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Central Coast Watershed Studies

CCoWS

Watsonville Sloughs Sediment Problems & Sources

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Preface

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Executive Summary

Sediment problems and sources were examined in the Watsonville Sloughs system. Watsonville Slough itself was listed on the California 303(d) list in 1998 as being impaired due to "sedimentation / siltation". This listing mandates a Total Maximum Daily Load (TMDL) planning process under the federal Clean Water Act, the responsibility of which is carried by the Central Coast Regional Water Quality Control Board (CCRWQCB). The first two steps in this process are problem definition and source analysis, the subject of the present study. We defined the study system as including each of the major sloughs in the area: Watsonville, Struve, Hanson, Harkins, and Gallighan.

In a typical river system, an ideal approach for a sediment TMDL is the determination of land use based sediment loads from field sampling of suspended sediment and discharge, modeling, or a combination of the two. This approach however did not work for Watsonville Sloughs given the short time-frame of this study. Average water-year precipitation in 2003 at Watsonville was below average and during the winter sampling period, from January to March, monthly rainfall totals were less than half of the average. Discharges were so low at many of the sites that measurements were often not possible. Low intensity storms and the lack of significant rainfall, in combination with the hydrologic regime of the watershed, prevented the calculation of total sediment loads for the watershed. Characteristics of the hydrologic regime that prevented the determination of total suspended sediment loads included: 1) the low gradient of the watershed, 2) back flow from the Pajaro River due to sand bar closure, and 3) sections of large ponded water in the mid-watershed due to subsidence. The strategy for this project was therefore shifted from total load analysis to the effects of suspended sediment concentrations and sedimentation on beneficial uses.

The system was described by Questa in 1995 as having erosion and sedimentation problems, and similarly by Swanson in 2003. This conclusion was apparently based on qualitative visual inspection, since no detailed data or photographic evidence were given. In particular, the problems cited by Questa appear to have been inferred rather than being actual observations of "obstuct[ion] and alter[ation] of drainage patterns, reduc[tion] in water clarity, blanket[ing] of vegetation and aquatic organisms, and transport [of] attached nutrients and pesticides to receiving waters". The inference appears to be based on visual observation of erosion on agricultural sites above Gallighan Slough, "choking" of Gallighan Slough with sediment, and the fact that Watsonville slough was dredged by Santa Cruz County Public Works Department and adjacent landowners to remove sediment for flood control until 1983.

This does not immediately constitute a problem under the Clean Water Act - because it either lacks data, or refers to uses of the system that are not protected under the Clean Water Act. A 'problem' can be defined as a situation where a beneficial use is adversely

impacted by a stressor. The CCRWQCB has defined certain beneficial uses for Watsonville Slough that are thus protected under the Clean Water Act, such as Warm Fresh Water Habitat, Estuarine Habitat, Spawning, Reproduction, and/or Early Development. Flood control is not on the list. Rather, it was our working assumption that protected beneficial uses of the Watsonville Slough primarily refer to habitat for birds, fish, and other aquatic fauna. The area is well known for its bird habitat, and native fish have been recorded recently.

We considered the potential for sediment-related problems impacting protected beneficial uses. Some working hypotheses were formed:

1. Suspended sediment concentrations could adversely impact aquatic organisms, such as through physiological impacts on gill tissues.
2. Sediment sources could be widespread, with perhaps a locally dominant influence from intensive land uses on the steep hills immediately above the sloughs.
3. Excessive sedimentation rates could adversely smother benthic habitat
4. Excessive sedimentation could lead to aggradation, ultimately reducing the aquatic habitat volume as part of an accelerated wetland succession toward a more terrestrial state.
5. Suspended sediment is a transport mechanism for nutrients and pesticides, which may adversely affect aquatic organisms (not within the scope of this study).

We collected quantitative data on suspended sediment concentrations, land subsidence, and sediment cores; as well as qualitative reconnaissance of sedimentation.

A total of 146 suspended sediment and turbidity samples were collected to determine if concentration alone may adversely affect aquatic organisms. The average suspended sediment concentration for each of the Watsonville Sloughs sites generally ranged from 10 mg/L to 100 mg/L. Levels greater than 1,000 mg/L were only observed at 2 sites in Hanson and Gallighan sloughs. With these 2 exceptions, the general suspended sediment concentrations observed in Watsonville Sloughs, for the 2003 rainfall/runoff year, could have mild effects on fish and aquatic invertebrates, but lethal effects would not generally be expected. Levels could potentially be much greater in higher rainfall/runoff years. Suspended sediment effects may also be exacerbated by conditions such as long duration and the combined effect of other stressors such as temperature, dissolved oxygen, and toxic pollutants such as pesticides.

Based on reconnaissance, we concur with previous investigators' visual observations of apparently excessive sediment in some of the sloughs, particularly Hanson Slough and upper Gallighan Slough. It is possible that the excessive sediment load in these areas may be sufficient to episodically smother benthic habitat in the sloughs. However, we were unable to document that this was the case because the critical confluences between stream and slough (where sedimentation is likely to occur) were inaccessible. In other areas of the sloughs, no clear visual evidence of slough sedimentation was observed during the monitoring period. We considered installing stakes and performing repeat cross-sections to track sedimentation over time directly, but decided against this given the short time-frame of the project. Any data gained in this manner would have been heavily biased by under-sampling of this highly inter-annually variable regime. Instead, we collected data on the long-term outcomes of sedimentation - via dating analysis of sediment cores, and measurement of land subsidence.

The results of the sediment core analysis indicated that in general, the late-European (1880-2004) average sedimentation rate (6.4 mm/year) is slightly higher than the pre-European (1420-1800) average sedimentation rate (5.1 mm/year) and considerably higher than the early-European (1800-1880) average sedimentation rate (2.6 mm/year). However, lead-210 data, suggest (not conclusively) that the recent (last 50 years) average sedimentation rate (1.7 mm/year) is substantially lower than even pre-European rates. This lower recent rate of sedimentation may be explained by decreased sediment supply to the lower reach of Watsonville Sloughs due to both land subsidence in the upper sloughs in the early 1900s and the installation of the tide gates in the 1940s which has resulted in the reduced circulation and sediment transport capacity. Sedimentation rates could not be determined for the upper sloughs due to destruction of the sedimentary record by past modifications such as draining, filling, farming, and channelization of the sloughs. Based on the (possible) decrease in sedimentation rates downstream of the Shell Road pump station in the past 50 years, we suspect that sediment rates have likely increased in the upper watershed. However, this would need to be confirmed by a long-term (i.e. 5 to 10 years) sediment accumulation study involving use of substrate reference markers and repeated channel cross-sections.

Based the results of a repeated survey of Harkins Sloughs Road near Struve Slough and Watsonville Slough and a permanent benchmark located near Harkins Slough at Harkins Slough Road, subsidence rates of the sloughs were estimated to range from 10 to 20 mm/year. In order to determine if habitat volume is being reduced, sedimentation rates in these upper portions of the sloughs would need to be in excess of 10 to 20 mm/year. The rate of sedimentation in the upper sloughs was not determined in this study.

With respect to the hypotheses given above, the following conclusions can be made:

1. Suspended sediment concentrations observed in Watsonville Sloughs are typical of coastal waterways in the region. Lethal effects to aquatic organisms would not

generally be expected based on suspended sediment levels observed in Watsonville Sloughs, with the exception of values observed at Hanson and Gallighan sloughs. Adverse effects such as altered behavior, stress, and alteration of food chain relationships by reduction in primary production are possible at these levels.

2. Significant suspended sources could not be isolated. Although 146 samples were taken from 13 sites distributed throughout the system during both summer and winter, there was no clear geographic pattern or land use pattern that clearly explained the variation in the suspended sediment data.
3. Smothering of benthic habitat by sedimentation was not significantly evident, but was also difficult to study. Sedimentation of perennial aquatic habitats could be studied in future using reference markers driven into the substrate and repeated cross-sections - but any attempt to use them in the present short-term study would have yielded highly biased data due to the episodic nature of sediment transport in the region. A longer-term (e.g. 5-year) study involving direct measurement of underwater sedimentation rates would be useful (e.g. using stakes, or cross-section surveys). A visual reconnaissance was conducted for signs of excessive recent sedimentation. Unequivocal smothering of habitat could only be documented (photographically) in upper Hanson and Gallighan sloughs. Other areas were either stable, contained coarse sediment, contained fine sediment in amounts that did not contradict the expectation of a natural system, were under water, or were not accessible.
4. Long-term aggradation of sediments and reduction in aquatic habitat volume was not evident. Aquatic habitat volume appears to be increasing due to land subsidence associated with de-watering of the area for peat mining and agriculture in the early 1900s, ground water pumping, and possibly local seismic activity. We re-surveyed an old road survey across Struve Slough and Watsonville Slough, and found evidence of subsidence on the order of 10 to 20 mm/year since 1952. Our sub-contractors excavated sediment cores in the tidal marsh of lower Watsonville Slough dating back to the 1400s and analyzed them using radiocarbon dating, pollen, and lead-210. The data suggested an anthropogenic increase in sedimentation surrounding the expansion of agriculture in the first half of the 1900s, but net sedimentation rates since about 1950 appear to have been lower than in pre-historic times. This is likely attributed to decreased sediment supply to the lower reaches resulting from subsidence and the construction of the tide gates in the 1940s.

In summary, the system probably has a moderate suspended sediment yield that is higher than would have occurred in pre-historic times, and lower than appears to occur from watersheds with a much higher proportion of land uses such as row-crop agriculture and grazing. Suspended sediments are readily deposited upon reaching the slough margins, and deposition does not appear to have resulted in long-term net aggradation, because this is apparently offset by land subsidence. On the whole, current sediment transport in the system could be characterized as being on a geomorphic trajectory toward restoration to natural pre-historic marsh conditions - before peat mining, and before ditching - albeit by un-natural means. Whether or not the trend of subsidence will continue is unknown. Frequent, longer periods of inundation (due to discontinued dredging, increased runoff, and subsidence) observed in recent decades could lead to increased peat formation under anoxic conditions. This in combination with reduced groundwater pumping (due to salt water intrusion and current efforts by the PVWMA to obtain additional sources of water) could potentially reduce the subsidence trend. If this were the case, future net sediment accumulation and reduction in habitat volume could possibly occur.

In the interest of effective use of limited TMDL resources, and with the awareness of other TMDLs relating to more clearly anthropogenic substances such as heavy metals and pesticides, we would recommend de-prioritization of the Watsonville Slough listing for sedimentation / siltation.

This is a risky conclusion, given the uncertainty in the inferences we have made from our data. This situation may be resolved pragmatically. If sediment problems in the sloughs were more prevalent than is apparent thus far, other, more directly observable water quality problems would be likely to co-occur - such as nutrient problems, and pesticide problems. The consequent remediation of these other problems would most likely result in inadvertent remediation of any sediment problems.

Recommendations:

- Additional monitoring for suspended sediment and turbidity to document levels for higher rainfall/runoff years.
- Sediment toxicity testing for fish and other aquatic species present in Watsonville Sloughs.
- The possibility of short-term (e.g. annual) smothering of the slough benthos by the apparently excessive stream sediment load remains poorly understood. We would recommend a 3 to 5 year study that installed stakes and repeatedly measured cross-sections with very high precision to track sedimentation of the benthos over this time scale.
- Long-term analyses could also be supplemented by analysis of additional sediment cores. In particular, sediment cores from above the tide gates would be useful - although ideal, undisturbed locations may not exist.

1 Introduction

Watsonville Slough is listed on the California 303d list under the Federal Clean Water Act as being impaired due to "sedimentation/siltation". Accordingly, the Central Coast Regional Water Quality Control Board is required to develop and implement a Total Maximum Daily Load (TMDL) specification for sediment. Although the tributary sloughs are not currently listed, the entire system, including the four tributaries, was investigated for this study.

The Watershed Institute at California State University Monterey Bay was contracted by the Central Coast Regional Water Quality Control Board (CCRWQCB) to provide technical assistance in the development of a TMDL for sediment in the Watsonville Slough system including: monitoring, a problem statement, and a preliminary source analysis. The specific objectives of this project were as follows:

- Review in report form, previous studies and existing data on the hydrology, geometry, and water quality of Watsonville Sloughs
- Collect, analyze, and present in report form, field data on the hydrology, geometry, and water quality of Watsonville Sloughs
- Produce in report form, a problem statement for sediment in Watsonville Sloughs, suitable for inclusion in a Technical TMDL document
- Produce in report form, a preliminary source analysis for sediment in Watsonville Sloughs, suitable for inclusion in a Technical TMDL document

1 Study Area

The Watsonville Slough system is located in Santa Cruz County and is comprised of Harkins, Gallighan, Hanson, Struve, and Watsonville Sloughs. The system drains an area of approximately 50 km^2 (13,000 acres) (Fig. 1.1). Sub-watershed areas are listed in Table 1.1. The Watsonville Sloughs watershed contains relatively steep headwaters in the northern Larkin Valley area with rural, grazing, and natural lands as the primary land use types. The mid-section of the watershed is characterized by the rapidly growing City of Watsonville to the east and hill slopes dominated by rural residential, landfills, agriculture, and natural lands to the west. The sloughs continue down to a broad alluvial flood plain, with irrigated agriculture as the primary land use in the Beach Road area and industrial land uses in the Lee Road area. Watsonville Slough finally drains to the Pajaro River Lagoon near a small residential dunes complex. The upper reaches are more stream-like, whereas the lower areas are low gradient and sluggish. The lowest reach of the Watsonville Slough, near the confluence with the Pajaro Lagoon, is tidally influenced.

Watsonville Slough itself is the remnant of a once more-extensive wetland and estuarine complex. The system has been historically modified to meet the needs of adjacent land uses, such as agriculture and urban development. Many areas of the slough system were channelized and filled to drain surface water beginning in the 1880s. Two pump stations were installed for flood control and to enable farming of the often-inundated lowlands. The two pump stations are located at Shell Road and at the confluence of Harkins Slough and Watsonville Slough. The Shell Road pump station and tide gates, currently maintained by the County of Santa Cruz, were installed in the 1940's and formed an abrupt boundary between saltwater (downstream) and freshwater (upstream). The Harkins Slough pump station, currently operated by the Pajaro Valley Water Management Agency, was also originally installed for flood control but today serves as a diversion project to deal with seawater intrusion (Swanson Hydrology and Geomorphology, 2003). A detailed historical review of the Watsonville Sloughs area is given in Section 6.2.1.

Table 1.1 Watsonville Sloughs sub-watershed boundaries

Slough	Approx. Area (acres)	Approx. Area (km²)
Watsonville*	3,493	14.1
Harkins**	5,282	21.4
Gallighan	1,452	5.9
Hanson	399	1.6
Struve	1,798	7.3
Total	12,424	50.3

*Excluding Harkins, Hanson, and Struve Slough

**Excluding Gallighan Slough

2 Review of Beneficial Uses & Water Quality Standards

2.1 Beneficial Uses

The Watsonville Sloughs system forms the largest wetland complex between Pescadero Marsh, approximately 80 km (50 miles) to the north, and Elkhorn Slough, immediately to the south. The sloughs are home to diverse plant communities, with wetland and riparian vegetation that provide nesting sites and habitat for a variety of migratory and wetland birds, many of which are threatened, endangered, or California species of concern (Busch, 2000; Swanson Hydrology and Geomorphology, 2003). Many wetland birds depend on abundant fish and macroinvertebrates for survival, and thus require a healthy functioning aquatic ecosystem free from excessive pollutants. Watsonville Sloughs serve as habitat for a variety of fish, amphibian, reptile, and small mammal species. The sloughs are also popular places for recreational activities such as fishing, nature walks, and bird watching. Struve Slough and Harkins Slough, which has an extensive deepwater section, are especially popular areas for these types of recreational activities.

Specific beneficial uses that apply to Watsonville Slough and its tributary sloughs are outlined in the Basin Plan for the Central Coast Region (1994) and are presented in Table 2.1.

Table 2.1 Beneficial uses that apply to Watsonville Sloughs (Basin Plan 1994)

Waterbody Name	REC1	REC2	WILD	WARM	SPWN	BIOL	RARE	EST	COMM	SHELL
Watsonville Slough	x	x	x	x	x	x	x	x	x	x
Harkins Slough	x	x	x	x	x	x	x	x	x	x
Gallighan Slough	x	x	x	x	x	x	x	x	x	x
Hanson Slough	x	x	x	x	x	x	x	x	x	x
Struve Slough	x	x	x	x	x	x	x	x	x	x

The beneficial uses given in Table 2.1 are defined as follows:

Water Contact Recreation (REC-1) - Uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, white water activities, fishing, or use of natural hot springs.

Non-Contact Water Recreation (REC-2) - Uses of water for recreational activities involving proximity to water, but not normally involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tide pool and marine life study, hunting, sightseeing, or aesthetic enjoyment in conjunction with the above activities.

Commercial and Sport Fishing (COMM) - Uses of water for commercial or recreational collection of fish, shellfish, or other organisms including, but not limited to, uses involving organisms intended for human consumption or bait purposes.

Warm Fresh Water Habitat (WARM) - Uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.

Estuarine Habitat (EST) - Uses of water that support estuarine ecosystems including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds). An estuary is generally described as a semi-enclosed body of water having a free connection with the open sea, at least part of the year and within which the seawater is diluted at least seasonally with fresh water drained from the land. Included are water bodies, which would naturally fit the definition if not controlled by tide gates or other such devices.

Wildlife Habitat (WILD) - Uses of water that support terrestrial ecosystems including, but not limited to, preservation and enhancement of terrestrial habitats, vegetation, wildlife (e.g., mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources.

Preservation of Biological Habitats of Special Significance (BIOL) - Uses of water that support designated areas or habitats, such as established refuges, parks, sanctuaries, ecological reserves, or Areas of Special Biological Significance (ASBS), where the preservation or enhancement of natural resources requires special protection.

Rare, Threatened, or Endangered Species (RARE) - Uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened, or endangered.

Spawning, Reproduction, and/or Early Development (SPWN) - Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.

Shellfish Harvesting (SHELL) - Uses of water that support habitats suitable for the collection of filter feeding shellfish (e.g., clams, oysters, and mussels) for human consumption, commercial, or sport purposes.

2.2 Water Quality Objectives

The specific water quality objectives that apply to sediment levels for Watsonville Sloughs are outlined in the Basin Plan for the California Regional Water Quality Control Board Central Coast Region (1994), as mandated by the California Porter-Cologne Water Quality Control Act (1969). The Basin Plan (1994) states that:

> Suspended Material: Waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses.
>
> Settleable Material: Waters shall not contain settleable material in concentrations that result in deposition of material that causes nuisance or adversely affects beneficial uses.
>
> Sediment: The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.
>
> Turbidity: Water shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses.
>
> > Increase in turbidity attributable to controllable water quality factors shall not exceed the following limits:
> >
> > 1. Where natural turbidity is between 0 and 50 Jackson Turbidity Units (JTU), increases shall not exceed 20 percent.
> > 2. Where natural turbidity is between 50 and 100 JTU, increases shall not exceed 10 JTU.
> > 3. Where natural turbidity is greater than 100 JTU, increases shall not exceed 10 percent.
> >
> > Allowable zones of dilution within which higher concentrations will be tolerated will be defined for each discharge in discharge permits.

The unit of measurement for the Basin Plan water quality objective for turbidity is the JTU (Jackson Turbidity Unit). Historically, JTU was the common unit for turbidity measurements using the Jackson candle turbidimeter. This visual method has been removed from the Standard Methods manual (APHA, 1998) and has since been replaced by methods that utilize instruments such as nephelometers. Turbidity measurements made with nephelometers result in either NTU or FTU. FTU is a unit used when formazin is the primary reference standard. For this project, turbidity was measured using a turbidimeter and the resulting unit was NTU (Nephelometric Turbidity Unit).

2.3 Potential sediment impacts to beneficial uses

The CCRWQCB water quality objectives that pertain to sediment, given in the previous section, are narrative stating that sediment "shall not cause nuisance or adversely affect beneficial uses" (Basin Plan, 1994). However, no studies have investigated the direct impacts that concentrations of sediment and/or sedimentation can have on the specific beneficial uses for Watsonville Sloughs. The precise nature of sediment impairment in Watsonville Sloughs is not well understood and is difficult to document.

The primary ways in which elevated levels of suspended sediment and/or sedimentation may adversely impact beneficial uses include:

- Direct physiological harm to aquatic organisms (i.e. gill abrasion)
- Transport of toxic pollutants attached to sediment (i.e. pesticides)
- Alteration of food chain relationships (i.e. reduction in primary productivity due to reduced light penetration production)
- Habitat alterations (i.e. substrate & vegetation changes, volume reduction)

It is presumed that sediment can transport attached pesticides and nutrients, which may affect aquatic organisms. Studies, such as Hunt et al. (1998) conducted in the Watsonville Sloughs Watershed, have demonstrated that elevated pesticide levels can lead to toxicity in macroinvertebrates. Swanson (2003) observed that impairments of water quality factors such as dissolved oxygen may be the result of excessive nutrient loading and could have led to a fish kill that was observed in Watsonville Slough in January 2001. However, impacts such as these are not directly caused by sediment and therefore must be addressed in other TMDLs.

The following sections describe potential impacts that suspended sediment and/or sedimentation may have on specific aquatic species. The presence of many of the species listed below has been documented in previous studies. Detailed inventories of the flora and fauna of Watsonville Sloughs have recently been compiled by J. Busch (2000) and by Swanson Hydrology and Geomorphology (2003) containing supplementary work by the Biotic Resources Group, Dana Bland and Associates, and Hagar Environmental Sciences.

2.3.1 Native Freshwater Fish

Several studies have shown that both suspended sediment and sedimentation can directly and indirectly affect aquatic organisms (Newcombe and Jensen, 1996 and Newcombe and MacDonald, 1991). This section details sediment impacts to fish.

The only known studies to date that have surveyed fish species in Watsonville Sloughs were conducted by Hagar Environmental Sciences as part of a conservation plan for Watsonville Slough by Swanson Hydrology and Geomorphology (2003) and by Cooling in (1984). The results of the Cooling study were summarized by Questa (1995). Hagar found Sacramento blackfish (native), threespine stickleback (native), carp (non-native), mosquitofish (non-native), and black crappie (non-native) in a deepwater section of Harkins Slough. Visual observations of mosquitofish (non-native), threespine stickleback (native), and prickly sculpin (native) were made in the headwaters of Harkins Slough near Larkin Valley. Threespine stickleback (native) were also found in Struve Slough. Cooling (1984) documented the presence of the following species in the sloughs: Sacramento blackfish (native), brown bullhead (non-native), carp (non-native), goldfish (non-native) and sunfish (non-native). Other native species that could be expected in Watsonville Sloughs but that have not been observed include: California roach, Sacramento sucker, pikeminnow, and possibly hitch (Swanson Hydrology and Geomorphology 2003).

Although federally threatened steelhead trout and federally endangered Tidewater goby would not be expected in the upper reaches of Watsonville Sloughs above the Shell Road pump station, the two species have in the past been observed in the lower estuarine reaches below Beach Road (Smith, 1993 as cited in Swanson, 2003). The lower reach of Watsonville Slough may currently provide useful habitat for young steelhead trout migrating to the ocean from the Pajaro River and undergoing the process of smoltification. This lower reach of Watsonville Slough also provides ideal habitat for Tidewater goby, although Tidewater goby have not been reported since 1993.

Newcombe and Jensen (1996) summarized that suspended sediment can impact steelhead trout and other fish by causing mortality, reducing growth rate, reducing resistance to disease, limiting egg and larvae development, disrupting movement and migration, reducing food availability, and disrupting feeding. Appendix A- Sediment Effects on Fish contains the results of a literature review pertaining to the effects that sediment concentrations and turbidity levels can have on fish species, in particular rainbow trout/steelhead, which are likely to only be found in the lower estuarine portion of Watsonville Sloughs. It should be noted that many of these studies were conducted in laboratories rather than in the wild where conditions are variable and primarily on salmonids rather than the assemblage of fishes found in the upper portions of Watsonville Sloughs. Therefore the results may not be directly applicable to Watsonville

Sloughs. The listed concentrations and responses are not intended for use as a reference to exact concentrations that would affect fish in Watsonville Sloughs, but more so to gain an understanding of the general range that can be expected to have an adverse effect on fish in general. Many factors can influence the degree of sediment impact such as sediment composition and size, duration, species adaptation to a given area, and simultaneous presence of different stressors such as elevated temperature, low dissolved oxygen, and other pollutants such as pesticides.

The various studies showed a wide range of sediment concentrations and related sub-lethal and lethal impacts. The studies were conducted primarily on salmonids and to a lesser extent on nonsalmonids. Appendix A- Sediment Effects on Fish includes only results for rainbow trout/ steelhead and other species that may inhabit Watsonville Sloughs. A summary of concentration ranges and resulting responses is given below.

Turbidity:

- 22 to 265 NTU-displacement and avoidance behavior

SSC:

- 16.5 to 110 mg/L-altered behavior such as reduced feeding
- 500 to 2,000 mg/L-stress
- 50 to 17,500 mg/L-physiological changes and damage to gills
- 70 to 500 mg/L-some mortality and a slight decrease in survival
- 1,000 to 160,000 mg/L-often significant population reduction

A similar range of sediment concentration is given in a fisheries handbook developed by the U.S. Army Corps of Engineers, which states that streams with concentrations ranging from 80 to 4,000 mg/L are not expected to support healthy fisheries (Bell, 1986). Birtwell (1999) concluded that sub-lethal effects were generally observed at levels ranging from tens to hundreds mg/L of suspended sediment and that lethal effects were generally observed at levels ranging hundreds to hundreds of thousands mg/L.

As illustrated in Appendix A- Sediment Effects on Fish, the majority of the studies that have examined the effects of sediment on fish have been conducted on salmonids rather than on the specific species that inhabit upper portions of Watsonville Sloughs such as Threespine stickleback, Sacramento blackfish, and Prickly sculpin, which could be more tolerant of sediment. Since the primary water quality standards for suspended sediment are narrative and rainbow trout/steelhead are known to utilize the lower reach of Watsonville Slough, the numbers presented in Appendix A may serve as the only guideline for suspended sediment concentrations until a specific study on beneficial uses and sediment toxicity is conducted for Watsonville Sloughs.

Sedimentation can impact fish species by altering spawning habitat. Many native fish of this region have specific substrate requirements for spawning. High rates of sediment accumulation, especially fines in spawning areas, may detrimentally impact fish reproduction. Table 2.2 summarizes specific spawning requirements for native fish that have been observed or are expected to occupy Watsonville Sloughs.

Table 2.2. Specific spawning requirements for selected native fish

Native Fish Species	Preferred Spawning Substrate	Preferred Spawning Location
Threespine stickleback*	sand and small pebbles with twigs and debris nearby	among beds of aquatic plants in estuaries and adjacent coastal streams, bays, and sloughs
Prickly sculpin*	large cobbles or flat rocks; artificial substrates such as concrete blocks and jetty crevices	flowing water with loose rocks
California roach**	30 to 50 mm	shallow flowing areas
Hitch**	clean fine to medium gravel	riffles of tributary streams; reservoirs and ponds
Sacramento sucker**	sand, gravel, and cobble	tributary streams mostly in gravel riffles
Pikeminnow**	rocks and gravel	gravel riffle streams and small foothill streams
Sacramento blackfish*	beds of aquatic vegetation and/or rocks	open, shallow water such as in sloughs, ponds, and reservoirs
Tidewater goby***	sand burrows or ditches with gravel, sand, or clay mud bottom	shallow weedy areas along coastal streams and lagoons; ditches

Sources: Moyle, 2002; Wang, 1983
* observed by Hagar, 2001.
**not observed but could potentially exist
***observed in lower reaches of Watsonville Slough by Smith, 1993.

The final way in which suspended sediment and/or sedimentation can adversely impact fish is by indirectly decreasing the abundance of aquatic invertebrates, an important food source for many of the fish species present in Watsonville Sloughs.

2.3.2 Aquatic Invertebrates

Newcombe and MacDonald (1991) reported that suspended sediment can affect benthic invertebrates, which feed on periphyton, by disrupting primary production as light penetration is reduced; and that suspended sediment can also affect filter feeding benthic invertebrates by clogging feeding structures, reducing feeding efficiency, and reducing growth rates, which could therefore lead to stress and possible mortality. Appendix B contains the results of a literature review pertaining to the effects that sediment concentrations and turbidity levels can have on various aquatic invertebrates. The results show that adverse effects on invertebrates (which may in turn have an indirect adverse affect on higher organisms) were observed at even lower levels than the than the sediment concentrations shown to have similar adverse effects on fish. Table 2.3 lists several families of aquatic invertebrates likely to be observed in central California that were found to be intolerant to disturbances such as sedimentation (Harrington and Born, 2000). The reduction of aquatic invertebrates can indirectly affect the abundance of organisms higher in the food chain such as fish and amphibians as food resources are reduced.

Table 2.3. Aquatic invertebrate species found to be intolerant to disturbances such as sedimentation

Order	Family
Diptera (aquatic flies)	Athericidae
	Blephariceridae
	Deuterophlebiidae
	Dixidae
Megaloptera (hellgrammites and alderflies)	Corydalidae
Trichoptera (caddisflies)	Calamoceratidae
	Goeridae
	Lepidostomatidae
	Odontoceridae
	Rhyacophilidae
	Uenoidae
Ephemeroptera (mayflies)	Ameletidae
	Ephemerellidae
	Isonychiidae
	Leptophlebiidae
Plecoptera (stoneflies)	Capniidae
	Chloroperlidae
	Leuctridae
	Peltoperlidae
	Perlidae
	Pteronarcyidae
Coleoptera (aquatic beetles)	Amphizoidae

Source: Harrington and Born, 2000.Water Quality Objectives

2.3.3 Amphibians and Reptiles

Suspended sediment and/or sedimentation may also adversely impact amphibians and reptiles that utilize the sloughs for portions of their life cycle. Amphibians and reptiles that are federally threatened, endangered, or species of concern that have been observed in the vicinity of Watsonville Sloughs include the following:

- Santa Cruz long-toed salamander-federally endangered
- California tiger salamander-federally threatened
- California red-legged frog-federally threatened
- Southwestern pond turtle-federal and state species of concern

Locations where these species have been observed are given in Figure 2.1 from the California Department of Fish and Game Natural Diversity Rarefind Database.

Effects of sediment and/or sedimentation on amphibians are likely to include reduction in invertebrates as a food source, reduction in feeding due to poor visibility, change in vegetation and potential filling of wetland which would alter habitat available for reproduction, delivery of pollutants that are attached to sediment grains such as pesticides, and asphyxiation of eggs (USFS, 2000 as cited in Center for Biological Diversity, 2001). However, these effects are not well documented for specific species.

2.3.4 Suspended Sediment and Turbidity Impact Levels

A summary of concentration ranges and resulting responses (primarily for rainbow trout) was given above in Section 2.3.1. Based on those concentration ranges, the following levels were chosen to categorize suspended sediment and turbidity levels measured in this study.

- **up to 2 NTU or 10 mg/L**: not likely to adversely affect fish and invertebrates
- **up to 20 NTU or 100 mg/L**: potential change in behavior and/or slight decrease in survival
- **up to 200 NTU or 1,000 mg/L**: stress, physiological changes, and potentially lethal effects

It is important to point out that these ranges are only being used to assist with identifying suspended sediment and turbidity levels that may adversely affect aquatic organisms. As previously mentioned, the extent of adverse effect from these studies was the result of a combination of experimental factors. Additional conditions in the Sloughs such as dissolved oxygen, temperature, duration, food availability and presence of other pollutants could alter the magnitude of the aquatic organism's response to suspended sediment or turbidity. Additionally, non-salmonid species present in the upper portions of the sloughs may actually tolerate higher concentrations; however, until specific studies are conducted on these species, we must rely on the results of studies such as those summarized above.

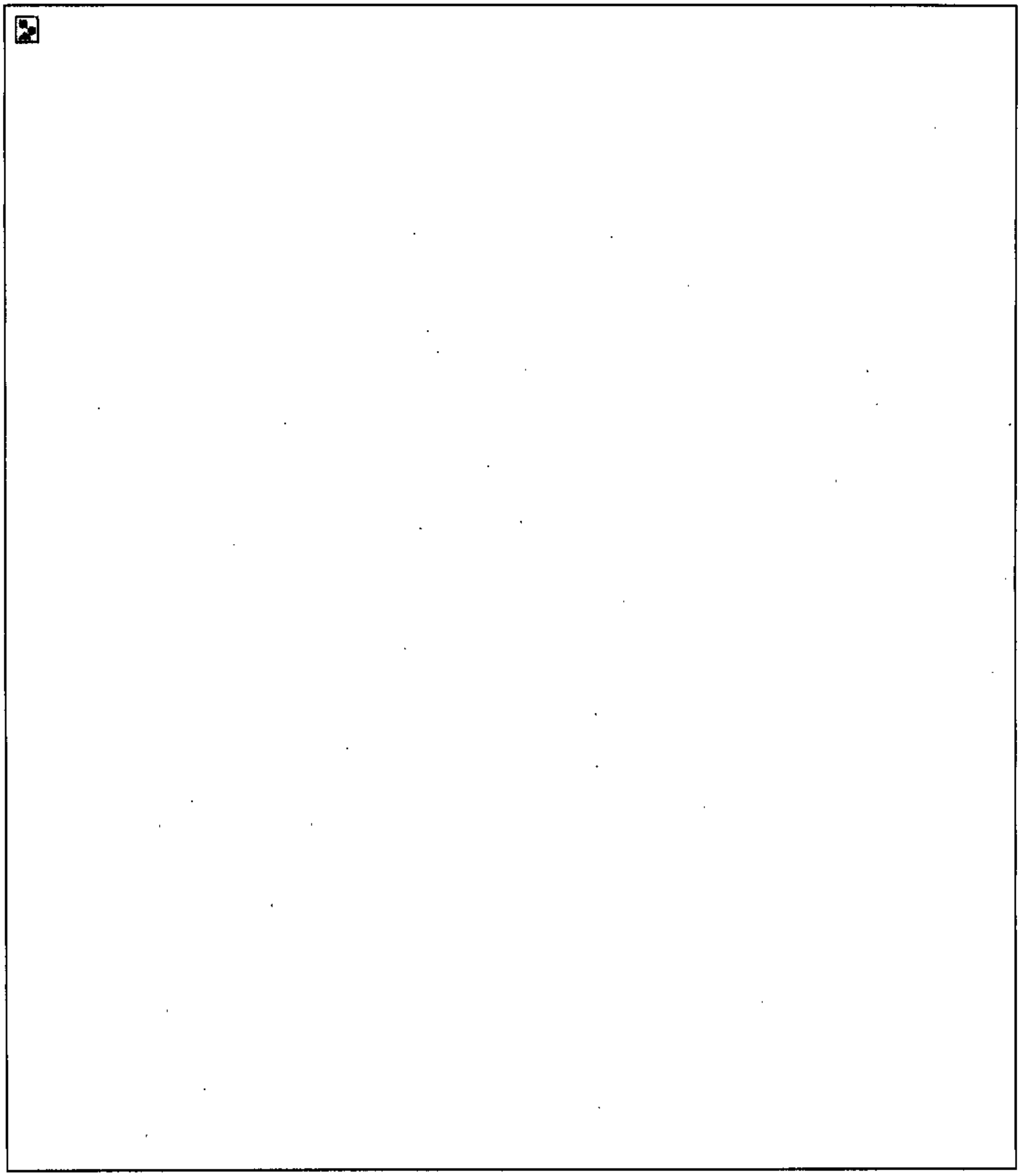


Figure 2.1 Observations of fish, reptile, and amphibian species of concern. California Department of Fish and Game Natural Diversity Database RareFind, Version 3.0.5, July 3,2004.

3 Review of Previous Studies

A number of water resources management and environmental studies have recently been completed in the Watsonville Sloughs area. The primary studies include:

- *Watsonville Sloughs Watershed Conservation and Enhancement Plan* (Swanson Hydrology & Geomorphology, 2003)
- *Pajaro River Watershed Water Quality Management Plan* (Applied Science and Engineering Inc., 1999)
- *Patterns of aquatic toxicity in an agriculturally dominated coastal watershed in California* (Hunt et al., 1999)
- *Water Resources Management Plan for Watsonville Slough System Santa Cruz County* (Questa Engineering Corporation, 1995)
- *State Mussel Watch Program* (State Water Resources Control Board, 1977-2000)
- *Toxic Substances Monitoring Program* (State Water Resources Control Board, 1978-2000)

Additional water quality monitoring has also been conducted in the Watsonville Sloughs system by the following organizations:

- Santa Cruz County Environmental Health
- Santa Cruz County Public Works
- City of Watsonville
- Central Coast Regional Water Quality Control Board
- Pajaro Valley Water Management Agency
- University of Santa Cruz - Marc Los Huertos
- Watershed Institute (1995-1997) - John Oliver
- Santa Cruz County Resource Conservation District
- Coastal Watershed Council

Numerous Environmental Impact Statements and Environmental Impact Reports have also been completed for various projects in the area, such as the Buena Vista Landfill and the Pajaro Valley Unified School District new high school near Struve and Harkins Sloughs that is currently under construction. These reports provide useful background information about the area and often involve extensive surveys of wildlife and plants, but do not contain detailed water quality data pertaining to sediment and/or sedimentation rates.

Table 3.1 summarizes the type of data and number of sites sampled in previous water quality studies for Watsonville Sloughs.

Table 3.1 Summary of previous water quality studies for Watsonville Sloughs

Project Agency		# sites in Watsonville Sloughs	Fecal Coliform	*E.Coli*	TSS	Turbidity	pH, temp, cond/salinity	DO	Nutrients	Pesticides	Metals	Oil & Grease	Water Depth	Chloride
Swanson Hydrology and Geomorphology (report 2003)*	YSI data loggers	4					X	X					X	
	Water depth	5											X	
	Vertical profiles	3 (above/below each site)					X (no pH)	X	X				X	
Hunt et al. (report 1999)*		4								X				
Questa Engineering Corporation (report 1995)*		10				X	X			X	X	X		
State Mussel Watch (sampling 1982 to 1993)		5								X	X			
Toxic Substance Monitoring Program (sampling 1980 to 1992)		7								X	X			
Santa Cruz County Env. Health		22	X (16 sites)	X (1 site)	X (4 sites)	X (8 sites)	X	X	X	X	X			X
Santa Cruz County Public Works Buena Vista Landfill NPDES monitoring (sampling 1992 to 2002)		4			X		X					X		X
City of Watsonville (sampling 1996 to 1998)		6			X	X	X	X	X					X
Watershed Institute-John Oliver (sampling 1995 to 1997)		3				X	X	X	X					
CCRWQCB - Metals, Oil & Grease, Pesticide (study 2002)		11								X	X	X		
PVWMA (sampling 1994 to present)	Diversion Project NPDES monitoring	5	X (4 sites)		X	X	X	X	X	X (2 sites)	X (2 sites)	X (1 site)	X (3 sites)	
	Other	5			X	X	X		X					X
Central Monterey Bay Wetlands Project - Coastal Watershed Council and Santa Cruz & Monterey Resource Conservation Districts (sampling July 2000 to June 2001)		10				X	X	X	X					
UCSC - Marc Los Huertos et al. (sampling October 2000 to September 2001)		2					X	X	X					

red text highlights data that pertain to suspended sediment and turbidity

3.1 Sediment Data

The California 303d listing of Watsonville Slough for "sedimentation/siltation" was based on a study by Applied Science and Engineering Inc. (1999), "The Pajaro River Watershed Water Quality Management Plan." However, no monitoring in Watsonville Sloughs was conducted for this study, although there was a review of previous sediment data collected by the Pajaro Valley Water Management Agency, City of Watsonville, County of Santa Cruz, and Questa Engineering Corporation. Despite these monitoring efforts, there are limited data upon which to base a TMDL for suspended sediment concentrations and sedimentation rates. Limitations of sediment data collected in previous studies in relation to TMDL development include:

- The TSS (total suspended sediment) method, which analyzes an aliquot of the entire water sample, used in previous studies tends to underestimate the total suspended sediment concentration. The SSC (suspended sediment concentration method, in which the entire sample is analyzed for sediment, produces a closer estimate of actual suspended sediment concentration (Gray et al., 2000).
- No data were collected on sedimentation rates.
- No data were collected on subsidence rates.
- No discharge measurements were taken, therefore calculation of sediment loads was not possible.
- Most of the data collected did not involve storm monitoring, during which the majority of sediment loading is likely to occur.

Several of the previous studies, in particular Swanson Hydrology and Geomorphology (2003) and Questa (1995), have described Watsonville Sloughs as a low gradient, sluggish system, with land subsidence occurring in many places, and indicate that sedimentation may be a problem. Questa Engineering Corporation (1995) concluded that sedimentation in the sloughs was a major water quality problem because deposited sediments "obstruct and alter drainage patterns, reduce water clarity, blanket vegetation and aquatic organisms, and transport attached nutrients and pesticides into the receiving waters." The study also concluded that agricultural lands were the primary source, based on erosion estimates determined by the Universal Soil Loss Equation, although some erosion also occurred as a result of urban and rural development. However, only indications as to the nature of the sedimentation problem have been made, and no data have actually been collected to determine actual sedimentation rates or the direct effect on beneficial uses.

Questa Engineering Corporation (1995) also conducted an erosion study using thee Universal Soil loss equation (USLE) and estimated that the highest rates of erosion were most likely to occur in Harkins and Gallighan Slough. Results of USLE should be used only as an estimate of the relative amount of sediment loss and are not an accurate prediction for actual sediment loss. Actual sediment loss would need to be verified by field observations and measurements (Trimble and Crosson, 2000) that are not within the scope and budget of this project. The results of the study are summarized in Table 3.2.

Table 3.2 Results of USLE study by Questa Engineering Corporation (1995)

Waterbody Name	Estimated Erosion (tons/acre)	Estimated Sediment Loss (tons/year)	Percent of Estimated Total Annual Sediment Loss
Gallighan	2.7	3731	32.3 %
Harkins	1.2	6543	56.6 %
Hanson	0.7	230	2.0 %
West Branch	0.3	182	1.6 %
Struve	0.1	101	0.9 %
Watsonville	0.4	766	6.6 %

Suspended sediment and turbidity data from previous studies were retrieved and examined to identify possible areas where sediment problems may exist. The site codes and locations are given in Table 3.3. The average for TSS concentration and turbidity values from previous studies are summarized in Table 3.4. The highest average TSS concentrations were measured at the 'BUE' sites located near Buena Vista Landfill in the Gallighan and Harkins Slough watershed. It should also be noted that the monitoring of 'BUE' sites was conducted during storm events by the County of Santa Cruz Public Works Department as part of the NPDES program. Average TSS data for all of the sites were less than 1,000 mg/L, with the exception of 2 of the 'BUE' sites, BUE-SP1 and BUE-SW1. For turbidity, the highest levels on average were measured at the Hanson Slough sites. The Watershed Institute conducted this monitoring during the rainy season with the objective of determining the effectiveness of restoration efforts. Turbidity averages were less than 200 NTU with the exception of HAN-004 and HAN-005.

Further analysis of sediment data from previous studies is presented in Figure 3.1 and 3.2. Median TSS values from all sites were was less than 1,000 mg/L. Median turbidity values from all sites except for the upper two Hanson Slough sites were less than 200 NTU. Sampling during storm events may have produced higher results.

Short term levels less than 1,000 mg/L and 200 NTU that were measured in previous studies would not generally be expected to have a lethal effect on fish in Watsonville Sloughs. With the exception of samples from the 'BUE' sites and Hanson Slough sites, the sediment values from previous studies are not alarming and could easily result for either an impaired watershed or an intact one. During storm events, even natural watersheds can have comparable numbers.

Table 3.3 Site code indices for previous studies

Site Code	Location
WAT-PAJ	Watsonville Slough mouth at confluence with Pajaro River Lagoon
WAT-SHE	Watsonville Slough at Shell Rd.
WAT-AND	Watsonville Slough at San Andreas Rd.
WAT-HSD	Watsonville Slough downstream of Harkins Slough confluence
WAT-HAR	Watsonville Slough at Harkins Slough Rd.
WAT-HSU	Watsonville Slough upstream of Harkins Slough confluence
WAT-RWY	Watsonville Slough at railroad crossing
WAT-LEE	Watsonville Slough at Lee Rd.
WAT-WAL	Watsonville Slough at Walker Rd.
BEA-CON	Beach Road Ditch at confluence with Watsonville Slough
BEA-SHE	Beach Road Ditch at Shell Rd.
HAR-INF	Harkins Slough Diversion Project influent
HAR-CON	Harkins Slough confluence with Watsonville Slough
HAR-HAR	Harkins Slough at Harkins Slough Rd.
GAL-BUE	Gallighan Slough and Buena Vista Dr.
GAL-LOW	Lower Gallighan Slough
GAL-HAR	Gallighan Slough near confluence with Harkins Slough
HAN-006	Hanson Slough restoration project-lower site
HAN-005	Hanson Slough restoration project-middle site
HAN-004	Hanson Slough restoration project-upper site
BUE-SP1	Buena Vista Landfill NPDES monitoring site
BUE-SW1	Buena Vista Landfill NPDES monitoring site
BUE-SW2	Buena Vista Landfill NPDES monitoring site
BUE-SW3	Buena Vista Landfill NPDES monitoring site
STR-LEE	Struve Slough at Lee Rd.
STR-HAR	Struve Slough at Harkins Slough Rd.

Table 3.4 Sediment data averages from previous studies. Note: utility of these averages is limited by factors previously outlined in this section.

Site Code	TSS Average (mg/L)		Turbidity	
	Average (mg/L)	# of samples	Average (NTU)	# of samples
WAT-PAJ			177	2
WAT-SHE	82	43	109	68
WAT-AND	85	73	80	94
WAT-HSD	372	17	118	17
WAT-HAR	309 (4*)	3		
WAT-HSU	145 (117*)	21	64	21
WAT-RWY	71	14	99	24
WAT-LEE	60	3		
WAT-WAL	6	2	15	4
BEA-CON	58	2	15	2
BEA-SHE	241	3		
HAR-INF	71	19	73	19
HAR-CON	67	102	103	131
HAR-HAR	79	15	104	26
GAL-LOW	42	1	51	3
GAL-HAR	122	2		
GAL-BUE			71	2
BUE-SP1***	13,938	15		
BUE-SW1***	1,407	18		
BUE-SW2***	661	18		
BUE-SW3***	390	18		
HAN-4**			1,564	9
HAN-5**			922	9
HAN-6**			200	9
STR-LEE	120 (13*)	2	28	19
STR-HAR	0	12		

*Average not including one flagged sample with possible error

**These sites are located at a restoration site on Hanson Slough. Site 6 is lower, Site 5 is middle, and Site 4 is upper. Samples were taken during the 95-96 rain season. High levels at Site 6 were attributed to streambed erosion that was the result of rerouting due to placement of a physical berm.

***TSS data collected during storm event monitoring by Santa Cruz County Public Works Department.

3.2 Hydrologic Data

The primary hydrologic data found in previous studies were automatic stage data collected by Swanson Hydrology and Geomorphology and the PVWMA. Table 3.5 lists the hydrologic metadata from these two studies. To date, no studies have been found that have measured stream discharge. The most probable reason for the lack of existing discharge data may be due to the sluggish nature of the Watsonville Sloughs system with limited water circulation occurring during most of the year. Pump records are available for the two pump stations at Shell Road and at the Harkins Slough diversion project.

Table 3.5 Previous studies hydrologic metadata.

Site Code	Data Type	Agency	Dates
WAT-PAJ	Continuous stage*	Swanson	Installed 28 Feb 2001
WAT-SHE	Continuous stage*	Swanson	Installed 13 Mar 2001
WAT-SHE	Continuous stage**	Swanson	31 Mar 2001 to 16 Apr 2001
WAT-SHE	Continuous stage**	PVWMA	*present*
WAT-BEA	Continuous stage**	Swanson	15 Feb 2001 to 30 Mar 2001
WAT-AND	Continuous stage**	PVWMA	present
WAT-RWY	Continuous stage*	Swanson	Installed 7 Mar 2001
WAT-RWY	Continuous stage*	PVWMA	present
WAT-FOR	Continuous stage**	Swanson	15 Feb 2001 to 30 Mar 2001
HAR-CON	Continuous stage*	PVWMA	present
HAR-RWY	Continuous stage*	Swanson	Installed 20 Apr 2001
HAR-RWY	Continuous stage*	PVWMA	present
HAR-HAR	Continuous stage*	Swanson	Installed 20 Apr 2001
HAR-HAR	Continuous stage**	Swanson	8 May 2001 to 31 May 2001
STR-HWY	Continuous stage**	Swanson	30 March 2001 to 8 May 2001

*pressure transducer data logger
**YSI multi-probe data logger

In a study by Questa Engineering Corporation (1995), a water budget analysis was conducted for Watsonville Sloughs although no discharge measurements were made. The runoff portion of the analysis was performed using the TR-55 computer model developed by the USDA Soil Conservation Service, which determines a runoff relationship based on rainfall totals, vegetative cover, cropping technique, soil properties, and the amount of impervious surface. The water budget analysis resulted in estimates of runoff and outflow for the Watsonville Sloughs system. The precipitation, runoff, and outflow estimates are presented in Table 3.6.

Table 3.6 Selected results of water budget analysis for Watsonville Slough system by Questa Engineering Corporation (1995)

Month	Precipitation (acre-feet)	Surface Runoff (acre-feet)	Outflow (acre-feet)
Sep	0.3	27.5	174.8
Oct	1.1	100.7	198.6
Nov	3.25	428.6	431.6
Dec	3.25	767.5	904.4
Jan	4.5	1107.0	1399.0
Feb	3.75	1075.4	1619.0
Mar	4.5	1107.0	1702.6
Apr	1.5	342.5	809.8
May	0.4	67.6	90.4
Jun	0	0	72.8
Jul	0	0	69.2
Aug	0	0	38.0
Total	22.55	5023.8	7510.3

3.3 Spatial Data

A variety of vector and raster based geographic information system (GIS) data exist and include the Watsonville Sloughs area. Digital Elevation Models (DEMs) are available from USGS in various resolutions. Stream layers and watershed boundaries are also available from USGS. Many of these layers were made available as part of the Water Analysis Tool for Environmental Review (WATER) dataset, which is distributed via the web from the Central Coast Joint Data Committee. City, county, and state governments usually make other layers such as roads, railways, and parcels. For instance, data is available from the California Spatial Information Library at: http://www.gis.ca.gov/data_index.epl
For the Watsonville Sloughs area, these layers are available from the County of Santa Cruz Planning Department.

