Central
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Studies

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# Watsonville Sloughs Pathogen Problems & Sources

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# Preface

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# Executive Summary

In order to determine exceedance of Basin Plan objectives, 163 samples from 15 sites in 5 waterways were taken during summer and winter in the Watsonville Sloughs system, and were analyzed for indicators of fecal coliforms and *Escherichia coli*. All sites exceeded objectives in either summer or winter (except the lowest site, in the Pajaro estuary). Levels were consistent between summer and winter, but did not follow any clear spatial pattern overall. Therefore, no single geographic area or land use could be isolated as the source based on exceedance monitoring.

Some exploratory sampling was conducted on an additional sequence of 9 closely spaced sites in the Struve system (a tributary to Watsonville Slough). This yielded some evidence of a geographically confined source. Dye tests in the surrounding sewer system were negative, so a surface source near the waterway itself is likely. With present resources, this level of detailed sampling is not feasible at the watershed scale.

Ultimately, genetic analysis of *E. coli* strains was chosen as the basis for source analysis. The three sites with highest exceedance levels were sampled in summer and winter (with replicates) and genetically analyzed using the toxin biomarker method. Numerous pathogen sources were indicated. On an annual basis, bird waste was indicated as the dominant source – but with low pathogenic risk. Cattle waste was indicated as the dominant winter source – with risk due to possible presence of the pathogenic H157:O7 strain. Dog waste was also numerically significant. Human waste represented a small fraction of total *E. coli* fauna, but has the highest pathogenic risk. In two samples, human waste was estimated to have exceeded 400 MPN/100mL. Rabbit sources were negligible. Untested sources may be present, but at levels not likely to exceed the sources that were tested.

Given the presence of these sources, coliform abundance is likely to be controlled to some extent by the conditions of the aquatic environment. For example, high coliform levels may be indicative of microbial growth in waterways (Rosen, 2000; Gerba, 2000). Agricultural and urban land use in particular may create optimal conditions for microbial growth: high nutrients, warm temperatures, high turbidity (low light), microbial predator control by pesticides, and sluggish, relatively deep water (ditches).

Recommendations:

- Further investigation:
    - Investigation to determine if there is a linkage between indicators of fecal contamination documented by the present study, the presence of actual pathogens, and public health problems
    - Detailed study of the environmental ecology and transport of indicator organisms (see Section 11.2)
    - Use of indicators with low potential for growth in waterways (e.g *Enterococcus*, Gerba, 2000)
- Precautionary control:
    - Pet waste management programs
    - Investigate possibility of compost sources, cattle access to streams, and inadequate feedlot runoff control
    - Investigation of septic and sewer leakage, illegal connections, homeless encampments
- Control of potential pathogen growth in waterways:
    - reduction of carbon, nutrient, and sediment sources
    - reduction of pesticide sources
    - conversion of disused ditches to wetlands

# 1 Introduction

Watsonville Slough is listed on the California 303d list under the Federal Clean Water Act as being impaired due to "pathogens". Accordingly, the Central Coast Regional Water Quality Control Board is required to develop and implement a Total Maximum Daily Load (TMDL) specification for pathogens. 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 pathogens 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 pathogens in Watsonville Sloughs, suitable for inclusion in a Technical TMDL document
- Produce in report form, a preliminary source analysis for pathogens in Watsonville Sloughs, suitable for inclusion in a Technical TMDL document

# 2 Study Area

The Watsonville Slough system is located in Santa Cruz County and is comprised of Harkins, Gallighan, Hanson, Struve, and Watsonville Sloughs (Fig. 2.1). The system drains an area of approximately 50 $km^2$ (13,000 acres) (Fig. 2.1). Sub-watershed areas are listed in Table 2.1. The Watsonville Sloughs watershed contains relatively steep headwaters with some natural land uses and drains an undulating rural residential area and a rapidly growing industrial-agricultural city. The sloughs continue down to a broad alluvial flood plain with irrigated agriculture as the primary land use, and finally drain near a small residential dunes complex to the Pajaro Lagoon, 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 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 have been channelized and filled to drain surface water. Two pump stations were also installed to enable the farming of the often inundated lowlands and to manage flooding. The two pump stations are located at Shell Road and at the confluence of Harkins Slough. The Harkins Slough pump station is currently operated by the Pajaro Valley Water Management Agency and serves as a diversion project to deal with seawater intrusion. 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, 2002). This subsidence, in addition to road crossings with inadequately sized culverts has led to impoundments of water in these areas and reduced water circulation throughout the slough system (Swanson Hydrology and Geomorphology, 2002).

The primary land uses are row crop agriculture, grazing, residential, urban, industrial, and commercial and are illustrated in Fig. 2.1.

**Table 2.1** Watsonville Sloughs sub-watershed boundaries

| Slough | Approx. Area (acres) | Approx. Area ($km^2$) |
|---|---|---|
| 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

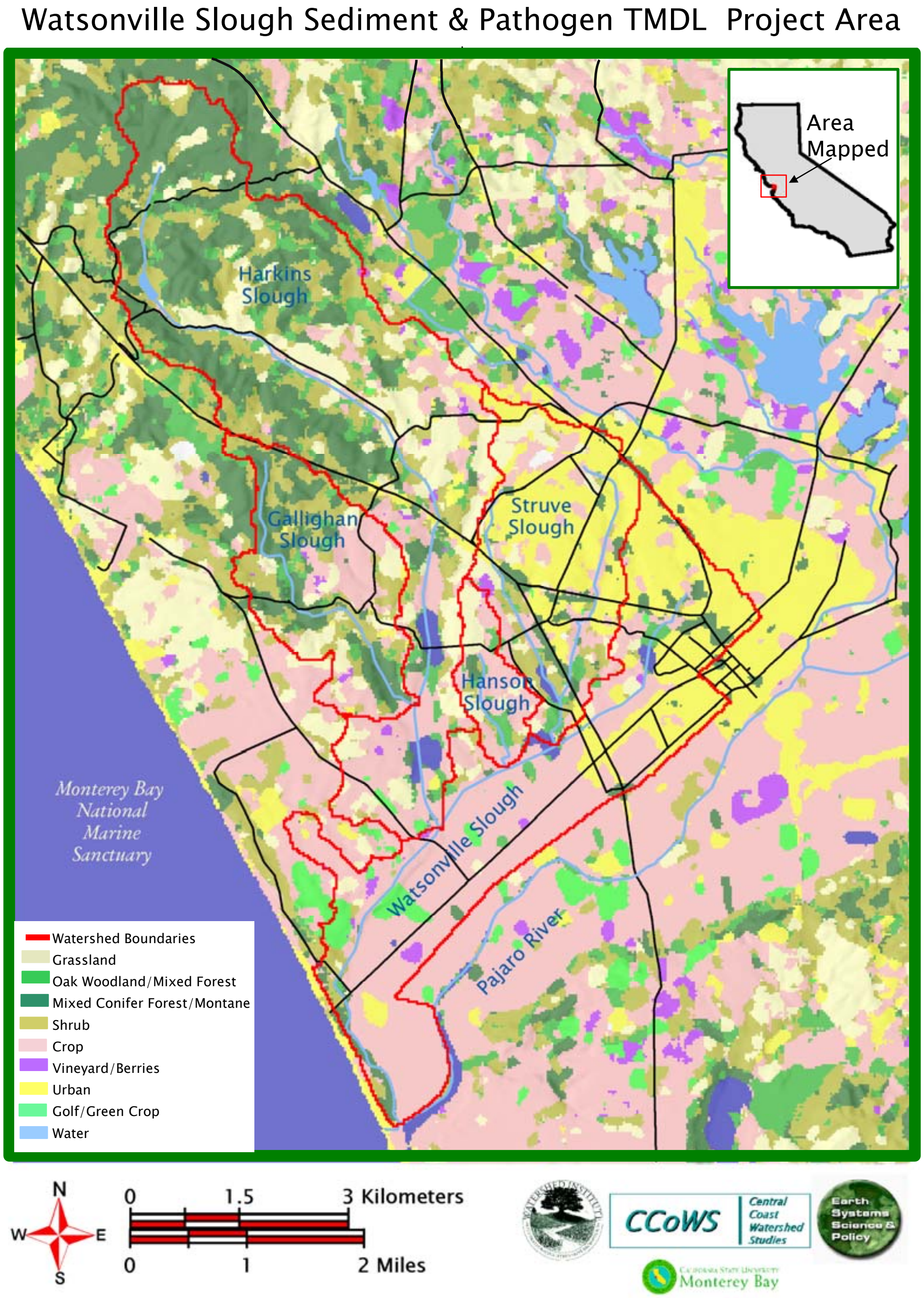



**Figure 2.1** Map showing the Watsonville Sloughs project area and watershed boundaries.

# 3 Review of Beneficial Uses & Water Quality Standards

## 3.1 Specific beneficial uses of Watsonville Sloughs

The Watsonville Sloughs area is recognized as 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 ecosystems, with unique plants 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; Swanso,n 2002). Wetland birds depend on abundant fish and macroinvertebrates for survival, and thus require a healthy functioning aquatic ecosystem free from excessive pollutants. Similarly, higher organisms such as falcons and hawks depend on the wetland birds for survival. Humans also enjoy this wetland area for recreation such as fishing, nature walks, and bird watching. Struve Slough and Harkins Slough, which has an extensive deepwater section, are especially popular areas for this.

The 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 3.1. More detailed inventories of the flora and fauna of Watsonville Sloughs have recently been compiled by J. Busch (2000) and by Swanson Hydrology and Geomorphology (2002) containing supplementary work by the Biotic Resources Group, Dana Bland and Associates, and Hagar Environmental Sciences.

**Table 3.1 Beneficial uses that apply to Watsonville Sloughs (Basin Plan 1994)**

| | |
|---|---|
| REC-1 | Water contact recreation |
| REC-2 | Non-contact water recreation |
| WILD | Wildlife habitat |
| WARM | Warm fresh water habitat |
| SPWN | Spawning, reproduction, and/or early development |
| BIOL | Preservation of biological habitat of special significance |
| RARE | Rare, threatened, or endangered species |
| EST | Estuarine habitat |
| COMM | Commercial and sport fishing |
| SHELL | Shellfish harvesting |

## 3.2 Potential pathogen impacts to beneficial uses

The presence of pathogens in water bodies has been demonstrated to pose significant health risks to humans (EPA, 2001). The beneficial uses most likely to be directly affected by pathogens and for which numeric water quality objectives have been established are SHELL, REC-1, and REC-2. Shellfish harvesting is not likely to be a current practice in Watsonville Sloughs, therefore the REC-1 objective was the primary guideline used in the current study.

### 3.3 Water Quality Objectives

The main water quality objectives that apply to pathogen levels for Watsonville Sloughs are outlined in the Basin Plan for the California Regional Water Quality Control Board Central Coast Region (1994). This plan, as mandated by the California Porter-Cologne Water Quality Control Act (1969), outlines "water quality objectives" that apply to Watsonville Slough.

The Basin Plan (1994) states that:

> Bacteria (REC-1)*: Fecal coliform concentration, based on a minimum of not less than five samples for any 30-day period, shall not exceed a log mean of 200/100 mL, nor shall more than ten percent of total samples during any 30-day period exceed 400/100 mL.
>
> Bacteria (REC-2)*: Fecal coliform concentration, based on a minimum of not less than five samples for any 30-day period, shall not exceed a log mean of 2000/100 mL, nor shall more than ten percent of samples collected during any 30-day period exceed 4000/100 mL.
>
> Bacteria (SHELL)*: At all areas where shellfish may be harvested for human consumption, the median total coliform concentration throughout the water column for any 30-day period shall not exceed 70/100 mL, nor shall more than ten percent of the samples collected during any 30-day period exceed 230/100 mL for a five-tube decimal dilution test or 330/100 mL when a three-tube decimal dilution test is used.
>
> *Numeric standards were developed using the Multiple Tube Fermentation technique.

