detect close to the method reporting limit.

Table 2-14. Summary of Total and Dissolved Trace Constituent Concentrations Measured in Santa Clara River Estuary Samples Collected 20 July 2004

		Concentration (µg/L)			
Site	**Form**	**Copper**	**Nickel**	**Selenium**	**Zinc**
A-2	Dissolved	3.44	8.03	2.95*	1.43
	Total	3.45	8.27	2.21	2.26
B-1	Dissolved	3.27	6.31	1.26	17.5*
	Total	3.47	6.66	1.74	17.2
B-3	Dissolved	3.35	7.85	2.03	2.17
	Total	3.67	8.11	2.23	3.65
C-2	Dissolved	3.03	8.38	3.41*	ND
	Total	3.41	8.85	2.91	1.53

*In these cases the dissolved concentration exceeds the total. However, both sets of results (i.e., total and dissolved) met analytical laboratory quality assurance and reporting criteria. In addition, true differences in concentrations are difficult to detect close to the method reporting limit.

Table 2-15. Summary of Total and Dissolved Constituent Concentrations Measured in Santa Clara River Estuary Samples Collected September 28, 2004

		Concentration (μg/L)				
Site	**Form**	**Cyanide**	**Copper**	**Nickel**	**Selenium**	**Zinc**
A-2	Dissolved	NM	<5.00	<5.00	7.30*	<5.00
	Total	<50	<5.00	<5.00	<5.00	<5.00
B-1	Dissolved	NM	8.38*	<5.00	7.47	16.5
	Total	<50	<5.00	<5.00	9.99	17.4
B-3	Dissolved	NM	<5.00	<5.00	<5.00	5.03*
	Total	<50	<5.00	<5.00	<5.00	<5.00
C-3	Dissolved	NM	<5.00	5.86	<5.00	<5.00
	Total	<50	<5.00	6.28	7.04	<5.00

*In these cases the dissolved concentration exceeds the total. However, both sets of results (i.e., total and dissolved) met analytical laboratory quality assurance and reporting criteria. In addition, true differences in concentrations are difficult to detect close to the method reporting limit.

NM – not measured.

Table 2-16. Summary of Total and Dissolved Constituent Concentrations Measured in Santa Clara River Estuary Samples Collected January 31, 2005.

		Concentration (μg/L)				
Site	**Form**	**Cyanide**	**Copper**	**Nickel**	**Selenium**	**Zinc**
A-2	Dissolved	NM	2.79	6.79	3.81*	10.3*
	Total	< 50	4.49	6.74	3.77	10.2
B-1	Dissolved	NM	4.87	6.10	4.26	21.9
	Total	<50	9.70	6.60	4.48	23.8
B-3	Dissolved	NM	2.77	6.58*	3.40	<5.00
	Total	<50	3.23	6.24	5.94	11.0
C-1	Dissolved	NM	3.39*	6.64*	3.65	<5.00
	Total	<50	3.11	6.30	3.77	11.0

*In these cases the dissolved concentration exceeds the total. However, both sets of results (i.e., total and dissolved) met analytical laboratory quality assurance and reporting criteria. In addition, true differences in concentrations are difficult to detect close to the method reporting limit.

NM – Not measured.

2.7 Development of a Site-Specific Copper Criterion

2.7.1 Methods

WER studies were carried out with mussels (*Mytilus* sp.) to develop a site-specific basis for adjusting the marine criterion for copper. Test methods were applied as described in USEPA (1994b and 2001). The water samples collected from the estuary were spiked with copper (as $CuCl_2$) and tested concurrently against copper-spiked solutions of filtered clean seawater obtained from Scripps Oceanographic Institute to derive an estimate of local site-specific factors that may influence the bioavailability of copper. Copper concentrations in test dilutions bracketing the EC_{50} were verified analytically using ICP-MS. The ratios between EC_{50} estimates for the toxicity of copper in natural and filtered seawater were then calculated to determine the extent to which site-specific water chemistry affected the toxicity of copper.

Average values for each event were calculated using the geometric mean ratio of the four samples tested in each event (Table 2-17). The overall WER value was then calculated as the geometric mean of the average values from each of the four events.

2.7.2 Results

2.8.2.1 March 2004

Copper EC_{50} values and WER calculations are summarized in Table 2-18. Mean normal development was 89 to 96 percent in unspiked lagoon samples, compared to 88 to 89 percent in the brine control. Total copper EC_{50} values calculated for lagoon samples based on measured copper concentrations ranged from 24.8 to >53.4 µg/L. For comparison, the mean EC_{50} calculated for polished seawater spiked with copper was 14.0 µg/L. The calculated WER values ranged from 1.77 to >3.8, with a geometric mean of 2.6.

2.7.2.2 July 2004

Copper EC_{50} values and WER calculations are summarized in Table 2-19. Mean normal development was 89 to 97 percent in the unspiked lagoon samples, compared to 88 to 89 percent in the brine control. EC_{50} values calculated for lagoon samples, based on measured total copper concentrations, ranged from 83.4 to 90.5 µg/L. For comparison, the mean EC_{50} calculated for polished seawater spiked with copper was 12.2 µg/L. The calculated WER values ranged from 6.84 to 7.42, with a geometric mean of 7.1.

2.7.2.3 September 2004

Copper EC_{50} values and WER calculations are summarized in Table 2-20. Mean normal development was 90 to 93 percent in the unspiked lagoon samples, compared to 92 percent in the laboratory control. Total copper EC_{50} values calculated for lagoon samples based on measured copper concentrations ranged from 18.2 to >85.1 µg/L. For comparison, the mean EC_{50} calculated for polished seawater spiked with copper was 11.5 µg/L. The calculated WER values ranged from 1.58 to > 7.40, with a geometric mean of 4.1.

2.7.2.4 January 2005

Copper EC_{50} values and WER calculations are summarized in Table 2-21. Mean normal development was 83 to 86 percent in the unspiked lagoon samples, compared to 95 percent in the laboratory control. Total copper EC_{50} values calculated for lagoon samples, based on measured copper concentrations, ranged from 31.6 to 92.5 µg/L. For comparison, the mean EC_{50} calculated for polished seawater spiked with copper was 17.9 µg/L. The calculated WER values ranged from 1.77 to 5.17, with a geometric mean of 2.53.

2.7.2.5 Overall Water Effect Ratio

The WER calculated across all of the testing events, taking into account seasonal as well as spatial variability, is 3.7. Applying this value to the current marine acute and chronic criteria for copper results in site-specific criteria estimates of 17.8 and 11.5 µg/L, respectively.

To evaluate whether this calculated criteria value would be protective, the calculated chronic (marine) value of 11.5 µg/L was compared to the actual no-effect concentrations in the individual copper spiking studies to determine if the revised value was in fact protective. This analysis revealed that, in all cases (n=15), the highest no-observed-effect-concentrations (NOECs) for mussel larvae were greater than the calculated site-specific water quality criteria value, indicating that, in fact, the calculated value is protective.

Table 2-17. WER Summary Table

Sampling Event	Geometric Mean WER
March 2004[a]	2.6
July 2004[b]	7.1
September 2004[a]	4.1
January 2005[c]	2.5
Geometric Mean Across Events	3.7

[a] Values are geometric means of WERs from sites A-2, B-1, B-3, C-3.
[b] Values are geometric means of WERs from sites A-2, B-1, B-3, C-2.
[c] Values are geometric means of WERs from sites B-1, B-3, C-1.

Table 2-18. Total Copper WER Values for Santa Clara River Estuary Calculated Using Scripps Polished Seawater . Samples Collected March 16, 2004.

Sample	EC_{50} (µg/L Total Cu)	Water-Effect Ratio
Site A-2	>53.4	>3.81
Site B-1	>50.2	>3.59
Site B-3	25.7	1.84
Site C-3	24.8	1.77
Polished Scripps Seawater (PSW) [a]	14.0	NA

[a] Seawater from Scripps was polished at AMEC by passing it through a 0.2-µm filter

Table 2-19. Total Copper WER Values for Santa Clara River Estuary Calculated Using Scripps Polished Seawater. Samples Collected July 20, 2004.

Sample	EC_{50} (µg/L Total Cu)	Water-Effect Ratio
Site A-2	83.4	6.84
Site B-1	85.4	7.00
Site B-3	90.5	7.42
Site C-2	85.3	6.99
Polished Scripps Seawater (PSW) [a]	12.2	NA

[a] Seawater from Scripps was polished at AMEC by passing it through a 0.2-µm filter

Table 2-20. Total Copper WER Values for Santa Clara River Estuary Calculated Using Scripps Polished Seawater[a]... Samples Collected September 28, 2004.

Sample	EC_{50} (µg/L Total Cu)	Water-Effect Ratio
Site A-2	18.2	1.58
Site B-1	81.3	7.07
Site B-3	39.7	3.45
Site C-3	>85.1	7.40
Polished Scripps Seawater (PSW) [a]	11.5	NA

[a] Seawater from Scripps was polished at Nautilus by passing it through a 0.2-µm filter.

Table 2-21. Total Copper WER Values for Santa Clara River Estuary Calculated Using Scripps Polished Seawater[a]. Samples Collected January 31, 2005.

Sample	EC_{50} (µg/L Total Cu)	Water-Effect Ratio
Site A-2	NR	NR
Site B-1	92.5	5.17
Site B-3	31.6	1.77
Site C-1	31.7	1.77
Polished Scripps Seawater (PSW)[a]	17.9	NA

[a] Seawater from Scripps was polished at Nautilus by passing it through a 0.2-µm filter.

NR - Not reported, contamination was observed in one or more of the test chambers.

2.8 Discussion

The comparison of historical copper concentrations and effluent toxicity provided two pieces of key information. First, the overall incidence of toxicity in the discharge samples was low, as was the magnitude of any effects observed. These data would suggest that the discharge is not having any significant deleterious effects on the receiving environment. Second, no relationship was found between effluent copper concentrations and toxicity. Based on comparisons with copper toxicity data obtained in laboratory water, copper generally does not appear to be present in the effluent at toxic concentrations. In the few instances where copper concentrations exceeded threshold toxicity levels found in laboratory water, no evidence of toxicity was observed, suggesting that the bioavailability of copper in the effluent is less than that found in laboratory water.

The analysis of species present in the lagoon suggested that the preponderance of species are freshwater, with some representation of euryhaline species, as well. The marine species identified appear to occur on an intermittent, or opportunistic basis. Comparison of the taxa present in the lagoon with copper toxicity databases indicated that matches were primarily found with freshwater taxa. Moreover, the two most sensitive taxa were freshwater taxa that have been reported, sometimes in high abundance, in the lagoon. Interestingly, these two taxa (*Daphnia* sp., and *Hyalella azteca*) are commonly used in tests that evaluate water quality; thus, the presence of these organisms suggests that water quality is reasonably good in the Santa Clara Estuary, and that copper is not limiting their distribution.

The water quality measurements taken during both dry and wet weather conditions generally suggest that conditions are relatively uniform throughout the estuary, although the extent of inundation changes dramatically when the sandbar is closed compared to when it is open. In general, salinities were consistently low except in deeper sections located in proximity to the ocean, and in isolated pockets of water left from the previous high tide event. The results obtained for DO were interesting, particularly the extent of supersaturation that occurred throughout the lagoon on a seasonal basis. Since these measurements were obtained using probes, it may be desirable to fix a number of samples in the field and conduct comparative analyses using titrametric methods to confirm these results.

The primary purpose of the sediment-sampling events was to determine if copper, and other contaminants of interest, are accumulating in the sediments of the estuary to levels that might result in adverse effects. In general, copper concentrations were uniformly low, except for two sites sampled in October 2003 that exhibited appreciably higher concentrations. Compared with the rest of the sites sampled in October 2003, and all of the sites sampled in March 2004, these two sites were also characterized by elevated TOC and % fines. These data suggest that, while the sediments in the estuary are uniformly coarse, there are seasonally localized depositional areas characterized by finer grain size and TOC. Interestingly, analysis of the October data found that the relationships between TOC, % fines, and copper were all strong, with R^2 values of 0.82 to 0.95, suggesting that copper concentrations were substrate-dependent. Regardless, sediment copper concentrations at all sites on both sampling dates were considerably less than the sediment quality guideline of 34 mg/kg proposed by Long et al. (1995), suggesting that they are unlikely to be associated with adverse effects. Analysis of nickel, selenium, and zinc concentrations in the sediments also suggested that they were below concentrations likely to be associated with adverse effects.

In general, only limited effects were observed in the sediment toxicity tests. None of the samples collected in October exhibited toxicity when tested with amphipods, and the limited toxicity observed with amphipods in a few of the samples collected in March appeared related to the comparatively high concentrations of coarse grain sizes in these samples. Only two of the samples collected in October exhibited toxicity in the bivalve larval development tests, and the responses appeared unrelated to copper or TOC concentrations, or to % fines. None of the sediment samples collected in March resulted in statistically significant toxicity in the larval bivalve tests, although the lowest proportion of surviving normal larvae was found in the sample collected at B-1. The lack of any obvious relationships between toxicity to bivalve larvae and sediment copper concentrations, as well as the sediment quality guideline for copper, are shown in Figure 2-38 for both testing events. A number of other factors (e.g., suspended particulates, ammonia, sulfide, or unidentified contaminants) could be responsible for the limited effects observed, but the actual cause cannot be determined without follow-up investigation.

Regardless, the relatively low number of samples that exhibited toxicity and the lack of contaminants of interest above threshold effects levels suggest that sediment quality throughout the lagoon is relatively good. Concentrations of selected contaminants were below sediment effect thresholds, and, with the limited exceptions noted above with bivalve larvae, the results of the toxicity tests further suggest that sediment quality is good across the lagoon. This is of particular importance considering that the October sampling event was during a dry weather period with the berm closed. Consequently, the sediment chemistry represented prolonged exposure to water that originated largely from the VWRF. Thus, the general lack of elevated contaminant concentrations and toxicity strongly indicates that the discharge originating from the VWRF is not causing widespread contamination of the sediments across the lagoon.

Based on water quality sampling and toxicity testing conducted quarterly for a year, water quality in the lagoon also appears to be good. This is consistent with the results of the sediment investigation in that concentrations of contaminants present in the water column would be expected to accumulate in the sediments, and this condition was not observed.

The responses of the fish and invertebrate freshwater organisms to samples collected in the lagoon generally reflected their tolerance to the salinities of the samples. Thus, for these test organisms, “toxicity” beyond that associated with the elevated salinities in the samples was not apparent. The one exception was a moderate reduction in reproductive output of *Ceriodaphnia* exposed to a sample collected at B-3 during the January 2005 testing event. Note that reproduction in all of the other samples collected during this event exceeded that observed in their corresponding controls. Conversely, the freshwater algal species tested did exhibit evidence of adverse effects beyond what might be attributed to salinity in one sampling event. However, differences in response between filtered and unfiltered samples were generally consistent across events, suggesting that this result could be due to sequestering of nutrients by native algae, bacteria, or detritus present in the samples, rather than to the presence of contaminants.

Of the marine species tested, the mussel larvae consistently exhibited no adverse effects in water samples collected from the lagoon. This is typically one of the most sensitive life history stages in the suite of marine chronic test protocols, and the most sensitive endpoint for identifying copper toxicity. Thus, on the basis of these results, copper concentrations in the lagoon do not appear to be at levels that would result in adverse effects to marine organisms.

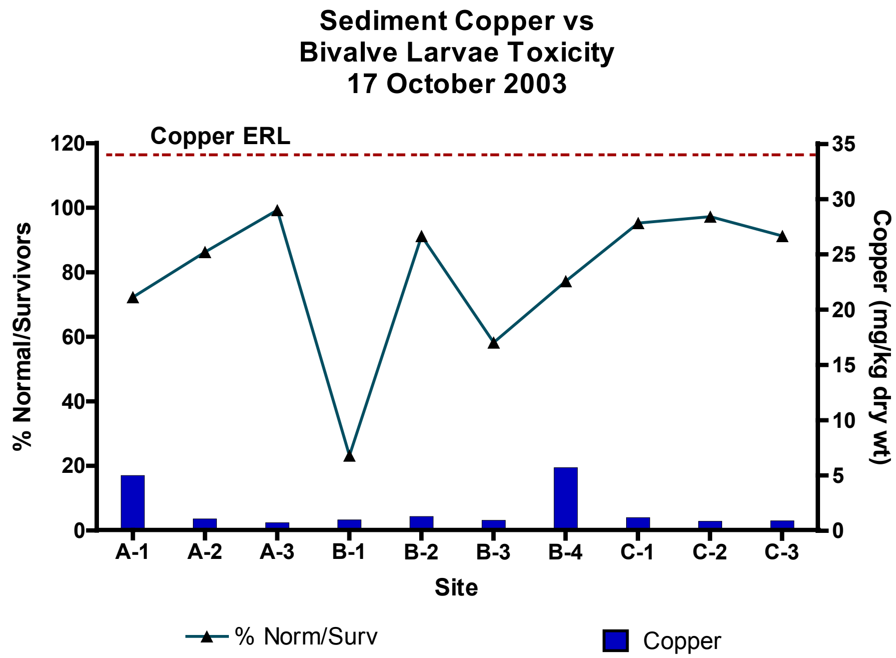
Topsmelt exhibited adverse effects in only one sampling event; both survival and growth were affected, with the degree of effect being most severe in the sample collected from the upstream portion of the lagoon. Since these samples were taken during a wet weather outflow condition, this response was most likely due to a toxicant that originated upstream of the lagoon.

Adverse effects observed with giant kelp were limited to two (A-2 and B-1) of the four samples collected during one of the sampling events. Growth was the only parameter affected, and the response was similar between sites.

Mysids exhibited a response in only one event, which was characterized as a dry weather berm open condition. While survival was not affected, marked reduction in growth was observed in samples from multiple locations within the lagoon, with the greatest effect noted in the sample collected at B-1 in the discharge channel. Interestingly, mysids exhibited no adverse effects on either survival or growth in samples collected from this site, or any other site, during the other testing events. The cause of the observed effect was not determined.

Overall, the frequency of toxicity was low. Samples were collected from four sites during four events, for a total of 16 samples, each of which was tested with seven species. Of this possible combination of 112 tests, evidence of adverse effects that might be related to contaminants was found in less than 10 percent of the tests conducted. In addition, with the exception of the upstream sample collected during a wet weather berm-open condition, and tested with topsmelt, none of the samples resulted in reduced survival of the exposed test organisms (with the exception of salinity effects on the freshwater test species). Thus, overall, the incidence and severity of the responses were low. Furthermore, with the exceptions described above, toxicity was not consistently related to site or species, suggesting that the causes were generally localized and variable. Given that the discharge from the VWRF should reflect relatively consistent inputs to the plant, as well as established treatment practices, such variability is not likely to reflect inputs from the VWRF. Notably, no toxicity was observed at any site in the lagoon during a dry weather berm-closed condition, when it would be likely that the VWRF would be contributing most, if not all, of the water present.

The results of the WER study provide a robust set of toxicity measurements, incorporating both spatial and temporal variability, that indicate site-specific adjustments to the marine criteria for copper are appropriate and will be protective of aquatic life. Because the WER procedures involve an averaging process to arrive at the final calculated ratio, the calculated chronic value of 11.5 µg/L was compared directly against the individual data sets used in the WER procedure to ensure that the calculated value would be fully protective in all locations of the lagoon under the conditions represented by all of the sampling events. This comparison indicated that the site-specific criterion was within the range of NOECs calculated from the different tests; thus, the calculated value would be protective of the most sensitive combination of event and location tested.



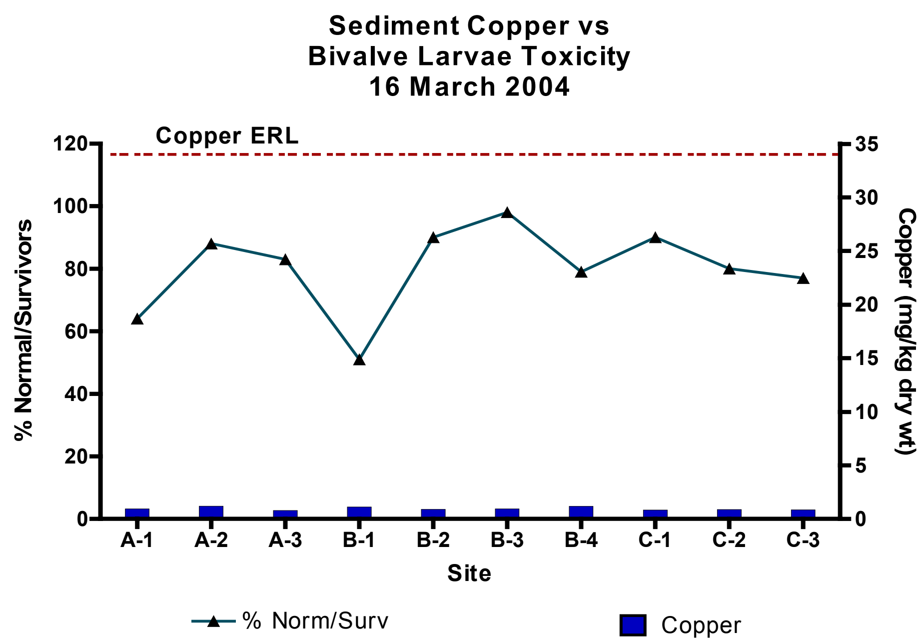


Figure 2-38. Relationship between sediment copper levels, copper effects-range low (ERL) values, and bivalve embryo development.

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3.0 EVALUATION OF ECOLOGICAL CONDITIONS IN THE SANTA CLARA RIVER ESTUARY

The Santa Clara River drains a large basin that encompasses a variety of climate zones. Its flow varies appreciably throughout the year, and it is subject to annual flooding. In its lower reaches, the river is characterized by a broad sandy bed and shallow depth. The first groups of humans in the area, the indigenous Chumash and Tatavium people, traded food, pelts, and plant material for clothing and basketry. European influence began in 1769, as Spanish missionaries moved north along the coast. The large ranchos and mission farms of the early Spanish and Mexican inhabitants were replaced in the late 1800s by intensive agricultural practices as American farming interests took over possession of the land.

Over time, diversion of the river for irrigation, groundwater pumping, construction of levees, and reclamation of the floodplain have all resulted in significant changes to the habitat and ecological function of the Santa Clara Estuary and floodplain. Today, the estuary is less than a tenth of its original size. To help place these changes into context, the following sections describe in greater detail the current and historic ecological conditions associated with the Santa Clara River Estuary. The ecological communities found in the study area are described first, followed by a comparison of current and historical conditions, and descriptions of plant and animal species of concern. Historic maps, aerial photographs, and information collected from a variety of sources were used to characterize these changes.

3.1 Dominant Habitats Found in the Santa Clara River Estuary

The Santa Clara River experiences large seasonal variations in flow. The estuary is a transitional zone between the river and the Pacific Ocean; because of the influence of both fresh and saltwater, it is a dynamic environment that supports a variety of habitats. These habitats include beach, southern foredune, salt marsh, active channel, freshwater marsh, mulefat and southern willow scrub, southern willow woodland, and giant reed dominated. Moreover, the habitat conditions can vary dramatically, depending upon the magnitude of flow from the Santa Clara River, and whether the mouth of the river is open or closed. When there is freshwater input from the river and the VWRF, and the sand berm at the mouth of the river is not breached, the estuary fills with water and a greater proportion of the study area is inundated with freshwater. When the sand berm at the mouth of the river is breached, water flows freely in and out of the lagoon. Under these conditions, the lagoon fills with a mixture of fresh and saltwater during the incoming tide, which drains back out through the breach as the tide recedes. At low tide, the lagoon may be nearly completely drained, exposing extensive sandflats. During the dry months, the Santa Clara River flow rates are low, and up to 100 percent of the non-tidal flows into the estuary come from the VWRF (City 2002).

The following sections describe the dominant plant communities and associated habitats that occur in the study area. Figure 3-1 shows the current extent of these communities.

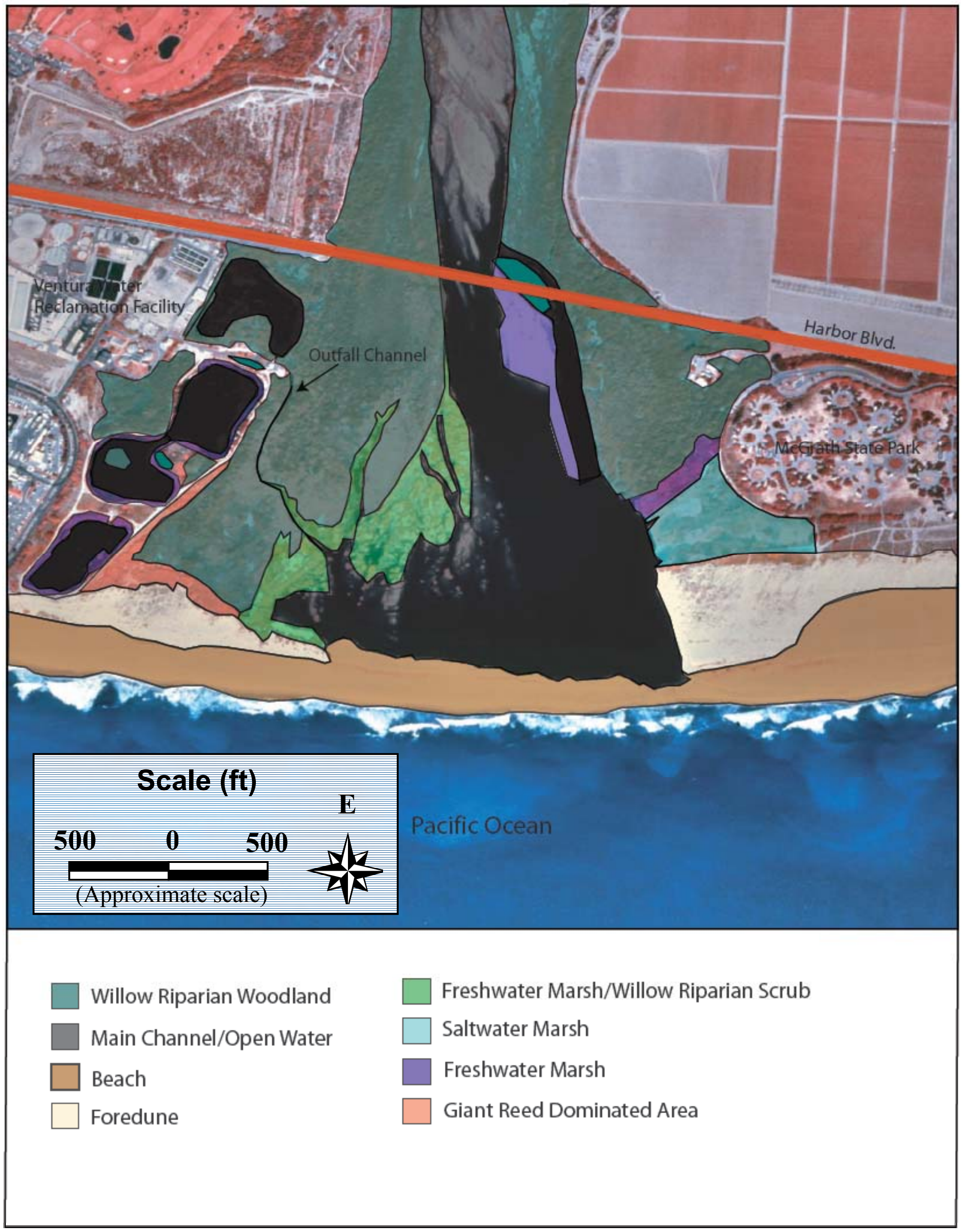

Figure 3-1. Plant communities within and adjacent to the Santa Clara River Estuary.

3.1.1 Beach

Beach refers to the open sandy area that stretches from the ocean shoreline to the vegetated foredunes. This environment is subject to wave and tidal action, and airborne salt and sand; the beach supports little vegetation. The Santa Clara River flows across the beach when the mouth of the lagoon is open. When the sandbar is closed, waves may wash over the beach into the lagoon during high surf.

Beach located west of the Santa Clara River.

Beaches are often divided into categories: the surf and foreshore zones. The surf zone includes that portion of the beach subject to tidal and wave action. The foreshore zone is the area between the surf zone and foredune habitats. The surf zone is habitat for birds, fish, and semi-sedentary invertebrates such as bivalves, tubeworms, and other species that burrow to survive desiccation, predation, and wave impact. These invertebrates attract a variety of shorebirds and gulls that actively forage in the surf zone. The foreshore is less typically used as foraging habitat, but it serves as roosting habitat for many bird species and important nesting habitat for endangered species such as the western snowy plover (*Charadrius alexandrinus nivosus*) and the California least tern (*Sterna antillarum browni*).

3.1.2 Southern Foredune

Southern foredune is the low herbaceous community found on active and semi-active dunes between mean high tide and the maximum level reached by the ocean open beaches. This community develops where accumulating sand forms dunes on the leeward side of coastal beaches (Holland 1986). Foredune vegetation has adapted to thrive under conditions that include high exposure to airborne sand and salts, and shifting substrate with low water-holding capacity and little organic matter (Breckon and Barbour 1974).

Sand verbena and beach evening primrose are shown in the foreground growing on a semi-stabilized dune. The invasive Hottentot fig (*Carpobrotus edulis*) and Veldt grass (*Ehrharta calycina*) are seen growing in the background.

Plant species typically associated with foredunes include sand verbena (*Abronia maritime*), beach-bur (*Ambrosia chamissonis*), beach evening-primrose (*Camissonia cheiranthifolia*), salt grass (*Distichlis spicata*), and sea rocket (*Cakile maritima*). This community has historically suffered encroachment by non-native plant species, such as sea fig (*Carpobrotus chilensis*) and Hottentot fig (*Carpobrotus edulis*), two succulent Aizoaceous plant species native to Chile and South Africa, respectively.

Very few animal species make exclusive use of the foredune environment, but shorebirds, gulls, terns, small mammals, reptiles, and insects are often observed there. Species that are permanent residents of the foredune environment are highly specialized and adapted to live under these conditions. Typical examples of these species include invertebrates such as the dune sand treading cricket (*Rhachocnemis validus*), and numerous beetle species that burrow in the sand during the day to escape predators.

3.1.3 Salt Marsh

Coastal salt marshes develop along the intertidal shores of bays and estuaries in areas that are frequently inundated with saltwater. In the study area, salt marsh is located in the area bounded on the north by the south bank of the Santa Clara River's main channel, on the south and east by the McGrath State Beach campground, and by the foredunes to the west (see Figure 3-1). Dominant plants closest to the main and side-channels are exposed to higher salt concentrations and include species better adapted to these conditions, such as fleshy jaumea (*Jaumea carnosa*), salt grass (*Distichlis spicata*), and pickleweed (*Salicornia bigelovii*). Other less common species include curly dock (*Rumex crispus*) and narrow-leaved cattail (*Typha angustifolia*). Areas less exposed to saltwater are dominated by the less salt-tolerant creeping wild rye (*Leymus triticoides*).

Many of the same animal species that inhabit freshwater marshes also use the salt marsh, including the red-winged blackbird (*Agelaius phoeniceus*), marsh wren (*Cistothorus palustris*), common yellowthroat (*Geothlypes trichas*), and western harvest mouse (*Reithrodontomys megalotis*). Additional species likely to occur in salt marshes are greater yellowlegs (*Tringa melanoleuca*), great egret (*Casmerodius albus*), Virginia rail (*Rallus limicola*), sora (*Porzana carolina*), and great blue heron (*Ardea herodias*).

Photograph illustrating dominant saltmarsh vegetation (foreground): Salt grass (*Distichlis spicata*) and pickleweed (*Salicornia* sp.).

3.1.4 Active Channel/Open Water

The active channel is the portion of the riverbed that is scoured by seasonal flood flows. Sandbars created by the deposition of alluvium as flood flows subside characterize the active channel. Sandbars adjacent to low-flow channels may be colonized by narrow-leaved willow (*Salix exigua*), mulefat (*Baccharis salicifolia*), and young cottonwoods (*Populus fremontii*) during the dry season. Cottonwoods and willows can tolerate salinity up to 1.5 to 2.0 ppt. As a result, presence or absence of these species can be used to indicate if a habitat is dominated by a freshwater or saltwater regime as they will be excluded from saltwater-dominated environments (Jackson et al. 1995). Periodic seasonal scour typically prevents these plants from reaching their normal heights. More stable sandbars may temporarily develop habitats that are dominated by willow scrub, mulefat scrub, and the invasive giant reed (*Arundo donax*).

Photograph shows vegetation establishing on sandbars within the main channel (note giant reed in center).

The active channel may be completely inundated, or almost completely dry, depending on flow conditions. During wetter periods, the diversity and abundance of waterfowl, piscivorous (fish-eating) birds, fish, insects, and amphibians can be high as these animals range throughout the entire channel area using open water habitats. Conversely, drier periods naturally result in a reduction of available open water habitat in the main channel. In the study area, flow from the VWRF, however, maintains at least minimal flow to the lower portion of the active channel year-round. Formation of the berm at the mouth of the channel typically leads to development of a lagoon as the estuary fills with water, inundating the active channel and low-lying portions of the study area.

Very few plants grow in open water. Certain species like duckweed (*Lemna minor*), however, have adapted to growing in open water and can form uniform vegetative carpets over open water under low-flow conditions.

3.1.5 Freshwater Marsh

Freshwater marsh is a type of wetland that occurs in areas that are inundated with freshwater for prolonged periods of time. The plant community is often characterized by emergent soft-stemmed vegetation (hydrophytes) adapted to survive under saturated soil conditions. Freshwater marshes in southern California typically comprise broad-leaved cattail (*Typha latifolia*), bulrushes (*Scirpus* sp.), sedges (*Carex* sp.), and rushes (*Juncus* sp.). The wetted margins of these marshes may have species such as rabbit's foot grass (*Polypogon monspeliensis*), yerba mansa (*Anemopsis californica*), dwarf and hoary nettle (*Urtica urens; U. diocia* ssp. *holosericea*), and cocklebur (*Xanthium stumarium*).

Marshes are considered high-value wildlife habitat that provide cover and critical foraging, nesting, and roosting habitat. Insects and other invertebrates are normally abundant in freshwater marshes, providing important food for many other species. Red-winged blackbird (*Agelaius phoeniceus*), marsh wren (*Cistothorus palustris*), and common yellowthroat (*Geothlypes trichas*) are among the many bird species that nest and forage in this habitat. Mammals, such as the western harvest mouse (*Reithrodontomys megalotis*), and reptiles, including garter snakes (*Thamnophis sirtalis*), are common occupants of marsh edges.

Freshwater marshes found in the study area occur in those areas where groundwater, river outflow, or side-channels provide sufficient water to maintain this community. Within the study area freshwater marshes occur in the wetter portions of the main river channel, and along the periphery of the outfall channel of the VWRF. They are somewhat adaptable to seasonal fluctuations in water availability, although the most developed freshwater marshes are associated with relatively stable water sources and substrate that is not subjected to scouring events (e.g., the outfall channel).

Freshwater marsh dominated by cattails (*Typha latifolia*) and bulrushes (*Scirpus* sp.) is shown here with the invasive giant reed to the right.

3.1.6 Mulefat Scrub/ Southern Willow Riparian Scrub and Woodland

Mulefat scrub and southern willow scrub represent middle stages of riparian woodland succession. Mulefat scrub is dominated by mulefat (*Baccharis salicifolia*). This habitat also supports narrow-leaved willow, giant reed, and tamarisk (*Tamarix* sp.). Mulefat scrub can be found within the active channel following floods, along the banks, and on the low floodplain terraces. Soils tend to be alluvium composed of sand or silt with varying degrees of cobbles and rocks. This is an early succession riparian habitat that is maintained by seasonal disturbances, such as floods. Mulefat scrub provides important foraging habitat for migratory and resident birds, as well as other species found in adjacent habitats.

In the study area, this community is often associated with other plant communities such as freshwater marsh or willow scrub and riparian habitats. Better representative stands of mulefat scrub occur in the upstream portion of the study area.

Southern willow scrub is characterized by dense riparian thickets dominated by several willow species including, arroyo willow (*Salix lasiolepis*), red willow (*Salix laevigata*), and narrow-leaved willow. Mulefat is often co-dominant with the willows. Other plant species that can be found in this habitat are Fremont cottonwood (*Populus fremontii*) and western sycamore (*Platanus racemosa*).

Southern willow riparian woodland is dominated by the same species that are found in the southern willow scrub plant community. Although exhibiting similar species composition, riparian woodland is comprised of more mature trees that occur in portions of the stream less affected by the high flows that occur in the main channel. Like its scrub counterpart, however, periodic flooding is necessary to maintain vegetation growth and allow for germination and establishment of component trees. Once established, willow riparian woodlands often have a well-developed understory that consists of willows, horsetails (*Equisetum* spp.), sedges (*Carex* sp.), blackberry (*Rubus ursinus*), hoary nettle, and poison oak (*Toxicodendron diversilobum*). It is also common to find freshwater marsh and southern willow scrub communities associated with southern willow riparian woodland.

Shown here are willow riparian woodland and an understory comprised of horsetails (*Equisetum* spp.), willow (*Salix* sp), and other herbaceous species.

Willow riparian habitat typically supports a large diversity of animals. Insects and other invertebrates abound in this community and provide opportunities for many other species to forage. Audubon's warbler (*Dendroica auduboni*) and ruby-crowned kinglet (*Regulus calendula*) are common migratory birds that use willow environments. California king snake (*Lampropeltis getulus*), western fence lizard (*Sceloporus occidentalis*), and Pacific tree frogs (*Hyla regilla)* are associated with the drier portions of these woodlands. Mammals, such as raccoons (*Procyon lotor*), bobcat (*Felis rufus*), and the introduced opossum (*Didelphis virginiana*) and feral pig (*Sus scrofa*), are also typical of these environments. A number of protected and sensitive species, including the southwestern willow flycatcher (*Empidonax traillii extimus*), yellow warbler (*Dendroica petechia*), and yellow-breasted chat (*Icteria virens*) are also associated with these woodlands.

3.2 Comparison of Current and Historical Ecological Conditions

3.2.1 Anecdotal Evidence of Historical Conditions of the Santa Clara River

The Santa Clara River watershed has undergone considerable development since the appearance of European, Mexican, and American settlers. The *Santa Clara River Enhancement and Management Plan Study: A History of the Santa Clara River* (Schwartzberg and Moore 1995) identified three chronological periods of development subsequent to the hunting and gathering activities practiced by local Indian communities. First, the Agrarian Era (1782-1870s) was associated with the arrival of Spanish and Mexican settlers, and the subsequent development of large ranchos and open-range grazing practices. This was followed by the Commercial Era (1870-1920) that was characterized by more intensive settlement and agricultural practices, increased oil extraction, and rising competition for use of water. The current Industrial Era (1920-present) has led to even more intensive development and utilization of natural resources throughout the watershed.

The rapid pace of development, combined with poor records describing the physical and biological characteristics of the river during the late 1700s and early 1800s, make it problematic to obtain an accurate description of historical conditions associated with river flows and biological attributes. However, a detailed search of the historical record provides insight into the changes that have occurred over time.

This review of historical conditions focused on information available for the Agrarian Era, and the Commercial Era prior to 1900. Sources evaluated included a wide variety of published accounts, maps, photographs, and anecdotal information from interviews and other narratives. This study used descriptions of flora and fauna, landmarks, and other indicators of location and season to identify and analyze information relevant to characterizing historical conditions associated with the Santa Clara River. In particular, there was interest in determining whether the anecdotal evidence supported the hypothesis that the estuary received surface flow from the river throughout the year prior to the initiation of discharge from the VWRF, or if water was present in the lower river only on a seasonal basis. Another task was to determine if the estuary was historically a brackish to freshwater system, or if it was primarily marine, in terms of water quality and the associated ecological community.

From the 1820s to the 1860s, raising livestock on large ranchos was the dominant occupation along the Santa Clara River as the Mexican government granted parcels of land to ranchers. Ranchos adjacent to the river, such as San Miguel, San Pedro, Rio de Santa Clara (also referred to as La Colonia), Santa Clara del Norte, Santa Paula Y Saticoy, Sespe, and San Francisco, supported large populations of cattle and sheep (Figure 3-2). Grazing and watering of livestock, and limited irrigation, shaped land use adjacent to the Santa Clara River during this period.

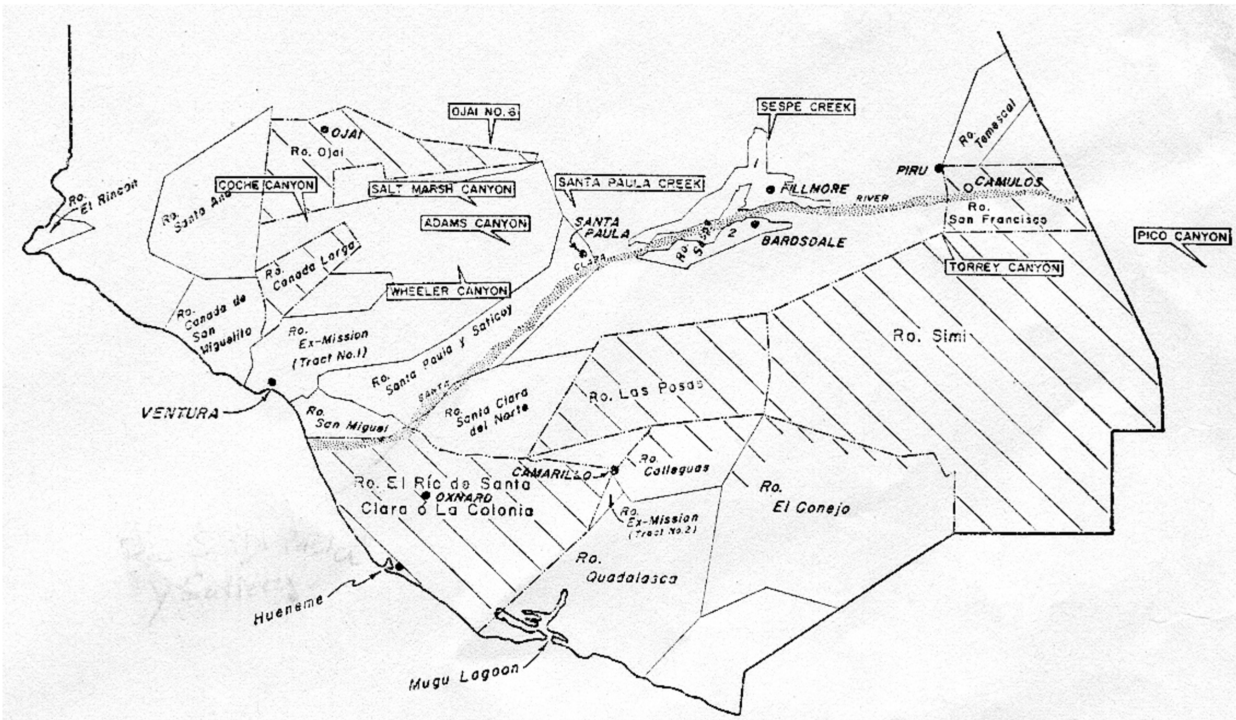

Figure 3-2. Ranchos of the Santa Clara River Valley (Hutchinson 1965)

This system began to change with the advent of American ownership of the land in 1848. Gradually, land use adjacent to the river shifted from ranching to more intensive agricultural practices. In the 1860s, interests from outside of California began to establish larger-scale agriculture and oil enterprises. Crops of sugar beets, walnuts, lima beans, and citrus relied on irrigation from the Santa Clara River and groundwater. During this era, Nathan Blanchard and Wallace L. Hardison founded the Limoneira lemon ranch that developed into the world's largest lemon producer (McBane 1994). Hardison also founded Union Oil with Thomas Bard. This company, like the Limoneira, rose to national prominence. In addition, the Oxnard Brothers American Sugar Beet factory introduced a new agricultural crop into Ventura County, creating additional demands on the river as a source of water. The growth of these industries served as the impetus for expansion of the Southern Pacific Railroad that, in 1887, linked Ventura with the rest of California. Ultimately, the combination of increased access to transportation and developing markets further contributed to the area's growth and over utilization of the river. Consequently, groundwater resources were rapidly developed, thus lowering the groundwater table, and resulting in problems with saltwater intrusion and further reducing surface water flow in the river (Schwartzberg and Moore 1995).

3.2.2 Historical Biological Attributes and Hydrology of the Lower Santa Clara River

Observations of flow in the Santa Clara River under conditions not influenced by human activities are scarce. Father Juan Crespi described the river as flowing in a moderately wide valley, well grown with willows and cottonwoods, and carrying a great deal of water; just upstream of Santa Paula, he estimated the sandy channel to be approximately 200 feet in width, with the river accounting for approximately one-third of the total width. These observations were made in August of 1769 (Schwartzberg and Moore 1995). [Note: Based on conservative assumptions of a wetted width of 50 feet, an average depth of 3 inches, and a flow velocity of 1 foot/sec, this observation would result in an estimated flow of 12.5 cfs or 8 mgd, otherwise equivalent to approximately 750 acre feet/month.]

An account, written in 1804 by Spanish missionary Father Jose Señan, describes the difficulty of crossing the river at Sespe after a storm, as well as river flows in general. "We assure you, from positive knowledge and experience, that the Santa Clara River has to be crossed a very short distance above the rancheria of Secpey [Sespe], where the least difficult ford is to be found; but in time of flood or after heavy rains it is impossible to cross the river for 2 or 3 days, and even then the passage is hazardous, for the water remains high for a considerable length of time. Throughout the rest of the year the river carries no small volume of water" (Nathan 1962; in Hutchinson 1965).

In this account, Father Señan describes the characteristics of the recession curve of a hydrograph for the Santa Clara River. This description is particularly important in terms of characterizing the potential duration of the migratory window for adult steelhead trout moving upstream to spawn. A decrease in the duration of this key watershed characteristic would be likely to adversely affect the success of the steelhead runs. Moreover, his comments suggest that significant flows in the river were present year-round.