A detailed review of existing land use/land cover data for the region is included in a report on the history of mapping in California's central coast region (Newman et al., 2003). The Newman et al. data were used as base maps in this study and were also used to calculate percent land use coverage, which is detailed in Section 4.2.

Spatial data for Watsonville Sloughs were included in previous studies by Questa Engineering Corporation (1995) and Swanson Hydrology and Geomorphology (2003). The spatial data presented in the two reports are summarized below:

Questa Engineering Corporation (1995):

- Roads layer
- Streams/sloughs layer
- Generalized vegetation map
- Slough bottoms vegetation map
- Watsonville Slough and sub-watershed boundaries map
- Channel conditions and drainage features map
- Areas of groundwater recharge map
- Hydrologic soil groups map
- Existing waste discharge facilities map

The details of any spatial data analysis performed were not included in report.

Swanson Hydrology and Geomorphology (2003):

- Location map with DEM, roads, railway, and streams layers
- Planning area boundaries map
- Watsonville Slough and sub-watershed boundaries map
- Soil Association map with layer from WATER dataset
- Geologic map with layer from USGS open-file report 97-489
- Channel characteristics and instrument location map
- Extent of flooding and control structures map
- Plant and Wildlife species of concern map
- Public access locations and recreation map
- Previous water quality site locations map
- Aerial photography (various years)

The details of any spatial data analysis performed were not included in report.

3.3.1 DEM and Watershed Boundaries

A DEM for Region 3, based on USGS data, was recently produced by CCoWS. Multiple USGS Spatial Data Transfer Standard 30-meter DEMs (STDS) were mosaicked using Tarsier Software developed by Watson and Rahman (2003). This DEM process is detailed in Newman et al. (2003). From this DEM, sub-watershed boundaries were determined for Watsonville Sloughs and are given in Table 1.1.

3.3.2 Land Use Land Cover

A spatially detailed land use land cover map for the entire Region 3 was recently created by CCoWS and is illustrated in Appendix B. The land use classification was completed using Landsat Enhanced Thematic Mapper (ETM) multi-band imagery and mosaicked slope data. The details of the classification and processes used to make this map can found at: http://science.csumb.edu/~ccows/2003/region3_lulc/ and are also briefly discussed in Section 4.2. Accuracy could be improved for specific smaller areas similar in size to Watsonville Sloughs.

A detailed multi-source data layer that includes the Watsonville region was recently produced by the Fire and Resource Assessment Program (FRAP). This 100 m resolution data layer, in GRID format, was derived from multiple sources and merged into a common classification system (California Wildlife Habitat Relationships, CWHR). Area and percent of each land use type within the Watsonville Sloughs watershed were calculated from this data layer and are given in Section 4.2.

4 Methodology & Site Locations

4.1 Field Sampling Plan

The sampling plan for sediment works toward an answer to the following question:

1. Does sediment adversely impact the beneficial uses of the Watsonville Sloughs?

Many beneficial uses are listed for Watsonville Sloughs (REC1, REC2, WILD, WARM, SPWN, BIOL, RARE, EST, COMM, SHELL). However, based on previous studies, it is most efficient to base the sediment sampling plan around a more focused group of beneficial uses: SPWN, RARE, EST, and WARM. This results in specific sampling questions:

> 1a. Do sediment **concentrations** reach levels that may be high enough to adversely impact SPWN, RARE, EST, and/or WARM, given the current understanding of sediment impacts on these beneficial uses?
>
> 1b. Do sediment loads cause benthic **accumulation** of sediment that may lead to an adverse impact on SPWN, RARE, EST, and/or WARM (given current understanding of sediment impacts on benthic habitat)?
>
> 1c. If yes to either 1a or 1b, what are possible sources?

As described in Section 3, previous studies have described Watsonville Sloughs as a low gradient, sluggish system, with land subsidence occurring in many places, and indicate that sedimentation may be a problem. A conceptual diagram of the hypothesized functioning of the Watsonville Sloughs system with respect to the way in which land use changes and subsidence may or may not lead to sediment problems within the sloughs is presented in Figure 4.0. The sediment monitoring plan for this study dealt with the two issues outlined in red in Figure 4.0, suspended sediment concentrations and accumulation of slough sediments.

The sediment monitoring plan involved 2 approaches:

1) Suspended sediment concentration & turbidity level sampling
2) Investigation of Sedimentation

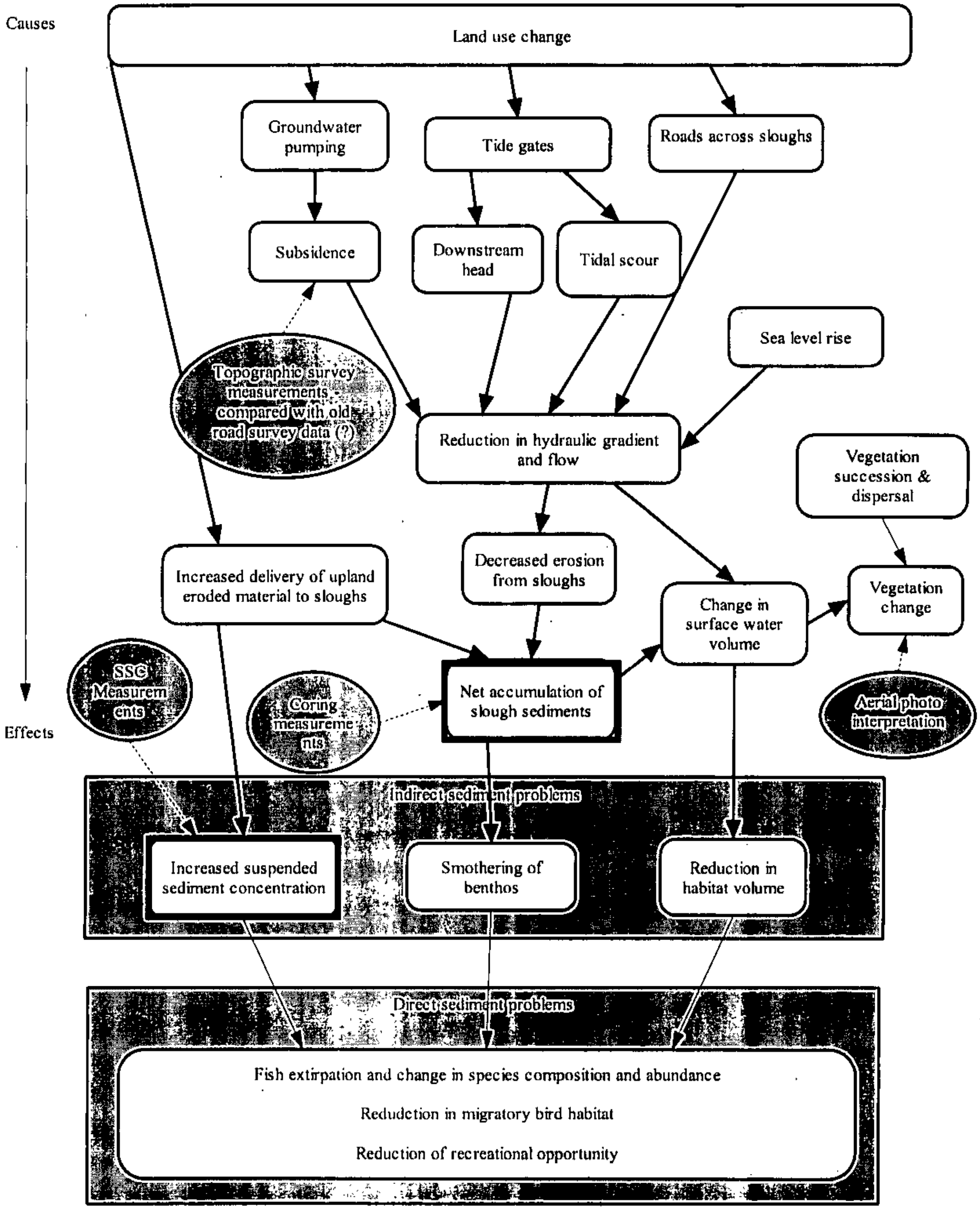


Figure 4.0 Conceptual diagram of the hypothesized functioning of the Watsonville Sloughs system with respect to the way in which land use changes may or may not lead to sediment problems within the slouohs.

4.1.1 Suspended Sediment

The first method for investigating sediment impairment involved synoptic monitoring to determine suspended sediment concentrations and turbidity levels. This coincided with the exceedance monitoring for pathogens and involved 2 monitoring campaigns at 13 sites throughout the watershed. The first monitoring campaign took place during the rainy season (mid-February to mid-March), and the second monitoring campaign was completed during the dry season (mid-June to mid-July). Each monitoring campaign consisted of 5 synoptic sampling runs within a 30-day period.

Samples were collected and analyzed by CCoWS for suspended sediment concentration (SSC) and turbidity. Detailed methods for sample collection and analysis are given in the quality assurance and field sampling plan for the project (Hager et al., 2003). When possible, discharge measurements were also taken, but this was only possible at sites in the upper watershed during storm events. The extent of potential impairment was determined by the number of samples whose suspended sediment concentrations were higher than the concentration ranges presented in Section 2.3, that were shown to have a negative impact on steelhead/rainbow trout, which may occupy the lower reach of Watsonville Slough.

4.1.2 Sedimentation

The second method for investigating sediment impairment involved watershed reconnaissance and estimations of sedimentation and subsidence rates.

The goal of the reconnaissance was to make field observations and document areas with visible sediment accumulation. In general this reconnaissance took place around the 13 primary sampling sites. The reconnaissance involved visual slough channel inspections for features and conditions such as:

- recent (unvegetated) sediment accumulation
- gully, sheet, or rill erosion
- channel instability and/or visible bank erosion
- sediment plumes
- obvious sources of sediment supply such as ditches, pipes, and drains
- changes in bed level at staff plate locations
- depositional features such as islands or bars
- changes in substrate
- overbank sediment deposits
- sediment accumulation in culverts or on road crossings

- buried aquatic vegetation

In years will low rainfall totals and low intensity storms, signs of sedimentation may not be apparent given the episodic nature of sedimentation. This limitation to the reconnaissance approach was recognized at the start of the project. An ideal approach would have involved repeated channel cross-sections and the use of reference markers driven into the substrate and determination of sediment accumulation at the markers over a long period of time such as 5 to 10 years. However, that was not possible given the short time frame of the study. With only reconnaissance during the current study year, the extent of impairment throughout the entire watershed could not be determined. An amendment was therefore granted by the Regional Board in the latter part of this project to examine long-term sedimentation trends in the sloughs by determining past and present sedimentation rates through the dating of sediment cores. Subsidence rates were also estimated in order to determine whether there is net subsidence or aggradation (relative to the NGVD) occurring in the sloughs.

University of California Berkeley was subcontracted by the Foundation of CSUMB to collect and analyze sediment cores. Sediment cores, approximately 3 m in depth, were taken at 2 locations in the lower portion of Watsonville Slough. One core was analyzed in great detail using a variety of methodologies in order to construct core chronology. Sediment core chronology was constructed using a combination of dating techniques including accelerator mass spectrometry radiocarbon dating, pollen analysis, diatom analysis, sediment chemistry (including anthropogenic lead), and lead-210. Cores were also analyzed for water, organic and carbonate content, magnetic susceptibility, and grain size. Chronology of sediment cores was used to determine sedimentation rates for several time periods including the following: pre-European (pre-1800), European (post-1800), and Modern (last 50 years).

Accelerator mass spectrometry radiocarbon dating based on the radioactive decay of ^{14}C was used to obtain a date for the pre-European period (pre-1800). The type of material dated was charcoal.

Based on the likely dates of introduction into the Watsonville area, the first appearance of non-native pollen, such as *Erodium cicutarium* (storksbill), *Rumex acetosella*, (sheep sorrel), *Plantago lanceolata* (English plantain) and *Eucalyptus globulus* (blue gum) in sediment cores were used as chronological markers. An extensive literature review was conducted to identify likely dates of introduction. The introduction dates from the historical review provided time ranges for European Period (post-1800).

Sediment chemistry, in particular anthropogenic lead, was also useful in constructing core chronology. Construction of roads and the use of automobiles run on leaded gasoline resulted in an increase in lead concentration in the early 1900s. Lead concentrations peaked in the 1970s and then began to decline in the late 1970s following the Clean Air Act, which mandated the phase out of leaded gasoline. Detection of this lead spike in combination with Lead-210 analysis provided dates for the Modern Period.

The details of the methods used by UC Berkeley are given in Appendix H-UC Berkeley Coring Study.

Aerial photo interpretation was conducted to document land use, vegetation, and channel changes in the watershed as well as to assist in the identification of potential coring sites at locations that had not been previously modified. Digital aerial imagery from 1929, 1931, 1935, 1940, 1952, 1954, 1957, 1962, 1972, 1980, 1992, and 2001 was obtained from the University of California Santa Cruz Map Room and from the County of Santa Cruz Public Works Department. All images were georeferenced using Microimages TNTMips software. Imagery was then imported into ArcMap for analysis, which involved annotation of images to document change throughout time.

In addition to determining sedimentation rates, subsidence rates were also estimated. Questa (1995) and Swanson Hydrology and Geomorphology (2003) both noted that subsidence is occurring in several areas throughout the watershed. One aspect of determining the extent of sedimentation impairment in relation to habitat volume is to determine net sediment accumulation. This requires estimates of subsidence rates of the sloughs. Subsidence rates were estimated by comparing early survey records in known subsidence areas to current elevation data.

The first step in the process involved a search for early survey records. Types of suitable records included permanent benchmarks, road construction and re-alignment surveys, and detailed topographic surveys.

In subsidence areas where suitable data were found, new surveys of the area were completed. Surveys were conducted using high accuracy digital theodolite survey equipment (TOPCON GTS 211D Electronic Total Station). The rate of subsidence was then determined by the change in elevation of the two surveys.

4.2 Sampling Locations

4.2.1 Land Cover Description for Watsonville Sloughs

The Watsonville Sloughs watershed is comprised of 5 sub-watersheds: Watsonville Slough, Harkins Slough, Gallighan Slough, Hanson Slough, and Struve Slough. A total of 13 primary sampling sites were selected throughout the 5 sub-watersheds and are shown in Figure 4.2. Figure 4.1 shows land cover data for the area as well as sub-watershed boundaries. The land cover data layer for the Watsonville Sloughs watershed and sub-watersheds was created by CCoWS in 2003 using multi-band imagery, 30-meter resolution Landsat Enhanced Thematic Mapper (ETM) scenes from 1999 through 2002. The raster format data layer was achieved using an unsupervised K-Means classification that is performed using TNTMips Microimages GIS software. Details of the entire classification process, including verification techniques are given in Newman et al., 2003. Table 4.1 lists class categories that were used in the classification.

Table 4.1 CCoWS Land Cover Categories

Grassland	Predominantly annual grasses (grazed and un-grazed); some dune. Also includes some areas of irrigated row crop land.
Shrub	Includes all chaparral and other scrublands. Also includes some coastal marsh.
Oak Woodland / Mixed Forest	Includes mixed woodlands and forests (e.g. oak, toyon, madrone, eucalyptus), urban trees, and riparian forest (e.g. alder, cottonwood, willow, sycamore). Also includes some overlap with conifer classes.
Mixed Conifer/Montane	Predominantly conifer and oak, urban forest, conifer with under story.
Crop	Includes mainly irrigated row crops (e.g. vegetables, strawberries) and irrigated feed crops (e.g. alfalfa). Also numerous dryland crops.
Golf / Green Crop	Predominantly golf turf grass areas and some very green crops such as lettuce.
Vineyard / Berries	Includes structured rows of grapes or berries.
Dry Soil	Reflective soils include some dryland farming, dry lakebed, dry riverbed, and mining.
Urban	Asphalt, concrete, industrial, commercial, and residential areas.
Water	Bodies of water (e.g. reservoirs and lakes).

The area and percent of each land use category within the 5 sub-watersheds are given in Table 4.2. The Sloughs watershed boundary and sub-watershed boundary vectors for Watsonville Sloughs were determined by CCoWS, using Tarsier terrain modeling software (Watson and Rahman 2003). Sub-watershed areas and total area of each land use type were then determined using TNTMips Microimages GIS software. The sub-boundary vectors were used to extract the sub-watershed areas (Watsonville Slough, Harkins Slough, Gallighan Slough, Hanson Slough, and Struve Slough) from the land use data raster layer. The raster format extractions were then converted into vector format in order to calculate the percent of each land use type for each sub-watershed. During this process, raster pixels were converted into 30 m x 30 m polygons. Each cell/polygon within the vector layer had an area of 900 m^2 and a unique cell value that corresponded to one of the ten land use types. In areas where the neighboring cells had the same value, polygons were merged. Like cell value polygon areas were then summed to determine the area of each land use type within the sub-watershed area. The area of each land use type within a sub-watershed was then divided by the summed area of all land use types in order to determine the percentage of each land use type. The percent difference between sub-watershed area calculated by the Tarsier derived boundary and sub-watershed area determined by the sum of calculated land use areas ranged from 4 to 7%. This difference was due to an overestimate that resulted from whole cells being included at edge locations where the boundary intersected the cell.

A more recent land use data layer for the entire state has been produced by the Fire and Resource Assessment Program (FRAP). The FRAP data layer was derived from multiple sources and merged into a single classification system, California Wildlife Habitat Relationships (CWHR). The FRAP layer uses a wide variety of detailed land use types and may provide a more accurate representation of land uses such as agriculture, urban, and grassland. The CCoWS data layer also provides detailed spatial resolution and may be a more accurate representation of land cover types such as chaparral, woodland, and forest, thus there are certain advantages to each data layer. The area and percent of each land use category within the 5 sub-watersheds determined from the FRAP layer are given in Table 4.2.

Table 4.2 Sub-watershed land use and land cover data by CCoWS and FRAP

CCoWS LULC	Grasslands	Shrub	Oak Woodland / Mixed Forest	Conifer Forest / Montane	Irrigated Row Crop	Golf / Green Crop	Vineyard / Berries	Bare Soil	Urban	Water
Watsonville	2.8%	5.1%	4.8%	8.3%	50.6%	4.4%	2.0%	0.2%	20.5%	1.4%
Harkins	15.4%	19.8%	20.7%	21.6%	14.0%	2.2%	2.4%	0.0%	2.8%	1.2%
Gallighan	14.0%	23.2%	12.5%	21.6%	21.0%	1.4%	3.8%	0.0%	2.6%	0.0%
Hanson	20.1%	12.0%	14.3%	7.4%	41.0%	1.4%	1.7%	0.1%	0.9%	1.1%
Struve	9.4%	10.6%	7.5%	9.7%	22.3%	1.6%	1.4%	1.0%	35.2%	1.3%
Total Study Area	11.1%	14.5%	13.3%	15.7%	27.0%	2.6%	2.3%	0.2%	12.2%	1.1%
FRAP Multi-source	Annual Grassland	Unknown Shrub Type	Coastal Oak Woodland	Unknown Conifer Type	Redwood	Agriculture			Urban	Water
Watsonville	1.0%	2.7%	0.0%	0.1%	0.0%	60.7%			35.4%	0.1%
Harkins	8.6%	24.8%	18.4%	1.0%	5.4%	35.5%			5.9%	0.4%
Gallighan	5.6%	18.8%	14.1%	1.4%	4.1%	48.7%			7.3%	0.0%
Hanson	9.9%	4.9%	0.0%	0.0%	0.0%	85.2%			0.0%	0.0%
Struve	3.0%	5.1%	0.0%	0.1%	0.0%	20.7%			71.0%	0.0%
Total Study Area	5.3%	14.6%	9.6%	0.6%	2.9%	43.4%			23.3%	0.2%
CCoWS (km²)	Grasslands	Shrub	Oak Woodland / Mixed Forest	Conifer Forest / Montane	Irrigated Row Crop	Golf / Green Crop	Vineyard / Berries	Bare Soil	Urban	Water
Watsonville	0.41	0.76	0.71	1.22	7.44	0.65	0.29	0.03	3.02	0.20
Harkins	3.55	4.54	4.75	4.95	3.22	0.49	0.56	0.00	0.63	0.27
Gallighan	0.86	1.42	0.76	1.32	1.28	0.08	0.23	0.00	0.16	0.00
Hanson	0.35	0.21	0.25	0.13	0.71	0.03	0.03	0.00	0.02	0.02
Struve	0.71	0.80	0.57	0.73	1.68	0.12	0.10	0.08	2.65	0.10
Total Study Area	5.87	7.72	7.04	8.36	14.35	1.37	1.21	0.11	6.48	0.59
FRAP Mulit-source (km²)	Annual Grassland	Unknown Shrub Type	Coastal Oak Woodland	Unknown Conifer Type	Redwood	Agriculture			Urban	Water
Watsonville	0.14	0.36	0.00	0.02	0.00	8.24			4.81	0.01
Harkins	1.78	5.15	3.81	0.20	1.13	7.38			1.23	0.08
Gallighan	0.33	1.11	0.83	0.08	0.24	2.87			0.43	0.00
Hanson	0.16	0.08	0.00	0.00	0.00	1.38			0.00	0.00
Struve	0.22	0.37	0.00	0.01	0.00	1.50			5.15	0.00
Total Study Area	2.63	7.07	4.64	0.31	1.37	21.37			11.62	0.09

4.2.2 Suspended Sediment Sampling Sites

The 13 primary sites that were monitored for this project are listed in Table 4.3. The location of these sites are shown in Figure 4.2. Sites were selected based on location within the watershed, land use representation, accessibility, safety, and use as a sampling location in previous studies. A brief description and photographs of each site are given in the following pages.

Table 4.3 Primary Monitoring Sites

CCoWS Site Code	Site Description	CCAMP* Site Code
WAT-PAJ	Watsonville Slough mouth at Pajaro Dunes Colony	
WAT-SHE	Watsonville Slough at Shell Road pump station	305WAT
WAT-AND	Watsonville Slough at San Andreas Road bridge	305WSH
WAT-LEE	Watsonville Slough at Lee Road bridge	305WSW
WAT-HAR	Watsonville Slough at Harkins Slough Road crossing	305WSE
HAR-CON	Harkins Slough confluence with Watsonville Slough (pump station)	305HGS
HAR-HAR	Harkins Slough at Harkins Slough Road crossing	305HAR
HAR-RAU	Harkins Slough upstream of Ranport Road crossing	
GAL-BUE	Galllghan Slough at Buena Vista Road (near landfill exit)	
HAN-HAR	Hanson Slough at Harkins Slough Road crossing	
STR-LEE	Struve Slough at Lee Road crossing	305SSV
STR-HAR	Struve Slough at Harkins Slough Road crossing	305SSE
STR-CHE	Struve Slough at Cherry Blossom Drive	

*Central Coast Ambient Monitoring Project

Figure 4.2 Map showing Watsonville Sloughs project area and primary monitoring sites.

WAT-PAJ

Sampling site WAT-PAJ (Fig. 4.3 -4.4) is located on Watsonville Slough at the confluence with the Pajaro River. Samples were collected just upstream of the confluence, which is accessed through the private Pajaro Dunes Colony. There is no bridge at this location; therefore samples were collected from the right bank. This is the lowermost site for the project and therefore receives all of the runoff from the tributary sloughs. The site is tidally influenced when the mouth of the Pajaro River is open. Adjacent land use is row crop agriculture on the left bank, and a small residential complex exists on the right bank.

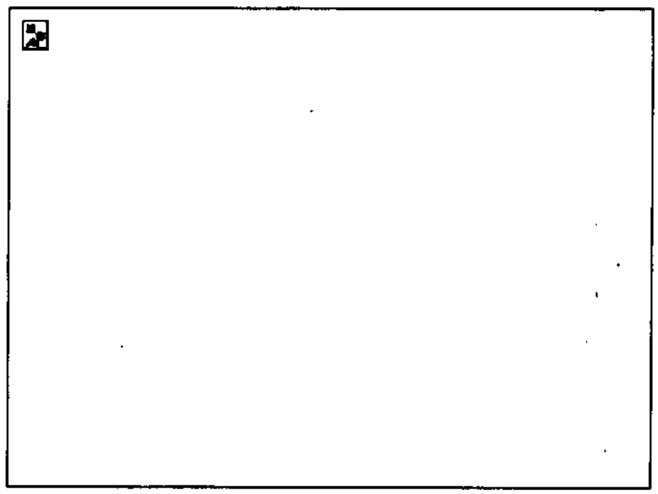


Figure 4.3 Watsonville Slough looking downstream to Pajaro River Lagoon (Photo: J. Casagrande Jul 02).

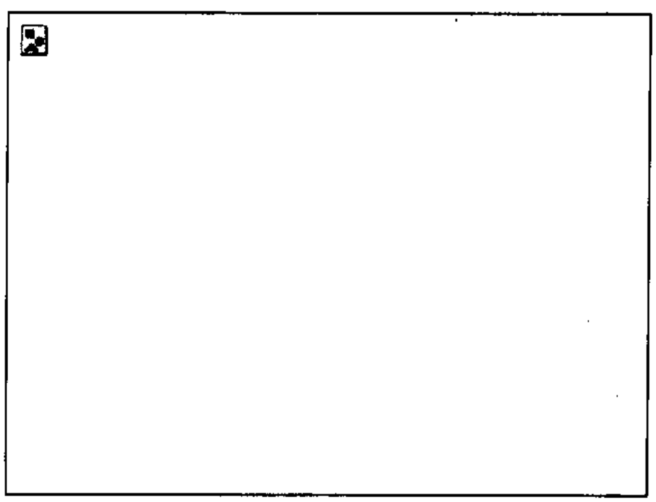


Figure 4.4 Watsonville Slough near Pajaro River looking upstream (Photo: J. Casagrande Jul 02).

WAT-SHE

Sampling site WAT-SHE (Fig. 4.5 - 4.6) is located on Watsonville Slough at Shell Road upstream of WAT-PAJ. Flow at this site is regulated by a pump station, which is operated by the County of Santa Cruz. The pump station and tide gates were installed to allow for cultivation of the fertile lands nearby (Swanson Hydrology and Geomorphology, 2003). The reach below this site is estuarine, whereas the upstream, channelized reach is predominantly freshwater. However, high tide storm surges during major rain events can lead to flooding and reversal in flow direction. Samples were collected on the eastern side of the pump house. Adjacent land use is predominantly row crop agriculture and state park.

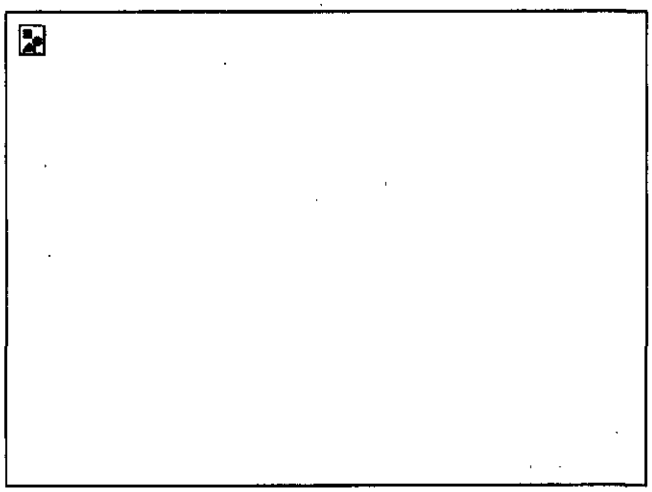


Figure 4.5 Watsonville Slough at Shell Rd. looking downstream (Photo: J. Casagrande Jul 02).

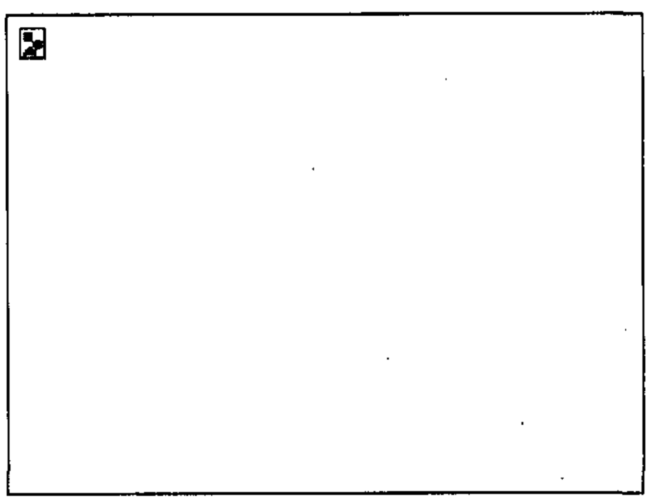


Figure 4.6 Watsonville Slough at Shell Rd. looking upstream (Photo: J. Casagrande Jul 02).

WAT-AND

Sampling site WAT-AND (Fig. 4.7 - 4.8) is located on Watsonville Slough at the San Andreas Road bridge. This site is located just downstream of the confluence with Harkins Slough and upstream of WAT-SHE. Samples were collected immediately upstream of the bridge. The slough is channelized with riparian vegetation on the right bank and row crop agriculture on the left bank. The photographs illustrated in Fig. 4.7 - 4.8 were taken just after a large rain event in December 2002. Storm waters filled the slough channel, and the direction of flow was reversed as water flowed up Watsonville Slough. The reversal in flow was likely either the result of a storm surge in combination with high tide or overflow from the Pajaro River before the sandbar at the mouth had completely breached.

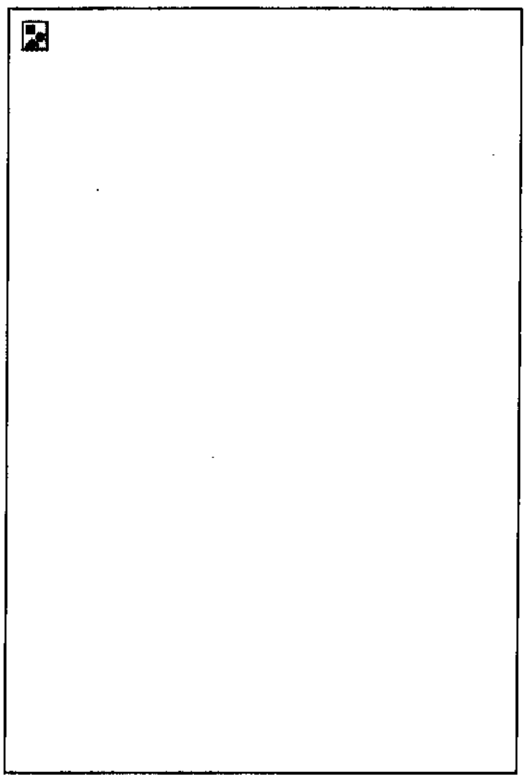


Figure 4.7 Watsonville Slough at San Andreas Rd. looking upstream. Note channel filled with vegetation (Photo: F. Watson Dec 02).

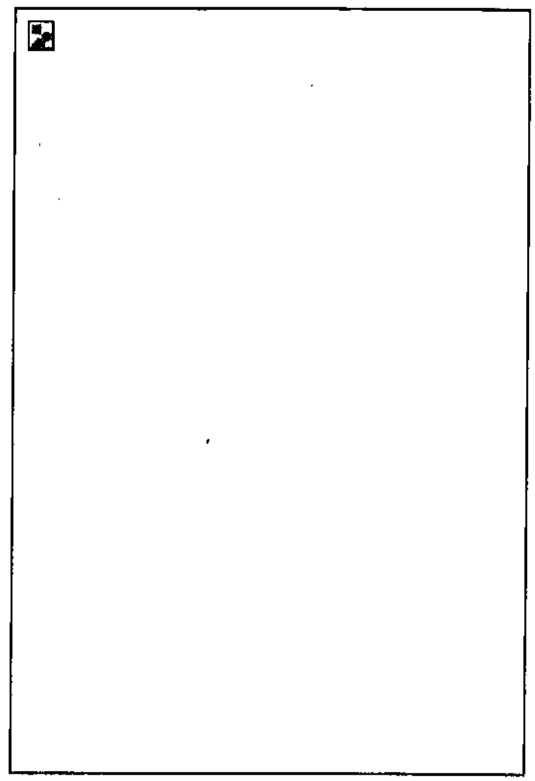


Figure 4.8 Watsonville Slough at San Andreas Rd. looking downstream (Photo: F. Watson Dec 02).

WAT-LEE

Sampling site WAT-LEE (Fig. 4.9 - 4.10) is located on Watsonville Slough at the Lee Road crossing. WAT-LEE is upstream of the confluences with Harkins, Hanson, and Struve Slough and west of Highway 1. Flow is directed through two large culverts as illustrated in Fig. 4.10. Samples were collected immediately upstream of the culverts. Adjacent land use is industry and row crop agriculture.

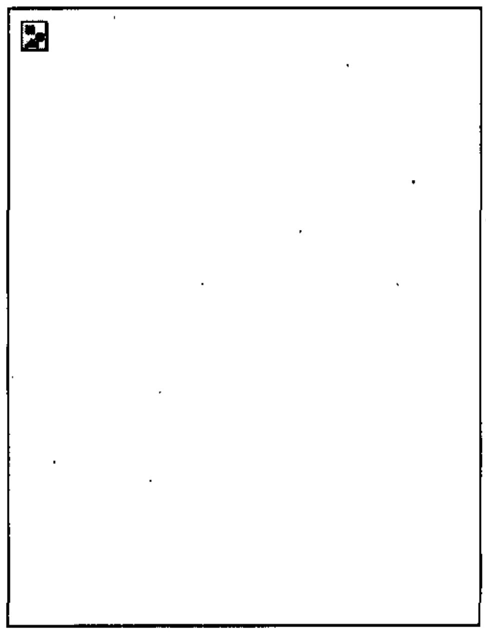


Figure 4.9 Watsonville Slough at Lee Rd. looking upstream (Photo: J. Hager Dec 02).

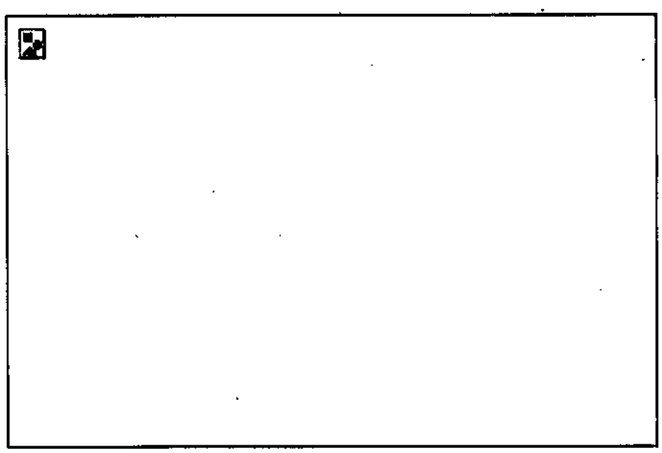


Figure 4.10 Watsonville Slough at Lee Rd. (Photo: F. Watson Dec 02).

WAT-HAR

Sampling site WAT-HAR (Fig. 4.11 - 4.12) is located on Watsonville Slough at the Harkins Slough Road crossing. This is the uppermost sampling location on Watsonville Slough. Land subsidence has lead to the winter closure of Harkins Slough Road, which is often flooded at this site. Samples were collected on the upstream side of Harkins Slough Road. At this site, Watsonville Slough is broad with limited flow and abundant aquatic and riparian vegetation. Adjacent land use is predominantly industry, with limited residential, urban, and agriculture nearby.

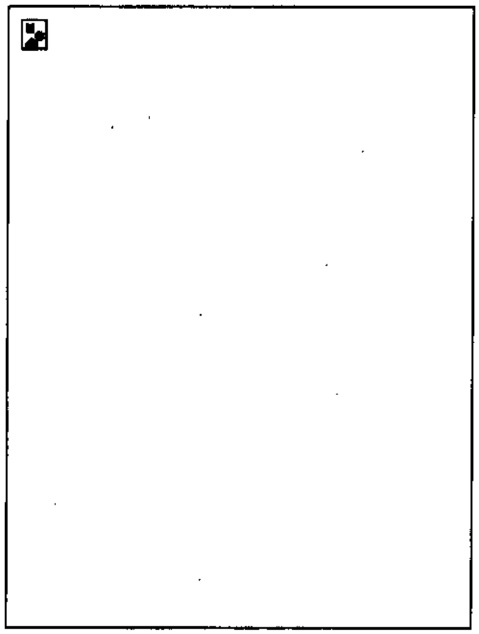


Figure 4.11 Watsonville Slough at Harkins Slough Rd. (Photo J. Casagrande Jul 02).

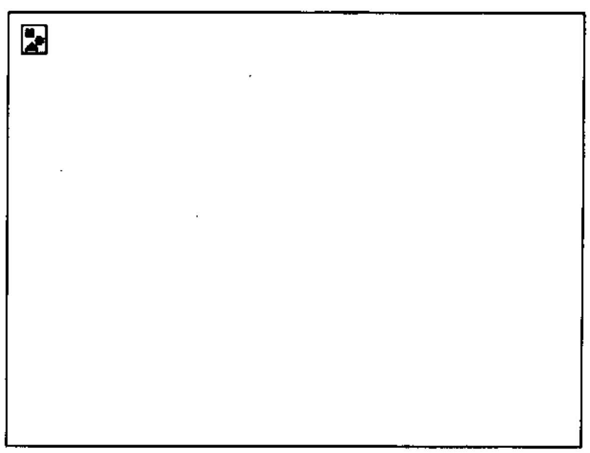


Figure 4.12 Watsonville Slough at Harkins Slough Rd. looking downstream (Photo: J. Hager Feb 03).

HAR-CON

Sampling site HAR-CON (Fig. 4.13 - 4.14) is located on Harkins Slough at the confluence with Watsonville Slough. Flow at HAR-CON is regulated by a pump station, which is currently operated by the PVWMA. The site is the location of a diversion project designed to prevent salt-water intrusion and to supply freshwater to the agricultural lands in the lower watershed. Winter flows are diverted from Harkins Slough and pumped to nearby percolation ponds for ground water recharge. Samples were taken immediately upstream of the pump station. Adjacent land use is predominantly row crop agriculture.

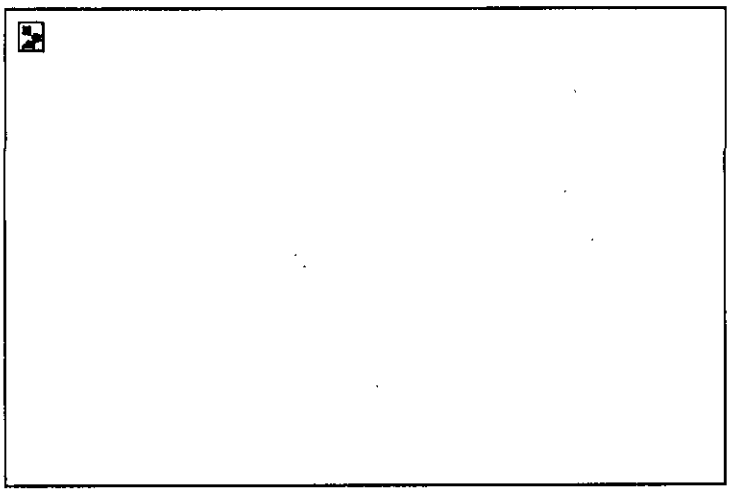


Figure 4.13 Harkins Slough at PVWMA diversion project (Photo: F. Watson Sep 02).

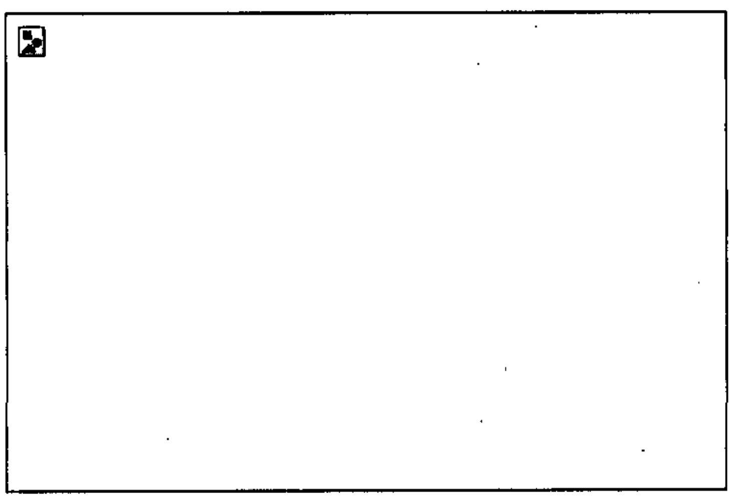


Figure 4.14 Harkins Slough at confluence with Watsonville Slough looking upstream. Note: ponding at right is flow from Watsonville Slough spilling upstream into Harkins Slough (Photo: F. Watson Dec 02).

HAR-HAR

This sampling site (Fig. 4.15 - 4.16) is located on Harkins Slough at the Harkins Slough Road crossing. This site is located just upstream of the confluence with Gallighan Slough. Harkins Slough at this location is a broad marsh area with limited flow and is heavily utilized by a variety of birds and waterfowl. The land and road has subsided most likely due to decaying peat, and as a result Harkins Slough Road is permanently closed at this location due to flooding. Samples are taken on the upstream side of the road crossing. Adjacent land use is predominantly grazing, row crop agriculture, small-scale residential, and natural wetland/marsh areas with bird watching as a common recreational activity.

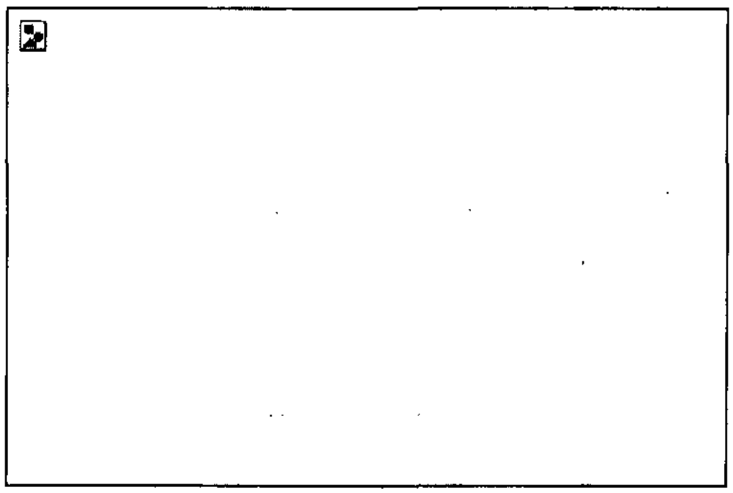


Figure 4.15 Harkins Slough at Harkins Slough Rd. (Photo: F. Watson Dec 02).

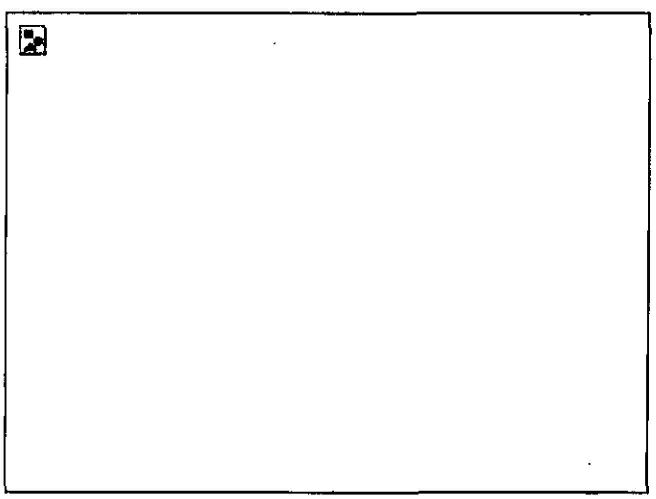


Figure 4.16 Harkins Slough at Harkins Slough Rd. looking upstream (Photo: J. Casagrande Jul 02).

HAR-RAU

HAR-RAU (Fig. 4.17 - 4.18) is located on Harkins Slough upstream of the Ranport Road crossing. This site is upstream of HAR-HAR and is the uppermost site on Harkins Slough. The site is located near the bottom of Larkin Valley just west of Highway 1. Harkins Slough is more stream-like at this site with a steeper gradient than downstream reaches and dense riparian vegetation. Flow at this site is directed through a box culvert (Figure 4.17). Samples were taken approximately 10 meters upstream of the culvert and immediately above the confluence with a small tributary creek. Figure 4.18 illustrates sediment-laden flow during a storm event in December 2002. Adjacent land use is primarily rural residential with grazing and row crop agriculture nearby.

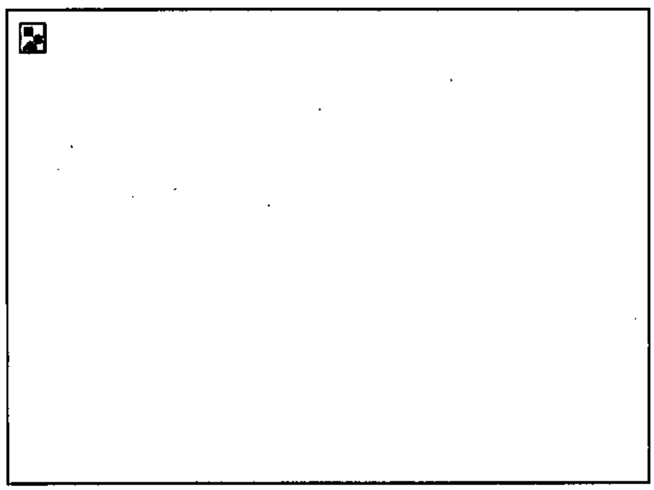


Figure 4.17 Harkins Slough at Ranport Rd. (Photo: D. Roques Feb 03).

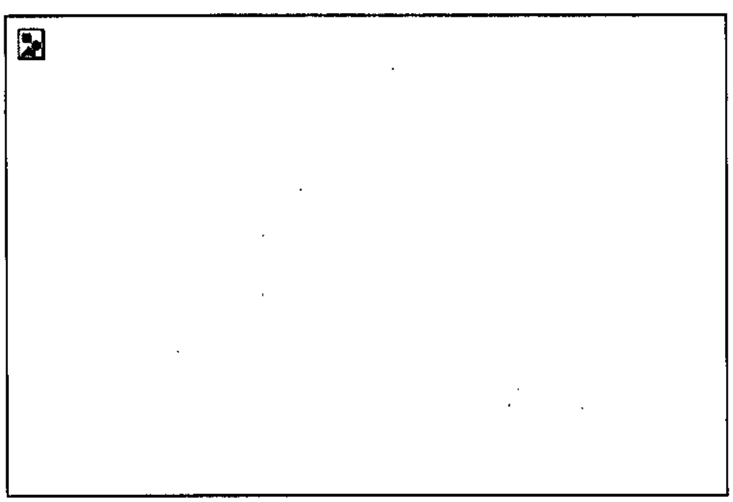


Figure 4.18 Harkins Slough at Ranport Rd. looking upstream (Photo: F. Watson Dec 02).

GAL-BUE

Sampling site GAL-BUE (Fig. 4.19 - 4.20) is located on Gallighan Slough at Buena Vista Road near the western exit for the Buena Vista County Landfill. GAL-BUE is the only sampling site on Gallighan Slough. The slough is stream-like in this area with moderate riparian vegetation. It drains a relatively steep area with rural residential, row crop agriculture, and a landfill as the dominant types of land use. Samples were collected immediately downstream of a culvert which directs flow beneath the road crossing.

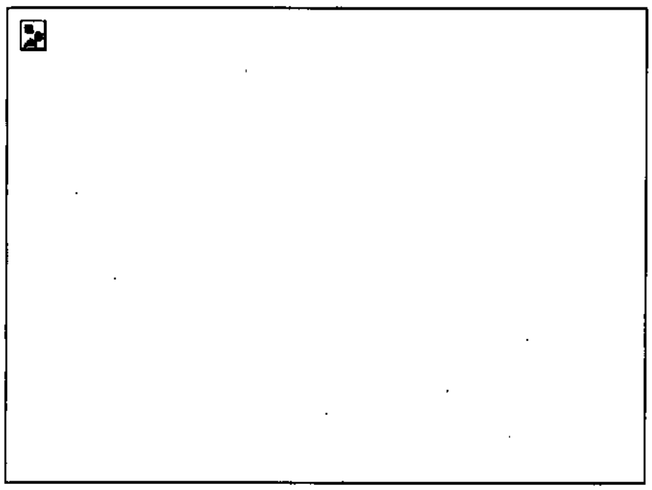


Figure 4.19 Gallighan Slough at Buena Vista Rd. looking downstream (Photo: D. Roques Feb 03).

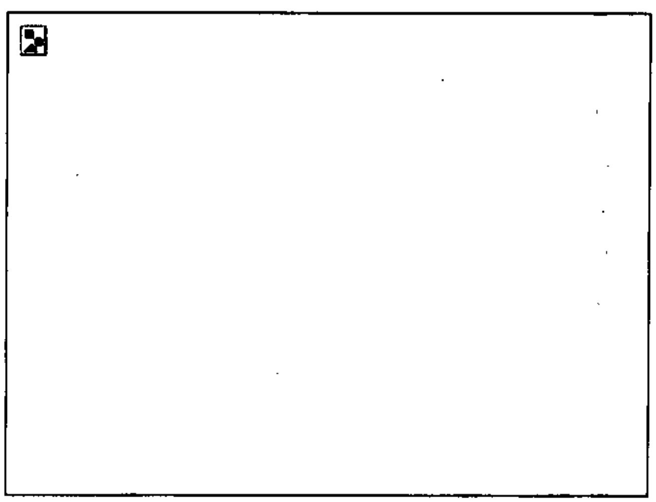


Figure 4.20 Gallighan Slough at Buena Vista Rd. looking upstream (Photo: D. Roques Feb 03).

HAN-HAR

This site (Fig. 4.21 – 4.22) is located on Hanson Slough at Harkins Slough Road. HAN-HAR is the only sampling site on Harkins Slough. At this location, Hanson Slough is characterized by a relatively small channel with dense vegetation on the downstream side (Fig. 4.21) and no riparian vegetation on the upstream side (Fig. 4.22). Hanson Slough is the smallest slough system in the project study area with a watershed area of approximately 2 km^2 (400 acres) and drains to Watsonville Slough connecting just upstream of the Harkins Slough confluence with Watsonville Slough. Adjacent land use is grazing, vineyard, and row crop agriculture.