An additional review of water quality standards was conducted in search of numeric standards and objectives for this region. However, no other studies provided numeric criteria for pathogens.

# 4 Coliform Background Information

An initial literature review was conducted to gain a better understanding of the complexities of coliform bacteria and the various factors that promote growth and survival. The results of this review are summarized below.

The family *Enterobacteriaceae* contains over 40 genera of bacteria, many of which constitute the total coliform group. The total coliform group are defined as, "aerobic and facultatively anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria that ferment lactose and acid production in 24 to 48 hours at 35°C" (Hurst et al., 2002). Total coliform bacteria are oxidase-negative and display b-galactosidase activity (Leclerc et al., 2001). The total coliform group is comprised of bacteria from both non-fecal and fecal origin and is comprised of at least 19 genera (Leclerc et al., 2001). Common habitats for total coliform include soil, groundwater, surface water, the intestinal tract of animals and humans, the surface of plants, epithilic algal-mat communities of pristine streams, wastes from the wood industry, and biofilms within drinking water distribution systems (Hurst et al., 2002). Some members are pathogenic, while others are not.

The total coliform group is often subdivided into various groups based on common characteristics. For instance, several genera that are often associated with plants include *Erwini*a, *Pantoea*, *Serratia*, and *Enterobacter* (Leclerc et al., 2001). Another such group is fecal coliform. Criteria of the fecal coliform group include: growth and fermentation of lactose with the production of gas and acid at 44.5°C ± 0.2°C (Hurst et al., 2002). The fecal coliform group is a more definitive indicator of fecal contamination. Coliform bacteria within this group have a positive correlation with fecal contamination from warm-blooded animals (Hurst et al., 2002). However, not all members of the group are of fecal origin. A more scientifically accurate description of the group is "thermotolerant" coliform (Hurst et al., 2002). Common members of the fecal or thermotolerant coliform group include *Klebsiella*, *Escherichia*, *Enterobacter*, and *Citrobacter*. There are also several genera among the fecal coliform group that contain ubiquitous species (Leclerc et al., 2001). For instance, *K. pneumoniae* is commonly found in the intestines of humans but has also been detected in sources that were absent of fecal contaminations, such as in effluent from the wood industry and in botanical environments. Similarly, certain species of *Enterobacter* and *Citrobacter*, are of fecal origin but have also been detected in soil, plant, and aquatic environments (Leclerc et al., 2001).

An even more specific indicator of fecal contamination is the species *Escherichia coli*. *E. coli* generally conforms to the criteria of the fecal coliform group but is distinguished by the lack of urease and the presence of b-glucuronidase (Hurst et al., 2002). *E. coli* comprises a large percentage of coliform detected in human and animal feces. Once again some strains are pathogenic, whereas some strains are not. *E. coli* bacteria are almost exclusively of enteric origin (Leclerc et al., 2001). An exception has been documented in tropical environments where *E. coli* has been detected in rainforest aquatic, plant, and soil systems (Hurst et al., 2002). Additionally, some strains of *E. coli* may not ferment lactose and are therefore non-gas producing (Leclerc et al., 2001). Detection of strains such as these may not be possible by tests like Multiple Tube Fermentation, which rely on the detection of gas for confirmation of coliform presence.

Each of the above groups is an indicator of pathogen presence, but there are many problems associated with each group. Coliform bacteria are a complex group of bacteria with atypical strains that can give rise to many false positive and false negative results using techniques such as Multiple Tube Fermentation (MTF) and Membrane Filtration (MF). For instance, bacteria of plant and soil origin can be detected using the fecal coliform test resulting in a false positive. Dormant or injured coliform resulting from stressors such as metals, disinfectants, and UV irradiation may not be detectable or may be nonculturable on certain media. Dormant bacteria such as these may still remain viable and infectious but can result in false negatives (Hurst et al., 2002). There are also genera of bacteria, such as *Aeromonas* of the *Aeromonadaceae* family, which can mimic coliform and may result in false positive results (Leclerc et al., 2001). Furthermore, there are additional limitations in the tests themselves. The Multiple Tube Fermentation method results in an estimate of the most probable number of bacteria, which is highly variable. For a given result of 1,600 MPN/100 mL, the 95% confidence limit ranges from 600 to 5,300 MPN/100 mL (APHA, 1998). Although generally regarded as a more precise method than Multiple Tube Fermentation, Membrane Filtration also has limitations. For instance, samples with high turbidity and/or non-target organisms may cause interference. Sediment can clog the filters and non-target organisms can mask the presence of coliform colonies (Hurst et al., 2002).

Detection of fecal coliform and *E. coli* using standard methods such as MTF and MF does not necessarily indicate fecal contamination. Unfortunately, it is highly likely that there is no one indicator organism that can prove fecal contamination and pathogen presence with absolute confidence. Proof of fecal contamination would require source and genetic identification. Although there are limitations to the coliform tests and indicator organisms, testing for *E. coli* is one of the best available methods for indication of potential fecal contamination.

Various conditions such as light, temperature, predation, nutrients, and sediment can affect coliform growth. Previous studies have shown that visible light has a negative affect on coliform bacteria (Evison, 1988; Bowie et al., 1985). Specifically, visible light may not cause cellular die-off of E. coli, but instead leads to dormancy and therefore the inability to reproduce (Barcina et al., 1989). Bacteria in this dormant phase may not be detectable by the Multiple Tube Fermentation technique used in the exceedance monitoring portion study.

McFeters and Stuart (1972), found that at temperatures between 5 to 15 degrees Celsius, *E. coli* survival was inversely proportion to temperature. In other words, as temperature increased, the concentration of *E. coli* decreased. At temperatures above this range, the relationship was less critical. Additionally this study indicated that the optimum pH range for *E. coli* survival was 5.5 to 7.5. Similarly, Bowie et al. (1985) noted that *E. coli* survive longer in solutions with pH values less than 8. Auer and Niehaus (1993) found no relationship between temperature and fecal coliform death rate and also sited several studies in which no relationship between temperature and fecal coliform bacteria was observed. However, Auer and Niehaus also sited several studies in which increases in temperature and increases in fecal coliform death rate were strongly correlated (Lantrip, 1983; Kittrell and Furfari, 1963, Hanes et al., 1966). More intensive review of literature is needed to fully determine the extent of temperature influence on fecal coliform survival.

Another factor that may affect coliform survival in aquatic ecosystems is the presence of predatory protozoa. For instance, Gonzalez et al. (1991) found that decreases in enteric bacteria were primarily due to protozoan predation and the effects of predatory bacteria were insignificant.

Nutrients also affect the survival rates of coliform bacteria. Bowie et al. (1985) stated that as nutrient levels increase, the rate of coliform disappearance decreases. However, salinity and coliform survival are inversely proportional (Bowie et al. 1985).

Coliform bacteria can attach to suspended sediment particles and it has been demonstrated that coliform bacteria adsorb to clay more than silt or sand (Mitchell and Chamberlin, 1978 as cited in Bowie et al., 1985). LeChevallier et al. (1988) suggested that attachment to sediment, macroinvertebrates, and organic matter may enhance coliform survival by preventing the exposure of bacteria surfaces to harsh environments. Furthermore, high coliform concentrations have been observed in the rising limb of hydrographs due to the entrainment of bacteria into the water column from the channel bed. This high concentration is followed by exponential decay in coliform concentration as the organisms are transported downstream and sedimentation occurs (Wilkinson et al., 1995).

As noted above, coliform bacteria have many adaptations allowing them to persist despite variations and harsh environmental conditions. The combined effects of these survival mechanisms may enable *in situ* aquatic growth of coliform bacteria. Therefore, a problem of elevated coliform levels for a given waterbody may not solely be addressed by bacterial sources, but rather also by controlling the conditions that promote growth.

# 5 Review of Previous Studies

A number of water resources management and environmental studies have been completed in the area. However, there is a lack of quantitative information on the extent, severity, and origins of pathogens in Watsonville Sloughs. The primary studies include:

- *Watsonville Sloughs Watershed Conservation and Enhancement Plan* (Swanson Hydrology & Geomorphology, 2002)
- *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
- California Department of Fish and Game

Numerous Environmental Impact Statements and Environmental Impact Reports have been completed for various development projects in the area, such as 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 pathogens.

Table 5.1 summarizes the type of data and number of sites sampled in previous water quality studies for Watsonville Sloughs.

**Table 5.1** 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 2002)* | 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 | | | | | |

* raw data not yet acquired

red text highlights data that pertain to pathogens

## 5.1 Coliform Data

The basis for the California 303d listing of Watsonville Sloughs for pathogens is not well documented and the extent of the impairment was unknown at the time of listing. Only two datasets for coliform levels exist for Watsonville Sloughs: Santa Cruz County Environmental Health and Pajaro Valley Water Management Agency. Table 5.2 provides sampling site locations for the 2 studies. The results from the 2 studies are summarized below. Although the data provide information on general levels, strength of any comparisons to data collected as part of the current study is limited due to differences in sampling techniques, analysis, sampling frequency, and rainfall patterns between the various years for which samples were taken. The primary uses of these data are to identify general levels for pathogens and to locate potential hot spots.

**Table 5.2** Site code indices for previous studies

| Site Code | Location |
|---|---|
| WAT-PAJ | Watsonville Slough mouth at confluence with Pajaro River Lagoon |
| WAT-BEA | Watsonville Slough at Beach Rd. |
| 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-EFF | Harkins Slough Diversion Project effluent |
| HAR-HAR | Harkins Slough at Harkins Slough Rd. |
| GAL-LOW | Lower Gallighan Slough |
| GAL-HAR | Gallighan Slough near confluence with Harkins Slough |
| STR-LEE | Struve Slough at Lee Rd. |
| STR-HAR | Struve Slough at Harkins Slough Rd. |
| STR-GVD | Struve Slough downstream of Green Valley Rd. |
| STR-ABD | Struve Slough downstream of Airport Blvd. |
| STR-AIR | Struve Slough at Airport Blvd. |

*Santa Cruz County Environmental Health Department*

The only consistent pathogen monitoring conducted in the Watsonville Slough system has been sampling for fecal coliform, an indicator of fecal contamination, using membrane filtration analysis by the Santa Cruz County Environmental Health Department (1977 to 2000). These data are summarized in Figure 5.1. Ten of the eleven sites sampled by the Santa Cruz Environmental Health Department exceeded the CCRWQCB's Basin Plan (1994) objective with more than 10% of the samples exceeding the 400 MPN/100mL[1] guideline for water contact recreation (Fig. 5.1).

The data summarized in Figure 5.1 indicate that current hot spots for potential fecal contamination (circled in red) may be the area near the confluence of Harkins Slough and Watsonville Slough and the heavily urbanized areas of upper Struve Slough. At least one site in each of the two areas had a geometric mean greater than 1,000 MPN/100 mL.

*Pajaro Valley Water Management Agency*

Limited sampling for pathogens has also been conducted by the Pajaro Valley Water Management Agency (PVWMA) for the Harkins Slough diversion project as part of the NPDES permit requirements (PVWMA 2002). Fecal coliform samples were analyzed using Multiple Tube Fermentation. Table 5.3 summarizes the PVWMA data. In general, the numbers measured by PVWMA were similar to values measured at sites sampled by the Santa Cruz County Environmental Health Department. The geometric means for fecal coliform samples at sites WAT-HSD and HAR-CON were greater than 400 MPN/100 mL.

**Table 5.3** Summary of fecal coliform data collected by PVWMA

| Site Code | PVWMA # of samples | Geometric Mean (MPN/100 mL) |
|---|---|---|
| WAT-HSD | 4 | 404 |
| WAT-HSU | 4 | 245 |
| HAR-EFF | 5 | 295 |
| HAR-CON | 4 | 585 |

[1] Most Probable Number per 100mL. This unit is derived from the Multiple Tube Fermentation Method (SM9221 & 9222).