Hutchinson (1965) recounts a description of the Santa Clara River Valley in the late 1860s as a:

… *wildly rugged, game-rich land in all its parishes—a land where major streams teemed with trout, where antelope raised tall dust plumes by their white-rumped wheelings, where Ramon Ortega could count one hundred shambling, feeding, grizzly bears while riding between the Sespe and Santa Paula Canyon.*

The lower reaches of the valley were generally flat, open grasslands, with a riparian corridor characterized by dense growths of willows, cottonwoods, and sycamores (Unknown 1956). All three of these species are typically found in riparian corridors; both willow and cottonwood in particular require relatively consistent access to ground or surface water; according to U.S. Fish and Wildlife Service (2002), even "smaller reductions in stream flow or groundwater levels can cause plants to undergo physiological stress and lose productivity…" These species are also sensitive to elevated salinities (U.S. Fish and Wildlife Service 1996).

The following account describes a crossing of the lower Santa Clara River at Rancho Santa Clara del Norte (near the current crossing of US 101) in August 1868. The anonymous author, an acquaintance of Thomas Bard, described the channel as wide, sandy, and shallow, and noted that "there was some water flowing where we crossed it, and quite a large body a few miles above "(Unknown 1956). It is important to note that these observations in the lower river were made in August, providing additional evidence of surface water flows, even during the summer. Hutchinson (1965) further noted that crossing the lower river was hazardous due to pockets of quicksand.

In 1867, the estuary itself was described as "a swampy land full of sloughs and lagunas (lakes) stretching ½ to ¾ miles across. Indeed, the marshes, sloughs and backwaters associated with the lower river and estuary historically supported large numbers of wintering waterfowl (Schwartzberg and Moore 1995).

Cooper (1887) and Everman (1886), as part of their observations of bird life in the area, noted that there were permanent flows in the river in the vicinity of Saticoy and described a combination of marshy shores and riparian woodland that extended for several miles along the lower river.

In addition, Everman (1886) reported "along the coast, near the mouth of the Santa Clara River, are several small lagoons or ponds where vast numbers of Ducks, Geese and other water birds winter, and where a few species remain to breed." During a winter hunting expedition on November 20, 1880, to the "lagunas" at the mouth of the Santa Clara River, Everman describes a scene of, "… thousands of Geese (*C. hyperboreus* [lesser snow goose], *C. rossii* [Ross's goose], and *Anser albifrons gambeli* [Gambel's greater white-fronted goose]) flew overhead…" Moreover, the presence of these species provides an indication of the type of habitat found in the area. During the winter, these species are typically associated with freshwater habitats where they feed on emergent vegetation, including *Scirpus americanus* (Sibley 2003). Clearly, the altered landscape does not currently support scenes such as this one described by Everman. Of interest, another species of goose, the black brant (*Branta barnicla*), which is commonly present as a winter migrant on saltwater bays and estuaries along the Pacific coast, is not mentioned in these historical accounts. The absence of this species suggests that suitable habitat (i.e., saltwater marsh and mudflats) was not present in the estuary.

By the mid-1870s, farmers were actively irrigating cropland in the upper Santa Clara River watershed, in an area known as Newhall Ranch (Rancho San Francisco) located near Piru. Thousands of acres were under cultivation for various crops, including alfalfa (Hutchinson 1965). Coincident with more intensive use of water for agriculture, a drought hit the area in the early 1880s. In 1883, it was reported that the lower Santa Clara River "became a dry bed of sand." Ironically, more intensive ground-water pumping led to even less consistent flows in the river, ultimately reducing the amount of acreage irrigated with surface water from 16,000 acres in the early 1900s, to only 2,500 acres in the 1960s (Schwartzberg and Moore 1995).

3.2.3 Changes in the Habitat Characteristics of the Lower Santa Clara River over Time

The morphology of the Santa Clara River has varied widely in its geologic history, as evidenced by fluvial deposits in the surrounding vicinity. The natural variation in river flows significantly altered the river's location and character on a regular basis. Since the early 1900s, development within the lower reaches of the floodplain has constricted the estuary and considerably reduced the surrounding habitats (e.g., wetlands). Historic aerial photographs and U.S. Geological Survey (USGS) hand-drawn maps were evaluated to provide a basis for identifying estuary-scale changes over time. Aerial photographs were acquired from the UCLA Spence and Fairchild Collection; University of California, Santa Barbara; Map and Imagery Laboratory's Teledyne Collection; and the Ventura Museum of History and Art's Fairchild collection. USGS maps (1855 and 1933) were acquired from the National Archives and Records Administration. While of interest, no individual map should be relied upon to provide detailed information regarding the precise location and extent of various habitats. Nonetheless, the maps do provide general information regarding the major habitat features over time.

Perhaps the most notable change to the estuary landscape has been the decrease in the total area of the estuary, which is also reflected in decreases in the areas of individual habitat types. Backwater habitat, which includes laguñas, perched ponds, and small ephemeral drainages, has dramatically decreased since 1929, and even more so when compared to conditions in the 1800s. In 1855, backwater habitat extended behind the sand dunes on the north side of the estuary up the coast in a band over 500 feet wide for at least 1 mile north of the lagoon (Figure 3-3, USGS 1855). To the south, habitat associated with the estuary, including side-channels and probably salt marsh, also extended for at least 0.5 miles. By 1933, approximately 50 percent of the backwater habitat extending to the north had been filled in (USGS 1933) and, by 1945, this feature had been entirely removed (aerial photo--Teledyne Corp. 1945). In addition, levee construction and subsequent development eliminated most of the remaining backwater habitat associated with willow riparian woodlands and scrub located on the north side of the lagoon. By 1933, approximately 16 acres of salt marsh and sandy side-channel drainages located just south of the lagoon had been converted to "flat sandy pasture land" (USGS 1933). In addition, as early as 1933, with the exception of a thin band directly adjacent to the Santa Clara River, nearly all of the willow riparian woodland located along the southern bank of the river had been diked and converted to "low prairie land" (USGS 1933).

In 1929, the area of the estuary and associated floodplain was approximately 1025 acres. By 2002, the total area remaining was only 108 acres, a decrease of nearly 90 percent (Figure 3-4). Moreover, the lagoon itself decreased in size by approximately 50 percent between 1855 and 1933; by 2002, the size of the lagoon was reduced to less than 10 percent of the area noted in the 1855 measurement. In addition, nearly all of the side-channel habitat had been filled in by 1933. Side-channels provide refugia for aquatic species during periods of high flow conditions and are an important habitat component that has been largely lost over time as a result of modifications to the floodplain and containment of the main channel within levees. Interestingly, the input of freshwater via the outfall channel from the VWRF provides surface water to the estuary even during the driest periods and has created a freshwater side-channel feature that is analogous to historic side-channel habitat that has been largely lost over time.

Review of the aerial photographs and maps ranging from 1855 to 2002 indicates that the most significant impacts include agriculture and urban development, and construction of levees and bridges. The banks of the Santa Clara River just upstream of the lagoon have been subject to agricultural encroachment for over a century. Early photographs of the estuary indicate that there was a broad floodplain composed of meandering side-channels that supported riparian woodlands at various stages of maturity. Subsequently, the overall extent of the willow riparian woodland decreased dramatically due to the construction of levees on the north and south side of the river. Moreover, the levees have prevented the former floodplain from being reworked by the river. As a result, the riparian areas behind the levees that were once periodically scoured have remained as mature willow riparian woodland at the expense of transitional vegetation communities and marshes.

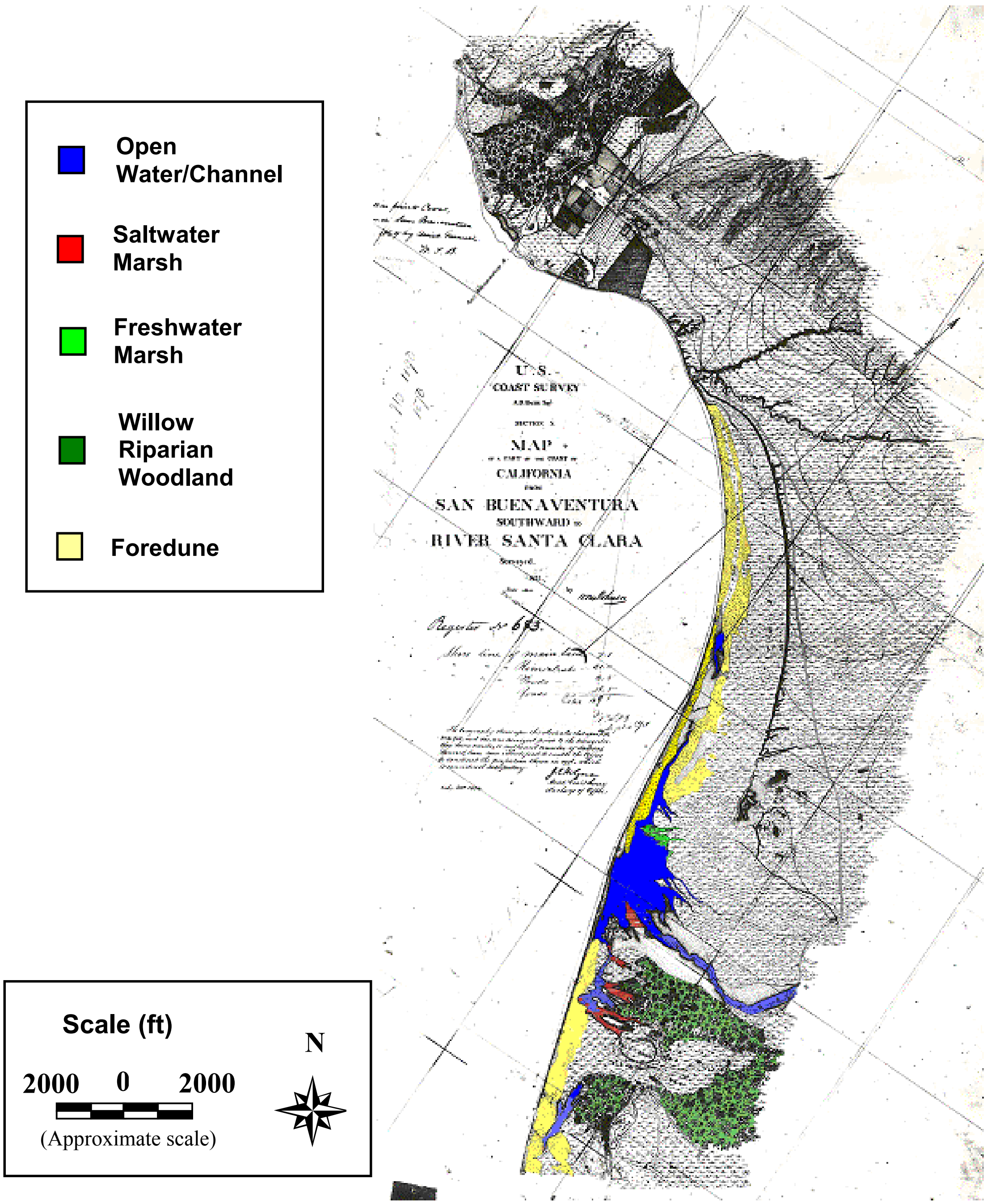

Figure 3-3. 1855 USGS topography map of the lower Santa Clara River and adjacent areas. Key features and plant communities are highlighted based upon the symbols depicted on the map (Shalowitz 1964).

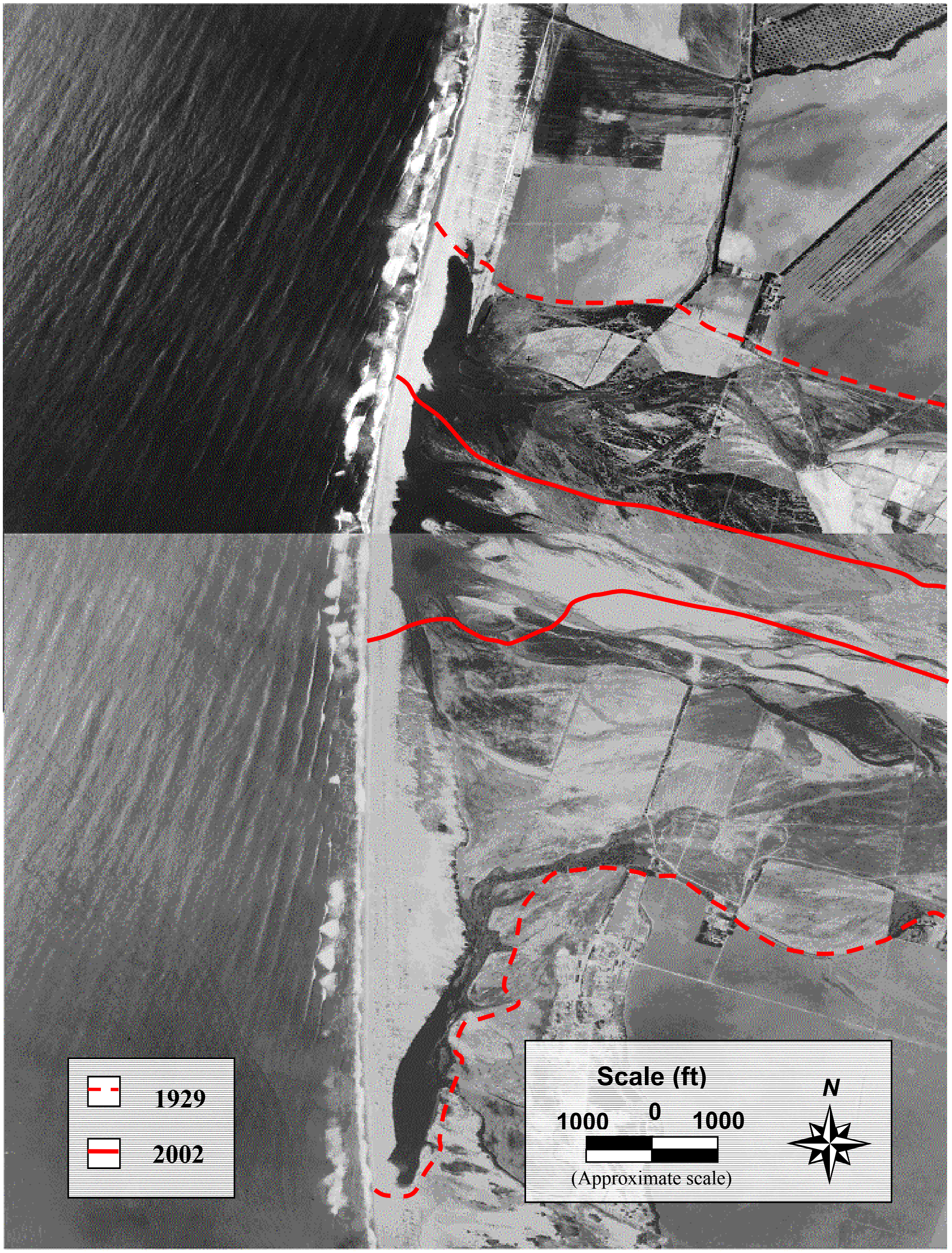

Figure 3-4. Comparison of approximate floodplain extent in 1929 and 2002.

The cumulative impact of these developments on habitat is shown in Figures 3-5a-c, which compare aerial photographs taken between 1929 and 2002. Clearly, a much more extensive delta environment, containing a mosaic of habitats, historically characterized the lower portions of the river and the estuary compared with current conditions. The cumulative impacts to the estuary and the associated biological community occur as a result of changes in water quality, the water-flow regime, hydro-geomorphology and, ultimately, overall habitat complexity.

Significant structural changes to the lower river and estuary include the levees that were built along the north and south banks of the lower river to control the meandering nature of the river that periodically caused flooding on reclaimed land. These levees, along with the Harbor Boulevard Bridge, were completed in 1957. Construction of the levees reduced the available channel width of the Santa Clara River by 75 percent and the bridge abutments further constricted the river channel to its current width of 1,000 feet (CDPR 1990). The habitat restrictions imposed by these structures on the river and floodplain are apparent in Figures 3-5c.

Constriction of the river through a smaller channel between the bridge abutments increased flow velocity through the channel and associated scouring. In addition, any remaining side-channels that historically received flows during large storm events were cut off from the main channel, not only further reducing habitat, but also the capacity to absorb higher flows, as well as the water that backed up in the lagoon when the sandbar at the river mouth closed. To alleviate this problem, it became necessary to artificially breach the sand berm at the mouth of the river to prevent the lagoon from flooding adjacent lands. The first report of this practice was made in 1957, and an easement was subsequently granted by California Department of Parks and Recreation to landowners affected by the potential flooding; however, the formal practice of breaching the sand berm at the mouth of the estuary was suspended in the late 1980s.

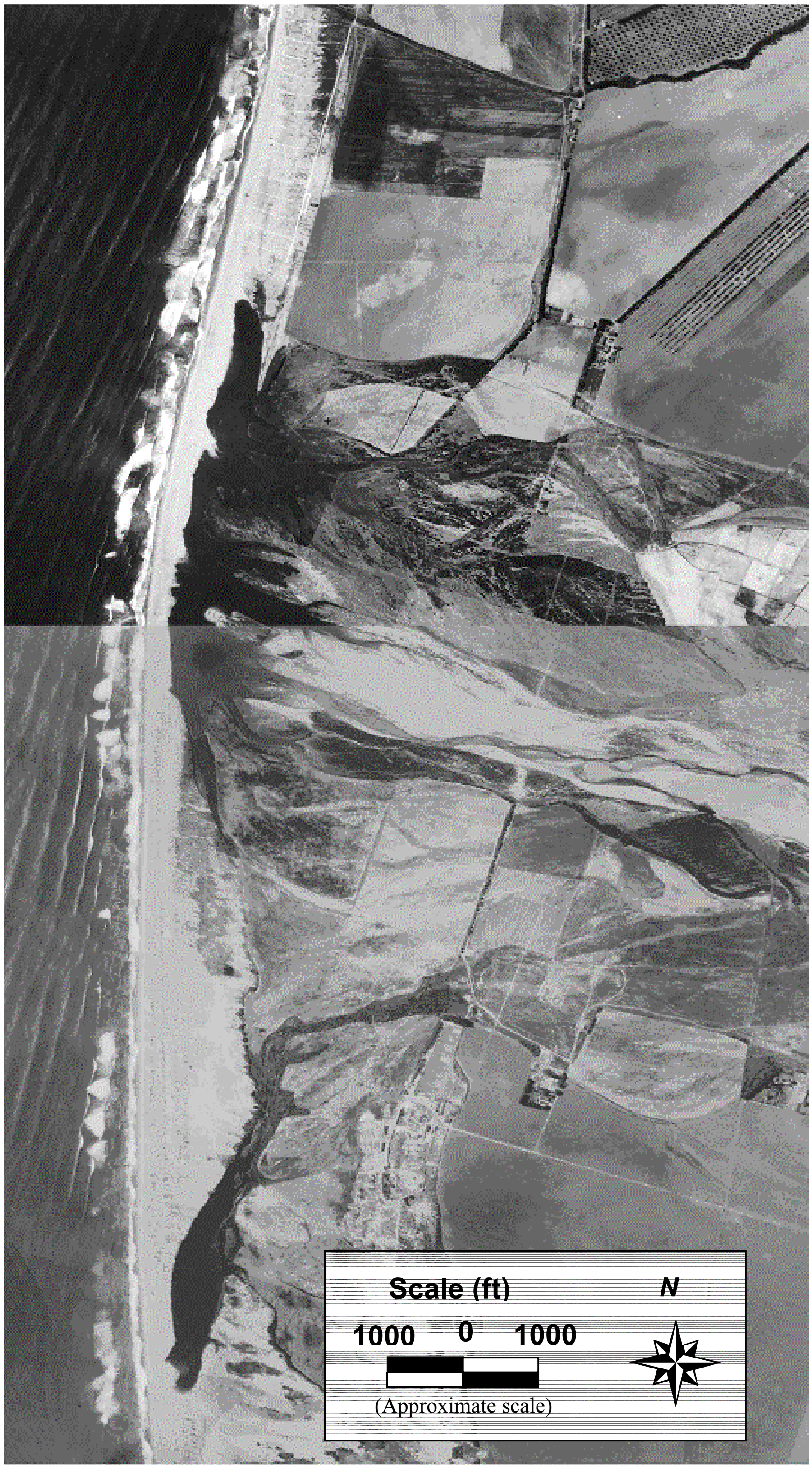

Figure 3-5a. Aerial photograph of the lower Santa Clara River and adjacent areas in 1929.

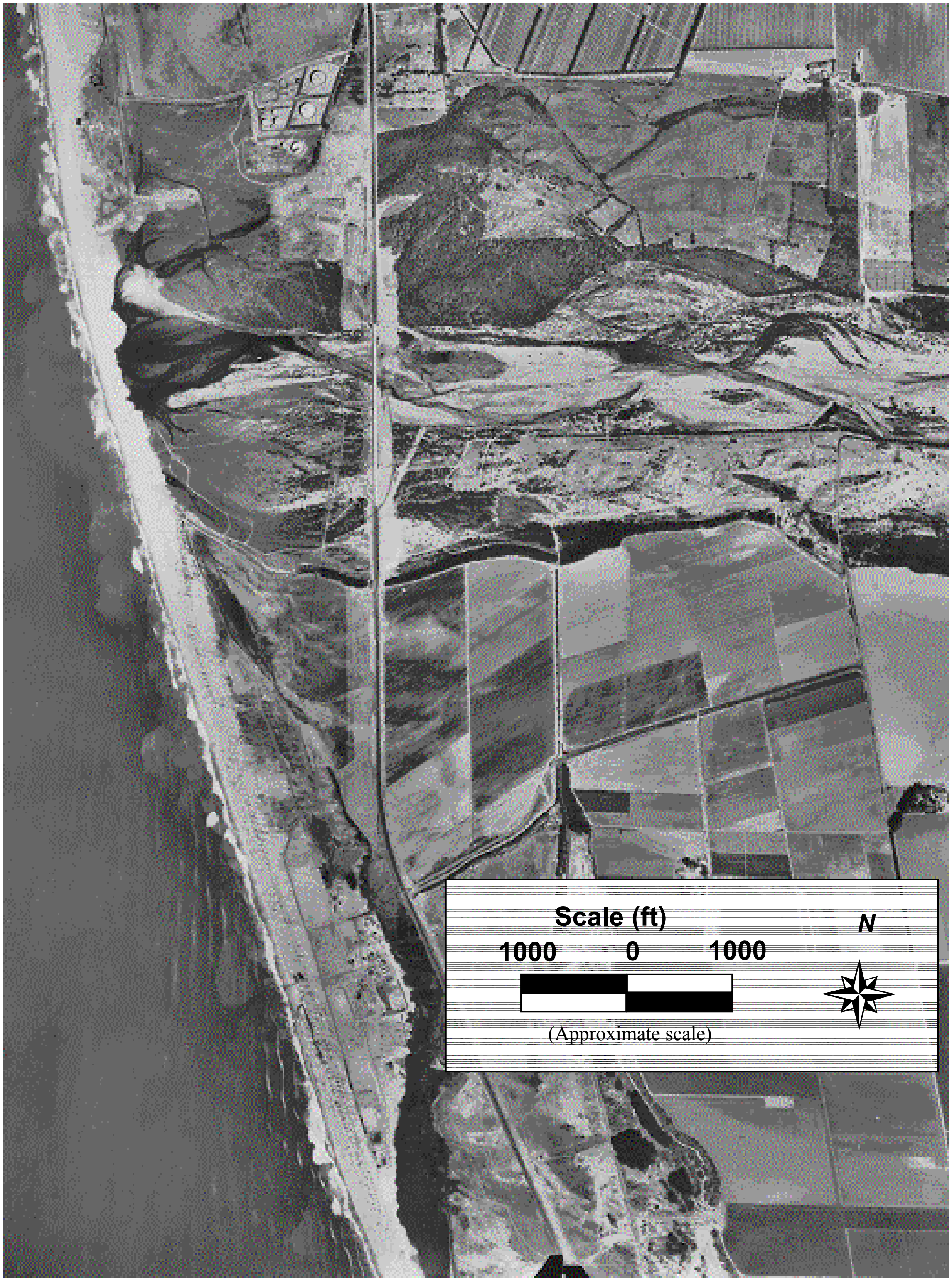

Figure 3-5b. Aerial photograph of the lower Santa Clara River in 1959.

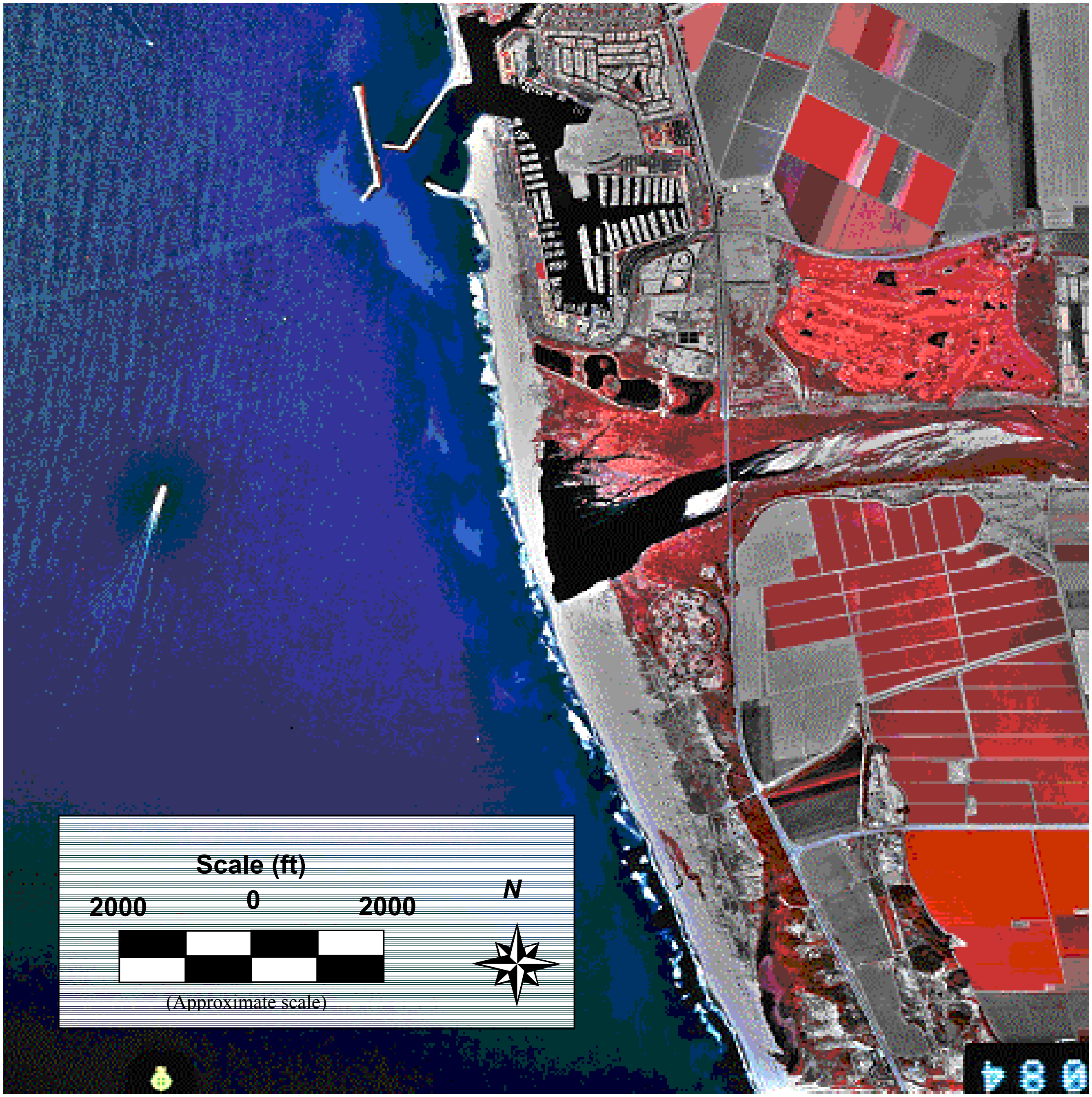

Figure 3-5c. Aerial photograph of the lower Santa Clara River in 2002.

3.2.4 Changes in Specific Habitat Types

Changes in habitat composition over time is an indicator of the health of an ecosystem. This approach is based on the assumption that an ecosystem with a diverse suite of plant communities can support a diverse set of animal species because of the complexity of microhabitats created by the layering of trees, shrubs, and herbaceous and aquatic vegetation. Since plants are sensitive to changes in salinity and hydrologic regimes, as well as substrate, analysis of plant communities should provide an indication of changes in habitat within the study area over time. Such changes could be due to modifications of flow dynamics related to upstream channel alterations, reduction of overall flows, elimination of habitat as land is reclaimed, alterations in water quality, and changes in the frequency of erosional and depositional events.

The composition of the plant communities was determined largely by analyzing aerial photographs. Acreage associated with each vegetation/habitat type was calculated by measuring the area encompassed by the corresponding mapped polygons. The composition and extent of the current plant community were determined during a field visit, and, subsequent to the field visit, polygons reflecting data collected in the field were overlaid onto a 2002 aerial photograph. Acreage associated with each vegetation/habitat type was calculated by measuring the area encompassed by the corresponding mapped polygons (see Figure 3-1). The composition of plant communities in 1929 was determined with photogrammetry techniques. In this case, vegetation was assigned to specific categories based on relative height, contours, and shading. Vegetation categories present in 1929 are shown in Figure 3-6.

A total of eight habitat types were identified in this analysis. Not all habitat types were found in both 1929 and 2002, but included beach, southern foredune, freshwater marsh/willow riparian scrub, salt marsh, freshwater marsh, willow riparian woodland, main channel/ open water, and giant reed dominated area. The extent of the different dominant habitats found within the study area in 1929 compared with 2002 is shown in Figure 3-7; direct comparisons may also be made by evaluating Figures 3-1 (2002) and 3-6 (1929).

In 1929, total acreage of the estuary and associated floodplain was estimated at approximately 1,025 acres. The two dominant plant communities were willow riparian woodland and main channel/open water, which respectively comprised approximately 403 and 277 acres. The next most dominant community, southern foredune, accounted for approximately 189 acres. Freshwater marsh/willow riparian scrub comprised approximately 99 acres. Although the 1855 USGS map suggests that there were approximately 16 acres of salt marsh, and approximately 3 acres of salt/brackish marsh were identified in the 2002 aerial photograph, as well as during the site visit, a salt marsh community was not apparent in the estuary in 1929 because all vegetation types appeared taller than those typically associated with salt marshes. Furthermore, the 1933 USGS map does not note the presence of salt marsh. Giant reed had not yet established itself in the estuary in 1929.

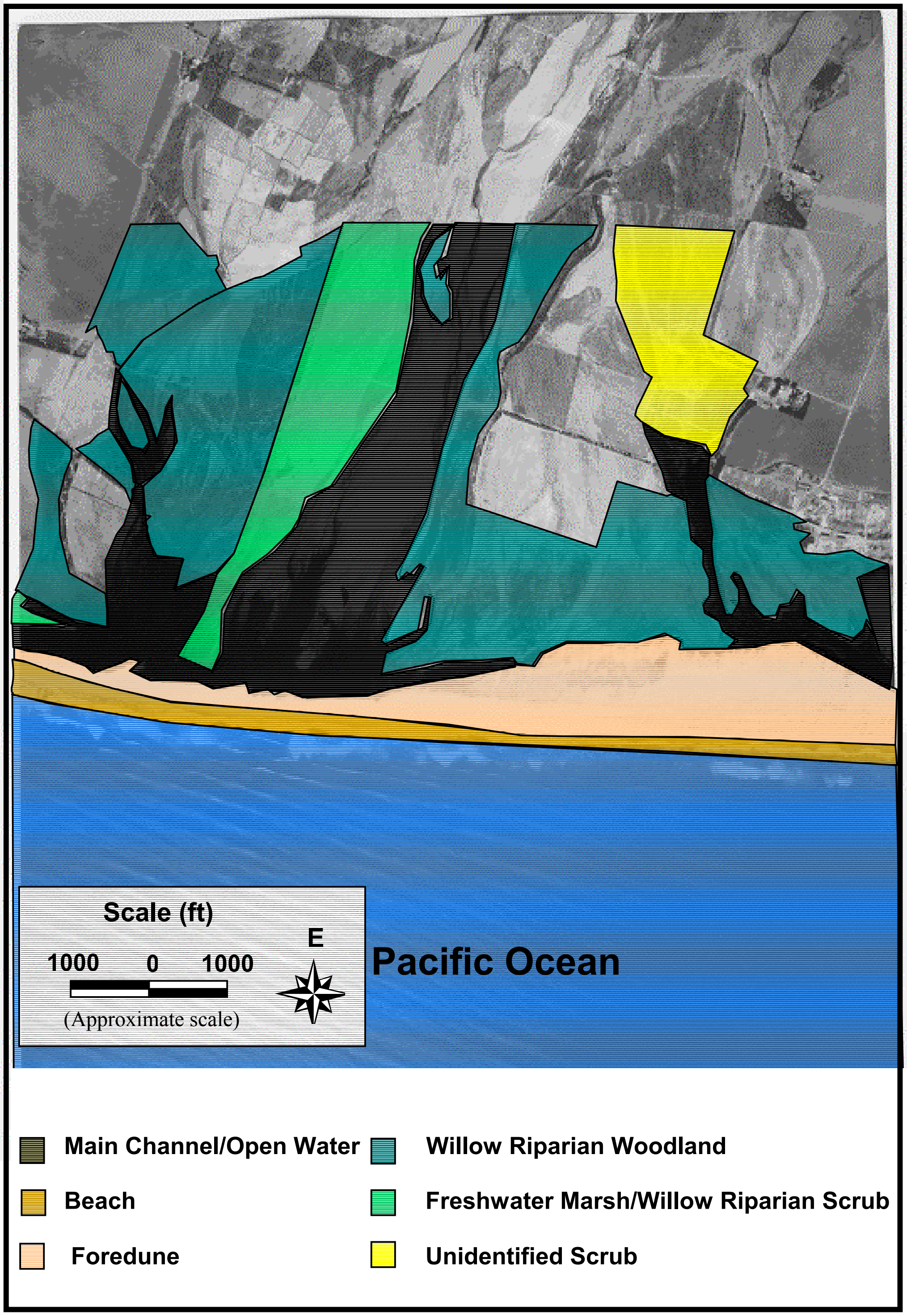

Figure 3-6. Historic distribution (1929) of plant communities within and adjacent to the Santa Clara River Estuary.

In 2002, the total area of the estuary was estimated at approximately 108 acres. The two dominant communities were willow riparian woodland and main channel/open water, which comprised 38 and 33 acres, respectively (these estimates do not include the upland habitat or open water associated with the wastewater treatment ponds). The next most dominant communities, beach and southern foredune, accounted for approximately 14 and 10 acres, respectively. The transitional community of freshwater marsh/ riparian willow scrub, comprised 7 acres of the landscape. Salt marsh and freshwater marsh together comprised approximately 5 acres of the total area. While the invasive giant reed dominated only approximately 1 acre (1 percent), of the total area analyzed, it is important to note that giant reed is present on much of the landscape of the study area. It is found mixed with native plant species throughout the riparian corridor down to the interface of the willow riparian woodland and southern foredune communities, along the north and south stream banks, and on gravel bars in the active channel. Given the highly adaptable characteristics of the species, it is likely that it will continue to increase in abundance in the estuary unless steps are taken to eradicate it.

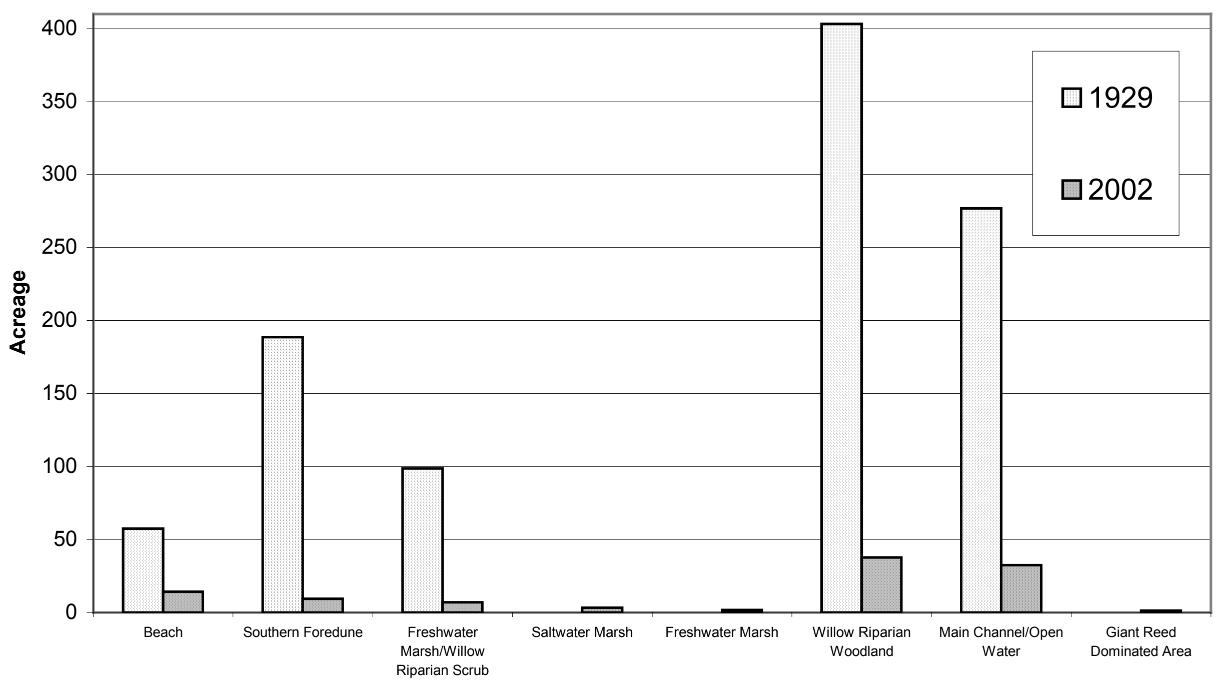

Figure 3-7. Comparison of habitat composition and extent within and adjacent to the Santa Clara River Estuary for the years of 1929 and 2002.

3.3 Plant and Animal Species of Concern

The diversity of habitats associated with the Santa Clara River Estuary has historically supported a wide variety of plant and animal species. The *Santa Clara River Enhancement and Management Plan Study: Biological Resources* provides a comprehensive list of all wildlife species with the potential for occurrence in habitats associated with the study area (Santa Clara River Project Steering Committee 1996b). However, as the sizes of these habitats have diminished over time, the abundance and distribution of many endemic species have also declined. Consequently, a number of species are the focus of regulatory concern, and particularly sensitive species receive various levels of State and Federal protection to conserve their status and/or promote their recovery.

There are 33 species potentially occurring in the study area that are considered "sensitive" by agencies entrusted with their protection (CDFG 2003, 2004; Santa Clara River Project Steering Committee 1996b). These include species afforded status under State and Federal Endangered Species Acts, rare species, and species placed on watch lists due to recent noticeable declines in their populations and distribution. Table 3-1 provides a list of these species, their status, habitat preferences, and likelihood of occurrence in the study area, based on recent observations and availability of suitable habitat.

Of the 33 sensitive species known to occur in the vicinity of the study area, 15 have been recently observed within the study area. Of these, only the tidewater goby (*Eucyclogobius newberryi*) would be considered a perennial resident within the study area. Historically, juvenile and adult steelhead were likely associated with the estuary throughout the year, and plant species of concern would also have been present in the study area on a perennial basis.

3.3.1 Plants

Plant distribution within the study area is largely determined by the physical factors resulting from anthropogenic changes (e.g., levees), the natural hydrologic regime (flood scour and deposition), and the extent and permanence of water in the soils. The vegetation on the sand and gravel bars in the active channel is limited by a disturbance regime that is dominated by seasonal high flows during winter storms that scour the active channel and remove or damage vegetation. As the frequency of disturbance decreases, these communities become more established and trend towards more mature willow riparian woodland communities. Aquatic plants dominate areas of the estuary that are inundated by water for most or all of the year. Farther outside the active channel, where the soils remain saturated, and the frequency of disturbance decreases, conditions facilitate the existence of established willow riparian woodland communities.

Ventura marsh milk-vetch (*Astragalus pycnostachyus* var. *lanosissimus*) and salt marsh bird's-beak (*Cordylanthus maritimus* ssp. *maritimus*) are the two sensitive plant species that could potentially exist in the study area, given the habitat conditions (Table 3-1). Neither of these species has been observed in the study area in recent biological surveys; Ventura Marsh milk-vetch was last observed in this study area in 1967 (CDFG

2003), and salt marsh bird's-beak was last collected in 1935, and last observed in 1960 (CDFG 2003). The decline of both of these species is attributed to human disturbance, such as off-road vehicle use, trampling, and displacement by non-native invasive plant species (CDFG 2003).

3.3.2 Animals

3.3.2.1 Invertebrates

The benthic macroinvertebrate fauna of the estuary have been extensively studied. Swanson et al. (1990) collected 20 sediment cores in August and November 1989. The U.S. Fish and Wildlife Service (1999) conducted 12 surveys from 1997 to 1999. Sampling techniques included minnow traps, benthic cores, and seines. In 1999, ENTRIX, Inc. collected benthic cores at four sites in the lagoon during winter, spring, and summer. Collectively, a total of 23 aquatic invertebrate species have been documented in the estuary. The terrestrial sandy beach tiger beetle (*Cicindela hirticollis gravida*) is the only sensitive invertebrate species known to occur in the study area. This species was last observed in 1970, in the dunes just south of the mouth of the lagoon (CDFG 2003).

3.3.2.2 Fish

A total of 14 fish species have been observed in the Santa Clara River Estuary. Four of these, southern steelhead trout (*Oncorhynchus mykiss iridius*), arroyo chub (*Gila orcutti*), Santa Ana sucker (*Catostamus santaanae*), and tidewater goby, are federally listed as endangered or species of concern. One additional fish species with regulatory status, the unarmored threespine stickleback (*Gasterosteus aculeatus williamsoni*), could potentially occur in the study area (AMEC 2004).

The tidewater goby was federally listed as endangered in 1994. It is estimated that the tidewater goby has disappeared from 74 percent of the coastal lagoons south of Morro Bay (CDFG 1995). The loss or degradation of habitat due to coastal development projects is currently the major factor affecting tidewater goby populations (CDFG 1995). Although tolerant of a wide range of salinities, tidewater gobies are typically found in areas of low salinity, and their predominate prey items tend to reflect low salinity habitats, rather than organisms found in higher salinity or marine habitats. Gobies are sensitive to impacts such as lack of freshwater due to diversions, pollution, siltation, and invasion of non-native species, such as the western mosquitofish (*Gambusia affinis*), which is a competitor, and the African clawed frog (*Xenopus laevis*), which is a predator.

A short lifespan, narrow habitat requirements, and population isolation are factors that contribute to the tidewater goby's susceptibility to environmental change (Ambrose and Orme 2000). The tidewater goby is typically an annual species (CDFG 1995). Spawning is most prevalent from spring to mid-summer (Capelli 1997); in most California estuaries, this coincides with a time when estuaries are closed. As a result, brackish to freshwater conditions often exist during the spawning period. Spawning may continue into the fall and winter as long as water temperatures remain warm and the mouth of the lagoon remains closed. Coarse sand (10-20 cm deep) is necessary for males to excavate burrows for incubating clutches of eggs. Following hatch, the larvae are pelagic, but the juveniles are benthic and the adults prefer vegetated areas, which provide protection from predators and substrate for prey. During large flood events, tidewater gobies utilize side-channels as refugia from the fast-moving water that often flushes them from estuaries into the open ocean. Gobies are an important part of estuarine food webs, as they provide prey for larger fish and piscivorous birds (Swanson et al. 1995).

Tidewater gobies are currently abundant in the estuary, at least partly due to an appropriate range of salinities and substrates. When not restricted by flows, this species is widely distributed throughout the lagoon. During a survey conducted in the spring of 2004, some of the highest densities of gobies were observed in the lower reaches of the VWRF outfall channel, which also likely functions as a refuge during periods of high outflows (Appendix B). In addition, vegetation associated with the channel provides cover. Overall, the evidence from field surveys suggests that the VWRF discharge is not resulting in adverse effects on the goby and, in fact, likely provides a number of benefits to the goby population, in addition to providing side-channel habitat.

According to the U.S. Fish and Wildlife Service, which has prepared a draft recovery plan for the tidewater goby (USFS 2004), the key threats to the goby that are relevant to the Santa Clara River population include agricultural discharges, sewage treatment effluent, water diversions, and exotic species. The discharge from the VWRF is tertiary-treated effluent and represents high-quality water. Moreover, it is regularly tested for toxicity, contaminants and nutrients, and current evidence indicates that it does not pose a threat to the lagoon in terms of contaminant or nutrient loads that might adversely affect water quality or harm aquatic organisms. This is further supported by lack of observations of fish kills in the lagoon, which are comparatively common occurrences in many other lagoons located in southern California. In addition, the presence of a continuous source of relatively high-quality water should tend to dilute the impacts of any nutrient or contaminant inputs related to agricultural or urban runoff that might enter the lagoon.

Water diversions that limit inputs of freshwater to lower reaches of streams tend to result in the increase of salinity in lagoons. Under these conditions, tidewater gobies will migrate to areas of lower salinity where possible. Again, the low salinity of the VWRF discharge compensates for reduced freshwater flows to the estuary, and tends to maintain the salinity of most of the lagoon within the optimal range for gobies.