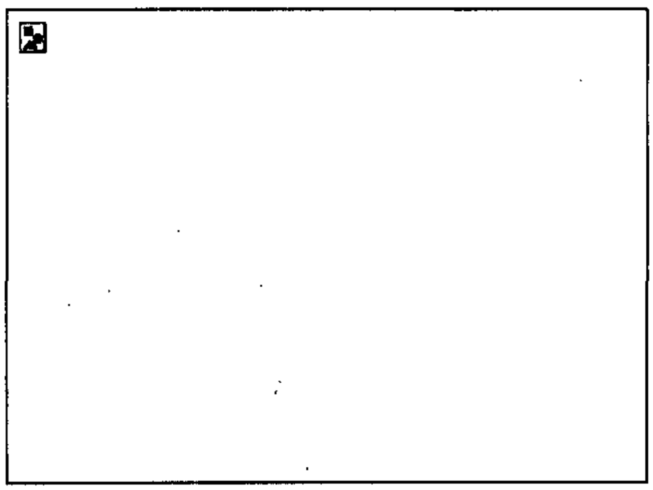


Figure 4.21 Hanson Slough at Harkins Slough Rd. looking downstream (Photo: I. Hager Feb 03).

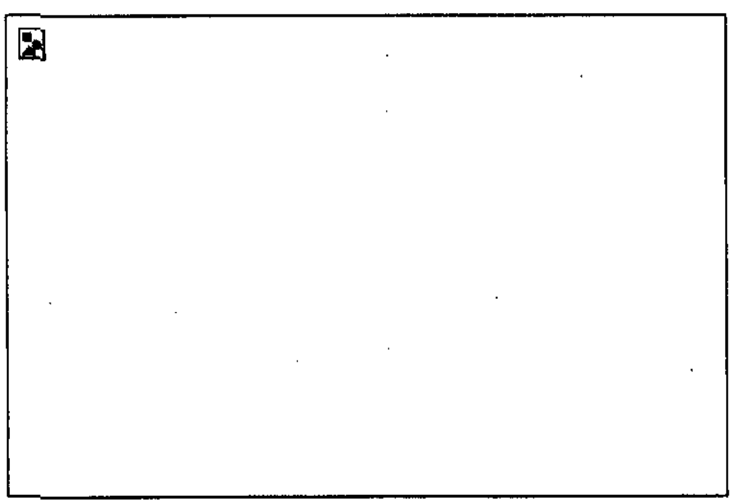


Figure 4.22 Hanson Slough at Harkins Slough Rd. looking upstream (Photo: F. Watson Nov 02).

STR-LEE

Sampling site, STR-LEE (Fig. 4.23 - 4.24), is located on Struve Slough at Lee Road just below the confluence of the main and west branch of the slough. The slough at this site is broad with limited flow and abundant aquatic vegetation. Just as the Harkins Slough Road crossing sites, Lee Road has also subsided and is often inundated with water and closed to traffic. Adjacent land use is industry and row crop agriculture with a mix of natural lands and urban/residential development upstream. Samples were collected immediately upstream of the road crossing.

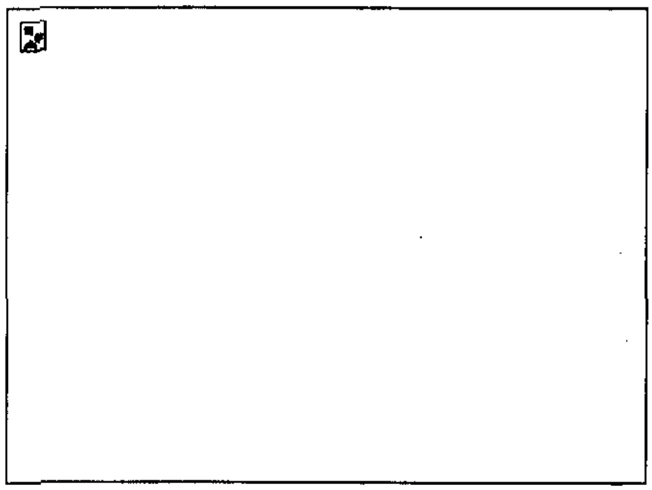


Figure 4.23 Struve Slough at Lee Rd. looking downstream (Photo: J. Casagrande Jul 02).

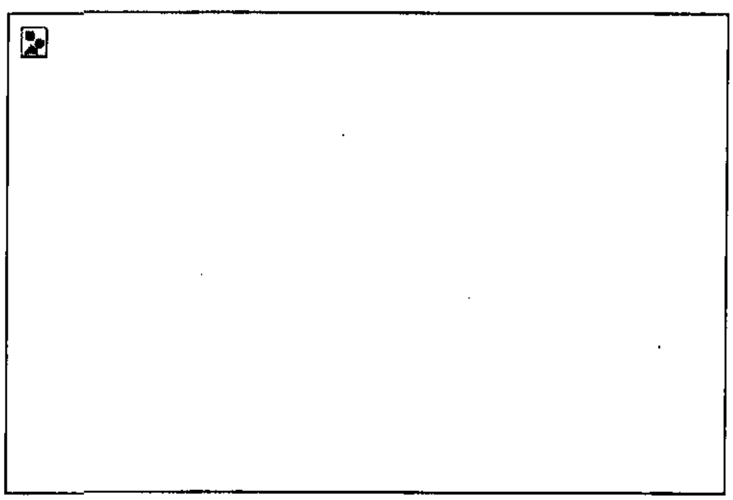


Figure 4.24 Struve Slough at Lee Rd. looking upstream (Photo: F. Watson Nov 02).

STR-HAR

This sampling site (Fig. 4.25 - 4.26) is located on Struve Slough at Harkins Slough Road east of Highway 1. The slough is broad with limited flow and abundant aquatic vegetation. This site is located upstream of STR-LEE and downstream of STR-CHE. Harkins Slough Road has subsided at this location and therefore is often submerged. Samples were taken immediately upstream of the road crossing. Adjacent land use is predominantly commercial (Fig. 4.26) with increasing residential development nearby.

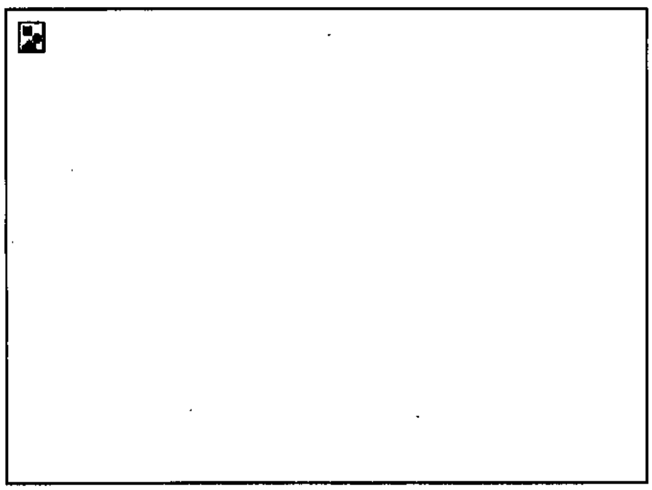


Figure 4.25 Struve Slough at Harkins Slough Rd. looking downstream (Photo: J. Casagrande Jul 02).

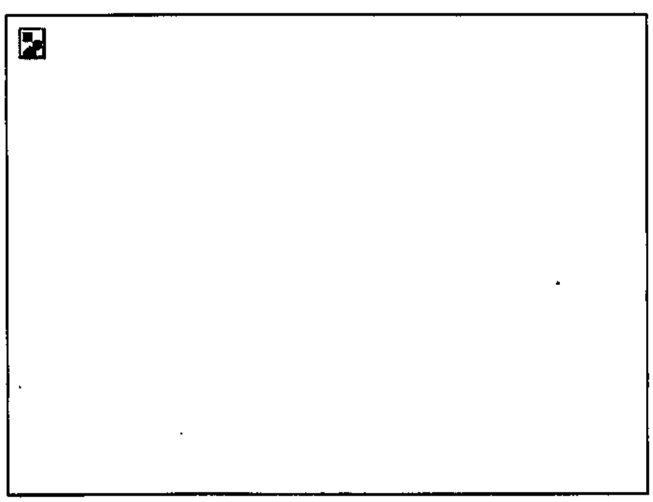


Figure 4.26 Struve Slough at Harkins Slough Rd. (Photo: J. Casagrande Jul 02).

STR-CHE

Sampling site STR-CHE is located on Struve Slough at Cherry Blossom Drive. This site is characterized by a small channel, which drains the local Airport and adjacent residential areas. The site was accessed through a new residential area along the east side of Loma Prieta Road via Cherry Blossom Drive, and samples were collected at the location illustrated in Figure Figure 4.27.

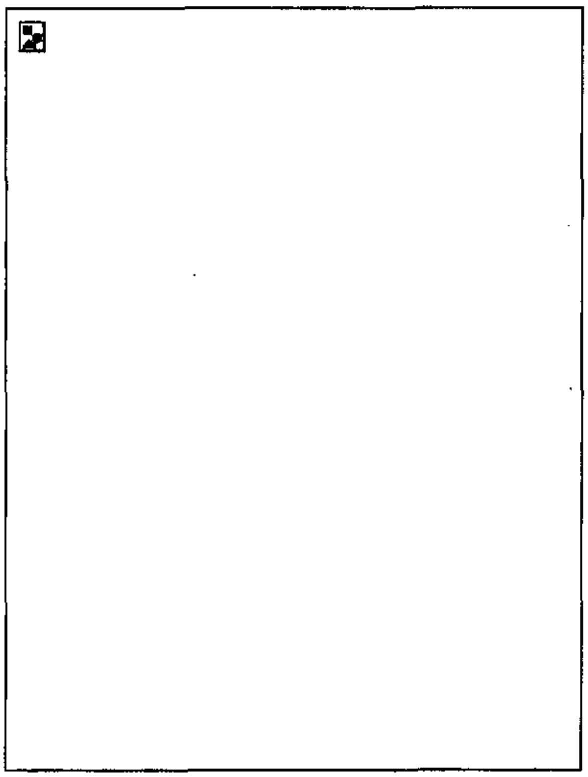


Figure 4.27 Struve Slough near Cherry Blossom Drive looking downstream (Photo: D. Roques Feb 03).

4.2.3 Sediment Coring Sites

A detailed field and aerial photograph search for potential sites was conducted for throughout the watershed, and the reach downstream of the pump station was determined to be the only suitable location for sediment coring. Ideally, sites would have been selected in additional areas, particularly the ponded areas of Harkins Slough, Struve Slough, and Watsonville Slough near Harkins Slough Road where sedimentation is likely to occur. However, these sites did not meet selection criteria required for the sediment core analysis. Appropriate sites for sediment are in areas that are free from disturbances and major modifications. Unfortunately, all areas upstream of Shell Road had been modified in some way that prevented coring. Specific modifications that limited site selection included the following:

- agricultural tilling (this disrupts the upper portions of the sediment which are important for lead-210 and anthropogenic lead analysis)
- placement of fill
- historic draining of the wetlands (this leads to longer dry periods which affect pollen preservation by oxidation)
- channelization and dredging (disruption and removal of sediment)

Two sediment-coring sites, WAT-A and WAT-B, were selected in the saltwater marsh area of the lower reach of Watsonville Slough downstream of the Shell Road pump station. The location of these sites is shown in Figure 4.28.

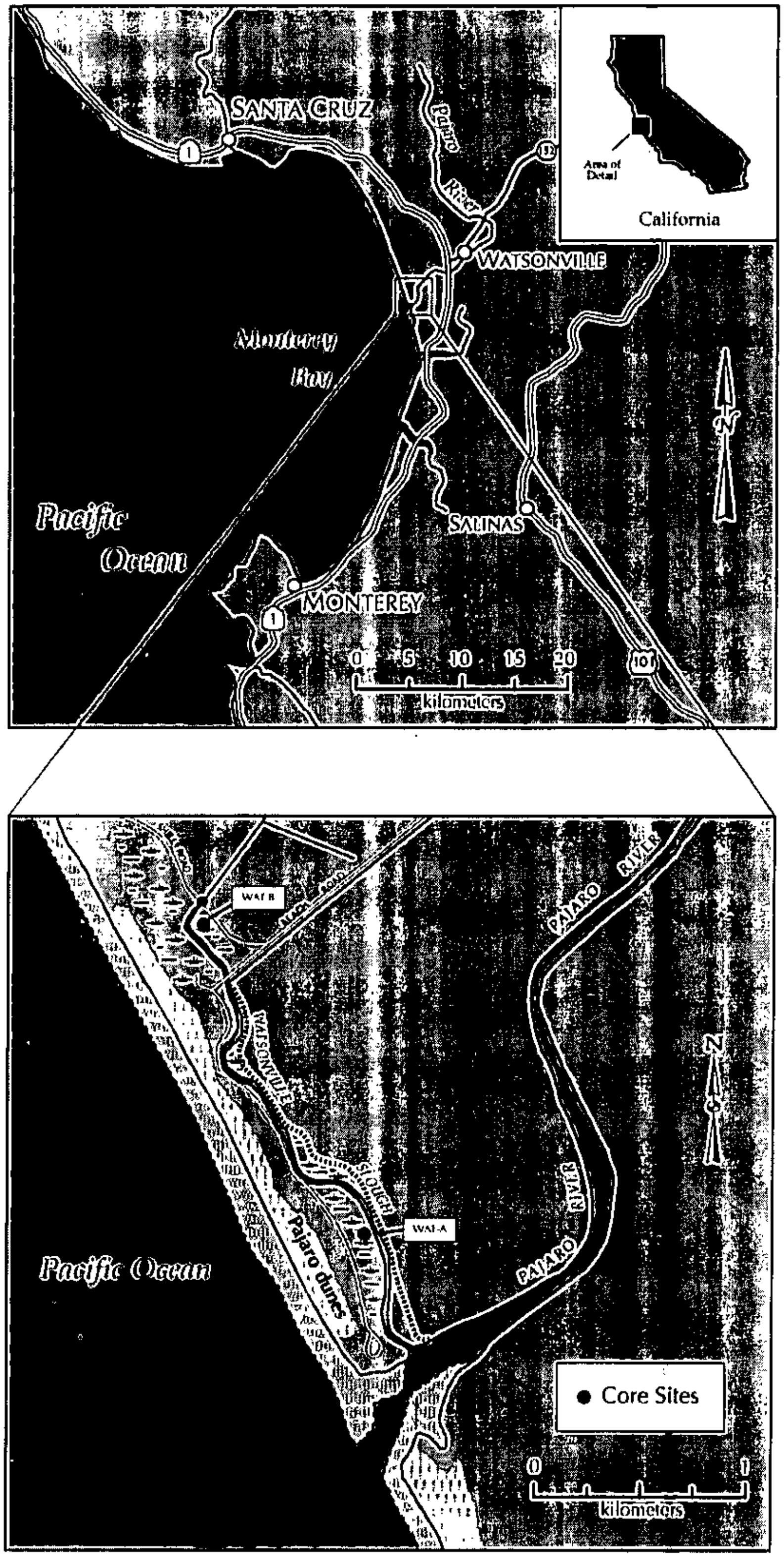


Figure 4.28 Map showing sediment core sites. Map from Byrne and Reidy (2005). Full report included in Appendix H.

5 Suspended Sediment & Turbidity Results and Discussion

5.1 Hydrology and Sampling Metadata

This section presents climate data, flow patterns, and metadata for the study. Field sampling commenced on 18 Feb 03 following approval of the quality assurance and field sampling plan on 11 Feb 03. Field sampling for the study consisted of 2 monitoring campaigns (1 rainy season, 1 dry season) that coincided with sampling for the pathogen TMDL. Sampling dates are listed below in Tables 5.1.

Table 5.1 Sampling Dates for Watsonville Sloughs Sediment TMDL (concurrent sampling with the Watsonville Sloughs Pathogen TMDL)

Rainy Season Monitoring
18-Feb-03
27-Feb-03
13-Mar-03
14-Mar-03
15-Mar-03
18-Mar-03
20-Mar-03
13-Apr-03
Dry Season Monitoring
19-Jun-04
26-Jun-03
01-Jul-03
13-Jul-03
16-Jul-03

Figures 5.1 to 5.3 show daily and monthly precipitation totals and maximum/minimum daily temperatures in the Watsonville area for the project time frame. The data were retrieved from the California Irrigation Management Information System Watsonville West Station #177 and the Green Valley Station #111 (CIMIS, 2003), as well as from the National Climatic Data Center Watsonville Waterworks Station #049473 (NCDC, 2003).

Based on 54 years of precipitation data (1949-2002) from the Watsonville Waterworks station (NCDC, 2003), the average water year (October to September) precipitation for the area is approximately 57 cm (22 inches). The total precipitation for the 2003 water year (Oct 2002 to September 2003), during which most of the monitoring took place, was approximately 51 cm (20 inches), just slightly below normal (NCDC, 2003). For comparison, total precipitation for the 2002 water year was approximately 31 cm (12 inches) and total precipitation for 2001 was 44 cm (17 inches)[1].

Rainfall patterns for the 2002/2003 winter deviated from monthly averages for the existing record of data for the area (Fig. 5.1). The monthly averages from 1948 to 2003 for the NCDC Watsonville Waterworks station were obtained from WRCC (2003) and current water year totals were obtained from NCDC (2003). Rainfall totals for December 2002 were more than double the monthly average, however this was before the start of the project. For February and March when sampling took place, monthly rainfall totals were less than half the average.

Daily precipitation values for the project time frame are presented in Figure 5.2. During the 30-day rainy season monitoring period from mid-February to mid-March, storms were not too intense. From February 18th to March 20th the total precipitation was approximately 5.1 cm (2 inches) at the CIMIS Watsonville West Station. The biggest rainfall event during the 30-day period was on March 14th and 15th (Fig. 5.2). The total for those 2 days was approximately 2.2 cm (0.85 inches) (CIMIS, 2003).

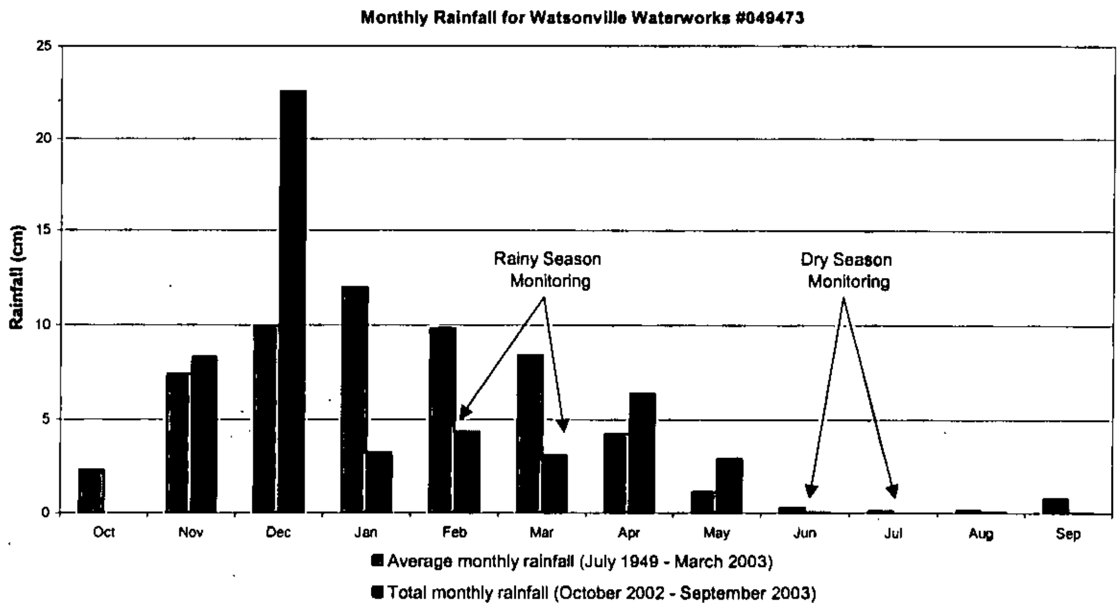


Figure 5.1 Monthly rainfall averages (1948-2003) for Watsonville Waterworks station (WRCC, 2003) and total monthly rainfall for 2003 water year for Watsonville Waterworks

[1] The NCDC dataset for 2001 was missing data for December 2001. The 2002 water year precipitation was calculated by CCoWS using NCDC-Watsonville Waterworks data with the missing December values replaced by CIMIS-Green Valley data. The two weather stations are within 5 km of each other.

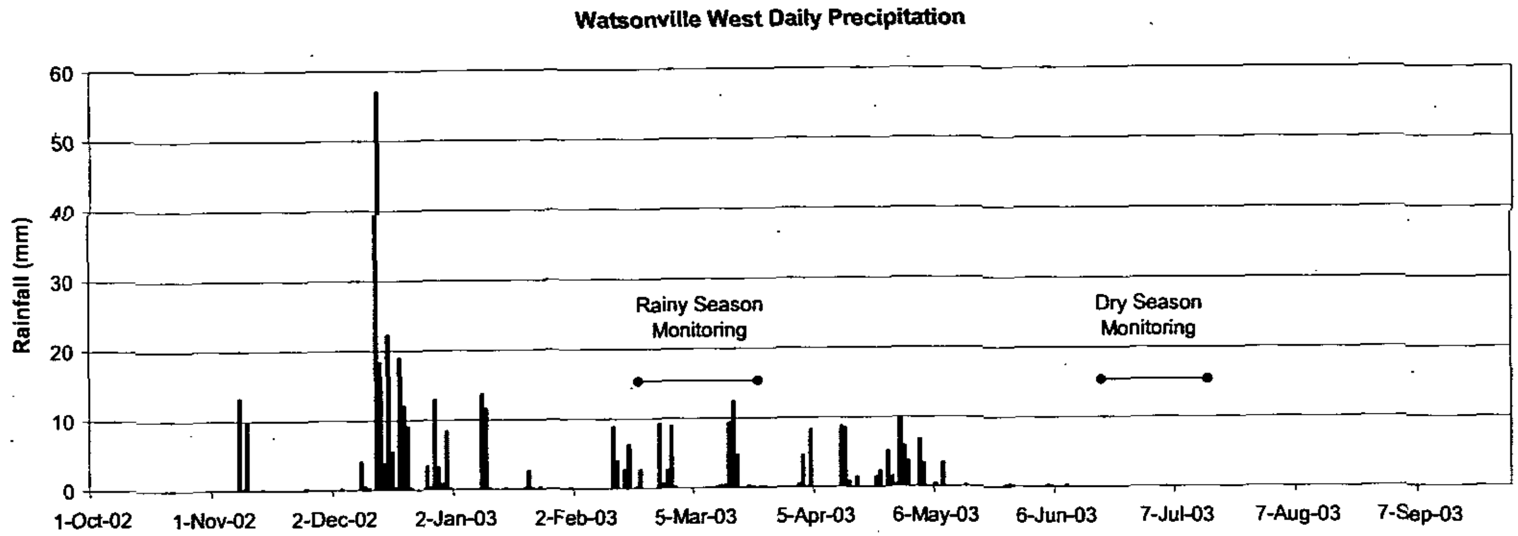


Figure 5.2 Daily precipitation data for CIMIS Watsonville West station. Data from 20-Dec-03 to 30-Dec-03 not available.

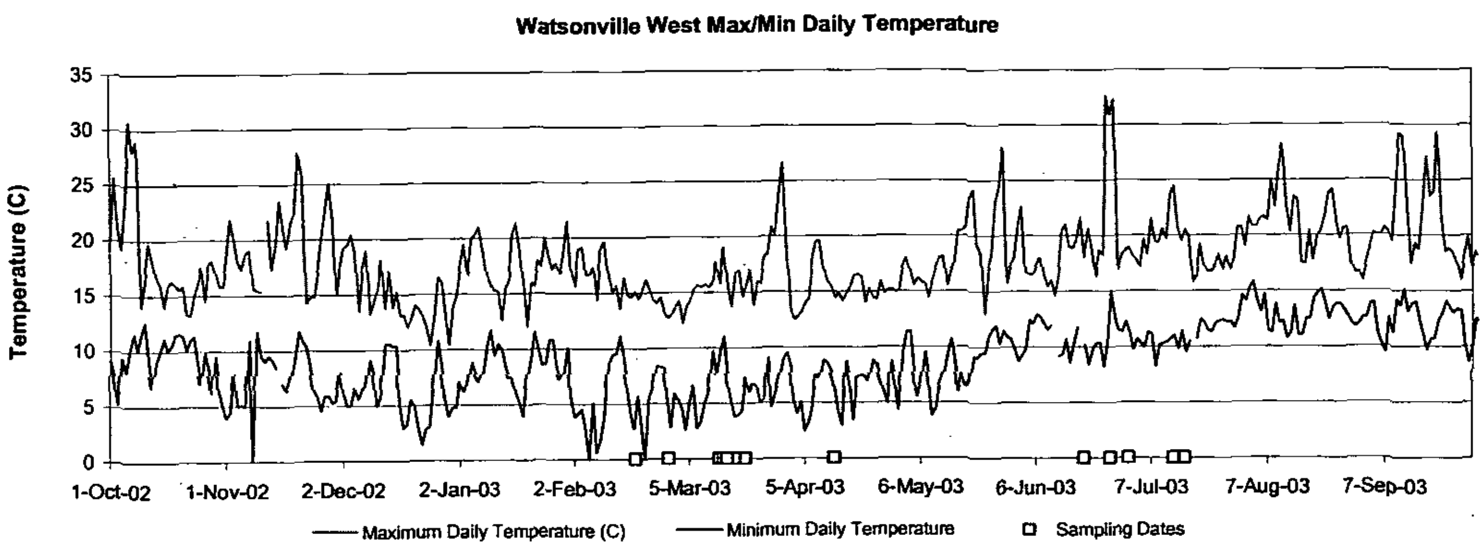


Figure 5.3 Daily maximum and minimum air temperature for CIMIS Watsonville West station.

For comparison, rainfall totals were much higher in December 2002, for which the monthly total was 22 cm (8.5 inches) (NCDC, 2003). The biggest rainfall events for the season occurred in mid to late December with rainfall totaling 17.5 cm (6.9 inches) from December 13th to 31st (CIMIS, 2003). The Quality Assurance Project Plan was not yet completed for the project therefore sampling was not conducted during this December event. Visits to several sites were made during the December event to observe flood flow patterns. A brief description of the observations is given below.

During this event, storm waters flowed up Watsonville Slough as flows were reversed. There was extensive flooding in lower Watsonville Slough. Water inundated Beach Road and Shell Road (Figure 5.4). Flows continued up Watsonville Slough, over the PVWMA pump station, and into Harkins Slough (Figure 5.6). Floodwater from Watsonville Slough also entered Harkins Slough from the east as flows from middle Watsonville Slough overtopped the channel and moved across adjacent agricultural fields (Figure 5.7).

Flows during the winter monitoring period were much lower than those observed during the December event due to the lack of intense rainfall. Discharge measurements were taken by CCoWS when possible. The largest flows were observed during the March 15th and April 13th storm events (Fig. 5.2). With the exception of upper sloughs sites, GAL-BUE, HAN-HAR, HAR-RAU, STR-CHE, and WAT-LEE, flow patterns throughout the Watsonville Sloughs system were generally sluggish due to the low gradient, and discharge measurements were not possible at many of the sites. During the summer months, flow ceased at several of the monitoring sites such as GAL-BUE and HAN-HAR. All discharge data collected throughout this project are presented in Table 5.2.

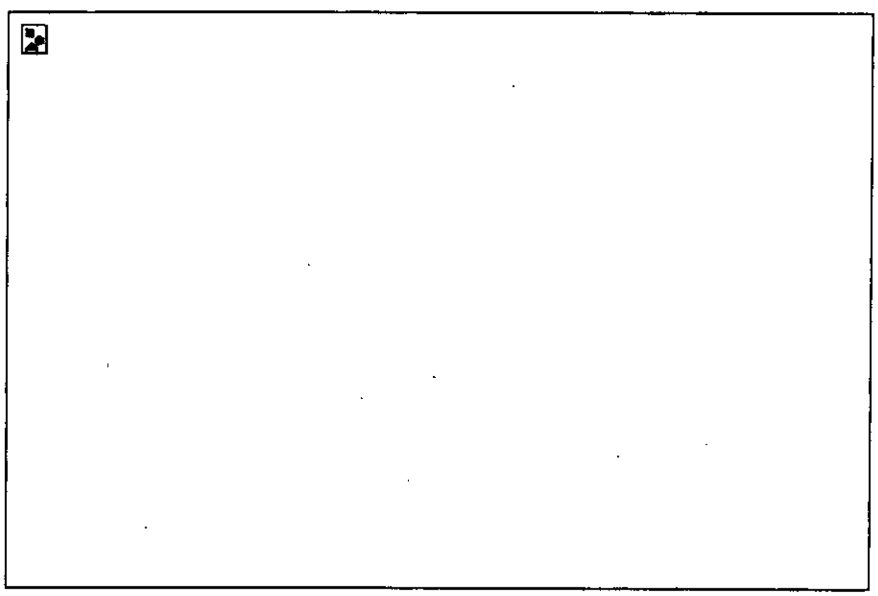


Figure 5.4 Flooding of Beach Road and Shell Road on 16 Dec 02 (Photo: F. Watson Dec 02).

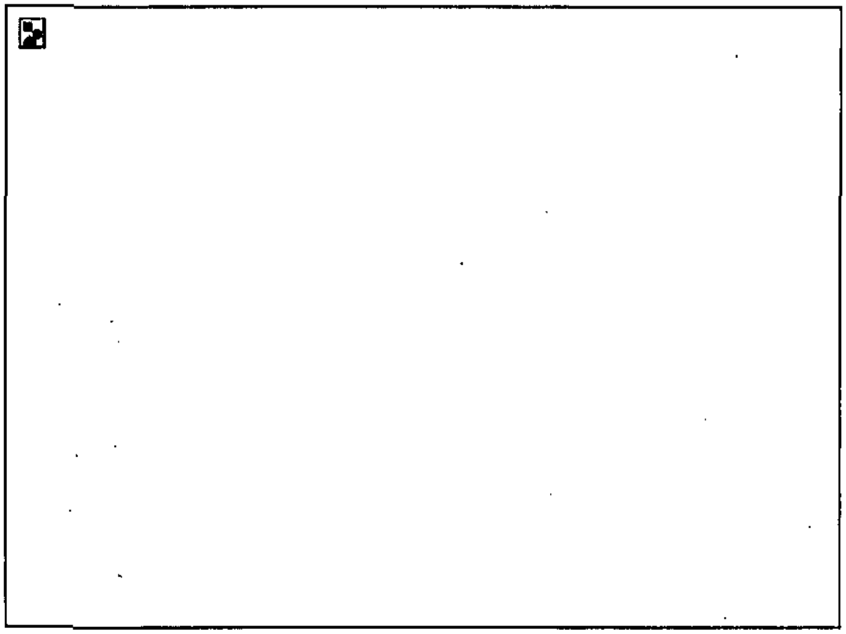


Figure 5.5 Flooding of nearby agricultural fields near Shell Road on 16 Dec 02 (Photo: F. Watson Dec 02).

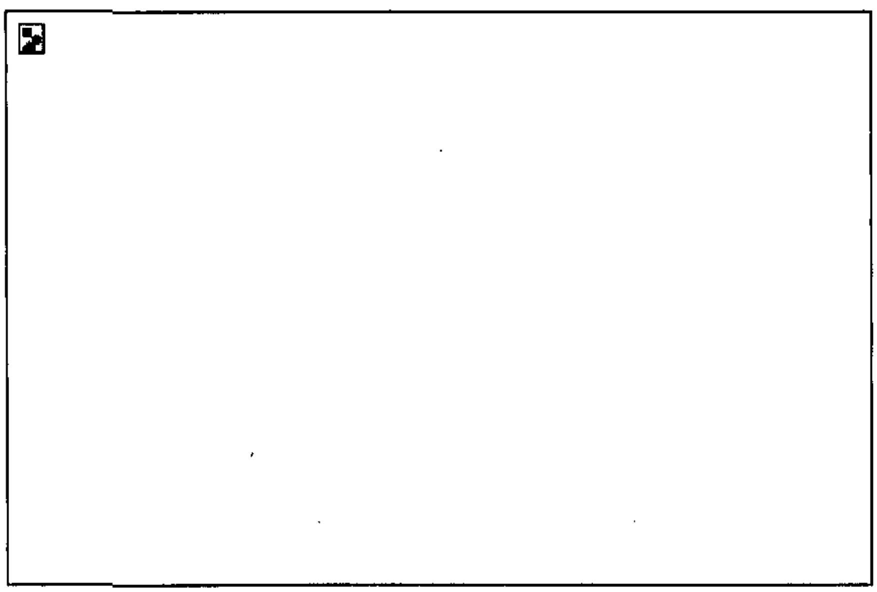


Figure 5.6 Reversal of flow toward Harkins Slough on 16 Dec 02 (Photo: F. Watson Dec 02).

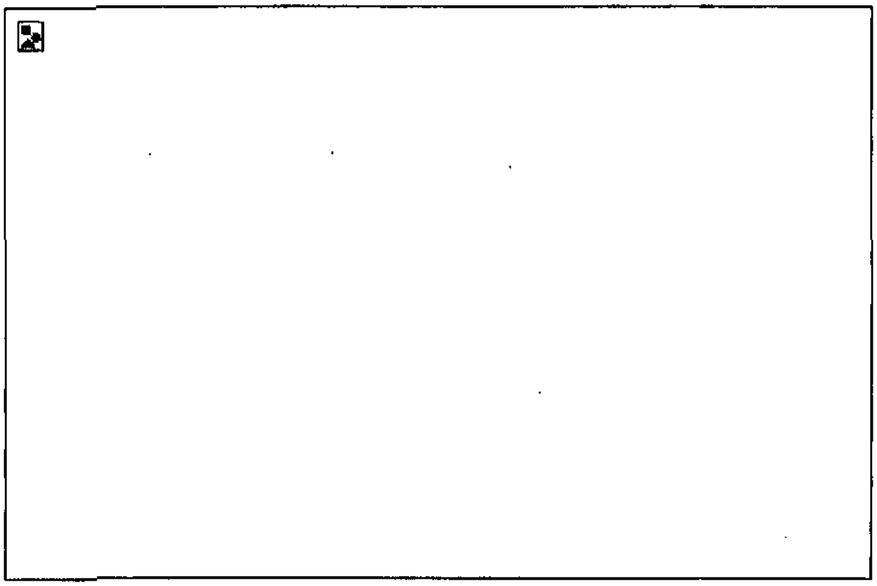


Figure 5.7 Flow into Harkins Slough from Watsonville Slough and adjacent agricultural field on 16 Dec 02 (Photo: F. Watson Dec 02).

Table 5.2 Watsonville Sloughs Discharges (m^3/s)

Date	GAL-BUE	HAN-HAR	HAR-RAU	STR-CHE	WAT-LEE
18-Feb-03	0.004	no flow	-	0.001	0.052
27-Feb-03	0.016	0.003	0.103	0.004	0.113
13-Mar-03	0.006	x	0.019	x	x
14-Mar-03	0.015	no flow	0.019	0.001	0.011
15-Mar-03	0.066	0.010	1.432	0.064	0.197
18-Mar-03	x	no flow	0.009	0.003	0.055
20-Mar-03	0.010	no flow	0.021	0.001	0.043
13-Apr-03	0.018	0.004	0.037	0.045	0.291
13-Apr-03	0.038	0.003	0.030	0.014	0.142
19-Jun-03	0.001	no flow	-	0.006	0.002
26-Jun-03	0.000	no flow	-	-	0.001
01-Jul-03	0.001	no flow	-	0.002	0.003
08-Jul-03	no flow	no flow	-	0.003	0.004
13-Jul-03	no flow	no flow	-	0.001	x
16-Jul-03	no flow	no flow	-	0.001	0.002

-     not enough flow for discharge measurement

x   site not visited or no measurement taken

5.2 General comment about prevailing discharge regime

In an ideal setting, pollutants in the watershed could be managed through specification of a Total Maximum Daily Load. Conventionally, this relies on the assumption that water always flows down the watershed, ultimately to the ocean. However, in the Watsonville Sloughs watershed, the largest flow observed during the present study actually flowed in the reverse direction to that which would normally be expected - i.e. back *into* the watershed from the mouth. This was because of a combination of factors, such as high ocean waves, backwater flow from the neighboring Pajaro River, a low-point in the watershed created by active pumping, and a history of land subsidence. This reversal of flow in Watsonville Sloughs is not atypical during the first storms of the season when the sand bar at the Pajaro Lagoon is often closed (pers. comm., J. Smith, 2004). The closure of the lagoon is due to the orientation of the lagoon and increased sediment transport by ocean currents during the first storms of the season. Presence of the sand bar prevents the Pajaro River from emptying to the ocean and excess water is then backed up into Watsonville Sloughs.

In several areas throughout the sloughs, circulation is poor and often results in ponded and low discharge rates due to a combination of factors that have been documented by Questa (1995) and Swanson Hydrology and Geomorphology (2003). Those factors include subsidence of roads due to the weight of road fill and low resistance of wetland peat soils, water impoundment behind roads with inadequately sized control structures, land subsidence throughout the sloughs due to groundwater pumping and peat decomposition, and the lack of channel dredging and decay drainage ditches in the lower portions of Watsonville Sloughs during recent decades. The primary ponded areas are lower Harkins slough near Harkins Slough Road (Fig. 5.8 and 5.9), Struve Slough at Harkins Slough Road and Lee Road (Fig. 5.10), Watsonville Slough between Harkins Slough Road and Ford Street (Fig. 5.11), and Watsonville Slough just downstream of Lee Road near the confluences with Struve Slough and Hanson Slough (Fig. 5.10).

In general, flows toward the ocean throughout the entire lower part of the Sloughs watershed are, by definition, sluggish or non-existent. An accounting of pollutant fate based on a balance of loads would be close to impossible. Therefore, attention was focused on the possible occurrence of net *accumulation* of pollutants within the sloughs over time - i.e. the outcomes of loads, rather than the loads themselves.

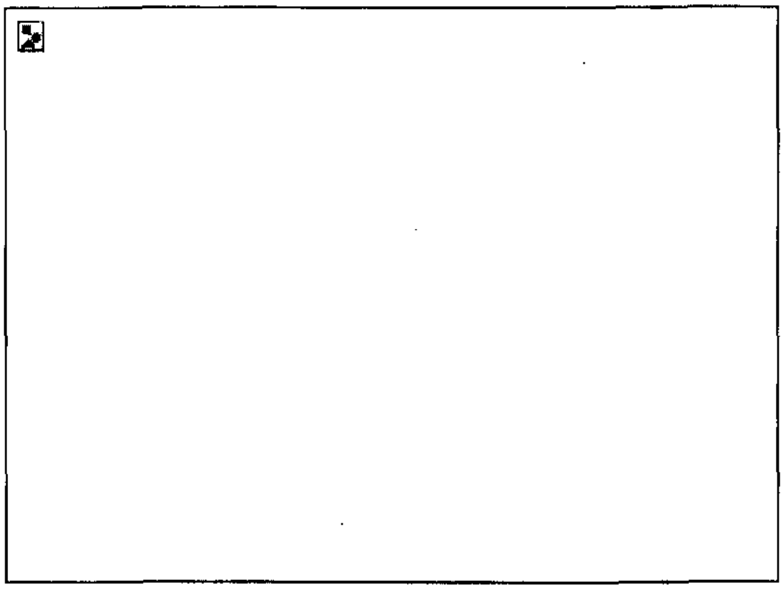


Figure 5.8 Ponded water at Harkins Slough near Harkins Slough Road (Harkins Slough Road center). (Photo: J. Hager May 03)

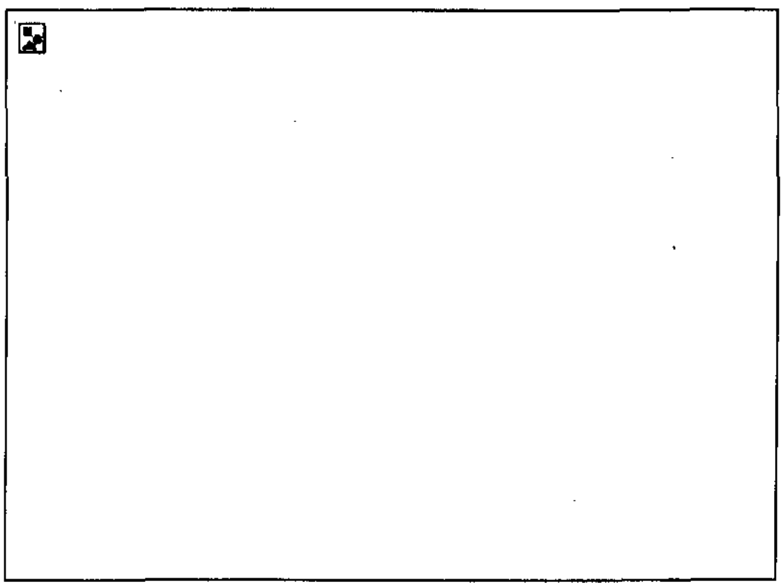


Figure 5.9 Ponded water at Harkins Slough just downstream of Harkins Slough Road (Harkins Slough Road in lower right corner). (Photo: J. Hager May 03).

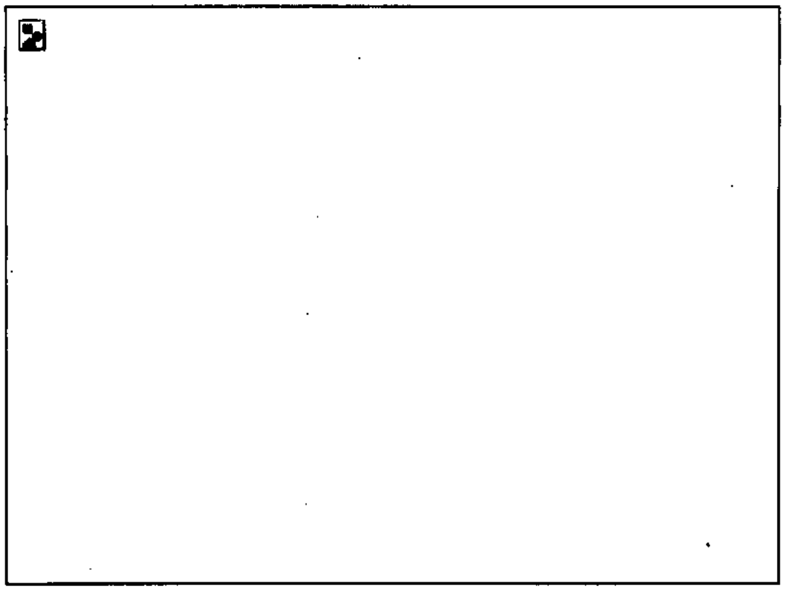


Figure 5.10 Ponded water at lower Struve and West Branch Struve Slough, lower Hanson Slough, and Watsonville Slough just downstream of Lee Road. (Photo: J. Hager May 03)

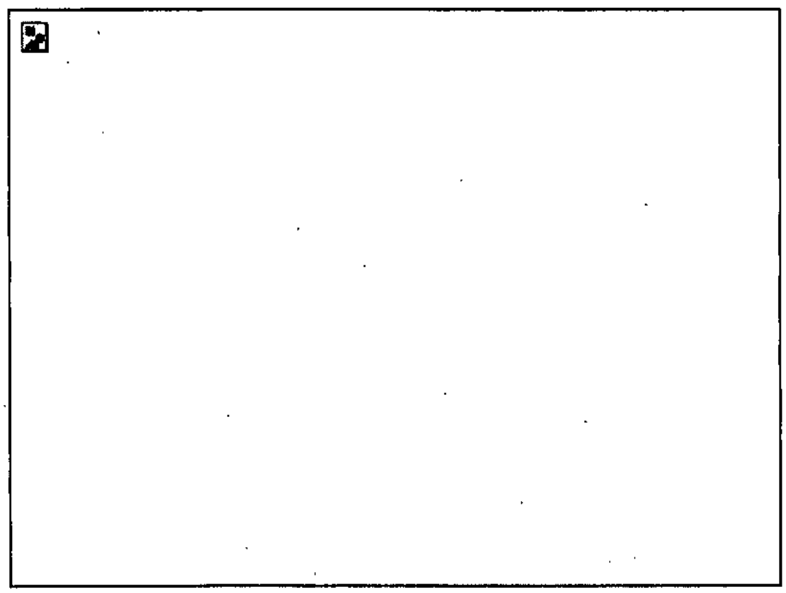


Figure 5.11 Ponded water at Watsonville Slough between Harkins Slough Road and Ford Street. (Photo: J. Hager May 03)

5.3 Suspended Sediment and Turbidity Results

The initial approach to investigating sediment impairment of Watsonville Sloughs was to conduct sampling for suspended sediment and turbidity and to attempt to determine suspended sediment loads when possible. The first stage of the monitoring involved sampling for SSC and turbidity at 13 sites throughout the watershed. Two 30-day monitoring campaigns, each consisting of at least five sampling runs, were conducted. The first monitoring campaign was from mid-February to mid-March during the rainy season. Sediment samples were taken near the peak of the March 15th event, the largest during the monitoring period. Only one significant storm event was monitored during the 30-day period, therefore an additional sampling run was completed during a small rain event on April. The second campaign took place from mid June to mid-July during the dry season. The results of the two campaigns are presented in the following sections.

Since the Basin plan objectives for suspended sediment are narrative and the turbidity objective relies on knowing the natural turbidity level in Watsonville Slough (which is unknown), it is difficult to determine if Watsonville Sloughs are impaired due to suspended sediment concentrations and turbidity levels and whether or not beneficial uses of Watsonville Sloughs are adversely impacted. We must rely on toxicity studies from other areas for species, which are suspected or have been documented to be present in Watsonville Sloughs, in order to determine if beneficial uses are being impacted. The results of sediment toxicity studies on fish and invertebrates, such as those detailed in Section 2.3, vary widely depending on age, size, duration of exposure, temperature, and composition. However, relative ranges are useful in determining 'potential' impacts. Based on toxicity studies by Newcombe and Jensen (1996), the following levels were chosen to categorize suspended sediment and turbidity levels measured for Watsonville Sloughs.

- **up to 2 NTU or 10 mg/L**: not likely to adversely affect fish and invertebrates
- **up to 20 NTU or 100 mg/L**: potential change in behavior and/or slight decrease in survival
- **up to 200 NTU or 1,000 mg/L**: stress, physiological changes, and potentially lethal effects

5.3.1 Winter Monitoring Campaign

Suspended Sediment Concentration

Winter suspended sediment concentrations for the 13 sampling sites ranged from 0 to 4,164 mg/L. A statistical summary of SSC data from the wintering monitoring campaign is presented in Table 5.3 and a map illustrating median SSC for each site is presented in

Figure 5.12. The highest median SSC values were observed at HAN-HAR and WAT-PAJ. Hanson Slough and Gallighan Slough had the highest average suspended sediment concentrations, although the average at Gallighan Slough was raised due to a single, very high concentration that was measured during the April 13th rain event. Concentrations were generally lowest in the ponded water sections of Watsonville Slough, Harkins Slough, and Struve Slough where it is likely that sedimentation may be occurring due to low water velocities (Figure 5.12).

Data presented in Table 5.4 are categorized based on the levels outlined in bold in the previous section. Shaded cells indicate that more than 50% of the samples were greater than the category value. For suspended sediment, 50% or more of the total samples from all sites were in exceedance of the 10 mg/L level. Only samples from site HAN-HAR and WAT-PAJ were in exceedance of the 100 mg/L level more than 50% of the time. Only HAN-HAR had samples that exceeded the 1,000 mg/L level more than 50% of the time.

Discharges were measured at sites WAT-LEE, HAN-HAR, GAL-BUE, HAR-RAU, and STR-CHE and instantaneous suspended sediment loads were calculated for those sites. Instantaneous loads and discharges are presented in Figure 5.14. Figure 5.14 plots variation in load for a given discharge for all data across all sites where loads could be estimated. Most of the data fall approximately along a single line, corresponding to a sediment-rating curve for the region. There is good evidence for increases in concentration with increasing flow, which is consistent with a power-law sediment transport capacity relationship (Shen and Julien, 2003). The exceptions in the data are HAN-HAR and GAL-BUE. At HAN-HAR, this could be due to either a significant sediment source in the watershed or an artifact of the small watershed area of this site with little opportunity for deposition in low gradient areas. The other outlier in the data is a single value at GAL-BUE. All other samples collected at this site throughout the monitoring period were not indicative of a significant sediment source. It is unlikely that the high was laboratory error because the corresponding turbidity sample was also extraordinarily high. Therefore a significant sediment source, possibly intermittent such as a bank failure, may exist. Although these load data suggest spatial variation due to sediment sources, it is important to recognize biases such as the small dataset, watershed area, runoff rates, and hydraulic control structures.

Turbidity

Winter turbidity values for the 13 sites ranged from 1 to 7,888 NTU. This value was more than 7 times greater than the upper range of the analysis instrument, thus requiring multiple dilutions in order to obtain the reading. A statistical summary of the turbidity data from the winter monitoring campaign is given in Table 5.3. The highest average turbidity levels were observed at HAN-HAR and GAL-BUE. At GAL-BUE, the high average was raised due to a single sample. The highest median turbidity levels were observed at HAN-HAR and WAT-AND. As was the case for SSC, the lowest average turbidity levels were usually observed at sites with ponded water.

Data presented in Table 5.4 are categorized based on the levels outlined in bold in the previous section. For turbidity, 50% or more of the total samples from all sites, except for STR-LEE, were in exceedance of the 2 NTU level. For 20 NTU level, 6 of the 13 sites had 50% or greater exceedance. At site HAN-HAR, all 3 samples were in exceedance of the 200 NTU level. However, only 3 samples were taken at this site due to either absence of water or lack of flow.