Santa Cruz County Environmental Health
Historic Fecal Coliform Data (CFU/100mL)

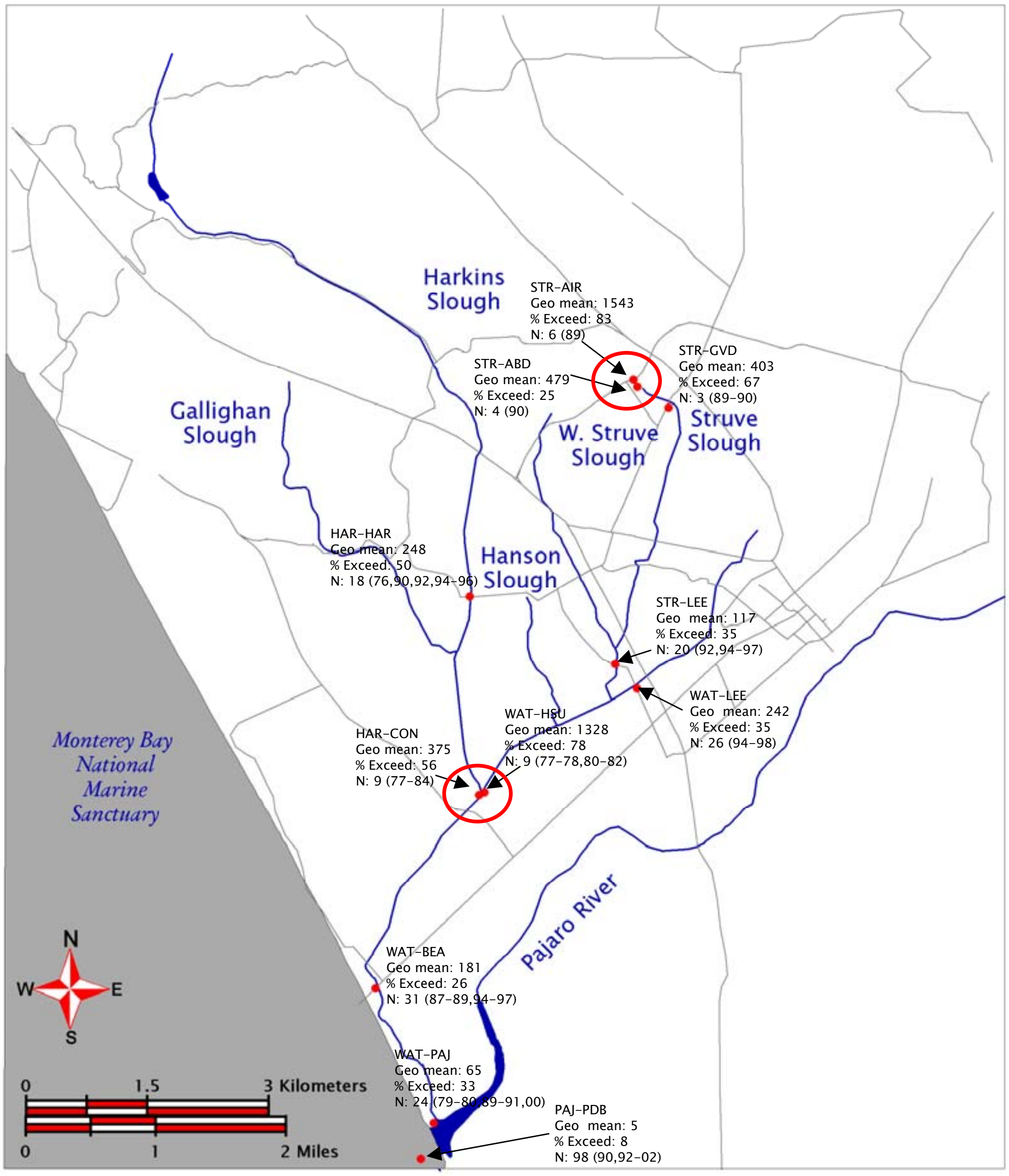



**Figure 5.1** Santa Cruz County Environmental Health fecal coliform data map showing geometric mean and % exceedence of Region 3 Basin Plan water contact recreation objective ("…nor shall more than 10% of all samples exceed 400 MPN per 100 mL"). Red circles indicate hot spot areas with at least one site having a geometric mean greater than 1,000 MPN/100 mL.

## 5.2 Hydrologic Data

The majority of studies reviewed did not involve collection and analysis of hydrologic data such as water level and discharge. The main hydrologic data found in previous studies were automatic stage data collected by Swanson Hydrology and Geomorphology and the PVWMA. Table 5.4 lists the hydrologic metadata from these two studies. The most probable reason for the lack of existing hydrologic data may be due to the sluggish nature of the Watsonville Sloughs system with limited water circulation occurring during most of the year. To date, no studies have been found that have measured stream discharge or closely examined channel geometry. Pump records are available for the two pump stations at Shell Road and at the Harkins Slough diversion project.

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 5.5.

**Table 5.4** 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

**Table 5.5** 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 |

## 5.3 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 for all maps in this report.

The only previous studies for Watsonville Sloughs that have included spatial data are Questa Engineering Corporation (1995) and Swanson Hydrology and Geomorphology (2002). The spatial data included 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 (2002):

- 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.

*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 2.1.

*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 6.2. 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 6.2.

# 6 Field Sampling Plan & Site Locations

## 6.1 Field Sampling Plan

The sampling plan for pathogens was driven by the following questions:

- Are pathogens in exdeedance of the Basin Plan objective (CCRWQCB 1994)?
- If so, what are the sources?

Given these questions, the approach for investigating pathogens in the Watsonville Sloughs watershed was to sample for the indicator bacteria, fecal coliform and *Escherichia coli* during storm-event and ambient conditions.

The goal of the first stage of the monitoring plan was to investigate fecal bacteria levels and to determine if a potential pathogen problem exists in the Watsonville Slough system. This involved 2 monitoring campaigns at 13 sites throughout the watershed for total coliform, fecal coliform, and *E. coli*. Each monitoring campaign consisted of 5 synoptic sampling runs within a 30-day period. The protocols for sample collection and analysis of pathogens are detailed in the quality assurance plan for the project (Hager and Watson, 2003).

The results of this first stage of monitoring, Section 7.3, demonstrated that the Watsonville Slough system was in exceedance of the Basin Plan objective for fecal coliform, therefore a preliminary source analysis was needed in order to proceed with TMDL development.

The second stage of the monitoring plan, a preliminary source analysis, involved conducting genetic analysis of samples from 3 sites that were identified as "hot spots" for fecal contamination and which were also representative of dominant land uses for the entire watershed. A total of 16 samples were analyzed by the laboratory group led by Dr. Betty Olson at the Department of Environmental Analysis and Design at the University of California, Irvine using the Toxin Gene Biomarker method. The Toxin Gene Biomarker method uses polymerase chain reaction (PCR) to identify toxin biomarker genes in *E. coli*.

When compared to other methods of genetic source identification of bacteria, the Toxin Gene Biomarker method was determined to be most appropriate for this study. Although other highly regarded methods, such as ribotyping and antibiotic resistance, provide detailed results with high specificity, there are many limitations to these methods when working on a limited budget. The success of ribotyping is dependent on an adequately sized library of known *E. coli* strains for comparison. Therefore, collection and analysis of known source samples for a specific geographic region are often first required. A large number of isolates must also be typed in order to obtain an appropriate representation of the *E. coli* population for a given water sample. The Toxin Gene Biomarker method was selected for Watsonville Sloughs preliminary source analysis, as it was most aligned with the scope and budget of this project. This method screens a larger proportion of the entire *E. coli* population of a single water sample and the biomarkers have proved to be geographically stable. The major limitation of this method is that only a limited number of toxin genes have been identified thus far. The biomarkers used in this study included: human, cow, bird, rabbit, and dog. Sources other than these were not identified.

## 6.2 Sampling Locations

*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 6.1. Figure 6.1 also shows land cover data for the area. 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 6.1 lists class categories that were used in the classification.

**Table 6.1** 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 6.2. The Sloughs watershed boundary and sub-watershed boundary vectors for Watsonville Sloughs were determined by CCoWS, using Tarsier 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 6.2.

Table 6.2 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 ($km^2$)** | **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 ($km^2$)** | **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 |

*Sampling Sites*

The 13 primary sites that were monitored for this project are listed in Table 6.3. The location of these sites are shown in Figure 6.1. Throughout the project, additional sites were sampled less frequently and are listed in Table 6.4.

**Table 6.3** 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 | Gallighan 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

**Table 6.4** Secondary Monitoring Sites

| CCoWS Site Code | Site Description | CCAMP Site Code |
|---|---|---|
| HAR-H1U | Harkins Slough just upstream of Hwy 1 crossing | |
| HAR-BUE | Harkins Slough at Buena Vista Road | 305WLV |
| HAR-PEA | Harkins Slough at Peaceful Oaks Lane | |
| HAR-916 | Harkins Slough upstream of HAR-PEA | |
| STR-CH1 | Struve Slough upstream of STR-CHE | |
| STR-CH2 | Struve Slough upstream of STR-CH1 | |
| STR-CH3 | Struve Slough upstream of STR-CH2 | |
| STR-CH4 | Struve Slough downstream of STR-CHE | |
| STR-CH5 | Struve Slough downstream of STR-CH4 | |
| STR-TRB | Small tributary to Struve Slough located just upstream of STR-CHE | |
| STR-PIP | Pipe near STR-CHE | |
| STR-AIR | Struve Slough at Airport Blvd. | |