Beach breaching is also a potential threat to the goby due to the potential for outflows to carry gobies out of the lagoon as the water drains. The continued input of water from the VWRF may affect the frequency of breaching as it causes the lagoon to fill even during periods of little or no input from the river itself. While breaching does in fact drain the lagoon, goby populations are maintained in remnant habitat located within the lagoon basin, including the main river channel, the VWRF outfall channel, and shallow depressions that trap water during the outflow event. Breaching events do provide advantages, however, in that they promote circulation and flushing of water in the lagoon, which help to maintain water quality. Furthermore, flushing the lagoon with sea water, as the flow reverses through the berm during the incoming tide, prevents the long-term establishment of freshwater exotic species (e.g., African clawed frogs, *Gambusia*, sunfish) that may compete with the gobies.

A recent study that investigated historic and current use of the estuary by steelhead (Kelley 2004) concluded that present conditions in the estuary provide poor steelhead smolt habitat. The estuary historically contained coarse sediments that provided habitat for prey species utilized by steelhead smolts. Today, increased siltation, in conjunction with water diversions that have altered the flood regime, have caused the estuary to fill with finer sediment, which affects the abundance and composition of food organisms. These changes have also resulted in decreased water depth, causing warmer conditions in dry seasons and greater exposure to predators. Moreover, the dramatic reduction in the overall size of the lagoon restricts its carrying capacity with respect to the numbers of juvenile steelhead (and other aquatic organisms, as well) that it is capable of supporting. In addition, changes in flow characteristics of the river following storm events limit the ability of the adults to migrate through the lower reaches of the river to upstream spawning grounds, as well as the potential for smolts to reach the estuary.

3.3.2.3 Amphibians and Reptiles

Two amphibians, Pacific treefrog and African clawed frog, have been observed in the study area. Three reptile species, silvery legless lizard (*Anniella pulchra pulchra*), western fence lizard (*Sceloporus occidentalis*) and San Diego gopher snake (*Pituophis melanoleucus annectens*), have been observed just outside of the study area, and there is a habitat within the study area that could potentially support these species. There are a total of seven sensitive amphibian and reptile species that could potentially occur within the area. The red-legged frog (*Rana aurora draytonii*) is the only amphibian in the area afforded legislative protection. Sensitive species of reptiles potentially occurring in the study area include southwestern pond turtle (*Clemmys marmorata pallida*), silvery legless lizard, south coast garter snake (*Thamnophis sirtalis* spp.), two-striped garter snake (*Thamnophis hammondii hammondii*), coast patch-nosed snake (*Salvadora hexalepis virgultea*), and San Diego horned lizard (*Phrynosoma coronatum blainvillei*) (AMEC 2004).

3.3.2.4 Birds

Both resident and migratory birds take advantage of the habitat complexity associated with estuaries. As a result, a diverse bird assemblage is present in the study area year-round and, not surprisingly, birds comprise the most extensive list of sensitive species potentially found in the area. A total of 18 sensitive species have been documented in the study area or have been reported nearby in habitats also found in the study area. Of these, 11 species have been observed in the study area within the last decade (CDFG 2003), including white-faced ibis (*Plegadis chihi*), Cooper's hawk (*Accipiter cooperii*), sharp-shinned hawk (*A. striatus*), Northern harrier (*Circus cyaneus*), western snowy plover (*Charadrius alexandrinus* ssp. *nivosus*), long-billed curlew (*Numenius americanus*), California least tern (*Sterna antillarum* ssp. *browni*), elegant tern (*Sterna elegans*), yellow warbler (*Dendroica petechia brewsteri*), bank swallow (*Riparia riparia*), and yellow-breasted chat (*Icteria virens*). Bank swallows appear to have been extirpated as breeding birds in the study area in the mid-1970s, western yellow-billed cuckoo (*Coccyzus americanus* ssp. *occidentalis*) were last recorded in 1942, and black rail (*Laterallus jamaicensis* ssp. *coturniculus*) populations are no longer found in Ventura County.

Table 3-1. Sensitive and Protected Species Potentially Supported by the Santa Clara River Estuary. Sources: CDFG 2003, 2004; Santa Clara River Project Steering Committee 1996b

Taxon	Species		Status	Habitat	Occurrence Potential/Potential Habitat in Estuary
Plants					
Family	**Common name**	**Scientific name**			
Fabaceae	Ventura marsh milk-vetch	*Astragalus pycnostachyus* var. *lanosissimus*	Federal Endangered California Endangered	Coastal salt marsh. Within reach of high tide or protected by barrier beaches, more rarely near seeps on sandy bluffs.	Low. Historically in coastal southern California; now known at one site in Ventura County. No longer found at mouth of Santa Clara River.
Scrophulariaceae	Salt marsh bird's-beak	*Cordylanthus maritimus* ssp. *maritimus*	Federal Endangered California Endangered	Coastal salt marsh, coastal dunes. Limited to the higher zones of salt marsh habitat.	Low. Historically present near the mouth of the Santa Clara River in the vicinity of McGrath State Beach. Has not been seen at this site since 1960.
Insects					
Order	**Common name**	**Scientific name**			
Coleoptera	Sandy beach tiger beetle	*Cicindela hirticollis* ssp. *gravida*	Federal Species of Concern	Common to areas with clean, dry, light-colored sand. Occur in bright sunlight in open sandy areas, on sandy beaches.	Moderate. Southern foredune habitat near the river mouth and all areas of alluvial scrub habitat have the potential to support this species.

Taxon	Species		Status	Habitat	Occurrence Potential/Potential Habitat in Estuary
Fishes					
Class	**Common name**	**Scientific name**			
Salmonidae	Southern steelhead trout	*Oncorhynchus mykiss* ssp. *iridius*	Federal Endangered California Species of Special Concern	Fast water in mainstream rivers; medium to large tributaries; riffle sections of natal streams. Reported from coastal streams in Monterey, San Luis Obispo, and Santa Barbara Counties; the Ventura, Santa Clara, Santa Ynez Rivers; and Malibu Creek.	Occurs. Active channel from mouth of the Santa Clara River to Piru Creek is potentially suitable habitat.
Cyprinidae	Arroyo chub	*Gila orcuttii*	Federal Species of Concern California Species of Special Concern	Weedy shallows of lakes and ponds; quiet waters of slow-moving rivers. Reported from Malibu Creek, Santa Clara, San Luis Rey, Santa Maria, Santa Ynez, Mojave, Cuyama, and Santa Margarita River drainages (Moyle et al. 1995).	Occurs. Adequate habitat exists. Arroyo chub have been found in recent fish surveys of the estuary.
Catostomidae	Santa Ana sucker	*Catostomus santaanae*	Federal Threatened California Species of Special Concern	Inhabits small, shallow streams. Large numbers in the upper Santa Clara River, but potentially in the lower portions of the river (Moyle et al. 1995; Swift et al. 1993).	Occurs. Adequate habitat exists. Santa Ana sucker. have been found in recent fish surveys of the estuary.

Taxon	Species		Status	Habitat	Occurrence Potential/Potential Habitat in Estuary
Gasterosteidae	Unarmored threespine stickleback	*Gasterosteus aculeatus* ssp. *williamsoni*	Federal Endangered California Endangered	Seasonally abundant but highly restricted in range to slow-moving streams surrounded by dense vegetation, with mud or sand substrates.	Low. Historic presence in side-channels possible. Tolerant of low-oxygen and impaired water quality.
Gobiidae	Tidewater goby	*Eucyclogobius newberryi*	Federal Endangered California Species of Special Concern	Benthic, restricted mostly to small coastal lagoons and near stream mouths in the uppermost brackish portions of larger bays.	Occurs. Gobies have been found in recent fish surveys of the estuary.
Amphibians and Reptiles					
Class	**Common name**	**Scientific name**			
Ranidae	California red-legged frog	*Rana aurora* ssp. *draytonii*	Federal Threatened California Species of Special Concern	Lowlands and foothills in or near permanent sources of deep water with dense, shrubby or emergent riparian vegetation. Requires 11-20 weeks of permanent water for larval development. Must have access to estivation habitat.	Low. No suitable habitat in the study area.
Emydidae	Southwestern pond turtle	*Clemmys marmorata* ssp. *pallida*	Federal Species of Concern California Species of Special Concern	Requires slow-water aquatic habitat; uncommon in high-gradient streams. Historically located in Pacific slope drainages from Washington, along the Columbia River to Arroyo Santa Domingo, northern Baja California, Mexico (Jennings and Hayes 1994).	Low. No suitable habitat in the study area.

Taxon	Species		Status	Habitat	Occurrence Potential/Potential Habitat in Estuary
Anniellidae	Silvery legless lizard	*Anniella pulchra* ssp. *pulchra*	Federal Species of Concern California Species of Special Concern	Herbaceous layers with loose soil in coastal scrub, chaparral, and open riparian habitats; sand of washes and beach dunes are preferred burrowing substrates.	High. Southern foredune, alluvial scrub, cottonwood/willow forest.
Amphibians and Reptiles, continued					
Class	**Common name**	**Scientific name**			
Colubridae	South coast garter snake	*Thamnophis sirtalis* spp.	Federal Species of Concern California Species of Special Concern	Restricted to freshwater marsh and upland habitats near permanent water that have good cover of riparian vegetation.	Occurs. Occurs along the Santa Clara River from the Coast to the Ventura/Los Angeles County line.
	Two-striped garter snake	*Thamnophis hammondii* ssp. *hammondii*	California Species of Special Concern	Highly aquatic; most commonly found in or near permanent water; occasionally found in small and intermittent streams with rocky beds.	Moderate. Riparian scrub, woodland, and forest; freshwater marsh.
	Coast patch-nosed snake	*Salvadora hexalepis* ssp. *virgultea*	Federal Species of Concern California Species of Special Concern	Inhabits grasslands, chaparral, sage scrub, and sandy and rocky areas on the lower slopes of mountains.	Low. Little habitat exists for this species.

Taxon	Species		Status	Habitat	Occurrence Potential/Potential Habitat in Estuary
Iguanidae	San Diego horned lizard	*Phrynosoma coronatum* ssp. *blainvillei*	Federal Species of Concern California Species of Special Concern	Associated with coastal sage scrub and riparian woodlands, especially areas level to gently sloping ground with well-drained, loose or sandy soil.	Low. Little habitat exists for this species in the study area.
Birds					
Class	**Common name**	**Scientific name**			
Ardeidae	Western least bittern	*Ixobrychus exilis* ssp. *hesperis*	Federal Species of Concern California Species of Special Concern	Nests in dense emergent wetland vegetation cattails and tules.	Moderate. Suitable freshwater marsh habitat exists in the study area.
Threshkiornithidae	White-faced ibis	*Plegadis chihi*	Federal Species of Concern California Species of Special Concern	Fresh emergent wetland vegetation, shallow lacustrine waters, and muddy ground of wet meadows and irrigated, or flooded pastures and croplands.	Occurs. May be found in the active channel or near the river mouth.
Accipitridae	Cooper's hawk	*Accipiter cooperii*	California Species of Special Concern	Mainly woodland species but may also be found around farm wood lots and urban areas.	Occurs. Fairly common in winter. Riparian scrub, woodlands, and forests.
	Sharp-shinned hawk	*Accipiter striatus*	California Species of Special Concern	Woodlands, parks, and residential areas.	Occurs. Riparian scrub, woodlands and forests.

Taxon	Species		Status	Habitat	Occurrence Potential/Potential Habitat in Estuary
	Northern harrier	*Circus cyaneus*	California Species of Special Concern	Prairie, slough, wet meadow, and marsh habitats; hunts over grassland, agricultural field, and coastal and freshwater marshes.	Occurs. Agricultural fields, and freshwater and coastal marsh.
Birds, continued					
Class	**Common name**	**Scientific name**			
Accipitridae	White-tailed kite	*Elanus caeruleus*	California fully protected	Nests in rolling foothills/valley margins with scattered oaks and river bottomlands or marshes adjacent to deciduous woodland. Forages in open grasslands, meadows, or marshes close to isolated, dense-topped trees for nesting and perching.	Low. Optimal habitat conditions do not exist in the study area.
Rallidae	California black rail	*Lateralius jamaicensis* ssp. *coturniculus*	Federal Species of Concern California Threatened	Wetlands dominated by rushes and cattails. Open grasslands, grazed pastures, or savannas are often associated with these wetlands.	Low. Black rail populations have been extirpated from Ventura County (Garret and Dunn 1981).
Charadriidae	Western snowy plover	*Charadrius alexandrinus* ssp. *nivosus*	Federal Threatened California Species of Special Concern	Sandy beaches, salt pond levees, and shores of large alkali lakes. Needs sandy, gravelly, or friable soils for nesting.	Occurs. Currently nests on McGrath State Beach adjacent to the mouth of the river.

Taxon	Species		Status	Habitat	Occurrence Potential/Potential Habitat in Estuary
Scolopacidae	Long-billed curlew	*Numenius americanus*	Federal Species of Concern California Species of Special Concern	Large coastal estuaries, salt marshes, tidal flats, upland herbaceous areas, and croplands.	Occurs. Suitable habitat exists in the study area.
Birds, continued					
Class	**Common name**	**Scientific name**			
Laridae	California least tern	*Sterna antillarum* ssp. *bronwni*	Federal Endangered California Endangered	Nests in colonies along the coast from San Francisco Bay south to northern Baja California. Breeds on bare or sparsely vegetated, flat substrates.	Occurs. Can be found from the Santa Clara River mouth south to McGrath Lake.
	Elegant tern	*Sterna elegans*	Federal Species of Concern California Species of Special Concern	Inshore coastal waters, bays, estuaries, and harbors.	Occurs. Can be found on beach, southern foredune, and active channel areas near the river mouth.
Cuculidae	Western yellow-billed cuckoo	*Coccyzus americanus* ssp. *occidentalis*	California Endangered	Dense woodland and riparian forests, including cottonwood and willow.	Low. Last recorded in the vicinity of the estuary in 1942.
Tyrannidae	Southwestern willow flycatcher	*Empidonax trailii* ssp.*extimus*	Federal Endangered California Endangered (*E. trailli*)	Riparian and wetland habitat. Prefers stands of willows, mulefat, arrow weed, tamarisk, and other riparian vegetation.	Low. No recorded instances of breeding have been recorded on the Santa Clara River. Willow riparian woodland is suitable habitat.

Taxon	Species		Status	Habitat	Occurrence Potential/Potential Habitat in Estuary
Laniidae	Loggerhead shrike	*Lanius ludovicianus*	Federal Species of Concern California Species of Concern	Inhabits grasslands, agriculture, chaparral, and desert scrub.	Low. May use marginal areas infrequently. Open scrub habitats, farmlands, vacant lots.
Birds, continued					
Class	**Common name**	**Scientific name**			
Vireonidae	Least Bell's vireo	*Vireo bellii* ssp. *pusillus*	Federal Endangered California Endangered	Riparian habitat, usually in dense willow-dominated thickets.	Low, not likely to occur. Potential habitat includes mulefat scrub and willow riparian woodlands.
Hirundinidae	Bank swallow	*Riparia riparia*	Federal Species of Concern California Threatened	Nests primarily in riparian and other lowland habitats west of the desert. Requires vertical banks/cliffs with fine-textured/sandy soils near streams, rivers, lakes, and ocean to dig nesting hole.	Occurs in migration. Breeding birds possibly extirpated. One or two pairs nested in the Santa Clara River Estuary in 1976.
Parulidae	Yellow warbler	*Dendroica petechia* ssp. *brewsteri*	California Species of Special Concern	Requires riparian woodland for breeding, but utilizes a wide variety of trees during migration.	Occurs. Nests and calls from taller trees. Riparian scrub, woodlands, and forests.
Icteridae	Yellow-breasted chat	*Icteria virens*	California Species of Special Concern	Dense riparian woodlands in coastal lowlands.	Occurs. Riparian scrub, woodlands, and forests.

Occurrence Potential/Potential Habitat Values

Occurs: Recorded within the study area in recent years.

High:	Species is expected to occur or utilize habitats during migration, life stages, or breeding; suitable habitat exists, and the study area is within known range and has connectivity to known habitats.
Moderate:	Species could occur within study area because suitable habitat exists, but there is no or little connectivity, or barriers to passage exist.
Low:	No suitable habitat within the study area, or the species has been extirpated (no longer occurs in this portion of historic range, but is not extinct).

3.4 Discussion

Clearly, the lower reaches of the Santa Clara River, including the study area, have been significantly altered by urban and agricultural development over time. As a result, most of the habitat historically available has been lost. Development in the vicinity of the study area, particularly levees and bridge abutments, has also affected hydrological function in terms of increasing water velocity and scouring, as well as reducing the capacity to absorb higher flows during flooding events, and when the lagoon backs up during river mouth closure periods.

Formation and maintenance of current habitat in the study area appear to be dominated by flood events, which are associated with both scouring and deposition of sediments. Compared with historical conditions, the levees have constrained the river and reduced the floodplain, which further increases the flood/scour impacts of the river on the estuary because most of the water is directed through the estuary, rather than being able to distribute across side-channels and sloughs. Productive and diverse marsh communities typically associated with estuaries account for less than 10 percent of the total area largely because of the absence of suitable flow regime and substrate. In terms of vegetation communities, there is very little transition area around the perimeter of the estuary, and the communities appear to transition rapidly into riparian scrub and woodland.

From an ecological perspective, all of the habitat types have been markedly reduced in size compared with historical conditions. This has had an immediate impact in terms of limiting carrying capacity for resident organisms; effectively limiting overall numbers of organisms that the area can support, as well as eliminating organisms whose size or home-range requirements exceed the available area. Consequently, the restricted habitat favors smaller organisms with limited home ranges and habitat requirements. The tidewater goby is an example of such an organism; its status as a protected species makes it an appropriate species for evaluating ecological conditions.

The lagoon remains the most conspicuous habitat component of the estuary. From the perspective of tidewater goby populations, key habitat includes the area of the lagoon, which limits population size; water quality, which needs to remain within ranges (e.g., temperature, DO, salinity) that do not limit survival or place physiological stress on the organisms; substrate suitable for spawning and incubating eggs; sufficient cover to provide protection from predators; and side-channel habitat that provides refugia from high stormwater outflows during flood events. Notably, the most stable side-channel freshwater marsh habitat is associated with the VWRF outflow channel. Photographs (Figure 3-8) taken of the discharge channel before and after a major storm event (50- to 100-year flood event) in early January 2005 demonstrate the stability of this habitat, as the vegetation adjacent to the discharge channel remained intact after the event.

In addition to providing refugia for aquatic organisms during times of high outflow events, the outfall channel is continuously wetted due to flows from the VWRF. Thus, it does not drain completely during outflow periods when the berm is open, as is the case with the few other remaining side-channels. Consequently, during extended outflow periods at low tide, the only water in the lagoon is in the main channel, in the outfall channel, and any depressions that hold water as the lagoon drains. It is during these periods of time when aquatic habitat is most limiting; the organisms are constrained to limited wetted areas where they are most vulnerable to predation, temperature exceedances, or desiccation. Again, the outfall channel provides the most valuable habitat under these conditions, because the vegetated perimeter and upper sections contain additional cover for organisms (e.g., tidewater gobies) that are present.

One of the key questions regarding operation of the VWRF and continuous discharge of treated freshwater effluent to the estuary is whether this freshwater discharge has altered the general characteristics of the estuary from a marine-dominated system to one dominated by freshwater. However, extensive review of the historical record suggests that the Santa Clara River Estuary was never a marine-dominated system. The earliest map of the area indicates only limited areas of potential salt marsh, and maps and aerial photographs taken prior to construction of the VWRF also show little or no evidence of salt marsh. In fact, most of the vegetation lining the lagoon in these photographs is a combination of freshwater marsh and willow riparian scrub, both of which indicate that the plants are exposed to low levels of salinity.

Another key issue related to potential impacts of the continuous flow from the VWRF is that this represents an “atypical” condition relative to the historical condition where it has been speculated that the Santa Clara River was dry in the lower reaches during the summer months and, consequently, flows reached the estuary only on a seasonal basis. However, review of the historical record suggests that flows were present in the lower reaches on a continuous basis, with particular reference to late summer months. These observations are also consistent with the historical presence of freshwater marshes extending upstream at least to Saticoy, as well as reports of comparatively long periods of elevated flows following storm events. Once groundwater pumping began in the basin, surface flow patterns in the lower reaches would have been severely altered as they drained into the depleted aquifer.

VWRF discharge channel prior to storm events (photograph taken 28 September 2004).

VWRF discharge channel after the storm events (photograph taken 31 January 2005).

Figure 3-8. Comparison of VWRF discharge channel before and after the January 2005 storm events.

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4.0 Evaluation of Hydrological Conditions in the Santa Clara River Estuary

4.1 Introduction and Study Goals

The hydrology and coastal lagoon assessments presented herein are part of a number of integrated environmental assessments of the Santa Clara River Estuary recently completed on behalf of the City that evaluate the potential impacts of treated effluent discharge on water quality and the habitat of species in the estuary. The hydrology investigations are aimed at characterizing current and historical hydrologic and geomorphic changes in the estuary. Study objectives include monitoring and analyzing seasonal changes in estuary inflow; water level, water quality (salinity/temperature/DO /pH) monitoring; assessing the long-term and seasonal changes in lagoon hydro-geomorphic conditions; and hydraulic analyses to characterize the coastal conditions and processes associated with inlet stability and closure. Specific assessments completed to address these objectives, which are presented in this report, are as follows:

- Perform extensive review of background reports, maps, aerial photographs, and data sets to describe the existing and historic hydrologic, geomorphic, and coastal conditions and processes in the estuary.

- Prepare a record of natural and actual surface water inflows into the lagoon to quantify the changes in the magnitude and seasonal pattern of freshwater inflow to the estuary.

- Assess the current and historical hydrologic and coastal conditions and processes controlling the ability for and timing of estuary inlet breaching and closure.

- Satisfy requirements of Regional Board Order No. R4-2004-0195 for additional monitoring that characterizes existing hydrology conditions and water quality. Monitoring completed under this study included continuous and seasonal/event monitoring of estuary water levels and water quality (temperature, salinity, DO, and pH) throughout the estuary.

4.2 Physical Setting

The Santa Clara River watershed covers approximately 1600 square miles and is one of the largest watersheds in southern California. The study area for this investigation consists of the lower Santa Clara River flooded area at the river mouth, and outfall to the Pacific Ocean). Given the shallow, freshwater-dominated, and seasonally closed-off nature of the Santa Clara River mouth, it is referred to as a "coastal lagoon" throughout this report (Sorensen et al. 1993). Based on water level monitoring and field observations, it is estimated that the coastal lagoon extends approximately 1 mile upstream of the river mouth and approximately 3,000 feet upstream of the Harbor Boulevard Bridge when fully flooded (see Figure 4-1). The northern side of the lagoon is bounded by the VWRF and Union Oil storage tank facility on the west side of Harbor Boulevard and Olivas Park golf course and agricultural fields to the east of Harbor Boulevard. The lagoon is bounded on the south (from west to east) by McGrath State Beach (west of Harbor Boulevard) and agricultural fields on the east side of Harbor Boulevard.

Several bridges have been built spanning the lagoon and lower river, including (from upstream to downstream) a highway and Southern Pacific railroad bridge at Montalvo in 1897 and 1898, respectively; the Victoria Avenue bridge in 1975; the existing Harbor Boulevard Bridge in 1955; and the former Bard Beach or Beach Road bridge that existed several hundred feet west of the Harbor Boulevard Bridge in the 1930s but only lasted several years (Schwartzberg and Moore 1995). Other historic anthropogenic influences along the lower river included duck ponds and duck blinds located near the river mouth and maintained by duck clubs during the first half of the twentieth century (ibid). Although no diversion rates, volumes, or diversion periods are cited, Freeman (1968) indicates that the duck clubs diverted lower river water, presumably to flood areas seasonally to attract waterfowl. These volumes may not be trivial as the Santa Clara Water Conservation District unsuccessfully attempted to curtail this use during the drought of 1949. The following report sections provide descriptions of existing and historic geomorphic conditions.

4.2.1 Geology and Geomorphic Conditions

The Santa Clara River and coastal lagoon are located in the Transverse Ranges geologic province of California (Norris and Web 1990). In contrast to most northwest-southeast trending mountain ranges in California, this province is characterized by east-west trending mountain ranges and valleys. The Santa Clara River valley is bounded on the north by the Topatopa Mountains and on the south by the Santa Susana Mountains, all of which drain the 1,600-square mile watershed. The main stem of the Santa Clara River follows the axis of a massive sedimentary syncline that extends from the Sierra Pelona vicinity westward beyond Ventura into the Pacific Ocean (Williams 1979). The lower 9 miles of the river flow across the Oxnard Plain before discharging into the Pacific Ocean approximately 2.5 miles south of downtown Ventura. The Oxnard Plain is a broad flat expanse of coalescing alluvial fans deposited from the Santa Clara River and Calleguas Creek. Because of the low slope and relatively high sediment load carried by the Santa Clara River, the river exists as a semi-meandering, braided channel across the Oxnard Plain in contrast to the confined channel that feeds it (Williams, 1979). Agricultural and urban development on the Oxnard Plain have acted to confine the channel and channel meandering within fixed boundaries. This is especially evident along the lower coastal lagoon reach where levees have been built to direct the lower river, especially during flooding events.

The lower Santa Clara River and its coastal lagoon comprise a dynamic system. Seasonally, the lower Santa Clara River may vary between a daily flooded and drained braided channel when there is an open connection to the ocean (typically winter) and a closed to semi-closed lagoon behind a beach barrier (typically summer). The duration and extent of these end-member states is controlled by the interplay of a variety of physical processes and human activities that control the construction or breaching of the barrier beach.

Episodic flood events appear to be an important control over the interior lagoon geometry and active channel alignment. It is during infrequent floods that a large volume of sediment is transported through the lagoon, resulting in an ever-changing positioning of interior bars and braided channels. Swanson et al. (1990) report that floods with a recurrence interval of once every 3 to 5 years scour away most of the vegetation that becomes established on the riverbed, realign channels, and create new sediment bars. In addition, it is during flood events that the offshore river-mouth delta is constructed or expanded. Most sediment generated in the upper watershed and, in turn, deposited within the lagoon or river delta is silt- and sand-sized material. The sandy, alluvial composition of the coastal lagoon allows the channel to more readily distribute energy on the floodplain and sandbars, and thus shift its position more frequently during high flows. Flood events are also responsible for periodic bank and levee erosion, major channel realignments, and southward expansion of the lagoon into historically leveed off lands of McGrath State Beach.

Just prior to the flood of December 28, 2004, the active channel in the Santa Clara River coastal lagoon was approximately 500 feet wide at the Harbor Boulevard Bridge and had a floodplain width of over 1,800 acre-feet. In general, the lagoon is broad and shallow when flooded, with average water depth of approximately 2 feet at mean higher high water (MHHW). The lagoon is deepest along its main outflow channel adjacent to the inlet with measured water depths of 6 feet at MHHW. A bathymetric map of the lagoon is provided in Figure 4-2. This map was generated from bathymetry presented in ESA (2003), a Lidar topographic survey completed for the U.S. Army Corps of Engineers, Los Angeles District (data obtained from Ventura County), and ground truthed by topographic surveys completed as part of this investigation and data presented in Swanson et al. (1990).

4.2.2 Historic Conditions and Changes

A variety of historic maps and aerial photographs were reviewed to estimate changes in lagoon size over time. The oldest map reviewed was the U.S. Coast and Geodetic Survey Nautical Chart of the Santa Clara River mouth dated 1855 (in CDPR 1990). The approximate boundaries of the lagoon in 1855 are plotted in Figure 4-3. For comparison, the approximate northern and southern boundaries of the lagoon in 1994 (date of background aerial image on map) are also indicated in Figure 4-3. Swanson et al. (1990) estimate the 1855 lagoon occupied an area of approximately 870 acres, with an average width of 5,000 feet. Based on the delineation presented in Figure 4-3, the 1855 lagoon was over 9,000 feet wide at the current Harbor Boulevard Bridge location. It's important to note that 1855 is likely representative of a natural or near-pristine lagoon conditions as the period of commercial agricultural development and surface water diversions along the lower river began later in the 1860s and 1870s (Freeman 1968; Schwartzberg and Moore 1995). However, accelerated agriculture development in the watershed began along the lower 15 miles of the Santa Clara River on the Oxnard Plain and little cultivation was attempted in the river valley above Santa Paula at this time (Schwartzberg and Moore 1995). Other sources reviewed depicting the historic extent of the lagoon include:

- Aerial photographs from 1929, 1934, 1945, 1953, 1957, 1969, 1974, 1977, 1978, 1987, 1994, 2002, and 2004;
- USGS topographic quadrangle maps dating from 1949;
- Beach Erosion Authority for Clean Oceans and Nourishment (BEACON) coastal photographs of the river mouth from 1972, 1979, 1987, 2002, and 2004;
- Lidar topographic survey of lower Santa Clara River completed for the U.S. Army Corps of Engineers, Los Angeles District, in 2001 (obtained from Ventura County); and
- A GPS survey completed as part of this study on February 9, 2005.

Based on a review of this information, selected lagoon boundaries for 1929 and 1959 are plotted in Figure 4-3, in addition to 1885 and 1994, to highlight the systematic urban and agricultural "land reclamation" and encroachment into the Santa Clara River lagoon between 1885 and 1994. Faint but distinct traces of historic channels on agricultural lands of the Oxnard Plain adjacent to the lower river can also be seen in historic aerial photographs and USGS topographic quadrangle maps, depicting the former broad meandering character of the river channel. As of 2004, levee construction along the lower river had reduced the active channel width by 75 percent, constricting the flow area in a fashion that centralizes scour and sediment transport. The constriction of flow proves to be especially damaging during major floods. Schwartzberg and Moore (1995) report that during the 1920s, rows of pilings or "breakwater" were installed down the middle of the river below the Montalvo bridge along with jetties and groins along the banks for flood control purposes. These structures were likely intended to direct flood flows in an effort to protect banks from erosion. Schwartzberg and Moore also report, "casual dumping of trash on both sides of the river" along the margins of the coastal lagoon. They state,

Near the river mouth, at the site of the marina, was the old Sears-Walker by the sea burn dump, where trash was often bulldozed into the Ocean. Behind the levee built to protect the Olivas Park golf course, the city of Ventura dumped street and green waste, but they are working to clean up this project.

Historic floods have occurred in 1811, 1815, 1820-21, 1825, 1840, 1862, 1884, 1909, 1913, 1914, 1938, 1969, 1978, 1980, 1983, 1992, and 1998 (Schwartzberg and Moore 1995; USDA 1953; CDPR 1990; ESA 2003; and Grunfest and Taft 1992). The January 1969 flood is the largest on record (estimated as the 100-year flood event: CDPR 1990) with a peak flow rate of 160,000 cubic feet per second (cfs). This flood realigned the main river channel, jumping the north bank immediately upstream of the Harbor Boulevard Bridge and flowing into the southeast corner of the Ventura Harbor at two independent locations (U.S. Army Corps 1970, 1971). The City's wastewater treatment plant, much of the Ventura Harbor, and associated infrastructure were destroyed during this event. Freakishly, this flood was followed by a 150,000-cfs flood a month later in February 1969. The damage from these events prompted the U.S. Army Corps to rebuild larger and longer levees along the north side of the river to protect against similar events. As a result, it appears from review of available maps and aerial photographs that the shoreline and levee system along the southern side of the lagoon is preferentially eroding during the floods following the 1969 event. The southward migration of the southern shoreline of the lagoon and river channel is depicted in Figure 4-4. As exemplified by the notable shoreline shift between 1969 and 2005, the vast majority of the bank erosion along this shoreline occurs during individual flood events. A good example of this episodic change is the shoreline retreat between 2004 and 2005, which occurred in response to the flood of December 28, 2004.

Various activities over the last century have also altered the typical southern California pattern of seasonal breaching and reconstruction of the barrier beach that forms the Santa Clara River coastal lagoon. An interesting, early anecdotal account of the sand-spit and coastal lagoon breaching and reconstruction is presented by Grunsky (1925), and includes:

The mouth of the river is closed to the ocean for a considerable period of time each year by a barrier of sand that is thrown up by the ocean waves. The crest of this barrier is usually at such a height that when the river begins to flow in early winter its water accumulates behind the same to a height which the landowners in the vicinity find undesirable. An artificial cut is then made through the barrier and the ponded water escapes. If there is abundant rainfall and a fair amount of runoff the cut is kept open by flowing water. If there is but little water to be discharged in the ocean the cut may be repeatedly closed by the ocean storms in a single season. No information is at hand as to whether there has ever been a time when the river maintained an open mouth throughout an entire year.

As described throughout this report, a number of different human activities have altered the seasonal cycle of lagoon formation, leading to an increased frequency and unseasonal timing of lagoon spit breaching and draining. In addition to farmers breaching the barrier beach, the McGrath State Beach 1979 General Plan indicates park personnel would routinely breach the estuary sandbar to prevent flooding in the campgrounds (ESA 2003). In addition, there are reliable accounts that surfers are known to have breached the barrier beach in order to create or enhance shoaling in the surf break to improve surfing conditions (Camm Swift, personal communication, 2004).

Based on review of an 1852 Land Grant map and the 1855 U.S. Coast and Geodetic Survey Chart, the natural character of the lagoon and alluvial river delta system is described in Schwartzberg and Moore (1995) as follows.

Two freshwater lakes, "lagunas agua dulce", appear near the sand dune border with the ocean and near the border of the river. These fresh water lakes could be bits of McGrath Lake or something similar, perhaps drainage ponds. An 1855 map shows McGrath Lake in the same position as it is today, and a sandbar across the mouth of the river.

ESA (2003) also report that McGrath Lake is a freshwater dune lake and historically was part of the Santa Clara River coastal lagoon. They also indicate that the lake was sustained primarily by groundwater inflow, with surface water runoff from surrounding areas likely contributing minor volumes of water and that the lake did not have a surface drain to the ocean, although occasional high ocean waves would wash over dune ridges. Based on review of an 1867 map, Schwartzberg and Moore go on to report the river mouth conditions as follows.

Surveyors estimated the mouth of the river at fifteen to twenty chains (330 to 440 yards), the sand dunes parallel to the ocean between 100 to 550 yards, and the "swampy land full of sloughs and lagunas [lakes] extending along the whole front of the rancho" between one-half to three-quarters of a mile wide.

This hummocky or pock-marked topography extending up to 1,000 yards inland from beach dunes is still quite evident between McGrath Lake and Channel Island Harbor on the USGS Oxnard 7.5-minute quadrangle map created in 1949 and photorevised/inspected in 1967.

Apart from the excerpts and information presented above, no other specific descriptions or accounts of lagoon conditions and processes (or water quality) were found during the review of background reports and materials as part of this study. However, historic descriptions of vegetation, topography, shallow groundwater conditions, and water development on the Oxnard Plain, as presented in Section 4.3, provide important insight into the main variables that would influence and maintain the water supply to the historic coastal lagoon and associated wetland/riparian systems.

4.3 Existing and Historic Groundwater Conditions

4.3.1 Regional Groundwater Basins

There is a sequence of groundwater basins that underlie the Santa Clara River that vary in character, available yield, and recharge rate. If not otherwise cited, much of the description of groundwater conditions presented herein is derived from three main references, including Hanson et al. (2003), ESA (2003), and United Water Conservation District (UWCD 2003). The groundwater basins discussed below are subareas within the Santa Clara River drainage basin and most groundwater basin boundaries are aligned with known faults and other geologic features. The degree to which one basin is hydraulically connected to another (lateral connection) or connection between aquifers within any given basin (vertical connection) is highly variable.

The Santa Clara River coastal lagoon lies atop the Mound groundwater basin. The size and location of the Mound basin and surrounding groundwater basins are indicated in Figure 4-5. The east-west contact between the Mound basin and adjacent Oxnard Plain basin lies near the southern border of McGrath State Beach and is defined by the east-west trending McGrath Fault. Because there is northwestward underflow from the Oxnard Plain basin into the Mound basin, and the stratigraphic units are correlative between basins, the following description of groundwater conditions is applicable to both basins. The Mound basin in bounded on the southeast by the Oxnard Plain Forebay basin and on the east by the Santa Paula basin (see Figure 4-5).

The Mound and Oxnard basins consist of an upper and lower aquifer system, commonly referred to as the UAS (upper aquifer system) and LAS (lower aquifer system). Unconsolidated sediments of the late Pleistocene and Holocene epochs are grouped into the UAS while the LAS is composed of complexly faulted and folded unconsolidated deposits of the older Pliocene and Pleistocene epochs. Collectively, these basins are up to 2,000 feet deep and contain gravel and sand deposited along the ancestral Santa Clara River, alluvial fan material propagating along the flanks of adjacent mountains, and a coastal plain/delta complex at the terminus of the Santa Clara River. The basins are underlain by consolidated Tertiary-aged sedimentary rocks that make up most of the surrounding mountains. These basement rocks are considered nearly impermeable except for some low permeability sandstones and fracture systems. Individual aquifers in the basin fill material are separated by laterally continuous, low permeability silt and clay layers.

In the Mound and Oxnard basins, the UAS consists of three aquifers. The deepest aquifer is called the Mugu aquifer and is generally found between 255 to 425 feet below ground surface (bgs). The middle aquifer is called the Oxnard aquifer and is generally located from 100 to 220 feet bgs. The Oxnard aquifer is the primary water supply aquifer on the Oxnard Plain. Both the Oxnard and Mugu aquifers are confined aquifers in the Mound and Oxnard Plain basins. Under pre-development conditions, these aquifers were also artesian with water reportedly rising up to 35 feet above ground surface in some of the first wells installed in the area (Freeman 1968). Both the Mugu and Oxnard aquifers extend westward several miles offshore and are hydraulically connected to the ocean. When water levels are high in these aquifers, flow is offshore to the west-southwest. However, excessive pumping and overdraft from these aquifers, evident by the late 1920s, reversed flow gradients and led to seawater intrusion. In addition to water quality deterioration, groundwater overdraft from basin aquifers has led to land subsidence, although both of these problems are more prominent in the vicinity of the Mugu and Hueneme submarine canyons.

Of greatest significance to this study is the uppermost aquifer in the UAS called the Shallow aquifer. Along the Santa Clara River floodplain, this unconfined aquifer consists of recent river channel sand and gravel, extending to between 60 and 100 feet in depth. Farther from the river, on the Oxnard Plain, the Shallow aquifer consists of fine- to medium-grained sand interbedded with clay and is referred to as the "semiperched aquifer." Water in the "semiperched aquifer" is of poor quality and is rarely used for water supply (UWCD 2001). On the Oxnard Plain, the Shallow aquifer occasionally becomes perched due to overdraft and dewatering of the underlying Oxnard aquifer. Within the Mound and Oxnard Plain basins, the Shallow and underlying Oxnard aquifers are separated by a confining clay layer that generally protects the underlying aquifer from poor quality, shallow aquifer water and surface land uses. However, hydrology studies of the Oxnard Plain indicate that when water gradients are favorable (i.e., over-pumping of Oxnard aquifer) there is movement of poor-quality, semi-perched zone waters down to the Oxnard aquifer through failed well casings (UWCD and Castaic Lake Water Agency 1996). This is also believed to be a water movement pathway between the UAS and LAS.

Recharge to the Shallow aquifer along the river occurs from percolation of stream flow, rainfall, and irrigation. Rainfall and irrigation return flows are the main source of recharge to the more distal parts of the Shallow aquifer on the Oxnard Plain (UWCD and Castaic Lake Water Agency 1996). The primary recharge to the Oxnard Plain basin confined UAS aquifers is from underflow from the Oxnard Plain Forebay. In the Oxnard Plain Forebay basin, there are relatively few clay layers separating the Shallow and Oxnard aquifers and recharge to the Forebay UAS is from stream flow infiltration, mountain-front recharge, and/or surface spreading of water diverted from the Santa Clara River. High water levels in the Forebay exert a positive pressure on the confined aquifers and water flows from the recharge areas toward the coast. Under pre-development conditions, there was natural groundwater flow from inland recharge areas to the offshore extensions where there are accounts of large volumes of groundwater discharge to the nearshore Mugu and Hueneme submarine canyons and artesian conditions in the UAS confined aquifers of the Oxnard Plain (Hanson et al. 2003).

4.3.2 Shallow Groundwater at McGrath State Beach

The ESA study (2003) provides information regarding the nearly contiguous, shallow groundwater conditions underlying the State Beach bordering the south side of the coastal lagoon. Unless otherwise cited, the characteristics and conclusions presented in this section of the report were derived from the information presented in the ESA study. The location and aerial extent of McGrath State Beach and shallow groundwater monitoring locations are indicated in Figure 4-6 (modified from Figure 4-6 in ESA 2003).

Tidal flat and sandy loam deposits displaying relatively poor drainage due to a high water table and slow surface water runoff underlie McGrath State Beach. A shallow, dense clay or clay-sand layer is laterally extensive beneath the most of McGrath State Beach. Groundwater is perched on top of this clay layer and studies indicate the perched water table extends beneath the agricultural fields located east of Harbor Boulevard. Within McGrath State Beach, shallow water table elevations range from 3.5 to 6.5 feet NAVD88, with the water table surface sloping towards the Santa Clara River when the lagoon is not flooded (see Figure 4-6). This head differential in the shallow water table surface indicates groundwater flows from northeast to southwest or towards the river and coastal lagoon. Nearby McGrath Lake represents a low point where the shallow groundwater is exposed. Based on observations by local farmers, fields east of Harbor Boulevard flood due to rising shallow groundwater levels if McGrath Lake is not pumped (ESA 2003).

By 1947, an earthen levee was built along the northern boundary of the McGrath State Beach property to protect the area from flooding (Schwartzberg and Moore 1995). The location and extent of this levee is indicated in Figure 4-4. The levee remained intact until around 1998 when it became impacted by bank erosion and lagoon expansion (see Figure 4-4). The levee also eliminated surface flow from the river onto the floodplain. The brackish marsh that lies behind (west-southwest) the levee is maintained by the shallow groundwater that seasonally seeps through the sandy surface soils and ponds in the marsh and other low elevation areas. These low-lying areas experience seasonal surface ponding due to the backing up of groundwater, flooding large portions of the State Beach campground and causing routine closure (Virginia Gardner, California State Parks, personal communication, 2004). Historically, a flap-gated culvert allowed water to drain from areas in the park back into the lagoon. However, the flap gate did not always function properly and flooding of the lagoon prohibited drainage. With the erosion and removal of the southern levee beginning in 1998, flooding from river and lagoon surface water has exacerbated and accelerated the flooding within the park.

The backup of near surface groundwater in the park is increased when the barrier beach is closed and there is ponding in the coastal lagoon. Monitoring by Swanson et al. (1990) in July 1989 indicated that when the lagoon was flooded, the lagoon water surface elevation (11.5 feet NGVD88 was notably higher than the ponded/flooded areas in the diked marsh and State Beach campground, as well as the water surface elevation of McGrath Lake, which is maintained at approximately 6.5 feet NAVD88. The relative head differentials of these hydraulically connected surfaces suggest a reversal in the usual groundwater flow gradient, with flow now being away from the flooded lagoon and lower river towards the south. The specific lagoon-barrier beach morphologic and hydrologic controls over shallow groundwater flow direction, and the specific conditions that control the local groundwater flow directions under both lagoon-flooded and lagoon-empty conditions are presented and discussed in Section 4.6 (Lagoon Water Budget).

The only information obtained regarding water quality of the shallow groundwater comes from sampling of McGrath Lake. The water quality of McGrath Lake has been characterized as poor due to the lack of circulation, inputs of agricultural water runoff, and contaminated sediments. Based on McGrath Lake water quality and information regarding shallow groundwater quality in similar coastal settings, agricultural practices likely have the largest impact on the shallow groundwater quality in the form of elevated salt content and residual concentrations of pesticides and nutrients. Schwartzberg and Moore (1995) indicate that prior to the 1920s, there was a high water table in the lowland regions of the Oxnard Plain and alkali accumulation prevented successful production of certain crops. They state:

However, significant tiling provided these areas with improved drainage. Starting at the turn of the century, fields used for sugar beets were "tiled" and local drainage districts were formed to assist with the process. Tiling now underlies a vast portion of the Oxnard Plain and part of the river valley. Many ditches drain, eventually, to the Pacific Ocean or McGrath Lake, but a number of agricultural drains from this tiling contribute their runoff to the Santa Clara River itself. The character of such run-off water differs from the river's water.

The UWCD (1980) also state that, "there is inevitably a deterioration of quality" of groundwater pumped and ultimately discharged to the river as agricultural return flow. They also state that both municipal and agricultural uses increase the salinity of water returned to the river.

4.4 History and Impacts of Water Development in the Watershed

The following sections provide background information and the results of hydrologic analyses used to analyze and describe changes in surface water flow to the coastal lagoon. These changes in water supply play an important role in how the lagoon has changed and functions as it does today.

4.4.1 Background

The climate of the Santa Clara River watershed is variable, ranging from a moist, Mediterranean type near the Pacific Coast to a desert-like climate at the extreme eastern boundary. Annual precipitation varies from about 8 inches in the easternmost part of the basin to 40 inches near the headwaters of Piru Creek (Williams 1979; Rantz 1969) Annual precipitation totals have varied from one-quarter of the annual average to as much as two times the annual average (U.S. Department of Agriculture 1953). Like most southern California streams, inter- and intra-annual flows can vary widely with little to no flow occurring in the summer months and intense storms typically giving rise to sudden high flows and potential flooding in the winter. On a broader time-scale, multi-year droughts significantly diminish the magnitude and duration of surface water flow and lower groundwater levels, especially in aquifers that experience considerable groundwater withdrawals by pumping. Many of the historic water conservation/development projects undertaken in the Santa Clara River basin have been in direct response to the water deficiencies experienced during drought (Freeman 1968). Freeman states that in the 1860s and 1870s, "valley groundwater basins were full to overflowing, resulting in a perennial surface flow in the river channel throughout the valley." Freeman also reports that this stream baseflow component of discharge was larger prior to the 1930s.

Detailed numerical groundwater modeling of pre- and post-development basin conditions by Hanson et al. (2003) indicates that groundwater pumping has led to declining water tables in the watershed. This, in turn, leads to decreases in evapotranspiration and stream baseflow. They estimate that the current stream baseflow averages only 33 percent of the simulated pre-development baseflow.