Table 5.3 Watsonville Sloughs SSC & Turbidity Data-Winter Monitoring Campaign

Site Code	Turbidity (NTU)						SSC (mg/L)					
	N	Min	Max	Mid	Mean	Median	N	Min	Max	Mid	Mean	Median
WAT-PAJ	6	4.39	22.40	13.40	11.40	10.49	6	9.06	264.33	136.70	126.70	114.92
WAT-SHE	6	3.21	23.70	13.46	14.50	16.40	6	24.54	43.95	34.25	35.19	35.16
WAT-AND	7	20.90	323.00	171.95	136.56	93.60	7	29.44	504.46	266.95	189.33	89.32
WAT-LEE	9	12.20	232.00	122.10	72.72	28.40	9	6.48	238.40	122.44	107.04	83.10
WAT-HAR	7	2.90	60.00	31.45	11.83	4.06	7	4.38	17.27	10.83	10.53	10.94
HAR-CON	7	14.20	170.00	92.10	56.10	29.80	7	10.17	225.13	117.65	81.32	75.84
HAR-HAR	6	4.61	13.50	9.06	9.54	9.63	6	2.20	56.09	29.14	24.98	21.55
HAR-RAU	9	9.68	244.00	126.84	74.55	16.70	9	0.00	206.68	103.34	40.12	14.67
GAL-BUE	9	9.97	7,888.00	3,948.99	935.33	41.60	8	21.91	4,163.59	2,092.75	572.61	43.77
HAN-HAR	3	347.00	4,272.00	2,309.50	2,292.67	2,259.00	3	778.10	3,030.90	1,904.50	2,088.09	2,455.28
STR-LEE	6	1.55	2.69	2.12	1.99	1.84	6	4.41	28.70	16.56	17.96	18.30
STR-HAR	6	1.40	24.90	13.15	7.93	3.81	6	2.56	31.94	17.25	15.70	14.27
STR-CHE	8	8.82	47.10	27.96	26.13	28.00	8	10.98	70.57	40.78	34.76	31.62

Table 5.4 Watsonville Sloughs SSC and Turbidity Exceedance-Winter Monitoring Campaign

Site Code	Turbidity				SSC			
	N	N Exceeding			N	N Exceeding		
		2 NTU	20 NTU	200 NTU		10 mg/L	100 mg/L	1,000 mg/L
WAT-PAJ	6	6	1	0	6	5	3	0
WAT-SHE	6	6	2	0	6	6	0	0
WAT-AND	7	7	7	2	7	7	3	0
WAT-LEE	9	9	6	1	9	8	4	0
WAT-HAR	7	7	1	0	7	4	0	0
HAR-CON	7	7	6	0	7	7	1	0
HAR-HAR	6	6	0	0	6	5	0	0
HAR-RAU	9	9	4	1	9	5	1	0
GAL-BUE	9	9	6	1	8	8	3	1
HAN-HAR	3	3	3	3	3	3	3	2
STR-LEE	6	2	0	0	6	5	0	0
STR-HAR	6	4	1	0	6	3	0	0
STR-CHE	8	8	5	0	8	8	0	0

50% of samples or greater in exceedance

5.3.2 Summer Monitoring Campaign

Suspended Sediment Concentration

Summer suspended sediment concentrations ranged from 0 to 335 mg/L. A statistical summary of SSC data is presented in Table 5.5 and a map illustrating median SSC for each site is given in Figure 5.13. The highest median SSC values were observed at HAR-HAR and WAT-PAJ. All other sites had medians that were less than 50 mg/L.

Data presented in Table 5.6 are categorized based on the levels detailed in the Section 2.3. Shaded cells indicate that more than 50% of the samples were greater than the category value. For suspended sediment, 50% or more of the total samples from 10 of the 13 sites were in exceedance of the 10 mg/L level. The only site that exceeded the 100 mg/L level more than 50% of the time was WAT-PAJ. No sites exceeded the exceeded the 1,000 mg/L level.

Discharges were measured at sites WAT-LEE, GAL-BUE, HAR-RAU, and STR-CHE and instantaneous suspended sediment loads were calculated for those sites. Some discharges were determined from stage versus discharge curves that have been constructed for the site. A plot of instantaneous suspended sediment load versus discharge is given in Figure 5.14, which was referred to in the previous section. This figure facilitates the determination of whether differences in suspended sediment load over time or between sites are independent of discharge, and may thus be related to other factors such as land use. In general, summer instantaneous loads were much lower than for winter, because discharges were lower. Only one site had similar discharges in summer and winter (STR-CHE), and at this site there did not appear to be any variation in load that was independent of discharge. Variation in SSC and suspended sediment load at a site appears to be primarily determined by variation in discharge. For most sites during both the winter and summer monitoring, there is no evidence for variation in suspended sediment load between sites or between seasons that is independent of discharge. The only exceptions to this pattern, as mentioned in the previous section, are winter samples from HAN-HAR and 1 winter sample from GAL-BUE.

Turbidity

Summer turbidity levels ranged from 3 to 106 NTU. A statistical summary of turbidity data is presented in Table 5.5. Median turbidity levels were highest at HAR-HAR and GAL-BUE. Most other sites had median levels that were less than 20 NTU.

Data presented in Table 5.6 are categorized based on the exceedance levels outlined in bold in Section 4.3. For turbidity, 4 of the 12 sites had 50% or greater exceedance of

Table 5.5 Watsonville Sloughs SSC Data (mg/L)-Summer Monitoring Campaign

Site Code	Turbidity (NTU)						SSC (mg/L)					
	N	Min	Max	Mid	Mean	Median	N	Min	Max	Mid	Mean	Median
WAT-PAJ	5	3.06	17.73	10.40	8.11	6.69	5	144.66	334.78	239.72	271.14	295.10
WAT-SHE	6	11.70	43.70	27.70	20.34	12.43	5	24.44	105.65	65.05	45.07	26.40
WAT-AND	5	8.81	18.70	13.75	13.99	13.80	5	10.82	29.37	20.10	24.42	28.31
WAT-LEE	5	20.70	49.60	35.15	29.80	26.90	5	35.22	69.18	52.20	50.40	40.17
WAT-HAR	5	3.65	25.30	14.48	14.35	16.10	5	5.37	57.54	31.46	21.57	15.59
HAR-CON	5	3.33	7.99	5.66	4.71	4.15	5	0.00	24.21	12.11	12.40	12.28
HAR-HAR	5	72.20	106.00	89.10	95.00	99.00	5	67.58	116.75	92.17	86.87	85.50
HAR-RAU	5	19.80	51.00	35.40	35.42	36.10	5	1.03	26.99	14.01	14.50	13.11
GAL-BUE	3	55.00	65.30	60.15	59.67	58.70	3	14.20	25.46	19.83	21.16	23.83
HAN-HAR	0	x	x	x	x	x	0	x	x	x	x	x
STR-LEE	5	3.42	15.70	9.56	7.89	6.50	5	0.00	28.67	14.34	9.36	6.68
STR-HAR	5	3.19	33.20	18.20	14.56	9.09	5	0.00	33.68	16.84	13.67	5.40
STR-CHE	5	4.40	14.00	9.20	9.54	10.70	5	0.00	139.00	69.50	45.88	15.67

Table 5.6 Watsonville Sloughs SSC and Turbidity Exceedance-Summer Monitoring Campaign

Site Code	Turbidity				SSC			
	N	N Exceeding			N	N Exceeding		
		2 NTU	20 NTU	200 NTU		10 mg/L	100 mg/L	1,000 mg/L
WAT-PAJ	5	5	0	0	5	5	5	0
WAT-SHE	6	6	2	0	5	5	1	0
WAT-AND	5	5	0	0	5	5	0	0
WAT-LEE	5	5	5	0	5	5	0	0
WAT-HAR	5	5	2	0	5	3	0	0
HAR-CON	5	5	0	0	5	4	0	0
HAR-HAR	5	5	5	0	5	5	1	0
HAR-RAU	5	5	4	0	5	3	0	0
GAL-BUE	3	3	3	0	3	3	0	0
HAN-HAR	0	0	0	0	0	0	0	0
STR-LEE	5	5	0	0	5	2	0	0
STR-HAR	5	5	2	0	5	2	0	0
STR-CHE	5	5	0	0	5	4	1	0

(shaded) 50% of samples or greater in exceedance

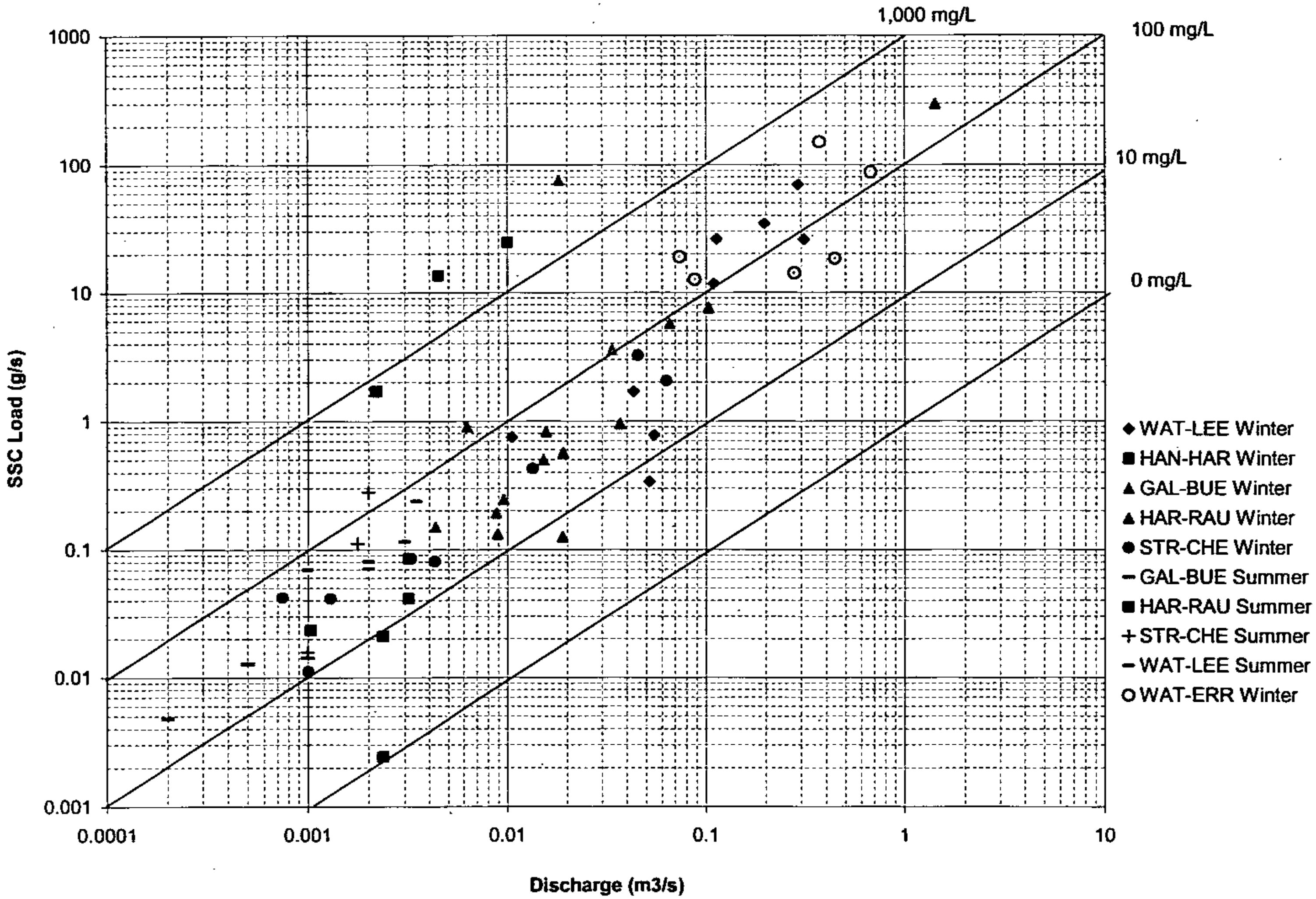


Figure 5.14 SSC vs Discharge.

5.4 Watershed Working Group Storm Monitoring

The Coalition of Central Coast County Farm Bureaus has developed an agricultural watershed management program for six counties throughout the Central Coast region of California. The Coalition was organized to increase agricultural participation in addressing water quality issues and to assist the Monterey Bay National Marine Sanctuary in the implementation of the Water Quality Protection Program Action Plan for Agriculture and Rural Lands (MBNMS 1999). A major component of each county's program includes the formation of voluntary networks of landowners, growers, and ranchers, known as 'watershed working groups'. Participants in the program work with technical assistance organizations to monitor water quality, improve management practices, and develop watershed plans to address nonpoint source pollution.

During the winter of 2003/2004, water quality monitoring was conducted by CCoWS for 3 of the watershed working groups that have formed in the region, including the Watsonville Slough watershed working group. The data from this monitoring is useful to include in this study because it provides suspended sediment data for a different water year.

Sampling was conducted at two sites WAT-SHE and WAT-ERR (just upstream from Highway 1) for 3 storm events during the winter of 2003/2004. The sampling dates of the monitoring are given in 5.7.

Table 5.7 Sampling dates for Watershed Working Group Storm Water Monitoring Project (Larson et al., 2004)

Watershed Working Group Storm Monitoring
28-Dec-03
30-Dec-03
31-Dec-03
01-Jan-04
02-Jan-04
05-Jan-04
01-Feb-04
02-Feb-04
03-Feb-04
04-Feb-04
05-Feb-04
23-Feb-04
25-Feb-04
26-Feb-04
27-Feb-04

The total precipitation for the 2004 water year during which the monitoring took place was approximately 57 cm (22 inches) at the Watsonville West station (CIMIS, 2005). Rainfall totals were 9.1 cm (3.6 inches) for the December event, 1.5 cm (0.6 inches) for the early February event, and 4.9 cm (1.9 inches) for the late February event. For the December event alone, precipitation totals were higher than totals for the entire winter monitoring period for the current study.

Suspended sediment and turbidity were analyzed for each sample. Discharge measurements were taken at WAT-ERR during one of the storms. As with the current study, discharge measurements were not taken at the Shell Road pump station. A statistical summary for the suspended sediment and turbidity data are given in Table 5.8 . In general, the values were slightly higher than values from 2003. The median at WAT-SHE during the winter 2003 sampling was 35.2 mg/L, whereas the median at WAT-SHE during the winter 2004 sampling was 45.9. As expected, a similar increase was also observed for turbidity. During the winter 2003, all WAT-SHE samples were between 10 mg/L and 100 mg/L. During the winter 2004, 7 of the 33 samples collected at WAT-SHE and WAT-ERR were greater than 100 mg/L (Table 5.9).

When discharges were measured, instantaneous suspended sediment loads were calculated. These data are graphed in the previous section (Figure 5.14). Loads from this season were higher than those from the 2002/2003 season. This is likely due to larger storm events, higher discharges, and therefore higher sediment transport capacity.

Table 5.8 SSC and Turbidity from Watershed Working Group Monitoring

Site Code	Turbidity (NTU)					
	N	Min	Max	Mid	Mean	Median
WAT-SHE	16.00	13.10	99.70	56.40	41.98	35.25
WAT-ERR	17.00	4.71	481.00	242.86	91.62	33.20
Site Code	**SSC (mg/L)**					
	N	Min	Max	Mid	Mean	Median
WAT-SHE	16.00	16.47	141.12	78.80	51.14	45.59
WAT-ERR	17.00	0.00	401.71	200.86	105.52	41.23

Table 5.9 SSC and Turbidity Exceedance

Site Code	Turbidity				SSC			
	N	N Exceeding			N	N Exceeding		
		2 NTU	20 NTU	200 NTU		10 mg/L	100 mg/L	1,000 mg/L
WAT-SHE	16	16	14	0	16	16	1	0
WAT-ERR	17	17	10	3	17	15	6	0

(shaded) 50% of samples or greater in exceedance

5.5 Regional Suspended Sediment Levels

This section compares suspended sediment levels between the Watsonville Sloughs system and the broader surrounding region in order to determine if potential problems in the Watsonville Sloughs system are unique, or simply examples of the region in general.

Data from the present study were compared with (1998-2001) CCAMP data from a number of sites which are listed in Table 5.10. The comparison is shown using whisker plots and is given in Figure 5.16. A schematic diagram describing the whisker plots is shown in Figure 5.15. The sites in Figure 5.16 are organized according to approximate hydrologic and geographic provinces.

It is important to note that the CCAMP and CCoWS data were collected using different sampling designs, different methods, and during different rainfall years. This project involved dry season and rainy season monitoring. Past CCoWS data has primarily been storm sampling for which samples were collected during the rising limb of the hydrograph, peak of the hydrograph, and falling limb of the hydrograph. CCAMP samples were collected approximately monthly and may or may not have coincided with storm events during the winter months. The individual whisker plots are shaded based on the sampling strategy (pink-CCoWS rainy and dry season, teal-CCoWS primarily storm events, yellow-combination of CCoWS and CCAMP dry season and storm sampling, and gray-CCAMP approximately monthly). CCAMP samples were analyzed using TSS method, which analyzes an aliquot of the entire water sample and tends to underestimate the total suspended sediment concentration, whereas CCoWS samples were analyzed with the SSC method in which the entire sample is analyzed for sediment (Gray et al., 2000). Another important consideration is that samples were collected during different rainfall years. Despite these limitations, this set of existing data is the only means by which general regional comparisons can be made.

The Watsonville median data were mostly between the range of 10 to 100 mg/L, as was the case for many of the sites in the region with the exception of some sites within the Castroville/Salinas drainages and on Salinas River northern tributaries that had median values greater than 100 mg/L. Median values greater than 1,000 mg/L were observed at 4 sites within the region on Chualar, Quail, Gabilan, and San Lorenzo Creeks. Only 12 sites in the region (STR-HAR, 6 sites on the Pajaro River mainstem, and 5 sites on Salinas River southern tributaries Arroyo Seco, Nacimiento, and Atascadero) had median values less than 10 mg/L. Overall, the Watsonville data compare most closely with data from the nearby Pajaro River and its many tributaries. This is not surprising given that the Pajaro watershed has a quite similar mix of land uses in its more coastal and northern parts (the southern and eastern parts are much drier grasslands and shrublands).

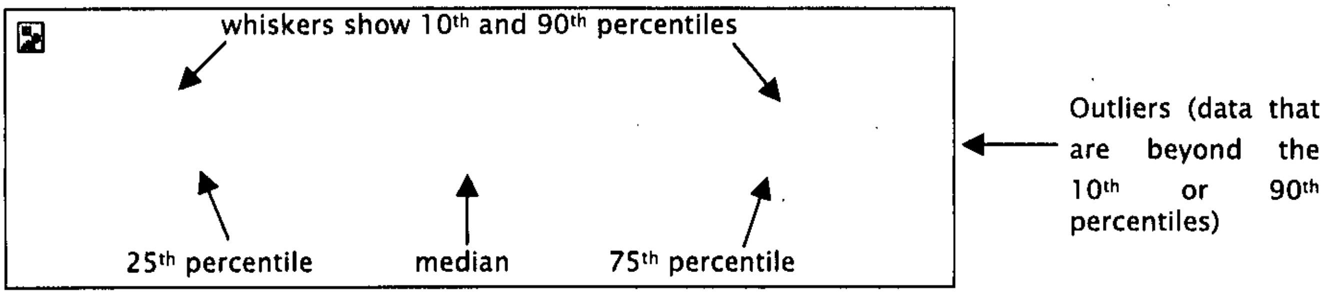


Figure 5.15 **Whisker plot schematic**

The relative propensity of a watershed to yield sediment load is perhaps better described by its sediment load per unit watershed area, rather than just the sediment load per se. Thus, a better regional comparison is obtained by plotting load per unit area against discharge per unit area, as in Figure 5.17. The Figure compares all existing Watsonville Sloughs data with data from eight USGS sites. Although site selection for the comparison was limited by the amount of both discharge and suspended sediment data that were available, the eight selected sites are representative of the region. A brief description of the sites is given in Table 5.10. The Watsonville data points fall predominantly below the regional pattern, with the exception of a few isolated data points as described earlier. Exceptions to this were 2 samples at HAN-HAR and 1 sample at GAL-BUE that were mentioned previously. Some of the highest loads were observed at SAL-CHU and Clear Creek. Biases to these results include the small dataset, runoff rates, and hydraulic control structures.

This leads us to characterize suspended sediment sources at Watsonville as being relatively low for mixed land-use watersheds, with the exception of isolated sites and isolated cases where sediment load is excessive. It is uncertain if these exceptions are systematic - such as being due to certain events from specific land uses above Gallighan Slough, or severe de-vegetation by cattle such was apparent in the small watershed above Hanson Slough - or random, being equally likely to occur anywhere throughout the system.

Table 5.10 CCoWS/CCAMP Site Codes for Regional Comparison

Waterway	CCoWS Site ID	CCAMP Site ID	Site Description	Sampled By
Watsonville Slough	WAT-ERR		Watsonville Slough at Errington Rd	CCoWS
Pajaro River Mainstem	PAJ-MCG	305THU	Pajaro River at McGowan Rd/Thurwachter Bridge	CCAMP
	PAJ-MUR	305MUR	Pajaro River at Murphy's Creek Rd	CCAMP
	PAJ-CHI	305CHI	Pajaro River at Chittenden Rd	CCAMP
	PAJ-BET	305PAJ	Pajaro River at Betabel Rd	CCAMP
Pajaro River Tributaries	MIL-FRA	305FRA	Miller Canal at Frazier Lake Rd	CCAMP
	SAW-RIV	305COR	Salsipuedes Creek at Riverside Rd	CCAMP
	SBR-156	305SAN	San Benito River at Hwy 156	CCAMP
	TRE-SOU	305TRE	Tres Pinos Creek at Southside Rd	CCAMP
	CND-BLO	305UVA	Carnadero Creek at Bloomfield Ave	CCoWS & CCAMP
	UVA-LUC		Uvas Creek at Lucchessa ave	CCoWS
	LLA-BLO	305LLA	Llagas Creek at Bloomfield Ave	CCAMP
	LLA-LUC	305LUC	Llagas Creek at Lucchessa Ave	CCAMP
	LLA-HOL	305HOL	Llagas Creek at Holsclaw Rd	CCAMP
	LLA-MCR	305MON	Llagas Creek at Monterey County Rd	CCAMP
	LLA-OGA	305OAK	Llagas Creek at Oak Glen Ave	CCAMP
	LLA-CHE	305CHE	Llagas Creek at Chesbro Reservoir	CCAMP
	TES-FAI	305TES	Tequisquita Slough at Fairview Rd	CCAMP
	PAC-LOV		Pacheco Creek at Lover's Lane	CCoWS
	PAC-156	305PAC	Pacheco Creek at Hwy 156	CCAMP
	PAC-WAL		Pacecho Creek at Walnut Ave	CCoWS
Castroville-Salinas Drainages	CAW-BOL	306CAR	Carneros Creek at Blohm Rd	CCAMP
	MCS-MOS	306MOS	Moro Cojo Slough at Moss Landing Rd	CCAMP
	MOS-SAN		Moss Landing at Sandholdt Rd	CCoWS
	OLS-POT	309POT	Old Salinas River at Potrero Rd (Tide Gates)	CCoWS & CCAMP
	OLS-MON	309OLD	Old Salinas River at Monterey Dunes Colony Rd	CCAMP
	TEM-MOL	309TDW	Tembladero Slough at Molera Rd	CCAMP
	TEM-PRE	309TEM	Tembladero Slough at Preston Rd	CCAMP
	EPL-EPL		Espinosa Lake	CCoWS
	EP1-ROG		Tributary to Espinosa Lake at Rodgers Rd	CCoWS
	REC-183		Reclamation Ditch at Hwy 183	CCoWS
	REC-JON		Reclamation Ditch at San Jon Rd	CCoWS
	REC-BOR	309ALD	Reclamation Ditch at Boronda Rd	CCAMP
	REC-VIC		Reclamation Ditch at Victor Rd	CCoWS
	GAB-VET		Gabilan Creek at Veterans Park bridge	CCoWS
	GAB-BOR	309GAB	Gabilan Creek at Boronda Rd	CCoWS & CCAMP
	GAB-NAT		Gabilan Creek at Natividad Rd	CCoWS
	GAB-HER		Gabilan Creek at Hebert Rd	CCoWS
	GAB-CRA		Gabilan Creek at Crazy Horse Rd	CCoWS
	GAB-OSR		Gabilan Creek at Old Stage Rd	CCoWS
	BOC-OSR		'Big Oak Creek' at Old Stage Rd (tributary to Towne Creek)	CCoWS
	TOW-OSR		Towne Creek at Old Stage Rd	CCoWS
	ALI-AIR	309ALU	Alisal Creek at Airport Rd	CCAMP
	ALI-OSR	309UAL	Alisal Creek at Old Stage Rd	CCAMP

Waterway	CCoWS Site ID	CCAMP Site ID	Site Description	Sampled By
Salinas River Mainstem	SAL-MON	309SBR	Salinas River at Del Monte Rd	CCoWS & CCAMP
	SAL-BLA		Salinas River at Blanco Rd	CCoWS
	SAL-DAV	309DAV	Salinas River at Davis Rd	CCoWS & CCAMP
	SAL-SPR		Salinas River at Hwy 68	CCoWS
	SAL-CHU	309SAC	Salinas River at Chualar River Rd	CCoWS & CCAMP
	SAL-GON		Salinas River at River Rd near Gonzales	CCoWS
	SALL-GRE	309GRN	Salinas River at Greenfield	CCoWS & CCAMP
	SAL-KIN	309KNG	Salinas River at King City	CCoWS & CCAMP
	SAL-BRA	309USA	Salinas River at Bradley Rd	CCoWS & CCAMP
	SAL-CAT	309DSA	Salinas River along Cattleman Rd	CCAMP
	SAL-CRE	309PSO	Salinas River at Creston Rd	CCoWS & CCAMP
	SAL-H41	309SAT	Salinas River at Hwy 41	CCAMP
Salinas River Northern Tributaries	BLA-PUM		Blanco Drain at pump station	CCoWS
	BLA-COO		Blanco Drain at Cooper Rd	CCoWS
	DRN-DAV	309SDR	Storm drain 300m upstream from Davis Rd	CCAMP
	QUA-POT	309QUA	Quail Creek at Potter Rd	CCAMP
	CHU-CRR		Chualar Creek at Chualar River Road	CCoWS
	CHU-FOL		Chualar Creek at Foletta Road	CCoWS
	CHU-OSR		Chualar Creek at Old Stage Road	CCoWS
	CH1-RWY		Tributary to Chualar Creek at railway culvert	CCoWS
Salinas River Southern Tributaries	ARR-ARR		Arroyo Seco River at Arroyo Seco Rd	CCoWS
	ARR-THO	309SET	Arroyo Seco River at Thorne Rd	CCoWS & CCAMP
	ARR-ELM	309SEC	Arroyo Seco River at Elm Rd	CCoWS & CCAMP
	SLC-FIR		San Lorenzo Creek at First St	CCoWS
	SLC-BIT	309LOR	San Lorenzo Creek along Bitterwater Rd	CCoWS & CCAMP
	ANT-101	309SAN	San Antonio River at Hwy 101	CCAMP
	NAC-101	309NAC	Nacimiento River at Hwy 101	CCAMP
	CHO-BIT	317CHO	Cholame Creek at Bitterwater Rd	CCAMP
	ATA-H41	309ATS	Atascadero Creek at Hwy 41	CCAMP

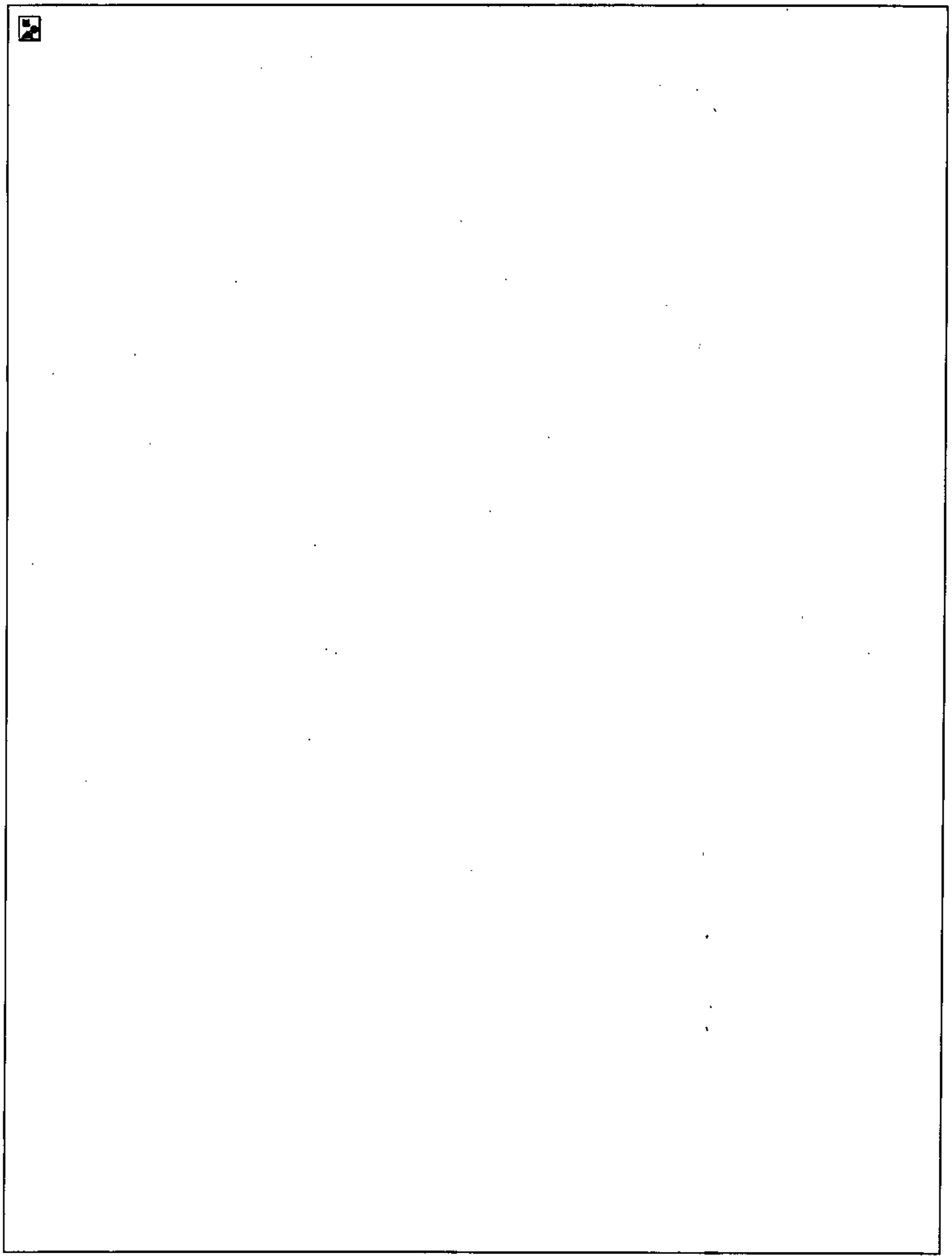


Figure 5.16 Regional suspended sediment levels (CCoWS and CCAMP data). Whisker plots highlighted in pink are CCoWS sites for which samples were collected duing both the rainy and dry season. Whisker plots highlighted in teal are CCoWS sites for which samples were collected primarily during storm events. Whisker plots highlighted in yellow include a combination of CCoWS and CCAMP data that were collected that are a mixture of ambient and storm sampling. Whisker plots highlighted in gray are CCAMP sites for which the data were collected approximately monthly. CCoWS data are SSC and CCAMP data are TSS (concerns with these differences are discussed in Section 3.1).

Table 5.11 Site information

Site	USGS ID	County	Drainage area (sq miles)	Percipitation ID (WRCC 2004)	Date of percipitation data	Avg annual ppt (in)	General character relative to other sites
Lopez Creek	11141280	San Luis Obispo County	21	SAN LUIS OBISPO POLYTEC (047851)	1 Jul 48 to 31 Jul 03	23.34	coastal drainage; mostly natural lands within Los Padres National Forest; some grazing on private lands; mix of vegetation types
				PISMO BEACH (046943)	1 Jul 49 to 31 Jul 03	17.21	
				TWITCHELL DAM (049111)	1 Mar 62 to 31 Jul 03	16.49	
Clear Creek	11154700	San Benito County	14	HOLLISTER (044022)	1 Jan 35 to 31 Oct 74	13.52	inland drainage; mostly natural lands with some other land uses such as recreation, mining, and agriculture; mix of vegetation types
				PINNACLES NM (046926)	1 Jul 49 to 31 Jul 03	16.53	
Corralitos Creek	11159200	Santa Cruz County	28	WATSONVILLE WATERWORKS (049473)	1 Jul 48 to 31 Jul 03	22.35	coastal drainage; redwoods in the upper watershed; combination of agriculture and urban in the lower watershed
				SANTA CRUZ, CALIFORNIA (047916)	1 Jul 48 to 31 Jul 03	30.48	
Soquel Creek	11160000	Santa Cruz County	40	SANTA CRUZ, CALIFORNIA (047916)	1 Jul 48 to 31 Jul 03	30.48	coastal drainage; redwoods in the upper watershed; urban in the lower watershed
Pajaro River @ Chittenden	11159000	Santa Cruz County	1,186	GILROY (043417)	16 May 57 to 31 Jul 03	20.77	very large drainage; diverse mixture of land use and vegetation types; contains several dense urban areas such as Gilroy, Hollister, and Morgan Hill
				HOLLISTER (044022)	1 Jan 35 to 31 Oct 74	13.52	
REC-JON	11152650	Monterey County	53	Salinas Airport (047669)	14 Jun 30 to 31 Jul 03	13.2	coastal drainage; predominantly agriculture and dense urban in the lower watersehd; grazing and natural lands in the upper watershed
OLS-POT	none	Monterey County	157	Salinas Airport (047669)	14 Jun 30 to 31 Jul 03	13.2	coastal drainage; tidally influenced; predominantly agriculture and dense urban in the lower watersehd; grazing and natural lands in the upper watershed
SAL-CHU	11152300	Monterey County	4,042	King City	1 Jan 27 to 31 Jul 03	11.15	very large drainage; variety of land uses with small scale urban centers such as Soledad, Greenfield, and King City; variety of vegetation types
GAL-BUE	none	Santa Cruz County	3	WATSONVILLE WATERWORKS (049473)	1 Jul 48 to 31 Jul 03	22.35	small drainage; predominantly agriculture, rural residential, and landfill
HAR-RAU	none	Santa Cruz County	15	WATSONVILLE WATERWORKS (049473)	1 Jul 48 to 31 Jul 03	22.35	small drainage; variety of land uses including grazing, rural residential, and agriculture
HAN-HAR	none	Santa Cruz County	<1	WATSONVILLE WATERWORKS (049473)	1 Jul 48 to 31 Jul 03	22.35	very small watershed; land uses grazing and agriculture
STR-CHE	none	Santa Cruz County	<1	WATSONVILLE WATERWORKS (049473)	1 Jul 48 to 31 Jul 03	22.35	very small watershed; land uses urban
WAT-LEE	none	Santa Cruz County	5	WATSONVILLE WATERWORKS (049473)	1 Jul 48 to 31 Jul 03	22.35	small watershed; land uses urban, industrial, and agriculture
WAT-ERR	none	Santa Cruz County	4	WATSONVILLE WATERWORKS (049473)	1 Jul 48 to 31 Jul 03	22.35	small watershed; land uses urban, industrial, and agriculture

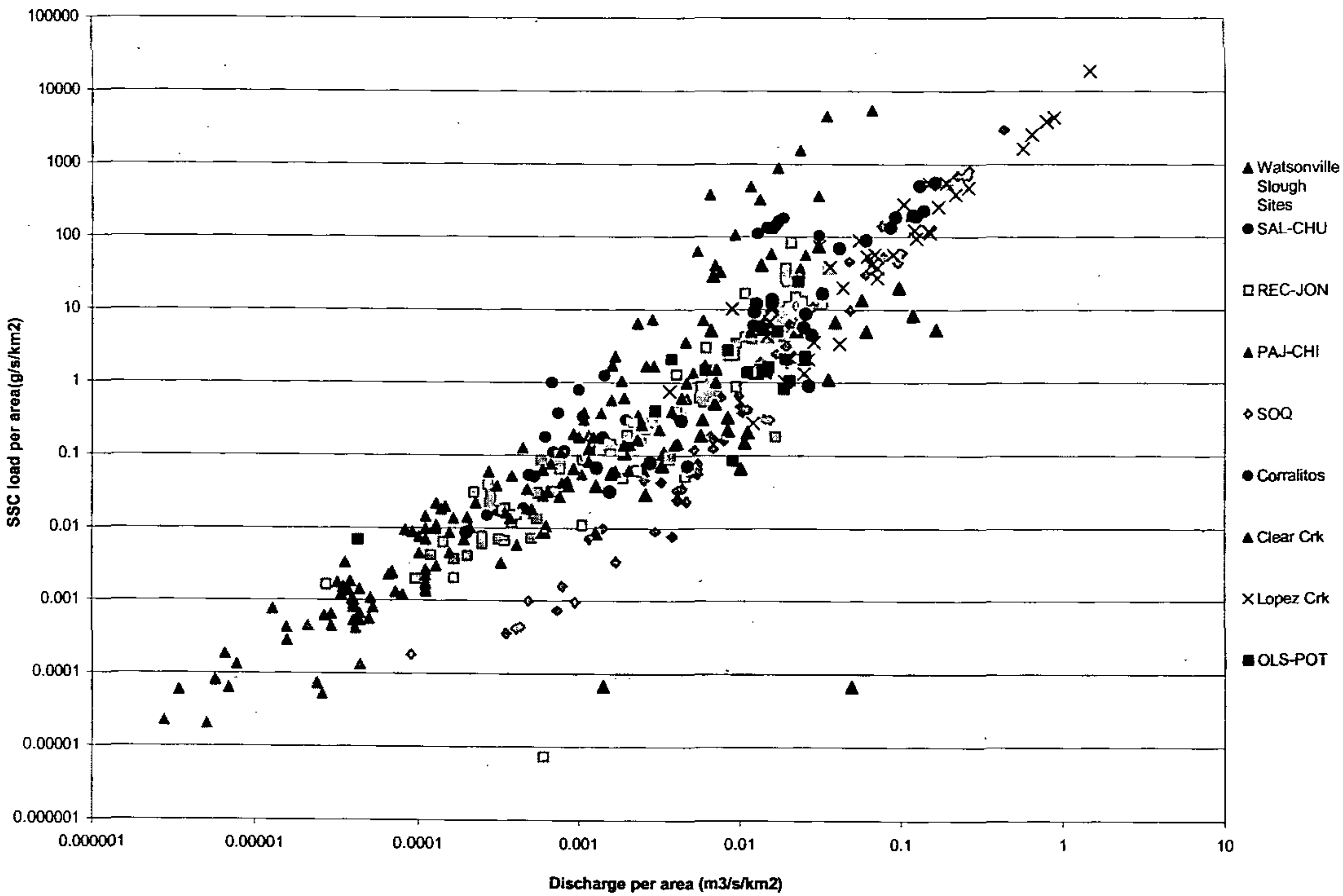


Figure 5.17 Regional comparison of SSC load per area vs Discharge per area. Sediment data for Watsonville Sloughs sites, SAL-CHU, REC-JON, and OLS-POT were collected by CCoWS. All other sediment data were collected by USGS.

5.6 Suspended Sediment Problems

Since the Basin Plan objectives for suspended sediment are narrative and turbidity objectives rely on knowing background levels, the following sediment and turbidity categories were used as a guideline to determined potential impacts to aquatic organisms.

- **up to 2 NTU (turbidity) or 10 mg/L (SSC)**: not likely to adversely affect fish and invertebrates
- **up to 20 NTU (turbidity) or 100 mg/L (SSC)**: potential change in behavior and/or slight decrease in survival
- **up to 200 NTU (turbidity) or 1,000 mg/L (SSC)**: stress, physiological changes, and potentially lethal effects

Average and median suspended sediment concentration for each of the Watsonville Sloughs sites was generally below 100 mg/L. Exceptions included WAT-PAJ, WAT-AND, WAT-LEE, GAL-BUE, and HAN-HAR during the rainy season and only WAT-PAJ during the summer campaign. Only 2 sites, GAL-BUE and HAN-HAR, (3 of 88 winter SSC samples) had levels greater than 1,000 mg/L. Except for the levels measured on these 3 occasions, the suspended sediment concentrations generally ranged from 10 mg/L to 100 mg/L. According to the levels outlined above, these general levels observed in Watsonville Sloughs could have mild effects on fish and aquatic invertebrates, but significant physiological changes and lethal effects would not generally be expected. This of course is dependent on other factors such as duration. The only sites where sediment sources may be a problem based on high winter SSC values and deviation from the suspended sediment load vs. discharge relationship are HAN-HAR and GAL-BUE. Monitoring large storm events such as the one in December, which was not monitored due to project timing, may detect other problematic areas, but without sufficient runoff and stream flow, identifying sediment sources may not be possible.

In comparison to other areas in the region, SSC values detected in Watsonville Sloughs were similar. Many of the regional sites had median suspended sediment values that were less than 100 mg/L. Exceptions to this trend occurred at many of the sites in the Castroville/Salinas drainages and northern tributaries to the Salinas River. When suspended sediment load per unit area data were plotted against discharge per unit area, Watsonville data points were predominantly below the regional pattern, with the exception of a few data points from Hanson and Gallighan sloughs.

In summary, with the exception of Hanson and Gallighan sloughs, lethal effects due to the suspended sediment levels observed in Watsonville Sloughs would not generally be expected. Furthermore, levels observed for Watsonville Sloughs are similar, and in some cases such as in Castroville/Salinas drainages, even much lower than levels observed regionally.

5.7 Critical Conditions and Seasonal Variation

5.7.1 Critical conditions

The conditions that are critical for a determination of sediment impairment of beneficial uses of Watsonville Sloughs are unknown. However, the best information available suggests that these conditions may include any one of the following occurring in an aquatic habitat within one of the sloughs (i.e. sluggish water, not streams):

- SSC
  - Continuous SSC above 100 mg/L
  - Shorter periods (e.g. one week) of SSC above 1,000 mg/L
- Turbidity
  - Continuous turbidity above 2 NTU
  - Shorter periods (e.g. one week) of turbidity above 200 NTU
- Sedimentation rates
  - Widespread accumulations of over 5 mm from a single storm
  - Long-term (e.g. decadal) sedimentation rates more than twice the pre-European rate, i.e. 2 x 5 mm/yr = 10 mm/yr
  - Long-term net aggradation of the entire slough system (e.g. such as would lead to an accelerated geomorphic and vegetation succession toward a more terrestrial state than the pre-historic geomorphic configuration of the system)

These conditions have been arbitrarily chosen based on our knowledge of the system and the literature discussed earlier. In order to confirm impairment of beneficial uses of Watsonville Sloughs, long-term (multiple rainfall/runoff years), more intensive monitoring would need to be conducted in the sloughs.

5.7.2 Seasonal variation

The variability of SSC within a given season may often be high due to differences in flow and timing of runoff, non-point source sediment contributions, and field sampling. Despite this variability, it would be expected that SSC values for the summer months would be lower than in winter months due to reduced runoff and stream flow, and therefore reduced ability to transport sediment. By just examining the summer and winter SSC means for each sampling site, 5 of 12 sites appeared to have higher SSC in the summer than in winter. The physical interpretation of this is not clear, so a series of t-tests (one for each site) were performed to test for differences in means for the two datasets. Since the population variance for the two datasets was unknown, a series of f-tests were first run to determine if the population variances differed. A pooled estimate for the standard deviation was calculated and used in the t-test for sites that were assumed not to have statistically different population variances. SSC was assumed to be log-normally distributed; therefore the t-tests were performed on log-transformed data. Only two sites could be shown to be different with 95% confidence. WAT-AND and HAR-HAR were found to be statistically different in winter and summer. SSC at WAT-AND was lower in the summer, whereas SSC at HAR-HAR was higher during the summer months. Increased SSC levels at HAR-HAR may be due to increases in phytoplankton as opposed to mineral suspended sediment/solids. During all summer visits to the site, the water had a greenish coloration and filters were often green as well.

In general, summer instantaneous loads were much lower than for winter. Variation in suspended sediment load for a given site appears to be primarily determined by variation in discharge. Only one site had similar discharges in summer and winter (STR-CHE), and at this site there did not appear to be any variation in load that was independent of discharge.

6 Sedimentation Results & Discussion

The investigation of sedimentation in Watsonville Sloughs involved several methods. The two primary approaches were: 1) reconnaissance to identify locations where sedimentation may be a problem, and 2) determination of long-term sedimentation rates. The determination of long-term sedimentation rates involved a historical review, aerial photo interpretation, determination of past and present sedimentation rates by dating of sediment cores, and estimates of subsidence rates.

6.1 Reconnaissance

The second monitoring approach for sediment involved conducting sediment accumulation surveys throughout the Watsonville Sloughs. The surveys consisted of field observations throughout the watershed and photo documentation of areas with visible sediment accumulation or supply. The reconnaissance included visual observations made at sampling sites during the exceedance monitoring and a walk along the railway line, which follows Gallighan Slough and intersects many of the potential flow pathways from agricultural areas down into both Gallighan and Harkins Sloughs.

During several watershed reconnaissance trips early in the project and also during the 10 major sampling runs, each of the 13 sites was visually inspected for signs of sediment accumulation and/or erosional features. Previous studies have suggested that potential problem areas for erosion and sediment accumulation are most likely to be Harkins, Gallighan Slough, and Hanson Slough. The terrain of Harkins and Gallighan Slough is steeper and more erodable than most other areas throughout the Watsonville Sloughs watershed (Questa, 1995). Much of this steep land is currently under agricultural production and without appropriate management practices could supply significant amounts of sediment to the surrounding water bodies. However, during the reconnaissance, management practices to reduce sediment delivery to the sloughs, such as sediment basins, grassed drainages, and grassed roadways, were often observed in visible areas of the steep agricultural lands (Figure 6.1 to 6.2). Although many of the agricultural operations in the area may extend up to the border of the sloughs, the extent of sediment delivery to the sloughs could not be determined. Many agricultural operators in the area may or may not have sediment management practices in place but that information is unknown without access to the lands. The surveys did not reveal any obvious signs of sediment input directly from the agricultural lands.

During visits to Hanson Slough, visible sediment accumulation was observed in the channel at site HAN-HAR (Figure 6.3). This accumulation is the result of deposition during receding flows. The magnitude of the sediment deposition may be a result of intensive grazing upstream and the lack of riparian vegetation (Figure 6.4).

Considerable sediment deposition was also observed in upper Gallighan Sloughs and tributary drainage ditches along Buena Vista Road (Figures 6.5 and 6.6). These locations were also noted as problems areas for sediment accumulation by Swanson Hydrology and Geomorphology (2003) and Questa (1995).

In addition to reconnaissance at the primary monitoring sites, the railway line which runs along Gallighan and Harkins Slough was walked on 7 Mar 03. Steep hill slopes border to the west of the railway, and several small tributary drainages crossed under the railway. These drainages were well buffered with Eucalyptus and abundant riparian vegetation. The primary land use of the western slopes is agriculture, but the lands were not visible from most of the railway. There were several small erosional features along the railway, but they did not appear to be a major source of sediment to the slough. There were no obvious signs of sediment delivery or accumulation in this area.

With the exceptions of Hanson Sloughs and upper Gallighan Sloughs, there were no other obvious signs of sediment accumulation observed throughout the watershed during site visits. The ponded areas of Watsonville, Harkins, and Struve Sloughs were inundated with water during site visits, and therefore no evidence of accumulation on road crossing/culverts or buried aquatic vegetation was visible.

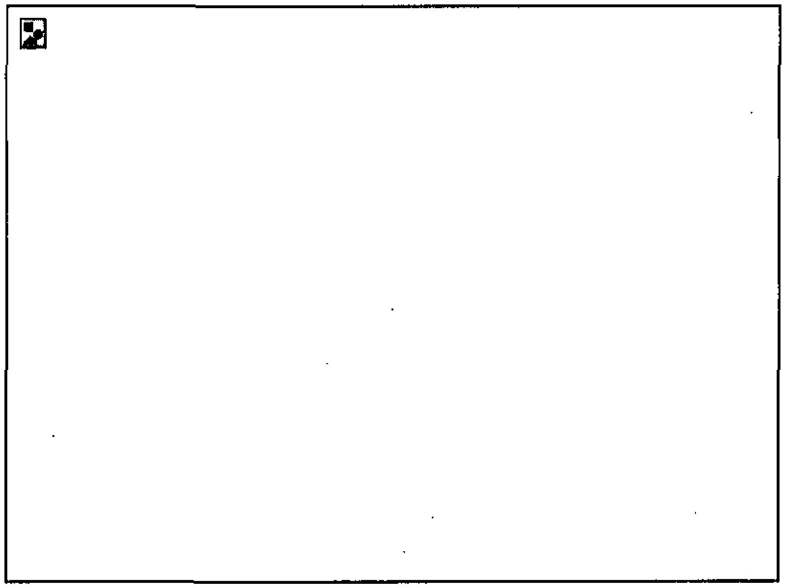


Figure 6.3 Sediment accumulation at sampling site HAN-HAR. (Photo: J. Hager Feb 03)

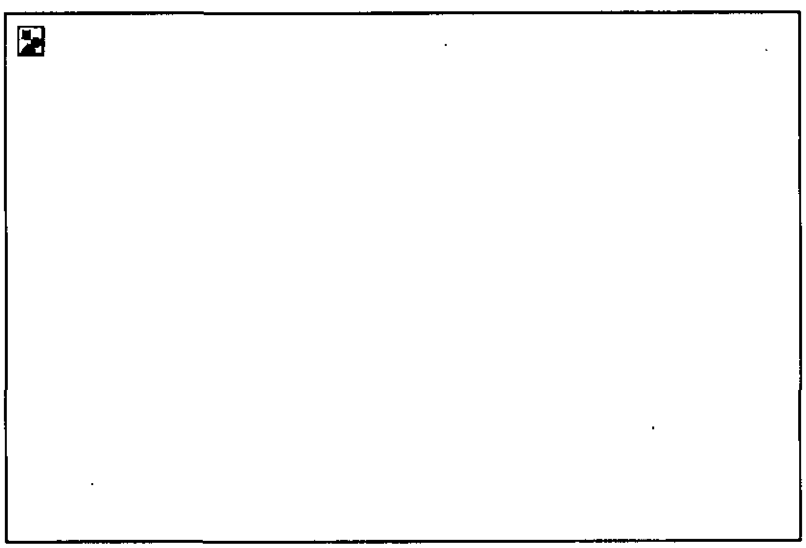


Figure 6.4 Hanson Slough upstream of HAN-HAR. Note absence of riparian vegetation likely due to intense grazing operations. (Photo: F. Watson Nov 02)

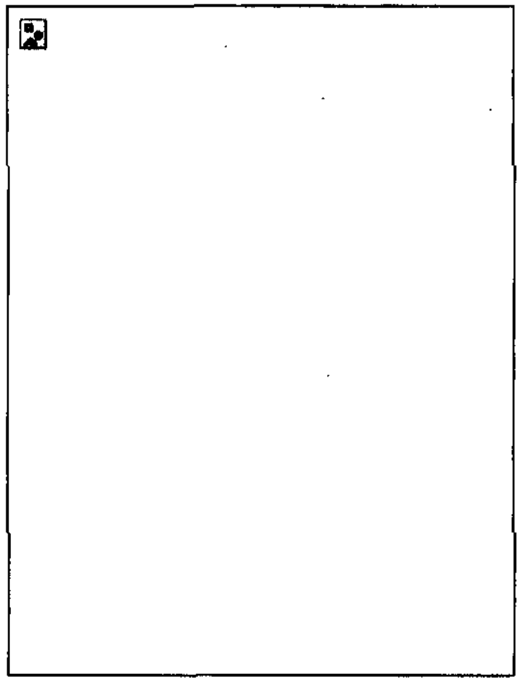


Figure 6.5 Sedimentation in Gallighan Slough along Buena Vista Drive just downstream of Whiskey Hill Road. (Photo: J. Hager Feb 05)

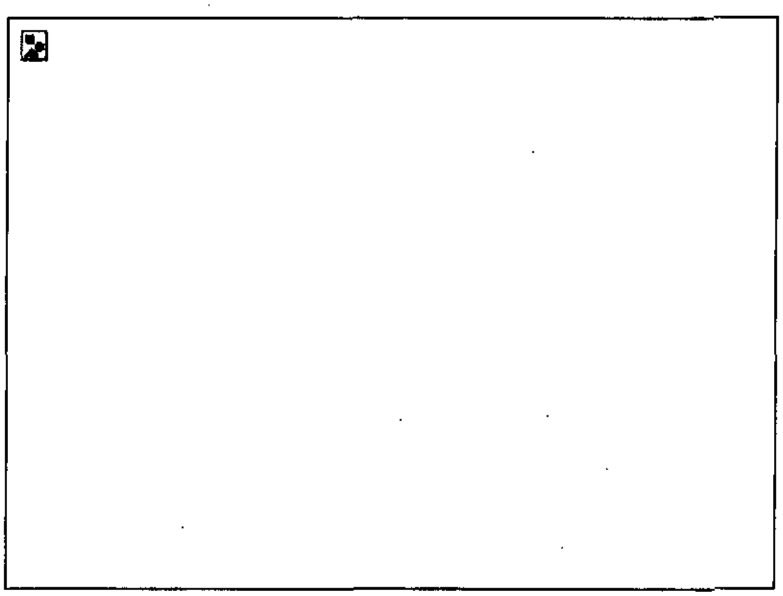


Figure 6.6 Sedimentation in tributary drainage to Harkins Slough along Buena Vista Drive near the entrance to the County Landfill. (Photo: J. Hager Feb 05)

6.2 Analysis of long-term sedimentation rates

Given the short time-frame of the study and the inability to effectively visually document the extent of sedimentation (which is often episodic) in the sloughs, a study to determine long-term sedimentation rates in the sloughs was undertaken.