Watsonville Slough Pathogen TMDL

Project Area

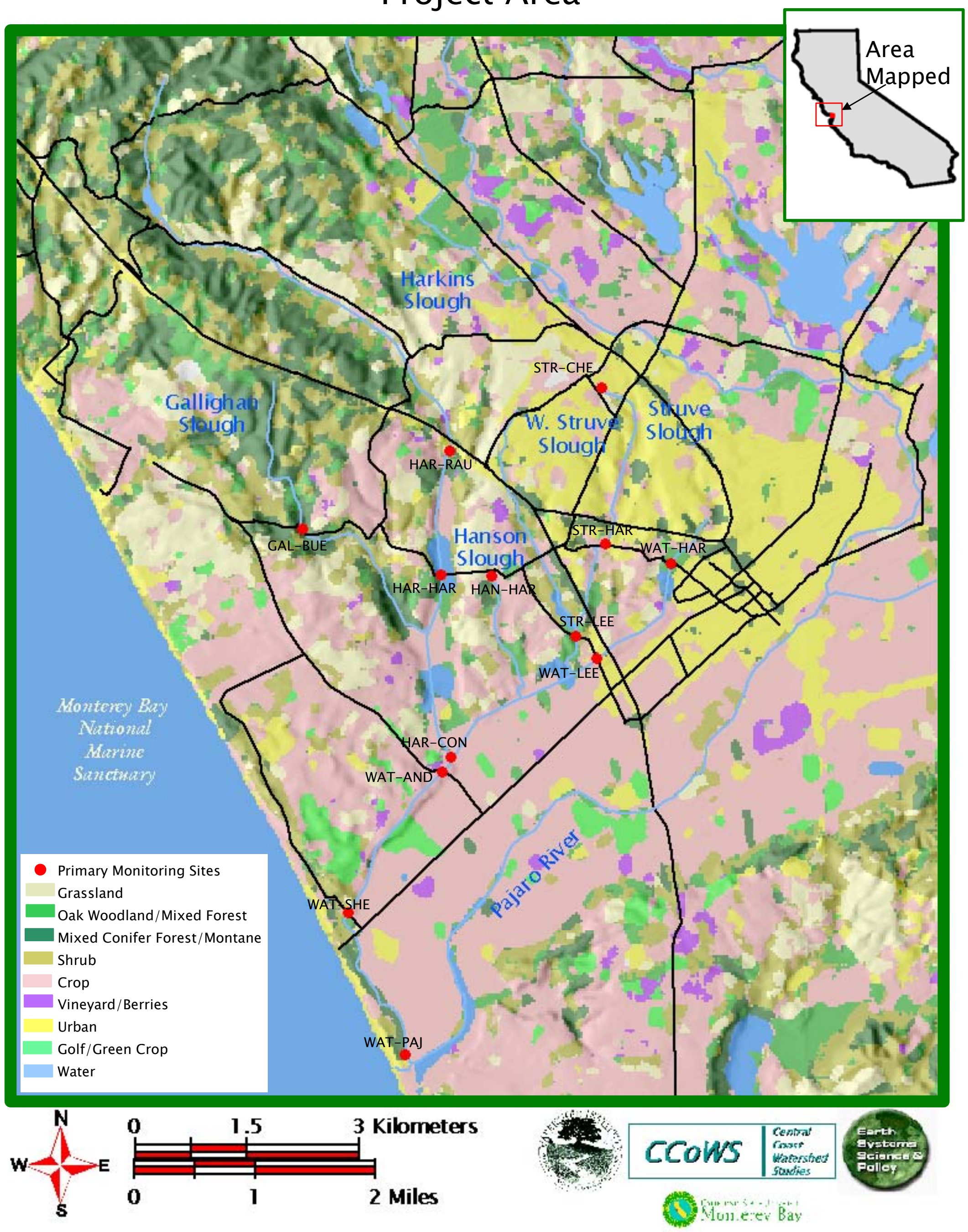



**Figure 6.1** Map showing Watsonville Sloughs project area and primary monitoring sites.

*WAT-PAJ*

Sampling site WAT-PAJ (Fig. 6.2 -6.3) 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 6.2** Watsonville Slough looking downstream to Pajaro River Lagoon (Photo: J. Casagrande Jul 02).

**Figure 6.3** Watsonville Slough near Pajaro River looking upstream (Photo: J. Casagrande Jul 02).

*WAT-SHE*

Sampling site WAT-SHE (Fig. 6.4 - 6.5) 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 6.4** Watsonville Slough at Shell Rd. looking downstream (Photo: J. Casagrande Jul 02).

**Figure 6.5** Watsonville Slough at Shell Rd. looking upstream (Photo: J. Casagrande Jul 02).

### *WAT-AND*

Sampling site WAT-AND (Fig. 6.6 - 6.7) 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. 6.6 - 6.7 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 6.6** Watsonville Slough at San Andreas Rd. looking upstream. Note channel filled with vegetation (Photo: F. Watson Dec 02).

**Figure 6.7** Watsonville Slough at San Andreas Rd. looking downstream (Photo: F. Watson Dec 02).

*WAT-LEE*

Sampling site WAT-LEE (Fig. 6.8 - 6.9) 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. 6.9. Samples were collected immediately upstream of the culverts. Adjacent land use is industry and row crop agriculture.

**Figure 6.8** Watsonville Slough at Lee Rd. looking upstream (Photo: J. Hager Dec 02).

**Figure 6.9** Watsonville Slough at Lee Rd. (Photo: F. Watson Dec 02).

*WAT-HAR*

Sampling site WAT-HAR (Fig. 6.10 - 6.11) 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 6.10** Watsonville Slough at Harkins Slough Rd. (Photo J. Casagrande Jul 02).

**Figure 6.11** Watsonville Slough at Harkins Slough Rd. looking downstream (Photo: J. Hager Feb 03).

*HAR-CON*

Sampling site HAR-CON (Fig. 6.12 - 6.13) 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 6.12** Harkins Slough at PVWMA diversion project (Photo: F. Watson Sep 02).

**Figure 6.13** 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. 6.14 – 6.15) 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 6.14** Harkins Slough at Harkins Slough Rd. (Photo: F. Watson Dec 02).

**Figure 6.15** Harkins Slough at Harkins Slough Rd. looking upstream (Photo: J. Casagrande Jul 02).

*HAR-RAU*

HAR-RAU (Fig. 6.16 - 6.17) 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 6.16). Samples were taken approximately 10 meters upstream of the culvert and immediately above the confluence with a small tributary creek. Figure 6.17 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 6.16** Harkins Slough at Ranport Rd. (Photo: D. Roques Feb 03).

**Figure 6.17** Harkins Slough at Ranport Rd. looking upstream (Photo: F. Watson Dec 02).

*GAL-BUE*

Sampling site GAL-BUE (Fig. 6.18 – 6.19) 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 6.18** Gallighan Slough at Buena Vista Rd. looking downstream (Photo: D. Roques Feb 03).

**Figure 6.19** Gallighan Slough at Buena Vista Rd. looking upstream (Photo: D. Roques Feb 03).

*HAN-HAR*

This site (Fig. 6.20 - 6.21) 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. 6.20) and no riparian vegetation on the upstream side (Fig. 6.21). 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 6.20** Hanson Slough at Harkins Slough Rd. looking downstream (Photo: J. Hager Feb 03).

**Figure 6.21** Hanson Slough at Harkins Slough Rd. looking upstream (Photo: F. Watson Nov 02).

*STR-LEE*

Sampling site, STR-LEE (Fig. 6.22 - 6.23), 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 6.22** Struve Slough at Lee Rd. looking downstream (Photo: J. Casagrande Jul 02).

**Figure 6.23** Struve Slough at Lee Rd. looking upstream (Photo: F. Watson Nov 02).

*STR-HAR*

This sampling site (Fig. 6.24 - 6.25) 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. 6.25) with increasing residential development nearby.

**Figure 6.24** Struve Slough at Harkins Slough Rd. looking downstream (Photo: J. Casagrande Jul 02).

**Figure 6.25** 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 6.26.

**Figure 6.26** Struve Slough near Cherry Blossom Drive looking downstream (Photo: D. Roques Feb 03).

# 7 Results

## 7.1 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 exceedance monitoring campaigns (1 rainy season, 1 dry season), multiple sampling runs for initial coliform source tracking, and 2 sampling runs for genetic analysis. Sampling dates and metadata are presented in Tables 7.1 to Table 7.3.

Figures 7.1 to 7.3 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) for the Watsonville Waterworks station (NCDC, 2003), the average water year (October to September) precipitation 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)[2].

Rainfall patterns for the 2002/2003 winter deviated from the monthly average for the existing record of data for the area (Fig. 7.1). 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. For January through March, monthly rainfall totals were less than half the average, but were above average in April and May.

Daily precipitation values for the project time frame are presented in Figure 7.2. 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. 7.4). The total for those 2 days was approximately 2.2 cm (0.85 inches) (CIMIS, 2003). For comparison, rainfall totals were much higher in December 2002, for which the monthly total was 22

[2] 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.

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 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 7.6). Flows continued up Watsonville Slough, over the PVWMA pump station, and into Harkins Slough (Figure 7.8). 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 7.9).

Flows during the winter exceedance monitoring period were much lower than those observed during the December event due to the lack of intense rainfall. Figure 7.5 shows hydrographs for local USGS stations during the winter monitoring period. There are no USGS gauging sites located throughout the slough system. Discharge measurements were taken by CCoWS when possible. The largest flows were observed during the March 15th and April 13th storm events (Fig. 7.4). 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 7.4.

## 7.2 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 flows 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. 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.

**Table 7.1** Sampling Dates

| Rainy Season Exceedance Monitoring |
|---|
| 18-Feb-03 |
| 27-Feb-03 |
| 14-Mar-03 |
| 18-Mar-03 |
| 20-Mar-03 |
| 18-Nov-03 |
| Rainy Season Coliform Source Tracking |
| 17-Apr-03 |
| 06-May-03 |
| Rainy Season Genetic Sampling |
| 9-Dec-03 |
| Dry Season Exceedance Monitoring |
| 19-Jun-03 |
| 26-Jun-03 |
| 01-Jul-03 |
| 08-Jul-03 |
| 16-Jul-03 |
| Dry Season Coliform Source Tracking |
| 4-Aug-03 |
| 5-Aug-03 |
| 18-Aug-03 |
| 26-Aug-03 |
| 4-Sep-03 |
| 9-Sep-03 |
| 10-Sep-03 |
| Dry Season Genetic Monitoring |
| 9-Sep-03 |

**Table 7.2** Winter Sampling Metadata (# of samples)

| Site Code | # of Visits | Stage | Stage Inverted* | Discharge | Total Coliform | Fecal Coliform | *E. coli* |
|---|---|---|---|---|---|---|---|
| WAT-PAJ | 6 | 6 | | | 7 | 7 | 7 |
| WAT-SHE | 6 | | 5 | | 5 | 5 | 5 |
| WAT-AND | 7 | 7 | | | 5 | 5 | 5 |
| WAT-LEE | 11 | 9 | | 8 | 5 | 6 | 6 |
| WAT-HAR | 6 | | | | 8 | 9 | 9 |
| HAR-CON | 7 | | | | 5 | 5 | 5 |
| HAR-HAR | 7 | 5 | 2 | | 8 | 9 | 8 |
| HAR-RAU | 13 | 10 | 2 | 8 | 9 | 8 | 8 |
| HAR-H1U | 2 | | | | 2 | 1 | 1 |
| HAR-BUE | 2 | | | | 2 | 1 | 1 |
| HAR-PEA | 2 | | | | 2 | 1 | 1 |
| HAR-916 | 2 | | | | 2 | 1 | 1 |
| GAL-BUE | 10 | 8 | | 8 | 5 | 5 | 5 |
| HAN-HAR | 5 | | | 4 | 1 | 1 | 1 |
| STR-LEE | 6 | | 6 | | 5 | 5 | 5 |
| STR-HAR | 6 | | 6 | | 6 | 6 | 5 |
| STR-CHE | 12 | 6 | | 8 | 11 | 8 | 8 |
| STR-CH1 | 2 | | | | 2 | 1 | 1 |
| STR-AIR | 1 | | | | 1 | 1 | |

*stage measured from a fixed, known point down to water level

**Table 7.3** Summer Sampling Metadata (# of samples)

| Site Code | # of Visits | Stage | Stage Inverted** | Discharge | Total Coliform | Fecal Coliform | *E. coli* |
|---|---|---|---|---|---|---|---|
| WAT-PAJ | 6 | 6 | | | 7 | 7 | 7 |
| WAT-SHE | 8 | | 4 | | 11 | 12 | 12 |
| WAT-AND | 6 | 6 | | | 6 | 8 | 8 |
| WAT-LEE | 6 | 6 | | 5 | 5 | 5 | 5 |
| WAT-HAR | 6 | | | | 8 | 8 | 8 |
| HAR-CON | 6 | | | | 5 | 5 | 5 |
| HAR-HAR | 8 | 7 | | | 9 | 9 | 9 |
| HAR-RAU | 6 | 6 | | | 5 | 5 | 5 |
| GAL-BUE | 6 | 4 | | 6 | 3 | 3 | 3 |
| HAN-HAR | 6 | | | 6 | | | |
| STR-LEE | 6 | | 3 | | 8 | 7 | 7 |
| STR-HAR | 6 | | 2 | | 5 | 5 | 5 |
| STR-CHE* | 14 | 9 | | 5 | 9 | 10 | 16 |
| STR-CH1* | 6 | | | | 3 | 2 | 6 |
| STR-CH2* | 3 | | | 2 | 1 | 1 | 1 |
| STR-CH3* | 3 | | | | 1 | 2 | 3 |
| STR-CH4* | 1 | | | | 1 | | 1 |
| STR-CH5* | 1 | | | | 1 | | 1 |
| STR-TRB* | 8 | | | | 5 | 4 | 8 |
| STR-PIP* | 8 | | | | 5 | 6 | 8 |
| STR-AIR* | 2 | | | | 2 | 1 | 2 |