An excellent graphic illustrating the history of wet and dry cycles in the Santa Clara River basin prepared by Freeman (1968) and later extended by Hanson et al. (2003) is presented here as Figure 4-7. This graphic illustrates the cyclical occurrence of droughts in the Santa Clara River watershed between 1770 and 1995 and resultant effects on surface water and groundwater availability. The backbone of this drought history is a rainfall cumulative departure curve. Such a curve is derived by summing the annual departures from "normal" conditions by subtracting the long-term average rainfall value from each annual rainfall total[1] for the period of record. Positive results indicate that the year experienced above average rainfall while the negative results indicate the

[1] In Figure 4-7, annual precipitation totals were calculated based on water years, which is the year-long period starting on 1 October and ending on 30 September of the named year.

year was drier than average. The curve itself is prepared by summing the annual departures and plotting the cumulative departure in a chronological fashion. A positive (rising) slope to the cumulative departure curve indicates extended wet periods of above average rainfall, while a negative (declining) slope indicates an extended period of below average rainfall (i.e., drought). Figure 4-7 also indicates years of notable floods. It's worth noting here that the perennial river flows through the 1860s and 1870s described by Freeman above occurred during the prolonged drought of 1843-1888, which may have not been sufficient to support local agriculture (as discussed below) but may have been sufficient to support and maintain healthy riparian and freshwater wetland habitats in the lower river and estuary.

Compounding the natural variable nature of runoff is the fact that the Santa Clara River watershed is a highly regulated system that has undergone considerable development of its water resources over the last century and a half. Agricultural and municipal water needs have probably placed the greatest demand increases on the basin's water supply. Under pre-development conditions, the largest discharge from the groundwater system was outflow to the Pacific Ocean and evapotranspiration. The introduction and expansion of groundwater pumping have diminished these outflows and now account for the largest source of outflow from the groundwater system. (Hanson et al. 2003).

Freeman (1968) reports that the Santa Clara River basin has undergone five classic technical advances in water development since European settlement, with the transition between each new development being spurned when demand exceeds available supply from a given technology. It's worth noting that older technical phases are not necessarily replaced by newer ones, simply augmented. The five distinct advances in water development in the Santa Clara River basin include (1) water diverted from surface streams; (2) groundwater pumping; (3) construction of surface storage reservoirs; (4) importation of water from out-of-basin sources; and (5) reclamation of sewage and industrial waste waters, and the desalinization of sea water. Another technology not singled out by Freeman, but which was a significant phase of water development in the Santa Clara River basin, was the construction and maintenance of spreading grounds to recharge groundwater aquifers. The development of this technology was coincident with groundwater pumping.

Water diversions from the Santa Clara River for agricultural purposes have been prominent in this watershed since the mid- to late-1800s. The 1860s and 1870s were periods of active diversion and use of surface flow for agricultural and domestic purposes (Freeman 1968). Examples of diversions include the Farmers Canal, constructed on the north side of the river between Santa Paula and Ventura in 1869. The 16-mile-long canal had a capacity of 40 cfs. In 1871, the Santa Clara Irrigating Company constructed a canal across the Oxnard Plain, terminating near Hueneme. Along the lower river and in proximity to the coastal lagoon, a 1912 U.S. Department of Agriculture map (in Freeman 1968) indicates the presence of five evenly spaced pumping plants along the north bank in the vicinity of the Harbor Boulevard Bridge. It appears these pumping plants are diverting surface water into the Mound Water Company pipeline. This same map indicates the presence of two additional pumping plants along the south bank; the westernmost plant located at the Harbor Boulevard Bridge and the other several hundred feet to the east. By 1912, up to 42 pumping plants were operating north of the Santa Clara River, providing water for irrigation and domestic use (Freeman 1968).

One of the earliest recorded large-scale diversions was the Fillmore Irrigation Company Canal, established on Sespe Creek (the largest Santa Clara River tributary in terms of runoff volume) in 1911 and still in operation today (Hanson et al. 2003). On the Santa Clara River, the Freeman Diversion was established in 1929 (managed by the UWCD and referred to as the Saticoy Diversion prior to 1991), downstream from the confluence with Santa Paula Creek near the City of Saticoy. The Freeman Diversion has a capacity of approximately 460 cfs and is the largest operating diversion on the Santa Clara River. Shortly after the Freeman Diversion, the Piru Creek and Santa Paula Creek diversions were established in 1930 and 1931, respectively. The Santa Paula Creek diversion was discontinued in 1941, but the Piru Creek diversion, managed by the UWCD, is still in operation. A more comprehensive history of surface water diversions to 1965 is found in Freeman (1968).

In an effort to meet increased water demands, the Santa Felicia Dam was completed on Piru Creek in May 1955, forming Lake Piru (capacity: 88,340 acre-feet). Since construction of the Santa Felicia Dam, controlled releases of water from Lake Piru have resulted in fewer days of no flow in the middle reaches of the Santa Clara River (Hanson et al. 2003). In December of 1971, Pyramid Dam and Pyramid Lake were completed (capacity: 171,200 acre-feet) upstream of Lake Piru. Only a month earlier, Castaic Dam/Lake (Castaic Lake, capacity: 323,700 acre-feet) was constructed on Castaic Creek in January 1972. The reservoirs between 1955 and 1972 (Lake Piru, Pyramid Lake, and Castaic Lake) represent the three largest structural controls on runoff in the Santa Clara River watershed. Lake Piru was designed primarily to impound runoff from the Piru Creek sub-basin, while Lake Pyramid was designed primarily to receive water imported by canal (California Aqueduct) and pipeline from northern California (Williams 1979). Castaic Lake, the largest of the three, receives runoff from both within and outside of the Santa Clara River watershed (in part, water from Pyramid Lake is actually transported through a tunnel to Castaic Lake).

Little information was obtained regarding measured pre-development groundwater levels in the study area. The first wells were drilled in the Oxnard Plain in 1870 following the severe drought of 1853-64 and during the sustained dry climate period of 1840-83 (Hanson et al., 2003) (see Figure 4-7). These first artesian wells were drilled to depths of 90 to 143 feet in the Oxnard aquifer. The increased number of wells installed in the Oxnard Plain after 1871 diminished the flow of the springs and artesian wells (Hanson et al. 2003).

As agricultural development continued to increase, coupled with a severe drought in the 1920s and the onset of urbanization in the 1940s, water use and demand in the Santa Clara River watershed increased, peaking in 1950 (Hanson et al. 2003). Surface water resources became fully developed in the early 1930s, leading to increased groundwater development. Spurring the increased water demand at this time was the invention of the turbine pump (used for pumping groundwater from deep wells) and the refrigerated railroad car, which allowed for the expansion of fresh-produce markets. As a result, agriculture in the watershed was transformed from predominantly dry land farming (e.g., walnuts and field crops) to year-round, irrigated farming such as citrus, avocados, and truck crops (Hanson et al. 2003). By 1967, about 800 wells equipped with turbine pumps provided more than 90 percent of the water demand in the basin (Hanson et al. 2003, and Freeman 1968).

The effects of groundwater overdraft (pumping more water than is replenished) were first notable in 1931 when water levels in parts of the Oxnard Plain fell below sea level resulting in seawater intrusion. Hanson et al. (2003) estimate that the regional groundwater flow was landward beginning in 1927 and continuing to the end of their study period in 1993. Groundwater overdraft also resulted in land subsidence, first occurring after 1920 but most severe during agricultural expansion of the 1950s and 1960s (Hanson et al. 2003). Groundwater levels reached a historic low in the UAS in 1951; the same time groundwater withdrawals approached maximum levels (ibid). Since the early 1900s, water levels in both the UAS and LAS had dropped from about 50 to 100 feet (ibid).

With increased awareness of groundwater overdraft and active management, the introduction of out-of-basin water supply, discharge of treated effluent, decreased groundwater pumping, and the creation of groundwater recharge areas, groundwater levels started to recover in groundwater basins in the late 1960s and early 1970s. By 1993, groundwater levels along the coastal portion of the UAS had recovered to elevations averaging 5 feet higher than levels in 1931 and water levels throughout most of the Oxnard Plain were above sea level (Hanson et al. 2003). This 1970 through 1993 recovery was interrupted briefly during the 1987-91 drought when water levels were below sea level in the Oxnard Plain (ibid).

4.4.2 Change in Lagoon Inflow: Analysis of Stream Flow Data

The development of flow duration curves is a useful means of examining and characterizing the changes in historic inflows to the Santa Clara River coastal lagoon. Flow duration curves for a given location express the distribution of flows as the percentage of time daily discharge values were equaled or exceeded. In seasonal flow systems, this methodology is much more informative than simply looking at average or median flow values. In relation to the coastal lagoon, the closest long-term stream gauging station on the Santa Clara River is the USGS' Montalvo station (USGS 11114000). The location of this gauge is provided in Figure 4-5. The period of mean daily flow records for the Montalvo station is water year (WY) 1928-32, 1950-93, and 1995-2002. It's important to emphasize here that the Montalvo flow records for 1928-32 reflect a period running up to maximum surface water and groundwater development in the watershed. Although future withdrawals and extractions would result in the most significant flow depletions, flow at Montalvo during the 1928-32 period was likely impacted to some degree by water development (especially since this was a drought period placing greater demands on water resources), resulting in flows that are not likely representative of natural conditions. However, given the significant increases in water diversion and regulation activities since 1928, this analysis still provides a picture of the increased impacts to surface water flow that occurred over the ensuing 73 years.

To identify changes in flow regime over time, it is important to select periods of record that experience similar climatic conditions (i.e., relative wetness and dryness of individual and multiple-year periods). If these hydrologic and meteorologic variables are held constant in highly regulated river systems, any long-term changes in flow regime are likely attributable to changes in upstream operations (e.g., reservoir storage/releases, diversions, etc.). To select suitable periods for flow duration analysis, both a double-mass curve of daily stream flow and a cumulative departure from long-term average rainfall were prepared and examined. The double-mass curve (Figure 4-8) was constructed using accumulated USGS daily flows measured on the Santa Clara River at Montalvo and Sespe Creek (upstream of the Fillmore Irrigation Company Canal) for overlapping periods. The main objective of this analysis is to compare a highly regulated flow record (i.e., Santa Clara River at Montalvo) against a relatively unregulated flow record (i.e., Sespe Creek). Any change in the slope of the plotted data suggests a point or period of time of altered operations on the regulated system.

A chart depicting the cumulative departure from the mean annual rainfall for Ventura, California (WY 1874-2003), is presented in Figure 4-9. The long-term mean annual rainfall at Ventura is 15.44 inches. The Ventura rainfall record was selected because it had the longest period of record of any historic rainfall station in the Santa Clara River watershed. The objective of this analysis is to identify and characterize long-term wet and dry periods. This cumulative departure curve was generated in a similar fashion to that described for Figure 4-7 above. The purpose of the rainfall departure curve was to identify periods of similar climatic conditions in the lower watershed.

Based on the information presented in Figure 4-8 and 4-9, a number of periods were selected for the flow duration analysis. The wide range in flow rates and flow durations is demonstrated by comparing flow duration curves for a chronological suite of years between 1950 and 2002. As indicated in Figure 4-9, the period 1950 into 1978 is a long-term drought cycle, followed by a relatively wet period between 1978 and 1983. The two periods 1984 through 1991 and 1992 through 2002 are representative of multi-year dry and wet periods, respectively. The flow duration curves for these periods are presented in Figure 4-10 and not only demonstrate the high variability in flow conditions at Montalvo between wet and dry periods, but also the wide range of flow durations experienced between wet and dry cycles of varying intensity.

In an attempt to normalize comparisons between drought cycles, multi-year droughts having similar average rainfall totals and antecedent moisture conditions were identified and compared. These periods included WY 1928-31, WY 1952-57, and WY 1986-89. Flow duration curves for these drought periods are presented in Figure 4-11. The earliest selected period (WY 1928-31) is particularly short and dry, while the remaining periods display higher average annual rainfall totals. The WY 1928-31 period is important, as it represents flow at Montalvo under a least-impacted or most natural state within the context of more recent developments within the system. Particularly striking about Figure 4-11 is the decrease in flow durations for the 1952-57 and 1986-89 time periods compared to 1928-31. Moreover, compared to the 1986-89 time period, the 1928-31 period experienced slightly less average annual rainfall and almost twice the net cumulative loss, yet the 1928-31 time period has significantly higher flows over most durations.

Although multi-year wet periods are represented by WY 1978-83 and WY 1992-02, older daily flow data for similar multi-year wet periods are not available for the USGS Montalvo gauge. Thus, a meaningful comparison cannot be made between wet cycles for the lower river to evaluate changes in lagoon inflow over time. However, the information reviewed to date and presented above indicates that, during dry climatic periods, Santa Clara River flows (especially base flows) at Montalvo have decreased over time.

Flow duration curves for similar, individual water year-types (i.e., years with near-equal total rainfall totals) extracted from each of the multi-year wet and dry periods presented in Figure 4-10 provide additional insight into the importance of pre-existing moisture conditions on lagoon inflow. Flow duration curves for years having similar total annual rainfall totals are presented in Figure 4-12. The years evaluated include WYs 1952, 1980, 1986, and 1993, and each year experienced nearly equal rainfall totals (23.78, 24.88, 24.13, and 24.53 inches, respectively). However, when compared, there is a clear segregation of flow characteristics between these years based on pre-existing moisture conditions – with sustained river flows at Montalvo occurring no more than 29 percent of the time during 1952 and 1986 but in excess of 96 percent of the time in 1980 and 1993. The key difference between these years is that 1952 and 1986 occurred within multi-year drought periods, while 1980 and 1993 each follow multi-year wet periods. Thus, these characteristics underscore the notion that it is not only important to compare similar water years when trying to identify long-term changes in lagoon inflow conditions, but it is equally, if not more, important to compare water years that fall within similar multi-year climatic periods. It is also worth noting that the difference in flow conditions during an above average rainfall year set within a dry period compared to a similar rainfall year set within a wet period is amplified due to the added demands placed on water resources operations and water supply during drought periods.

4.4.3 Change in Lagoon Inflow: Unimpaired Inflow Assessment

The following section presents a summary of the approach, methods, and results of hydrologic analyses performed to estimate historic "natural" freshwater inflow to the Santa Clara River coastal lagoon. These monthly total inflow estimates for the 1928 through 2001 period represent "natural" hydrologic conditions or those that would have been present assuming an undeveloped/unregulated watershed (i.e., unaffected by surface water diversions, State Water Project imports, groundwater pumping, and other water management operations). These estimates are compared to actual measured inflow to the coastal lagoon in order to describe the changes in hydrologic inflow conditions to the lagoon.

4.4.3.1 Approach and Methods

Characterizing unimpaired flows is an important step in assessing and quantifying to what extent anthropogenic activities have altered the rate and timing of freshwater inflow to the Santa Clara River coastal lagoon. An important assumption in the analysis is that unimpaired flow estimates at the USGS gauge at Montalvo are representative of natural lagoon inflow. There are at least two potential problems with this assumption, however. First, as indicated above, the earliest flow records for the Montalvo gauge may reflect a watershed undergoing the early stages of intense water development. This may mean that summer baseflows in 1928 were already reduced from historic unimpaired conditions and the relative difference in impacts calculated and presented below are under estimated. Second, Murray McEachron of the UCWD (personal communication, 2004) noted that loss of channel flow to groundwater recharge may periodically be significant for the stretch of the Santa Clara River from Montalvo to the coastal lagoon.

The analytical approach developed for this study relied on generating inflow estimates that were in close agreement with the annual natural flow record for the USGS stream gauge at Montalvo, developed by Brownlie and Taylor (1981) for the 1928-75 period. Brownlie and Taylor's study centered on a water balance approach to develop total annual flow estimates at the Montalvo gauge. Their water balance accounted for: measured annual flow at Montalvo, recharge basin diversions at Saticoy and Fillmore; upper basin reservoir releases, and instream infiltration losses. Estimates for many of these variables came from United Conservation Water District studies and internal reports. The accuracy and validity of natural flow estimates developed under this study are predicated on closely matching those, developed by an alternate method, by Brownlie and Taylor.

This study relied on identifying and evaluating correlations between natural or minimally influenced stream flow at Montalvo and other hydrologic variables, primarily stream flow on Sespe, Piru, and Santa Paula Creeks. In addition, a regression analysis of monthly rainfall versus total flow at the Montalvo gauge for periods of unimpaired flow was completed. A wide variety of simple linear and simple polynomial regressions were developed and evaluated between each independent/dependent variable pair. Finally, a number of multiple linear regression analyses were completed using various numbers and combinations of monthly stream flow and rainfall variables. The major differences between this study and the study completed by Brownlie and Taylor are the generation of monthly (versus annual) lagoon inflow estimates and the use of local stream- and rainfall-runoff correlations to estimate natural flows at Montalvo. Again, as a quality control check, this analysis included a comparison of summed annual flows from our analysis versus annual totals reported by Brownlie and Taylor for the corresponding 1928-75 period.

The method used in estimating unimpaired flow at Montalvo for the 1928-2001 period is controlled by the timing of when upstream diversions and reservoirs came on-line and began influencing the flow at Montalvo. Prior to 1955, the most significant control structure influencing flow at Montalvo was the Saticoy diversion dam.[2] After construction of the dam in 1929, diversions at Saticoy gradually increase through 1975. Water is diverted from the Santa Clara River to local percolation basins. Thus, the unimpaired flow at Montalvo for the pre-1955 period can be estimated using a simple water balance, summing the USGS gauged flow and diversions made at Saticoy, as reported by the UWCD. Unfortunately, flow on the Santa Clara River at Montalvo was not gauged during water years WY 1933-49. Estimates of natural flow for this period were made

[2] Bouquet reservoir was completed in 1934 on Bouquet Canyon Creek in the far upper reaches of the watershed. This reservoir has a relatively small capacity (10^6 cubic meters) and a 35-square-kilometer drainage area. Brownlie and Taylor (1981) report that this structure has a negligible impact on flow at Montalvo.

through correlation to an unimpaired flow record for a neighboring river, as discussed below.

After 1955, the flow at Montalvo is influenced by construction of Lake Piru (completed May 1955), Pyramid Lake (completed December 1971), and Castaic Lake (completed January 1972). Brownlie and Taylor estimated the “natural” annual flow at Montalvo for the 1956 through 1975 period through the water balance accounting procedure mentioned above. It is assumed that local water resource managers consider these data reasonable estimates as they are integrated into a 1979 study prepared by the USGS in cooperation with Ventura County Flood Control District, UWCD, and the California Department of Boating and Waterways (Williams 1979).

4.4.3.2 Simple Regression Analyses

Because many of the variables that went into the Brownlie and Taylor water balance came from water district sources and were either dated, representative, or based on annual averages, or unavailable at the time of this study, estimates of monthly unimpaired flow at Montalvo for the post-1955 period (this study) were made by correlation to available local flow and/or rainfall records. Regression models are fairly simple to understand and provide insight into the relative sensitivity between simulated variables. The relationships and variables selected should be representative of physically based cause-effect (causal) relations controlling runoff in the basin – rainfall and tributary inflow in the case of flow at Montalvo. Therefore, correlations that were investigated included flow at the Montalvo gauge and flow at the USGS gauges on Sespe and Santa Paula Creeks. The correlation period consisted of WY 1928-32 and WY 1950-54. In addition, correlations between flow at Montalvo and rainfall at Ventura were evaluated. The results of these regression analyses are presented in Table 4-1.

The large squared correlation coefficient values for the Montalvo-Sespe Creek and Montalvo-Santa Paula Creek correlations presented in Table 4-1 are interpreted as an indication of a strong causal relationship between these variables. The relatively small squared correlation coefficient value for the Montalvo-rainfall relationship signifies a relatively weaker relationship. Therefore, further analyses of rainfall versus flow relationships were investigated. Specifically, a comparison between total annual cumulative rainfall versus total annual flow at Montalvo was made and provided some insight into local rainfall-runoff relationships. A comparative plot of these data (see Figure 4-13) suggests that no significant flow occurs at Montalvo until 6 to 7 inches of cumulative rain has fallen in Ventura. Thereafter, a strong relationship appears to exist between cumulative rainfall and cumulative flow at Montalvo. The polynomial equation that defines the trend line indicated in Figure 4-13 was used to estimate cumulative flow at Montalvo. After disaggregating the cumulative flow values into total monthly flows, these estimates were compared to the Natural Flow at Montalvo estimate (dependent variable) described in Table 4-1. A summary of this simple linear regression analysis is presented in Table 4-2. The squared correlation coefficient for the cumulative rainfall based flow estimate (r^2=0.74) suggests this correlation provides a better estimate of total monthly natural flow volumes at Montalvo than the rainfall-runoff correlation using monthly rainfall totals. The regression line in Figure 4-13 also indicates that there is no flow at the Montalvo gauge until approximately 7 inches of cumulative rainfall has fallen in Ventura.

4.4.3.3 Multiple Linear Regression Analyses

To investigate whether stronger correlations could be found between independent and dependent hydrologic variables, a number of multiple variable regression analyses were completed. These analyses evaluated the strength of simultaneous correlation between flow at Montalvo and multiple independent hydrologic variables. A summary of the multiple linear regression analysis variables, correlation periods, number of observations (statistical population), and squared multiple regression correlation coefficients are presented in Table 4-3.

Table 4-1. Results of Monthly Total Flow/Rainfall Simple Linear/Polynomial Regressions

Dependent Variable	***Independent Variable***	***Correlation Period***	***Number of Observations***	***Simple Linear or Polynomial Squared Correlation Coefficient (R^2)***
Natural Flow at Montalvo [(a)]	Flow at Santa Paula Creek	WY 1928-32 & WY 1950-54	123	0.97
Natural Flow at Montalvo [(a)]	Flow on Sespe Creek [(b)]	WY 1928-32 & WY 1950-54	123	0.96
Natural Flow at Montalvo [(a)]	Rainfall at Ventura	WY 1928-32 & WY 1950-54	123	0.36

Table Notes: (a) Natural flow at Montalvo estimated as sum of monthly flow at USGS Montalvo gauge plus monthly UWCD Saticoy diversions; (b) Flow on Sespe Creek is corrected for Fillmore Irrigation Company diversions (since 1911).

Table 4-2. Results of Monthly Total Cumulative Rainfall to Flow Regression Analysis

Dependent Variable	***Independent Variable***	***Correlation Period***	***Number of Observations***	***Simple Linear or Polynomial Squared Correlation Coefficient (R^2)***
Natural Flow at Montalvo [(a)]	Flow at Montalvo derived from Cumulative Rainfall	WY 1929-32 & WY 1950-54	112	0.74

Table Notes: (a) Natural flow at Montalvo estimated as sum of monthly flow at USGS Montalvo gauge plus monthly UWCD Saticoy diversions.

4.4.3.4 Regression Model Selection and Calibration

To evaluate which regression-based model produced the best estimates of unimpaired (natural) flow at Montalvo, the total annual natural flow estimates (derived by summing the individual monthly flow values) for each regression model (this study) were compared to the total annual natural flow estimates derived by Brownlie and Taylor for the entire WY 1928-75 period. Squared correlation coefficients between annual natural flow estimates for each simple and multiple regression model and the Brownlie and Taylor estimates are presented in Table 4-4. A graphical comparison of annual natural flow estimates for simple and multiple regression models are presented in Figures 4-14 and 4-15, respectively. Multiple regression model #2 provided the largest squared correlation coefficient (R^2=0.98).

Table 4-3. Results of Monthly Total Flow/Rainfall Multiple Linear Regression Analysis

Dependent Variable	***Independent Variables***	***Correlation Period***	***Number of Observations***	***Squared Multiple Linear Correlation Coefficient (R^2)***
Multiple Regression Analysis #1: Natural Flow at Montalvo [(a)]	a) Flow at Santa Paula Creek b) Flow on Sespe Creek [(b)] c) Total Monthly Ventura Rainfall	WY 1929-32 & WY 1950-54	112	0.98
Multiple Regression Analysis #2: Natural Flow at Montalvo [(a)]	a) Flow on Sespe Creek [(b)] b) Flow at Montalvo derived from Cum. Rainfall [(c)]	WY 1929-32 & WY 1950-54	112	0.97
Multiple Regression Analysis #3: Natural Flow at Montalvo [(a)]	a) Flow at Santa Paula Creek b) Flow on Sespe Creek [(b)] c) Flow at Montalvo derived from Cum. Rainfall [(c)]	WY 1929-32 & WY 1950-54	112	0.98
Multiple Regression Analysis #4: Natural Flow at Montalvo [(a)]	a) Flow at Santa Paula Creek b) Flow at Montalvo derived from Cum. Rainfall [(c)]	WY 1929-32 & WY 1950-54	112	0.97

Table Notes: (a) Natural flow at Montalvo estimated as sum of monthly flow at USGS Montalvo gauge plus monthly UWCD Saticoy diversions; (b) Flow on Sespe Creek is corrected for Fillmore Irrigation Company diversions (since 1911); and (c) Monthly flow estimates at Montalvo based on cumulative rainfall-flow correlation presented in Table 4-2.

4.4.3.5 Natural vs. Actual Flow at Montalvo Gauge

The final unimpaired monthly flow estimates for the USGS Montalvo gauge for the WY 1928-2001 period are presented in Table 4-5. Because there is incomplete flow data for independent variables over the entire WY 1928-2001 period, the final natural flow estimates are a mixture of the flow estimation methods as follows (in chronological order).

- WY 1928-32: USGS gauged flow + UWCD measured Saticoy diversions;
- WY 1933-49: Estimated unimpaired flow using Multiple Linear Regression #2;
- WY 1950-54: USGS gauged flow + UWCD measured Saticoy diversions;
- WY 1955-92: Estimated unimpaired flow using Multiple Linear Regression #2, with the following exceptions:
  - November 1985 – January 1986: Multiple Linear Regression #4;
  - March 1986: Multiple Linear Regression #4;
  - May 1986 – June 1986: Multiple Linear Regression #4;
  - September 1986: Multiple Linear Regression #4;
  - December 1987: Multiple Linear Regression #4;
  - October 1988 – September 1989: Multiple Linear Regression #4;
- WY 1993-2001: Estimated unimpaired flow using Multiple Linear Regression #4.

The actual (measured) total monthly flows at the USGS Montalvo gauge, for the same period,[3] are presented in Table 4-6. A comparison of the final annual unimpaired flow estimates from this study (Table 4-5) versus those estimated by Brownlie and Taylor for the 1928-75 period are plotted in Figure 4-16. The squared simple linear correlation coefficient (R^2) for this relationship is 0.98.

Because there is a high degree of annual and seasonal variability in natural and actual flows at the Montalvo gauge, a probability analysis was completed to segregate the annual flow records into a suite of water year-types. Water year-types and their associated (arbitrary) probability of exceedance ranges include:

• Extremely Wet Year:	<10% probability of flow being equaled or exceeded		
• Wet Year-Type:	10% to 40%	"	"
• "Normal" Year-Type:	40% to 60%	"	"
• Dry Year-Type:	60% to 90%	"	"
• Critically Dry Year-Type:	>90%	"	"

[3] As indicated above, the USGS did not gauge flows at the Montalvo gauge over the WY1933-49 period. Estimates of actual gauged flow for this period were made by subtracting the UWCD's measured Saticoy diversion volumes from the unimpaired flow estimates derived from this study.

Table 4-4. Comparison of Regression Model Annual Natural Flow Estimates at Montalvo vs. Brownlie and Taylor Annual Estimates: Water Years 1928-75

***Dependent* Variable**	***Regression Model Estimate – Independent Variable***	***Number of Observations***	***Simple (R^2) and Multiple Linear (R^2) Correlation Coefficients***
Annual Natural Flow at Montalvo: Brownlie & Taylor	Flow at Santa Paula Creek	48	0.80
Annual Natural Flow at Montalvo: Brownlie & Taylor	Flow on Sespe Creek [(a)]	48	0.94
Annual Natural Flow at Montalvo: Brownlie & Taylor	Rainfall derived Flow at Montalvo [(b)]	48	0.54
Annual Natural Flow at Montalvo: Brownlie & Taylor	Multiple Linear Regression Model #1 [(c)]	48	0.95
Annual Natural Flow at Montalvo: Brownlie & Taylor	Multiple Linear Regression Model #2 [(c)]	48	0.98
Annual Natural Flow at Montalvo: Brownlie & Taylor	Multiple Linear Regression Model #3 [(c)]	48	0.95
Annual Natural Flow at Montalvo: Brownlie & Taylor	Multiple Linear Regression Model #4 [(c)]	48	0.92

Table Notes: (a) Flow on Sespe Creek is corrected for Fillmore Irrigation Company diversions (since 1911); (b) Monthly flow estimates at Montalvo based on cumulative rainfall-cumulative flow correlation presented in Table 4-2; and (c) see Table 4-3 for list of independent variables used in multi-variant regression model.

Table 4-7 presents the calculated natural and actual average monthly/annual flow rates for these representative water year-types.

The difference between the estimated monthly average (WY 1928-2001) natural flow at the Montalvo gauge versus the flow that was actually measured is presented in Figures 4-17 and 4-18. Figure 4-17 presents a comparison between normal and dry water year-types, while Figure 4-18 presents a comparison for extremely wet, wet, and critically dry water year-types. On an annual basis, actual flows at Montalvo are 3, 17, 31, 53, and 74 percent lower than natural flow estimates during extremely wet, wet, normal, dry, and critically dry year-types, respectively (see Table 4-7, Figure 4-17, and Figure 4-18). In summary, there is a notable decrease in monthly flow rates between natural and actual flow at the Montalvo gauge during all months of all water year-types, with the greatest relative changes occurring during the summer months. These decreases are due to urban/agricultural development and regulation of water resources in the Santa Clara River basin.

4.4.3.6 Natural vs. Actual Inflow to the Santa Clara River Coastal Lagoon

As indicated above, it is assumed that the natural (unregulated) inflow to the Santa Clara River coastal lagoon is essentially equivalent to the estimated natural flow at the USGS Montalvo gauge. For purposes of this study, the actual inflow to the lagoon is assumed to be equal to the actual measured flow at the Montalvo gauge (Table 4-6) plus direct water treatment plant discharges to the lagoon by the Ventura Public Works Department. Monthly and annual treatment plant releases to the lagoon for the 1972-2004 period are presented in Table 4-8. Total annual water treatment discharges to the lagoon for the WY 1975-2003 period are plotted in Figure 4-19. Estimated actual monthly freshwater inflows to the lagoon, calculated as the sum of the actual flow at Montalvo plus the long-term average (WY 1975-2004) monthly water treatment discharge volumes, are also presented in Table 4-6. A comparison of the natural and actual lagoon inflow for the representative water year-types are presented in Figures 4-20 and 4-21 – normal and dry year-types in Figure 4-20 and extremely wet, wet, and critically dry water year-types in Figure 4-21. Similar to the estimated and actual flows at the upstream Montalvo gauge, Figures 4-20 and 4-21 and Table 4-7 indicate that there is a decrease in the total annual inflow volume to the Santa Clara River coastal lagoon between natural and actual conditions in all year-types except critically dry. Actual annual inflow to the lagoon during critically dry years is approximately 11 percent greater than the natural estimated inflow for the same year-type. Total annual decreases in lagoon inflow for the representative extremely wet through dry year-types are from 2 to 25 percent lower than annual totals for natural lagoon inflow (see Table 4-7). However, unlike the flows at the upstream Montalvo gauge, these plots and data suggest there is a seasonal increase in actual inflow above estimated natural lagoon inflow volumes during some portion of the summer and fall of all water year-types. During the remainder of the year, actual inflow to the lagoon has been less than it would have been under natural conditions – of sufficient magnitudes to offset any summer increases and accounting for the overall annual decrease in lagoon inflow.

Currently, there is concern over the impact of the discharge from the VWRF on the frequency of the berm breaching. Given that total flows entering the estuary in most months is less than what was historically present, it would seem that flows from the VWRF would have had little effect in terms of increasing the frequency of berm breaching over time. However, during summer dry periods, under current conditions when no water reaches the estuary from upstream sources, the VWRF discharge is clearly the dominant source of water to the estuary and would provide sufficient flow that would eventually force the berm open. However, it should be noted that the frequency of breaching under current conditions is strongly affected by the elimination of most of the floodplain and side-channels (i.e., lagoon storage area) that has occurred over time. Thus, the water filling the lagoon has limited area in which to disperse, increasing the elevation of the lagoon with respect to a given volume, and ultimately destabilizing the berm at a much earlier stage in the filling cycle than historically would have been the case.

4.4.3.7 Limitations of Assessment

In the absence of a detailed historical record, extrapolations from more recent conditions were used as a basis for deriving estimates of historical hydrological conditions. Given that even the earliest years of consistent flow monitoring occurred after development was already well underway in the watershed, this analysis contains a level of uncertainty that cannot be eliminated. Moreover, this uncertainty is biased in that it is probably greatest during periods of low flows when demands on the system (i.e., diversions and groundwater deficits) are greatest relative to natural flows.

A variety of techniques and considerable professional judgment, interpretation, and simplifying assumptions are used to develop the unimpaired flow record of inflow to the Santa Clara River lagoon. For example, as noted above, UWCD staff indicate that infiltration and loss of river flow may periodically be significant for the stretch of the Santa Clara River from Montalvo to the coastal lagoon. This analysis also does not quantify seasonal contributions of groundwater and/or agricultural return flows between Montalvo and the lagoon. As such, these estimates should be considered a best approximation. The limitations of these data should be realized before using them for any other purposes than that intended for this study.

4.5 Hydrology, Morphology, and Water Quality Monitoring

To better describe and analyze lagoon conditions, Kamman Hydrology & Engineering, Inc. (KHE) implemented a hydrologic field-monitoring program consisting of continuous lagoon water level (elevation) and water quality measurements (temperature and conductivity/salinity) over the period January 23, 2004 through January 13, 2005. In addition, KHE collected vertical water quality profiles within the lagoon at numerous locations during site visits on November 6, 2003 and February 18, 2004. The discrete sampling information supplemented similar vertical water quality profiles completed by Nautilus Environmental, LLC on October 17, 2003; March 16, 2004; July 20, 2004; September 28, 2004, and January 31, 2005.

Staff from the VWRF have also been conducting daily lagoon observations since June 7, 2001. These observations include detailed notes on the daily condition of the river mouth/barrier beach, inlet channel dimensions, lagoon water levels, net lagoon flow rates, and presence of wave overwash. KHE used these data to define and describe the geomorphic character and seasonal conditions within the current lagoon system.

Data from these monitoring efforts, along with an analysis of available coastal data for the study period are presented below. Long-shore sediment transport data were not collected or available for the study period, so a qualitative description of these conditions is presented below. A comprehensive discussion of all the changes in lagoon hydrology, water quality, and geomorphic conditions and changes observed over the monitoring period is presented in the final section in this chapter.

4.5.1 Lagoon Water Levels

Water levels were measured on a 30-minute interval within a tidal slough channel extending into McGrath State Beach along the southern side of the lagoon. The location of the water level and water quality gauging station is indicated on the lower graph of Figure 4-5. After a thorough reconnaissance of possible gauging locations within the lagoon, this site was deemed the most protected, accessible, and vandal-free site for long-term deployment of monitoring equipment. Monitoring equipment consisted of a Global Water-brand WL400 water level sensor cabled through a 3-inch-diameter PVC stilling well to a GL400 multi-channel data logger. The logger was secured within a locked steel box and mounted on the east channel bank. Water surface elevations were tied to the NAVD88 vertical datum during elevation surveys completed on October 21, 2004, and February 9, 2005. A plot of measured lagoon water levels is presented in Figure 4-22. The monitoring station data logger failed to record data between July 15, 2004, and October 21, 2004. Although the "overwrite previous data" programming option was selected, this function failed to work and no data were stored in the data logger over this period.

It is also important to note that the base of the slough channel in which the water level sensor was deployed was at an elevation of approximately 4.0 feet NAVD88. As indicated earlier, the deepest elevation of the interior lagoon near the mouth is approximately 0.5 feet NAVD88, the observed depth of scour during a largescalebreaching event. During most breached periods, it is estimated that shoaling outside and within the mouth of the inlet channel raises the bed of the channel 2 to 3 feet, effectively reducing exchange between ocean and lagoon when ocean water levels drop below these ebb and flood deltas. During open inlet and low tide conditions, the water surface elevation within the lagoon is actually lower than the recorded water level because the base of the tidal slough channel where the instrument is deployed is elevated higher than the bed of the lagoon. Thus, water levels below this 4.0-foot elevation are not represented in the water level record.

4.5.2 Ocean Tides

The closest active NOAA tide gauge to the Santa Clara River mouth is at Santa Monica Pier (65 miles to the east-southeast). Ocean tides for Santa Monica reported by National Oceanic and Atmospheric Administration (NOAA) for the lagoon-monitoring period are plotted against lagoon water levels in Figure 4-22. No tidal data or tidal datums were available for the Ventura Harbor. However, tidal datums for active tide gauges located north (Santa Barbara) and south (Santa Monica) of the project site are quite consistent. As such, the average of these datums is considered representative of the open ocean tidal conditions at the mouth of the Santa Clara River. Tidal datums for each of the sites are presented in Table 4-8, and the Santa Monica tidal data plotted in Figure 4-22 are believed representative of ocean water level conditions adjacent to the Santa Clara River mouth. This assumption is supported by the close agreement and synchronicity of peak tide levels between the Santa Monica data and water levels measured in the Santa Clara River coastal lagoon (see Figure 4-22).

The diurnal and semidiurnal components of the measured tides at Santa Monica are mixed. The resulting daily tidal regime has two high waters and two low waters, with the levels in each pair displaying different magnitudes. Based on the tidal statistics presented in Table 4-8, the range between mean higher high water (MHHW) and mean lower low water (MLLW) is about 5.40 feet. During lagoon inlet formation, the lower scour depth elevation through the barrier breach is controlled by the minimum (MLLW) tide level that occurs during inlet formation as well as the volume of the lagoon, and barrier beach and inlet channel formation processes. Exchange of tidal waters between ocean and lagoon also work to keep the inlet open. Thus, the magnitude of the maximum tidal range plays an important role in scouring and maintaining an open inlet in two ways.

Table 4-8. Tidal Ranges at Santa Clara River Mouth (Tidal Epoch 1983-2001)

Description	*MLLW Datum (feet)*	*NAVD88 Datum (feet)*
MHHW	5.40	5.26
MHW	4.67	4.53
MTL	2.81	2.67
NGVD29	2.68	2.54
MLW	0.96	0.82
NAVD88	0.14	0.00
MLLW	0.00	-0.14

First, the tidal range will control the maximum potential volume (tidal prism) exchanged through the inlet (inlet channel bed elevation will also control this volume). The greater the tidal prism, the greater the scour potential to maintain an open inlet. Secondly, it appears from the plot of Santa Monica tides that the daily higher-high water normally precedes the lower-low water, creating a maximum seaward gradient (ebb dominance) through the inlet during the larger of the semidiurnal ebb tide events. Velocities and scour potential are greatest during this period and, if not countered by the onshore wave influences that push sand into the mouth of the inlet, tidal inlet scour could possibly keep the inlet open indefinitely.

4.5.3 Lagoon Inflow

The USGS provided KHE with provisional mean daily flow estimates for the Montalvo gauge for WY 2004, which are plotted against lagoon water levels in Figure 4-22. Although these data are preliminary estimates and should not be considered final, they do indicate periods of freshwater storm runoff reaching the lagoon. It appears that the only storm flow to affect lagoon water level captured over the first half of the monitoring period occurred on February 26, 2004 (see Figure 4-22).

At the time this report was written, the USGS indicated that after September 30, 2004, they ceased generating flow estimates at the Montalvo gauge due to maintenance funding issues (Thomas C Haltom, USGS, Sacramento, California, personal communication, February 2005). The best remaining available flow record in the Santa Clara River watershed that indicates likely periods of freshwater inflow to the lagoon is the USGS gauge on Sespe Creek near Fillmore, California. Flow on Sespe Creek near Fillmore for the post-September 30, 2004, monitoring period is also plotted against lagoon water level in Figure 4-22. These data indicate significant storm and lagoon inflow activity in late December 2004 and early January 2005. The USGS data are missing for flow at the Sespe Creek gauge between January 8 and January 13, 2005, likely due to flood damage. The lagoon water level record indicates the passage of at least two large flood hydrographs during this period. Treatment plant effluent discharges to the lagoon remained relatively constant over the monitoring period, ranging from 7.8 to 10.5 million gallons per day (mgd) (12.1 to 16.2 cfs) and averaging 8.9mgd (13.8 cfs).

4.5.4 Water Quality

4.5.4.1 Continuous Water Quality Monitoring

In addition to the water level probe, Global Water-brand conductivity, temperature, and DO probes were also deployed at the lagoon gauging station. Parameter measurements were recorded at 30-minute intervals. The maximum range of the specific conductance probe is around 11,000 microsiemans per centimeter (µS/cm), which is roughly equivalent to a salinity of 6.0 ppt. A plot of recorded conductivity is presented by the orange fill area on the upper graphic of Figure 4-22 (again, note that conductivities above 11,000 µs are truncated from the record). Periods of time in which there are orange bars spanning the entire range of the conductivity scale indicate periods of marine conditions or lagoon flooding from the ocean. Summer or dry-season periods with no conductivity readings indicate the probe was likely out of (above) the water. The daily tidal range during these periods was below the bottom elevation of the base of monitored slough channel. During the flood flows of late December 2004 and early January 2005, the low conductivity levels recorded in the lagoon are attributable to freshwater flooding.

Measured temperature readings are also plotted (in °C) on the upper graphic of Figure 4-22. The high daily fluctuations observed in temperature are likely due to complete or temporary exposure of the temperature probe to the atmosphere (i.e., air temperature, not water, is being recorded). This was due to the relatively high elevation of the tidal channel where monitoring equipment was deployed. Lower daily variability in recorded temperatures occurs during periods in which the lagoon remains flooded and the temperature probe remains submerged (e.g., see the period May 7 through May 15, 2004). Unfortunately, the repeated and regular exposure of the DO probe to the atmosphere created chronic calibration problems. These data were determined to be of suspect quality and are not presented here. However, the results of the discrete water quality sampling, presented next, provides a general picture of DO conditions in the estuary over the monitoring period.

4.5.4.2 Discrete Water Quality Monitoring

<u>November 6, 2003</u>

Discrete water quality measurements were completed during the late afternoon of November 6, 2003, between 14:30 and 16:30. The sand-spit between the ocean and estuary was breached 2 days prior to this monitoring event. Monitoring was completed just prior to the low tide of a spring tidal cycle. As a result, the estuary was draining to the Pacific Ocean during the monitoring period and no significant ponding was observed. Water in the lagoon area consisted of Santa Clara River flow and treated effluent outfall from the VWRF. Maximum water depths did not exceed 1.5 feet. Some localized areas of perched ponding occurred along the southern margin of the lagoon.

KHE staff took water quality measurements at a total of 13 sampling locations throughout the estuary (sampling locations 60-72 in Figure 4-23). The geographic coordinates (latitude, longitude) of each location were recorded with a handheld GPS unit. In situ water quality parameters were measured using a YSI 556 MPS (Multi-Probe System) handheld unit equipped with temperature, DO conductivity/salinity, and pH probes. The calibration and measurement accuracy of each probe was checked and deemed accurate the day prior to monitoring. All parameter measurements were stored within the unit's internal memory and downloaded directly to a personal computer (PC) avoiding any transcription errors. Because of the shallow water depths and complete mixing throughout the water column (verified in the field) only a single water quality measurement was completed at each location (i.e., vertical profiles on a 1-foot interval were not possible).

Water quality monitoring results at each location are presented in Table 4-9, as well as the minimum, maximum, and average values for each parameter. Sampling locations 60 through 62 are in the treated effluent channel draining to the main estuary and inlet channel. Effluent flow was estimated at 9 cfs. Locations 63 and 64 reflect the mixing zone of the treated effluent with Santa Clara River flow. Sampling location 65 was in the center of the sand-spit breach. With the exception of locations 67 and 69, all remaining samples were collected in the main Santa Clara River channel. In general, salinity, DO, and temperature concentrations decrease in an upstream direction. However, it is possible that the DO probe did not have sufficient time to equilibrate to lagoon conditions when the monitoring was initiated, and, thus, the reported DO values should be considered as potentially suspect. There was no significant change in pH concentration throughout the estuary. Measurements at locations 67 and 69 were completed in localized ponded areas perched above the adjacent channel and estuary bottom. Water in these ponded areas (and the elevated salinities) likely reflects seawater remaining from the earlier high tide that flooded the estuary.

February 18, 2004, Sampling:

KHE collected vertical water quality profiles during the morning of February 18, 2004, between 06:30 and 11:00. The inlet between the ocean and estuary was closed. Monitoring was initiated just prior to a peak high tide of a spring tidal cycle. Significant wave overwash was observed occurring over the inlet and the beach (west towards Surfer's Knoll parking lot). Consistent, light rain was experienced during the first 2 hours of monitoring. Water in the lagoon area consisted of Santa Clara River inflow, treated effluent inflow from the City's plant, and seawater as a result of prior high tide flooding and wave overwash. Much of the lower estuary (i.e., west of the Harbor Boulevard Bridge) was inundated. The maximum water depth sampled was approximately 6 feet, with the average sampling depth around 2 feet.

Water quality measurements were taken at a total of 26 sampling locations throughout the lagoon (sampling locations 102 through 127 in Figure 4-23). At approximately two-thirds of the sampling locations, depth stratified measurements (i.e., vertical profiles on 1-foot interval) were taken. Shallow water depths at the remaining locations (around 1 foot deep) necessitated only a single measurement. For all locations, if water quality readings at the surface (depth of 0.5 feet) were noticeably different from those recorded at the 1-foot interval, then the surface reading was also recorded.