Sediment core chronology was constructed using a combination of dating techniques including accelerator mass spectrometry radiocarbon dating, pollen analysis, diatom analysis, sediment chemistry (including anthropogenic lead), and lead-210 (subcontractor report given in Appendix H-UC Berkeley Coring Study). Cores were also analyzed for water, organic and carbonate content, magnetic susceptibility, and grain size. Based on the likely dates of introduction into the Watsonville area, the first appearance of non-native plant pollen in sediment cores were used as chronological markers.

Supplemental work was conducted in support of the sediment coring study. This work included a detailed historical review including determination of the likely dates of introduction of non-native plant pollen such as *Erodium cicutarium*, *Eucalyptus globulus* and certain species of *Plantago* and *Rumex* into the Watsonville Sloughs area, aerial photograph interpretation to document major changes in the watershed, and estimation of subsidence rates to determine net sediment accumulation.

6.2.1 Historical Review

A historical literature review was conducted in order to determine approximate dates of non-native plant introductions and to gain a better understanding of change and development in the Watsonville area. A brief history of the region is given below and a general timeline is given in Table 6.5.

Costanoan/Ohlone Natives

The first inhabitants of the Watsonville area were the Costanoan/Ohlone natives. The Costanoans occupied the area from San Francisco Bay south to Big Sur and east to the Central Valley (Bean, 1994). It is suggested that coastal California was first occupied approximately 10,000 years ago (Meighan, 1965 as cited in Gordon, 1996). The Costanoans were a hunter and gathering society with acorns, grass seeds, fish, shellfish, waterfowl, and a variety of large and small mammals as major food sources (Bean, 1973 and Gordon, 1996). Agriculture was not known to be a major activity in the community (Bean, 1973). Burning of the landscape was a commonly used practice that promoted the growth of certain plants and facilitated hunting and the harvesting of grain (Gordon, 1996). It is estimated that at least 275,000 natives were living within the current boundary of California at the time of Spanish settlement in 1769 (Bean, 1973) and that the Costanoan population was approximately 11,000 at that same time (Gordon, 1996). Village sizes are thought to have ranged from 100 to 500 people (Bean, 1973).

There were several known settlements throughout the Monterey Bay region. Evidence of settlements and camps has been found along many coastal riparian areas as well as on the Pajaro Dunes (City of Watsonville, 2003). The tribulet that occupied the Watsonville region was the Calendaruc (Milliken, 2002). In 1975, a burial ground was located at Lee Road as the site was being excavated for construction of a warehouse. Five acres of the burial ground adjacent to the slough was given back to the native people (Orozco, 2002). Another excavation near Lakeview Middle School in Watsonville, archaeological site CA-SCR-44 near Kelly Lake, revealed the presence of an extensive village and burial ground. Radiocarbon dating for two samples from the site resulted in calibrated dates of 155-390 A.D. and 1,007-795 B.C. (Breschini and Haversat, 2000).

The Costanoans were the only known inhabitants of the Watsonville area prior to European exploration during the 16th century and Spanish and Mexican settlement in the late 18th century.

Early European Exploration

The first European explorer to reach upper California, referred to earlier as 'Alta California', was Juan Rodríguez Cabrillo. In 1542, the Cabrillo expedition arrived in San Diego and explored several areas to the north up to Point Conception (Bean, 1973). In 1595, the expedition led by Sebastián Rodríquez Cermeño arrived in Drake's Bay, north of San Francisco. The expedition sailed south from Drake's Bay and may have been the first to discover Monterey Bay (Bean, 1973). The next explorer to visit the Monterey Bay region was Vizcaíno in 1602 (Bean, 1973). However, the most extensive exploration of the Monterey Bay region, and the first documentation of the Pajaro Valley, was by the Portolá-Serra expedition in 1769, which is described in more detail below.

Spanish and Mexican Settlements

In 1767, control of the Spanish missions of Baja California, formerly led by the Jesuits, was granted to the military led by General José de Gálvez and Captain Gaspar de Portolá and the Franciscans under the guidance of Father Junípero Serra. Together the leaders organized a missionary expedition to Alta California with Father Crespi as chaplain and diarist (Bean, 1973). On October 6th through 10th,1769, the Portola-Serra expedition explored the Pajaro River and Watsonville area (Bolton, 1927). Based on excerpts from the diary of Fray Juan Crespi transcribed by Bolton, exploration of the Pajaro area was documented as follows:

Friday, October 6–The explorers returned in the afternoon with very joyful news, saying that they had found a river (Pajaro River) with a great deal of verdure and Castilian trees, and that they had seen a point with many pines to the north, although it was learned afterwards that they had been mistaken of account of the heavy fog. They also saw tracks of large animals with cloven hoofs, and which they judged to be buffalo[2]*, and a populous village of heathen who were living in barracks or huts covered with grass. They said they must number more than 500 souls...*

Sunday, October 8–...we left the place (near Del Monte Junction, possibly Espinosa Lake) about eight in the morning, going north through hills higher than the preceding. At each bay formed by the land there was a lagoon of greater or lesser magnitude, which made it necessary for us to make many detours...We halted on the bank of the river which the explorers had discovered not far from the burned village, which was near its very verdant and pleasant plain, full of cottonwoods, alders, tall oaks, live oaks, and other species not known to us. We saw in this place a bird which the heathen had killed and stuffed with straw; to some of our party it looked like a royal eagle. It was measured from tip to tip of the wings and found to measure eleven spans. For this reason the soldiers called the stream Río del Pájaro, and I added the name of La Señora Santa Ana. I could not make observations on account of the fog.

Tuesday, October 10–About eight in the morning we set out northwest. We could not make march as long as was intended, because the sick men were worse, and each day their number increased so we must have traveled but little more than one league, over plains and low hills, well forested with very high trees of a red color, not known to us. They have a very different leaf from cedars, and although the wood resembles cedar somewhat in color, it is very different, and has not the same odor; moreover, the wood of the trees that we have found is very brittle. In this region there is a great abundance of these trees and because none of the expedition recognizes them, they are named redwood from their color. We stopped near a lagoon (College Lake or Pinto Lake, evidently), which has much pasture about it and a heavy growth of the redwoods. In this march many tracks of animals resembling those of domestic cattle have been encountered, and there is some discussion as to whether they may not be buffalo. Some very large deer have also been seen, which they call stags to differentiate them from ordinary deer. The droppings of some mule-like animals have also been found. Bands of them have been seen, and it is said that they are long-eared and have short, flat tails. In the lagoons many cranes are also seen...

Following the 1769 expedition, new missions were established throughout Alta California.

Table 6.1 is a partial list of the Spanish missions, founding dates, and the proximity to Watsonville. Small-scale agriculture, cattle and sheep ranching, construction of

[2] Based on published historic range maps for Bison (Reynolds et al., 2003), this was likely a misinterpretation.

elaborate churches and gardens, and conversion of the natives to Christianity were all integral parts of the Spanish missions.

Throughout the late 1700s and early 1800s Spanish missionary and military expansion in Alta California continued. Presidios were created in San Diego, Santa Barbara, Monterey, and San Francisco (Bean, 1973). From the late 1770s to the late 1790s, pueblos were created in San Jose, Los Angeles, and Branciforte near Santa Cruz (Bean, 1973). By 1781, there were approximately 600 people in Alta California, not including the native Costanoans, and within 50 years, the population grew by 5 times (Bean, 1973). Table 6.2, taken from Elliot (1879), lists the population and number of livestock for selected missions and pueblos in 1832.

Table 6.1 Spanish Missions in the Watsonville vicinity

Missions near Watsonville	Date Founded	Approx. Distance from Watsonville (Miles)
Mission San Carlos Borromeo de Carmelo	1770	30
Mission San Antonio de Padua	1771	90
Mission San Francisco de Asis	1776	90
Mission Santa Clara de Asis	1777	50
Mission Santa Cruz	1791	20
Mission Nuestra Senora de la Soledad	1791	50
Mission San Juan Buatista	1797	20
Mission San Jose de Guadalupe	1797	60

Table 6.2 Population and Livestock numbers for selected missions and pueblos

Mission or Pueblo Name	Population	Black Cattle	Horses	Sheep
Mission Santa Cruz	366	3,500	940	5,403
Presidio of Monterey	708	5,641	3,310	-
Villa de Branciforte	130	1,000	1,000	-
Mission San Juan Buatista	987	7,070	401	7,017
Mission San Carlos Borromeo de Carmelo	236	2,050	470	4,400
Mission Nuestra Senora de la Soledad	334	6,599	1,070	6,358
Mission San Antonio de Padua	671	5,000	1,060	10,000
Mission San Miguel Arcangel	748	3,762	940	8,990
Mission San Luis Obispo de Toloso	329	2,000	800	1,200
Total	4,509	36,632	9,991	43,468

Mexico gained independence from Spain in 1821 (Bean, 1973) and an order for secularization of the missions was given by the Mexican government in the early 1830s

(Breschini, 1983). In the years prior to and following secularization, land was granted from the Mexican government and ranchos were formed throughout California with cattle ranching as the primary industry. Mexican land grants within the vicinity of Watsonville are given in Table 6.3 (Lydon, 1989). By 1847, 40 people had ranchland claims for grazing (City of Watsonville, 2003).

Table 6.3 Mexican land grants in the Watsonville vicinity

Land Grant	Acreage
Aptos	6,686
Bolsa del Pajaro	5,496
Los Corralitos	15,400
Salsipuedes	31,201
San Andreas	8,912
Vega del Rio del Pajaro	4,310

City of Watsonville

In 1852 the town of Watsonville was founded on the eastern portion of the Bolsa del Pajaro (Lewis, 1976). On March 30,1868 Watsonville was incorporated as a village and was later incorporated as a city in 1903 (Hayward, 1931). Following the founding of Watsonville in the early 1850s, the population increased steadily as did agriculture. shows that by 1853, lands surrounding lower Watsonville Slough in the current Beach Road area were in agricultural production.

Rapid expansion in farming throughout the Watsonville area occurred in the period of the late 1800s to early 1900s. The population of Watsonville grew from approximately 460 in 1860 (Atkinson, 1934) to more than 2,000 in 1871 (Lewis, 1976). Figure 6.7 shows population growth from 1860 to 2000. The number of registered farms in the Pajaro region increased from 181 in 1860 to 425 in 1910 (Rand, 1989). In 1851, the primary crops were barley, wheat, and potatoes, but soon after there was a shift to new crops such as apples, prunes, hops, strawberries, and lettuce. The first apple orchard, along with apricots, pears, and peaches, was planted in 1854 (Kegebein et al., 1989). The first commercial planting of strawberries in the Pajaro Valley occurred in 1865 and by the late 1880's the valley was the center of strawberry production (Cooley, 1989). Sugar Beets were planted in the 1870s and 1880s (Cooley et al., 1989), hops and prunes were grown in the 1880s and 1890s, and lettuce was first planted in 1914 (Boston et al., 1989). Commercial production of mushrooms began in the 1930s (Borg, 1989).

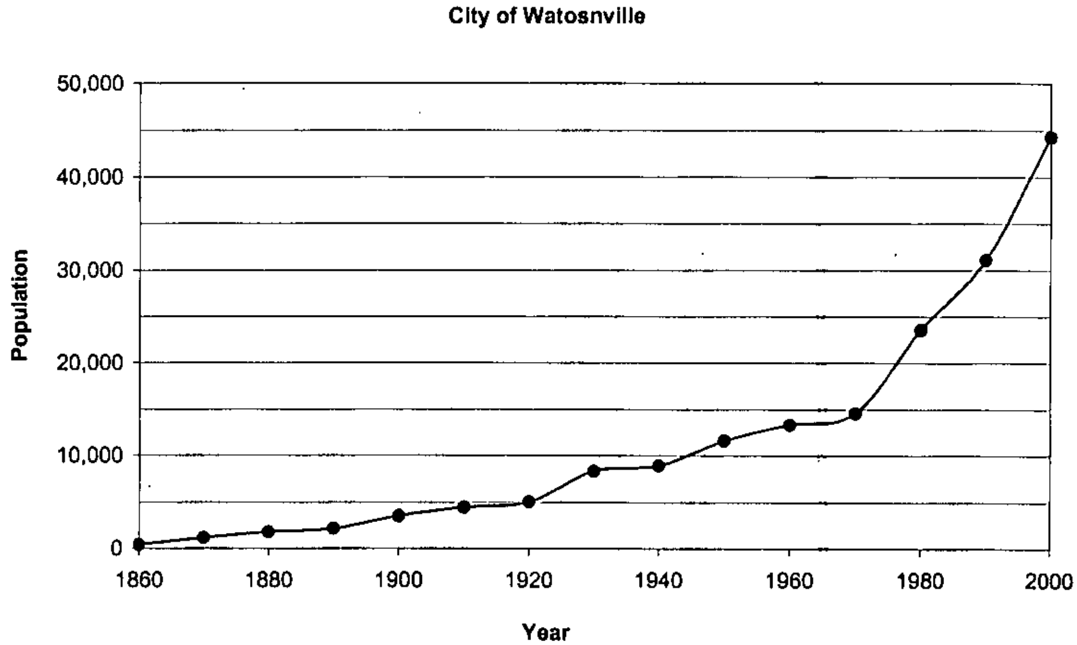


Figure 6.7 Population of the City of Watsonville from 1860 through 2000.

The construction of small ports and railway connections in the Watsonville area facilitated the shift from grain and potato crops to the more intensive crops such as lettuce and strawberries, for which the Pajaro Valley is famous. In 1868, a small shipping port, consisting of a wharf and warehouse, was started by Nelson and Goodall at the mouth of the Pajaro River (Lewis, 1978). Soon after, in 1871, the Southern Pacific Railroad connected Watsonville to the Santa Clara valley (City of Watsonville, 2004). Construction of railway lines by several different smaller companies continued as extensions and connections were made to Santa Cruz in 1876 (Schwing, 1999), Spreckels in 1897, and Salinas in 1906 (Anderson, 2000). In 1903, the Watsonville Transportation Company formed and constructed 'Port Rogers' near present day Sunset Beach. Railroad tracks were constructed from downtown Watsonville, along Beach Road to the port (Lewis, 1976). The port was damaged by a storm in 1904 but was later rebuilt as 'Port Watsonville' by the Watsonville Railway and Navigation Company in 1911 (Anderson, 2000). 'Port Watsonville' was destroyed by a storm in 1912 (Anderson, 2000).

By 1913, Southern Pacific Railroad had taken over the railway business of both freight and passenger services (Anderson, 2000). The Nelson and Goodall property at Pajaro Landing, 'Camp Goodall', was leased by Charles Ford in 1881 and a cottage, hotel, dance pavilion, and horse racetrack and stables were built near the present site of Pajaro Dunes Colony and Palm Beach (Lewis, 1978). The property was later purchased by Locke-Paddon in 1919 and the resort was named 'Palm Beach'. In 1931, a racetrack and grand stand for motorized racing was constructed (Lewis, 1978). The location 'Camp Goodall' is shown in the 1912 topographic map of the area, Figure 6.13, and remnants of the racetrack are visible in the 1952 aerial of lower Watsonville Slough given in Appendix G-Aerial Photos.

By 1931, the margins of Watsonville Slough had been drained and were in cultivation. A detailed study of the marsh and aquatic plants in the Pajaro region was conducted by Hayward in 1931. Hayward noted that lower Gallighan and Harkins Sloughs were also "cultivated extensively" (Hayward, 1931). The Shell Road pump station and tides gates were constructed in the early 1940's to prevent flooding of lowland areas and thus permitting cultivation in the Beach Road area (Swanson, 2003). Cultivation on the slough margins and channelization of the lowlands and sloughs is also evident in the series of aerial photographs presented in Appendix G-Aerial Photos. A more detailed analysis of historic aerial photographs was completed as part of this project and is given in Section 6.2.2.

Non-native Plant Introductions

It is thought that the combination of European exploration, the Mexican/Spanish settlement of California, and American settlement from the east during the Gold Rush years led to widespread introduction and spread of non-native and invasive plants such as *Erodium, Rumex, Plantago,* and *Eucalyptus.* The dates of likely introduction of these non-natives into the Watsonville area derived from this review and previous work by the subcontractors were used in the pollen analysis and construction of core chronology. The major botanical surveys and additional literature that were reviewed include the following:

- *A Catalogue of the Plants Growing in the Vicinity of San Francisco* (Bolander, 1870).
- *Botany Volume I.* (plant collections by the Geological Survey of California-Brewer et al., 1876).
- *Botany Volume II.* (plant collections by the Geological Survey of California-Watson, 1880).
- *Catalogue of Flowering Plants and Ferns of Santa Cruz County, California* (Anderson, 1892)
- *Eucalyptus Cultivated in the United States* (McClatchie, 1902).
- *The Marsh and Aquatic Plants of the Pajaro Valley* (Hayward, 1931).
- *The Plant Content of Adobe Bricks* (Hendry and Kelly, 1925)
- *An Approach to Southwestern Agricultural History through Adobe Brick Analysis* (Hendry and Bellue, 1936).
- *The Adobe Brick as a Historical Source* (Hendry, 1939).

- *That Fabulous Captain Waterman* (Weir, 1957).
- *Ruderal Vegetation Along Some California Roadsides* (Frenkel, 1970).
- *Watsonville: Memories That Linger* (Lewis, 1976).
- *Pre-mission invasion of Erodium cicutarium* (Mensing and Byrne, 1980).
- *Eucalyptus Helped Solve a Timber Problem: 1853-1880* (Groenendaal, 1983).

A brief summary of the introduction of these plants into the Central Coast region is given below.

Erodium cicutarium (redstem storksbill)

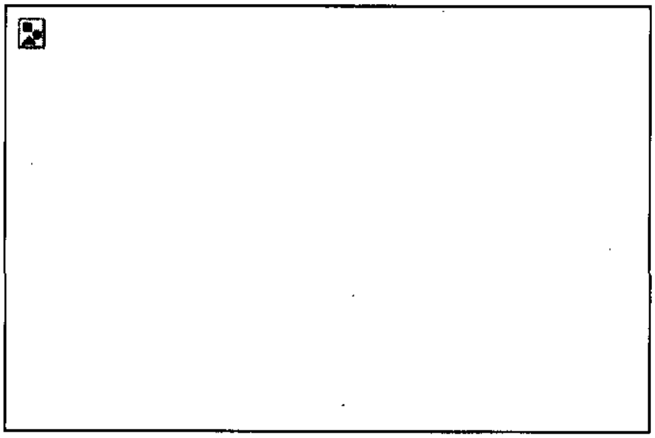


Figure 6.8 *Erodium sp.* Photograph by Charles Webber © California Academy of Sciences

Analysis of the plant content of adobe bricks by Hendry and Kelly (1925) revealed widespread presence of *Erodium cicutarium* (Fig. 6.8) throughout the region. *E. cicutarium* was found in adobe bricks from the following locations: Mission San Antonio (approximate date of construction-1787), Mission Nuestra Senora de la Soledad (approximate date of construction-1793 to 1797), Mission San Jose de Guadalupe (approximate date of construction -1811), Mission San Juan Bautista (1797), Rancho El Sansal near Salinas (approximate date of construction -1834), and La Natividad Rancho (approximate date of construction -1837). Furthermore, Hendry (1939) summarized the *E. cicutarium* was probably introduced into California in the pre-mission period prior to 1769. This theory was recently confirmed by Mensing and Byrne (1998) who demonstrated that *E. cicutarium* was present in Santa Barbara area prior the formation of the Spanish missionary expeditions in 1769. Presence of *E. cicutarium* in the San Francisco vicinity (area 100 miles to north and south) was documented by Bolander in 1870. *E. cicutarium* was documented as "very common throughout the State" by Brewer et al. (1876). *E. cicutarium* was also included in the catalogue of plants in Santa Cruz county by Anderson (1892). Based on the presence of *E. cicutarium* in adobe bricks of

Mission San Juan Bautista (1797), approximately 20 miles away from Watsonville, an assigned date of 1800 ± 20 years was used in the core chronology.

Rumex acetosella (Sheep sorrel)

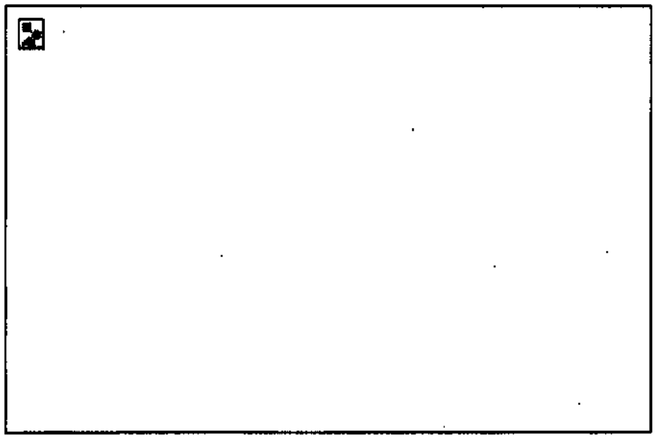


Figure 6.9 *Rumex acetosella.* Photograph by Charles Webber © California Academy of Sciences

Based on the results of adobe brick analysis by Hendry and Kelly (1925), two species of non-native *Rumex* were present in samples taken from multiple missions in the Watsonville vicinity. *Rumex crispus* was found at Mission La Soledad (approximate date of construction-1793 to 1797) and Rumex sp. (possibly Sheep Sorrel) was found at La Natividad Rancho (approximate date of construction-1837). Occurrence of *R. acetosella* (Fig. 6.9) was documented in the San Francisco vicinity (area 100 miles north and south of San Francisco) by Bolander in 1870. Based on studies by Hendry (1925 and 1936), Brewer et al. (1876), and Watson (1880), Frenkel listed the approximate period of entry of *R. acetosella* as the Mexican period (1825-1848). During surveys that began in 1860, *R. acetosella* was noted by Watson as "a very widespread weed" (Watson, 1880). *R. acetosella* was also noted as occurring in Santa Cruz county by Anderson in 1892.

A detailed survey of marsh and aquatic plants in the Pajaro Valley was conducted in 1928, 1929, and 1931 by Hayward. Hayward noted the presence of several species of *Rumex* in the Watsonville Sloughs area. *R. acetosella* was found in the area near Struve Slough and also surrounding several lakes near the town of Watsonville (Hayward, 1931).

Plantago lanceolata (English Plantain)

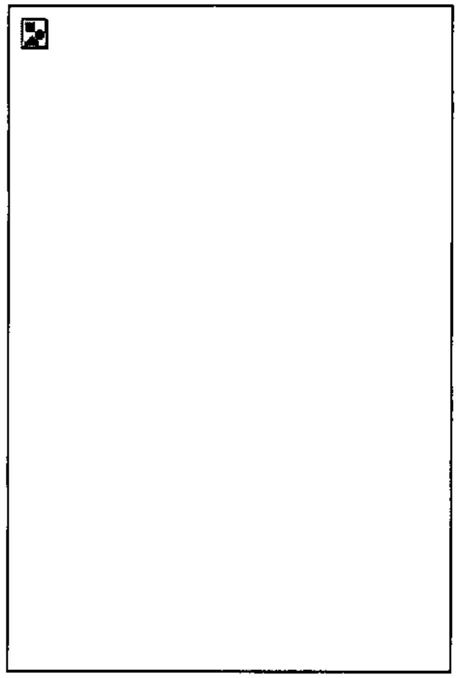


Figure 6.10 *Plantago lanceolata* Photograph © 2005 Louis-M. Landry.

Non-native species of Plantago were not noted in the Bolander's Plants of the San Francisco vicinity in 1870. Based on studies by Hendry (1925 and 1936), Brewer et al. (1876), and Watson (1880), Frenkel (1970) listed the approximate period of entry of the of *Plantago lanceolata* (Fig. 6.10) as the American period (1849-1860). In Brewer et al. (1876) *P. lanceolata* was described as not widely distributed and was collected near San Francisco (Brewer et al., 1876). *P. lanceolata* was also noted as occurring in Santa Cruz county by Anderson in 1892. Hayward (1931) documented *P. lanceolata* along upper Watsonville Slough, Struve Slough, and near Kelly Lake.

Eucalyptus (Eucalyptus)

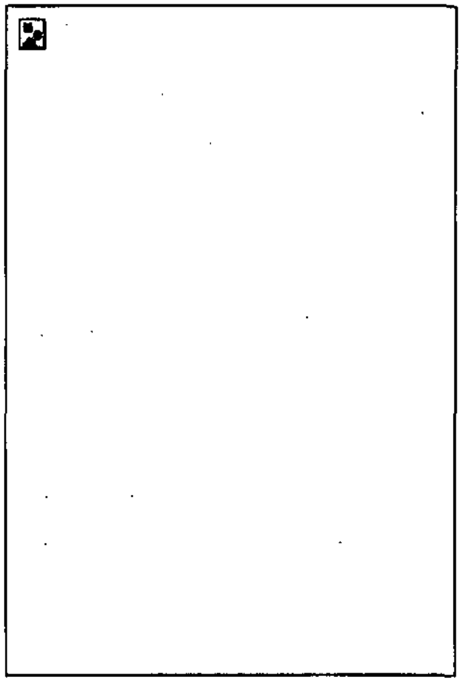


Figure 6.11 *Eucalyptus globulus* Photograph by Charles Webber © California Academy of Sciences

Unlike the three species listed above, *Eucalyptus globulus* (Fig. 6.11) was not present in adobe bricks analyzed by Hendry et al. (1925, 1936, and 1939). The introduction of *Eucalyptus* occurred during the Gold Rush and American settlement period. Several documents list 1853 and 1856 as the first dates for plantings of *Eucalyptus* in California, although there is some debate as to who actually planted the first *Eucalyptus* and the exact location. In the biography of clipper ship Captain Bob Waterman by Weir (1957), it is reported that in 1853 Captain Waterman requested that Jim Douglas bring back a bag of blue gum seeds from Australia. The seeds were then planted on Captain Waterman's farm in Suisun Valley in Solano County and were also given to new settlers to be planted throughout the surrounding region (Weir, 1957). McClatchie (1902) claimed that *Eucalyptus* was first introduced to California in 1856 by William C. Walker, a nursery owner from San Francisco and that 14 different species of *Eucalyptus* were planted in that year. Regardless of whether it was 1853 or 1856, it is well documented that Eucalyptus was present in the San Francisco Bay area in the 1850s. By the 1860s and 1870s, planting of the fast-growing Eucalyptus was widely promoted for a variety of uses such as ornamental, firewood, timber, oil, wind breaks, shade, and medicinal, and seed was readily available in nurseries throughout California (Groenendaal, 1983). Eucalyptus usually begin to producing seeds at 4 or 5 years (Skolmen and Ledig, 2004), so actual seed production in California may have began as early as 1857 or 1858.

The town of Watsonville was founded in 1852 and due to the close proximity to San Francisco it is likely that Eucalyptus was planted in the Watsonville area soon after the introduction into San Francisco. There is record of the planting of Australian gum trees in the Plaza at Watsonville in the early 1870s (Lewis, 1976). An 1879 photo, in Watsonville: Memories that Linger by Lewis, shows Eucalyptus trees greater than 30 feet in height growing in the Plaza (Lewis, 1976). A study of planted California stands of Eucalyptus less than 5 years of age resulted in annual growth of 2m (6.7 ft) (Metcalf as cited in Skolmen and Ledig, 2004). Therefore, the trees shown in the 1879 photo are likely to be greater than 5 years old and may have been producing seed at that time. Based on this photo, an assigned date of 1880 ± 10 years for Eucalyptus was used in the core chronology.

A summary table of these non-native plant introductions is given below in Table 6.4.

Table 6.4 Summary of selected botanical surveys/studies relevant to non-native plant introductions in the Watsonville Sloughs area.

Plant	Hendry (1939); Hendry et al. (1925) (analysis of adobe bricks)	Bolander (1870) (catalog of plants in the vicinity of San Francisco)	Watson (1880); Brewer et al. (1876) (Geological Survey of California plant collections)	Anderson (1892) (catalog of plants in Santa Cruz County)	Hayward (1931) (thesis on marsh and aquatic plants in the Pajaro region)	Assigned date for pollen found in sediment cores
Erodium cicutarium	Mission San Antonio ~1787 Mission La Soledad ~1793-1797 Mission San Jose ~1811 Mission San Juan Bautista ~1797 Rancho El Sansal near Salinas ~1834 La Natividad Rancho ~1837	Yes	"very common throughout the state"	Yes	Not noted	1800 ±20 years
Rumex acetosella	La Natividad Rancho ~1837 (*Rumex sp.*-possibly Sheep Sorrel)	Not noted	"a very widespread weed"	Yes	Near Struve Slough and Watsonville lakes	
Plantago lanceolata	No	Not noted	"not widely established"; collected near San Francisco	Yes	Near upper Watsonville Slough, Struve Slough and Kelly Lake	
Eucalyptus globulus	No	Not noted	Not noted	Not noted	Not noted	1880 ±20 years

Table 6.5 Watsonville Timeline

Pre-European		~10,000 ya	Coastal california first inhabited
		1,007-795 BC	Radiocarbon date of artifacts from CA-SCR-44 site near Lakeview Middle School
		155-390	Radiocarbon date of artifacts from CA-SCR-44 site near Lakeview Middle School
		1425-1560	Radiocarbon date of artifacts from CA-SCR-44 site near Lakeview Middle School
		1542	Juan Rodriguez Cabrillo explored California from San Diego up to Point Conception
		1579	Sir Francis Drake arrived in Drakes Bay
		1595	Sebastian Rodriguez Cermeno arrived in Drake's Bay; may have been the 1st to discover Monterey Bay
		1602	Sebastian Vizcaino arrived Monterey Bay
		pre-1769	*Erodium cicutariam* (redstem stork's bill) likely introduced to California
European	Spanish & Mexican	**1769**	**Portola-Serra expedition to Alta California; first to documentation of Pajaro Valley on October 6th**
		1770-1797	Presidio of Monterey (1770), Mission San Carlos Borromeo (1770), Mission San Carlos Borromeo de Carmelo moved to current location (1771), Mission San Antonio de Padua (1771), Presidio of San Francisco (1776), Mission San Francisco de Asis (1776), Mission Santa Clara de Asis (1777), Pueblo de San Jose (1777), Mission Santa Cruz (1791), Mission Nuestra Senora de la Soledad (1791), Mission San Juan Buatista (1797), Mission
		~1800	**Approximate date of *Erodium cicutariam* (redstem stork's bill) introduction into Watsonville**
		1821	Mexico gained independence from Spain
		1825-1848	*Rumex acetosella* (common sheep sorrel), *Rumex conglomerates* (knotted or clustered dock), Plantago major (common plantain), Plantago lanceolata (narrowleaf plantain) likely introduced to California
		1833	Mexican government gave order for secularization of the missions
	Early American	1848	Treaty of Guadalupe Hidalgo; Beginning of Gold Rush in California
		1851	First farmers settled in Pajaro Valley; primary crops grain and potatoes
		1852	Town of Watsonville founded
		1853	*Eucalyptus* first introduced to California
		1858	First commercial apple orchard in Pajaro Valley
		1865	First commercial planting of strawberries in Pajaro Valley
		1868	Watsonville incorporated; small shipping port constructed at mouth of Pajaro River
		1871	Southern Pacific Railroad linked Watsonville to Santa Clara Valley
		~1880	**Approximate date of *Eucalyptus* introduction into Watsonville**
		1881	Camp Goodall, at present day Pajaro Dunes Colony and Palm Beach, expanded to include horse racetrack, stables, cottage, hotel, and dance pavillion
		late 1880s	Reclamation of slough lands by Chinese for farming
		early 1890s	Construction of drainage ditches and Harkins Slough Road
		early 1900s	Increased manufacturing of gasoline powered automobiles
		1903	Port Rogers constructed at present day Sunset State Beach
		1914	Lettuce first planted in Pajaro Valley
		1920s	Sharp increase in population of Watsonville
		1931	Camp Goodall resort expanded to include motorized racetrack and grand stands
	Modern	1940's	Shell Road pump station and tide gates installed
		1970's	Clean Air Act of 1970 required leaded gasoline to be phased out by mid 1980's

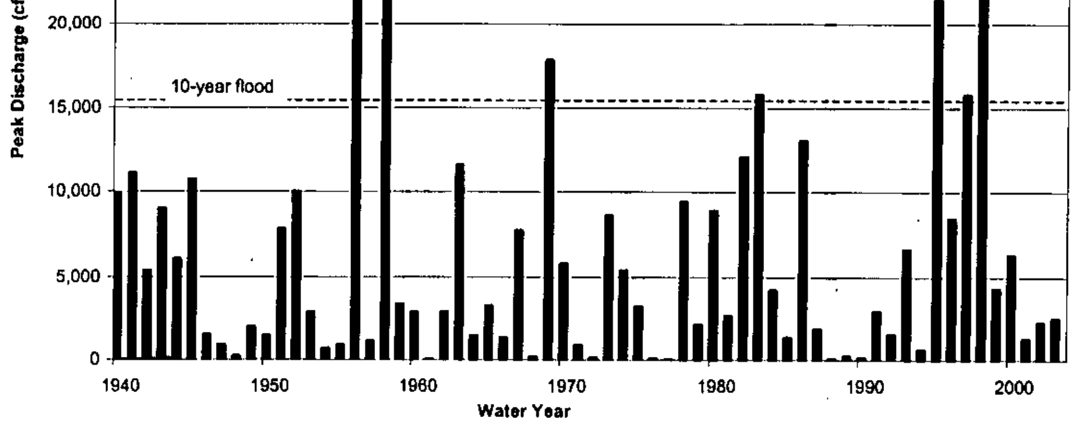
Figure 6.12 Extract of 1853 US Coast Survey Map showing Watsonville Sloughs area. Source for map annotations is Swanson Hydrology and Geomorphology 2003. Original map on file at UCSC map library.

Figure 6.14 Extract of 1954 USGS Watsonville West quadrangle topographic map showing Watsonville Sloughs area.

Historic Flooding of the Pajaro River

The Watsonville Sloughs system drains to the Pajaro River and is influenced by Pajaro River flood events. Due to the orientation of the Pajaro River lagoon and long shore sediment transport, the first winter storm often closes the sand bar causing Pajaro River flows to backup into Watsonville Sloughs (J. Smith, pers comm., 2004). During receding flood flows, sediments derived from the upper Pajaro watershed as well as Watsonville Slough sediments may be deposited in lower Watsonville Slough. This may be an important factor to consider when examining sediment cores. Deposition from large events may be useful in the dating process by appearing as a single graded unit in the sediment core stratigraphy.

Seven flood events greater than 10-year-flood magnitude have been recorded at the USGS Chittenden station (#11159000) since 1939. The flood events include: 1956, 1958, 1969, 1983, 1995, 1997, and the largest event in 1998. Other large flood events, prior to the installation of the USGS gauging site, that have been documented include 1852, 1890, 1911, 1914, 1917, 1931, and 1938 (Lydon, 1998).



6.2.2 Aerial Photo Interpretation

Aerial photo interpretation was conducted to determine the extent of land use, vegetation, and channel morphology changes in the Watsonville Sloughs Watershed. A critical part of determining whether or not a sediment problem exists in Watsonville Sloughs and understanding the current hydrologic function in the watershed involved first researching the conditions of the sloughs prior to settlement and documenting how they have been modified through time. Aerial imagery of Watsonville Sloughs was obtained for the following years: 1929, 1931, 1935, 1940, 1952, 1954, 1957, 1962, 1972, 1980, 1992, and 2003. The interpretation involved documenting timing of channelization of the sloughs, farming in drained portions of the slough, installation of the pumping stations, changes in the area of inundation, major changes vegetation, and locating areas that have not been modified. A selected set of aerials is given in Appendix G-Aerial Photos. The photos are arranged based on general locations including: lower Watsonville Slough, middle Watsonville Slough-San Andreas Road, middle Watsonville Slough-Lee Road, upper Watsonville Slough, and Harkins, Gallighan, Hanson Sloughs. A selection of 3 aerials from each of these locations is given in Appendix G-Aerial Photos.

The conclusions that were made from this interpretation include the following:

- Channelization, draining of the sloughs, and removal of slough vegetation began prior to 1928.
- The slough margins and reclaimed areas were being farmed by 1928.
- A meandering tributary to the current estuarine portion of Watsonville Sloughs was visible in 1928 but was removed by 1952. Other than this, and few changes in vegetation there does not appear to have been many changes to the sloughs between the late 20's and early 50's. The primary land use in the lower sloughs remained agriculture and draining and farming of the reclaimed lands continued.
- The channel in the current estuarine portion of lower Watsonville Slough does not appear to have been modified.
- There was large increase in urban expansion between the 50's and the 90's.
- There was revegetation of the sloughs between the 50's and the 90's. Especially in and around areas that are ponded today such at sampling sites HAR-HAR, STR-HAR, WAT-HAR, and in the area where Hanson, Watsonville, and Struve meet.
- With the exception of the lower estuarine portion of Watsonville Slough, there does not appear to be any locations where the sloughs have not been significantly modified by channelization and other alterations such as road construction and removal of marsh vegetation.

6.2.3 Coring Results

Two sediment cores (Fig. 6.15) were collected in lower Watsonville Slough at sites WAT-A and WAT-B (Fig. 4.28) in March 2004. The coring results yielded approximate estimates of sedimentation rates since about 1420 (1400-1470), with acceptable markers from 1800±20 and 1880±10 for the pre-European (1400-1800) and European periods (after 1800); and weaker markers from 1952, 1966, 1978, 1990, and 2004 for the recent or modern period (last 50 years). Figures 6.16 and 6.17 from Byrne and Reidy (2005) (given in the Appendix to this report) show the sedimentation rates determined from the sediment cores.

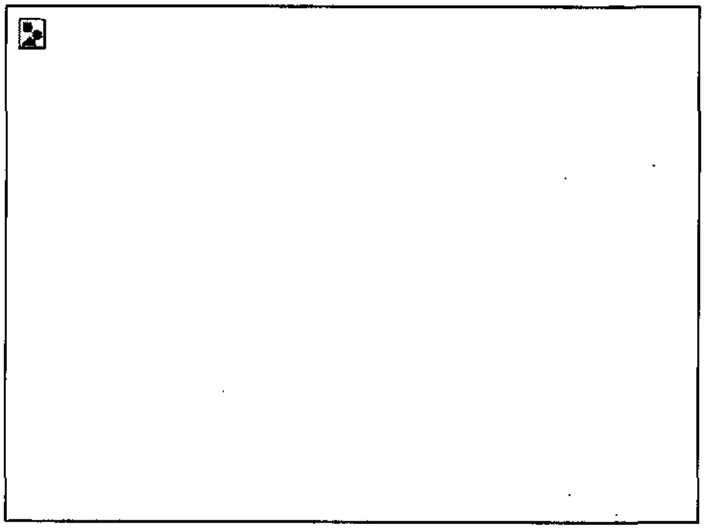


Figure 6.15 Section of sediment core from WAT-A. (Photo: J. Hager)

Based on radiocarbon dating, and pollen dating using *Erodium* and *Eucalyptus*, the average sedimentation rate may have increased the late European period, being estimated as 6.4 mm/yr since 1880 versus 5.1 mm/yr between 1420 and 1800 (the pre-European period) and 2.6 mm/yr between 1800 and 1880 (early European period) (Fig. 6.16). Note however that a constant sedimentation rate of 5.1 mm/yr for the full period between 1400 and 2004 is also approximately within the margin of error of the data.

Perhaps of more interest is that the lead-210 data indicate a sharp decline in sedimentation rates in lower Watsonville Slough beginning in the past 50 years (although note that these data are weaker than is normally accepted due to level of background lead-210 activity in the sediment core, as cautioned by Byrne and Reidy, 2005). This is consistent with both land subsidence in the upper sloughs in the early 1900s, and the installation of the tide gates in the 1940s. It is also supported by slightly lower sand fractions (indicating an interruption in sand supply) and poorer pollen preservation (indicating greater pollen oxidation due to longer surface exposure and thus lower burial rates) in the recent sediments.

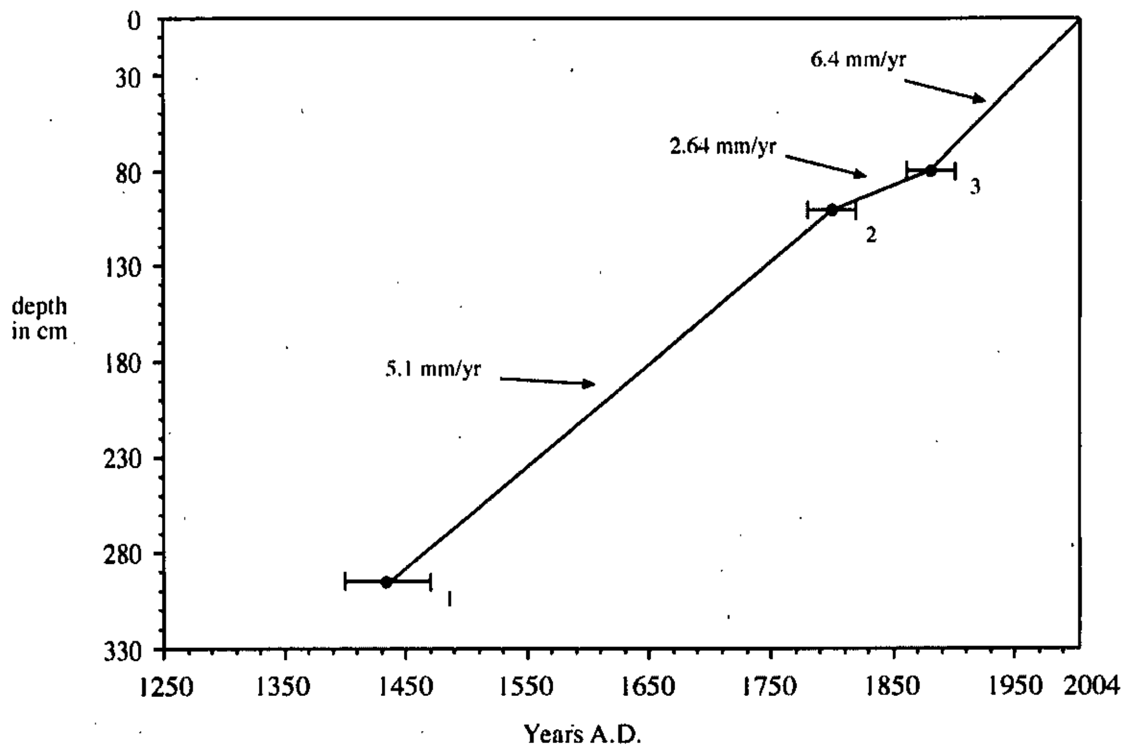


Figure 6.16 Age V Depth Curve for Watsonville Slough (A.D. 1420-2004). Average sedimentation rates are shown between chronological markers (Byrne and Reidy, 2005).

1. Two sigma radiocarbon age range; 477-556 cal yr B.P. (A.D. 1400-1470).
2. First appearance of Erodium cicutarium (A.D. 1800±20 yr).
3. First appearance of Eucalyptus spp.(A.D. 1880±10 yr).

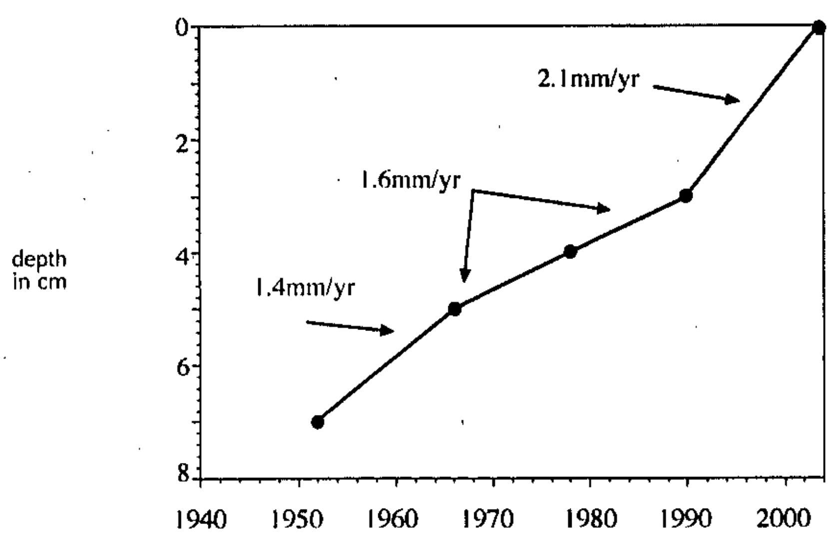


Figure 6.17 Recent (last 50 years) sedimentation rates based on Lead-210 activity (Byrne and Reidy, 2005).

The upper sloughs were once mined for peat and farmed. This resulted in dewatering, removal of substrate, and land subsidence (land subsidence may also be related to groundwater pumping and/or local seismic activity). The sloughs now may be undergoing a geomorphic and vegetation succession back to a state that is more like their natural state. Sediment supply may have increased due to intensive land use in the watershed, and sediment transport through the system may remain somewhat reduced by low gradients (land subsidence), tide gates, and undersized culverts. This may be allowing the upper sloughs to fill back up with sediment, at the expense of reduced sediment supply to the lower sloughs. If we accept the lead analyses (noting Byrne & Reidy's uncertainties), then the coring data tend to support this possibility.

There are of course other possibilities. For example, recent apparent reductions in sedimentation of lower Watsonville Slough could be due to an overall decline in sediment supply (which seems unlikely given the level of urban and agricultural development in the region), or increased erosion somehow related to changes in the flow regime of the Pajaro River immediately downstream (which is at least worth considering, given changes in the Pajaro watershed and the management of its levees). Other alternatives could be argued in the event that the lead analyses were shown to be inaccurate, and that sedimentation in lower Watsonville slough had in fact not decreased in recent years.

6.2.4 Subsidence

One potential mechanism of impairment by sedimentation is reduction of habitat volume. Determination of the extent of sedimentation impairment in relation to habitat volume in Watsonville Sloughs requires estimates of subsidence rates of the sloughs in order to determine net sediment accumulation. Subsidence rates were estimated by comparing early survey records in known subsidence areas to current elevation data.

An extensive search for existing survey records resulted in only a couple suitable surveys. Many permanent USGS, city, and county elevation benchmarks exist throughout the watershed, however, only 3 benchmarks were located near the lowland areas of the sloughs. All other elevation benchmarks were located in upland areas where substantial subsidence would not be expected. The 3 useful benchmarks were surveyed in 1967 and were re-surveyed in 1989. Survey data were obtained from the Santa Cruz County Public Works Department. Table 6.6 lists the benchmark ID code, location, and difference in elevation from 1967 to 1989.

Table 6.6 Benchmark Elevation Difference from 1967 to 1989

ID	1967 Elevation (ft)	1989 Unadjusted Elevation (ft)	Difference (ft)	Difference (m)	Location
143	6.61	6.25	0.36	0.11	S end of Shell Rd. flood control dam 'SD1'
153	17.14	16.83	0.32	0.10	NW end of San Andreas Rd. bridge 'SA2'
146	14.7	13.78	0.92	0.28	Harkins Slough Rd. and Rountree Ln.

Based on these benchmark data the average subsidence rate from 1967 to 1989 was approximately 5 mm/year at the Shell Road Pump Station dam and San Andreas Road bridge. It is important to note that this may have been a combination of actual subsidence of the slough bottom and settling of the bridge foundation. At the benchmark near Harkins Slough Road, the average subsidence rate from 1967 to 1989 was approximately 12.7 mm/year. This rate is more likely a representation of actual subsidence rates as the benchmark was not located on a road or bridge. This benchmark was located less than 15 m from the right bank of Harkins Slough. An important limitation to these rates is that we do not know the accuracy of survey for either year. Surveyor error and differences in instrumentation and methods may have easily resulted in error that would change these calculated rates.

Road surveys for Harkins Slough Road (1952) and Lee Road (1950) were obtained from the Santa Cruz County Public Works Department. The extent of the Harkins Slough Road re-alignment survey covered Watsonville Slough (WAT-HAR) and Struve Slough (STR-WAT), but not Harkins Slough (HAR-HAR). The Lee Road re-alignment survey covered Struve Slough (STR-LEE). The surveys did not include permanent benchmark controls that could be relocated. City of Watsonville staff indicated that at various times, sections of the road surface have been raised to compensate for subsidence, and to allow for increased traffic (such as during re-direction of traffic from Highway 1 following the 1989 Loma Prieta earthquake related Highway 1 collapse at Struve Slough).

In late 2004, we conducted detailed re-survey of the above road sections using high accuracy digital theodolite survey equipment (TOPCON GTS 211D Electronic Total Station) (in the vicinity of sites STR-LEE, STR-HAR, and WAT-HAR).