*Includes samples collected by CCoWS and the City of Watsonville

**stage measured from a fixed, known point down to water level

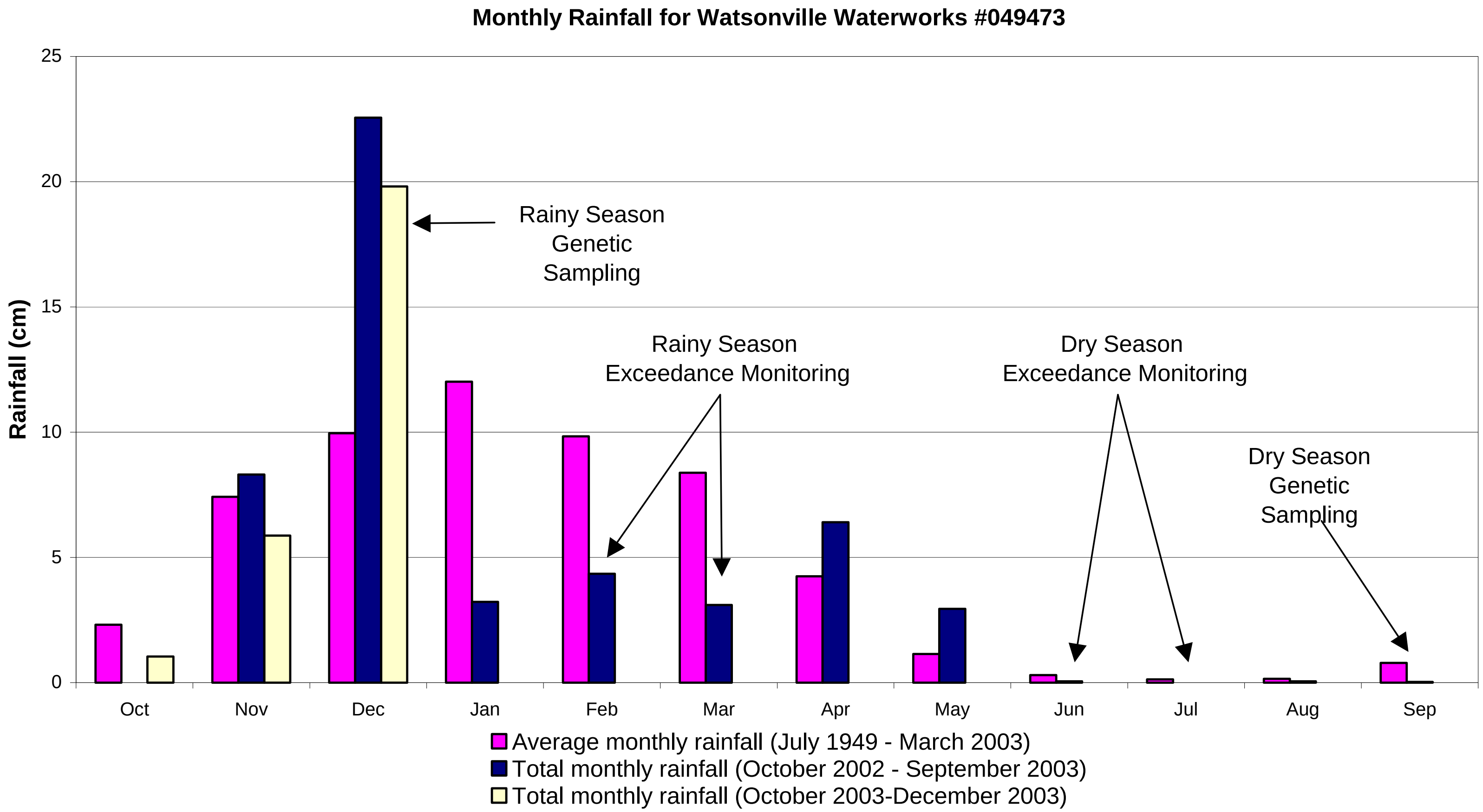



**Figure 7.1** Monthly rainfall averages (1948-2003) for Watsonville Waterworks station (WRCC, 2003) and total monthly rainfall for 2003 water year for Watsonville Waterworks station (NCDC, 2004).

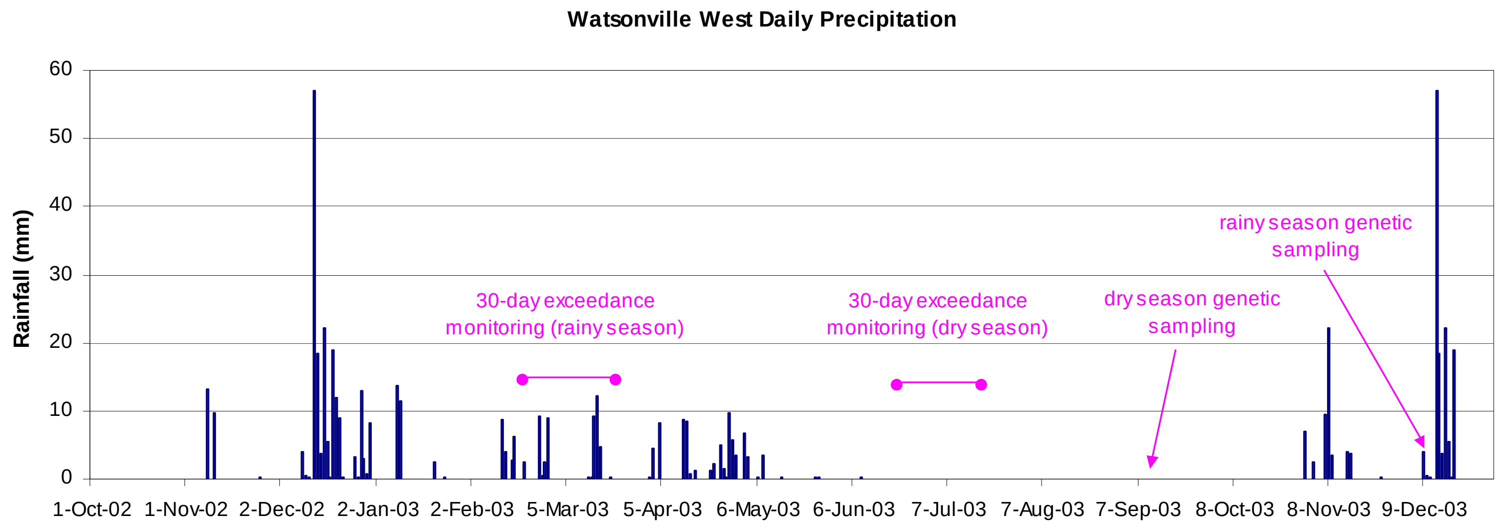



**Figure 7.2** Daily precipitation data for CIMIS Watsonville West station. Data from 20-Dec-03 to 30-Dec-03 not available.

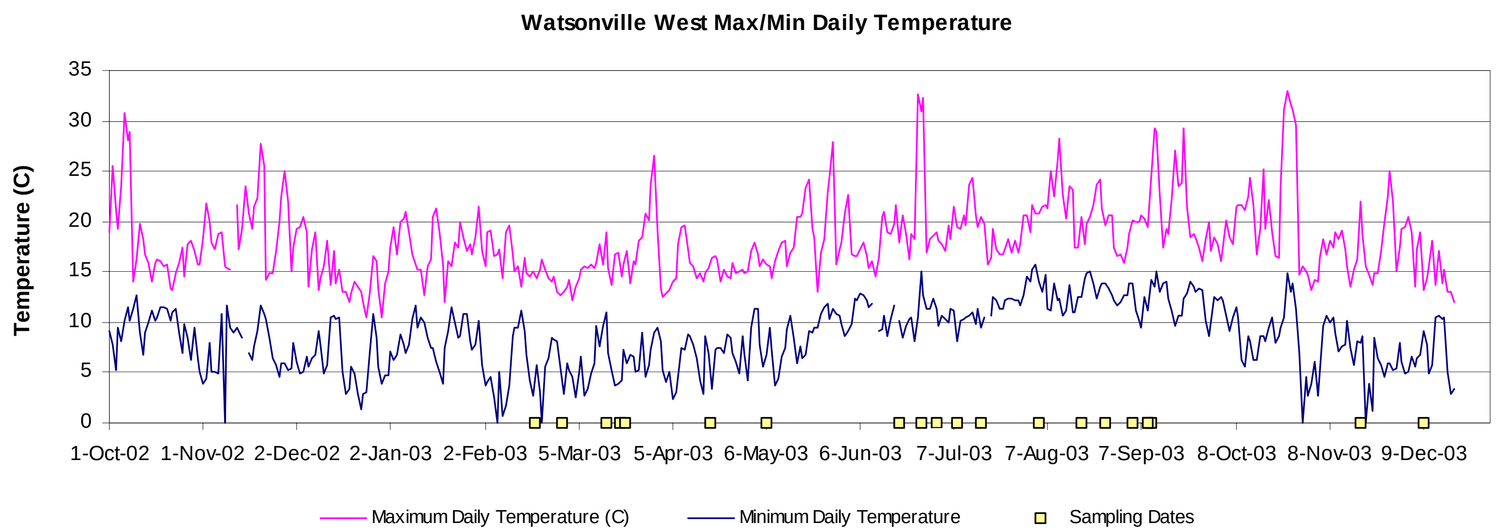



**Figure 7.3** Daily maximum and minimum air temperature for CIMIS Watsonville West station.

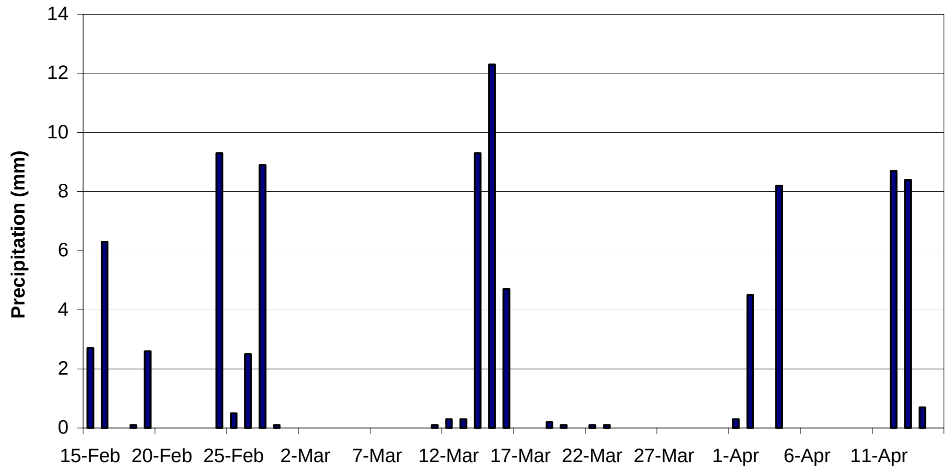



**Figure 7.4** Precipitation data for rainy season monitoring period at CIMIS Watsonville West, station.

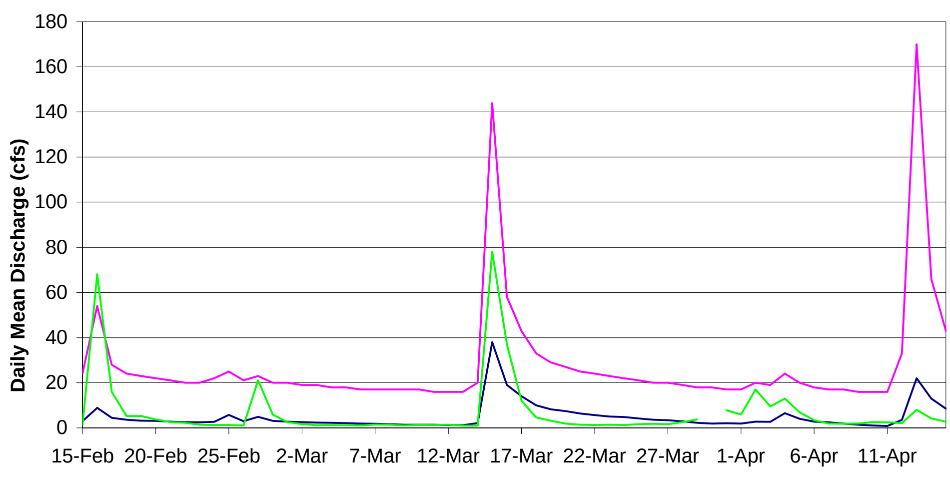



**Figure 7.5** Daily mean discharge at nearby USGS stations for rainy season monitoring.

**Table 7.4** 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

**Figure 7.6** Flooding of Beach Road and Shell Road on 16 Dec 02 (Photo: F. Watson Dec 02).

**Figure 7.7** Flooding of nearby agricultural fields near Shell Road on 16 Dec 02 (Photo: F. Watson Dec 02).

**Figure 7.8** Reversal of flow toward Harkins Slough on 16 Dec 02 (Photo: F. Watson Dec 02).

**Figure 7.9** Flow into Harkins Slough from Watsonville Slough and adjacent agricultural field on 16 Dec 02 (Photo: F. Watson Dec 02).