Water quality monitoring results are presented in Table 4-9. Measurements at locations 110 through 112 were collected in the treated effluent channel draining to the main estuary. Locations 122-125 were in the main channel of the Santa Clara River, moving upstream from the Harbor Boulevard Bridge. Sampling location 115 was in the slough channel adjacent to the McGrath State Beach campground, near the water level gauge installation. All remaining samples were collected in the main, open-water areas of the lagoon. In general, water temperature did not vary significantly with depth and most locations exhibited temperatures within a few degrees of the average recorded temperature for the day, 13.54 °C. The highest temperatures were recorded in the treated effluent channel, and the lowest temperatures were recorded in the open-water lagoon just to the north of the campground (locations 116 through 118). Salinity generally decreased with depth and with distance upstream toward freshwater inputs. The most obvious salinity gradients with distance are found moving upstream in the treated effluent channel and the main channel of the Santa Clara River. Salinity stratification with depth is most obvious in the treated effluent channel. DO concentrations varied between 8.66 and 12.52 mg/L (with most samples falling between 10 and 11 mg/L) and generally decreased with depth. The lowest DO value was recorded in the treated effluent channel (location 112) and the highest value was recorded near the Harbor Boulevard Bridge (location 122). There was no significant change in pH concentration throughout the lagoon.

4.5.5 Littoral Sand Transport

Along the California coast, there are currents parallel and close to the shoreline caused by the angular approach of waves to the coast. These currents are called littoral or long-shore currents. Fine-grained sediment is transported within this current and serves as the source of sands that build and maintain beaches. Given the undulatory nature of the California coastline, there are numerous stretches where independent long-shore currents develop. Each littoral current has sources and sinks of sediment. The collective sediment flow pattern associated with the current is termed a littoral cell.

The Santa Barbara littoral cell lies off the Ventura County coast, extending from the mouth of the Santa Maria River, around Point Conception, and terminating at the Mugu Submarine Canyon located at Mugu Point (California Department of Boating and Waterways and State Coastal Conservancy 2002). The cell delivers sediment along beaches in a north-south and west-east direction paralleling the alignment of the coast. Rivers contribute 99.5 percent of the sand input to the Santa Barbara littoral cell while the remaining 0.5 percent is attributed to bluff erosion (ibid). Dam construction within the watersheds feeding the Santa Barbara littoral cell has significantly reduced sand input by 40.5 percent. This state of reduced sediment supply to the littoral cell has existed over the last 30 to 40 years (ibid). Damming and gravel extraction in the Santa Clara River watershed has reduced the average annual sand delivery to the coast by approximately 75 percent (CDPR 1990). Long-term beach erosion and narrowing is well documented along the Ventura County coast and are believed to be attributable to sediment trapping by dams, especially the Ventura and Santa Clara Rivers (California Department of Boating and Waterways, and State Coastal Conservancy 2002).

The existing littoral cell in the vicinity of the Santa Clara River mouth is further disrupted by the annual sediment dredging that occurs at the entrance of the Ventura Harbor located 0.5 miles north of the Santa Clara River mouth. The Ventura Port District developed the harbor in 1963 as a small craft harbor. Constructed breakwaters or jetties extending into the ocean define and protect the harbor inlet channel. A detached breakwater aligned parallel to shore and intersecting the north jetty at its mid-length was constructed in the early 1970s. The main purpose of the detached breakwater was to form two sand traps that would capture sand from the littoral cell and keep it from infilling the entrance to the channel and harbor. The combined capacity of the sand traps is estimated at 837,000 cubic yards (U.S. Army Corps of Engineers 2002). The U.S. Army Corps of Engineers, Los Angeles District currently maintains navigable channels by dredging the entrance channel and sand traps outside of the harbor. On an annual basis, they remove an average of approximately 695,000 cubic yards of sand. It is estimated that 84 percent of the shoaling in the entrance channel and sand traps come from down coast littoral drift (ibid). The remaining 16 percent comes from shoaling (delta formation) off the Santa Clara River mouth and intervening beaches. Based on review of original Corps designs (U.S. Army Corps 1970, 1971) the majority of dredged sands have historically been piped south of the Santa Clara River mouth onto McGrath State Beach. Unknown volumes of dredged sands are also reportedly placed onto South Beach (located between the harbor and river mouth) at an unknown frequency. Based on a littoral cell sediment budget in the U.S. Army Corps of Engineers 2002 report, up to 100 percent of the littoral cell sand being delivered to the Ventura Harbor is bypassing the Santa Clara River mouth through dredging and piping. This sand bypass activity reduces sand supply to the barrier beach and river mouth. The inlet stability analysis presented in Section 4.8 attempts to characterize and quantify this impact of bypassing relative to existing and historic littoral sand supply rates.

4.5.6 Geomorphic and Water Quality Changes over the Monitoring Period

The Santa Clara River coastal lagoon exhibited several dynamic states during the monitoring period. This section of the report ties together the monitoring data and observations into a detailed description of the cause and effect relationships that control lagoon geomorphology and water quality. These changes will be expressed in terms of dominant physical processes and consequences to lagoon conditions.

Throughout the year, the lagoon is subject to a variety of hydrologic influences and forces that may contribute independently or in concert to the opening and closing of the inlet. A breached barrier beach/open mouth may be a result of:

- High flows within the river that overtops and erodes the barrier beach;
- Steady filling due to the wastewater effluent that reaches a threshold and overtops and erodes the barrier beach;
- Ocean wave over wash that attacks and erodes the barrier beach; and
- Mechanical breach by human activity.

A closed barrier beach may be a result of:

- Beach sediment deposited at the mouth arresting tidal exchange;

- Low or no freshwater flows inhibiting sediment movement out of the lagoon;
- High sediment deposits in the offshore delta of the lagoon due to episodic flood events that are carried onshore due to wave action; and
- Erosion of the lagoon banks and filling of the mouth of the lagoon.

The Santa Clara River lagoon exhibited several dynamic states over the monitoring period. The first is a closed barrier beach with steady filling due to effluent flows from the VWRF. This regime is usually associated with zero to nominal river inflows into the system and predominantly occurs during the dry season. The second state is a breached barrier beach with tidal and freshwater exchange passing through the mouth of the lagoon. This state is also associated with effluent from the VWRF and high or low freshwater flows from the Santa Clara River. This regime was observed during both the wet season and the dry seasons.

One of the most unique states of the lagoon is a closed barrier beach with steady filling due to treated effluent releases from the treatment plant. This regime is usually associated with low to nominal river inflows and typically occurs on a repeated basis throughout the summer. Based on continuous water level monitoring and results from the water budget analysis discussed below, it appears that it takes approximately 6 weeks for the lagoon to fill with treated effluent releases if barrier beach construction can keep pace with rising water levels. Initially, upon closure, the lagoon appears filled with high salinity water, with salinities slowly decreasing as the lagoon is flooded (see Figure 4-22). Discrete water quality measurements within the lagoon during flooded conditions (e.g., 10/17/03 and 7/20/04) indicate brackish water salinities throughout the lagoon (generally averaging between 2 and 3 ppt) with salinity stratification in the deeper portions of the lagoon (up to 12 ppt) near the former inlet mouth and main river channel. Water temperatures are uniform throughout the lagoon and water column and appear to be similar to seasonal average air temperature. Dissolved oxygen concentrations remain above 15 mg/L throughout the main body of the lagoon, with more variable conditions (4.0 to 7.5 mg/L) occurring at the upstream end of the treated effluent discharge channel. With the exception of near neutral conditions at the upstream end of the treated effluent discharge channel, measured pH levels within the lagoon are relatively high during flooded conditions, averaging around 8.5 units during the 10/17/03 monitoring period and 9.5 units on 7/20/04. Maximum water surface elevations under flooded conditions are between 10.0 and 10.5 feet NAVD88 with maximum lagoon water depths over 6 feet. Periods of wave overwash may erode the top of the barrier beach and lead to short-term connection to the ocean without whole-scale inlet formation and lagoon draining. These events also cause influxes of higher salinity water and brief reversal in the freshening of water quality. Such types of events are best identified by the sharp, weeklong increases in flooded lagoon conductivity observed in Figure 4-22. It is important to note that wave overwash events occurred during spring tide periods when the combined effect of wave height and high tides are sufficient to overtop the barrier beach.

Two mechanisms were observed controlling breaching of the barrier beach during the monitoring period. The first type of breach occurs during dry weather and no/low river inflow and is driven by lagoon floodwaters, primarily from treatment plant discharge, overtopping the barrier beach and scouring a wide and deep channel. These types of breaching events occur quickly (less than 1 day) and are reflected in the sharp drop in lagoon water level in January, May, July, and early December 2004 (see Figure 4-22). The second type of breaching event is driven by wet season storm inflows filling the lagoon and scouring an inlet through the barrier beach. Such an event occurred around 12/28/04. A third type of breaching that historically occurred at the Santa Clara River mouth, but was not observed during the monitoring period, is the intentional breaching by humans for flood control or recreational purposes.

Once the lagoon is breached and an inlet channel is well established, there appear to be variable periods of time before active barrier beach reconstruction and inlet closure occurs. During wet periods, the increased scour potential of high river inflows maintains the inlet in combination with tidal exchange and treated effluent discharges. These periods almost always occur during the winter months when wave energy and beach erosion potential is high. When the inlet is open to tidal exchange, lagoon water quality varies widely based on the relative influxes of ocean water and freshwater river inflows. Thus, during high tidal conditions the lagoon water quality will be marine in nature. Upon draining during the ebb tide, freshwater inflow will dominate again, the extent depends on the relative magnitude of treated effluent and river flow magnitudes.

When the lagoon drains during a low tide event, pockets of high salinity water may remain perched within depressions. During a flood tide, some stratification or complete vertical freshening caused by freshwater inflow occurs at the upstream ends of the treated effluent discharge channel and the main river channel, near the eastern extent of tidal influence. Based on the continuous and discrete water quality measurements, lagoon water quality is as variable as the ever-fluctuating water levels experienced during open or partially open inlet conditions. In the Santa Clara River lagoon, the periods between large-scale infilling may also be interspersed with short periods of inlet closure, which prevent tidal exchange over lower tide ranges.

Historically, flooding and draining of the Santa Clara River lagoon likely occurred on a more seasonal cycle, with barrier beach formation and lagoon flooding occurring during the summer, and breaching occurring during the winter in response to winter storms. This seasonal barrier beach construction and destruction pattern was also reinforced by the typical seasonal wave climate pattern. As presented in Section 4.7 below, the lower summer wave energy promotes beach construction while the increase in wave energy in the winter promotes beach face erosion at a greater rate than beach replenishment. In conclusion, it appears the existing Santa Clara River lagoon is experiencing more frequent breaching events than under natural conditions, especially during the summer periods due to treated effluent inflows. However, given the decreased quantity of summer baseflow into the estuary, likely diminished shallow groundwater exchange, and poor water quality of remaining lagoon inflows due to agricultural returns, water quality in the lagoon would likely suffer large-scale degradation and eutrophication of water quality without the treatment plant's freshwater input and the more frequent tidal exchange brought about by the increased frequency of barrier beach breaching.

4.6 Lagoon Water Budget

There are five primary freshwater sources of inflow to the Santa Clara River coastal lagoon: river inflow, rainfall, VWRF-treated effluent discharge, agricultural return flows, and shallow groundwater inflow. Reasonable daily estimates for the first three sources are available, but the quantity and quality of agricultural return flows and shallow groundwater inflow are not known. To better quantify these unknown variables, KHE developed a series of water budgets for the lagoon. Other variables incorporated into the water budget included lagoon volume (based on the water level-volume relationship discussed below), lagoon evapotranspiration rates, and estimates of seepage losses through the barrier beach. Water budgets were completed only for monitoring periods during which there were no direct rainfall contributions to the lagoon and when the barrier inlet was closed, eliminating tidal exchange with the ocean. The specific monitoring periods that met these conditions along with description of selected hydrologic conditions are presented in Table 4-10.

Table 4-10. Water Budget Modeling Periods and Hydrologic Conditions

Dates	***River inflow***	***Initial water level (NAVD88)***	***Maximum Water level (NAVD88)***
Unknown- 1/28/04	Yes	Unknown	9.97 ft
2/7/2004-2/10/2004	No	6.52 ft	7.59 ft
4/8/2004-5/16/2004	No	6.11 ft	10.12 ft
6/26/2004-7/15/2004	No	5.58 ft	>8.75
11/4/2004-12/14/2004	No	6.18 ft	10.58 ft

Water budgets were computed on a daily time step. Inflows included the Santa Clara River flows and daily effluent from the wastewater treatment facility while daily outflows included evaporation from the lagoon surface and beach face/dune seepage. Daily estimates in net water accumulation in the lagoon were calculated from measured lagoon water levels and a stage-volume relationship of the lagoon. This left groundwater seepage[4] and agricultural return flows as the primary unknown variables. Supplying measured values for all the other known variables provided an estimate of a term that reflects the combined sum or flux of the groundwater and agriculture return flow terms.

The stage-volume relationship for the lagoon was developed from the bathymetric map presented as Figure 4-2. As indicated in Section 4.2.1 of this report, this bathymetry map was developed utilizing published surface contours from a 2001 LIDAR topographic

[4] Beach seepage was calculated based on average daily lagoon-ocean head differentials and barrier-beach-lagoon interface 3000-feet wide and beach width of 20-feet. Using a hydraulic conductivity of 4 feet per day at the maximum, seepage rate was 1.1 mgd.

survey and the lagoon contours from the *McGrath State Beach Natural Resources Management Plan* (ESA 2003). The lagoon boundaries included:

- The mouth of the estuary;
- The northern and southern lagoon edges; and
- The Eastern boundary estimated to be the maximum extent of tidal excursion (approximately 6,000 feet upstream of the mouth).

KHE contracted McGee Survey Consulting to complete a supplemental survey in February 2005 to ground truth the bathymetric map and tie the tide gauge to a known vertical datum. Volumes of water within the lagoon at discrete stages were calculated and a stage-volume relationship was fitted to the data.

A water budget was prepared for each of the filling events indicated in Table 4-10. As indicated in this same table, the maximum measured water levels at the time of breaching for most of the events was approximately 10 feet in elevation (NAVD88). Water budget results for each period indicate that during filling of the lagoon to an elevation of approximately 8 feet, the measured daily inflow volumes are higher than predicted by the water budget. This excess supply to the lagoon may be attributed to groundwater seepage and/or agricultural return flows. Water budget results for each analyzed period also consistently indicate that once the lagoon water level exceeds 8 feet in elevation, the measured inflow volumes (and cumulative lagoon volume) are lower than predicted using the water budget. This consistent transition in the lagoon from a gaining to losing system at a water level of 8 feet may be attributable to a reversal in the groundwater gradient, with net flow from the lagoon into the surrounding shallow groundwater system and/or increased beach face seepage to the ocean at lagoon water levels above 8 feet. A plot of the daily difference (measured value minus predicted value) of lagoon volume versus measured lagoon water level for the 6/27/04 through 7/15/04 infilling event is presented in Figure 4-24. A potential groundwater gradient reversal between the shallow aquifer underlying McGrath State Beach and the lagoon at some threshold water table elevation is supported by the field measurements and observations made during previous investigations at the park as described in Section 4.3 of this report. This result may also explain the flooding of the adjacent McGrath State Beach, which has historically been attributable to rising groundwater levels flooding the park. It is important to note however, that these results may be limited in quantifying the influence of groundwater exchange since the stage-volume curve used in this analysis may not accurately depict lagoon over bank areas, side-channels and other storage areas at higher elevations. Regardless, if a significant portion of the additional inflow to the lagoon at lower stages is attributed to agricultural return flows, these flows have a significant influence on lagoon water quality.

4.7 Lagoon Inlet Stability Assessment

As mentioned in Section 4.5.6, the lagoon inlet may be in an open or closed state depending on a balance of numerous competing forces. The physical processes that contribute to the state of the inlet may be categorized as contributing to or part of the following:

- Barrier beach formation;
- Wave power at the mouth of the lagoon; and
- Inlet dynamics.

The purpose of the inlet stability assessment is to characterize the inlet condition after a recent breaching event to determine whether it is stable and will remain open under a specific hydrologic regime or evolve towards the closed condition. This assessment focuses on the non-filling periods between those periods studied in the water balance.

4.7.1 Barrier Beach Formation

The construction of a barrier beach is controlled by any or all of the following factors:

- Littoral sand transport and supply into the mouth of the lagoon;
- Sediment load from the Santa Clara River deposited at the mouth of the lagoon;
- The amount and timing of dredged material placement from the Ventura Harbor placed on the northern boundary of the lagoon beach face; and
- Cross-shore transport of material from the offshore delta sandbar towards the lagoon mouth.

The balance of these factors and breaching factors (mainly elevated lagoon inflow and tidal exchange) determines the capacity for formation of the barrier beach and relative stability once formed.

4.7.2 Wave Climate at the River Mouth

Because real-time measurements of wave power at the mouth of the Santa Clara River lagoon are not available, deepwater wave power, calculated from offshore buoys, is used to estimate the power arriving at the offshore 6-foot (2-meter) depth contour. To determine the validity of this estimate, historical data from nearshore and offshore buoys were analyzed over the same periods of record. Significant wave heights compared at the Harvest platform, Point Arguello and the nearshore Channel Islands Harbor buoys have reasonable tracing of the seasonal and storm related sea states. One of the assumptions associated with this analysis is that the nearshore buoy measures the significant wave height after the effects of energy loss due to refraction and diffraction occurs to the waves as they propagate into the nearshore zone. Using the ratio of offshore/nearshore significant heights, an estimate of the significant wave height reaching the offshore delta of the Santa Clara River was calculated. A representative seasonal plot of offshore (Point Arguello), nearshore (Channel Island Harbor) and estimated Santa Clara River mouth wave heights is shown in Figure 4-2.5. This figure captures the seasonal distribution of larger amplitude wave heights during winter, in association with storms, and the lower amplitude wave heights of the summer. The shadowing effects of wave directional climates due to the offshore Channel Islands was not applied to the wave height distribution estimates at the mouth of the lagoon.

The estimated lagoon wave heights were then used to calculate the wave energy per unit width reaching the nearshore waters using the following relation (U.S. Army Corps of Engineers 1984):

$$E_L = 1/8\ p\ g\ H^2 L$$

Where: p is the unit density of water

g is the acceleration due to gravity

H is the wave height

L is the wavelength

Wave height and period are the standard measurements reported by the coastal buoy arrays, and by using the reported wave period, the wavelength (L) may be calculated. A plot of estimated monthly wave power at the river mouth is presented in Figure 4-26. Similar to wave height, Figure 4-26illustrates the classic seasonal sinusoidal distribution of higher wave energy in winter and lower wave energy in the summer. This deepwater wave surrogate estimate for nearshore wave power assumes that waves remain unchanged as they move closer to the shore, but this is generally not a correct assumption. When considering both wave height and wave power, periods of maximum wave height and wave energy have the greatest destructive (erosive) effect on the barrier beach while periods of lower wave energy and relatively low wave height predominate in summer and result in barrier beach reconstruction/buildup.

4.7.3 Inlet Dynamics

The volume of water that is exchanged into or out of a lagoon between mean MHHW and MLLW is defined as the tidal prism. This volume is estimated using known (surveyed) marsh and tidal channel topography and actual tidal ranges. There are several alternate definitions and measures of tidal prism, but all exclude contributions from freshwater inflow. However, for purposes of this study, the contributions of treated effluent and river inflow are important contributions to the amount of water exchanged through the lagoon inlet. This analysis also assumes that during a flood tide the lagoon is filling with ocean water and captures all of the effluent and river baseflow behind the rising tide (high flows associated with storm events would most likely overtop the tidal water level and/or flood adjacent areas). Thus the “tidal prism” released back into the ocean during an ebb tide is greater than the volume of ocean water that solely entered the lagoon during the flood tide. During the ebb tide, water exits the mouth of the lagoon until the low tidal water level or the sill height of the lagoon mouth is reached. For the tidal lagoon to remain open, the velocity of water moving out of the mouth must be sufficient to carry the sediment deposited.

Empirical relationships developed by Bruun (1978) examine inlet stability as a function of tidal prism and littoral sand transport to the inlet mouth during one tidal cycle. The results of his analyses, expressed as inlet stability indexes, are presented in Table 4-11. To simplify applying these indexes throughout the stability analyses, each index has been assigned a letter from A to E as indicated in Table 4-11.

Table 4-11. Bruun Inlet Stability Indexes

Bruun Inlet Stability Index Range	***Bruun's Description of Inlet Conditions (relative to inlet remaining open)***	***Santa Clara River Study Rating***
150 < B	Conditions are relatively good (inlet open and stable), little bar formation and good flushing of the inlet.	A
100 < B <150	Conditions become less satisfactory and offshore bar formation becomes more pronounced.	B
50 < B<100	Entrance bar may be rather large, usually associated with a channel and all inlets are typical "bar bypassers."	C
20 < B < 50	Waves break over the bar during storms and the inlet is opened through the freshwater flows associated with the precipitation season.	D
B < 20	This is descriptive of an unstable overflow channel rather than a permanent inlet.	E

Where: $B = P/ Q_{lst}$

P is tidal prism,

Q_{lst} is transport of sediment towards the mouth in one tidal period

A traditional estimate of tidal prism during one tidal cycle has been defined by the following relationship (U.S. Army Corps of Engineers 1984):

$$P = 2A_b a_b$$

Where: A_b is area of the bay

a_b is the water level range within the bay due to one tidal cycle

This relation of tidal prism is limited because it assumes a constant area of filling within the lagoon due to vertically sided banks. Estimates of long-shore sediment transport rates during a tidal or daily cycle are also limited but can be estimated from yearly or seasonal aggregates available in recent sediment budget studies (U.S. Army Corps of Engineers 2002).

4.7.4 Analytical Assessment

The measurement of water levels within the lagoon, coupled with the stage-volume model developed for the water budget, provided an estimate of the freshwater augmented tidal prism within the lagoon. Utilizing a daily time step, the maximum daily recorded high water was used to calculate the mean tidal prism. The tides in the Santa Clara River system were also assumed truncated at an elevation of 3.5 feet NAVD88, which is the observed elevation of shoaling at the river mouth. Bruun stability indexes were then calculated for the following three scenarios for each of the selected post-breach monitoring periods.

- Existing Conditions Scenario: The current estimate of 500,000 cubic yards per year (cy/yr) of sediment is being delivered to the mouth of the lagoon and an additional 178,000 cy/yr is deposited at the river mouth delta. Treated effluent releases to lagoon per City estimates.

- No Sand Bypass Scenario: Same as existing conditions scenario except no dredged sand is bypassed to McGrath State Beach – results in increase of 640,000 cy/yr of material delivered to river mouth.

- No Effluent Scenario: Same as existing conditions scenario except the lagoon tidal prism is decreased by subtracting the volume of wastewater effluent discharged into the lagoon (assumes approximately 1.5 mgd over a 6-hour flood tide period).

The latter two scenarios were developed and analyzed to evaluate how changes in sediment supply to the river mouth and changes in lagoon inflow affect inlet stability.

Predicted inlet stability indexes for the three analyzed scenarios are presented in Table 4-12. Selected lagoon inflow, lagoon water level and river mouth sediment supply conditions for analysis periods are also presented in Table 4-12. The two February 2004 analysis periods are representative of winter storm inflow conditions as captured by the high river to lagoon inflow rates and high wave power conditions. In addition, both of these periods occur during spring tide conditions, resulting in relatively high tidal prism estimates. Based on the calculated Bruun stability indexes, the inlet appears apt to remain open under both the Existing Conditions and No Effluent scenarios during these periods. These scenarios are dominated by the high lagoon inflow rates. However, the increased sand supply associated with the No Sand Bypass scenario leaves the inlet a little less stable or more prone to infilling under the same inflow and wave power conditions.

The March 2004 and October-November 2004 analysis periods represent similar lagoon inflow (low river inflow relative to treated effluent contributions) and high seasonal wave power conditions. However, under the Existing Conditions scenario, the inlet appears more unstable (evolving towards closure) during the March 2004 period. This is likely because the March 2004 analysis period spans an equal amount of spring and neap tidal periods while the October-November 2004 period occurs during a spring tide period. Thus, the tidal prism estimate for the later period is slightly greater than the earlier analysis period. The relatively high inlet stability index (B) estimated for the Existing Conditions scenario for the May-June 2004 period is somewhat unexpected given the lack of river inflow to the lagoon and low seasonal wave power. However, this period preferentially spans spring tide conditions and the lagoon experiences some of the largest tidal prism exchanges over the summer dry period.

Under the remaining No Sand Bypass and No Effluent scenarios, there is no significant difference in inlet stability when compared to the Existing Conditions scenario for the March 2004 period. However, inlet stability drops one category, relative to Existing Conditions, during both the May-June and October-November analysis periods.

The stability analysis results presented and discussed above represent average conditions over the period analyzed. Another important finding or trend shown by the stability assessment analysis but not necessarily captured in the results presented in Table 4-12, is that inter-period stability varied significantly between neap and spring tidal cycles. During neap tidal periods, tidal exchange and lagoon tidal prism volumes are reduced when compared to spring tidal periods. As a result, inlet stability is reduced during neap tidal periods and the timing of barrier beach reconstruction may be closely linked to the amplitude of these tidal periods – the sensitivity of which cannot be determined using the Bruun inlet stability method alone.

In summary, it appears that the inlet is less stable (i.e., prone to infilling) during the summer months (low river inflow). Increased littoral sand supply to the river mouth and reduced treated effluent discharge to the lagoon would create less stable inlet conditions, promoting more rapid inlet closure and barrier beach formation. As indicated by long-term lagoon visual observations and results of hydrologic monitoring, high runoff and river flow effectively scour and maintain an open inlet and lagoon system. Although reasonable estimates of increased littoral sand supply to the river mouth and reduced lagoon inflow during summer months could be combined to approximate "pre-development lagoon conditions," a similar stability analysis was not attempted for such conditions here. To do so, reliable pre-development lagoon bathymetry data would be necessary to estimate the tidal prism volumes used in the Bruun analysis.

Table 4-12. Results of Inlet Stability Assessment

Time period	***Maximum River Inflow Rate (cfs)***	***Seasonal Wave Power***	***Average Recorded Water Level (NAVD88)***	***Stability Index Existing Conditions Scenario***	***Stability Index No Sand Bypass Scenario***	***Stability Index No Effluent Scenario***
1/29-2/6/04	205	High	5.33 ft	B	C	B
2/14-2/24/04	607	High	6.01ft	A	B	A
3/6-3/27/04	3.7	High	5.04 ft	C	C	C
5/18-6/23/04	0	Low	5.20 ft	B	C	C
10/23-11/3/04	0	High	5.05 ft	B	C	C

4.8 Summary and Conclusions

The hydrologic, geomorphic, and coastal processes investigations presented above were successful in describing and quantifying the long-term and seasonal changes in hydro-geomorphic, water quality, and ecological habitat conditions of the Santa Clara River coastal lagoon. The following bullets summarize the key findings and conclusions of this investigation.

- Agricultural and urban development within Ventura County has significantly reduced the size of the coastal lagoon and constricted the width of the lower river channel and floodplain corridor.

- Development in the watershed has also significantly encroached into the former lagoon footprint, leading to levee construction and bank stabilization measures that constricted lower channel and lagoon width; focusing flood energy within a narrower area; and reducing lagoon size and storage capacity, which leads to reduce storage volume and tidal exchange that scours the lagoon inlet.

- Surface water and groundwater development activities within the Santa Clara River basin have significantly if not permanently altered the hydrologic conditions acting on the coastal lagoon. Impacts on the lagoon include significantly decreased surface water delivery from the upper watershed; significantly reduced groundwater supply to the river baseflow that, in turn, feeds the lagoon; and altered dry-season treated effluent releases relative to natural freshwater inflow rates.

- Sand supply to the littoral cell and mouth of the Santa Clara River has been significantly reduced due to sediment trapping behind dams in Ventura County and the bypassing of material dredged at the Ventura Harbor past the river mouth. These reductions in sand supply have impacted barrier beach reconstruction.

- The major variables that have increased the frequency of barrier beach breaching and reduced the ability for inlet closure include (1) reduced lagoon area and storage volume; (2) altered lagoon inflow rates; and (3) reduced sand supply to the river mouth.

- The water quality of the lagoon has been adversely impacted by reduced freshwater inflow, increased agricultural return flows, degraded groundwater quality, and urban runoff.

- In addition to the increased frequency and predictability of barrier beach breaching events, the release of treated water effluent to the lagoon and resulting increase in tidal prism increase inlet scour and reduce the rate at which the barrier beach reforms.

- The treated effluent discharges have led to more frequent lagoon flooding and breaching of the barrier beach over natural conditions during the summer months and during the winter dry periods. Given the likely high nutrient content of lagoon summer inflow sources, treated wastewater effluent releases have a net beneficial effect by eliminating the onset of eutrophication within the flooded lagoon during summer months.

In general terms, numerous physical conditions and hydrologic/geomorphic processes have significantly altered the Santa Clara River coastal lagoon to a point where restoring a single variable to more natural pre-existing state will not significantly alter and/or benefit the function and habitat quality of the lagoon. Eliminating treated effluent discharges to the lagoon will reduce the frequency of barrier beach breaching but will also result in a ponded lagoon in the summer of significantly reduced water quality and degraded aquatic habitat.

4.9 References

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TABLES

TABLE 4-5: ESTIMATED NATURAL MONTHLY/ANNUAL FLOW VOLUMES ON SANTA CLARA RIVER AT MONTALVO (volumes in acre-feet)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
1928	0	0	707	573	7,220	5,657	1,339	4	0	0	0	0	**15,500**
1929	49	1,615	4,976	4,450	6,382	7,067	7,939	1,042	337	63	50	70	**34,039**
1930	78	211	509	3,519	605	14,105	2,083	1,069	526	100	79	110	**22,995**
1931	78	213	512	1,789	12,432	2,189	3,579	1,610	528	0	0	0	**22,930**
1932	0	1,195	23,392	6,457	93,859	8,845	3,061	1,089	660	153	18	304	**139,034**
1933	0	0	75	25,953	10,146	6,575	2,342	604	0	0	0	0	**45,695**
1934	0	0	22,373	39,476	11,913	6,257	1,159	0	0	0	0	0	**81,177**
1935	3,016	2,635	20,735	49,229	9,533	19,172	17,942	5,918	744	0	0	0	**128,923**
1936	0	0	286	88	60,638	7,862	6,125	779	0	0	0	0	**75,779**
1937	4,450	106	25,648	18,290	104,751	88,828	27,623	7,719	2,329	0	0	0	**279,743**
1938	0	0	6,223	3,219	121,355	230,748	23,811	11,305	4,820	1,660	0	0	**403,141**
1939	0	0	15,004	9,588	6,774	16,679	5,507	1,236	0	0	0	4,318	**59,105**
1940	1,175	984	1,299	5,195	22,657	7,553	3,980	2,135	547	0	0	0	**45,525**
1941	74	52	29,606	50,959	173,185	212,457	115,562	30,165	12,449	6,449	3,896	2,744	**637,598**
1942	2,778	3,006	17,403	8,782	5,308	4,045	13,864	5,037	1,913	520	158	107	**62,921**
1943	131	387	723	101,508	67,399	92,133	13,633	6,867	3,432	1,604	847	492	**289,157**
1944	542	908	14,354	7,448	58,499	108,968	25,913	11,289	6,066	2,824	1,367	820	**238,998**
1945	994	11,465	3,185	2,496	37,436	14,196	9,738	3,682	1,804	621	274	38	**85,929**
1946	246	788	31,859	4,619	4,924	33,255	25,892	5,071	1,498	406	57	0	**108,615**
1947	65	20,099	32,778	9,601	4,159	2,915	2,514	863	396	0	0	0	**73,390**
1948	0	0	210	296	782	2,519	2,798	971	249	0	0	0	**7,826**
1949	0	0	307	667	691	6,291	1,749	655	0	0	0	0	**10,360**
1950	0	0	979	2,777	7,628	2,770	998	0	0	0	0	0	**15,151**
1951	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1952	0	0	639	111,952	8,820	65,925	18,476	7,736	1,856	798	125	830	**217,158**
1953	1,112	2,139	4,759	6,977	3,788	2,827	1,492	1,407	657	0	0	0	**25,158**
1954	0	644	1,007	4,480	7,819	8,057	6,387	2,674	1,060	164	0	0	**32,292**
1955	0	0	0	3,332	1,849	3,203	1,238	6,092	1,192	36	0	0	**16,942**
1956	0	0	3,501	14,889	4,338	2,541	4,355	6,734	1,268	0	0	0	**37,627**
1957	0	0	0	15,822	8,657	5,936	2,142	1,903	407	0	0	0	**34,868**
1958	0	0	23,728	4,732	76,800	80,193	171,092	15,371	5,946	2,835	1,231	951	**382,879**
1959	667	919	1,118	5,308	31,160	6,889	3,225	1,525	232	0	0	0	**51,042**
1960	0	0	0	5,410	4,862	1,933	0	1,039	0	0	0	0	**13,244**
1961	0	4,088	2,169	2,361	1,374	644	165	0	0	0	0	0	**10,800**
1962	0	1,312	6,618	1,815	235,948	31,763	11,902	5,629	2,496	818	150	26	**298,478**
1963	70	81	360	621	10,351	2,371	2,548	2,313	0	0	0	0	**18,715**
1964	0	2,864	621	3,298	1,150	0	7,018	870	0	0	0	0	**15,821**
1965	0	51	8,256	2,078	712	0	19,504	3,445	842	0	0	0	**34,887**
1966	0	138,699	74,985	30,853	15,344	7,691	3,935	2,315	908	200	0	0	**274,930**
1967	0	5,673	73,758	33,289	11,962	44,935	63,076	26,536	7,848	3,068	1,197	831	**272,174**
1968	768	9,531	4,335	1,753	3,296	5,762	2,281	1,514	377	0	0	0	**29,616**
1969	0	0	257	377,547	323,429	84,783	25,516	11,870	6,285	3,190	1,999	1,192	**836,067**
1970	1,468	1,793	1,988	2,993	23,950	49,235	4,820	2,767	1,083	381	63	91	**90,633**
1971	328	39,553	19,406	25,291	8,573	5,549	3,679	2,437	1,618	508	134	19	**107,095**
1972	73	179	29,171	8,785	3,888	2,778	1,367	621	109	0	0	0	**46,972**
1973	0	4,044	1,378	16,392	184,858	38,682	16,493	6,573	2,766	1,344	508	292	**273,331**
1974	331	1,367	2,722	43,710	6,807	17,157	5,780	2,945	1,129	252	0	0	**82,201**
1975	31	227	12,321	1,604	7,773	59,264	12,768	5,440	1,837	599	152	0	**102,015**
1976	0	24	363	408	25,039	5,782	2,897	1,186	284	0	0	1,727	**37,710**
1977	779	377	447	914	1,183	0	962	7,048	820	0	0	0	**12,530**
1978	0	0	19,549	75,763	281,547	240,791	74,742	20,304	9,312	4,947	2,778	2,514	**732,247**
1979	1,818	2,919	5,455	28,153	36,839	45,707	34,731	9,690	4,427	1,830	870	656	**173,095**
1980	746	1,050	1,977	18,621	139,979	62,010	13,740	7,612	4,624	2,132	1,118	798	**254,407**
1981	655	875	1,796	3,298	3,659	26,066	5,659	2,361	634	0	0	0	**45,003**
1982	0	602	768	3,851	2,935	19,072	32,999	4,427	1,538	343	0	0	**66,536**
1983	0	4,547	27,229	76,195	69,864	240,186	60,130	36,099	10,465	5,715	4,360	2,536	**537,325**
1984	8,854	7,581	27,069	7,868	4,332	3,438	2,337	1,062	333	16	0	0	**62,889**
1985	0	1,181	10,627	4,070	1,446	1,476	1,640	655	0	0	0	0	**21,096**
1986	61	2,688	3,838	10,795	74,569	44,911	15,964	7,390	3,779	1,220	0	950	**166,164**
1987	746	2,154	1,412	1,751	1,476	4,068	1,804	1,277	62	0	0	0	**14,749**
1988	0	656	1,364	6,246	26,173	27,338	6,949	3,196	539	252	9	0	**72,723**
1989	0	130	1,543	837	6,502	3,298	930	647	247	0	0	0	**14,135**
1990	0	0	0	2,417	3,506	1,051	0	0	0	0	0	0	**6,974**
1991	0	0	0	0	7,698	92,662	23,925	5,523	1,460	554	0	0	**131,822**
1992	0	0	2,993	9,995	200,469	86,458	28,883	11,503	4,820	2,919	1,141	777	**349,958**
1993	1,028	1,345	13,790	114,527	255,364	109,782	36,491	18,285	11,120	6,906	3,852	2,622	**575,111**
1994	2,802	2,570	3,431	3,721	22,215	9,728	4,926	3,963	2,069	1,166	227	369	**57,187**
1995	721	1,652	1,519	228,412	50,599	150,615	35,812	19,485	11,669	6,893	3,242	2,233	**512,855**
1996	2,410	2,079	2,197	3,765	23,816	15,096	6,383	3,466	1,864	866	503	439	**62,882**
1997	1,350	2,669	35,195	52,434	22,989	10,584	4,641	3,305	2,130	1,413	542	22	**137,274**
1998	716	2,584	11,209	10,914	388,010	74,778	55,064	61,229	23,968	13,183	7,729	5,671	**655,055**
1999	4,341	3,554	3,460	3,949	4,622	4,712	6,474	2,521	1,590	665	290	36	**36,214**
2000	261	392	503	604	21,400	18,484	12,064	5,447	2,445	1,430	493	233	**63,756**
2001	329	599	638	6,121	32,897	114,751	19,399	9,248	4,366	3,158	1,597	1,306	**194,407**
AVERAGE	**624**	**4,041**	**9,522**	**23,755**	**47,634**	**38,406**	**16,189**	**6,295**	**2,470**	**1,138**	**555**	**488**	**151,116**

TABLE 4-6: ACTUAL MONTHLY/ANNUAL FLOW VOLUMES ON SANTA CLARA RIVER AT MONTALVO (volumes in acre-feet)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
1928	0	0	707	573	7,220	5,657	1,339	4	0	0	0	0	**15,500**
1929	0	1,482	4,655	4,003	6,109	5,694	6,843	568	6	0	0	0	**29,359**
1930	0	0	0	2,810	172	11,929	346	318	0	0	0	0	**15,575**
1931	0	0	0	1,076	11,996	0	1,833	855	0	0	0	0	**15,760**
1932	0	964	22,689	4,261	93,859	6,641	1,023	0	0	0	0	0	**129,438**
1933	0	0	0	25,513	8,559	4,086	453	0	0	0	0	0	**38,612**
1934	0	0	22,127	39,476	11,889	2,858	0	0	0	0	0	0	**76,349**
1935	3,016	2,015	18,966	47,710	5,461	17,666	15,132	1,505	0	0	0	0	**111,470**
1936	0	0	286	88	60,118	1,827	2,129	0	0	0	0	0	**64,448**
1937	4,450	106	25,129	16,113	104,751	87,055	24,508	2,007	0	0	0	0	**264,119**
1938	0	0	5,278	0	121,355	230,748	23,811	8,753	899	0	0	0	**390,844**
1939	0	0	15,004	9,105	4,949	15,582	1,742	0	0	0	0	4,318	**50,699**
1940	1,175	984	1,299	3,675	20,585	2,836	716	0	0	0	0	0	**31,270**
1941	74	52	29,606	50,879	172,869	212,457	115,562	30,165	12,449	6,449	3,896	2,744	**637,202**
1942	2,778	3,006	17,403	8,782	5,308	4,045	13,864	5,037	1,913	520	158	107	**62,921**
1943	131	387	723	101,508	67,399	92,133	13,633	6,867	3,432	1,604	847	492	**289,157**
1944	542	908	14,354	7,448	58,499	108,968	25,913	11,289	6,066	2,824	915	0	**237,726**
1945	994	11,465	3,185	2,496	37,436	14,196	9,738	2,581	628	0	0	0	**82,719**
1946	0	0	30,081	4,619	4,924	31,096	24,750	721	0	0	57	0	**96,249**
1947	0	19,838	29,035	5,905	502	0	0	0	0	0	0	0	**55,280**
1948	0	0	0	0	782	2,461	0	0	249	0	0	0	**3,492**
1949	0	0	307	264	0	4,391	859	655	0	0	0	0	**6,476**
1950	0	0	80	683	4,693	0	0	0	0	0	0	0	**5,455**
1951	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1952	0	0	639	111,110	3,149	64,255	12,377	260	0	0	0	0	**191,791**
1953	0	3	2,533	769	2	0	1	0	0	0	0	0	**3,308**
1954	0	0	0	3,013	4,704	4,483	166	0	0	0	0	0	**12,366**
1955	0	0	0	108	53	0	26	756	0	0	0	0	**943**
1956	0	0	0	14,204	0	0	0	0	0	0	0	0	**14,204**
1957	0	0	0	3,462	1,444	713	0	0	0	0	0	0	**5,619**
1958	0	0	12,913	781	49,151	56,139	158,759	732	16	9	6	4	**278,509**
1959	6	5	1	2,066	17,217	17	8	5	0	0	0	0	**19,324**
1960	0	0	0	58	208	6	51	0	0	0	0	0	**324**
1961	0	456	2	0	0	0	0	0	0	0	0	0	**459**
1962	0	114	1,254	7	220,875	2,189	18	0	0	0	0	0	**224,457**
1963	0	0	0	0	5,454	732	30	0	1	0	0	0	**6,217**
1964	0	815	0	1,217	1	228	2,458	0	0	0	0	0	**4,719**
1965	0	2	3,228	0	0	2	4,356	0	0	0	0	0	**7,587**
1966	0	95,387	56,385	1,857	492	0	0	0	0	0	0	0	**154,120**
1967	0	3,499	49,683	12,236	0	13,589	31,954	3,265	0	0	0	0	**114,226**
1968	0	5,522	184	191	314	3,400	124	25	8	4	0	0	**9,772**
1969	0	0	0	336,773	406,205	123,961	18,625	1,697	595	510	544	607	**889,516**
1970	633	809	133	0	10,330	39,722	366	36	71	23	6	3	**52,132**
1971	3	34,037	23,858	4,249	2,866	1,144	431	24	18	6	2	2	**66,640**
1972	2	2	26,256	3,019	143	117	81	42	8	2	0	45	**29,718**
1973	17	1,470	1	21,767	139,067	38,430	36	9	4	0	0	0	**200,801**
1974	0	168	401	51,404	18	10,638	7	0	0	0	0	0	**62,636**
1975	0	0	9,285	3	5,998	35,540	1,458	2	0	0	0	0	**52,286**
1976	0	0	1,027	1,390	13,885	2	1	0	0	0	0	376	**16,679**
1977	0	0	0	5,337	13	6	0	1,328	0	0	0	0	**6,685**
1978	0	0	8,055	49,314	225,929	332,468	53,733	598	424	20	11	156	**670,707**
1979	41	348	3,683	29,392	29,546	57,676	56,470	320	280	73	8	4	**177,841**
1980	27	170	1,623	31,113	242,923	98,566	14,519	8,424	1,119	1,273	48	288	**400,094**
1981	477	283	113	3,714	1,749	23,673	672	370	45	44	34	7	**31,181**
1982	2	22	17	275	61	10,453	21,005	89	15	2	0	0	**31,942**
1983	0	5,570	28,285	54,848	64,702	368,009	71,942	45,256	4,564	1,771	17	1,886	**646,847**
1984	2,134	8,390	21,152	7,379	1,383	1,377	29	0	0	0	0	0	**41,843**
1985	0	0	4,458	440	200	0	0	0	0	0	0	0	**5,099**
1986	0	4	389	12,605	94,026	43,472	4,153	0	0	0	0	0	**154,649**
1987	0	73	0	76	0	523	0	31	0	0	0	0	**702**
1988	0	0	959	2,810	7,942	8,362	2,594	0	0	0	0	0	**22,668**
1989	0	0	445	0	462	0	0	0	0	0	0	0	**907**
1990	0	0	0	0	1,588	0	0	0	0	0	0	0	**1,588**
1991	0	0	0	0	1,472	75,938	2,172	0	0	0	0	0	**79,582**
1992	0	0	1,593	3,142	170,002	57,861	14,757	33	10	9	6	5	**247,416**
1993	1,051	86	7,256	221,359	343,391	169,401	61,290	16,171	10,830	3,800	8	4	**834,647**
1994	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1995	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1996	1,045	1,381	1,316	3,351	37,377	11,744	1,565	575	71	0	0	0	**58,425**
1997	4,427	2,458	19,984	24,657	7,498	1,599	827	124	0	0	0	0	**61,572**
1998	0	481	25,272	5,602	395,708	65,547	95,803	67,760	15,947	5,989	1,470	1,023	**680,602**
1999	652	1,202	589	1,875	1,611	2,164	3,445	121	102	37	0	142	**11,941**
2000	28	1	0	9	25,770	14,388	8,212	683	154	242	0	6	**49,492**
2001	461	345	46	6,579	28,602	109,511	4,784	1,420	382	99	0	6	**152,236**
AVERAGE	**327**	**2,761**	**7,486**	**18,521**	**45,581**	**36,627**	**12,615**	**2,993**	**815**	**342**	**109**	**165**	**128,340**

TABLE 4-7: ESTIMATED NATURAL AND ACTUAL RIVER FLOW AT MONTALVO AND INFLOW TO COASTAL LAGOON FOR REPRESENTATIVE WATER YEAR-TYPES (volumes in acre-feet)

ESTIMATED NATURAL FLOW AT MONTALVO & LAGOON INFLOW

Water Year-Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Ex. Wet	363	1,454	14,737	133,474	220,285	159,056	57,617	28,205	12,181	6,755	3,980	2,787	640,894
Wet	593	9,339	17,539	24,674	69,356	62,411	26,390	7,980	3,201	1,366	502	413	223,764
Normal	1,294	3,294	10,085	9,805	18,306	13,823	7,485	2,564	966	365	108	350	68,445
Dry	432	1,244	2,360	5,285	6,918	5,653	4,176	1,972	491	49	20	93	28,692
Crit. Dry	97	574	585	1,613	2,362	1,967	826	1,295	165	0	0	0	9,484