Since we did not have accurate NGVD vertical control for either the 1950s surveys, or our own survey, we aligned the two surveys by matching the elevation of older sections of road surface where re-surfacing was less likely, and where the road runs over relatively stable substrate (i.e. uphill from the sloughs themselves). Vertical matching points were chosen just uphill of the sloughs, since the higher sections of road have been re-built to accommodate hilltop development.

The results of the Harkins Slough Road survey are given in Figure 6.18. There is clear evidence of significant lowering of the road surface elevation of about 1 meter at Watsonville Slough, and up to two meters at Struve Slough (as well as evidence that the hill crest was lowered during major road improvements concurrent with the urban development of the hilltop area). In order to relate these values to changes in slough surface elevation, the vertical relief between the road surface and the slough surface must be considered. The relief in 2004 was about one meter - i.e. the road surface is about one meter above the slough surface. The relief in 1952 is unknown. The roads are known to sink into the sloughs, and to have been re-surfaced to compensate for this to some un-documented degree (either under-compensated, equilibrated, or over-compensated). For changes in road-slough relief to completely explain the drop in road surface elevation, the 1952 road surface over Struve Slough would need to have been on a causeway standing about 3 meters above the slough in places. This seems quite unlikely given the lack of geotechnical evidence for two meters of differential slumping. Thus, some of the change in road surface elevation is likely to be due to overall subsidence of the slough system. A figure of half to one meter of subsidence is our best estimate. This equates to about 10 to 20 mm/yr, which agrees with the figure based on benchmark re-survey of 12.7 mm/yr. It is of course is also consistent with the common observation that ponding of water in the sloughs is more common in recent times.

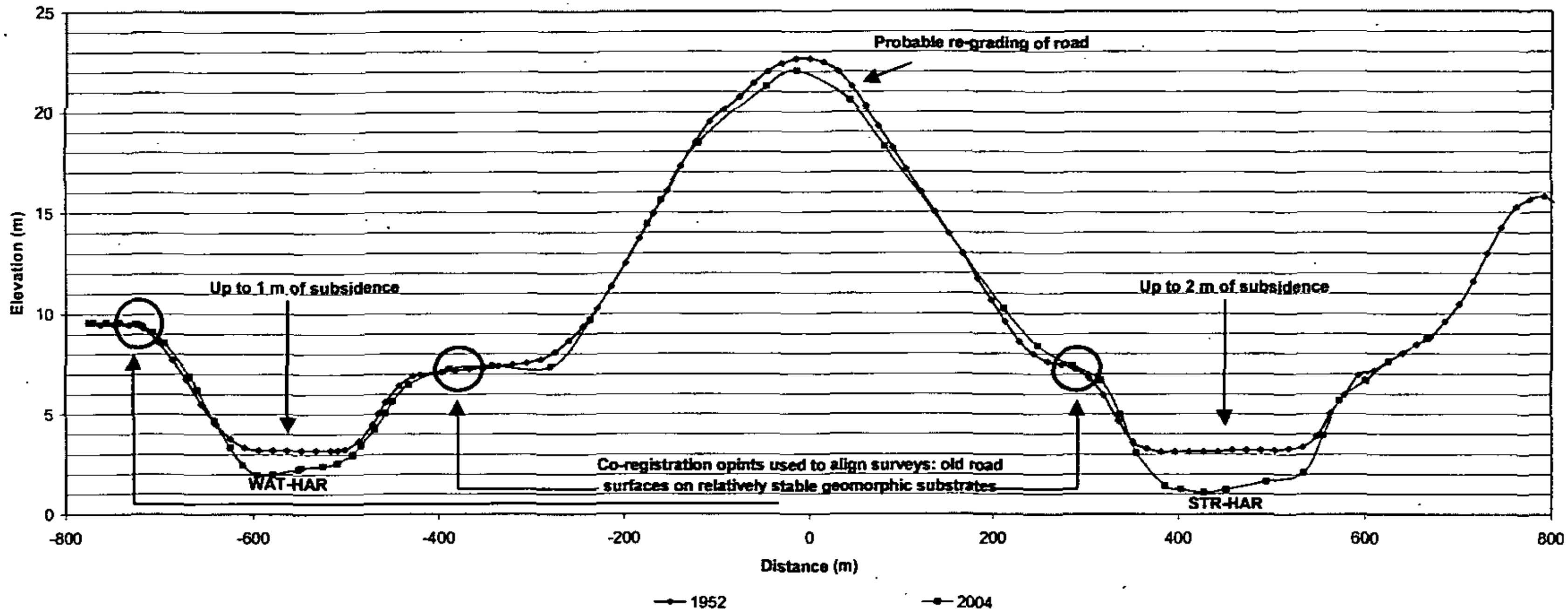


Figure 6.18 Harkins Slough Road survey

6.3 Sedimentation Problems

The reconnaissance observations revealed signs of considerable levels of sediment accumulation in upper Hanson and Gallighan sloughs. Accumulation in other areas was not observed due to lack of visibility due to ponded water and/or low levels for the given rainfall/runoff year.

The results of the sediment core analysis indicate that in general, the late-European (1880-2004) average sedimentation rate (6.4 mm/year) is slightly higher than the pre-European (1420-1800) average sedimentation rate (5.1 mm/year) and considerably higher than the early-European (1800-1880) average sedimentation rate (2.6 mm/year). However, lead-210 data, suggest (not conclusively) that the recent (last 50 years) average sedimentation rate (1.7 mm/year) is substantially lower than even pre-European rates. This lower recent rate of sedimentation may be explained by decreased sediment supply to the lower reach of Watsonville Sloughs due to both land subsidence in the upper sloughs in the early 1900s and the installation of the tide gates in the 1940s which has resulted in the reduced circulation and sediment transport capacity. Sedimentation rates could not be determined for the upper sloughs due destruction of the sedimentary record by past modifications such as draining, filling, farming, and channelization of the sloughs. Based on the (possible) decrease in sedimentation rates downstream of the Shell Road pump station in the past 50 years, we suspect that sediment rates have likely increased in the upper watershed. However, this would need to be confirmed by a long-term (i.e. 5 to 10 years) sediment accumulation study involving use of substrate reference markers and repeated channel cross-sections.

Based the results of a repeated survey of Harkins Sloughs Road near Struve Slough and Watsonville Slough and a permanent benchmark located near Harkins Slough at Harkins Slough Road, subsidence rates of the sloughs were estimated to range from 10 to 20 mm/year. In order to determine if habitat volume is being reduced, sedimentation rates in these upper portions of the sloughs would need to be in excess of 10 to 20 mm/year. As mentioned above, a long-term study is needed in order to determine rates in these areas of the sloughs since the sedimentary record has likely been destroyed.

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Appendix A- Sediment Effects on Fish

Source	Species	Life Stage	Exposure Concentration (mg/L)	Exposure Duration (h)	Fish Response	Reference
Newcombe and Jensen 1996	Steelhead	Adult	500	3	Signs of sublethal stress	Redding and Schreck (1982)
	Steelhead	Adult	500	9	Blood cell count and blood chemistry change	Redding and Schreck (1982)
	Trout	Adult	16.5	24	Feeding behavior apparently reduced	Townsend (1983); Ott (1984)
	Trout	Adult	75	168	Reduced quality of rearing habitat	Slaney et al. (1977b)
	Trout	Adult	270	312	Gill tissue damaged	Herbert and Merkens (1961)
	Trout	Adult	525	588	No mortality (other end points not investigated)	Griffin (1938)
	Trout	Adult	300	720	Decrease in population size	Peters (1967)
	Trout (rainbow)	Adult	66	1	Avoidance behavior manifested part of the time	Lawrence and Scherer (1974)
	Trout (rainbow)	Adult	665	1	Overhead cover abandoned	Lawrence and Scherer (1974)
	Trout (rainbow)	Adult	100	0.10	Fish avoided turbid water	Suchanek et al. (1984a,1984b)
	Trout (rainbow)	Adult	100	0.25	Rate of coughing increased	Hughes (1975)
	Trout (rainbow)	Adult	250	0.25	Rate of coughing increased	Hughes (1975)

Source	Species	Life Stage	Exposure Concentration (mg/L)	Exposure Duration (h)	Fish Response	Reference
Newcombe and Jensen 1996	Trout (rainbow)	Adult	810	504	Gills of fish that survived had thickened epithelium	Herbert and Merkens (1961)
	Trout (rainbow)	Adult	17,500	168	Fish survived; gill epithelium proliferated and thickened	Slanina (1962)
	Trout (rainbow)	Adult	50	960	Rate of weight gain reduced	Herbert and Richards (1963)
	Trout (rainbow)	Adult	810	504	Some fish died	Herbert and Merkens (1961)
	Trout (rainbow)	Adult	270	3240	Survival rate reduced	Herbert and Merkens (1961)
	Trout (rainbow)	Adult	200	24	Test fish began to die on first day	Herbert and Richards (1963)
	Trout (rainbow)	Adult	18	720	Abundance reduced	Peters (1967)
	Trout (rainbow)	Adult	4,250	588	Mortality rate 50%	Herbert and Wakeford (1962)
	Trout (rainbow)	Adult	49,838	96	Mortality rate 50%	Lawrence and Scherer (1974)
	Trout (rainbow)	Adult	80,000	24	No mortality	D. Herbert, personal comm. to Alabaster and Lloyd (1980)
	Trout (rainbow)	Adult	3,500	1,488	Catastrophic reduction in population size	Herbert and Merkens (1961)

Source	Species	Life Stage	Exposure Concentration (mg/L)	Exposure Duration (h)	Fish Response	Reference
Newcombe and Jensen 1996	Trout (rainbow)	Adult	160,000	24	Mortality rate 100%	D. Herbert, personal comm. to Alabaster and Lloyd (1980)
	Trout (rainbow)	Yearling	90	456	Mortality rates 0-20%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	90	456	Mortality rates 0-15%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	270	456	Mortality rates 10-35%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	810	456	Mortality rates 35-85%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	810	456	Mortality rates 5-80%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	270	456	Mortality rates 25-80%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	7,433	672	Mortality rate 40%	Herbert and Wakeford (1962)
	Trout (rainbow)	Yearling	4,250	672	Mortality rate 50%	Herbert and Wakeford (1962)
	Trout (rainbow)	Yearling	2,120	672	Mortality rate 100%	Herbert and Wakeford (1962)
	Trout (rainbow)	Juvenile	4,887	384	Hyperplasin of gill tissue	Gouldes (1983)
	Trout (rainbow)	Juvenile	4,887	384	Parasitic infection of gill tissue	Gouldes (1983)
	Trout (rainbow)	Juvenile	171	96	Particles pentrated cells of branchial epithelium	Gouldes (1983)

Source	Species	Life Stage	Exposure Concentration (mg/L)	Exposure Duration (h)	Fish Response	Reference
Newcombe and Jensen 1996	Trout (rainbow)	Juvenile	4,315	57	Mortality rate ~100%	Newcombe et al. (1995)
	Carp (common)	Adult	25,000	336	Some mortality	Wallen (1951)
	Goldfish	Adult	25,000	336	Some mortality	Wallen (1951)
	Sunfish (green)	Adult	9,600	1	Rate of ventilation increased	Horkel and Pearson (1976)
	Sunfish (redear)	Adult	62.5	720	Weight gain reduced ~50% compared to controls	Buck (1956)
	Sunfish (redear)	Adult	144.5	720	Growth retarded	Buck (1956)
	Sunfish (redear)	Adult	144.5	720	Fish unable to reproduce	Buck (1956)
	Stickleback (threespine)	Adult	28,000	96	No mortality in test designed to identify lethal threshold	LeGore and DesVoigne (1973)
Lloyd 1987	Rainbow Trout (Great Britain)	Juvenile	270 (ppm)		Reduced survival (marked)	Herbert and Merkens (1961)
	Rainbow Trout (Great Britain)	Juvenile	200 (ppm)		Reduced survival (marked)	Herbert and Richards (1963)
	Rainbow Trout (Oregon)	Juvenile	1,000-2,500 (ppm)		Reduced survival (marked)	Campbell (1954)
	Rainbow Trout (Great Britain)	Juvenile	90 (ppm)		Reduced survival (slight)	Herbert and Merkens (1961)

Source	Species	Life Stage	Exposure Concentration (mg/L)	Exposure Duration (h)	Fish Response	Reference
Lloyd 1987	Rainbow Trout (Great Britain)	Juvenile	50 (ppm)		Reduced growth (slight)	Herbert and Richards (1963)
	Rainbow Trout (Arizona)	Juvenile	<70 (JTU)		Reduced food conversion	Olson et al. (1973)
	Rainbow Trout (Arizona)	Juvenile	70 (JTU)		Reduced feeding	Olson et al. (1973)
	Rainbow Trout (Great Britain)	Juvenile	110		Reduced condition factor	Scullion and Edwards (1980)
	Rainbow Trout (Great Britain)	Juvenile	110		Altered diet (terrestrial instead of aquatic)	Scullion and Edwards (1980)
	Steelhead (Oregon)	Juvenile	2,000		Stress (increased plasma cortisol, hematocrit, and susceptibility to pathogens)	Redding and Schreck (1980)
	Rainbow Trout (Great Britain)	Juvenile	270 (ppm)		Disease (fin rot)	Herbert and Merkens (1961)
	Rainbow Trout (Great Britain)	Juvenile	100 (ppm); 200 (ppm)		Disease (fin rot)	Herbert and Merkens (1961)
	Steelhead (Idaho)	Juvenile	22-265 (NTU)		Avoidance	Sigler (1980), Sigler et al. (1984)

Source	Species	Life Stage	Exposure Concentration (mg/L)	Exposure Duration (h)	Fish Response	Reference
Lloyd 1987	Steelhead (Idaho)	Juvenile	40-50 (NTU)		Displacement	Sigler (1980)
	Rainbow Trout (Great Britain)	Juvenile	110		Displacement	Scullion and Edwards (1980)
	Trout		25 JTU		Altered behavior (feeding)	Langer (1980)
Newcombe and MacDonald (1991)	Rainbow trout		68	720	25% reduction in population size	Peters (1967)
	Rainbow trout		1,000-6,000	1,440	85% reduction in population size	Herbert and Merkens (1961)
	Steelhead		84	336	Reduction in growth rate	Sigler et al. (1984)
	Rainbow trout		50	1,848	Reduction in growth rate	Sykora et al. (1972)
Bell (1986)	Mosquitofish		181,500 (average)	396	fatal	Bell (1986)
	Goldfish		197,000 (average)	288	fatal	Bell (1986)
	Green sunfish		166,500 (average)	132	fatal	Bell (1986)
	River carpsucker		165,000 (average)	230	fatal	Bell (1986)
	Channel catfish		85,000 (average)	223	fatal	Bell (1986)
	Black crappie		145,000 (average)	48	fatal	Bell (1986)

Appendix B–Sediment Effects on Macroinvertebrates

Source: Newcombe and MacDonald (1991)

Taxon	Exposure Concentration (mg/L)	Exposure Duration (h)	Response	Reference
Zooplankton	24	0.15	Reduced capacity to assimilate food	McCabe and O'Brien (1983)
Benthic invertebrates	8	2.5	Lethal: increased rate of drift	Rosenberg and Wiens (1978)
Macro invertebrates	53–92	24	Lethal: reduction in population size	Gammon (1970)
Benthic invertebrates	1,700	2	Lethal: alteration to community structure and drift patterns	Fairchild et al. (1987)
Zoobenthos	10–15	720	Lethal: reduction in standing crop	Rosenberg and Snow (1977)
Benthic invertebrates	8	1,440	Lethal: up to 50% reduction in standing crop	Rosenberg and Wiens (1978)
Cladocera	82–392	72	Lethal: survival and reproduction harmed	Robertson (1957); from Alabaster and Lloyd (1982)
Benthic fauna	29	720	Lethal: populations of Trichoptera, Ephemeroptera, Crustacea, and Mollusca, disappear	M.P. Vivier, personal comm. in Alabaster and Lloyd (1982)
Benthic invertebrates	16	1,440	Lethal: reduction in standing crop	Slaney et al. (1977b)
Cladocera and Copepoda	300–500	72	Lethal: gills and gut clogged	Stephan (1953) cited in Alabaster and Lloyd (1982)
Benthic invertebrates	32	1,440	Lethal: reduction in standing crop	Slaney et al. (1977b)
Zoobenthos	>100	672	Lethal: reduction in standing crop	Rosenberg and Snow (1977)
Benthic invertebrates	62	2,400	Lethal: 77% reduction in population size	Wagener and LaPerriere (1985)

Taxon	Exposure Concentration (mg/L)	Exposure Duration (h)	Response	Reference
Benthic invertebrates	77	2,400	Lethal: 53% reduction in population size	Wagener and LaPerriere (1985)
Bottom fauna	261-390	720	Lethal: reduction in population size	Tebo (1955)
Benthic invertebrates	390	720	Lethal: reduction in population size	Tebo (1955)
Benthic invertebrates	278	2,400	Lethal: 80% reduction in population size	Wagener and LaPerriere (1985)
Stream invertebrates	130	8,760	Lethal: 40% reduction in species diversity	Nuttall and Bielby (1973)
Benthic invertebrates	743	2,400	Lethal: 85% reduction in population size	Wagener and LaPerriere (1985)
Benthic invertebrates	5,108	2,400	Lethal: 94% reduction in population size	Wagener and LaPerriere (1985)
Stream invertebrates	25,000	8,760	Lethal: reduction or elimination of populations	Nuttall and Bielby (1973)

Appendix C-Suspended Sediment and Turbidity Data from Previous Studies

Questa/AMBAG report 1995			
CCoWS Site Code	Date	Location	TSS (mg/L)
GAL-HAR	15 Nov 94	Gallighan Slough @ 629 Harkins Slough Rd.	220
GAL-HAR	14 Dec 94	Gallighan Slough @ 629 Harkins Slough Rd.	24
HAR-HAR	07 Sep 94	Harkins @ Harkins Slough Rd.	7
HAR-HAR	15 Nov 94	Harkins @ Harkins Slough Rd.	330
HAR-HAR	14 Dec 94	Harkins @ Harkins Slough Rd.	70
HAR-	14 Dec 94	Harkins Slough @ Larkins Valley Rd. b/w Racehorse Rd. and Moon Valley Ranch Rd.	ND
WAT-HSU	07 Sep 94	Watsonville Slough upstream of Harkins Slough confluence	720
WAT-HSU	15 Nov 94	Watsonville Slough upstream of Harkins Slough confluence	600
WAT-HSU	14 Dec 94	Watsonville Slough upstream of Harkins Slough confluence	210
WAT-LEE	07 Sep 94	Watsonville Slough @ Lee Rd.	25
WAT-LEE	15 Nov 94	Watsonville Slough @ Lee Rd.	140
WAT-LEE	14 Dec 94	Watsonville Slough @ Lee Rd.	16
WAT-SHE	07 Sep 94	Watsonville Slough @ Shell Rd. pump	66
WAT-SHE	15 Nov 94	Watsonville Slough @ Shell Rd. pump	340
WAT-SHE	14 Dec 94	Watsonville Slough @ Shell Rd. pump	42
WAT-HAR	07 Sep 94	Watsonville Slough @ Harkins Slough Rd.	920
WAT-HAR	15 Nov 94	Watsonville Slough @ Harkins Slough Rd.	8
WAT-HAR	14 Dec 94	Watsonville Slough @ Harkins Slough Rd.	ND
BEA-SHE	07 Sep 94	Beach Rd. Ditch @ Beach Rd. and Shell Rd.	82
BEA-SHE	15 Nov 94	Beach Rd. Ditch @ Beach Rd. and Shell Rd.	580
BEA-SHE	14 Dec 94	Beach Rd. Ditch @ Beach Rd. and Shell Rd.	60
STR-LEE	07 Sep 94	Struve Slough @ Lee Rd.	1300
STR-LEE	15 Nov 94	Struve Slough @ Lee Rd.	20
STR-LEE	14 Dec 94	Struve Slough @ Lee Rd.	ND
STR-HAR	15 Nov 94	Struve Slough @ Harkins Slough Rd.	ND
STR-HAR	14 Dec 94	Struve Slough @ Harkins Slough Rd.	ND

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Santa Cruz County Environmental Health				
CCoWS Site Code	Date	Location	TSS (mg/L)	Turbidity (NTU)
HAR-CON	16 Jun 76	Harkins Slough @ San Andreas Rd.		8.3
HAR-CON	23 May 77	Harkins Slough @ Watsonville Slough		25
HAR-CON	27 Apr 78	Harkins Slough @ Watsonville Slough	51	48
HAR-CON	12 Dec 79	Harkins Slough @ Watsonville Slough		20
HAR-CON	22 Apr 80	Harkins Slough @ Watsonville Slough		55.8
HAR-CON	24 Sep 80	Harkins Slough @ Watsonville Slough		23
HAR-HAR	16 Jun 76	Harkins Slough @ Harkins Slough Rd.		4.5
WAT-HSU	23 May 77	Watsonville Slough above Harkins Slough confluence		7.2
WAT-HSU	27 Apr 78	Watsonville Slough above Harkins Slough confluence	15	8.4
WAT-HSU	22 Apr 80	Watsonville Slough above Harkins Slough confluence		22.5
WAT-HSU	24 Sep 80	Watsonville Slough above Harkins Slough confluence		5.1
WAT-SHE	23 May 77	Watsonville Slough @ Shell Rd.		3.9
WAT-SHE	27 Apr 78	Watsonville Slough @ Shell Rd.	67	46
WAT-SHE	29 May 80	Watsonville Slough @ Shell Rd.		15
WAT-SHE	24 Sep 80	Watsonville Slough @ Shell Rd.		14
WAT-SHE	28 Sep 82	Watsonville Slough @ Shell Rd.		15
WAT-PAJ	12 Dec 79	Watsonville Slough @ Pajaro River		8.5
WAT-PAJ	22 Apr 80	Watsonville Slough @ Pajaro River		345
STR-LEE	29 May 80	Struve Slough @ Lee Rd.		52.5
GAL-BUE	16 Jun 76	Gallighan Slough drainage by Buena Vista		110
GAL-BUE	23 May 77	Gallighan Slough drainage by Buena Vista		32
GAL-LOW	27 Apr 78	Gallighan Slough lower	42	56
GAL-LOW	23 Apr 80	Gallighan Slough lower		63.3
GAL-LOW	24 Sep 80	Gallighan Slough lower		34.5

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City of Watsonville				
CCoWS Site Code	Date	Location	TSS (mg/L)	Turbidity (NTU)
WAT-SHE	19 Sep 96	Watsonville Slough at Shell Road		66.1
WAT-SHE	19 Sep 96	Watsonville Slough at Shell Road		64.2
WAT-SHE	19 Sep 96	Watsonville Slough at Shell Road	51	73.7
WAT-SHE	08 Oct 96	Watsonville Slough at Shell Road		126
WAT-SHE	08 Oct 96	Watsonville Slough at Shell Road	32	122
WAT-SHE	25 Oct 96	Watsonville Slough at Shell Road		54.6
WAT-SHE	25 Oct 96	Watsonville Slough at Shell Road	54	58.1
WAT-SHE	29 Oct 96	Watsonville Slough at Shell Road		86.2
WAT-SHE	29 Oct 96	Watsonville Slough at Shell Road	88	69.4
WAT-SHE	19 Nov 96	Watsonville Slough at Shell Road		17.9
WAT-SHE	19 Nov 96	Watsonville Slough at Shell Road	12	20.1
WAT-SHE	03 Jan 97	Watsonville Slough at Shell Road		184
WAT-SHE	03 Jan 97	Watsonville Slough at Shell Road	40	186
WAT-SHE	29 Jan 97	Watsonville Slough at Shell Road		106
WAT-SHE	29 Jan 97	Watsonville Slough at Shell Road	30	109
WAT-SHE	08 Apr 97	Watsonville Slough at Shell Road		112
WAT-SHE	08 Apr 97	Watsonville Slough at Shell Road	55	106
WAT-SHE	16 Jun 97	Watsonville Slough at Shell Road		165
WAT-SHE	16 Jun 97	Watsonville Slough at Shell Road	64	173
WAT-SHE	17 Sep 97	Watsonville Slough at Shell Road		154
WAT-SHE	17 Sep 97	Watsonville Slough at Shell Road	98	152
WAT-SHE	19 Nov 97	Watsonville Slough at Shell Road		79.1
WAT-SHE	19 Nov 97	Watsonville Slough at Shell Road	48	84.2
WAT-SHE	08 Apr 98	Watsonville Slough at Shell Road		267
WAT-SHE	08 Apr 98	Watsonville Slough at Shell Road	192	291
WAT-AND	19 Sep 96	Watsonville Slough at San Andreas Rd.		47.8
WAT-AND	19 Sep 96	Watsonville Slough at San Andreas Rd.		40.3
WAT-AND	19 Sep 96	Watsonville Slough at San Andreas Rd.	34	42.7
WAT-AND	08 Oct 96	Watsonville Slough at San Andreas Rd.		65.1
WAT-AND	08 Oct 96	Watsonville Slough at San Andreas Rd.	38	36.1
WAT-AND	25 Oct 96	Watsonville Slough at San Andreas Rd.		19.5

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WAT-AND	25 Oct 96	Watsonville Slough at San Andreas Rd.	7	19.5
WAT-AND	29 Oct 96	Watsonville Slough at San Andreas Rd.		52.6
WAT-AND	29 Oct 96	Watsonville Slough at San Andreas Rd.	82	59.9
WAT-AND	19 Nov 96	Watsonville Slough at San Andreas Rd.		76.6
WAT-AND	19 Nov 96	Watsonville Slough at San Andreas Rd.	66	73.7
WAT-AND	03 Jan 97	Watsonville Slough at San Andreas Rd.		NS
WAT-AND	03 Jan 97	Watsonville Slough at San Andreas Rd.	NS	NS
WAT-AND	29 Jan 97	Watsonville Slough at San Andreas Rd.		65.1
WAT-AND	29 Jan 97	Watsonville Slough at San Andreas Rd.	32	66.8
WAT-AND	08 Apr 97	Watsonville Slough at San Andreas Rd.		82.8
WAT-AND	08 Apr 97	Watsonville Slough at San Andreas Rd.	54	83.1
WAT-AND	16 Jun 97	Watsonville Slough at San Andreas Rd.		193
WAT-AND	16 Jun 97	Watsonville Slough at San Andreas Rd.	99	209
WAT-AND	17 Sep 97	Watsonville Slough at San Andreas Rd.		250
WAT-AND	17 Sep 97	Watsonville Slough at San Andreas Rd.	17	251
WAT-AND	19 Nov 97	Watsonville Slough at San Andreas Rd.		71.9
WAT-AND	19 Nov 97	Watsonville Slough at San Andreas Rd.	57	74.6
WAT-AND	08 Apr 98	Watsonville Slough at San Andreas Rd.		88
WAT-AND	08 Apr 98	Watsonville Slough at San Andreas Rd.	74	84
HAR-CON	19 Sep 96	Harkins Slough at San Andreas Rd.		37
HAR-CON	19 Sep 96	Harkins Slough at San Andreas Rd.		36
HAR-CON	19 Sep 96	Harkins Slough at San Andreas Rd.	28	34
HAR-CON	08 Oct 96	Harkins Slough at San Andreas Rd.		63.3
HAR-CON	08 Oct 96	Harkins Slough at San Andreas Rd.	54	65.1
HAR-CON	25 Oct 96	Harkins Slough at San Andreas Rd.		19
HAR-CON	25 Oct 96	Harkins Slough at San Andreas Rd.	8	18
HAR-CON	29 Oct 96	Harkins Slough at San Andreas Rd.		20.1
HAR-CON	29 Oct 96	Harkins Slough at San Andreas Rd.	27	20.3
HAR-CON	19 Nov 96	Harkins Slough at San Andreas Rd.		27.7
HAR-CON	19 Nov 96	Harkins Slough at San Andreas Rd.	16	23.2
HAR-CON	03 Jan 97	Harkins Slough at San Andreas Rd.		202
HAR-CON	03 Jan 97	Harkins Slough at San Andreas Rd.	38	208
HAR-CON	29 Jan 97	Harkins Slough at San Andreas Rd.		145

HAR-CON	29 Jan 97	Harkins Slough at San Andreas Rd.	16	143
HAR-CON	08 Apr 97	Harkins Slough at San Andreas Rd.		146
HAR-CON	08 Apr 97	Harkins Slough at San Andreas Rd.	49	150
HAR-CON	16 Jun 97	Harkins Slough at San Andreas Rd.		251
HAR-CON	16 Jun 97	Harkins Slough at San Andreas Rd.	150	243
HAR-CON	17 Sep 97	Harkins Slough at San Andreas Rd.		207
HAR-CON	17 Sep 97	Harkins Slough at San Andreas Rd.	14	202
HAR-CON	19 Nov 97	Harkins Slough at San Andreas Rd.		43.1
HAR-CON	19 Nov 97	Harkins Slough at San Andreas Rd.	31	51.5
HAR-CON	08 Apr 98	Harkins Slough at San Andreas Rd.		91
HAR-CON	08 Apr 98	Harkins Slough at San Andreas Rd.	34	85
STR-LEE	29 Oct 96	Struve Slough at Lee Rd.		95.7
STR-LEE	29 Oct 96	Struve Slough at Lee Rd.	48	97.6
STR-LEE	19 Nov 96	Struve Slough at Lee Rd.		25.3
STR-LEE	19 Nov 96	Struve Slough at Lee Rd.	4	15.4
STR-LEE	03 Jan 97	Struve Slough at Lee Rd.		18.3
STR-LEE	03 Jan 97	Struve Slough at Lee Rd.	2	14.6
STR-LEE	29 Jan 97	Struve Slough at Lee Rd.		9.03
STR-LEE	29 Jan 97	Struve Slough at Lee Rd.	2	9.39
STR-LEE	08 Apr 97	Struve Slough at Lee Rd.		4.97
STR-LEE	08 Apr 97	Struve Slough at Lee Rd.	2	4.5
STR-LEE	16 Jun 97	Struve Slough at Lee Rd.		15.7
STR-LEE	16 Jun 97	Struve Slough at Lee Rd.	5	18.9
STR-LEE	17 Sep 97	Struve Slough at Lee Rd.		26.1
STR-LEE	17 Sep 97	Struve Slough at Lee Rd.	34	26
STR-LEE	19 Nov 97	Struve Slough at Lee Rd.		45.6
STR-LEE	19 Nov 97	Struve Slough at Lee Rd.	20	45.9
STR-LEE	08 Apr 98	Struve Slough at Lee Rd.		3.79
STR-LEE	08 Apr 98	Struve Slough at Lee Rd.	3	3.86
HAR-HAR	19 Sep 96	Harkins Slough at Harkins Slough Rd.		9.72
HAR-HAR	19 Sep 96	Harkins Slough at Harkins Slough Rd.		8.67
HAR-HAR	19 Sep 96	Harkins Slough at Harkins Slough Rd.	10	11.9
HAR-HAR	08 Oct 96	Harkins Slough at Harkins Slough Rd.		194

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HAR-HAR	08 Oct 96	Harkins Slough at Harkins Slough Rd.	220	210
HAR-HAR	25 Oct 96	Harkins Slough at Harkins Slough Rd.		41.8
HAR-HAR	25 Oct 96	Harkins Slough at Harkins Slough Rd.	27	41.5
HAR-HAR	29 Oct 96	Harkins Slough at Harkins Slough Rd.		47.4
HAR-HAR	29 Oct 96	Harkins Slough at Harkins Slough Rd.	56	45.6
HAR-HAR	19 Nov 96	Harkins Slough at Harkins Slough Rd.		152
HAR-HAR	19 Nov 96	Harkins Slough at Harkins Slough Rd.	18	157
HAR-HAR	03 Jan 97	Harkins Slough at Harkins Slough Rd.		252
HAR-HAR	03 Jan 97	Harkins Slough at Harkins Slough Rd.	62	233
HAR-HAR	29 Jan 97	Harkins Slough at Harkins Slough Rd.		199
HAR-HAR	29 Jan 97	Harkins Slough at Harkins Slough Rd.	41	193
HAR-HAR	08 Apr 97	Harkins Slough at Harkins Slough Rd.		47.3
HAR-HAR	08 Apr 97	Harkins Slough at Harkins Slough Rd.	42	50.6
HAR-HAR	16 Jun 97	Harkins Slough at Harkins Slough Rd.		214
HAR-HAR	16 Jun 97	Harkins Slough at Harkins Slough Rd.	118	194
HAR-HAR	17 Sep 97	Harkins Slough at Harkins Slough Rd.		44.3
HAR-HAR	17 Sep 97	Harkins Slough at Harkins Slough Rd.	58	49.3
HAR-HAR	19 Nov 97	Harkins Slough at Harkins Slough Rd.		109
HAR-HAR	19 Nov 97	Harkins Slough at Harkins Slough Rd.	92	96
HAR-HAR	08 Apr 98	Harkins Slough at Harkins Slough Rd.		55.4
HAR-HAR	08 Apr 98	Harkins Slough at Harkins Slough Rd.	32	54.8
WAT-WAL	19 Nov 97	Watsonville Slough at Walker St.		20.5
WAT-WAL	19 Nov 97	Watsonville Slough at Walker St.	6	21
WAT-WAL	08 Apr 98	Watsonville Slough at Walker St.		8.36
WAT-WAL	08 Apr 98	Watsonville Slough at Walker St.	5	8.24
WAT-AND	08 Oct 96	Watsonville Slough at San Andreas Rd.	68	38
WAT-AND	08 Oct 96	Watsonville Slough at San Andreas Rd.	130	98
WAT-AND	08 Oct 96	Watsonville Slough at San Andreas Rd.	88	64
WAT-AND	09 Oct 96	Watsonville Slough at San Andreas Rd.	60	48
WAT-AND	09 Oct 96	Watsonville Slough at San Andreas Rd.	52	36
WAT-AND	09 Oct 96	Watsonville Slough at San Andreas Rd.	46	30
WAT-AND	23 Oct 96	Watsonville Slough at San Andreas Rd.	38	31
WAT-AND	24 Oct 96	Watsonville Slough at San Andreas Rd.	20	30

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WAT-AND	24 Oct 96	Watsonville Slough at San Andreas Rd.	36	19
WAT-AND	25 Oct 96	Watsonville Slough at San Andreas Rd.	19	29
WAT-AND	25 Oct 96	Watsonville Slough at San Andreas Rd.	68	18
WAT-AND	29 Oct 96	Watsonville Slough at San Andreas Rd.	64	32
WAT-AND	29 Oct 96	Watsonville Slough at San Andreas Rd.	47	55
WAT-AND	30 Oct 96	Watsonville Slough at San Andreas Rd.	29	31
WAT-AND	30 Oct 96	Watsonville Slough at San Andreas Rd.	72	55
WAT-AND	31 Oct 96	Watsonville Slough at San Andreas Rd.	20	20
WAT-AND	19 Nov 96	Watsonville Slough at San Andreas Rd.	27	31
WAT-AND	20 Nov 96	Watsonville Slough at San Andreas Rd.	31	36
WAT-AND	20 Nov 96	Watsonville Slough at San Andreas Rd.	40	17
WAT-AND	21 Nov 96	Watsonville Slough at San Andreas Rd.	57	36
WAT-AND	21 Nov 96	Watsonville Slough at San Andreas Rd.	55	33
WAT-SHE	03 Jan 97	Watsonville Slough at Shell Road	68	130
WAT-SHE	03 Jan 97	Watsonville Slough at Shell Road	48	111
WAT-SHE	04 Jan 97	Watsonville Slough at Shell Road	52	121
WAT-SHE	04 Jan 97	Watsonville Slough at Shell Road	54	109
WAT-SHE	04 Jan 97	Watsonville Slough at Shell Road	52	112
WAT-SHE	05 Jan 97	Watsonville Slough at Shell Road	58	111
WAT-SHE	29 Jan 97	Watsonville Slough at Shell Road	38	89
WAT-SHE	29 Jan 97	Watsonville Slough at Shell Road	42	95
WAT-SHE	30 Jan 97	Watsonville Slough at Shell Road	98	93
WAT-SHE	30 Jan 97	Watsonville Slough at Shell Road	32	78
WAT-SHE	30 Jan 97	Watsonville Slough at Shell Road	36	92
WAT-SHE	31 Jan 97	Watsonville Slough at Shell Road	31	97
WAT-AND	08 Apr 97	Watsonville Slough at San Andreas Rd.	70	48
WAT-AND	09 Apr 97	Watsonville Slough at San Andreas Rd.	104	95
WAT-AND	09 Apr 97	Watsonville Slough at San Andreas Rd.	61	74
WAT-AND	10 Apr 97	Watsonville Slough at San Andreas Rd.	61	94
WAT-AND	6/16/97	Watsonville Slough at San Andreas Rd.	84	62
WAT-AND	17 Jun 97	Watsonville Slough at San Andreas Rd.	130	92
WAT-AND	17 Jun 97	Watsonville Slough at San Andreas Rd.	82	71
WAT-AND	18 Jun 97	Watsonville Slough at San Andreas Rd.	82	66

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WAT-AND	18 Sep 97	Watsonville Slough at San Andreas Rd.	624	190
WAT-AND	19 Sep 97	Watsonville Slough at San Andreas Rd.	100	39
WAT-AND	19 Sep 97	Watsonville Slough at San Andreas Rd.	100	45
WAT-AND	20 Sep 97	Watsonville Slough at San Andreas Rd.	56	27
WAT-AND	13 Nov 97	Watsonville Slough at San Andreas Rd.	23	7
WAT-AND	13 Nov 97	Watsonville Slough at San Andreas Rd.	352	233
WAT-AND	14 Nov 97	Watsonville Slough at San Andreas Rd.	56	44
WAT-AND	15 Nov 97	Watsonville Slough at San Andreas Rd.	70	50
WAT-AND	16 Nov 97	Watsonville Slough at San Andreas Rd.	119	107
WAT-AND	17 Nov 97	Watsonville Slough at San Andreas Rd.	78	55
WAT-AND	18 Nov 97	Watsonville Slough at San Andreas Rd.	75	55
WAT-AND	26 Mar 98	Watsonville Slough at San Andreas Rd.	184	90.7
WAT-AND	27 Mar 98	Watsonville Slough at San Andreas Rd.	156	100.0
WAT-AND	28 Mar 98	Watsonville Slough at San Andreas Rd.	146	86.9
WAT-AND	29 Mar 98	Watsonville Slough at San Andreas Rd.	120	89.9
WAT-AND	30 Mar 98	Watsonville Slough at San Andreas Rd.	160	47.6
WAT-AND	31 Mar 98	Watsonville Slough at San Andreas Rd.	122	90.8
WAT-AND	01 Apr 98	Watsonville Slough at San Andreas Rd.	190	187.0
HAR-CON	24 Sep 96	Harkins Slough at San Andreas Rd.	41	
HAR-CON	24 Sep 96	Harkins Slough at San Andreas Rd.	133	
HAR-CON	25 Sep 96	Harkins Slough at San Andreas Rd.	70	
HAR-CON	25 Sep 96	Harkins Slough at San Andreas Rd.	48	
HAR-CON	25 Sep 96	Harkins Slough at San Andreas Rd.	38	
HAR-CON	25 Sep 96	Harkins Slough at San Andreas Rd.	58	
HAR-CON	24 Oct 96	Harkins Slough at San Andreas Rd.	15	15
HAR-CON	24 Oct 96	Harkins Slough at San Andreas Rd.	15	14
HAR-CON	25 Oct 96	Harkins Slough at San Andreas Rd.	23	17
HAR-CON	25 Oct 96	Harkins Slough at San Andreas Rd.	25	14
HAR-CON	25 Oct 96	Harkins Slough at San Andreas Rd.	14	12
HAR-CON	29 Oct 96	Harkins Slough at San Andreas Rd.	38	36
HAR-CON	19 Nov 96	Harkins Slough at San Andreas Rd.	22	15
HAR-CON	20 Nov 96	Harkins Slough at San Andreas Rd.	70	100
HAR-CON	20 Nov 96	Harkins Slough at San Andreas Rd.	55	60

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HAR-CON	21 Nov 96	Harkins Slough at San Andreas Rd.	69	75
HAR-CON	21 Nov 96	Harkins Slough at San Andreas Rd.	84	33
HAR-CON	03 Jan 97	Harkins Slough at San Andreas Rd.	60	168
HAR-CON	03 Jan 97	Harkins Slough at San Andreas Rd.	40	168
HAR-CON	04 Jan 97	Harkins Slough at San Andreas Rd.	40	159
HAR-CON	04 Jan 97	Harkins Slough at San Andreas Rd.	38	149
HAR-CON	04 Jan 97	Harkins Slough at San Andreas Rd.	30	142
HAR-CON	05 Jan 97	Harkins Slough at San Andreas Rd.	28	131
HAR-CON	29 Jan 97	Harkins Slough at San Andreas Rd.	40	131
HAR-CON	29 Jan 97	Harkins Slough at San Andreas Rd.	30	129
HAR-CON	30 Jan 97	Harkins Slough at San Andreas Rd.	32	133
HAR-CON	30 Jan 97	Harkins Slough at San Andreas Rd.	30	132
HAR-CON	30 Jan 97	Harkins Slough at San Andreas Rd.	37	115
HAR-CON	31 Jan 97	Harkins Slough at San Andreas Rd.	21	129
HAR-CON	08 Apr 97	Harkins Slough at San Andreas Rd.	79	118
HAR-CON	09 Apr 97	Harkins Slough at San Andreas Rd.	58	105
HAR-CON	09 Apr 97	Harkins Slough at San Andreas Rd.	125	189
HAR-CON	10 Apr 97	Harkins Slough at San Andreas Rd.	77	136
HAR-CON	16 Jun 97	Harkins Slough at San Andreas Rd.	212	187
HAR-CON	17 Jun 97	Harkins Slough at San Andreas Rd.	156	180
HAR-CON	17 Jun 97	Harkins Slough at San Andreas Rd.	136	153
HAR-CON	18 Jun 97	Harkins Slough at San Andreas Rd.	130	129
HAR-CON	24 Sep 97	Harkins Slough at San Andreas Rd.	10	8
HAR-CON	25 Sep 97	Harkins Slough at San Andreas Rd.	6	4
HAR-CON	25 Sep 97	Harkins Slough at San Andreas Rd.	10	5
HAR-CON	26 Sep 97	Harkins Slough at San Andreas Rd.	6	5
HAR-CON	13 Nov 97	Harkins Slough at San Andreas Rd.	12	1
HAR-CON	13 Nov 97	Harkins Slough at San Andreas Rd.	22	9
HAR-CON	14 Nov 97	Harkins Slough at San Andreas Rd.	112	70
HAR-CON	15 Nov 97	Harkins Slough at San Andreas Rd.	50	25
HAR-CON	16 Nov 97	Harkins Slough at San Andreas Rd.	48	49
HAR-CON	17 Nov 97	Harkins Slough at San Andreas Rd.	18	24
HAR-CON	18 Nov 97	Harkins Slough at San Andreas Rd.	12	19

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HAR-CON	26 Mar 98	Harkins Slough at San Andreas Rd.	274	542
HAR-CON	*27 Mar 98*	*Harkins Slough at San Andreas Rd.*	*166*	*243*
HAR-CON	28 Mar 98	Harkins Slough at San Andreas Rd.	162	152
HAR-CON	29 Mar 98	Harkins Slough at San Andreas Rd.	104	164
HAR-CON	30 Mar 98	Harkins Slough at San Andreas Rd.	88	293
HAR-CON	31 Mar 98	Harkins Slough at San Andreas Rd.	190	286
HAR-CON	01 Apr 98	Harkins Slough at San Andreas Rd.	326	378

Watershed Institute-John Oliver			
Site Code	Date	Location	Turbidity (NTU)
HAN-4	12-Dec-95	Upper Hansen Slough	1614
HAN-4	16-Jan-96	Upper Hansen Slough	1063
HAN-4	24-Jan-96	Upper Hansen Slough	1776
HAN-4	31-Jan-96	Upper Hansen Slough	1660
HAN-4	19-Feb-96	Upper Hansen Slough	1506
HAN-4	29-Feb-96	Upper Hansen Slough	641
HAN-4	17-Nov-96	Upper Hansen Slough	2029
HAN-4	22-Nov-96	Upper Hansen Slough	1750
HAN-4	05-Dec-96	Upper Hansen Slough	2039
HAN-5	12-Dec-95	Middle Hansen Slough	566
HAN-5	16-Jan-96	Middle Hansen Slough	691
HAN-5	24-Jan-96	Middle Hansen Slough	813
HAN-5	31-Jan-96	Middle Hansen Slough	851
HAN-5	19-Feb-96	Middle Hansen Slough	1413
HAN-5	29-Feb-96	Middle Hansen Slough	898
HAN-5	17-Nov-96	Middle Hansen Slough	610
HAN-5	22-Nov-96	Middle Hansen Slough	1198
HAN-5	05-Dec-96	Middle Hansen Slough	1255
HAN-6	12-Dec-95	Lower Hansen Slough	162
HAN-6	16-Jan-96	Lower Hansen Slough	115
HAN-6	24-Jan-96	Lower Hansen Slough	24.6
HAN-6	31-Jan-96	Lower Hansen Slough	632.8
HAN-6	19-Feb-96	Lower Hansen Slough	47.4
HAN-6	29-Feb-96	Lower Hansen Slough	81.9
HAN-6	17-Nov-96	Lower Hansen Slough	641
HAN-6	22-Nov-96	Lower Hansen Slough	53.9
HAN-6	05-Dec-96	Lower Hansen Slough	42.3

Pajaro Valley Water Management Agency				
CCoWS Site Code	Date	Location	TSS (mg/L)	Turbidity (NTU)
BEA-CON	18-Feb-95	Beach Road Ditch at confluence with Watsonville Slough	81	
BEA-CON	18-Feb-95	Beach Rd. Ditch at confluence with Watsonville Slough		21
BEA-CON	24-May-96	Beach Road Ditch at confluence with Watsonville Slough	34	
BEA-CON	24-May-96	Beach Rd. Ditch at confluence with Watsonville Slough		9.3
HAR-CON	18-Oct-94	Harkins Slough at confluence with Watsonville Slough		41
HAR-CON	15-Nov-94	Harkins Slough at confluence with Watsonville Slough		380
HAR-CON	8-Dec-94	Harkins Slough at confluence with Watsonville Slough		44
HAR-CON	4-Jan-95	Harkins Slough at confluence with Watsonville Slough		195
HAR-CON	18-Feb-95	Harkins Slough at confluence with Watsonville Slough	44	
HAR-CON	18-Feb-95	Harkins Slough at confluence with Watsonville Slough		136
HAR-CON	18-Dec-95	Harkins Slough at confluence with Watsonville Slough	56	
HAR-CON	18-Dec-95	Harkins Slough at confluence with Watsonville Slough		355
HAR-CON	16-Jan-96	Harkins Slough at confluence with Watsonville Slough	112	
HAR-CON	16-Jan-96	Harkins Slough at confluence with Watsonville Slough		152
HAR-CON	12-Feb-96	Harkins Slough at confluence with Watsonville Slough	22	
HAR-CON	12-Feb-96	Harkins Slough at confluence with Watsonville Slough		91
HAR-CON	18-Mar-96	Harkins Slough at confluence with Watsonville Slough	15	
HAR-CON	18-Mar-96	Harkins Slough at confluence with Watsonville Slough		89
HAR-CON	22-Apr-96	Harkins Slough at confluence with Watsonville Slough		185
HAR-CON	24-May-96	Harkins Slough at confluence with Watsonville Slough	55	
HAR-CON	24-May-96	Harkins Slough at confluence with Watsonville Slough		58
HAR-CON	21-Nov-96	Harkins Slough at confluence with Watsonville Slough		31
HAR-CON	7-Jan-97	Harkins Slough at confluence with Watsonville Slough	35	

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HAR-CON	7-Jan-97	Harkins Slough at confluence with Watsonville Slough		191
HAR-CON	20-Mar-97	Harkins Slough at confluence with Watsonville Slough	77	
HAR-CON	20-Mar-97	Harkins Slough at confluence with Watsonville Slough		96
HAR-CON	22-Apr-97	Harkins Slough at confluence with Watsonville Slough	107	
HAR-CON	22-Apr-97	Harkins Slough at confluence with Watsonville Slough		176
HAR-CON	19-May-97	Harkins Slough at confluence with Watsonville Slough	98	
HAR-CON	19-May-97	Harkins Slough at confluence with Watsonville Slough		115
HAR-CON	17-Jun-97	Harkins Slough at confluence with Watsonville Slough	138	
HAR-CON	17-Jun-97	Harkins Slough at confluence with Watsonville Slough		198
HAR-CON	3-Dec-97	Harkins Slough at confluence with Watsonville Slough		85
HAR-CON	12-Jan-98	Harkins Slough at confluence with Watsonville Slough	51	
HAR-CON	12-Jan-98	Harkins Slough at confluence with Watsonville Slough		80
HAR-CON	30-Mar-98	Harkins Slough at confluence with Watsonville Slough	78	
HAR-CON	30-Mar-98	Harkins Slough at confluence with Watsonville Slough		160
HAR-CON	8-May-98	Harkins Slough at confluence with Watsonville Slough	168	
HAR-CON	8-May-98	Harkins Slough at confluence with Watsonville Slough		168
HAR-CON	28-May-98	Harkins Slough at confluence with Watsonville Slough		130
HAR-CON	1-Jul-98	Harkins Slough at confluence with Watsonville Slough	32	
HAR-CON	1-Jul-98	Harkins Slough at confluence with Watsonville Slough		28
HAR-CON	19-Jan-99	Harkins Slough at confluence with Watsonville Slough		160
HAR-CON	2-Feb-99	Harkins Slough at confluence with Watsonville Slough	46	
HAR-CON	2-Feb-99	Harkins Slough at confluence with Watsonville Slough		78
HAR-CON	2-Feb-99	Harkins Slough at confluence with Watsonville Slough		52
HAR-CON	1-Mar-99	Harkins Slough at confluence with Watsonville Slough	42	
HAR-CON	1-Mar-99	Harkins Slough at confluence with Watsonville Slough		164