### 7.3 Exceedance Monitoring

The first stage of the monitoring involved sampling for total coliform, fecal coliform, and *E. coli* at 13 sites throughout the watershed. Five sampling runs were conducted within a 30-day period to determine if the sloughs were in exceedance of the water quality objectives pertaining to fecal coliform for contact recreation, which are outlined in the Basin Plan (CCRWQCB, 1994):

> Bacteria (REC-1): Fecal coliform concentration, based on a minimum of not less than five samples for any 30-day period, shall not exceed a log mean of 200/100 mL, nor shall more than 10 percent of the total samples during any 30-day period exceed 400/100 mL.

*Winter Monitoring Campaign*

The results of the winter monitoring campaign are presented in Table 7.5 and 7.6. Nine of the twelve sites were in exceedance of the fecal coliform objective for contact recreation with more than 10% of the samples exceeding 400 MPN/100 mL. It could not be determined whether or not Hanson Slough was in exceedance because only 1 sample was collected due to absence of water/flow at the site. Sites that were not in exceedance included: STR-LEE, WAT-PAJ, and WAT-HAR. Based on the calculated geometric mean, 8 of the 12 sites were in exceedance of the objective, having a geometric mean greater than 200 MPN/100 mL. Sites that were not in exceedance based on geometric mean only included: STR-HAR, STR-LEE, WAT-HAR, and WAT-PAJ. Similar results were obtained for *E. coli* (Table 7.6).

**Table 7.5** Watsonville Sloughs Winter Fecal Coliform Data

| Date | WAT-PAJ | WAT-SHE | WAT-AND | WAT-LEE | WAT-HAR | HAR-CON | HAR-HAR | HAR-RAU | GAL-BUE | HAN-HAR | STR-LEE | STR-HAR | STR-CHE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18-Feb-03 | 130 | 300 | 1,600 | 80 | 37 | 1,600 | 900 | 500 | 220 | no flow | 4 | 13 | >=1,600 |
| 27-Feb-03 | 220 | 1,600 | 1,600 | 300 | 170 | 220 | >=1,600 | >=1,600 | >=1,600 | >=1,600 | 8 | >=1,600 | 16,000 |
| 14-Mar-03 | 240 | 1,700 | 5,000 | 1,600 | 80 | 2,400 | 1,100 | 400 | 300 | no flow | 8 | 20 | 16,000 |
| 18-Mar-03 | 143 | 500 | 5,000 | 95 | 40 | 5,000 | 1,000 | 500 | 80 | no flow | <20 | 40 | 170 |
| 20-Mar-03 | 240 | 170 | 300 | 1,700 | 23 | 130 | 5,000 | 700 | 80 | no flow | 20 | 20 | 2,400 |
| **Max** | 240 | 1,700 | 5,000 | 1,700 | 170 | 5,000 | 5,000 | 1,600 | 1,600 | 1,600 | 20 | 1,600 | 16,000 |
| **Min** | 130 | 170 | 300 | 80 | 23 | 130 | 900 | 400 | 80 | 1,600 | 4 | 13 | 170 |
| **Geometric mean** | 188 | 586 | 1,806 | 362 | 54 | 887 | 1,513 | 645 | 232 | 1,600 | 10 | 51 | 2,784 |
| **% Exceedance** | 0 | 60 | 80 | 40 | 0 | 60 | 100 | 80 | 20 | 100 | 0 | 20 | 80 |

Shaded region show exceedance Basin Plan fecal coliform REC-1 objective: geometric mean >200 MPN/100 mL or more than 10% of samples exceeded 400 MPN/100 mL

**Table 7.6** Watsonville Sloughs Winter E. coli Data

| Date | WAT-PAJ | WAT-SHE | WAT-AND | WAT-LEE | WAT-HAR | HAR-CON | HAR-HAR | HAR-RAU | GAL-BUE | HAN-HAR | STR-LEE | STR-HAR | STR-CHE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18-Feb-03 | 80 | 300 | 1,600 | 80 | 22 | 1,600 | 900 | 300 | 170 | no flow | 4 | 8 | >=1,600 |
| 27-Feb-03 | 140 | 1,600 | 1,600 | 300 | 110 | 220 | >=1600 | >=1,600 | >=1,600 | >=1,600 | 4 | 1,600 | 16,000 |
| 14-Mar-03 | 130 | 1,700 | 3,000 | 500 | 80 | 800 | 1,100 | 367 | 300 | no flow | 8 | 20 | 16,000 |
| 18-Mar-03 | 143 | 300 | 3,000 | 390 | 40 | 5,000 | 420 | 500 | 20 | no flow | <20 | 40 | 170 |
| 20-Mar-03 | 240 | 170 | 300 | 1,700 | 23 | 130 | 5,000 | 700 | 80 | no flow | 20 | 20 | 2,400 |
| **Max** | 240 | 1,700 | 3,000 | 1,700 | 110 | 5,000 | 5,000 | 1,600 | 1,600 | 1,600 | 20 | 1,600 | 16,000 |
| **Min** | 80 | 170 | 300 | 80 | 22 | 130 | 420 | 300 | 20 | 1,600 | 4 | 8 | 170 |
| **Geometric mean** | 138 | 529 | 1,472 | 380 | 45 | 712 | 1,272 | 573 | 167 | 1,600 | 9 | 46 | 2,784 |
| **% Exceedance** | 0 | 40 | 80 | 40 | 0 | 60 | 100 | 60 | 20 | 100 | 0 | 20 | 80 |

Shaded region show exceedance Basin Plan fecal coliform REC-1 objective: geometric mean >200 MPN/100 mL or more than 10% of samples exceeded 400 MPN/100 mL

As illustrated in Figures 7.1, 7.2, and 7.4, rainfall during the monitoring period was not as intense as the events of late December. The most significant rainfall event occurred around March 15th, however coliform samples were not collected during the peak of the event. Laboratories were closed for the weekend; therefore samples could not be collected until March 18th when flows had receded. A less intense storm was monitored in late February. Samples were collected February 27th, after approximately 11 mm of rainfall on the night of the February 26th. Hydrographs for local USGS sites are given in Figure 7.5.

The data results for E. coli are illustrated in Figure 7.10. Although there is temporal variation within sites, several sites were consistently lower or higher than others. For instance, *E. coli* values at STR-CHE ranged from 170 to 16,000 MPN/100 mL, but the geometric mean was the highest of all sites. On February 27th, a large increase was observed at most sites (Fig. 7.10). One hypothesis may be that runoff transports bacteria from various sources leading to increases in the receiving waters. However, this trend was not consistently observed for the results collected before and after the March 15th rain event (Fig. 7.10), although it is important to note that the peak of the storm was not sampled. *E. coli* values at some sites increased following the rain, while other sites showed decreases in E. coli levels. It is currently unclear as to whether these responses are a function of sources or rather environmental conditions that may promote growth or decay.

A map summarizing the fecal coliform data is presented in Figure 7.11. Hot spots, sites with a geometric mean greater than 1,000 MPN/100 mL, are circled in red and include

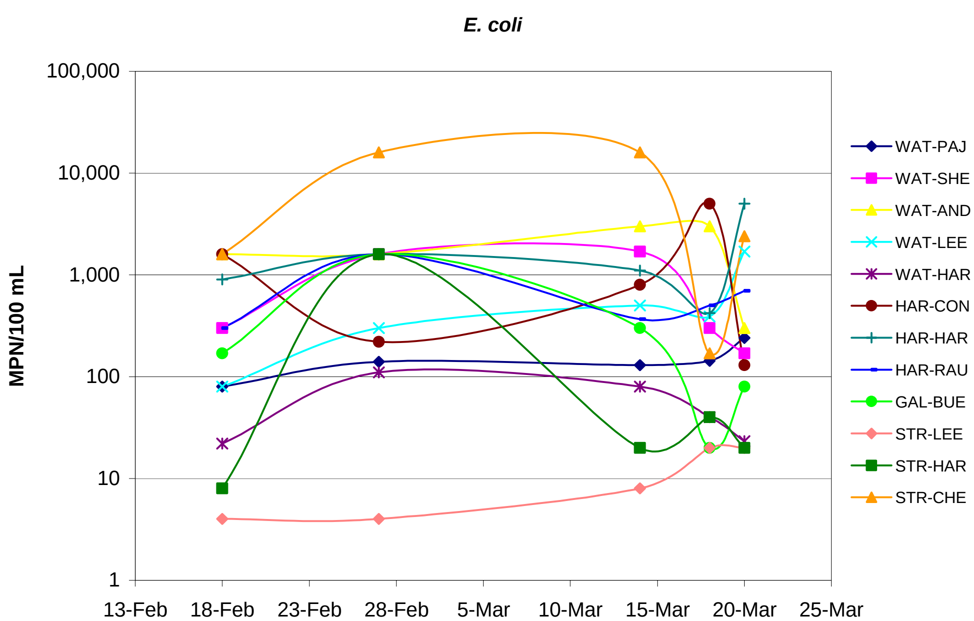



**Figure 7.10** Watsonville Sloughs Winter E. coli data.

WAT-AND, HAR-HAR, and STR-CHE. These areas were selected as likely locations for the genetic source identification portion of this study. STR-CHE had the highest geometric mean, 2,784 MPN/100 mL, and HAR-HAR had an exceedance of 100%.

Compared to historic data collected by Santa Cruz County Environmental Health (Fig. 5.1), upper Struve Slough and middle Watsonville Slough near the confluence with Harkins Slough had elevated levels of fecal coliform in both datasets. Fecal coliform levels reported by Santa Cruz County at HAR-HAR were much lower than the levels measured by CCoWS and exceedance of the Basin Plan objective was 50%. Although it is interesting to find similar areas with elevated coliform levels in 2003 and during the 1970s to 1990s, it should be noted that Santa Cruz County data were not collected within a consecutive 30-day period, a different laboratory method was used, and environmental and weather conditions most likely differed considerably.

*Initial Source Tracking*

Since HAR-HAR and STR-CHE were consistently higher than the other sampling sites, additional monitoring was conducted upstream of these sites in an attempt to identify and isolate the source of fecal coliform prior to genetic analysis.