ACTUAL FLOW AT MONTALVO

Water Year-Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Ex. Wet	161	884	14,068	102,682	229,829	181,692	59,565	23,092	6,401	2,648	849	917	622,789
Wet	596	6,464	13,571	20,053	65,996	55,919	19,613	2,080	556	268	86	36	185,237
Normal	476	2,818	8,580	8,510	13,778	8,458	3,834	565	179	49	10	280	47,537
Dry	110	494	899	3,276	4,226	3,149	1,086	145	8	4	2	25	13,422
Crit. Dry	0	57	94	707	382	858	114	248	31	0	0	0	2,491

ACTUAL INFLOW TO LAGOON (sum of Montalvo + treatment plant effluent)

Water Year-Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Ex. Wet	823	1,544	14,764	103,413	230,526	182,441	60,227	23,737	7,014	3,275	1,491	1,538	630,793
Wet	1,259	7,124	14,267	20,783	66,693	56,668	20,275	2,724	1,168	895	727	658	193,242
Normal	1,139	3,478	9,276	9,241	14,475	9,207	4,496	1,210	791	676	651	901	55,542
Dry	772	1,154	1,595	4,006	4,924	3,898	1,748	790	620	631	643	646	21,427
Crit. Dry	663	717	791	1,438	1,079	1,607	776	893	644	627	641	621	10,496

TABLE 4-9: Santa Clara River Estuary Discrete Sampling Data

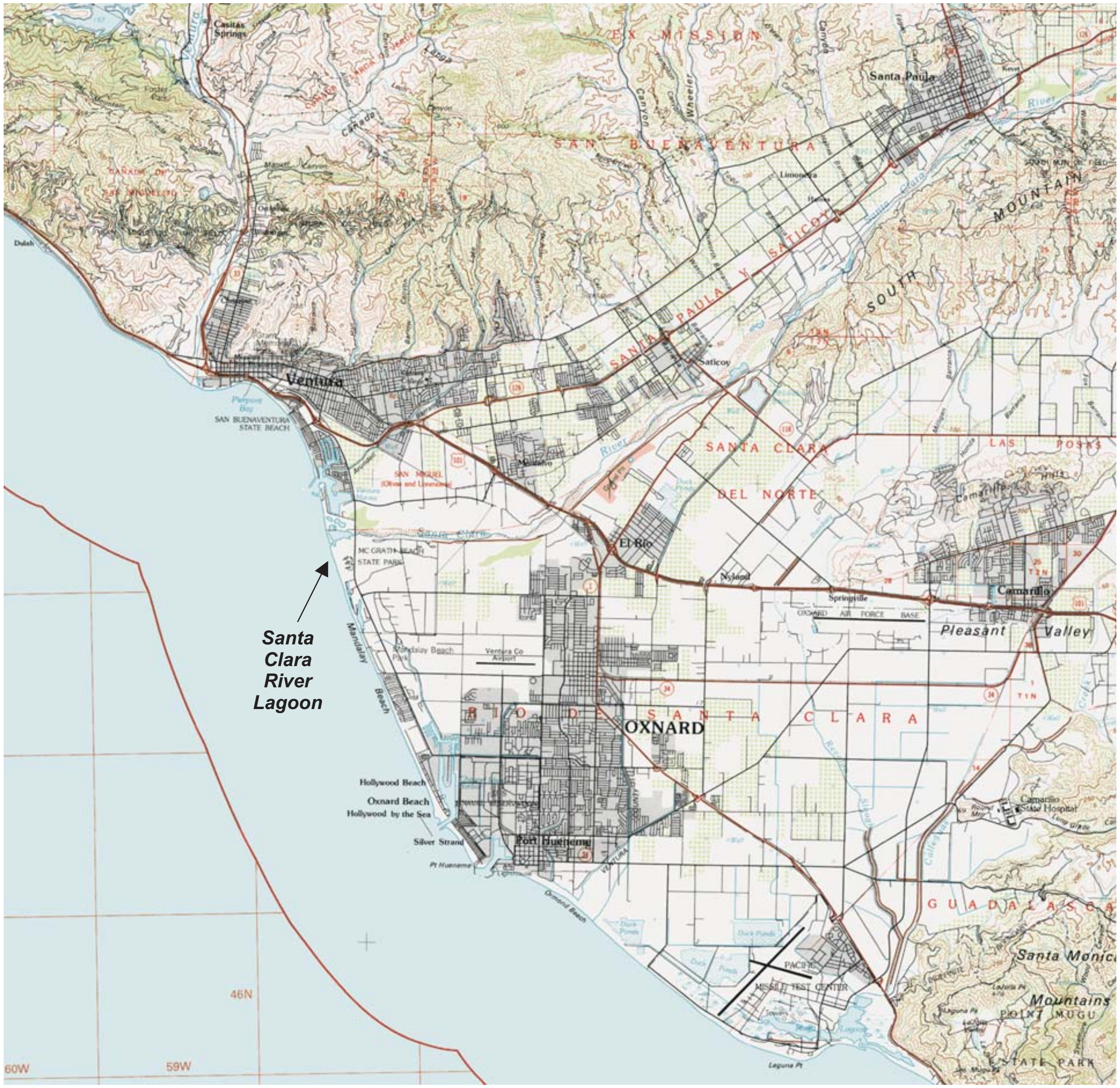
Date (m/d/y)	Time (hh:mm:ss)	WAYPOINT #	Lat (d.d)	Lon (d.d)	Depth (ft)	Temp (deg C)	Salinity (ppt)	pH	DO conc (mg/L)	DO sat (%)	SpCond (mS/cm)
11/6/2003	14:34:11	60	34.23445	119.26486	0.5	20.13	1.29	7.61	322.41	3581.6	2.502
11/6/2003	14:40:45	61	34.23179	119.26482	0.5	20.54	1.58	7.45	163.73	1836.9	3.030
11/6/2003	14:47:53	62	34.23094	119.26316	0.5	20.53	1.73	7.44	78.06	876.4	3.301
11/6/2003	14:51:25	63	34.22985	119.26321	0.5	20.30	1.90	7.42	65.87	736.8	3.590
11/6/2003	14:54:08	64	34.22988	119.26331	0.5	21.57	8.60	7.62	47.74	569.2	14.769
11/6/2003	15:02:55	65	34.22924	119.26414	0.5	21.60	6.51	7.67	30.61	360.8	11.417
11/6/2003	15:09:27	66	34.23026	119.26232	0.5	21.09	4.41	7.76	24.01	276.8	7.944
11/6/2003	15:19:22	67	34.23011	119.26208	0.5	21.25	13.67	7.71	21.31	260.2	22.615
11/6/2003	15:24:40	68	34.23112	119.26117	0.5	21.04	3.19	7.76	16.75	191.6	5.871
11/6/2003	15:30:46	69	34.23093	119.26079	0.5	20.33	11.64	7.55	14.64	173.5	19.498
11/6/2003	15:37:36	70	34.23220	119.26074	0.5	20.09	2.71	7.71	14.59	163.3	5.035
11/6/2003	15:54:03	71	34.23328	119.25979	0.5	19.89	2.28	7.63	10.65	118.5	4.274
11/6/2003	16:19:21	72	34.23385	119.25627	0.5	18.96	1.59	7.71	10.14	110.2	3.032
2/18/2004	7:18:10	102	34.23021	119.26103	1.0	13.65	15.70	7.94	11.31	120.0	25.661
2/18/2004	7:18:38				2.0	14.18	20.13	7.97	11.24	124.0	32.202
2/18/2004	7:19:13				3.0	14.71	22.69	8.02	11.36	128.7	35.894
2/18/2004	7:25:05	103	34.22987	119.26294	1.0	12.96	17.13	7.95	11.12	117.3	27.806
2/18/2004	7:25:25				2.0	13.14	23.02	7.92	10.77	118.4	36.400
2/18/2004	7:26:21				3.0	13.34	23.96	7.92	10.71	118.9	37.753
2/18/2004	7:26:39				4.0	13.34	24.35	7.91	10.60	118.0	38.301
2/18/2004	7:27:05				5.0	13.33	24.67	7.92	10.45	116.5	38.760
2/18/2004	7:27:32				6.0	13.37	24.43	7.73	10.46	116.5	38.417
2/18/2004	7:32:20	104	34.23056	119.26297	1.0	13.04	21.94	7.91	10.77	117.3	34.860
2/18/2004	7:32:40				2.0	13.06	24.16	7.92	10.57	116.8	38.046
2/18/2004	7:33:04				3.0	13.08	24.18	7.93	10.57	116.9	38.075
2/18/2004	7:33:33				4.0	13.09	24.73	7.91	10.56	117.1	38.852
2/18/2004	7:39:48	105	34.23115	119.26307	1.0	12.77	22.25	7.87	10.45	113.3	35.313
2/18/2004	7:40:12				2.0	13.04	24.03	7.90	10.18	112.3	37.859
2/18/2004	7:40:35				3.0	13.07	24.49	7.92	10.24	113.4	38.520
2/18/2004	7:44:45	106	34.23180	119.26350	1.0	12.53	22.31	7.84	10.62	114.7	35.401
2/18/2004	7:49:21	107	34.23280	119.26424	1.0	13.19	19.69	7.75	10.48	112.9	31.574
2/18/2004	7:54:37	108	34.23409	119.26473	1.0	13.43	17.10	7.75	9.86	105.0	27.748
2/18/2004	7:59:03	109	34.23525	119.26482	1.0	13.38	17.14	7.78	10.56	112.5	27.816
2/18/2004	8:12:35	110	34.23492	119.26357	0.5	16.00	2.27	7.39	9.83	101.0	4.241
2/18/2004	8:06:52				1.0	14.52	16.99	7.77	9.82	107.0	27.571
2/18/2004	8:07:15				2.0	15.09	19.59	7.87	9.37	104.9	31.397
2/18/2004	8:07:55				3.0	15.08	21.05	7.95	9.59	108.4	33.514
2/18/2004	8:17:27	111	34.23534	119.26314	0.5	15.64	1.51	7.52	10.68	108.4	2.883
2/18/2004	8:17:47				1.0	16.83	1.56	7.32	9.58	99.7	2.982
2/18/2004	8:18:34				2.0	15.77	18.38	7.82	8.81	99.3	29.615
2/18/2004	8:19:06				3.0	15.58	19.30	7.92	9.10	102.8	30.962
2/18/2004	8:19:42				4.0	15.43	20.61	7.97	9.34	106.0	32.881
2/18/2004	8:24:33	112	34.23578	119.26257	0.5	17.02	1.31	7.31	11.81	123.2	2.520
2/18/2004	8:24:59				1.0	17.08	1.30	7.26	10.63	111.0	2.513
2/18/2004	8:26:04				2.0	16.98	3.16	7.22	8.66	91.3	5.789
2/18/2004	8:39:06	113	34.23182	119.26211	0.5	12.89	14.91	7.86	10.65	110.6	24.483
2/18/2004	8:39:23				1.0	13.14	15.44	7.89	10.78	113.0	25.281
2/18/2004	8:39:38				2.0	13.67	19.63	7.91	10.29	111.9	31.472
2/18/2004	8:43:39	114	34.23111	119.26170	1.0	12.29	22.63	7.89	10.64	114.5	35.874
2/18/2004	8:43:58				2.0	13.02	22.99	7.89	10.26	112.4	36.369
2/18/2004	8:44:21				3.0	13.08	24.13	7.91	10.23	113.0	37.997
2/18/2004	8:44:55				4.0	13.10	24.59	7.87	10.23	113.4	38.654
2/18/2004	8:55:07	115	34.22996	119.26053	1.0	13.48	22.29	7.88	11.20	123.4	35.351
2/18/2004	8:55:28				2.0	13.57	23.08	7.89	10.88	120.6	36.474
2/18/2004	9:10:51	116	34.23122	119.26016	1.0	11.49	23.47	7.89	11.94	127.0	37.111
2/18/2004	9:11:02				2.0	12.52	23.20	7.90	11.03	119.7	36.679
2/18/2004	9:11:22				3.0	13.03	24.79	7.90	10.59	117.4	38.944
2/18/2004	9:16:29	117	34.23202	119.26069	1.0	11.41	23.78	7.87	11.66	124.1	37.560
2/18/2004	9:16:46				2.0	12.79	23.16	7.90	10.67	116.5	36.615
2/18/2004	9:17:04				3.0	13.02	23.36	7.90	10.71	117.6	36.897
2/18/2004	9:22:17	118	34.23183	119.25940	1.0	11.11	24.69	7.86	11.93	126.9	38.884
2/18/2004	9:22:39				2.0	13.05	23.85	7.92	10.75	118.5	37.603

TABLE 4-9: Santa Clara River Estuary Discrete Sampling Data (continued)

Date (m/d/y)	Time (hh:mm:ss)	WAYPOINT #	Lat (d.d)	Lon (d.d)	Depth (ft)	Temp (deg C)	Salinity (ppt)	pH	DO conc (mg/L)	DO sat (%)	SpCond (mS/cm)
2/18/2004	9:27:46	119	34.23207	119.25814	1.0	12.03	17.99	7.93	12.25	127.3	29.110
2/18/2004	9:34:15	120	34.23329	119.25904	1.0	13.43	20.92	7.94	10.91	119.0	33.362
2/18/2004	9:34:28				2.0	13.77	20.77	7.95	10.86	119.2	33.141
2/18/2004	9:39:17	121	34.23363	119.25807	1.0	11.84	19.27	7.88	11.95	124.7	31.002
2/18/2004	9:39:27				2.0	13.33	18.74	7.93	10.88	116.9	30.179
2/18/2004	9:45:13	122	34.23409	119.25654	1.0	11.50	17.21	7.83	12.52	128.0	27.970
2/18/2004	9:52:19	123	34.23465	119.25459	1.0	12.75	8.28	7.64	10.94	108.7	14.230
2/18/2004	10:02:59	124	34.23555	119.25289	1.0	12.76	2.38	7.51	8.95	85.7	4.431
2/18/2004	10:10:06	125	34.23603	119.25115	1.0	12.62	1.50	7.53	11.26	107.0	2.876
2/18/2004	10:30:03	126	34.23375	119.25920	0.5	13.15	21.07	7.91	10.86	117.9	33.583
2/18/2004	10:30:13				1.0	13.38	20.91	7.92	10.77	117.4	33.350
2/18/2004	10:31:50				2.0	13.23	25.49	7.90	10.39	116.1	39.928
2/18/2004	10:38:42	127	34.23301	119.26033	1.0	12.71	21.53	8.00	11.35	122.4	34.272
2/18/2004	10:38:54				2.0	13.28	21.35	7.98	10.80	117.8	33.996
2/18/2004	10:40:57				3.0	13.17	23.94	7.93	10.92	120.7	37.730

11/6/2003						
min	**18.96**	**1.29**	**7.42**	**10.14**	**110.20**	**2.50**
max	**21.60**	**13.67**	**7.76**	**322.41**	**3581.60**	**22.62**
avg	**20.56**	**4.70**	**7.62**	**63.12**	**711.98**	**8.22**
2/18/2003						
min	**11.11**	**1.30**	**7.22**	**8.66**	**85.70**	**2.51**
max	**17.08**	**25.49**	**8.02**	**12.52**	**128.70**	**39.93**
avg	**13.54**	**18.85**	**7.83**	**10.63**	**114.73**	**30.06**

FIGURES



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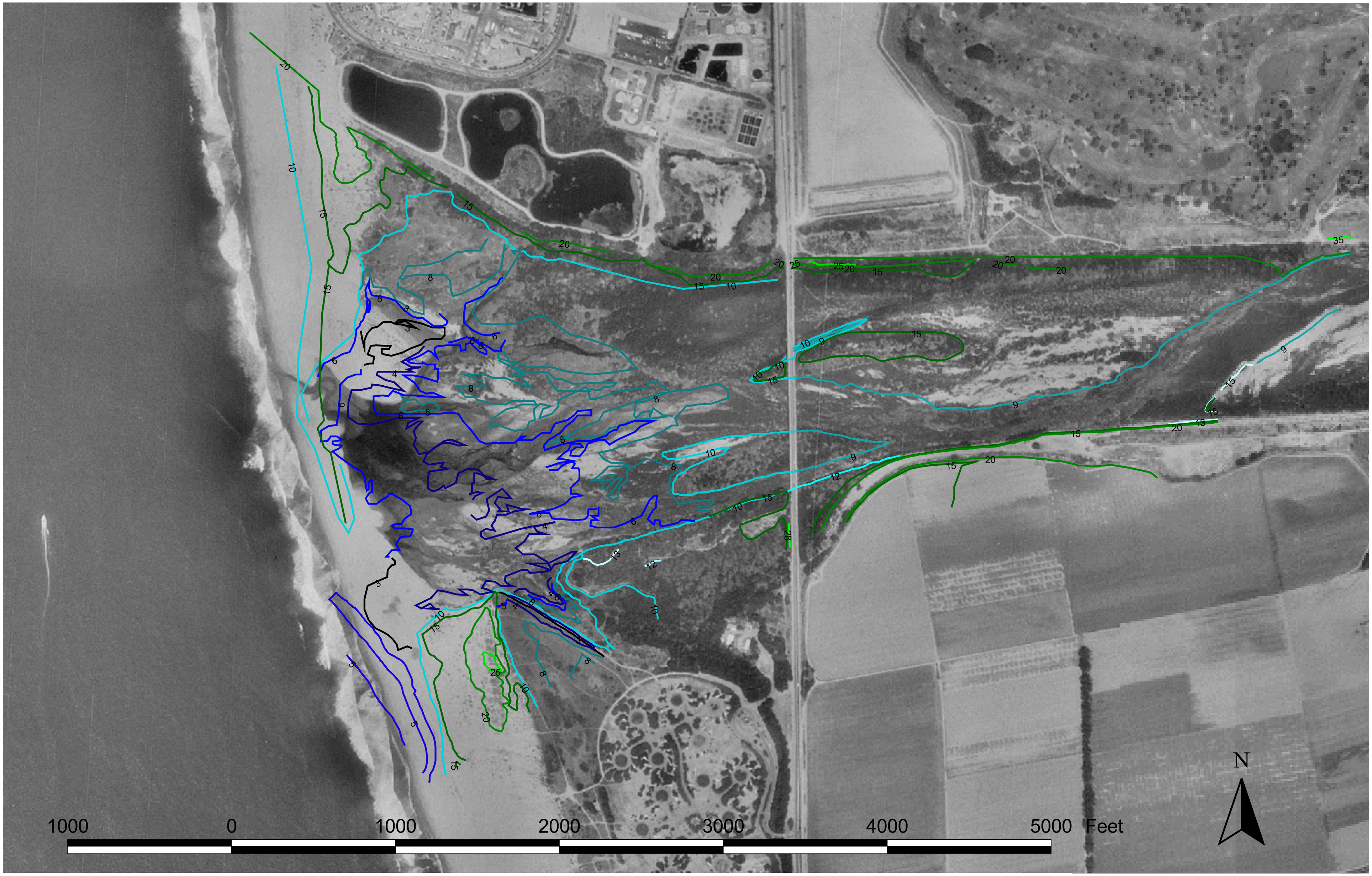
Site Location Map - Santa Clara River Coastal Lagoon

ENVIRONMENTAL STUDY OF SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE

4-1



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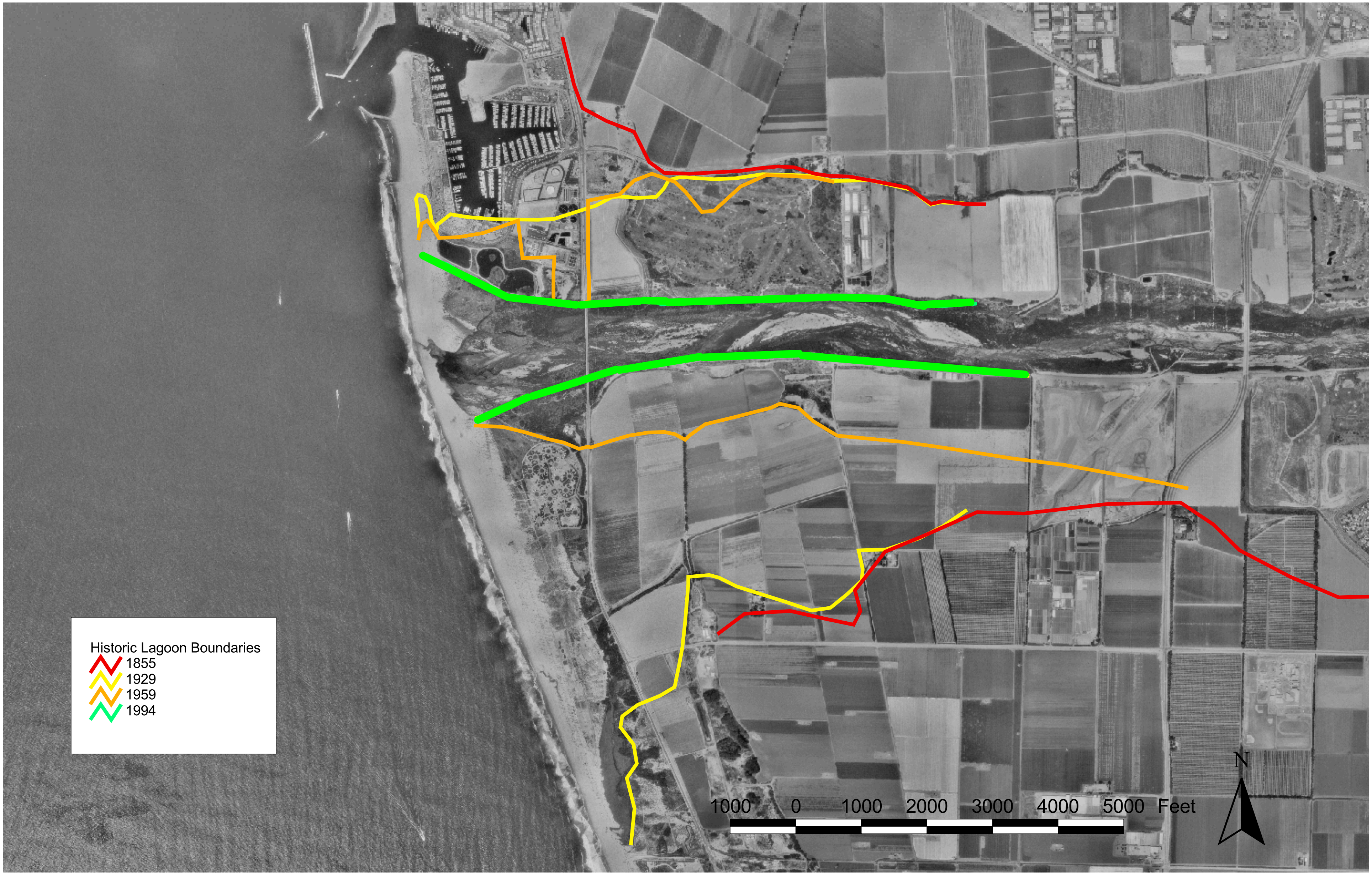
Bathymetry of Santa Clara River Coastal Lagoon (circa 2002-2004)

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE 4-2



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Historic Lagoon Boundaries

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE 4-3

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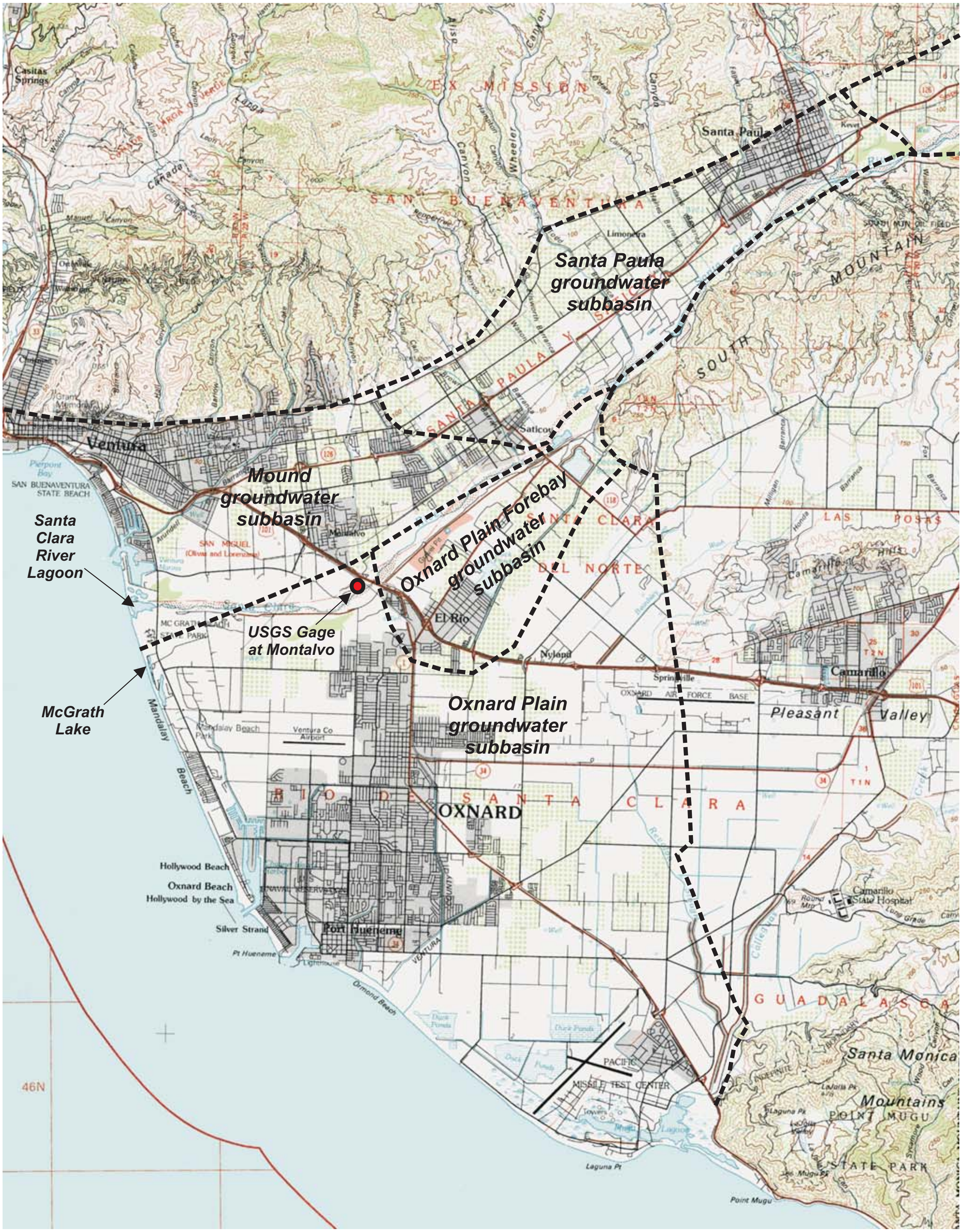
Recent Migration of Lagoon South Bank

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE

4-4



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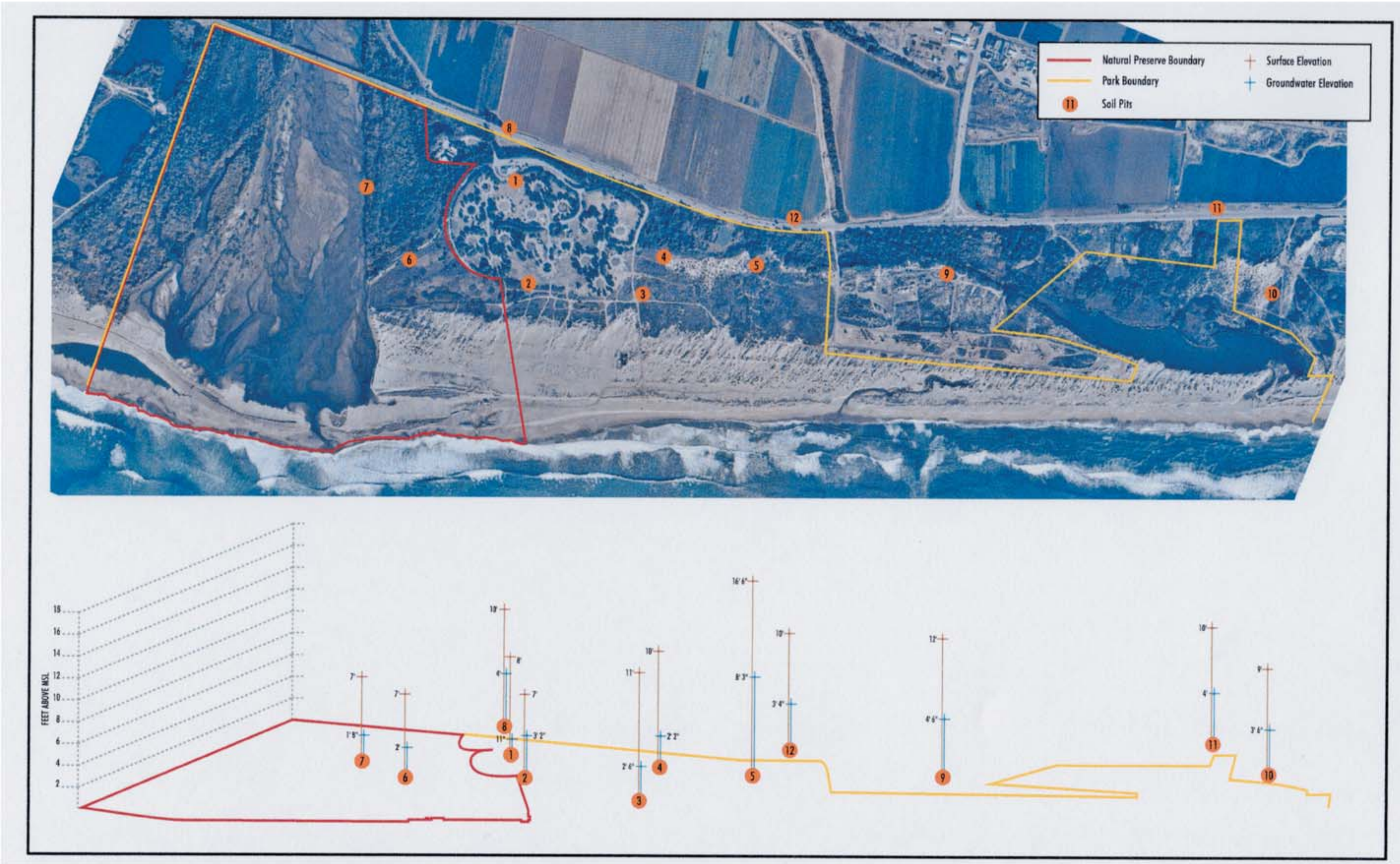
Vicinity Hydrologic Features

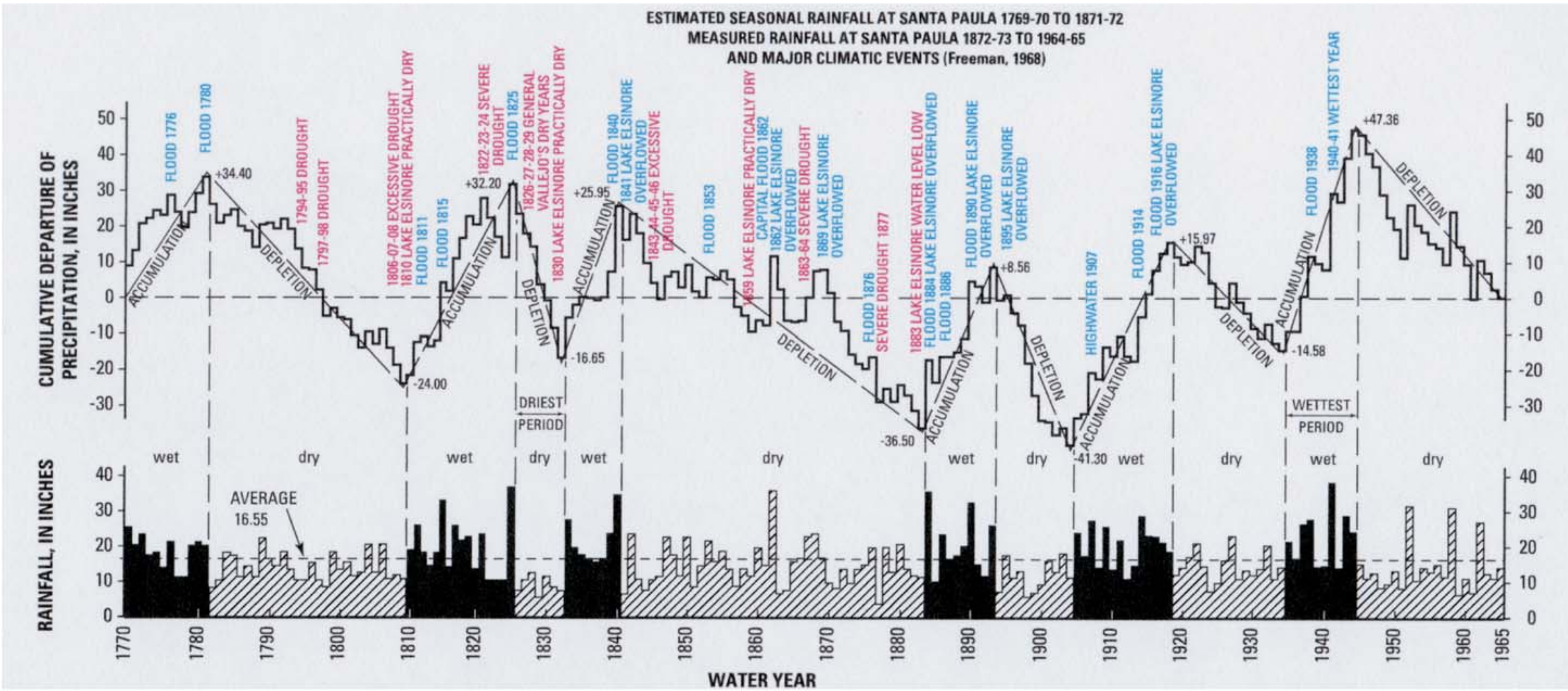
ENVIRONMENTAL STUDY OF SANTA CLARA RIVER ESTUARY HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE 4-5



Source: McGrath State Beach Natural Resources Management Plan (ESA 2003)

KAMMAN HYDROLOGY & ENGINEERING, INC. 101 Lucas Valley Road, Suite 120 San Rafael, CA 94903 (415)491-9600	Shallow Groundwater Conditions at McGrath State Beach **ENVIRONMENTAL STUDY OF SANTA CLARA RIVER ESTUARY HYDROLOGY AND COASTAL LAGOON ASSESSMENTS**	**FIGURE** **4-6**



Source: Hanson et al., 2003 (originally developed by Freeman, 1968)

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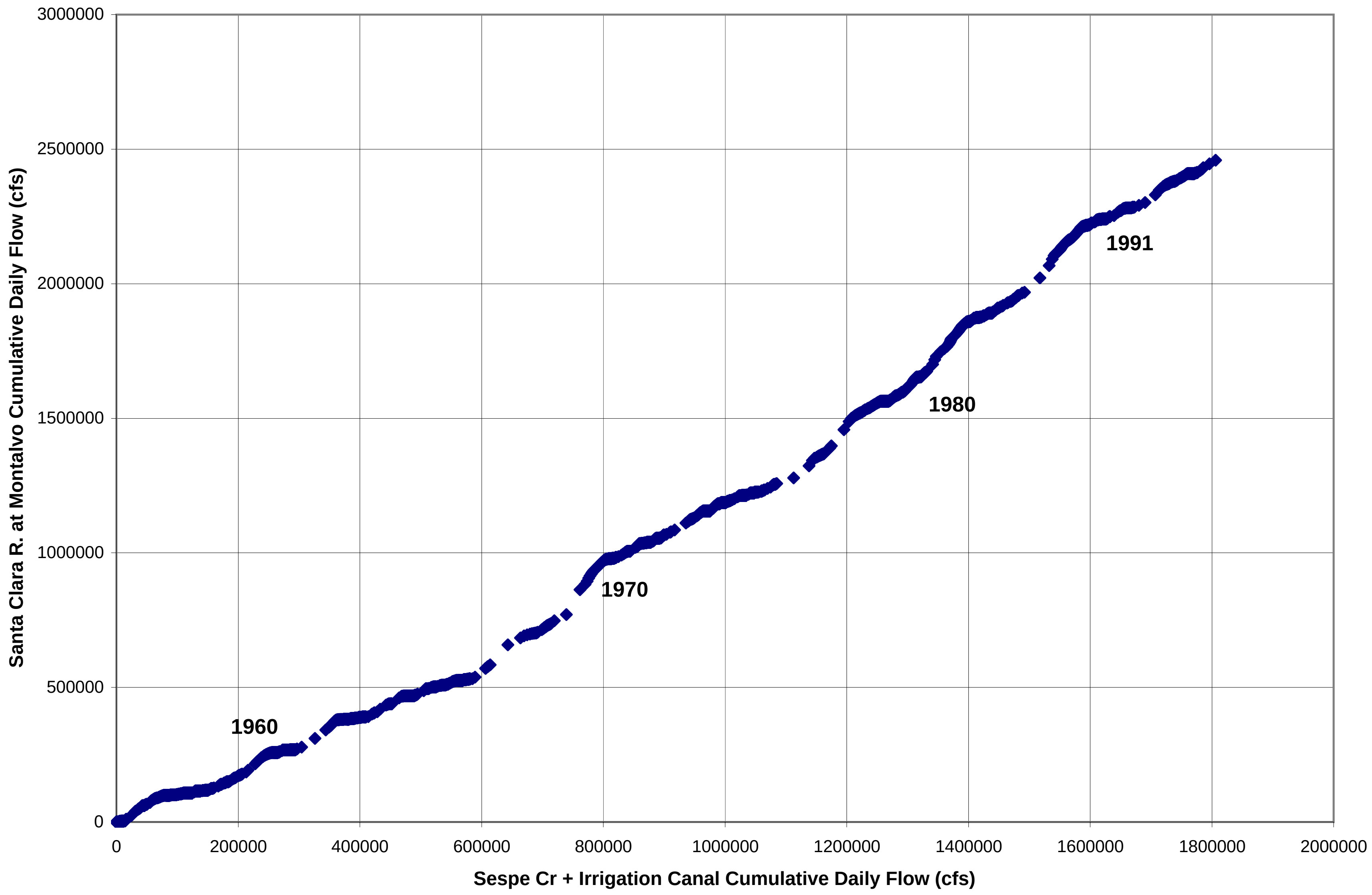
Cumulative Departure of Rainfall at Santa Paula, CA (1770-1995)

ENVIRONMENTAL STUDY OF SANTA CLARA RIVER ESTUARY HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE 4-7



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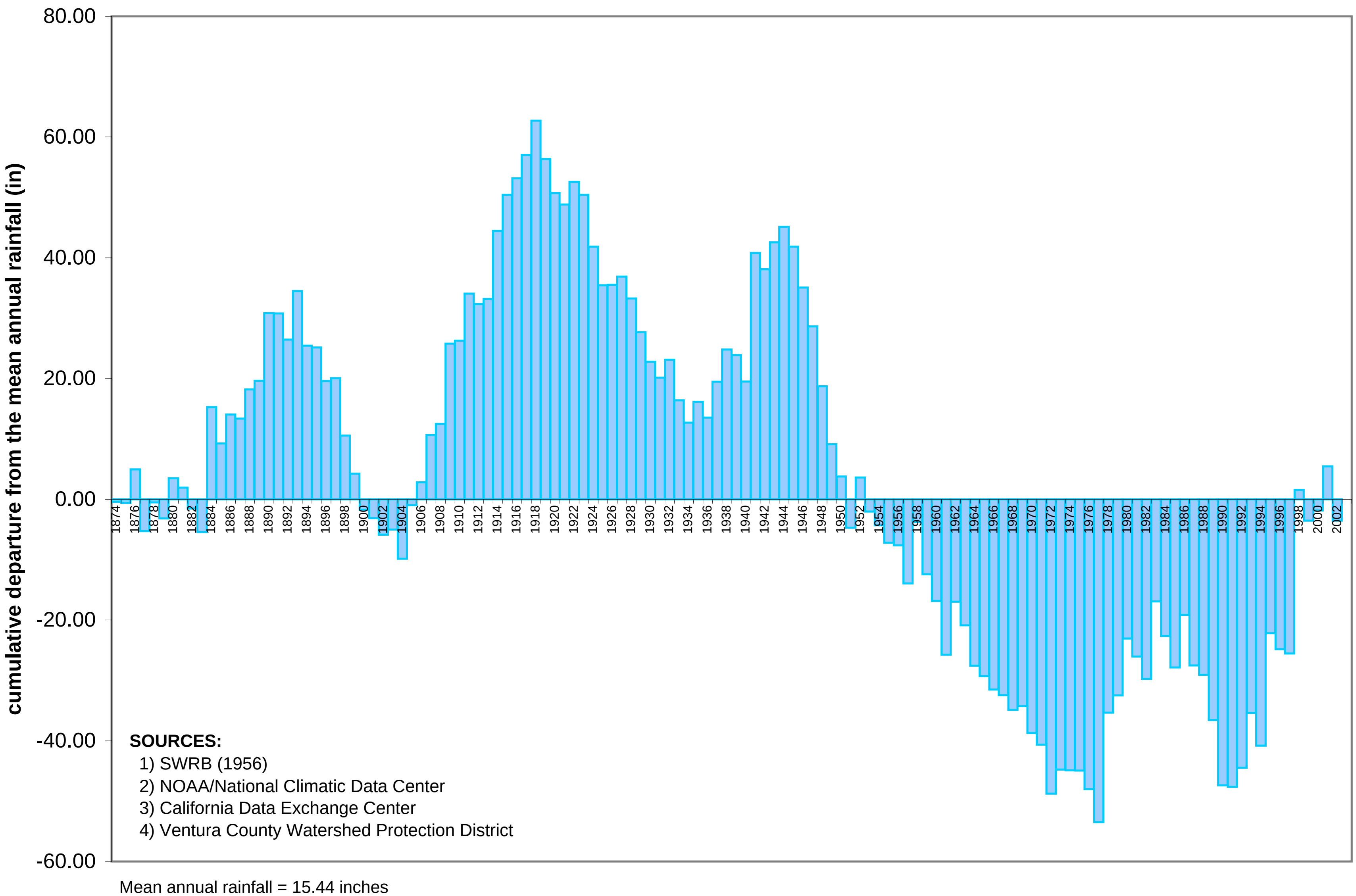
Double Mass Curve: Cumulative Flow on Santa Clara River at Montalvo vs. Sespe Creek

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE

4-8



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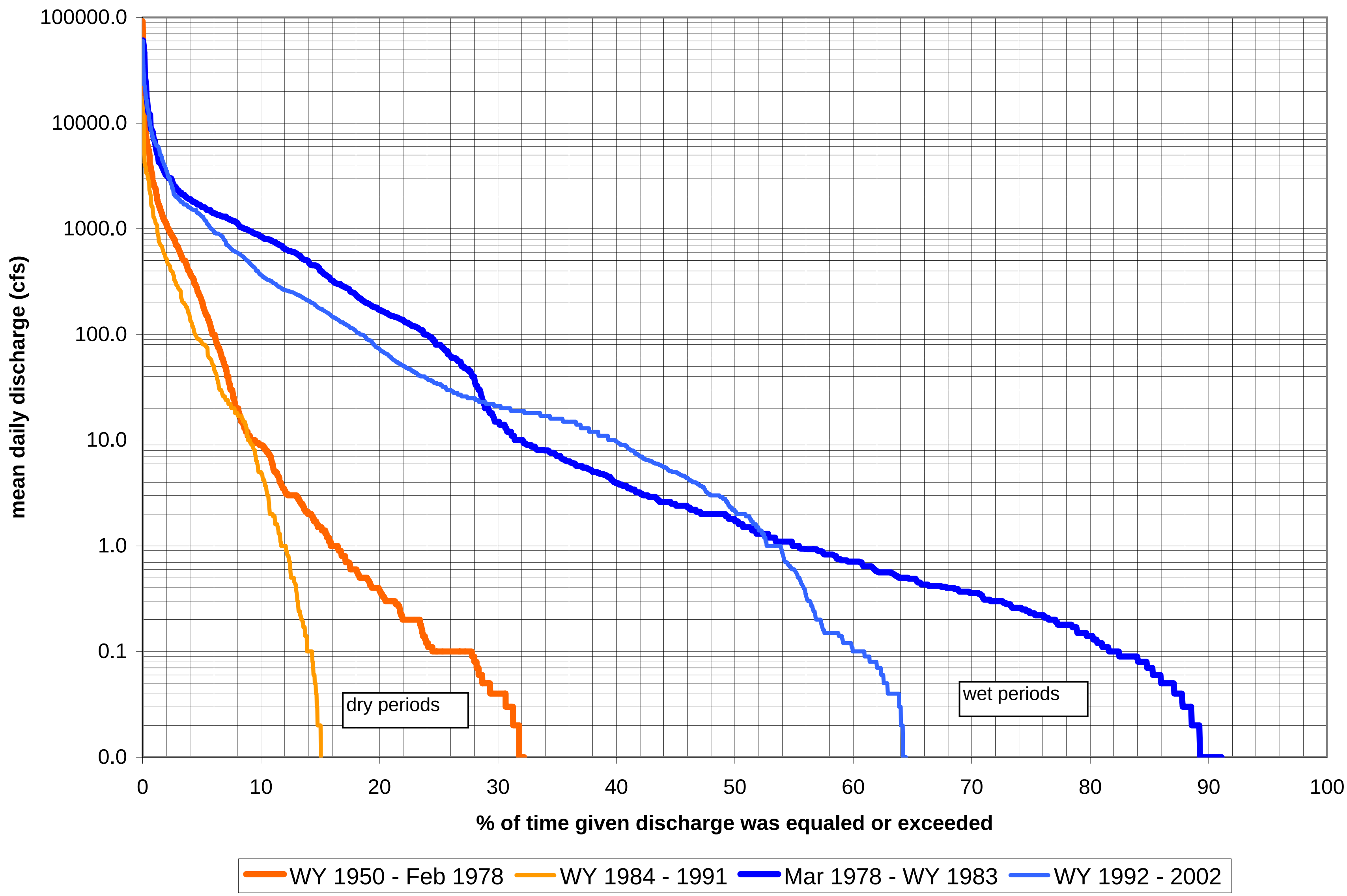
Cumulative Annual Rainfall Departure Curve: Ventura, CA (1874-2003)