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HAR-CON	24-Nov-99	Harkins Slough at confluence with Watsonville Slough		2.4
HAR-CON	25-Jan-00	Harkins Slough at confluence with Watsonville Slough		42
HAR-CON	9-Feb-00	Harkins Slough at confluence with Watsonville Slough		47
HAR-CON	24-Feb-00	Harkins Slough at confluence with Watsonville Slough		155
HAR-CON	14-Mar-00	Harkins Slough at confluence with Watsonville Slough		70
HAR-CON	23-Mar-00	Harkins Slough at confluence with Watsonville Slough		42
HAR-CON	18-Apr-00	Harkins Slough at confluence with Watsonville Slough		56
HAR-CON	9-Jan-02	Harkins Slough 25' upstream of confluence	52	57
HAR-CON	15-Jan-02	Harkins Slough 25' upstream of confluence	37	35
HAR-CON	23-Jan-02	Harkins Slough 25' upstream of confluence	27	36
HAR-CON	28-Jan-02	Harkins Slough 25' upstream of confluence	34	39
HAR-CON	6-Feb-02	Harkins Slough 25' upstream of confluence	48	55
HAR-CON	12-Feb-02	Harkins Slough 25' upstream of confluence	56	64
HAR-CON	21-Feb-02	Harkins Slough 25' upstream of confluence	66	131
HAR-CON	27-Feb-02	Harkins Slough 25' upstream of confluence	118	81
HAR-CON	5-Mar-02	Harkins Slough 25' upstream of confluence	53	55
HAR-CON	13-Mar-02	Harkins Slough 25' upstream of confluence	55	57
HAR-CON	19-Mar-02	Harkins Slough 25' upstream of confluence	128	63
HAR-CON	27-Mar-02	Harkins Slough 25' upstream of confluence	125	66
HAR-CON	3-Apr-02	Harkins Slough 25' upstream of confluence	106	81
HAR-CON	10-Apr-02	Harkins Slough 25' upstream of confluence	154	119
HAR-CON	16-Apr-02	Harkins Slough 25' upstream of confluence	119	69
HAR-CON	24-Apr-02	Harkins Slough 25' upstream of confluence	68	65
HAR-CON	1-May-02	Harkins Slough 25' upstream of confluence	65	66
HAR-INF	9-Jan-02	Harkins Slough Diversion Influent	52	72

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HAR-INF	15-Jan-02	Harkins Slough Diversion Influent	31	46
HAR-INF	23-Jan-02	Harkins Slough Diversion Influent	26	39
HAR-INF	28-Jan-02	Harkins Slough Diversion Influent	28	40.1
HAR-INF	6-Feb-02	Harkins Slough Diversion Influent	28	37.6
HAR-INF	13-Feb-02	Harkins Slough Diversion Influent	26	37.2
HAR-INF	21-Feb-02	Harkins Slough Diversion Influent	78	141.5
HAR-INF	27-Feb-02	Harkins Slough Diversion Influent	95	85.9
HAR-INF	5-Mar-02	Harkins Slough Diversion Influent	53	56.3
HAR-INF	13-Mar-02	Harkins Slough Diversion Influent	92	76.8
HAR-INF	27-Mar-02	Harkins Slough Diversion Influent	116	107.6
HAR-INF	3-Apr-02	Harkins Slough Diversion Influent	106	70.6
HAR-INF	10-Apr-02	Harkins Slough Diversion Influent	224	116.5
HAR-INF	16-Apr-02	Harkins Slough Diversion Influent	46	72.8
HAR-INF	24-Apr-02	Harkins Slough Diversion Influent	103	75.5
HAR-INF	1-May-02	Harkins Slough Diversion Influent	65	62.5
HAR-INF	8-May-02	Harkins Slough Diversion Influent	42	55.6
HAR-INF	15-May-02	Harkins Slough Diversion Influent	75	130.8
HAR-INF	22-May-02	Harkins Slough Diversion Influent	56	72
WAT-AND	18-Feb-95	Watsonville Slough at San Andreas Rd.	41	
WAT-AND	18-Feb-95	Watsonville Slough at San Andreas Rd.		105
WAT-AND	18-Dec-95	Watsonville Slough at San Andreas Rd.	42	
WAT-AND	18-Dec-95	Watsonville Slough at San Andreas Rd.		245
WAT-AND	16-Jan-96	Watsonville Slough at San Andreas Rd.	86	
WAT-AND	16-Jan-96	Watsonville Slough at San Andreas Rd.		99
WAT-AND	12-Feb-96	Watsonville Slough at San Andreas Rd.	71	

WAT-AND	12-Feb-96	Watsonville Slough at San Andreas Rd.		105
WAT-AND	19-Mar-96	Watsonville Slough at San Andreas Rd.	17	
WAT-AND	19-Mar-96	Watsonville Slough at San Andreas Rd.		76
WAT-AND	22-Apr-96	Watsonville Slough at San Andreas Rd.		205
WAT-AND	24-May-96	Watsonville Slough at San Andreas Rd.	73	
WAT-AND	24-May-96	Watsonville Slough at San Andreas Rd.		91
WAT-AND	21-Nov-96	Watsonville Slough at San Andreas Rd.		59
WAT-AND	7-Jan-97	Watsonville Slough at San Andreas Rd.	36	
WAT-AND	7-Jan-97	Watsonville Slough at San Andreas Rd.		131
WAT-AND	22-Apr-97	Watsonville Slough at San Andreas Rd.	133	
WAT-AND	22-Apr-97	Watsonville Slough at San Andreas Rd.		177
WAT-AND	19-May-97	Watsonville Slough at San Andreas Rd.	107	
WAT-AND	19-May-97	Watsonville Slough at San Andreas Rd.		129
WAT-AND	17-Jun-97	Watsonville Slough at San Andreas Rd.	134	
WAT-AND	17-Jun-97	Watsonville Slough at San Andreas Rd.		157
WAT-AND	2-Feb-99	Watsonville Slough at San Andreas Rd.	37	
WAT-AND	2-Feb-99	Watsonville Slough at San Andreas Rd.		58
WAT-AND	1-Mar-99	Watsonville Slough at San Andreas Rd.	53	
WAT-AND	1-Mar-99	Watsonville Slough at San Andreas Rd.		134
WAT-AND	20-Apr-99	Watsonville Slough at San Andreas Rd.	70	
WAT-AND	20-Apr-99	Watsonville Slough at San Andreas Rd.		63
WAT-AND	24-Nov-99	Watsonville Slough at San Andreas Rd.		2.6
WAT-AND	25-Jan-00	Watsonville Slough at San Andreas Rd.		46
WAT-AND	24-Feb-00	Watsonville Slough at San Andreas Rd.		114
WAT-AND	6-Mar-00	Watsonville Slough at San Andreas Rd.	128	

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WAT-AND	6-Mar-00	Watsonville Slough at San Andreas Rd.		217
WAT-AND	14-Mar-00	Watsonville Slough at San Andreas Rd.		49
WAT-AND	23-Mar-00	Watsonville Slough at San Andreas Rd.		38
WAT-AND	18-Apr-00	Watsonville Slough at San Andreas Rd.		51
WAT-AND	8-May-00	Watsonville Slough at San Andreas Rd.	132	
WAT-AND	8-May-00	Watsonville Slough at San Andreas Rd.		213
WAT-HSD	9-Jan-02	Watsonville Slough 50' downstream of pump station	49	57
WAT-HSD	15-Jan-02	Watsonville Slough 50' downstream of pump station	31	45
WAT-HSD	23-Jan-02	Watsonville Slough 50' downstream of pump station	28	39
WAT-HSD	28-Jan-02	Watsonville Slough 50' downstream of pump station	120	66
WAT-HSD	6-Feb-02	Watsonville Slough 50' downstream of pump station	40	46
WAT-HSD	12-Feb-02	Watsonville Slough 50' downstream of pump station	650	130
WAT-HSD	21-Feb-02	Watsonville Slough 50' downstream of pump station	98	155
WAT-HSD	27-Feb-02	Watsonville Slough 50' downstream of pump station	923	214
WAT-HSD	5-Mar-02	Watsonville Slough 50' downstream of pump station	129	135
WAT-HSD	13-Mar-02	Watsonville Slough 50' downstream of pump station	639	104
WAT-HSD	19-Mar-02	Watsonville Slough 50' downstream of pump station	725	103
WAT-HSD	27-Mar-02	Watsonville Slough 50' downstream of pump station	312	117
WAT-HSD	3-Apr-02	Watsonville Slough 50' downstream of pump station	64	130
WAT-HSD	10-Apr-02	Watsonville Slough 50' downstream of pump station	1150	117
WAT-HSD	16-Apr-02	Watsonville Slough 50' downstream of pump station	684	98
WAT-HSD	24-Apr-02	Watsonville Slough 50' downstream of pump station	355	186
WAT-HSD	1-May-02	Watsonville Slough 50' downstream of pump station	329	264
WAT-HSU	9-Jan-02	Watsonville Slough 50' upstream of pump station	18	61
WAT-HSU	15-Jan-02	Watsonville Slough 50' upstream of pump station	15	28

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WAT-HSU	23-Jan-02	Watsonville Slough 50' upstream of pump station	24	30
WAT-HSU	28-Jan-02	Watsonville Slough 50' upstream of pump station	33	40
WAT-HSU	6-Feb-02	Watsonville Slough 50' upstream of pump station	18	35
WAT-HSU	12-Feb-02	Watsonville Slough 50' upstream of pump station	48	52
WAT-HSU	21-Feb-02	Watsonville Slough 50' upstream of pump station	67	127
WAT-HSU	27-Feb-02	Watsonville Slough 50' upstream of pump station	70	71
WAT-HSU	5-Mar-02	Watsonville Slough 50' upstream of pump station	114	127
WAT-HSU	13-Mar-02	Watsonville Slough 50' upstream of pump station	79	76
WAT-HSU	19-Mar-02	Watsonville Slough 50' upstream of pump station	63	66
WAT-HSU	27-Mar-02	Watsonville Slough 50' upstream of pump station	113	112
WAT-HSU	3-Apr-02	Watsonville Slough 50' upstream of pump station	99	69
WAT-HSU	10-Apr-02	Watsonville Slough 50' upstream of pump station	154	117
WAT-HSU	16-Apr-02	Watsonville Slough 50' upstream of pump station	137	98
WAT-HSU	24-Apr-02	Watsonville Slough 50' upstream of pump station	88	83
WAT-HSU	1-May-02	Watsonville Slough 50' upstream of pump station	369	110
WAT-RWY	18-Oct-94	Watsonville Slough at Railroad crossing		40
WAT-RWY	15-Nov-94	Watsonville Slough at Railroad crossing		460
WAT-RWY	8-Dec-94	Watsonville Slough at Railroad crossing		260
WAT-RWY	21-Jan-95	Watsonville Slough at Railroad crossing		94
WAT-RWY	18-Feb-95	Watsonville Slough at Railroad crossing	36	
WAT-RWY	18-Feb-95	Watsonville Slough at Railroad crossing		45
WAT-RWY	19-Mar-96	Watsonville Slough at Railroad crossing	32	
WAT-RWY	19-Mar-96	Watsonville Slough at Railroad crossing		52
WAT-RWY	24-May-96	Watsonville Slough at Railroad crossing	50	
WAT-RWY	24-May-96	Watsonville Slough at Railroad crossing		40

WAT-RWY	22-Nov-96	Watsonville Slough at Railroad crossing	95	
WAT-RWY	22-Nov-96	Watsonville Slough at Railroad crossing		157
WAT-RWY	7-Jan-97	Watsonville Slough at Railroad crossing	29	
WAT-RWY	7-Jan-97	Watsonville Slough at Railroad crossing		68
WAT-RWY	20-Mar-97	Watsonville Slough at Railroad crossing	87	
WAT-RWY	20-Mar-97	Watsonville Slough at Railroad crossing		90
WAT-RWY	22-Apr-97	Watsonville Slough at Railroad crossing	112	
WAT-RWY	22-Apr-97	Watsonville Slough at Railroad crossing		86
WAT-RWY	19-May-97	Watsonville Slough at Railroad crossing	43	
WAT-RWY	19-May-97	Watsonville Slough at Railroad crossing		44
WAT-RWY	12-Jan-98	Watsonville Slough at Railroad crossing	73	
WAT-RWY	12-Jan-98	Watsonville Slough at Railroad crossing		89
WAT-RWY	3-Apr-98	Watsonville Slough at Railroad crossing	147	
WAT-RWY	3-Apr-98	Watsonville Slough at Railroad crossing		113
WAT-RWY	8-May-98	Watsonville Slough at Railroad crossing	123	
WAT-RWY	8-May-98	Watsonville Slough at Railroad crossing		235
WAT-RWY	2-Feb-99	Watsonville Slough at Railroad crossing	38	
WAT-RWY	2-Feb-99	Watsonville Slough at Railroad crossing		53
WAT-RWY	1-Mar-99	Watsonville Slough at Railroad crossing	53	
WAT-RWY	1-Mar-99	Watsonville Slough at Railroad crossing		60
WAT-RWY	20-Apr-99	Watsonville Slough at Railroad crossing	80	
WAT-RWY	20-Apr-99	Watsonville Slough at Railroad crossing		82
WAT-RWY	24-Nov-99	Watsonville Slough at Railroad crossing		3.9
WAT-RWY	25-Jan-00	Watsonville Slough at Railroad crossing		51
WAT-RWY	24-Feb-00	Watsonville Slough at Railroad crossing		148

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WAT-RWY	14-Mar-00	Watsonville Slough at Railroad crossing		24
WAT-RWY	23-Mar-00	Watsonville Slough at Railroad crossing		24
WAT-RWY	18-Apr-00	Watsonville Slough at Railroad crossing		61
WAT-SHE	18-Oct-94	Watsonville Slough at Shell Rd.		44
WAT-SHE	21-Jan-95	Watsonville Slough at Shell Rd.		157
WAT-SHE	18-Feb-95	Watsonville Slough at Shell Rd.		105
WAT-SHE	3-Apr-95	Watsonville Slough at Shell Rd.		182
WAT-SHE	17-Jan-96	Watsonville Slough at Shell Road	74	
WAT-SHE	17-Jan-96	Watsonville Slough at Shell Rd.		92
WAT-SHE	18-Mar-96	Watsonville Slough at Shell Road	28	
WAT-SHE	18-Mar-96	Watsonville Slough at Shell Rd.		77
WAT-SHE	24-May-96	Watsonville Slough at Shell Road	195	
WAT-SHE	24-May-96	Watsonville Slough at Shell Rd.		254
WAT-SHE	22-Nov-96	Watsonville Slough at Shell Road	28	
WAT-SHE	22-Nov-96	Watsonville Slough at Shell Rd.		72
WAT-SHE	7-Jan-97	Watsonville Slough at Shell Road	36	
WAT-SHE	7-Jan-97	Watsonville Slough at Shell Rd.		132
WAT-SHE	22-Apr-97	Watsonville Slough at Shell Road	120	
WAT-SHE	22-Apr-97	Watsonville Slough at Shell Rd.		122
WAT-SHE	19-May-97	Watsonville Slough at Shell Road	98	
WAT-SHE	19-May-97	Watsonville Slough at Shell Rd.		107
WAT-SHE	17-Jun-97	Watsonville Slough at Shell Road	107	
WAT-SHE	17-Jun-97	Watsonville Slough at Shell Rd.		131
WAT-SHE	12-Jan-98	Watsonville Slough at Shell Road	110	
WAT-SHE	12-Jan-98	Watsonville Slough at Shell Rd.		170

WAT-SHE	5-Mar-98	Watsonville Slough at Shell Road	69	
WAT-SHE	5-Mar-98	Watsonville Slough at Shell Rd.		224
WAT-SHE	30-Mar-98	Watsonville Slough at Shell Road	95	
WAT-SHE	30-Mar-98	Watsonville Slough at Shell Rd.		173
WAT-SHE	8-May-98	Watsonville Slough at Shell Road	257	
WAT-SHE	8-May-98	Watsonville Slough at Shell Rd.		307
WAT-SHE	1-Jul-98	Watsonville Slough at Shell Rd.		88
WAT-SHE	2-Feb-99	Watsonville Slough at Shell Road	92	
WAT-SHE	2-Feb-99	Watsonville Slough at Shell Rd.		106
WAT-SHE	1-Mar-99	Watsonville Slough at Shell Road	60	
WAT-SHE	1-Mar-99	Watsonville Slough at Shell Rd.		124
WAT-SHE	20-Apr-99	Watsonville Slough at Shell Road	278	
WAT-SHE	20-Apr-99	Watsonville Slough at Shell Rd.		166
WAT-SHE	24-Nov-99	Watsonville Slough at Shell Rd.		21
WAT-SHE	25-Jan-00	Watsonville Slough at Shell Rd.		52
WAT-SHE	24-Feb-00	Watsonville Slough at Shell Rd.		105
WAT-SHE	14-Mar-00	Watsonville Slough at Shell Rd.		52
WAT-SHE	23-Mar-00	Watsonville Slough at Shell Rd.		50
WAT-SHE	18-Apr-00	Watsonville Slough at Shell Rd.		63

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Appendix D-Region 3 Land Use Land Cover Map

SSC/TSS
Exceeding 27
Total Samples 330

Binomal
Allows
54 into

Table 4.2

Appendix E-CCoWS Data

Date/Time	Site Code	SSC (mg/L)	Turbidity (NTU)	Discharge (m^3/s)
18-Feb-03	GAL-BUE	35.087	41.6	0.004
27-Feb-03	GAL-BUE	52.447	98.3	0.0156
13-Mar-03	GAL-BUE	143.864	19.6	0.006
14-Mar-03	GAL-BUE	32.779	26.9	0.015
15-Mar-03	GAL-BUE	86.361	197	0.066
15-Mar-03	GAL-BUE	105.589	123	
18-Mar-03	GAL-BUE	21.908	9.97	
20-Mar-03	GAL-BUE	25.638	13.6	0.01
13-Apr-03	GAL-BUE	4163.59	7888	0.0182
13-Apr-03	GAL-BUE			0.0382
19-Jun-03	GAL-BUE	14.2	65.3	0.001
26-Jun-03	GAL-BUE	23.83	55	0.0002
01-Jul-03	GAL-BUE	25.46	58.7	0.0005
08-Jul-03	GAL-BUE			0
13-Jul-03	GAL-BUE			0
16-Jul-03	GAL-BUE			0
27-Feb-03	HAN-HAR	778.1	347	0.0025
15-Mar-03	HAN-HAR	2455.284	2259	0.01
13-Apr-03	HAN-HAR	3030.901	4272	0.004
13-Apr-03	HAN-HAR			0.003
19-Jun-03	HAN-HAR			0
26-Jun-03	HAN-HAR			0
01-Jul-03	HAN-HAR			0
08-Jul-03	HAN-HAR			0
13-Jul-03	HAN-HAR			0
16-Jul-03	HAN-HAR			0
18-Feb-03	HAR-CON	10.172	14.2	
27-Feb-03	HAR-CON	91.2	80.7	
14-Mar-03	HAR-CON	55.52	24	
15-Mar-03	HAR-CON	225.131	170	
18-Mar-03	HAR-CON	75.841	50.1	
20-Mar-03	HAR-CON	89.53	29.8	

13-Apr-03	HAR-CON	21.87215	23.9	
19-Jun-03	HAR-CON	0	3.33	
26-Jun-03	HAR-CON	12.28	3.62	
01-Jul-03	HAR-CON	10.2	4.45	
13-Jul-03	HAR-CON	24.21	4.15	
16-Jul-03	HAR-CON	15.32	7.99	
18-Feb-03	HAR-HAR	2.197	8.86	
27-Feb-03	HAR-HAR	10.835	11.9	
14-Mar-03	HAR-HAR	12.43	13.5	
15-Mar-03	HAR-HAR	36.069	4.61	
18-Mar-03	HAR-HAR	56.091	7.77	
20-Mar-03	HAR-HAR	28.655	10.4	
19-Jun-03	HAR-HAR	67.58	92.8	
26-Jun-03	HAR-HAR	68.7	72.2	
01-Jul-03	HAR-HAR	85.5	106	
13-Jul-03	HAR-HAR	116.75	105	
16-Jul-03	HAR-HAR	95.81	99	
18-Feb-03	HAR-RAU	5.042	12.2	
27-Feb-03	HAR-RAU	73.112	180	0.1034
13-Mar-03	HAR-RAU	29.376	9.96	0.019
14-Mar-03	HAR-RAU	2.2	9.49	0.019
15-Mar-03	HAR-RAU	206.68	244	1.4321
15-Mar-03	HAR-RAU	0	134	
18-Mar-03	HAR-RAU	14.666	16.7	0.009
20-Mar-03	HAR-RAU	0	13.7	0.021
13-Apr-03	HAR-RAU	25.565	37.7	0.037
13-Apr-03	HAR-RAU			0.0298
19-Jun-03	HAR-RAU	8.87	51	
26-Jun-03	HAR-RAU	13.11	31.9	
01-Jul-03	HAR-RAU	1.03	19.8	
13-Jul-03	HAR-RAU	26.99	36.1	
16-Jul-03	HAR-RAU	22.51	38.3	
18-Feb-03	STR-CHE	10.976	22.6	0.001
27-Feb-03	STR-CHE	18.682	39.1	0.004
14-Mar-03	STR-CHE	31.576	8.82	0.001

15-Mar-03	STR-CHE	32.13	33.4	0.0635
15-Mar-03	STR-CHE	31.65	34.6	
18-Mar-03	STR-CHE	26.194	11.8	0.003
20-Mar-03	STR-CHE	56.255	11.6	0.001
13-Apr-03	STR-CHE	70.572	47.1	0.0455
13-Apr-03	STR-CHE			0.0143
19-Jun-03	STR-CHE	0	11.6	0.006
26-Jun-03	STR-CHE	62.71	14	
01-Jul-03	STR-CHE	139	7.02	0.002
08-Jul-03	STR-CHE			0.003
13-Jul-03	STR-CHE	12	10.7	0.001
16-Jul-03	STR-CHE	15.67	4.4	0.001
18-Feb-03	STR-HAR	24.463	4.56	
27-Feb-03	STR-HAR	20.187	24.9	
14-Mar-03	STR-HAR	31.936	1.87	
15-Mar-03	STR-HAR	2.56	3.06	
18-Mar-03	STR-HAR	8.352	11.8	
20-Mar-03	STR-HAR	6.722	1.4	
19-Jun-03	STR-HAR	0	6.64	
26-Jun-03	STR-HAR	5.4	3.19	
01-Jul-03	STR-HAR	3.31	9.09	
13-Jul-03	STR-HAR	33.68	20.7	
16-Jul-03	STR-HAR	25.96	33.2	
18-Feb-03	STR-LEE	4.411	2.69	
27-Feb-03	STR-LEE	13.901	2.4	
14-Mar-03	STR-LEE	24.16	1.93	
15-Mar-03	STR-LEE	18.893	1.55	
18-Mar-03	STR-LEE	28.704	1.74	
20-Mar-03	STR-LEE	17.7	1.62	
19-Jun-03	STR-LEE	5.97	3.1	
26-Jun-03	STR-LEE	10.49	4.68	
01-Jul-03	STR-LEE	0.95	6.5	
13-Jul-03	STR-LEE	0	9.13	
16-Jul-03	STR-LEE	28.67	15.7	
18-Feb-03	WAT-AND	29.441	20.9	

27-Feb-03	WAT-AND	242.133	183	
14-Mar-03	WAT-AND	370.59	248	
15-Mar-03	WAT-AND	505.458	323	
18-Mar-03	WAT-AND	40.858	93.6	
20-Mar-03	WAT-AND	48.484	40.3	
13-Apr-03	WAT-AND	89.32	47.1	
19-Jun-03	WAT-AND	10.82	13.8	
26-Jun-03	WAT-AND	28.31	18.7	
01-Jul-03	WAT-AND	18.02	4.16	
13-Jul-03	WAT-AND	29.21	12.9	
16-Jul-03	WAT-AND	29.37	15	
28-Dec-03	WAT-ERR	0	60	
30-Dec-03	WAT-ERR	128.7	83.2	0.675
30-Dec-03	WAT-ERR	50.3	33.2	0.279
31-Dec-03	WAT-ERR	401.71	271	0.372
01-Jan-04	WAT-ERR	254.643	481	0.074
02-Jan-04	WAT-ERR	41.225	18.3	0.443
05-Jan-04	WAT-ERR	143.06	153	0.088
01-Feb-04	WAT-ERR	29.185	11.4	
02-Feb-04	WAT-ERR	220.88	291	
03-Feb-04	WAT-ERR	36.24	40.2	
04-Feb-04	WAT-ERR	11.62	10.7	
05-Feb-04	WAT-ERR	5.447	4.71	
23-Feb-04	WAT-ERR	15.691	5.55	
25-Feb-04	WAT-ERR	354.867	24.3	
26-Feb-04	WAT-ERR	19.395	17.8	
27-Feb-04	WAT-ERR	13.5864	10.5	
01-Mar-04	WAT-ERR	67.26	41.7	
18-Feb-03	WAT-HAR	4.384	2.88	
27-Feb-03	WAT-HAR	15.12	4.54	
14-Mar-03	WAT-HAR	6.7	4.06	
15-Mar-03	WAT-HAR	10.942	6.1	
18-Mar-03	WAT-HAR	6.598	3.4	
20-Mar-03	WAT-HAR	0	2.57	
19-Jun-03	WAT-HAR	5.44	3.65	

26-Jun-03	WAT-HAR	14.16	3.93	
01-Jul-03	WAT-HAR	5.37	5.38	
13-Jul-03	WAT-HAR	57.54	21.3	
16-Jul-03	WAT-HAR	23.91	25.3	
18-Feb-03	WAT-LEE	6.483	15.2	0.052
27-Feb-03	WAT-LEE	230.09	90.6	0.113
13-Mar-03	WAT-LEE	83.104	22.3	
14-Mar-03	WAT-LEE	70.886	28.4	0.0105
15-Mar-03	WAT-LEE	174.89	129	0.1974
15-Mar-03	WAT-LEE	106.6	112	
18-Mar-03	WAT-LEE	14.009	12.2	0.055
20-Mar-03	WAT-LEE	38.933	12.8	0.0433
13-Apr-03	WAT-LEE	238.4	232	0.2913
13-Apr-03	WAT-LEE			0.1421
19-Jun-03	WAT-LEE	35.22	20.7	0.002
26-Jun-03	WAT-LEE	69.15	29.1	0.001
01-Jul-03	WAT-LEE	38.27	26.9	0.003
08-Jul-03	WAT-LEE			0.004
13-Jul-03	WAT-LEE	69.18	49.6	
16-Jul-03	WAT-LEE	40.17	22.7	0.002
18-Feb-03	WAT-PAJ	264.328	4.39	
27-Feb-03	WAT-PAJ	43.953	22.4	
14-Mar-03	WAT-PAJ	239.024	7.83	
15-Mar-03	WAT-PAJ	185.89	11.9	
18-Mar-03	WAT-PAJ	13.145	7.17	
20-Mar-03	WAT-PAJ	9.062	12.8	
19-Jun-03	WAT-PAJ	334.78	8.76	
26-Jun-03	WAT-PAJ	144.66	3.06	
01-Jul-03	WAT-PAJ	295.1	6.69	
13-Jul-03	WAT-PAJ	300.63	4.32	
16-Jul-03	WAT-PAJ	264.54	17.4	
18-Feb-03	WAT-SHE	24.541	19.5	
27-Feb-03	WAT-SHE	43.947	22.4	
14-Mar-03	WAT-SHE	30.06	23.7	
15-Mar-03	WAT-SHE	35.46	13.3	

18-Mar-03	WAT-SHE	34.859	3.21	
20-Mar-03	WAT-SHE	42.278	4.91	
19-Jun-03	WAT-SHE	44.29	30	
26-Jun-03	WAT-SHE	24.44	11.7	
01-Jul-03	WAT-SHE	26.4	11.8	
08-Jul-03	WAT-SHE		13	
13-Jul-03	WAT-SHE	19.23	11.7	
16-Jul-03	WAT-SHE	105.65	43.7	
30-Dec-03	WAT-SHE	17.484	36.9	
30-Dec-03	WAT-SHE	141.124	26.6	
30-Dec-03	WAT-SHE	16.466	33.5	
31-Dec-03	WAT-SHE	64.525	36.7	
01-Jan-04	WAT-SHE	29.6598	84	
02-Jan-04	WAT-SHE	39.457	35.9	
05-Jan-04	WAT-SHE	20.656	29	
01-Feb-04	WAT-SHE	56.04	19.8	
02-Feb-04	WAT-SHE	37.5	13.1	
03-Feb-04	WAT-SHE	58.91	65.1	
04-Feb-04	WAT-SHE	86.69	34.6	
23-Feb-04	WAT-SHE	29.962	23.4	
25-Feb-04	WAT-SHE	51.7134	99.7	
26-Feb-04	WAT-SHE	64.4183	38.5	
27-Feb-04	WAT-SHE	39.0513	26	
01-Mar-04	WAT-SHE	64.511	68.8	

Appendix F-Quality Assurance

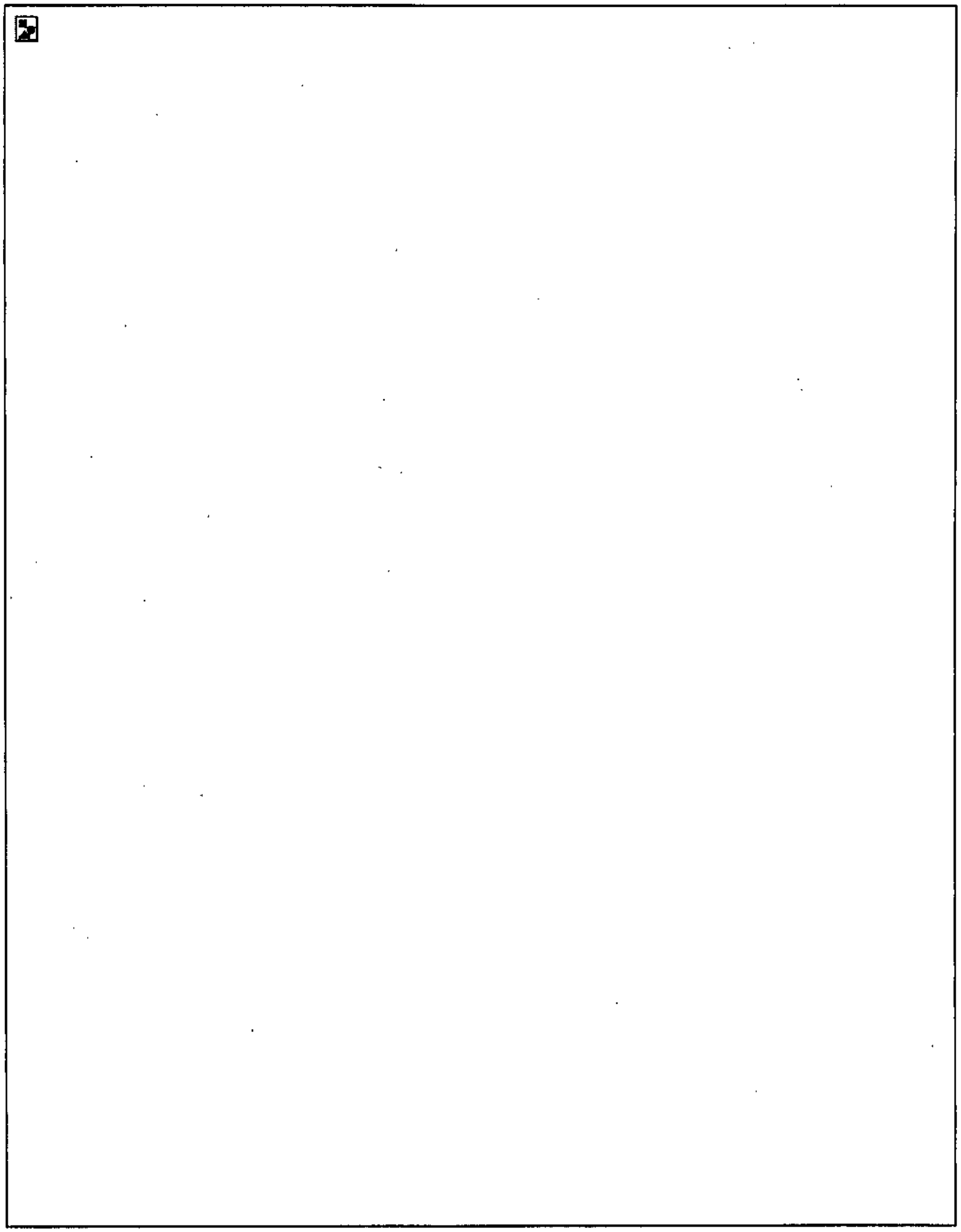
QAPP was completed prior to commencement of the project. The document can be found at the following website:
http://science.csumb.edu/~ccows/2002/watsonville/CCoWS_WatsonvilleQAPP_030604.pdf

Quality assurance evaluations were completed for the 5 major sampling runs of each monitoring campaign. In general, the quality assurance evaluations were satisfactory.

For SSC standards during both winter and summer monitoring, the relative percent difference ranged from 1% to 13%, and the average was 4.9%. These values were well within the data quality objective of 40% accuracy for SSC. All turbidity standards were within the known range of the factory prepared standard. SSC field blanks ranged from 0 to 11.4 mg/L, and the average concentration was 4.7 mg/L. All turbidity field blanks had absolute differences less than 0.6 NTU. These values are acceptably low relative to the moderate and severe categories that were used to define the problem.

The coefficient of variance for the SSC replicates ranged from 6 to 143%. The average coefficient of variance for SSC replicates was 50%. Although the variability of the replicates is somewhat high, it is not unexpected as many of the concentrations were less than 20 mg/L. As SSC decreases, the relative accuracy in the laboratory measurement also decreases. Some differences in the replicate samples for suspended sediment may have resulted from environmental variation and/or laboratory and field sampling error.

Appendix G-Aerial Photos



Aerial photo of lower Watsonville Slough (1928). Aerial on file at the UCSC Map Room.

Aerial photo of lower Watsonville Slough (2001). Aerial on file at the UCSC Map Room. Original source is the California Department of Water Resources.

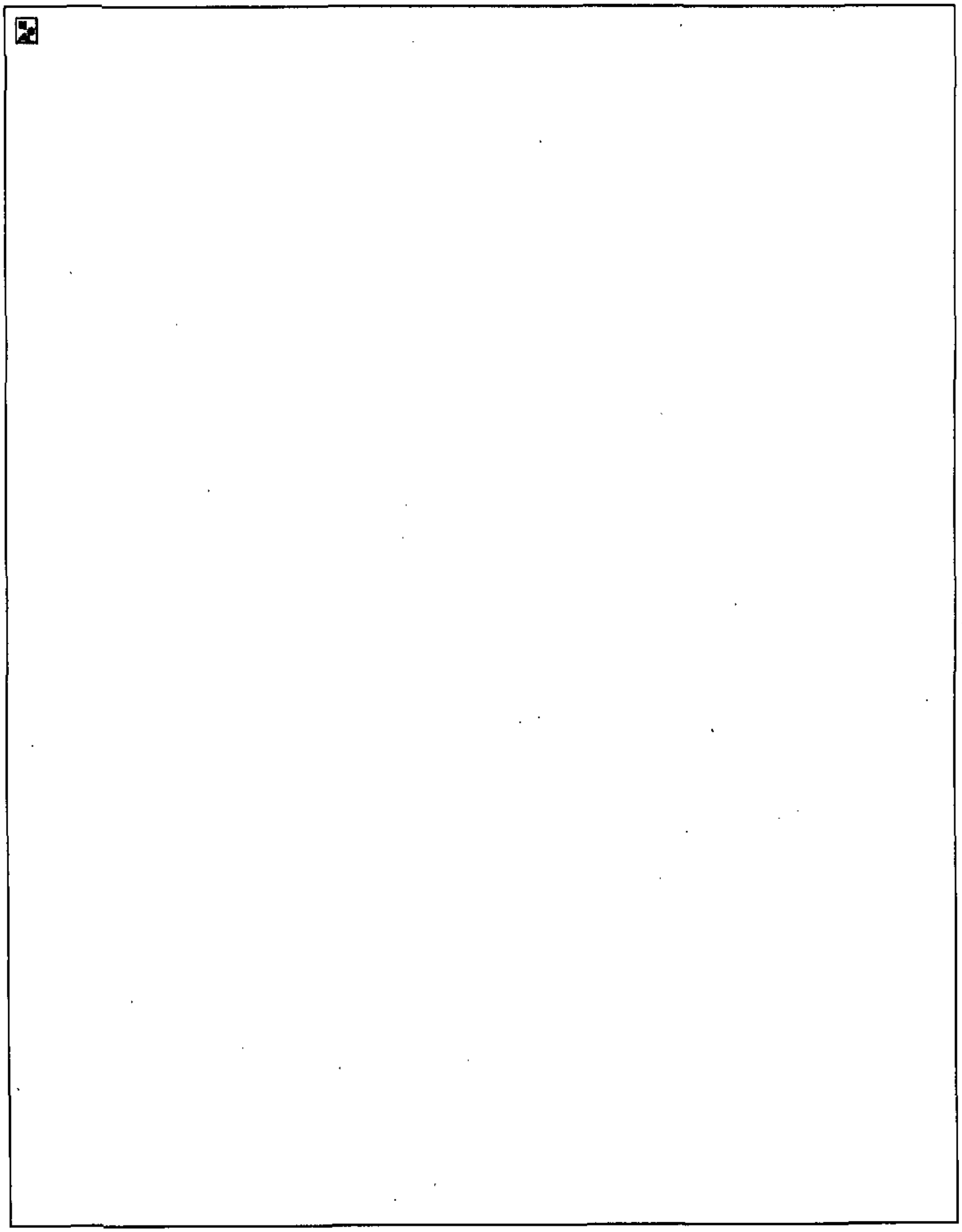
Aerial photo of middle Watsonville Slough-San Andreas Road (1940). Aerial on file at the UCSC Map Room. Original source is the US Army Air Force.

Aerial photo of Middle Watsonville Slough-Lee Road (1928). Aerial on file at the UCSC Map Room.

Digital orthophotoquad of Middle Watsonville Slough-Lee Road (1993) from the California Spatial Information Library, 2004.

Aerial photo of Upper Watsonville Slough (1952). Aerial on file at the UCSC Map Room. Original source is the USGS.

Aerial photo of Harkins, Gallighan, Hanson (1931). Aerial on file at the UCSC Map Room.



Digital orthophotoquad of Harkins, Gallighan, Hanson (1993) from the California Spatial Information Library, 2004.

Appendix H-UC Berkeley Coring Study

Recent Sedimentation Rates at Watsonville Slough,
Santa Cruz County, California

Final Report

By

Roger Byrne and Liam Reidy,
Department of Geography,
University of California, Berkeley

Submitted to:
Dr. Fred Watson
The Watershed Institute
Earth Systems Science and Policy
California State University Monterey Bay
CA 92508

Feb 25th, 2005

1. Purpose of the Study

Watsonville Slough is listed on the California 303d List under the Federal Clean Water Act as being impaired due to "pathogens" and "sedimentation/siltation". Accordingly, the Central Coast Regional Water Quality Control Board is required to develop and implement a Total Maximum Daily Load (TMDL) specification for pathogens and sediment. Dr. Roger Byrne of the Department of Geography at the University of California, Berkeley was contracted to provide technical assistance in the development of a TMDL for sediment in the Watsonville Slough system. More specifically to determine recent (last 500 years) sedimentation rates in the lower Watsonville Slough by stratigraphic analyses of sediment cores (Figure 1). Developing baseline sedimentation rates is important for developing TMDL's for the Watsonville Slough watershed. An important question is whether or not twentieth century erosion in the watershed of the slough has resulted in sedimentation rates that are significantly higher than "natural" or pre-European levels (before ca. 1800).

Whether or not this is the case, however, requires the examination of sedimentation rates through time. This study, therefore, reconstructs sedimentation rates in the lower reaches of Watsonville Slough for the last 600 years.

2. Summary of Results

The main conclusions of this study are:

1. Sedimentation rates for Watsonville Slough during the period from ca. 1400-1800 ranged from 4.8 mm/yr to 5.4 mm/yr. The average rate of 5.1 mm/yr.
2. Sedimentation rates for the period ca. 1800 to 1880 ranged from 2.0 mm/yr to 3.3 mm/yr. The average rate of 2.5 mm/yr is half of the pre-European rate.
3. The period of highest sedimentation rates was 1880-2004. Sedimentation rates for this period ranged from 5.9 mm/yr to 7.00 mm/yr.
4. The average sedimentation rate for the period 1950-2005 is 1.7 mm/yr, the lowest rate for the last 600 years.

3. Study Site

1.2 Study Area

Watsonville Slough receives approximately runoff from an area of 12,500-acre (19.5 sq. miles) from southern Santa Cruz County (Figure 1). The City of Watsonville lies in the southwestern portion of the watershed. The watershed is characterized by southward draining valleys that flow into Watsonville Slough (Figure 2). The Slough originates in the southeastern side of the watershed within the City of Watsonville. It extends westward along the northern edge of the Pajaro River floodplain, intercepting drainage from tributary sloughs before discharging into the mouth of the Pajaro River. The valleys of tributary sloughs (Gallighan, Harkins, Hanson, West Branch Struve, and Struve) are entrenched within coastal terraces where the terrain is characterized by flat valley floors of marsh and riparian wetlands with steep adjacent hillsides covered with grassland, oak woodland and chaparral. Harkins Slough is the longest drainage extending 7 miles inland through Larkin Valley to the headwaters situated 620 feet above sea level; Watsonville Slough extends into the Pajaro River at an elevation of 5 feet below mean sea level.

Tributary sloughs continue down to a broad alluvial floodplain with intense irrigated agriculture, and finally drain near a small residential dunes complex at the confluence of the Pajaro river and Watsonville Slough, and thence to Monterey Bay and the Pacific Ocean. The upper reaches are more stream-like, whereas the lower areas are low gradient and sluggish. The lowest reach of the Watsonville Slough, near the confluence with the Pajaro Lagoon, is tidally influenced. Watsonville Slough itself is the remnant of a once more-extensive estuarine wetland. The slough system has been historically modified to meet the needs of adjacent land uses such as agriculture and urban development. For instance, some areas of the slough system have been channelized to drain surface water. Several pump stations were also installed to prevent tidal influences upstream and to manage floodwaters. The two pump stations are located at Shell Road and at the confluence of Harkins Slough. Culverts were also installed at the major road crossings to prevent flooding. Additionally, there has been a history of land subsidence, which is most likely the result of shallow groundwater pumping and the decomposition of underlying peat (Swanson Hydrology and Geomorphology 2003). The primary land uses in the area are row crop agriculture, grazing, residential, urban, industrial, and commercial.

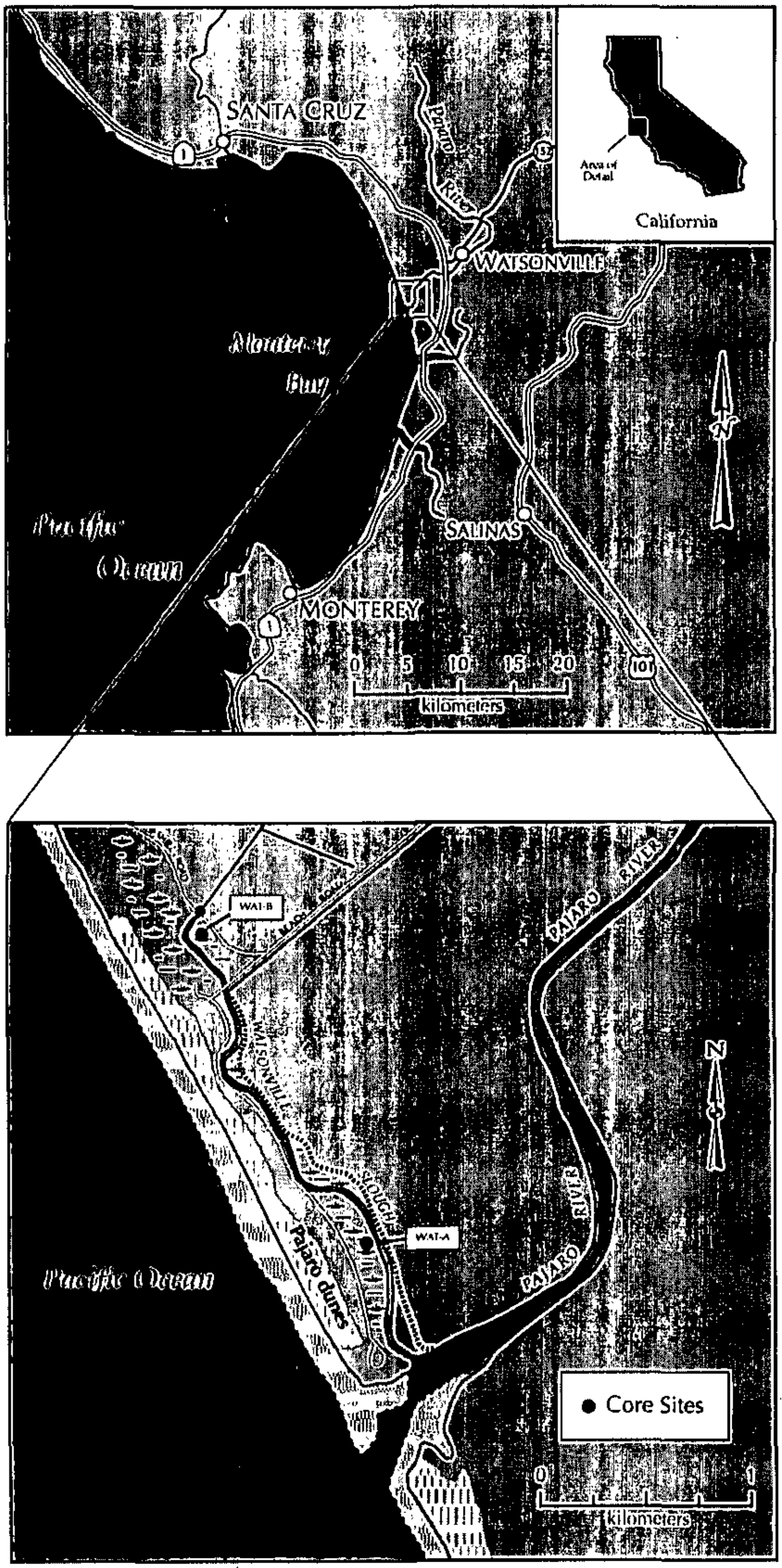


Figure 1. Location of the study area and core sites.

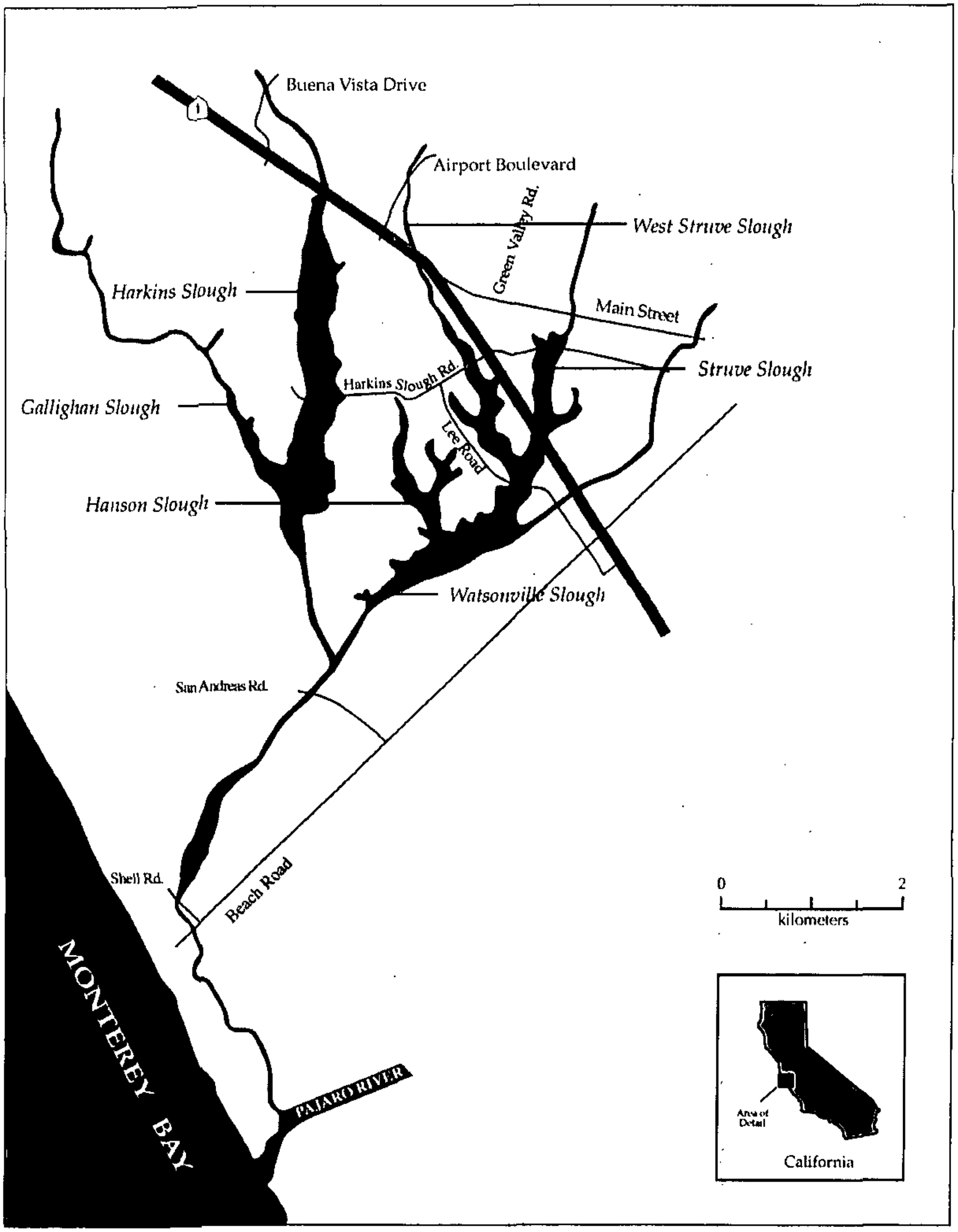


Figure 2. Watsonville Slough, Santa Cruz County, California.

4. Fieldwork and Core Recovery

In March, 2004, Liam Reidy and students from the University of California Berkeley, (UCB) Geography Department, recovered two sediment cores in Watsonville Slough (WAT04-A and WAT04-B) (Table 1, Figure 1). Core sites were restricted to the marsh areas in the lower reaches of Watsonville Slough, south of Shell Road, east of the barrier beach due to the lack of suitable sites in the tributary sloughs (Figure 1). Both core sites are tidally influenced. A hand operated Livingston piston corer was used to extract the cores. Recovery of longer cores was not possible due to occurrence of sandy layers at depth (Figure 3). Cores were encased in plastic core liners and/or plastic wrap with aluminum foil and transported to the UCB Pollen Laboratory for sub-sampling and analysis. After initial laboratory work core WAT04-A was chosen for subsequent stratigraphic analyses.