Samples were collected at STR-CHE and at two other upstream locations (Figures 7.12 to 7.13). STR-CH1 is located approximately 20 meters upstream of STR-CHE, and STR-AIR is located upstream of STR-CH1 and immediately downstream of the Airport Blvd. road crossing. The small watershed upstream of Airport Blvd. is within the property boundaries of the local airport and was not accessible. On April 17$^{th}$, sites STR-CH1 and STR-AIR had lower fecal coliform levels (300 and 220 MPN/100 mL respectively) than site STR-CHE (654 MPN/100 mL) (Fig. 7.12 ). On May 6$^{th}$ this pattern was reversed; *E. coli* levels were a slightly higher at STR-CH1 (310 MPN/ 100 mL) than at STR-CHE (100 MPN/100 mL) (Fig. 7.13). Laboratory results from May 6$^{th}$ at STR-AIR were discarded due to a possible laboratory error. During both sampling runs, *E. coli* and fecal coliform values for STR-CHE were lower in relation to the geometric mean that was observed for the winter exceedance monitoring.

The winter exceedance monitoring showed that fecal coliform levels were elevated at WAT-AND but were not as high at WAT-LEE. Since all sites on Harkins Slough were in exceedance of the objective, it may be a possibility that high levels at WAT-AND are a result of inputs from Harkins Slough. To address this notion, additional sampling was conducted in Harkins Slough.

Samples were collected from 5 sites in upper Harkins Slough in an attempt to isolate locations where very high levels and potential sources may exist. On April 17$^{th}$, the fecal coliform level at site HAR-H1U (2,400 MPN/100 mL), which is located just upstream of the Highway 1 crossing, was considerably higher than upstream sites HAR-BUE (230 MPN/100 mL), HAR-PEA (170 MPN/100 mL), and HAR-916 (50 MPN/100 mL), and also higher than HAR-RAU (170 MPN/100 mL), which is located just downstream (Fig. 7.12 ). However, on May 6$^{th}$ the highest levels of *E. coli* occurred at HAR-BUE (478 MPN/100 mL), which located just downstream of the Buena Vista Rd. crossing (Fig. 7.13). Once again, with the exception of 2,400 MPN/100 mL value reported at HAR-H1U on April 17$^{th}$, *E. coli* and fecal coliform levels were considerably lower than the geometric means observed at HAR-HAR and HAR-RAU during the exceedance monitoring.

The primary conclusion to be drawn from the initial source tracking exercise was that the coliform levels throughout Watsonville Sloughs were too variable to permit a simple source analysis based on a few samples at multiple sites. There was no single site that had much higher levels than the other sites on both occasions, and there were not enough data to show a statistical difference between sites. Although there appeared to be differences between sites on a given day, these could be due to variation in the laboratory method. For instance, on April 17$^{th}$ the values detected in upper Struve Slough were 654 and 300 MPN/100 mL using multiple tube fermentation. The 95% confidence limits for 300 MPN/100 mL range from 100 to 1,300 MPN/100 mL. Therefore, the difference between STR-CHE and STR-CH1 on that day could potentially be attributed to limitations of the analysis method rather than actual differences due to source.

Watsonville Slough Pathogen TMDL
Fecal Coliform Monitoring Results FEB & MAR 2003

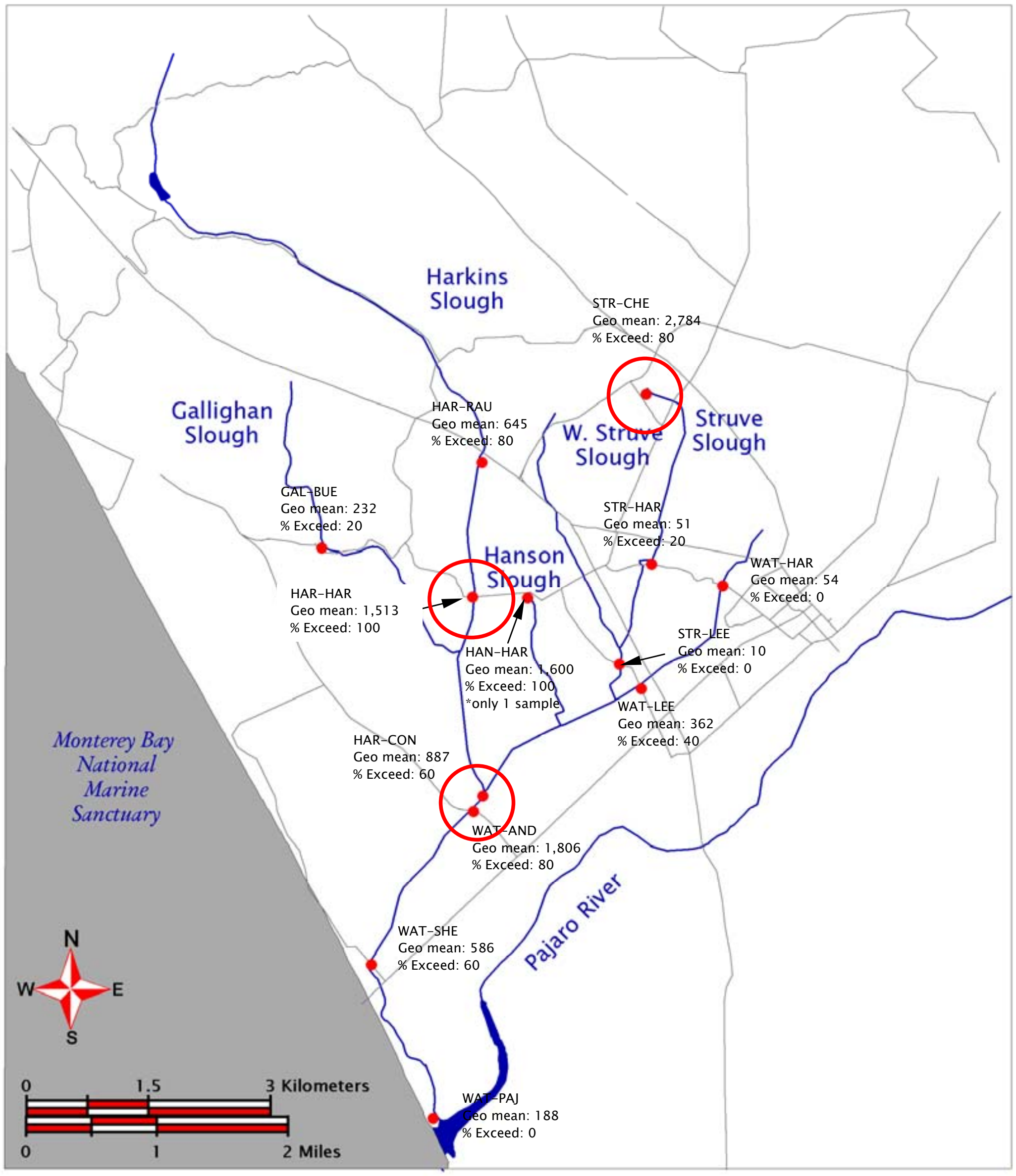



**Figure 7.11** Watsonville Sloughs fecal coliform data collected by CCoWS during winter monitoring campaign. Red circles indicate sites with a geometric mean > 1,000 MPN/100mL. Note that only 1 sample was collected from HAN-HAR due to lack of water at the site.

Watsonville Slough Pathogen TMDL

Coliform (MPN/100 mL) Source Monitoring 17 April 03

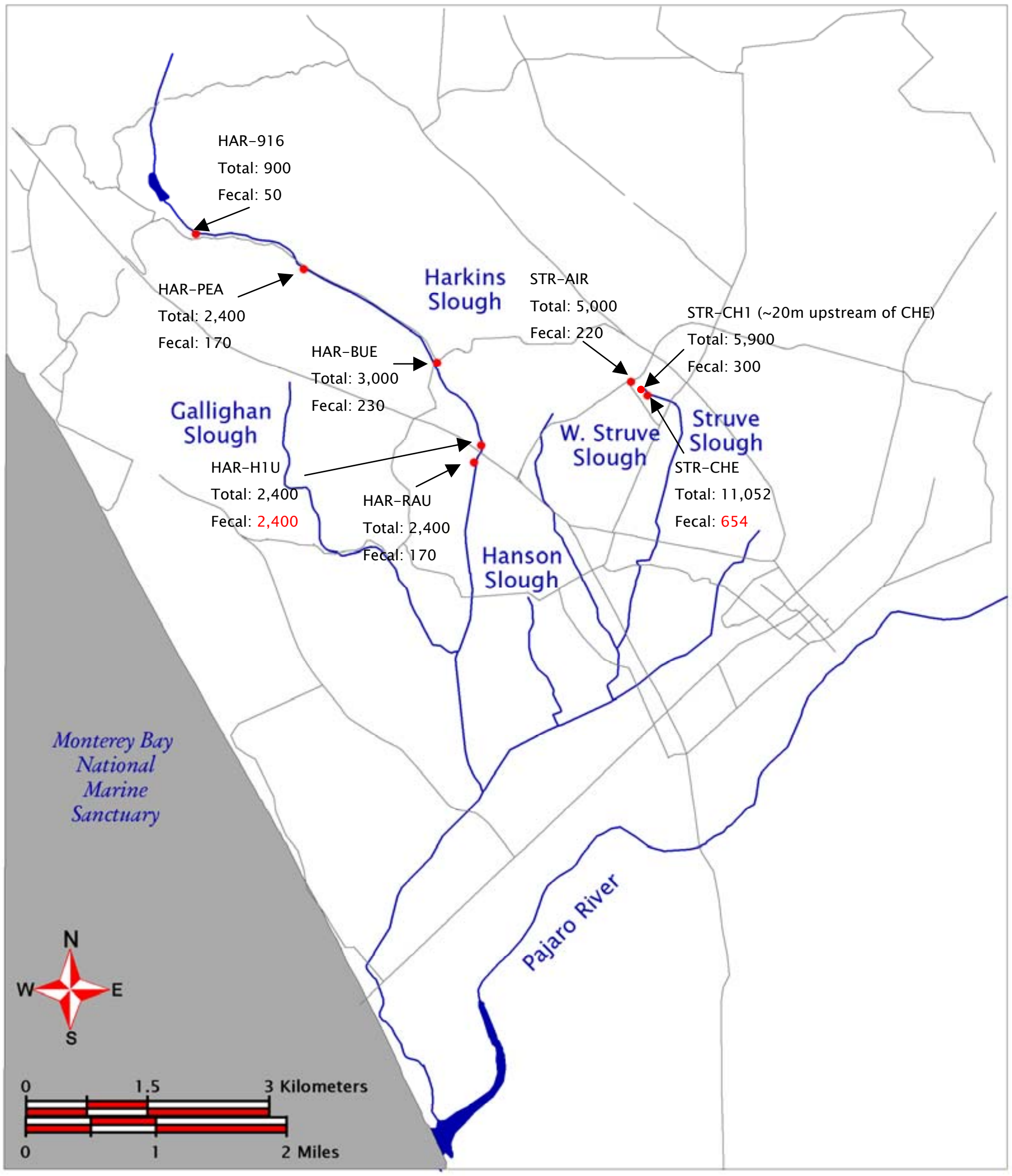



**Figure 7.12** Coliform source monitoring results from 17 April 03. Red text indicates the site with the highest value within that watershed.