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE **4-9**



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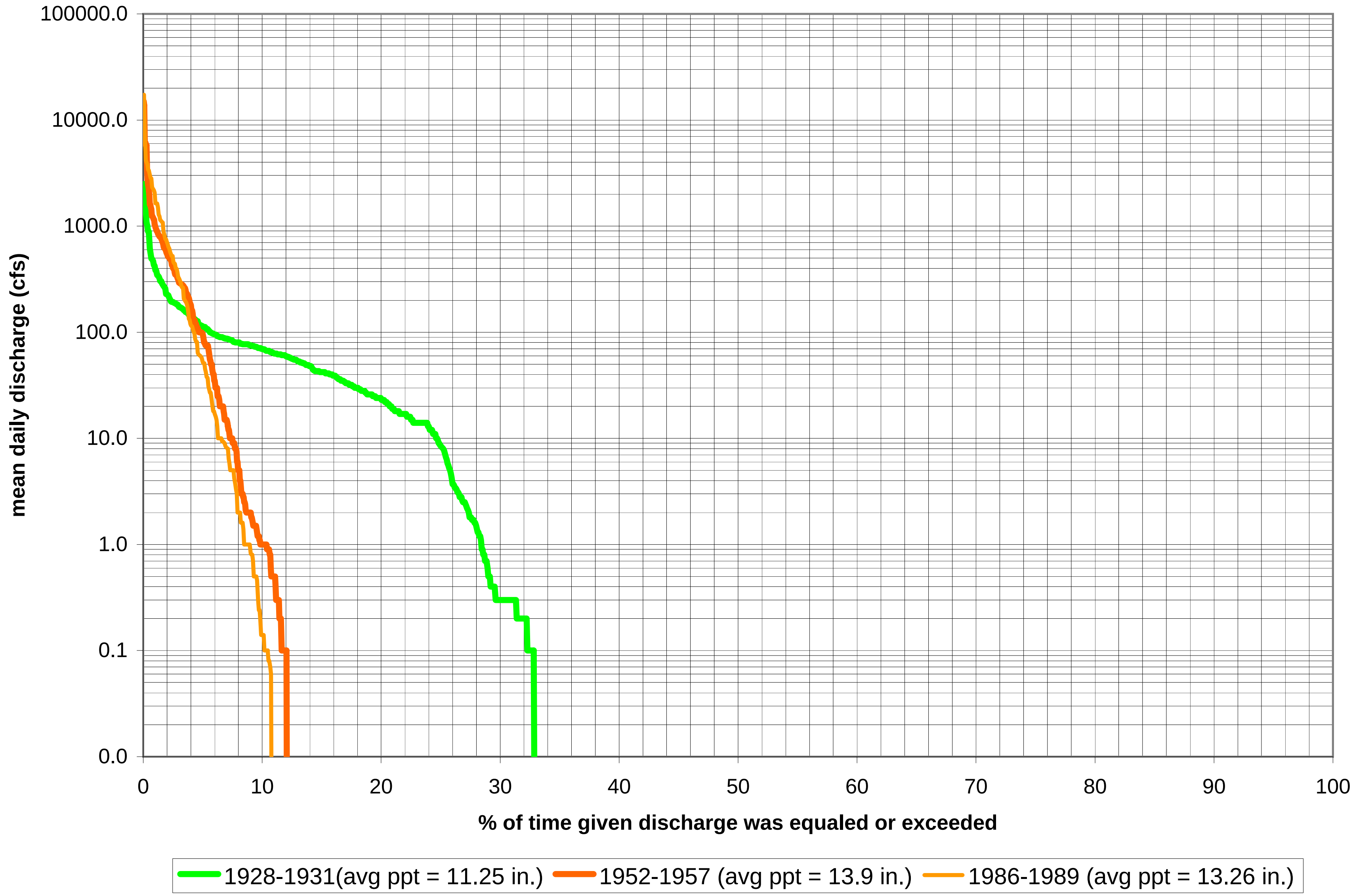
Flow Duration Curves for Santa Clara River at Montalvo

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE

4-10



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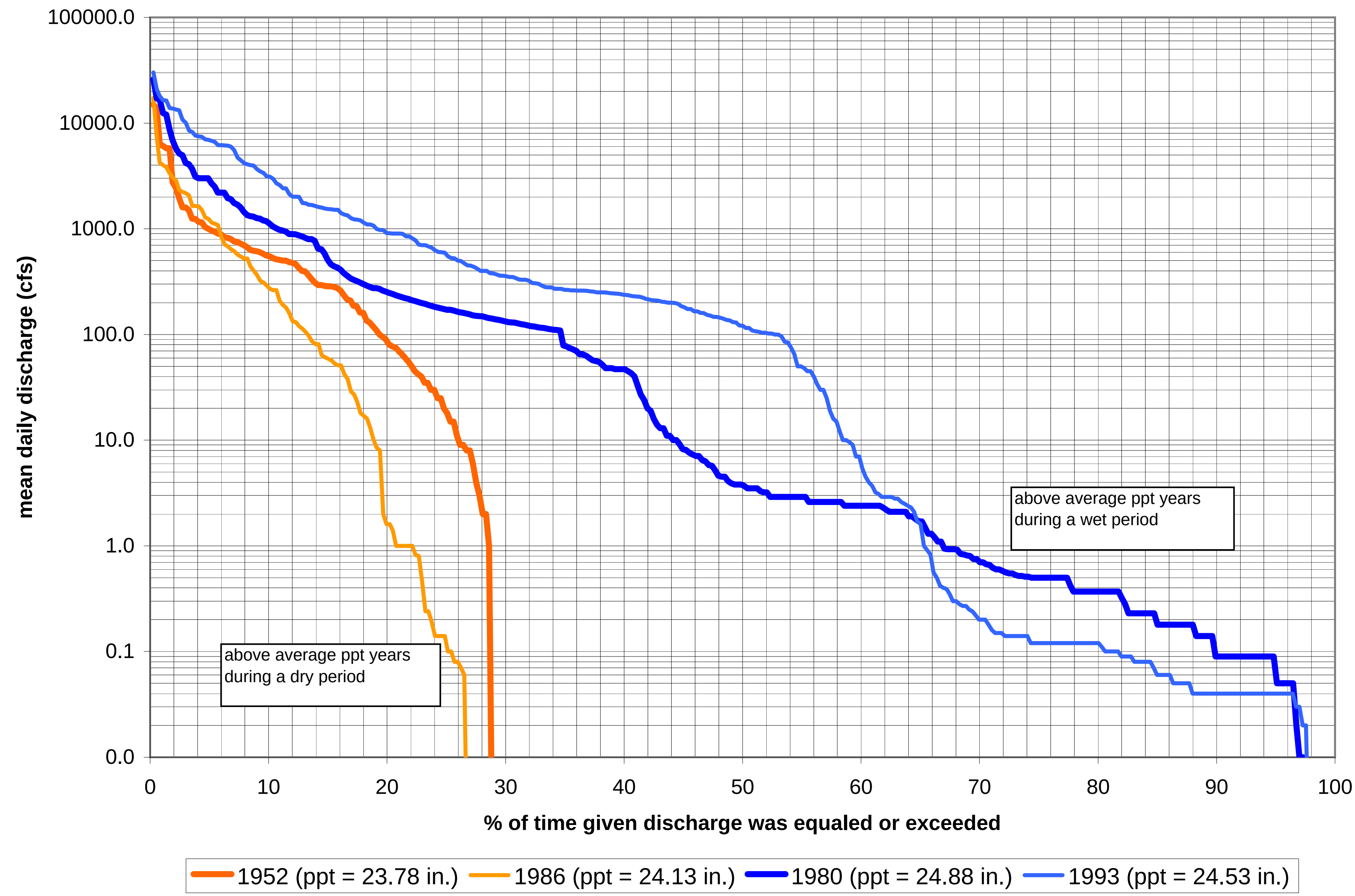
Flow Duration Curves for Santa Clara River at Montalvo - Dry Years

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE

4-11



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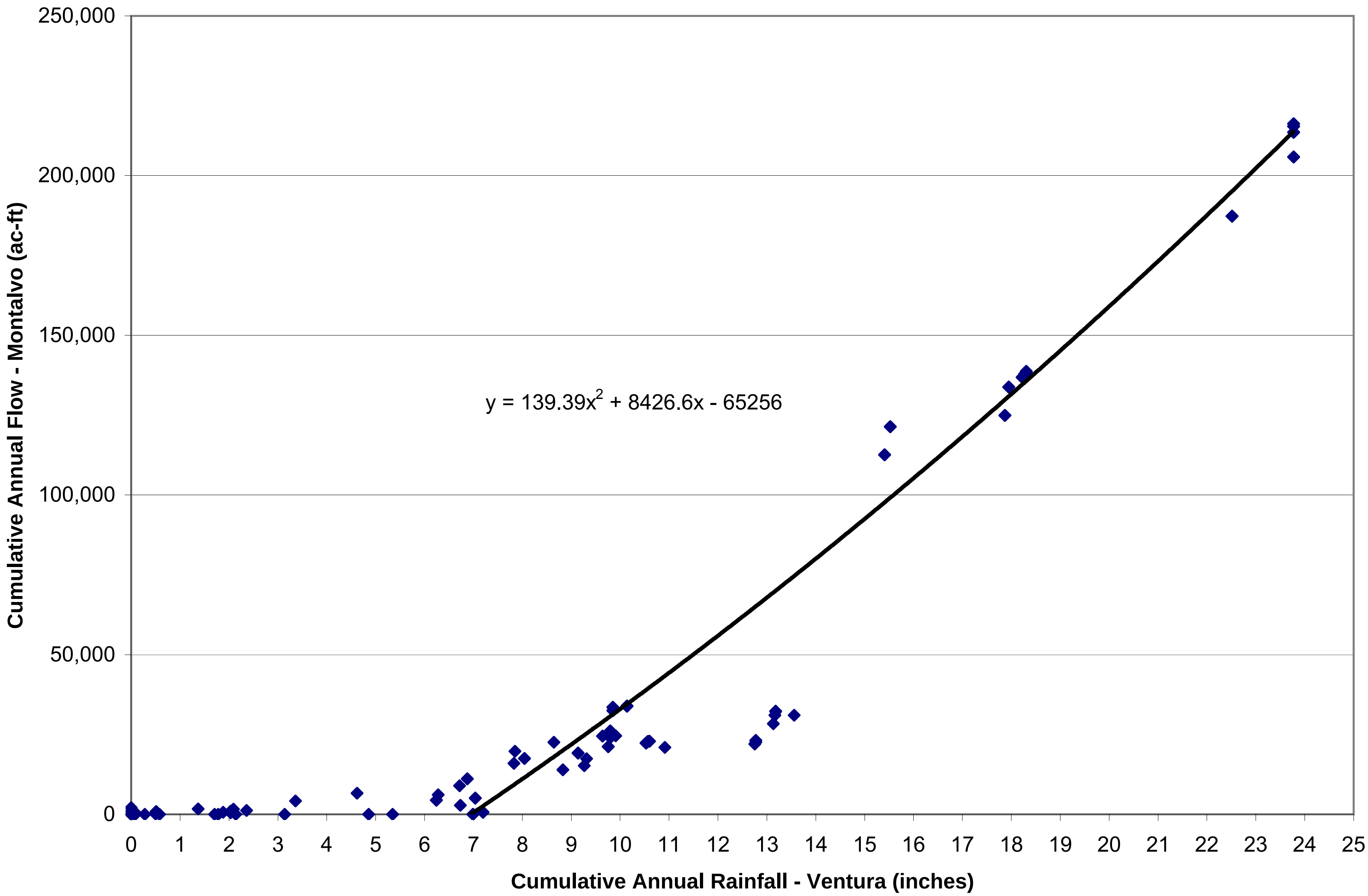
Flow Duration Curves for Santa Clara River at Montalvo

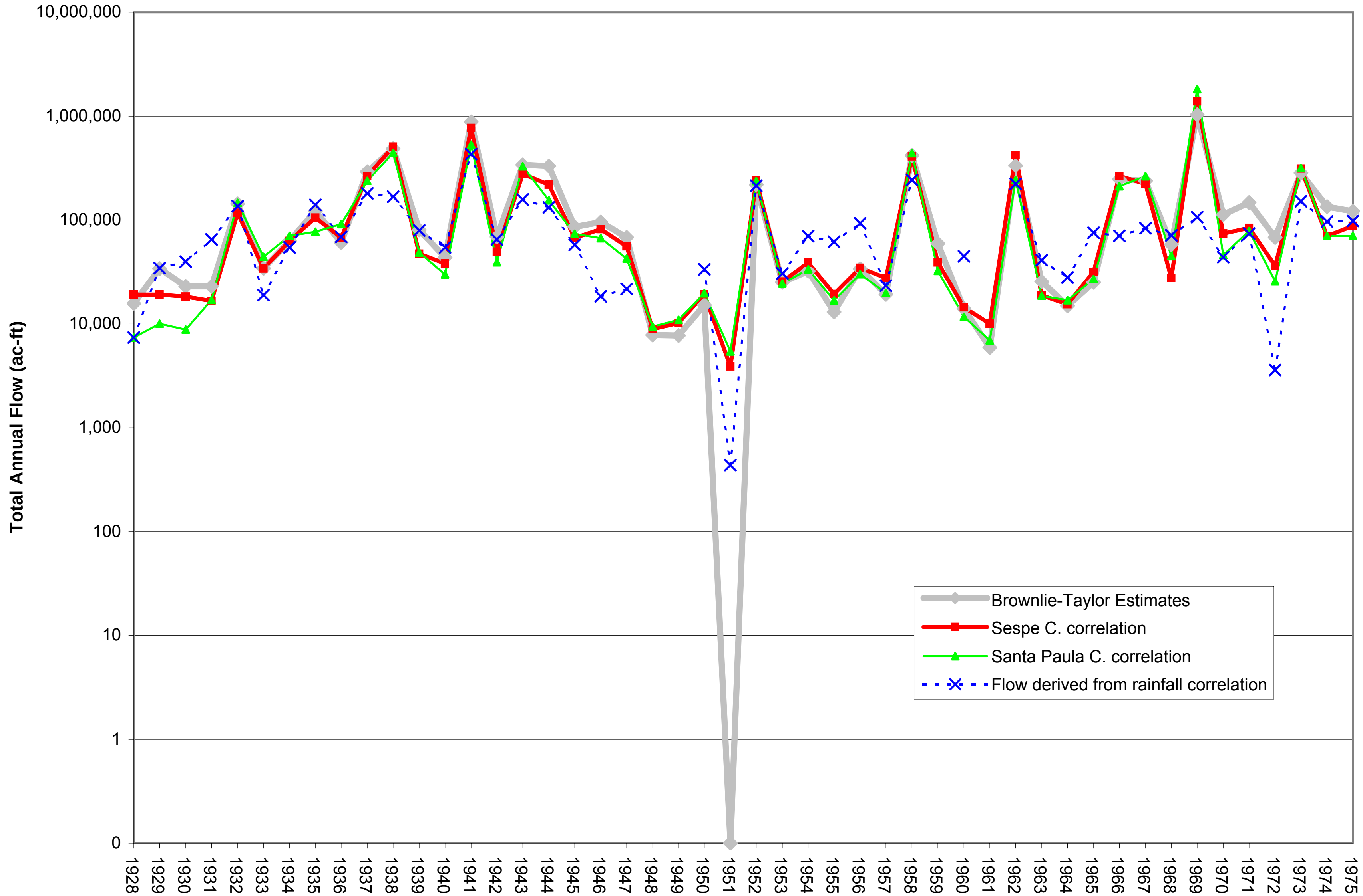
ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE

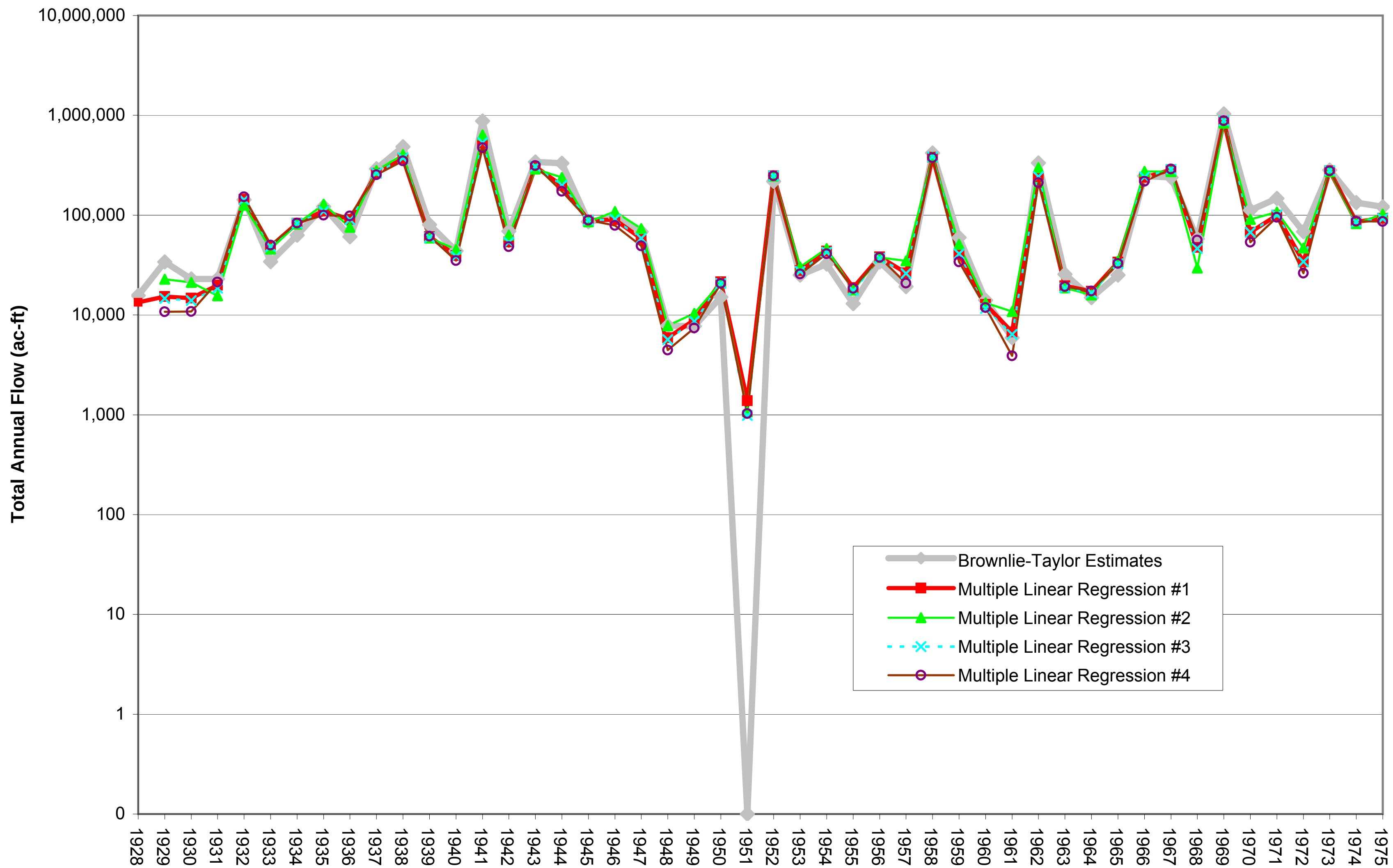
4-12



Kamman Hydrology & Engineering, Inc.	Annual Cumulative Rainfall at Ventura vs. Cumulative Flow at Montalvo ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY HYDROLOGY AND COASTAL LAGOON ASSESSMENTS	FIGURE **4-13**



Kamman Hydrology & Engineering, Inc.	Annual Natural Flow: Simple Linear Regression Estimates vs. Brownlie & Taylor Estimates ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY HYDROLOGY AND COASTAL LAGOON ASSESSMENTS	FIGURE **4-14**



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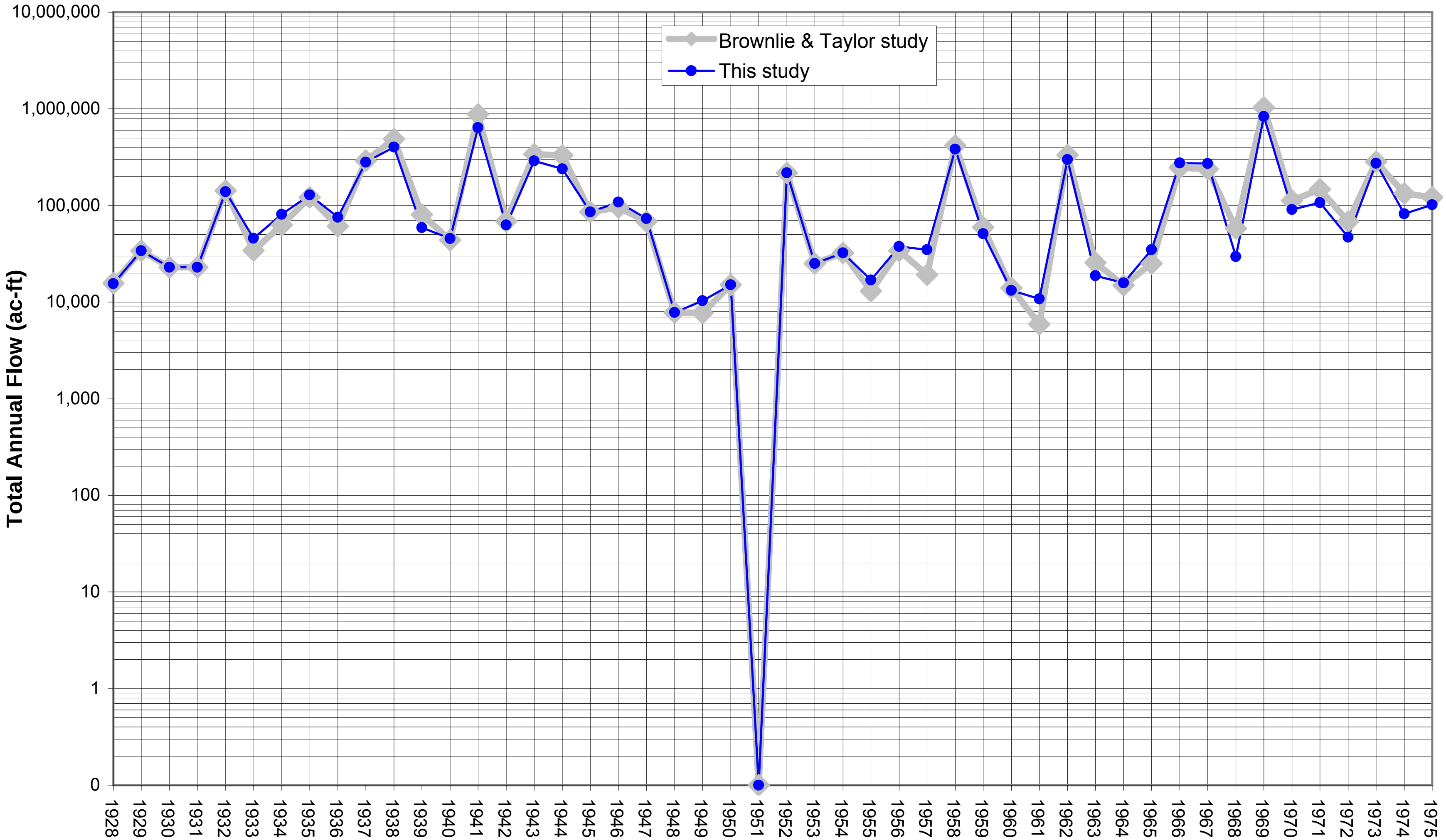
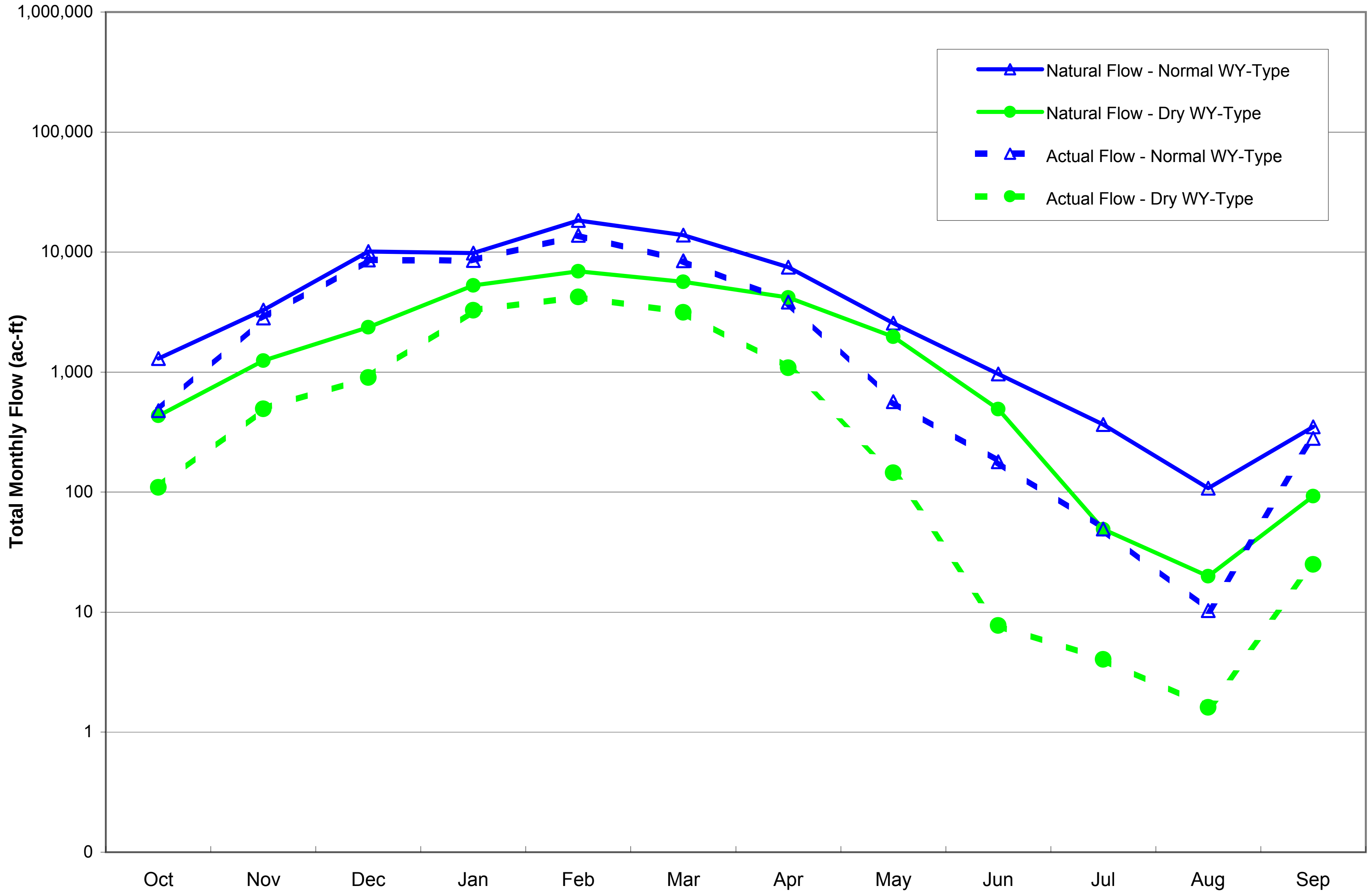
Annual Natural Flow: Multiple Linear Regression Estimates vs. Brownlie & Taylor Estimates

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE
4-15



Kamman Hydrology & Engineering, Inc.	Comparison of Annual Natural Flow at Montalvo: This Study vs. Brownlie & Taylor ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY HYDROLOGY AND COASTAL LAGOON ASSESSMENTS	FIGURE **4-16**



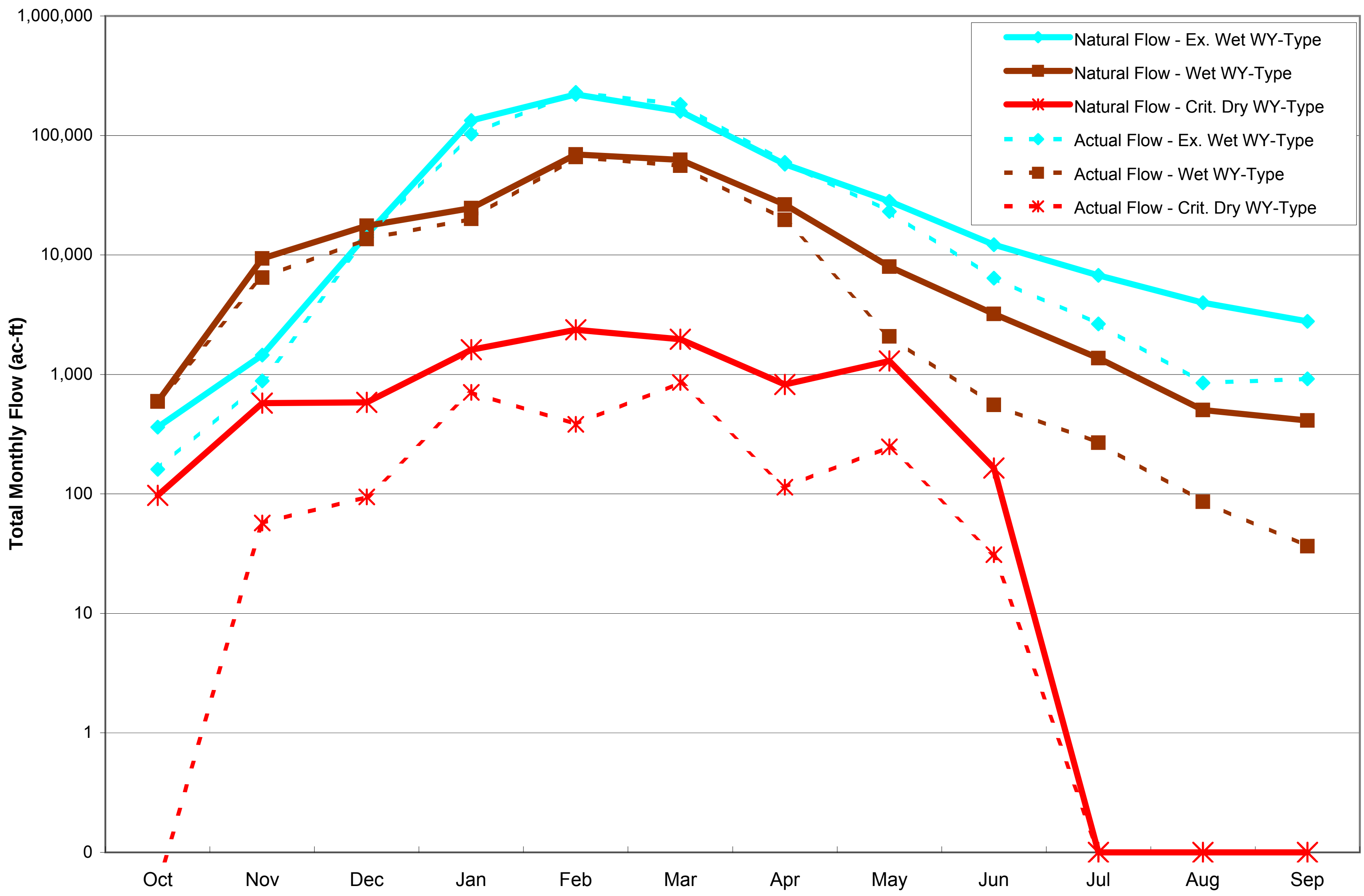
Kamman Hydrology & Engineering, Inc.

Natural vs. Actual Flow at Montalvo: Normal and Dry Year-Types

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE

4-17



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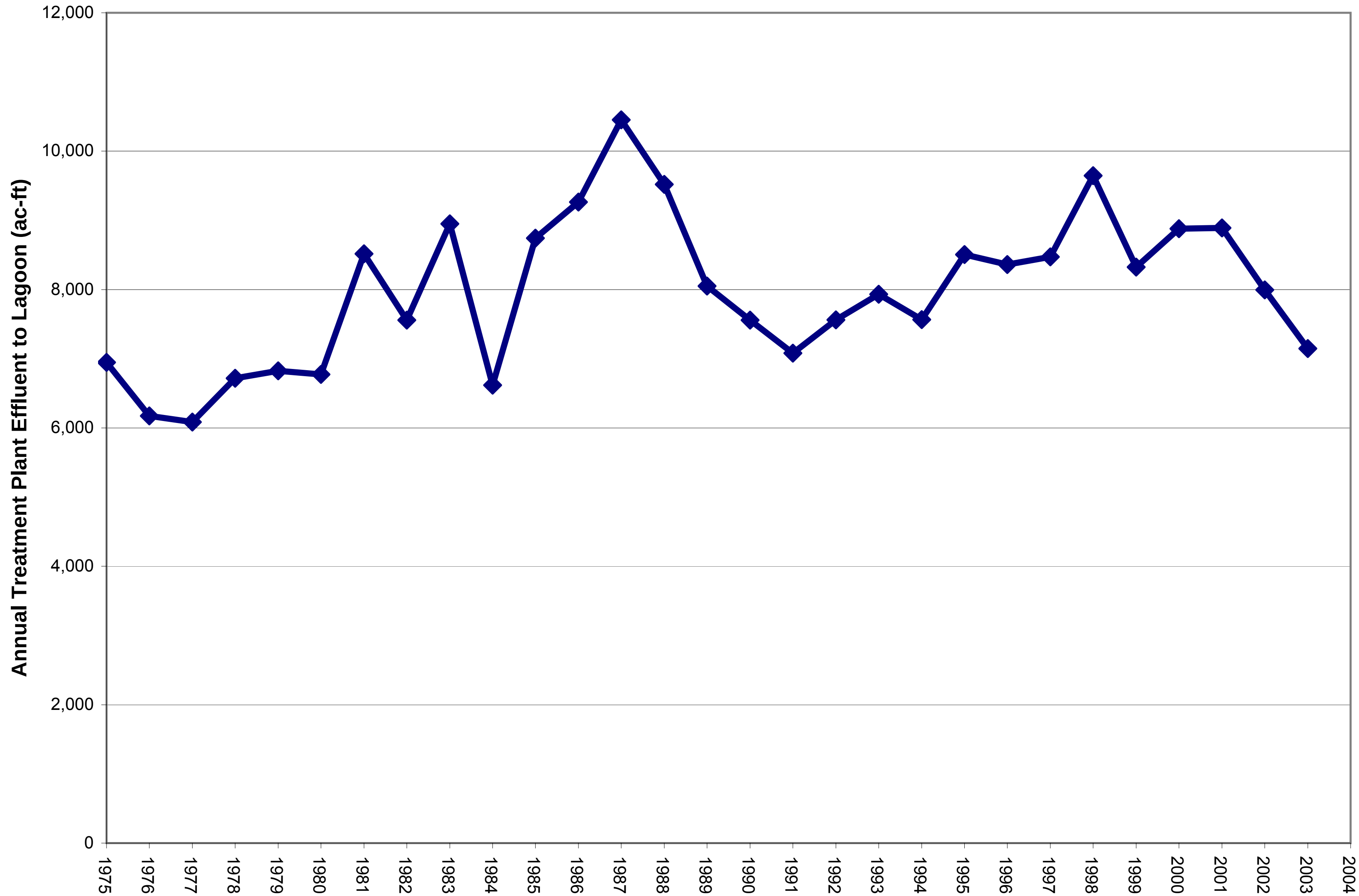
Natural vs. Actual Flow at Montalvo: Wet and Critically Dry Year-Types

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE

4-18



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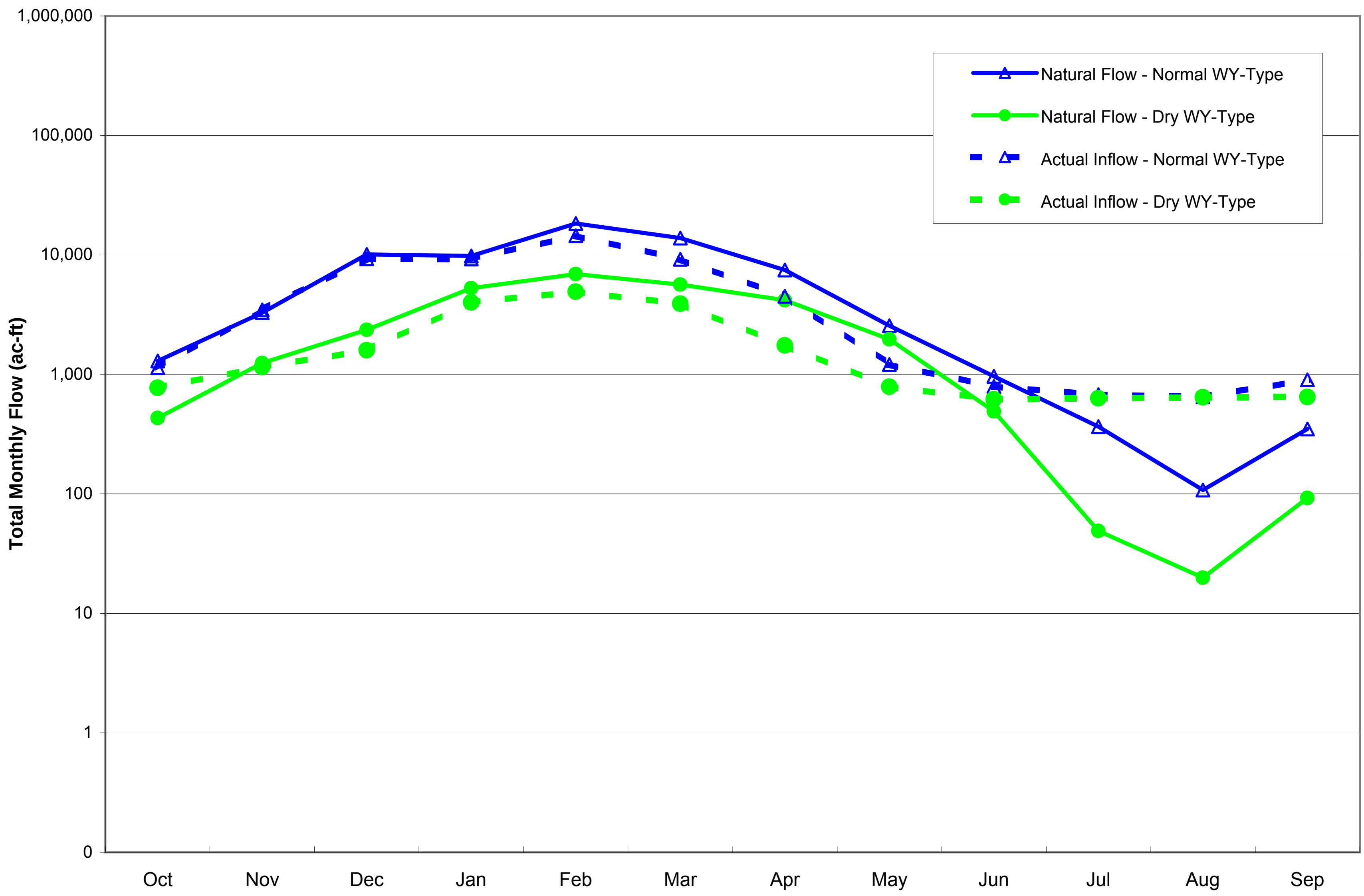
Annual Treatment Plant Effluent Discharge to Santa Clara River Coastal Lagoon

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE **4-19**



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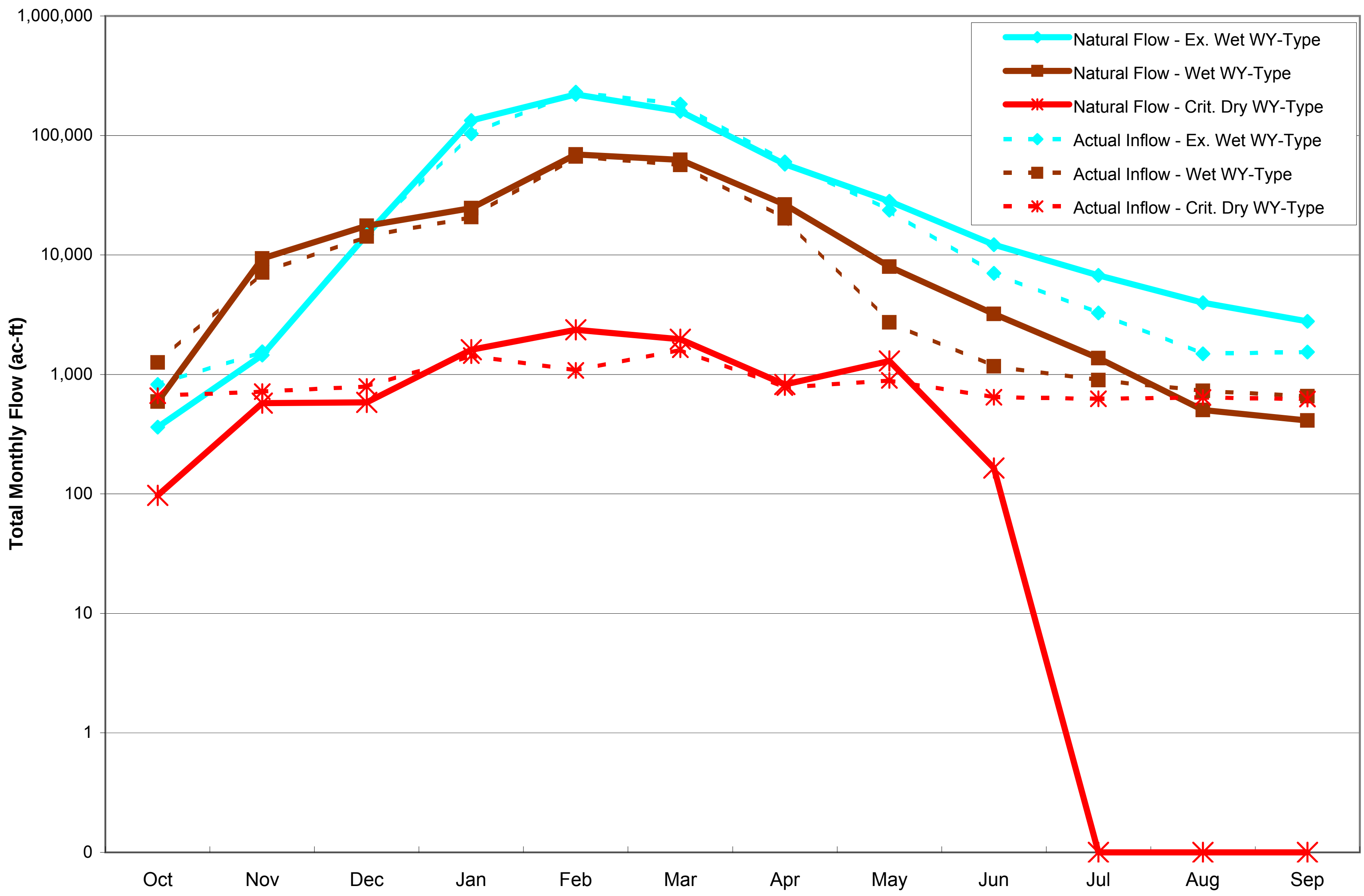
Natural vs. Actual Inflow to Lagoon: Normal and Dry Year-Types

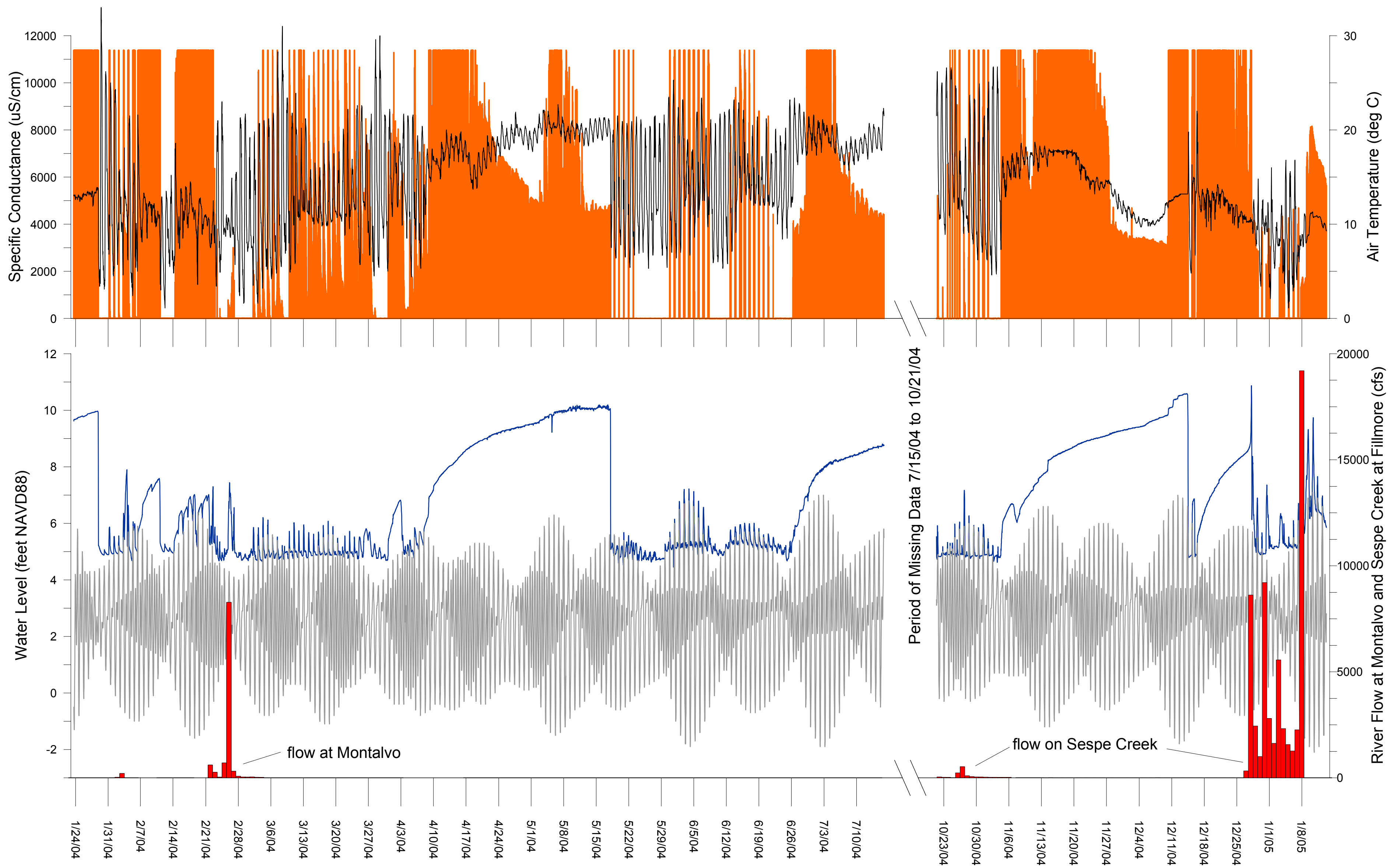
ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE

4-20



Kamman Hydrology & Engineering, Inc.	Natural vs. Actual Inflow to Lagoon: Wet and Critically Dry Year-Types ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY HYDROLOGY AND COASTAL LAGOON ASSESSMENTS	FIGURE **4-21**



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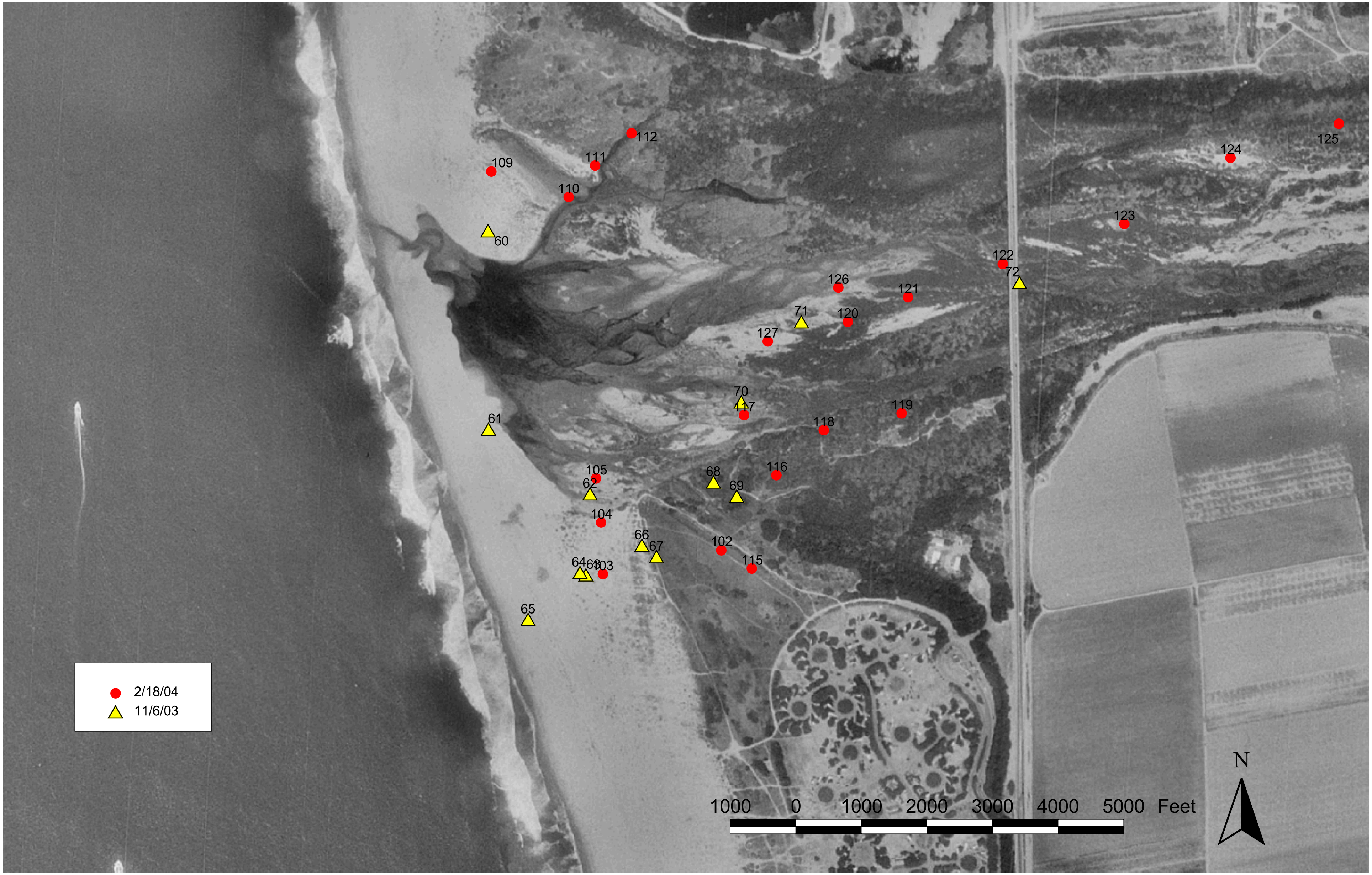
Hydrologic Monitoring Data: 1/23/04 to 1/14/05

ENVIRONMENTAL STUDY OF SANTA CLARA RIVER ESTUARY HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE 4-22



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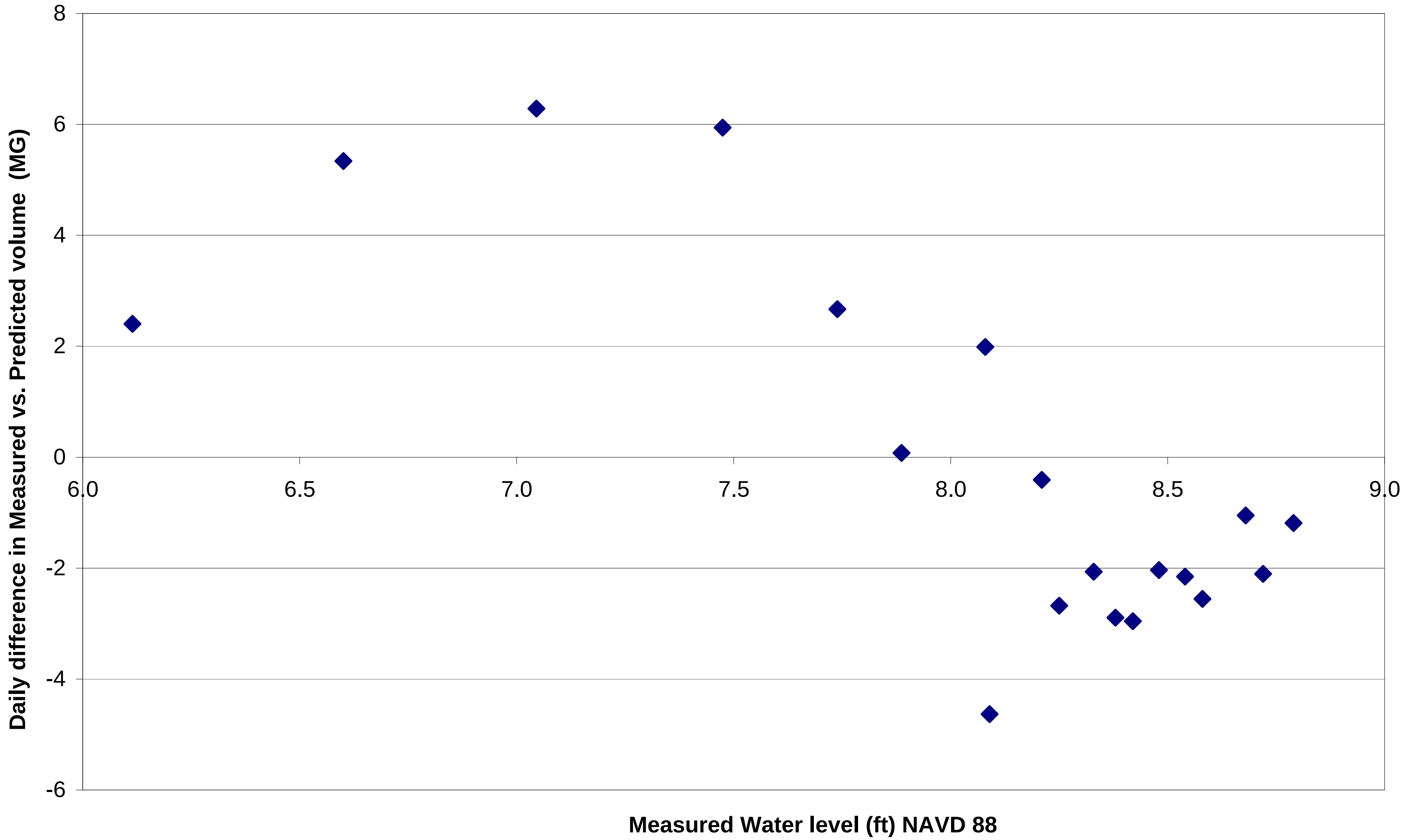
Discrete Water Quality Measurement Locations

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE 4-23

Prepared by Nautilus Environmental



Kamman Hydrology
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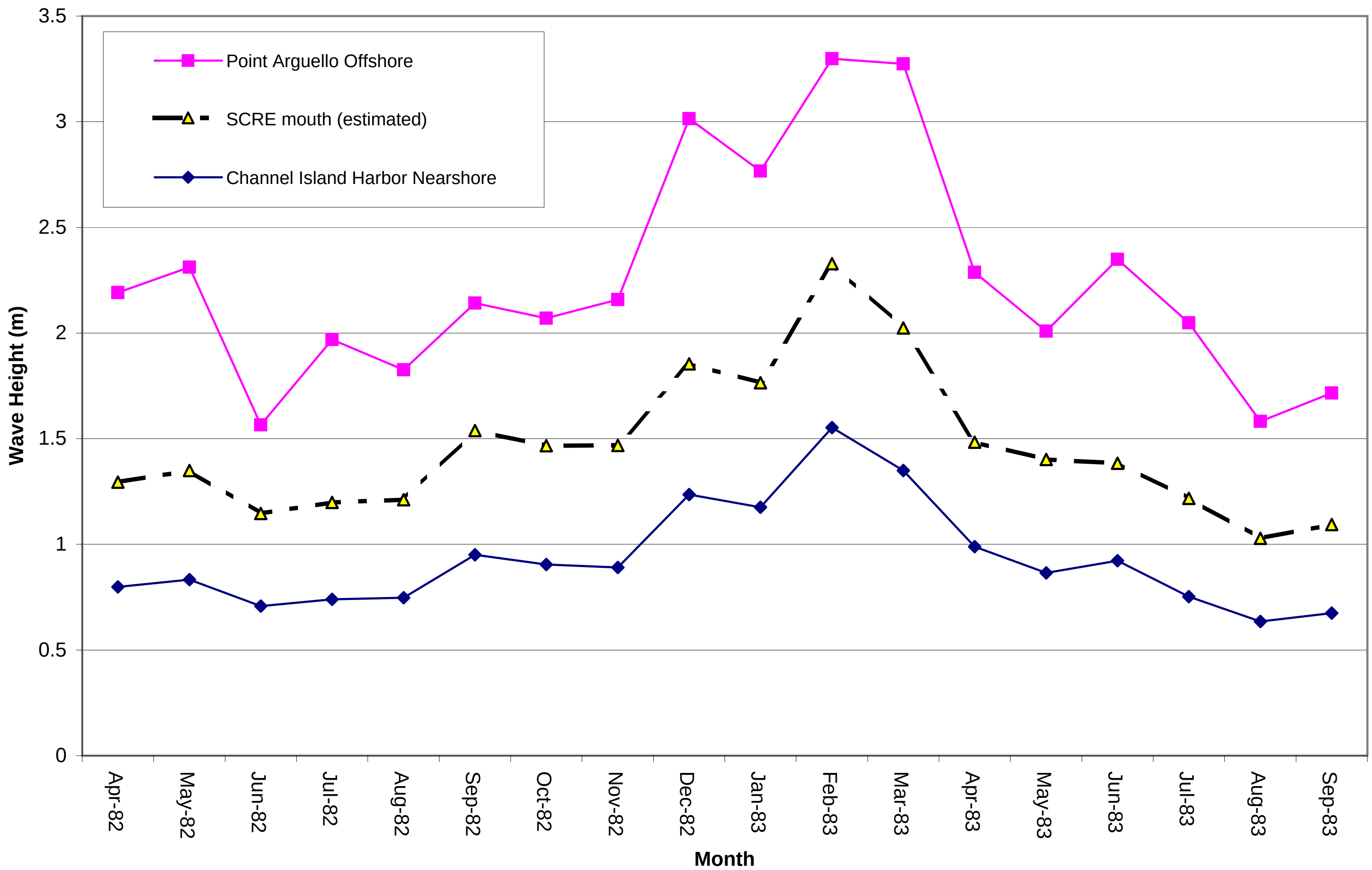
Daily Water Budget: June 27 through July 15, 2004

ENVIRONMENTAL STUDY OF SANTA CLARA RIVER ESTUARY
HYDROLOGY NAD COASTAL LAGOON ASSESSMENTS

FIGURE

4-24



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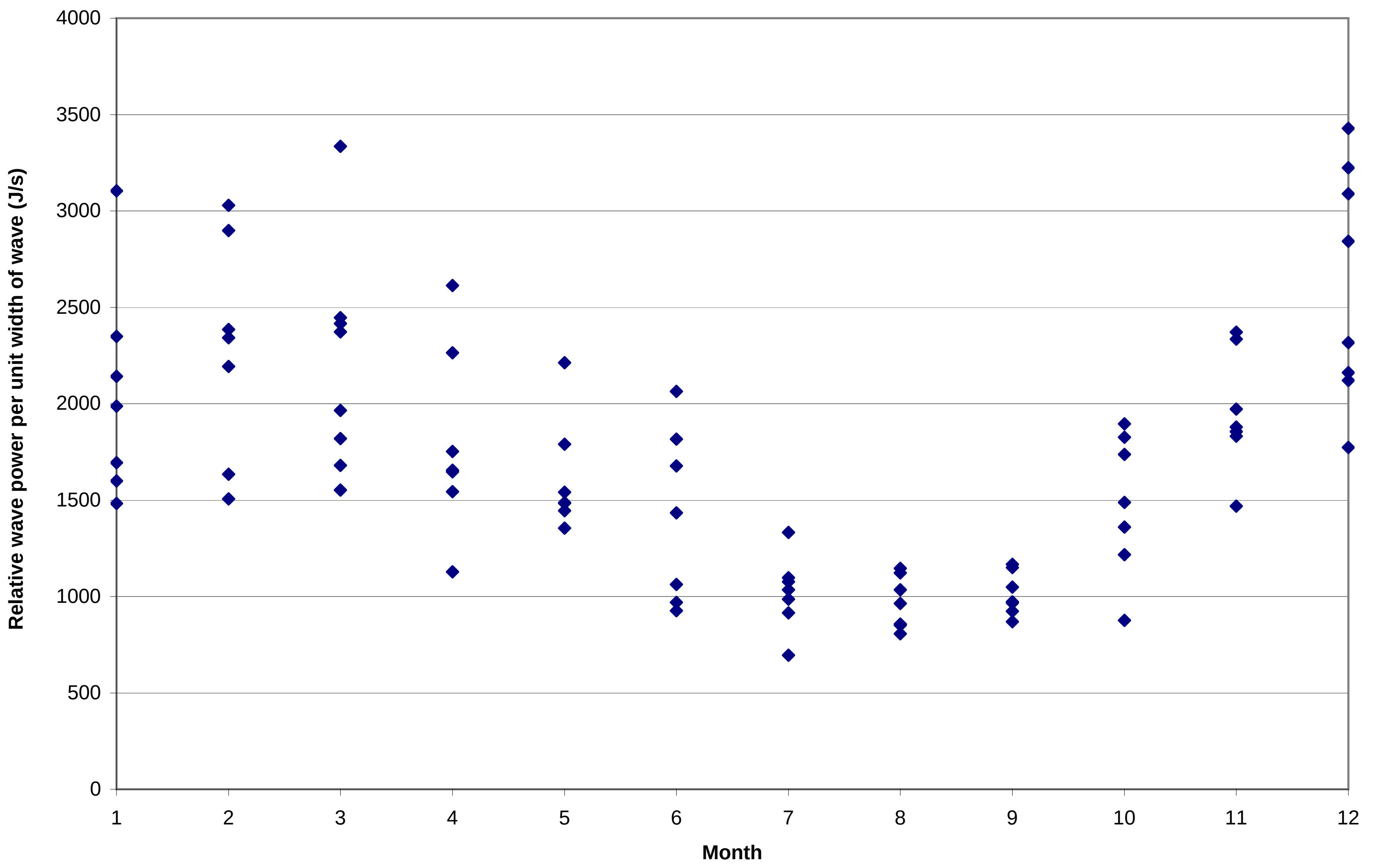
Comparison of Seasonal Wave Height Variation for 1982-83

ENVIRONMENTAL STUDY OF THE SANTA CLARA RIVER ESTUARY
HYDROLOGY AND COASTAL LAGOON ASSESSMENTS

FIGURE

4-25



Kamman Hydrology & Engineering, Inc.

Monthly Predicted Wave Power: December 1995 to December 2002 at the 2m Depth Contour

Environmental Study of Santa Clara River Estuary
Hydrology and Coastal Lagoon Assessments

FIGURE

4-26

5.0 SUMMARY AND CONCLUSIONS

This study incorporated several independent lines of evidence to assess potential impacts and benefits associated with discharging treated wastewater from the VWRF directly into the estuary of the Santa Clara River. The toxicological component investigated the potential for the discharge to cause toxicity, as well as introduce unacceptable levels of contaminants into the receiving environment. The ecological component characterized historical conditions associated with the estuary, changes that have occurred in the estuary over time, the presence of species of special concern, and whether the discharge has fundamentally altered the biological community associated with the estuary. Finally, the hydrological component evaluated the effect of diversions on flows into the estuary, the relationship of current freshwater flows into the estuary with those likely to have occurred historically in the absence of diversions, and the relative contribution of flows from the VWRF to total flows reaching the estuary. In addition, this component evaluated the influence of the discharge on the frequency of breaching the barrier beach formed at the mouth of the lagoon and identified major factors that affect formation of the berm at the mouth of the lagoon. Key findings are presented below in the context of overall questions regarding the potential influence of the VWRF discharge on the Santa Clara River Estuary.

<u>Are contaminants present in the VWRF discharge adversely affecting sediment quality in the estuary?</u>

Analysis of chemical concentrations indicated that contaminants of concern in the discharge (i.e., copper, zinc, and nickel) are generally below concentrations considered representative of the threshold for adverse effects (sediment quality guidelines are not available for selenium). Sediment toxicity was observed only on an intermittent basis and was not related to concentrations of these constituents. Thus, these data suggest that sediment quality across the estuary is good and is not being adversely impacted by the discharge.

<u>Are contaminants present in the VWRF discharge adversely affecting water quality in the estuary?</u>

During the current study, over 100 toxicity tests were conducted on samples collected from the lagoon using both freshwater and marine test species; approximately 10 percent of these tests exhibited adverse effects. Most of the samples that exhibited toxicity were collected during periods of stormwater or dry weather outflow events, suggesting that upstream and groundwater sources are potential contributors to toxicity. Conversely, no toxicity was observed in samples collected during a dry weather period when the lagoon was full; this condition should be associated with maximum influence of VWRF effluent on lagoon water quality.

Are copper concentrations present in the VWRF discharge likely to result in adverse effects in the estuary?

Analysis of effluent toxicity tests over a 3-year period indicated a low overall incidence of adverse effects; moreover, these responses were not related to effluent copper concentrations. Based on sediment concentrations, copper is not accumulating in the estuary and is not present at concentrations likely to result in adverse effects. In terms of water quality, copper was generally present at concentrations below freshwater criteria values, and usually below marine criteria values. Both sediment and water samples were subjected to intensive testing with mussel larvae, which comprise the most sensitive combination of species and test protocol used to derive the marine copper criteria values. In most cases, mussel larvae did not exhibit adverse effects when tested with sediment or water samples. Moreover, in cases where the mussel larvae did exhibit responses to the test samples, the responses were not related to copper concentrations. These data strongly suggest that copper is not present in the estuary at concentrations of concern. Furthermore, some of the most sensitive freshwater taxa to copper (i.e., *Daphnia* and *Hyalella*) are found in the estuary, indicating that copper is not limiting their distribution.

Is the current marine water quality criterion for copper appropriate for the Santa Clara River Estuary?

It is widely recognized that site-specific factors may influence the toxicity of various contaminants, including copper. Consequently, water effect ratio (WER) studies were conducted with mussel larvae (*Mytilus* sp.) on samples collected from the lagoon during different seasons and outflow conditions to determine if the bioavailability of copper in samples from the lagoon differed from that found in clean laboratory seawater. The results of these studies clearly indicated that bioavailability was reduced in samples of lagoon water, resulting in concomitant reductions in copper toxicity. Based on these results, site-specific marine acute and chronic water quality criteria were calculated as 17.8 and 11.5 µ/L, respectively. Comparison of these calculated values with the results from the individual toxicity tests indicated that they would be protective across the full range of samples tested.

How does the estuary compare in its present form with its condition prior to the onset of development?

Historically, the estuary and associated floodplain and wetlands comprised a variety of habitats rich in biological resources, including side-channels, marshes, small lakes, and riparian woodlands, in addition to the lagoon. Over time, development has reduced the remaining area to less than 10 percent of what was present in the late 1800s, resulting in a loss of complexity, as well as carrying capacity. In addition, since river flows are contained by levees within a smaller area, the estuary is dominated by flood scouring and sediment deposition that occur during high outflow periods typically associated with winter precipitation events.

What are key habitat components associated with the current estuary conditions?

The estuary currently supports riparian scrub and woodland, the lagoon at the mouth of the Santa Clara River, and limited amounts of fresh- and saltwater marsh. The VWRF discharge channel is particularly important because it supports the majority of remaining freshwater marsh and provides stable side-channel habitat during outflow periods. Not only does this channel provide refugia during high outflow events, continuous flows present in the discharge channel provide stable habitat during periods when the lagoon is draining, and the remaining water is confined to the main river channel and isolated depressions that retain water during the receding tide.

Does the estuary support species of special concern?

A number of species of concern utilize the estuary to varying degrees. Probably the key species of concern are tidewater gobies and steelhead. The gobies utilize the lagoon during all phases of their life cycle; whereas, steelhead might be expected to be present as juveniles prior to entering the ocean, and as adults during their spawning migration.

Does the estuary provide satisfactory habitat for species of special concern?

Tidewater gobies are abundant throughout the lagoon. Water quality and substrate composition are within ranges preferred by the gobies, and the discharge channel provides stable habitat under all flow conditions. The lagoon has limited carrying capacity for juvenile steelhead due to their larger size compared with the gobies. In addition, changes in sediment depositional patterns in the lagoon may have reduced the abundance of preferred food items for juvenile steelhead.

Was the estuary historically dominated by salt marsh?

Salt marsh comprised only a small portion of habitat described in the earliest map of the estuary. This habitat component was not mentioned in a USGS map prepared in 1933 and is not apparent in an aerial photograph of the estuary taken in 1929. The riparian woodlands and scrub adjacent to the lagoon in the earliest maps further suggest that the lagoon was dominated by water of low salinity, and historical descriptions of waterfowl using the area identify species typically associated with freshwater marshes. Collectively, these data indicate that salt marsh was never a dominant habitat component associated with the estuary.

Has the discharge from the VWRF significantly altered habitats associated with the estuary compared with historical conditions?

A comparison of aerial photographs taken before and after construction of the VWRF indicates that general vegetation patterns have remained similar over time. This conclusion is supported by the results of the hydrological investigation, which show that flows from the VWRF are a small component of overall flows reaching the estuary on an annual basis in the absence of upstream diversions and currently dominate flows into the estuary only during a relatively short period under summer low-flow river conditions.

Thus, it would not be expected that fundamental changes in the vegetation community would occur without more substantive changes in the overall flow regime.

How has the natural flow regime entering the estuary changed over time?

Hydrological impacts on the system have been intensive and pervasive, largely due to agricultural and urban development in the basin. Modifications to the system include diversion of surface water, groundwater pumping, water storage, imports from outside of the system, diversions to infiltration basins to help reduce saltwater intrusion into local groundwater aquifers, and manipulation of flow patterns to meet requirements of various end-users. Upstream water appropriations have reduced annual flows at Montalvo by as much as 74 percent, with the greatest effect occurring in dry years. Moreover, depleted aquifers and water appropriation have altered flow duration curves, further reducing fish passage opportunities for species such as steelhead.

What other factors have affected hydrological function, compared with historical conditions?

Levee construction has significantly reduced the overall floodplain and storage capacity of the lagoon. Moreover, beach formation at the mouth of the Santa Clara River has been affected by reductions in sand reaching the mouth of the river due to trapping behind upstream dams, and disposal of material dredged from Ventura Harbor to the south of the river mouth.

What were the historical flow conditions entering the estuary?

It is problematic to characterize flow conditions prior to the intensive development of water resources since historical records are limited, and detailed flow gauges were not established in the system until after significant development of water resources had already occurred. However, anecdotal records note the presence of water in the lower river, even during August, the period of lowest flows. Extensive freshwater marshes associated with the lower river would also not have been possible without the presence of perennial flows. Another account describes perennial flows occurring over a period of two decades, a period that encompassed several years of low precipitation. Indeed, accounts of the river going dry are not found until the late 1800s; this was clearly a significant event as it resulted in tens of thousands of head of livestock being herded thousands of miles to more favorable grazing conditions. Collectively, these records provide consistent evidence for perennial flows at least to the latter part of the nineteenth century.

How do flows from the VWRF compare with the current flow regime?

On an annual basis, the contribution of flows from the VWRF to the estuary varies with respect to the overall total inflow to the estuary. Upstream appropriations reduce the amount of water that would naturally flow to the estuary, with this effect being most apparent during dry years and seasons. However, flows from the VWRF make up a portion of the total amount of water diverted, ensuring that the estuary receives at least some of the water that has been directed to other uses upstream. In fact, during dry weather periods, when most, if not all, of the river flows have been diverted for other uses, the VWRF may provide up to 100 percent of the freshwater entering the estuary. For example, during the period of record between 1928 and 2001, no flows were recorded at Montalvo for 257 of the possible 370 months in the dry weather period from June through October. Clearly, the VWRF input to the estuary would be highly important during these critical flow-limited periods.

<u>What is the relationship of discharge from the VWRF to the frequency of lagoon breaching?</u>

The cycle and duration of lagoon breaching and reconstruction are a functions of lagoon capacity, outflow, and sediment delivery to the river mouth, with outflow and capacity having greater importance in terms of triggering a breach, and sediment accumulation affecting the duration of the breach (i.e., the speed of barrier beach reconstruction). Under current flow conditions, the effect of the VWRF discharge will be proportional to its contribution to overall flows entering the lagoon. Thus, under current dry weather conditions, flows from the VWRF dominate inputs to the lagoon and consequently trigger breaching events when the lagoon water level exceeds the barrier beach height. However, analysis of natural flow patterns suggests that current dry weather discharges from the VWRF are within the range of natural flows and, consequently, are not likely to be associated with a major increase in the frequency of berm breaching by themselves alone. Conversely, reduction in the overall capacity of the lagoon has limited the volume of water that can be retained before the berm is breached.

The following conclusions were made regarding benefits associated with the VWRF discharge.

<u>Side-channel habitat.</u>

As habitat, the discharge channel supports a freshwater marsh and provides substrate and cover for various organisms, including tidewater goby. Its stability also provides an important refuge during high outflow events. In addition, the channel receives continuous flows from the VWRF, which means that it remains wetted even during periods when the berm is open and the lagoon drains on low tide. Thus, it provides habitat stability during all periods of variability associated with lagoon function and river outflows.

<u>Water quantity and quality</u>.

Water discharged from the VWRF makes up a portion of flows that would typically reach the estuary, but have been diverted for other uses upstream. Moreover, the discharge currently comprises virtually all of the water that reaches the estuary during summer dry periods. In addition, water discharged from the VWRF is of consistently high quality, with respect to TDS and contaminant levels, compared with other potential sources of water to the lagoon, such as groundwater, agricultural return water, and runoff from urban areas located upstream.

Lagoon circulation

Circulation and flushing of the lagoon provide valuable ecological function in terms of maintaining water quality, providing access to and from the ocean for different life-history stages, limiting the colonization of the lagoon by strictly freshwater species, and maintaining discrete habitat components that contribute to overall diversity (e.g., salt and freshwater marsh). During dry periods, the VWRF discharge provides flows that ensure that the berm will be periodically breached, and that flushing of the lagoon will occur on a regular basis.

Collectively, these data suggest that the discharge and associated channel provide substantial benefits in terms of maintaining ecological function associated with the Santa Clara Estuary. The results of this, and other studies, suggest that the estuary is currently operating as a viable, if highly modified, ecological unit. Both water and sediment quality are generally good, and habitat conditions appear to be relatively stable. Moreover, the lagoon provides high-quality habitat for tidewater goby. Therefore, given the complexity of the system, altering any of the components currently contributing to ecological function should not be undertaken without careful consideration.

5.0 SUMMARY AND CONCLUSIONS

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How does the estuary compare in its present form with its condition prior to the onset of development?

Historically, the estuary and associated floodplain and wetlands comprised a variety of habitats rich in biological resources, including side-channels, marshes, small lakes, and riparian woodlands, in addition to the lagoon. Over time, development has reduced the remaining area to less than 10 percent of what was present in the late 1800s, resulting in a loss of complexity, as well as carrying capacity. In addition, since river flows are contained by levees within a smaller area, the estuary is dominated by flood scouring and sediment deposition that occur during high outflow periods typically associated with winter precipitation events.

<u>What are key habitat components associated with the current estuary conditions?</u>

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<u>Does the estuary support species of special concern?</u>

A number of species of concern utilize the estuary to varying degrees. Probably the key species of concern are tidewater gobies and steelhead. The gobies utilize the lagoon during all phases of their life cycle; whereas, steelhead might be expected to be present as juveniles prior to entering the ocean, and as adults during their spawning migration.

<u>Does the estuary provide satisfactory habitat for species of special concern?</u>

Tidewater gobies are abundant throughout the lagoon. Water quality and substrate composition are within ranges preferred by the gobies, and the discharge channel provides stable habitat under all flow conditions. The lagoon has limited carrying capacity for juvenile steelhead due to their larger size compared with the gobies. In addition, changes in sediment depositional patterns in the lagoon may have reduced the abundance of preferred food items for juvenile steelhead.

<u>Was the estuary historically dominated by salt marsh?</u>

Salt marsh comprised only a small portion of habitat described in the earliest map of the estuary. This habitat component was not mentioned in a USGS map prepared in 1933 and is not apparent in an aerial photograph of the estuary taken in 1929. The riparian woodlands and scrub adjacent to the lagoon in the earliest maps further suggest that the lagoon was dominated by water of low salinity, and historical descriptions of waterfowl using the area identify species typically associated with freshwater marshes. Collectively, these data indicate that salt marsh was never a dominant habitat component associated with the estuary.

<u>Has the discharge from the VWRF significantly altered habitats associated with the estuary compared with historical conditions?</u>

A comparison of aerial photographs taken before and after construction of the VWRF indicates that general vegetation patterns have remained similar over time. This conclusion is supported by the results of the hydrological investigation, which show that flows from the VWRF are a small component of overall flows reaching the estuary on an annual basis in the absence of upstream diversions and currently dominate flows into the estuary only during a relatively short period under summer low-flow river conditions.

Thus, it would not be expected that fundamental changes in the vegetation community would occur without more substantive changes in the overall flow regime. This conclusion is further illustrated by Figure 5-1, which shows the average monthly flows that would be expected to reach the estuary, based on the period of record between 1928 and 2001 (data from Table 4-5), compared with the minimum discharge level stipulated in the permit (i.e., 5.6 mgd), as well as the 5-year average monthly effluent flow rate. Clearly, even during dry-weather months, the amount of effluent entering the estuary is not dramatically different from the amount of river flows that would be predicted to enter the estuary, but are diverted for uses upstream.

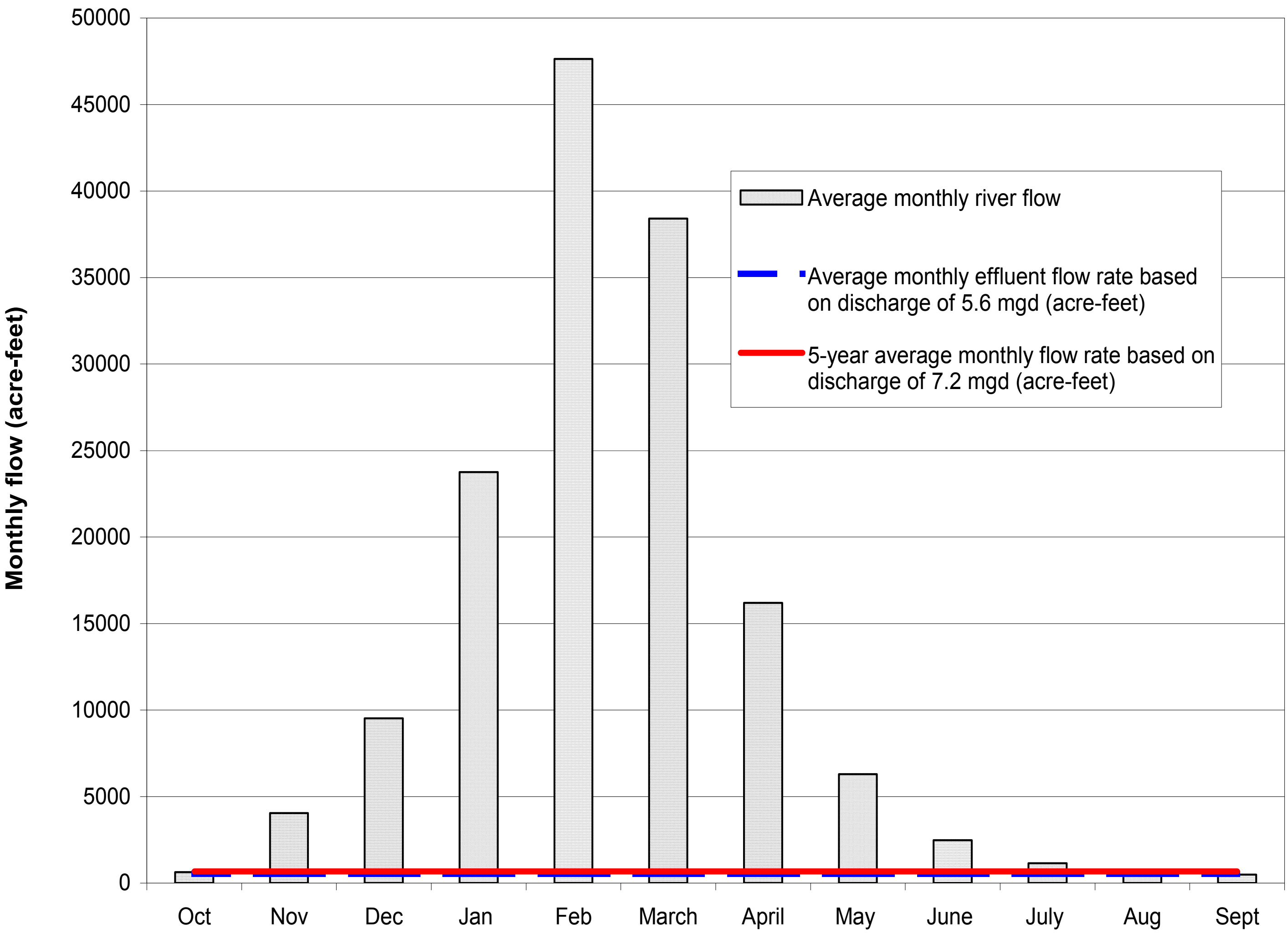

Figure 5-1. Comparison of estimated average natural monthly river flow (1928-2001) with average monthly effluent discharge and minimum permitted discharge.

<u>How has the natural flow regime entering the estuary changed over time?</u>

Hydrological impacts on the system have been intensive and pervasive, largely due to agricultural and urban development in the basin. Modifications to the system include diversion of surface water, groundwater pumping, water storage, imports from outside of the system, diversions to infiltration basins to help reduce saltwater intrusion into local groundwater aquifers, and manipulation of flow patterns to meet requirements of various end-users. Upstream water appropriations have reduced annual flows at Montalvo by as much as 74 percent, with the greatest effect occurring in dry years. Moreover, depleted aquifers and water appropriation have altered flow duration curves, further reducing fish passage opportunities for species such as steelhead.

What other factors have affected hydrological function, compared with historical conditions?

Levee construction has significantly reduced the overall floodplain and storage capacity of the lagoon. Moreover, beach formation at the mouth of the Santa Clara River has been affected by reductions in sand reaching the mouth of the river due to trapping behind upstream dams, and disposal of material dredged from Ventura Harbor to the south of the river mouth.

What were the historical flow conditions entering the estuary?

It is problematic to characterize flow conditions prior to the intensive development of water resources since historical records are limited, and detailed flow gauges were not established in the system until after significant development of water resources had already occurred. However, anecdotal records note the presence of water in the lower river, even during August, the period of lowest flows. Extensive freshwater marshes associated with the lower river would also not have been possible without the presence of perennial flows. Another account describes perennial flows occurring over a period of two decades, a period that encompassed several years of low precipitation. Indeed, accounts of the river going dry are not found until the late 1800s; this was clearly a significant event as it resulted in tens of thousands of head of livestock being herded thousands of miles to more favorable grazing conditions. Collectively, these records provide consistent evidence for perennial flows at least to the latter part of the nineteenth century.

How do flows from the VWRF compare with the current flow regime?

On an annual basis, the contribution of flows from the VWRF to the estuary varies with respect to the overall total inflow to the estuary. Upstream appropriations reduce the amount of water that would naturally flow to the estuary, with this effect being most apparent during dry years and seasons. However, flows from the VWRF make up a portion of the total amount of water diverted, ensuring that the estuary receives at least some of the water that has been directed to other uses upstream. In fact, during dry weather periods, when most, if not all, of the river flows have been diverted for other uses, the VWRF may provide up to 100 percent of the freshwater entering the estuary. For example, during the period of record between 1928 and 2001, no flows were recorded at Montalvo for 257 of the possible 370 months in the dry weather period from June through October. Clearly, the VWRF input to the estuary would be highly important during these critical flow-limited periods.

What is the relationship of discharge from the VWRF to the frequency of lagoon breaching?

The cycle and duration of lagoon breaching and reconstruction are a functions of lagoon capacity, outflow, and sediment delivery to the river mouth, with outflow and capacity having greater importance in terms of triggering a breach, and sediment accumulation affecting the duration of the breach (i.e., the speed of barrier beach reconstruction). Under current flow conditions, the effect of the VWRF discharge will be proportional to its contribution to overall flows entering the lagoon. Thus, under current dry weather conditions, flows from the VWRF dominate inputs to the lagoon and consequently trigger breaching events when the lagoon water level exceeds the barrier beach height. However, analysis of natural flow patterns suggests that current dry weather discharges from the VWRF are within the range of natural flows and, consequently, are not likely to be associated with a major increase in the frequency of berm breaching by themselves alone. Conversely, reduction in the overall capacity of the lagoon has limited the volume of water that can be retained before the berm is breached.

The following conclusions were made regarding benefits to the estuary associated with the VWRF discharge. These benefits clearly enhance beneficial uses ascribed to the estuary, particularly with respect to improving habitat and water quality above levels that would be likely to be present in the absence of the discharge. Thus, they have direct positive implications for terrestrial and aquatic organisms that may use the estuary on a transient or permanent basis, including species that currently require special protection. Moreover, these benefits provide indirect effects in that an estuary with improved habitat diversity, water quality and community structure is likely to enhance the recreational aspects associated with the estuary.

Specific areas of enhancement include:

Habitat

1. The discharge channel supports freshwater marsh, improving habitat diversity. Marsh is a key habitat component of estuaries that supports both aquatic and terrestrial organisms. Most of the marsh historically associated with the Santa Clara River Estuary has been lost due to reclamation projects and appropriation of river flows for other uses. Continuous freshwater flows ensure maintenance of plant communities and habitat in the estuary even during dry periods. Without input from the VWRF, such inflows would be largely absent due to upstream diversions of river flows during most of the dry months between June and October.
2. The discharge channel provides side-channel habitat (i.e., refugia) during outflow events. Historically, the estuary was composed of a complex network of channels, sloughs and small ponds, which provided extensive off-channel habitat for aquatic organisms during flood periods when high flows rushed to the ocean. Today, virtually all such historic side-channel habitat has been lost due to extensive levee construction on both sides of the lower river. These levees have

constrained the channel, increasing current velocity and scouring during high outflow events. In contrast, the discharge channel provides a stable low-flow environment that remains relatively unaffected by high outflow events, reducing the probability that resident aquatic organisms will be swept out to sea.

3. In addition, the discharge channel maintains a continuous source of water during breach outflow events when the lagoon drains, providing habitat stability. When the lagoon drains during normal breaching events, water remains only in the main river channel and in a few perched ponds trapped in depressions, thus reducing aquatic habitat to <10 percent of what is available during periods when the lagoon is flooded. Organisms in these shallow exposed areas are vulnerable to predation, as well as impacts of elevated temperature. Under these conditions, the discharge channel retains its integrity as desirable habitat. In addition, the edges of the discharge channel are heavily vegetated, providing both cover and food.
4. Current habitat conditions in the lagoon are consistent with the requirements of the tidewater goby, which have been listed by the U.S. Fish and Wildlife Service as "Endangered," due to declines in their distribution and abundance, their existence in semi-isolated population units, their susceptibility to certain types of disturbances, and their limited ability to disperse and colonize new habitats. Poor water quality is one factor that has been identified as an issue limiting goby populations. In this case, the discharge from the VWRF is not only consistent with general water chemistry (e.g., salinity) preferred by the goby, its overall quality is higher than the urban, agricultural, and groundwater inputs that would seasonally dominate in-flows to the lagoon in the absence of the VWRF discharge. Another factor identified as potentially affecting goby populations is being swept from their preferred lagoon habitats during periods of high outflows. As described above, the discharge provides a clear benefit to the gobies in that the side channel and associated habitat provides a refuge from high out-flows during flood events.

<u>Water Quality</u>

1. Effluent from the VWRF is high-quality water in terms of lower total dissolved solids (TDS) and contaminant and nutrient loads, compared with urban, agricultural, and groundwater inputs to the lagoon. In the absence of flows from the VWRF, the lagoon would be dominated by inputs from these other sources, particularly during dry periods. Elevated TDS, contaminants and nutrients all contribute to reductions in overall water quality. Indeed, elevated nutrients can result in eutrophication that, in the absence of sufficient circulation, can lead to fish kills as oxygen levels in the water decrease to concentrations that no longer support aquatic life. This situation has been noted in a number of lagoons in southern California in which the natural flow regime has become dominated by urban and agricultural inputs.

<u>Hydrology</u>

1. Discharge from the VWRF makes up a portion of water that historically flowed to the estuary, but is now appropriated for uses upstream. Anecdotal evidence

indicates that perennial flows existed in lower river, even during dry months, providing water to the estuary and marshes that extended well upstream. However, beginning in the late 1800s, intensive development of water resources in the basin reduced groundwater reserves and altered surface flows in the river. Upstream appropriations of water for agricultural use and managing salt-water intrusion have reduced annual flows to the estuary by as much as 75 percent, depending on the water year, and eliminated surface flows to the estuary during most of the dry weather months. For example, between 1928 and 2001, no natural river flows reached the estuary in approximately 70% of the dry weather months between June and October. Thus, in dry months, flows from the VWRF are clearly an important component of freshwater inputs to the estuary, accounting for up to 100% of fresh water entering the estuary.

2. Under current conditions, the discharge is responsible for berm breaching that occurs during the summer months, improving lagoon circulation and flushing. Many southern California lagoons undergo periods of hypoxia due to elevated nutrients, eutrophication and high temperatures during the summer months. This can result in fish kills, plant die-offs, etc., all of which are indicative of poor water quality conditions and demonstrate reduced ability to support the aquatic community. Indeed, minimizing such adverse conditions are of concern in terms of maintaining viable tidewater goby populations. To the extent that the discharge comprises most of the freshwater flows reaching the estuary during dry months, it provides most of the impetus required to initiate the breaching process.
3. In the process of filling the lagoon, the discharge not only provides water of high quality, it creates a differential in the hydraulic pressure gradient such that subsurface flows are directed towards McGrath Lake. Otherwise, these flows (including groundwater and seepage from agricultural operations) would be towards the lagoon, further degrading water quality in the lagoon.

Collectively, these data suggest that the discharge and associated channel provide substantial enhancements in terms of maintaining ecological function associated with the Santa Clara Estuary. The results of this, and other studies, suggest that the estuary is currently operating as a viable, if highly modified, ecological unit. Both water and sediment quality are generally good, and habitat conditions appear to be relatively stable. Moreover, the lagoon provides high-quality habitat for tidewater goby. Therefore, given the complexity of the system, altering any of the components currently contributing to ecological function should not be undertaken without careful consideration.