Core I.D.	Total Length
WAT04-A	330 cm
WAT04-B	389 cm

Table 1. Core Information.

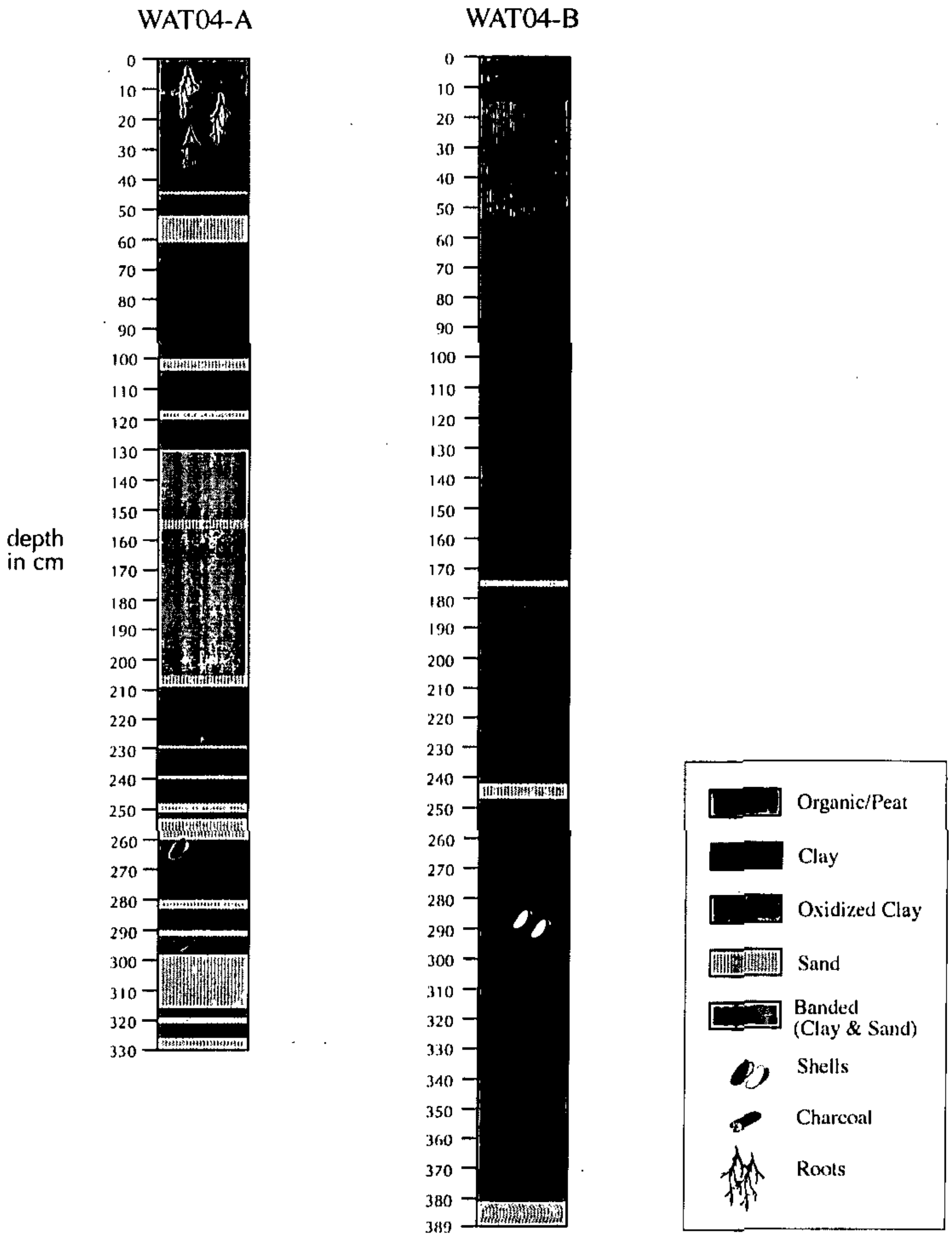


Figure 3. Stratigraphic description of WAT04-A and B.

5. Laboratory Methods

The determination of sedimentation rates depends on accurate core chronology. Several dating methods were used in an effort to establish the Watsonville Slough sedimentation rates; accelerator mass spectrometry radiocarbon dating (AMS ^{14}C), pollen analysis, lead-210 (^{210}Pb). In addition the cores were analyzed for water, organic and carbonate content, diatoms, sediment chemistry, magnetic susceptibility and grain size variation. These analyses can provide a means of cross correlating cores.

5.1 Percent Water Content.

Determination of percent water content is a quick and easy way to document changes in sediment lithology. Three cm^3 of wet sediment was placed into a pre-weighed beaker and weighed. The sediment was then dried at 60°C for 24 hours. The dry sediment was re-weighed to determine the percent weight water loss to evaporation (i.e., percent water content). Percent water content was determined for core WAT04-A at 5.0 cm intervals.

5.2 Percent Total Organic Matter

Total organic matter was determined using the loss on ignition method (Dean, 1974). Samples were extracted from WAT04-A at 5 cm intervals. All samples were dried at room temperature prior to grinding with a mortar and pestle. Ground samples were placed in a drying oven at 105°C for 24 hours to remove water. Dried samples were transferred to pre-weighed crucibles, weighed to obtain dry sediment weight, and heated to 550°C in a Barnstead Thermolyne Furnace Model 1400 for two hours. After two hours the samples were re-weighed to obtain the percentage total organic matter from total weight loss.

5.3 Percent Total Carbonate

Total carbonate was determined also using the loss on ignition method (Dean, 1974). Samples were extracted from cores WAT04-A at 5.0 cm intervals. Following the 550°C analysis and weighing, crucibles were re-heated to 950°C for two hours. After two hours the samples were re-weighed and percentage total carbonate was calculated.

5.4 Magnetic Susceptibility

Cores WAT04-A and B were scanned at 1 cm intervals to measure magnetic susceptibility using a Bartington MS2 Magnetic Susceptibility instrument. Measurements are reported as mass magnetic susceptibility whole core units (K values). The magnetic properties of minerals can provide the first index of environmental change in sediment cores and allow cores to be cross correlated if they have been deposited under the same geomorphic regimes.

5.5 Grain Size Analysis

Grain size measurements for fifty four samples from WAT04-A were measured using a Malvern Masterizer 2000 Laser Diffraction System linked to a Hydro 2000G. Results were divided into three size classes (clay 0.02μm-3.89μm; silt 3.90μm-73.99μm; sand 74.00μm-2000.00μm).

5.6 Sediment Chemistry.

Fifty-eight samples from WAT04-A were also analyzed for bulk elemental composition using x-ray fluorescence (XRF) with a Phillips PW 2400 XRF scanner in the Department of Earth and Planetary Science at UC Berkeley. XRF analysis determines the elemental composition of the inorganic component of the sediments and potentially provides information about the history of land use in a watershed. Samples were prepared by combustion at 550°C for one hour to remove water and organic material. Three grams of inorganic sediment per sample were ground to a powder, treated with a bonding agent, and compressed into pellets prior to XRF analysis.

5.7 Lead-210 (^{210}Pb) Analysis

Core WAT04-A was analyzed for ^{210}Pb activity, using alpha spectrometry at My Core Scientific Inc, Canada. Lead-210 analysis is a classic dating technique for young (<200 years) sediments (Krishnaswami et al., 1971; Anderson et al., 1987; Chillrud et al., 1999). Lead-210 is rapidly deposited into sedimentary environments, such as lakes, via atmospheric fallout facilitated by precipitation. Eighteen samples were analyzed in order to define the levels of unsupported ^{210}Pb in the sediments following standard methods (Appleby and Oldfield, 1978). Blanks and standards were measured to verify the performance of all aspects of the procedures and the instrumentation.

5.8 Radiocarbon Dating

A well preserved piece of charcoal (a small twig) from near the base of WAT04-A (295 cm) was provided to Lawrence Livermore Laboratory (LLNL) for accelerator mass spectrometry (AMS) radiocarbon dating. Using standard techniques, LLNL determines the radiocarbon age on the total organic carbon fraction of the charcoal.

5.9 Pollen Analysis.

Pollen analysis provides information about the history of vegetation change including the first appearance of exotic species. In California the first appearance of exotic species in sediment cores is a well-tested method for use in determining recent sedimentation rates (Mudie and Byrne, 1980). Core WAT04-A was analyzed for fossil pollen at regular intervals (5, 10 or 20 cm). Standard pollen extraction and preparation procedures were followed (Faegri and Iversen, 1975). One tablet containing approximately 13,911 *Lycopodium* spores were added to each sample as a control (Stockmarr, 1971). Samples were then processed with the following treatments: hydrochloric acid (10 per cent), potassium hydroxide (10 per cent), hydrofluoric acid (48 per cent), isopropanol wash, nitric acid (70 per cent), glacial acetic acid wash, and acetolysis (9 parts acetic anhydride and 1 part concentrated sulfuric acid). The residues from the chemical digestion were stained with safranin, dehydrated with tertiary butyl alcohol, suspended in silicone oil, and mounted on microscope slides. Pollen counts were made on a Zeiss transmitted light microscope at 400x and 100x magnification. Pollen grains were identified with the aid of the University of California Museum of Paleontology (UCMP) Pollen Reference Collection and published keys (McAndrews et al., 1973; Kapp et al, 2000). Some grains could not be identified and were labeled "unknown". Damaged, torn or crumpled grains that were unidentifiable were counted as "indeterminate". Twenty two samples were analyzed from WAT04-A. Pollen diagrams were constructed using Calpalyn (Bauer et al., 1991).

5.10 Diatom Analysis

Twenty samples from WAT04-A were processed for diatoms using standard techniques and were pretreated with 30% H2O2, 36% HCl, and 16 N HNO3. Prepared material was mounted on prepared microscope slides using Naphrax, and identifications were made using an Olympus BH-2 microscope equipped with 50x and 100x oil immersion lenses. Diatoms were analyzed by Dr. Scott Starratt, United States Geological Survey, Menlo Park, California.

6. Results

6.1 Percent Water Content

Figure 4 shows the percent water content for WAT04-A. As expected, the percent water content values are highest near the core tops where the compaction of sediment is minimal, thus reducing the migration of water from the sediment pore spaces. The percent water content in core WAT04-A ranges from ~14 percent to ~47 percent

6.2 Percent Total Organic Matter

Results for percent total organic matter are presented in Figure 4. The percent organic content in core WAT04-A ranges from ~3 percent to ~25 precent Two notable peaks in percent organic matter occur at 0 cm and 85 cm.

6.3 Percent Total Carbonate

Results for percent total carbonate matter are presented in Figure 4. Carbonate values are high at 0 cm and 140 cm.

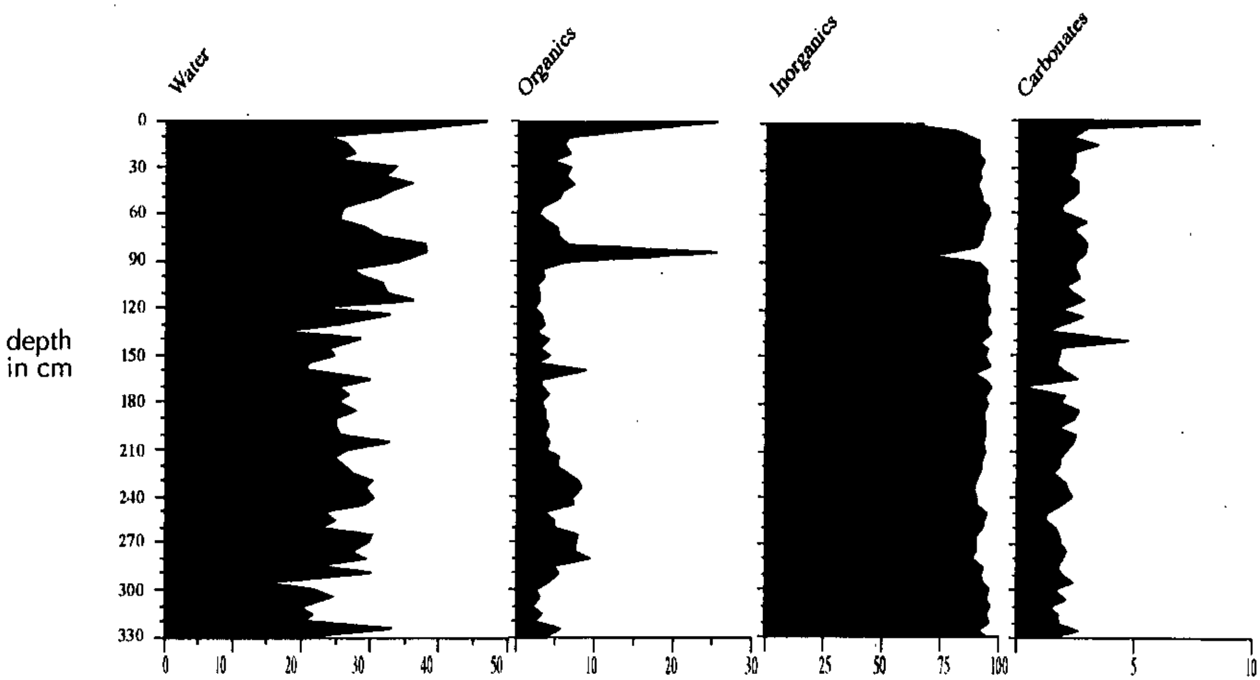


Figure 4. Loss on ignition data for WAT04-A (Values in %).

6.4 Magnetic Susceptibility

Mean whole core (K) values for each 1 cm interval throughout Core WAT04-A and B are shown in Figure 5. There are a number of distinct peaks in the magnetic susceptibility profiles of both cores. In WAT04-A peaks occur between 5-10 cm, 150-155 cm, 210-215 cm, 300-310 cm and 325-330 cm. In WAT04-B *spikes occur at 65-70cm, 90-95 cm, 195-200 cm, 240-250 cm and 380-390 cm.* Many of the peaks in magnetics coincide stratigraphically with sand lenses especially in core WAT04-A.

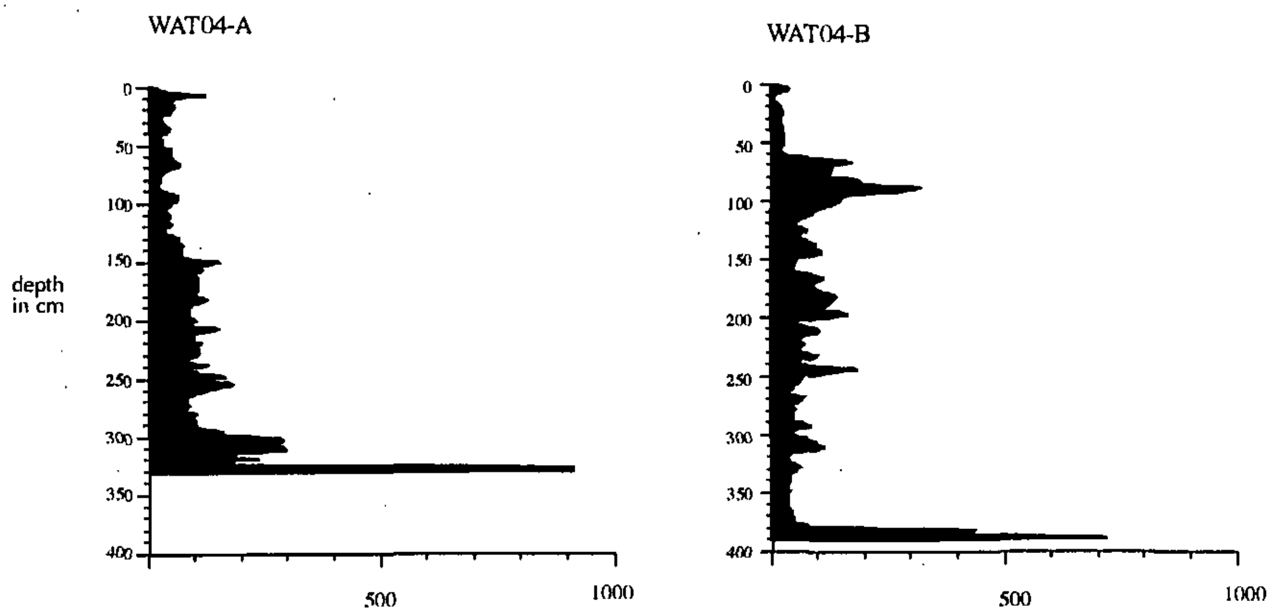


Figure 5. Magnetic susceptibility data for WAT04-A and B.

6.5 Grain Size Analysis

Results for grain size particle analysis on WAT04-A is presented in Figure 6. Clay size particles (0.02-3.89μm) vary between 7-35 percent in the samples analyzed. Silt size particles (3.90-73.99μm) vary between 33-88 percent. Sand particles (74.00-2000μm) vary between 0-60 percent. In general there is an increase in smaller grain size material in the near surface sediments.

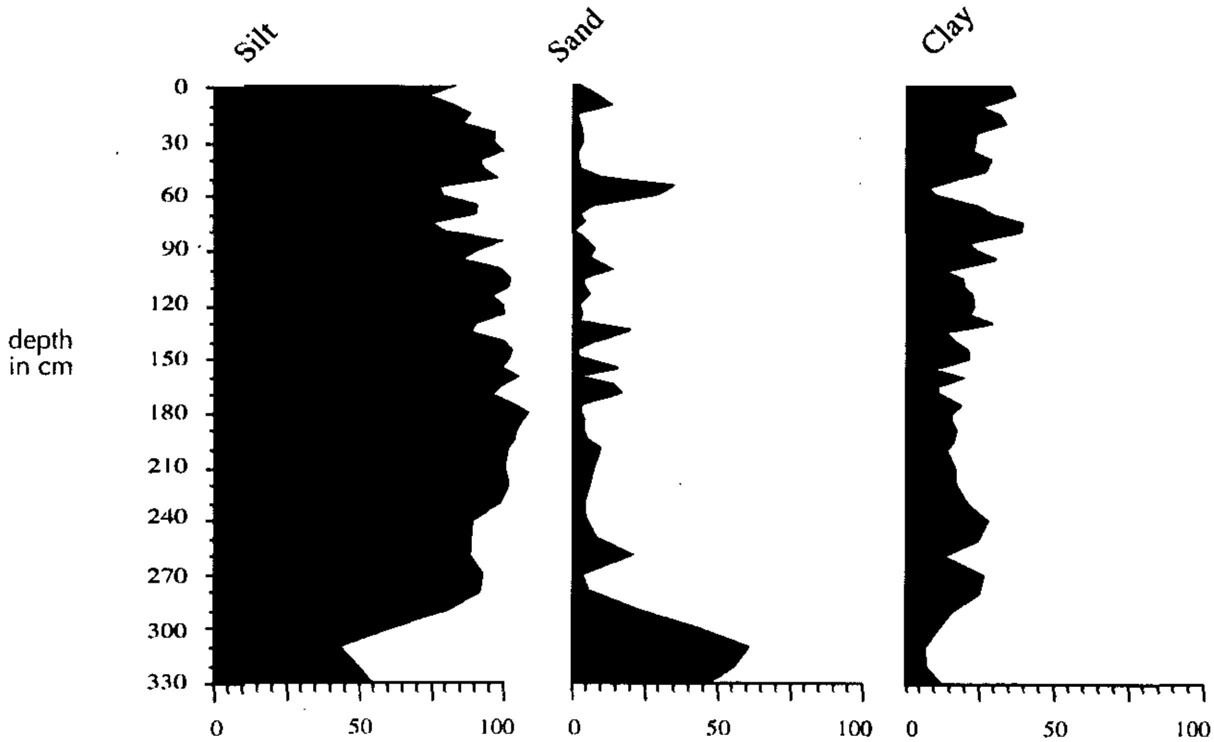


Figure 6. Grain size data for WAT04-A.

6.6 Sediment Chemistry

A total of 36 elements were measured by X-Ray Fluorescence (XRF) in samples from WAT04-A. Lead results (Pb), copper (Cu), arsenic (As), and zinc (Zn) showed the most variation. Lead potentially provides a chronological marker for the near surface sediments (Figure 7). Lead concentrations vary from 8- 1748 ppm (parts per million). Lead levels peak to 1494 ppm at 65 cm and to 1748 ppm at 8 cm. Above 8 cm lead concentrations gradually decline to 55 ppm in the surface sample. Zn concentrations display similar results to Pb. Zn varies from 61 ppm to 155 ppm in WAT-A. At 6 cm Zn reaches its highest level at 155 ppm. Cu concentrations vary between 21 -51 ppm, reaching a peak of 51 in the surface sample. Arsenic concentrations vary between 4 ppm to 36 ppm again reaching its highest concentrations in the surface sample.

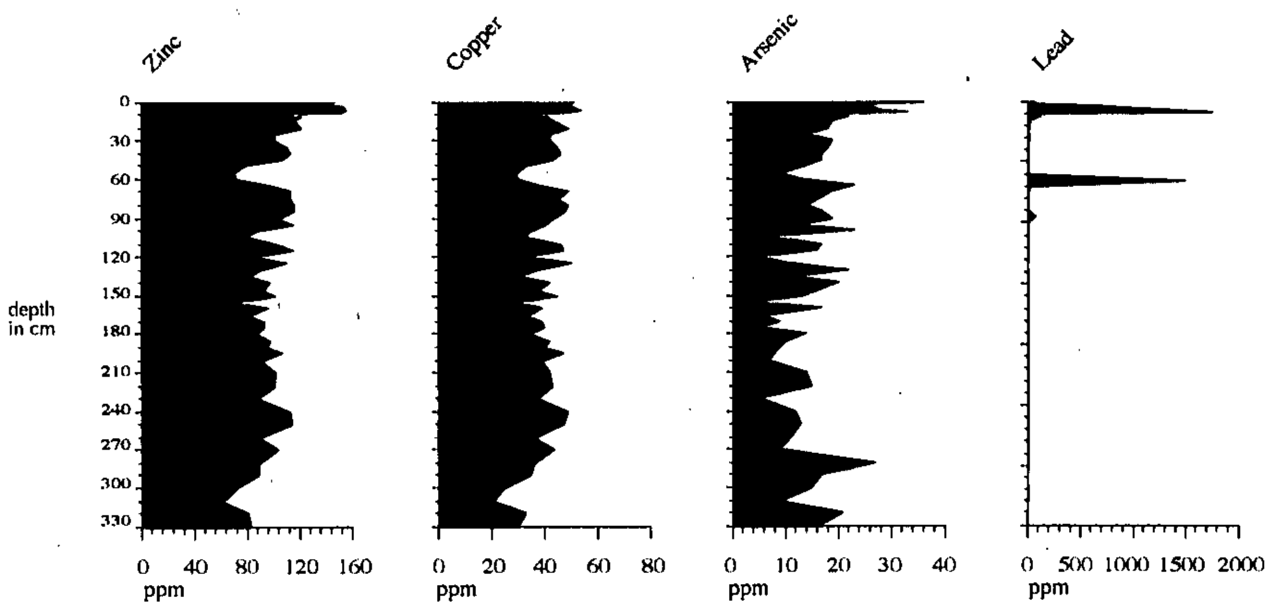


Figure 7. Geochemistry data for WAT04-A.

6.7 Lead-210 (^{210}Pb) Analysis

Concentrations of lead-210 activity were very low in core WAT04-A (Figure 8). This is usually indicative of environments where either the input from the atmosphere is very low (due to the prevailing wind direction) or the sediment accumulation rate is high. In this case, the former explanation agrees with the dating. In coastal California, the deposition of ^{210}Pb in measurable quantities is limited by the infrequent precipitation and the prevailing wind direction. As a result, the lead-210 analysis on WAT04-A only provides useful information for dating the top 7 cm of the core (Table 2).

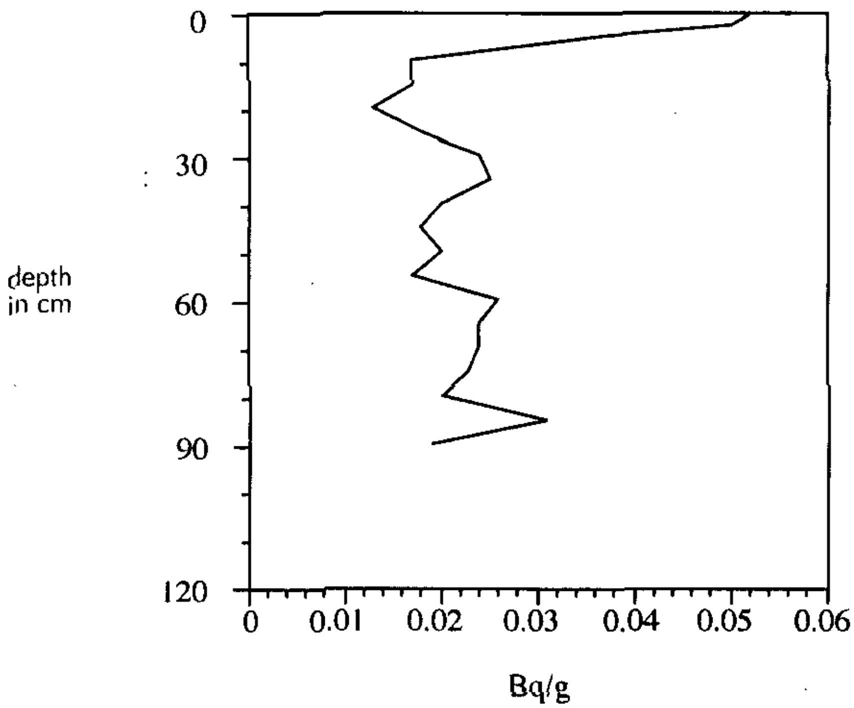


Figure 8. Lead-210 activity for WAT04-A

Depth	Activity (Bq/g)	Date
0	0.052	2004
1.5	0.050	1998
2.5	0.037	1990
3.5	0.017	1978
4.5	0.017	1966
7	0.013	1952

Table 2. Lead-210 activity and estimated chronology .

6.8 Radiocarbon Dating

A small twig recovered from a depth of 295 cm in WAT04-A was dated by the AMS ^{14}C method. The mean age indicated in calendar years is A.D. 1420.

Depth (cm)	Lab No.	Radiocarbon Age ^{14}C yr B.P.	Calibrated Age Range 2 Sigma	Mean Age Estimate (cal yr A.D.)
295	CAMS 111290	495 ± 40	477-556	1420

Table 3. AMS radiocarbon determination for the WAT04-A core. Calibrated ages and age ranges were calculated using Calib 4.4 (Stuiver et al., 1998).

6.9 Pollen Analysis

Pollen analysis on core material from WAT04-A proved difficult. Overall pollen preservation was poor and pollen concentrations low in many of the samples analyzed. Low pollen concentrations is often indicative of high sedimentation rates while low pollen preservation and may indicate a very low sedimentation rate. Slides prepared for pollen analysis were scanned at the 100x and 400x for important chronological markers (*Erodium cicutarium, Rumex acetosella, Plantago lanceolata, Eucalyptus*). Multiple slides from critical levels were scanned to determine the first appearance of important these non-native pollen types. The first non-native type to appear is *Erodium cicutarium* at 100 cm. We assign a date of 1800 ±20 to this level. *Erodium* is present in most of the samples examined above 100 cm in which pollen was preserved (Figure 9). Non-native *Eucalyptus* pollen was first encountered at 80 cm which we assume to represent 1880±10. *Plantago lanceolata* was first encountered at 5 cm which represents the modern period. A large amount of Chenopodiaceae pollen was encountered in the surface sample (0 cm) which represents the *Salicornia* (pickleweed) growing around the coring site.

6.10 Diatom Analysis

Diatoms were present in the WAT04-A core but concentrations were low and preservation poor to allow accurate quantitative analysis or develop a paleoecological reconstruction.

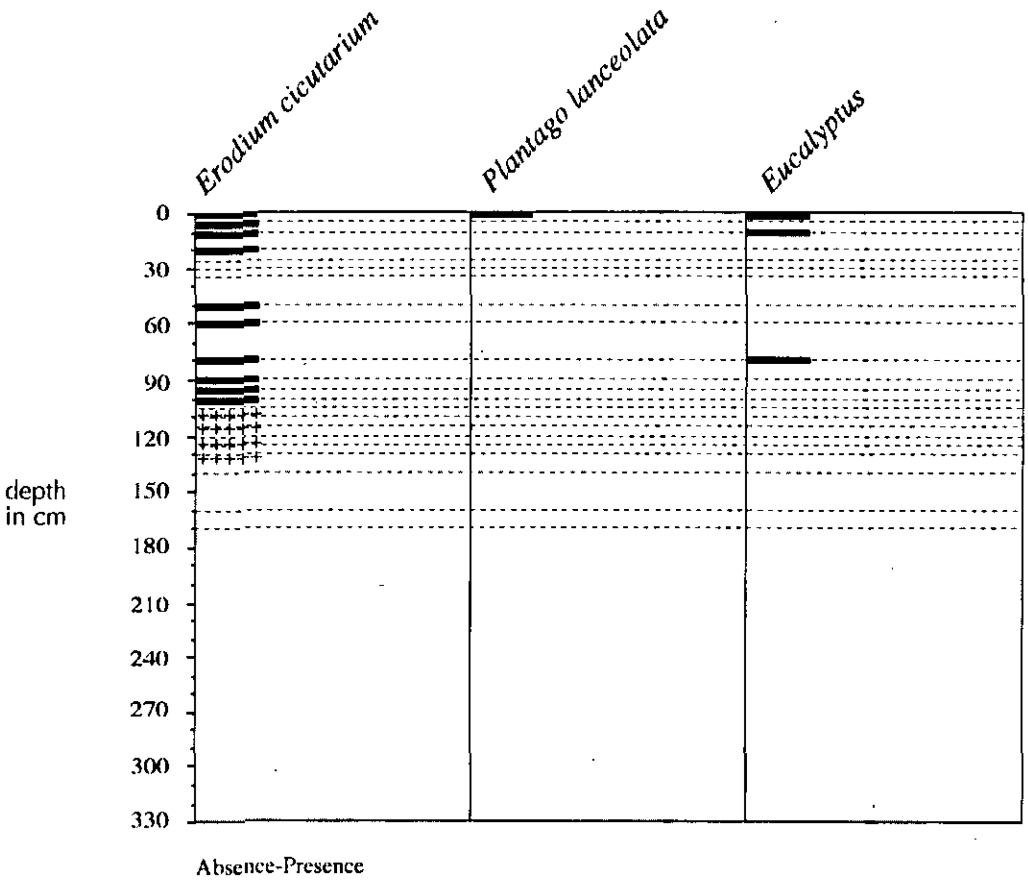


Figure 9. Non-native pollen data for WAT04-A. Cross symbols indicate a minimum of 5 slides scanned for *Erodium cicutarium*. Dashed line indicates sample examined.

7. Discussion

7.1. Developing Core Chronology

We have constructed a core chronology for Watsonville using the following lines of evidence: radiocarbon dating, the first appearance of non-native pollen types, and lead-210 dating. Peaks in elemental lead concentrations are not used to date WAT04-A as we suspect that the lead spikes encountered are associated with lead shot and not lead from automobiles which has been used in the past cores. Grain size, magnetic susceptibility, and other diatom analysis did not provide useful information to help develop core chronology and are not included in the age model determination.

7.1.1 Radiocarbon Dating: The charcoal from 295 cm in WAT04-A produced a radiocarbon date of 495±40 C14 year B.P. which yields a calibrated age estimate of A.D. 1420.

7.1.2 Pollen Chronology: Many plant species not indigenous to California have been introduced into the Watsonville area during the period of European settlement, and in some cases their pollen can be readily identified. These non-native pollen types are therefore useful chronological markers, especially if the history of introduction is well known. Three important non-native pollen types in the Watsonville core are *Erodium cicutarium*, *Plantago lanceolata* and *Eucalyptus*. *Erodium, Plantago* and *Eucalyptus* pollen have been used to indicate European settlement horizons in sediment cores from coastal California (Mudie and Byrne, 1980; Cole and Liu, 1994; Mensing and Byrne, 1998; Bicknell. and Mackey, 1998; Cole and Wahl, 2000; Reidy, 2001). The first appearance of *Erodium* at 100 cm probably reflects the arrival of the Spanish in the Watsonville area during the second half of the 18th Century (1769-1800). Adobe bricks used to construct Mission San Juan Buatista (est. 1797) and Mission Santa Cruz, (est. 1791) which have been analyzed for macrofossil remains by Hendry (1925) both contain the fruits of non-native *Erodium*. Both missions are located about 36 km from the core site. We therefore assign a date of 1800±20 yr for the first appearance of *Erodium* in the Watsonville core (Figure 9).

The introduction of *Eucalyptus* into California is well documented (Weir, 1957). It was first introduced in 1853 and by the 1870's was widely planted around the state, especially in urban areas. The town of Watsonville was established in 1852 and it is likely that *Eucalyptus* was planted not long after its introduction to San Francisco. Australian gum trees were planted in the plaza at Watsonville in the early 1870's (Lewis, 1976). An 1879 photograph from Watsonville town center shows *Eucalyptus* trees taller than 30 feet growing in the Plaza (Lewis, 1976). *Eucalyptus* pollen was first encountered at a depth of 80 cm (Figure 9). The first appearance of *Eucalyptus* is probably the result of these early plantings at the end of the nineteenth century. We therefore assign a date of 1880±10 yr for the first appearance of *Eucalyptus* in the core (Figure 9). This date is consistent with the first appearance of *Eucalyptus* at other sites in California where the history of local planting is well known (Reidy, 2001).

7.2 Sedimentation Rates

7.2.1 Long Term Rates: The radiocarbon date and pollen "dates" were used to calculate long term sedimentation rates (Figure 10). Maximum sedimentation rates indicated are 7.00 mm/yr for the period ca. 1880-2004. Four chronological markers, including the surface age, were used to calculate linear sedimentation rates from ca. 1420 to 2004 (Figure 10): The radiocarbon date at A.D. 1420 (295 cm), the first appearance of *Erodium* at 1800±20 (100 cm), the first appearance of *Eucalyptus* at 1880±10 (80 cm), and the surface date 2004 (0 cm). The overall average sedimentation rate is 4.77 mm/yr.

The range of European sedimentation rates in WAT04-A is based on the first appearance of *Erodium* at 1800±20 (100 cm) and of *Eucalyptus* at 1880±10 (80 cm). The minimum sedimentation rate is 2.0 mm/yr and the maximum rate is 7.00 mm/yr. The average sedimentation rate for the period 1800-1880 is 2.65 mm/yr (Figure 10).

In summary, the average sedimentation rate, for immediate pre-European period is 5.1 mm/yr which is slightly greater than the average European sedimentation rate of 4.45 mm/yr.

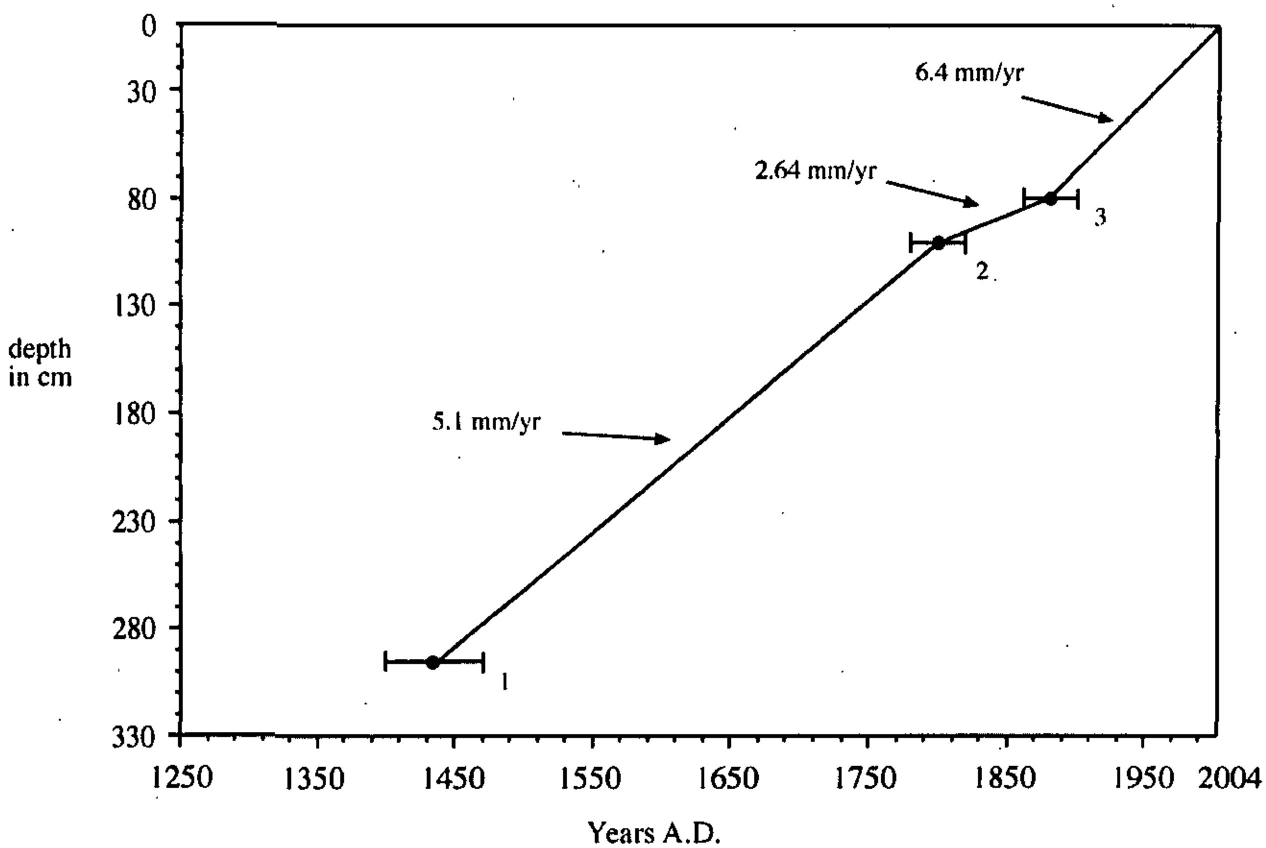


Figure 10. Age V Depth Curve for Watsonville Slough (A.D. 1420-2004). Average sedimentation rates are shown between chronological markers.

1. Two sigma radiocarbon age range; 477-556 cal yr B.P. (A.D. 1400-1470).
2. First appearance of *Erodium cicutarium* (A.D. 1800±20 yr).
3. First appearance of *Eucalyptus* spp. (A.D. 1880±10 yr).

Table 3. Watsonville Sedimentation Rates.

Time Period	Average (mm/yr)	Range (mm/yr)
Pre-European (A.D. 1400-1800)	5.1	4.8 to 5.4
European (A.D. 1800-2004)	4.45	2.0 to 7.00
Recent (last 50 years)	1.7	1.4 to 2.1

7.2.2 Recent Sedimentation Rates (last 50 years): Lead-210 dating of the near surface sediments from Core WAT04-A indicate a very low sedimentation rate during the past half century (Figure 11). Comparable lead-210 data from Mountain Lake, San Francisco suggests that the top 7 cm of WAT04-A represents the last 50 years. However this comparison is not completely conclusive in itself because of uncertainties with respect to the level of background lead-210 activity in the Watsonville core (Figure 8). Based on the lead-210 dates the average sedimentation rate during the past 50 years has been approximately 1.67 mm/yr which is ~2x less than the immediate pre-European sedimentation rate reported above. A plausible explanation for such a low sedimentation rate is the construction of the tide gates at Shell Road in the early 1940's which may have reduced sediment supply to the lower reaches of the slough. In addition, land subsidence in the upper sloughs may also have reduced sediment supply the core site during the twentieth century.

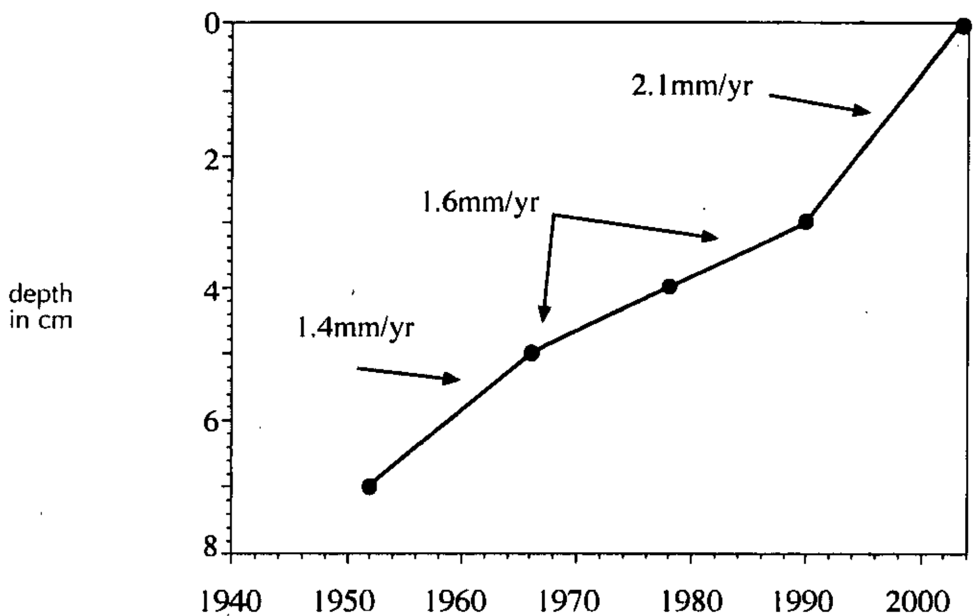


Figure 11. Recent (last 50 years) sedimentation rates based on Lead-210 activity.

7.2.3 Impact of Compaction on Sedimentation Rates: Linear sedimentation rates can vary depending upon the degree of compaction, which in near surface sediments is largely due to variations in water content or sediment type, e.g., peat or clay. WAT04-A shows little variation in sediment type but water content does increase towards the surface (Figure 3). The water content in the top 5 cm is about 40 percent whereas in the lower 325 cm values are about 25 percent. The average difference of 15 percent water content effects the sedimentation rates accordingly. However, this difference is insignificant when compared with the difference between the average European sedimentation rate and the pre-European rate as shown in Table 3.

8. Summary

Despite intensive agricultural land use in the upper reaches of the Watsonville Slough watershed recent sedimentation rates are relatively low when compared to other coastal marshes systems in California.

1. Twentieth century sedimentation rates in the lower reaches of Watsonville Slough range from 5.9 mm/yr to 7.00 mm/yr, the average of which is 6.4 mm/yr.

2. The estimated sedimentation rates for the period ca. 1800 to ca. 1880 range from 2.0 to 3.3 mm/yr, the average of which is 2.65 mm/yr. This is about ~2.5x less than the late twentieth century averages (based on the pollen data).

3. The average sedimentation rate (6.4 mm/yr) for the period 1880-2004 is the highest sedimentation rate recorded in the core.

4. Sedimentation rates derived from lead-210 activity suggest that the rate of sediment accumulation during the last fifty years has been very low (~1.7 mm/yr). This rate is approximately half the overall European periodaverage of 4.45 mm/yr.

5 Sedimentation rates in the core analyzed can be assumed to be close to the minimum values insofar as the cores were taken from the lower reaches of the slough system below the tide gates at Shell Road. However, more definitive estimates will depend on a more extensive coring effort.

9. Acknowledgments

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Region 3's "Data available" table 06/14/2004

Staff contact at region 3 – Shanta Keeling 805-549-3464. skeeling@rb3.swrcb.ca.gov

From EPA

Name/Title/Org.	Data dates	Type & Sample Media	Comments	QC (Hi, med, lo)
Newer data				
Regional Board staff Shanta Keeling Morro Bay special sampling for metals	3/9/01 – 10/02	Metals sampling, water chemistry, sediment and tissue	This information was used to evaluate a 303(d) listing for Morro Bay for metals. Sampling results prompted staff to recommend "delisting" during the next listing cycle. This report is available upon request.	High
Continuing data Many of the sources below have "newer data" (i.e. data from May 2001 – present) and also have data before May 2001. Data before May 2001 was reviewed for the 2002 list, with the exception of CCAMP Santa Barbara data.				
Central Coast Ambient Monitoring Program (CCAMP). Santa Barbara and Santa Lucia watershed rotations. Sand crab data, Santa Maria Lagoon, Granite Canyon Marine Pollution Studies Contact Karen Worcester – Regional Water Quality Control Board. 805-549-3333.	May 2001-present	Water, tissue, sediment Crab tissue data available for mouth of Santa Maria River…	No CCAMP data from the Santa Barbara area watersheds were used in the 2002 303(d) listing process. Santa Barbara CCAMP data begins January 2001. EPA has CCAMP data (CCAMP, CCAMP BMI, Vandenburg AFB) on ftp site.	High
Cities				
City of Santa Barbara Peter von Langen contact from Regional Board (805-549-3688)		Stormwater data from mult. Sites	Stormwater sampling per NPDES requirements; PDF format available	
City of Salinas Donette Dunaway contact from Regional Board (805-549-3698)		Stormwater data (water) Duffy & Assoc.	Report format only; PDF format	

Staff contact at region 3 – Shanta Keeling 805-549-3464. skeeling@rb3.swrcb.ca.gov

Counties				
County of Santa Barbara Contact Tommy Liddell, (tliddel@co.santa_barbara.ca.us) County of Santa Barbara. Also look at http://www.countyofsb.org/project_cleanwater/default.htm	May 2001-present	Grab water samples, storm water sampling, benthic invertebrates	NPDES related: TXT format available. Periodic sampling from 98, 00, and 01 and Feb-March 03 available soon….follow-up	High
County of Santa Cruz Steve Peters(831-454-5010)/John Ricker (454-2022)	May 2001-present	Stormwater/NPDES requirements	Data reported to RB3 in PDF format	
Note: All counties (those that have more than 50,000 people visit the beach annually) have to do AB 411 bacteria monitoring. Might be useful to check out their data.				

Other				
USGS	Pre 2001 - present	Water column chemistry flow integrated grab sampling		High
Vandenberg Air Force Base Contact Gary Sanchez 606-7541	Pre 2001-present	Grab water samples for conventional water quality	EPA approved QAPP? Left v-message for Sanchez	
Monterey Bay Citizen Watershed Monitoring Network Contact Bridget Hoover 831.833.9303	2001 - present	Grab water samples for conventional water quality	Volunteer data collected under EPA QAPP for first flush and snapshot day data	High
Morro Bay Volunteer Monitoring Program Contact Ann Kitajima 805.772.3834	Pre 2001-present	Grab water samples for conventional water quality and benthic macroinvertebrates	Volunteer data collected under EPA QAPP….all data collected for on-going TMDLs in LosOsos and Chorro Creeks (already listed)	High
Elkhorn Slough	Pre 2001-	Grab water samples for	EPA approved QAPP?	

Staff contact at region 3 – Shanta Keeling 805-549-3464. skeeling@rb3.swrcb.ca.gov

Foundation Contact John Haskins john@elkhornslough.org 831-728-2822	present	conventional water quality	Left e-mail and v-mail messages
SNAPSHOT DAY NMFS organized…follow-up Cheryl McGovern may be contact			
State Board re: bact. Data collected for beaches	Check w/ PK		
PG&E Properties	Sally Krenn		
Cal Poly Properties			
Cities	NPDES stormwater sampling		
Fred Watson Watershed Institute CSUMB 831/582-4452			
John Hunt/Brian Anderson Granite Canyon	Toxicity Pesticides Santa Maria River		

Region 3's "Data available" table
January 20, 2004
Staff contact at region 3 – Shanta Keeling 805-549-3464. skeeling@rb3.swrcb.ca.gov

Name/Title/Org.	Data dates	Type & Sample Media	Comments	QC (Hi, med, lo)
Newer data				
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Continuing data Many of the sources below have "newer data" (i.e. data from May 2001 – present) and also have data before May 2001. Data before May 2001 was reviewed for the 2002 list, with the exception of CCAMP Santa Barbara data.				
Central Coast Ambient Monitoring Program (CCAMP). Santa Barbara and Santa Lucia watershed rotations. Sand crab data, Santa Maria Lagoon, Granite Canyon Marine Pollution Studies Contact Karen Worcester – Regional Water Quality Control Board. 805-549-3333.	May 2001-present	Water, tissue, sediment Crab tissue data available for mouth of Santa Maria River…	No CCAMP data from the Santa Barbara area watersheds were used in the 2002 303(d) listing process. Santa Barbara CCAMP data begins January 2001.	High
Cities				
City of Santa Barbara Peter von Langen contact from Regional Board (805-549-3688)		Stormwater data from mult. Sites	Stormwater sampling per NPDES requirements; PDF format available	
City of Salinas Donette Dunaway contact from Regional Board (805-549-3698)		Stormwater data (water) Duffy & Assoc.	Report format only; PDF format	
Counties				
County of Santa Barbara	May 2001-	Grab water samples,	NPDES related: TXT	High

Input to Tetra Tech Ap. site VAFB BMI

only data we have VAFB BMI

Region 3's "Data available" table
January 20, 2004
Staff contact at region 3 – Shanta Keeling 805-549-3464. skeeling@rb3.swrcb.ca.gov

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Counties				
County of Santa Barbara	May 2001-	Grab water samples,	NPDES related: TXT	High

input to Tetra Tech ~~Wp. site~~ VAFB BMI

only ... we ... VAFB BMI

Descriptive information (relating to abreviations) is on the first 3 worksheets (sites, analytes and flags).

Please check flags and notes columns when using data. All data collected is contained in the spreadsh

Please feel free to contact me with any question about the data. Mary 805 542 4768

Region 3's "Data available" table
January 20, 2004
Staff contact at region 3 – Shanta Keeling 805-549-3464. skeeling@rb3.swrcb.ca.gov

Contact Tommy Liddell, (tliddel@co.santa_barbara.ca.us) County of Santa Barbara. Also look at http://www.countyofsb.org/project_cleanwater/default.htm	present	storm water sampling, benthic invertebrates	format available. Periodic sampling from 98, 00, and 01 and Feb-March 03 available soon….follow-up	
County of Santa Cruz Steve Peters(831-454-5010)/John Ricker (454-2022)	May 2001-present	Stormwater/NPDES requirements	Data reported to RB3 in PDF format	

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State Board re: bact. Data	Check w/			

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January 20, 2004
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collected for beaches	PK
PG&E Properties	Sally Krenn
Cal Poly Properties	
Cities	NPDES stormwater sampling
Fred Watson Watershed Institute CSUMB 831/582-4452	
John Hunt/Brian Anderson Granite Canyon	Toxicity Pesticides Santa Maria River
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not e-files
hardcopy only
1 person coordinates

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