Watsonville Slough Pathogen TMDL

Coliform (MPN/100 mL) Source Monitoring 06 May 03

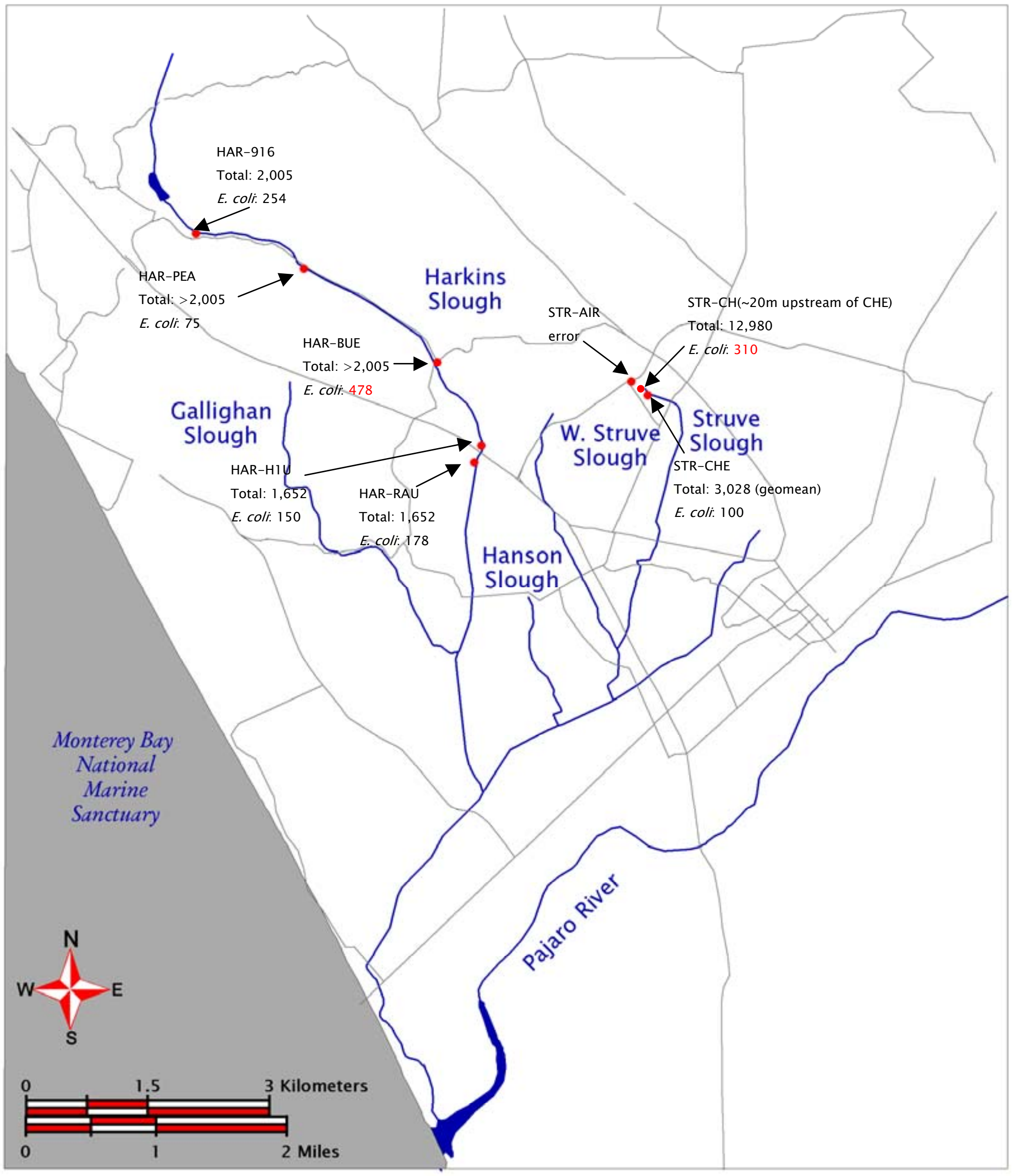



**Figure 7.13** Coliform source monitoring from 6 May 03. Red text indicates the site with the highest value within that watershed.

*Summer Monitoring Campaign*

The results of the summer monitoring campaign are presented in Table 7.7 and 7.8. Hanson Slough was dry during the summer monitoring period and was not included in the data tables. Eleven of the twelve primary monitoring sites were in exceedance of the fecal coliform objective for contact recreation with more than 10% of the samples exceeding 400 MPN/100 mL. The only primary monitoring site that was not in exceedance of the Basin Plan for fecal coliform was WAT-PAJ. Based on the calculated geometric mean, 8 of the 12 primary sites were in exceedance of the fecal coliform objective, having a geometric mean greater than 200 MPN/100 mL. Sites that were not in exceedance based on geometric mean only included: WAT-PAJ, WAT-HAR, HAR-CON, and HAR-RAU. Similar results were obtained for *E. coli* (Table 7.8). Although WAT-AND and GAL-BUE were in exceedance of the Basin Plan it should be noted that less than 5 samples were taken at these sites. At WAT-AND only 4 samples were taken do to a field error, and at GAL-BUE, only 3 samples were taken due to lack of sufficient water at the site. Gallighan Slough at GAL-BUE did not flow during the last 2 weeks of the summer monitoring campaign.

A map summarizing the fecal coliform data is presented in Figure 7.15. Hot spots, sites with a geometric mean greater than 1,000 MPN/100 mL are circled in red and include WAT-SHE, HAR-HAR, and STR-CHE. Sites STR-CHE and HAR-HAR were also identified as hot spots during the winter exceedance monitoring. STR-CHE had the highest geometric mean of all sites (5,144 MPN/100 mL) and both STR-CHE and WAT-SHE had 100% exceedance of the Basin Plan objective.

Just as for the winter results, there was temporal variation for a given site. For example, *E. coli* values at STR-CHE ranged from below the Basin Plan objective of 400 MPN/100 mL on one sampling date to 8,135 MPN/100 mL on another date. For a single sampling run, some sites showed increases from the previous run while others decreased (Fig. 7.14).

**Table 7.7** Watsonville Sloughs Summer Fecal Coliform Data

| Date | WAT-PAJ | WAT-SHE | WAT-AND | WAT-LEE | WAT-HAR | HAR-CON | HAR-HAR | HAR-RAU | GAL-BUE | STR-LEE | STR-HAR | STR-CHE | STR-PIP | STR-TRB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19-Jun-03 | <20 | 800 | 500 | 300 | 80 | 40 | 270 | 130 | 70 | 1,367 | 800 | 3,000 | x | x |
| 26-Jun-03 | 20 | 1,300 | 8,150 | 2,400 | 1,108 | 1,300 | 5,000 | 40 | 16,000 | 5,000 | 230 | 5,000 | >=16,000 | x |
| 01-Jul-03 | 110 | 3,000 | 675 | 500 | 50 | 2,400 | 3,000 | 900 | 80 | 340 | 300 | 16,000 | <20 | x |
| 08-Jul-03 | 22 | 750 | 170 | 230 | 50 | 40 | 5,000 | 8 | no flow | 130 | 500 | 3,000 | x | 300 |
| 16-Jul-03 | 77 | 1,300 | x | 800 | 300 | 20 | 9,000 | 170 | no flow | 170 | 220 | 5,000 | 300 | x |
| Max | 110 | 3,000 | 8,150 | 2,400 | 1,108 | 2,400 | 9,000 | 900 | 16,000 | 5,000 | 800 | 16,000 | 16,000 | 300 |
| Min | 20 | 750 | 170 | 230 | 50 | 20 | 270 | 8 | 70 | 130 | 220 | 3,000 | 20 | 300 |
| Geometric Mean | 38 | 1,249 | 827 | 581 | 146 | 158 | 2,832 | 91 | 447 | 552 | 360 | 5,144 | 458 | 300 |
| % Exceedance | 0 | 100 | 75 | 60 | 20 | 40 | 80 | 20 | 33 | 40 | 40 | 100 | 33 | 0 |
| x | No sample collected | | | | | | | | | | | | | |
| (shaded) | Shaded region show exceedance Basin Plan fecal coliform REC-1 objective: geometric mean >200 MPN/100 mL or more than 10% of samples exceeded 400 MPN/100 mL | | | | | | | | | | | | | |

**Table 7.8** Watsonville Sloughs Summer E. coli Data

| Date | WAT-PAJ | WAT-SHE | WAT-AND | WAT-LEE | WAT-HAR | HAR-CON | HAR-HAR | HAR-RAU | GAL-BUE | STR-LEE | STR-HAR | STR-CHE | STR-PIP | STR-TRB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19-Jun-03 | <20 | 500 | 500 | 170 | 20 | 20 | 120 | 130 | 70 | 260 | 800 | 3,000 | x | x |
| 26-Jun-03 | 20 | 1,300 | 400 | 170 | 153 | 20 | 800 | 40 | 700 | 3,000 | 230 | 300 | 9,000 | x |
| 01-Jul-03 | 110 | 2,400 | 675 | 500 | 50 | 2,400 | 2,400 | 900 | 14 | 340 | 130 | 8,135 | <20 | x |
| 08-Jul-03 | 22 | 750 | 170 | 230 | 50 | 40 | 1,700 | 4 | no flow | 130 | 500 | 1,300 | x | 300 |
| 16-Jul-03 | 77 | 1,300 | x | 800 | 300 | 20 | 2,200 | 170 | no flow | 170 | 170 | 5,000 | 70 | x |
| Max | 110 | 2,400 | 675 | 800 | 300 | 2,400 | 2,400 | 900 | 700 | 3,000 | 800 | 8,135 | 9,000 | 300 |
| Min | 20 | 500 | 170 | 170 | 20 | 20 | 120 | 4 | 14 | 130 | 130 | 300 | 20 | 300 |
| Geometric Mean | 38 | 1,087 | 389 | 305 | 74 | 60 | 971 | 80 | 88 | 358 | 289 | 2,165 | 233 | 300 |
| % Exceedance | 0 | 100 | 50 | 40 | 0 | 20 | 80 | 20 | 33 | 20 | 40 | 80 | 33 | 0 |
| x | No sample collected | | | | | | | | | | | | | |
| (shaded) | Shaded region show exceedance Basin Plan fecal coliform REC-1 objective: geometric mean >200 MPN/100 mL or more than 10% of samples exceeded 400 MPN/100 mL | | | | | | | | | | | | | |

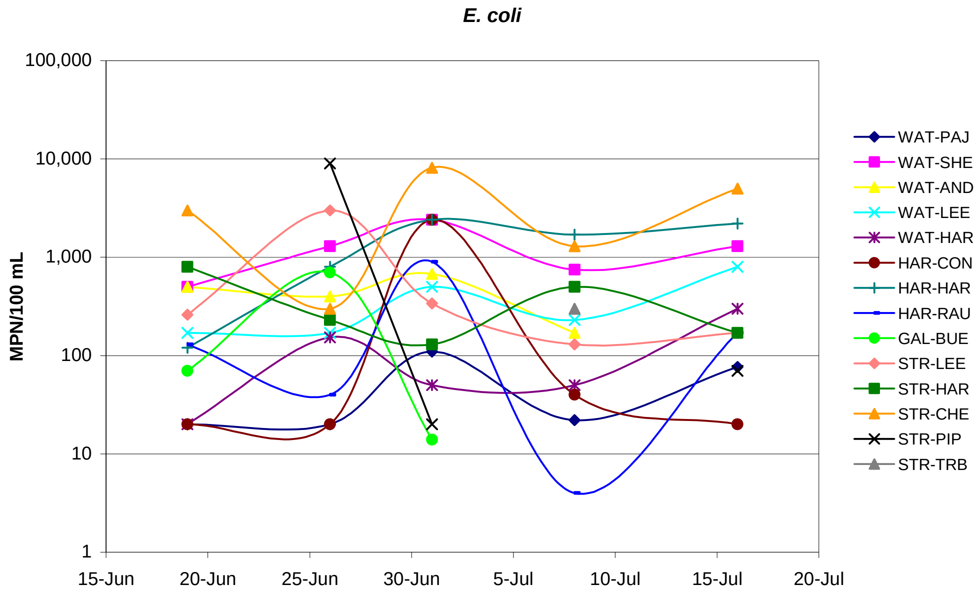



**Figure 7.14** Watsonville Sloughs Summer E. coli data.

Watsonville Slough Pathogen TMDL
Fecal Coliform Monitoring Results June & July 2003

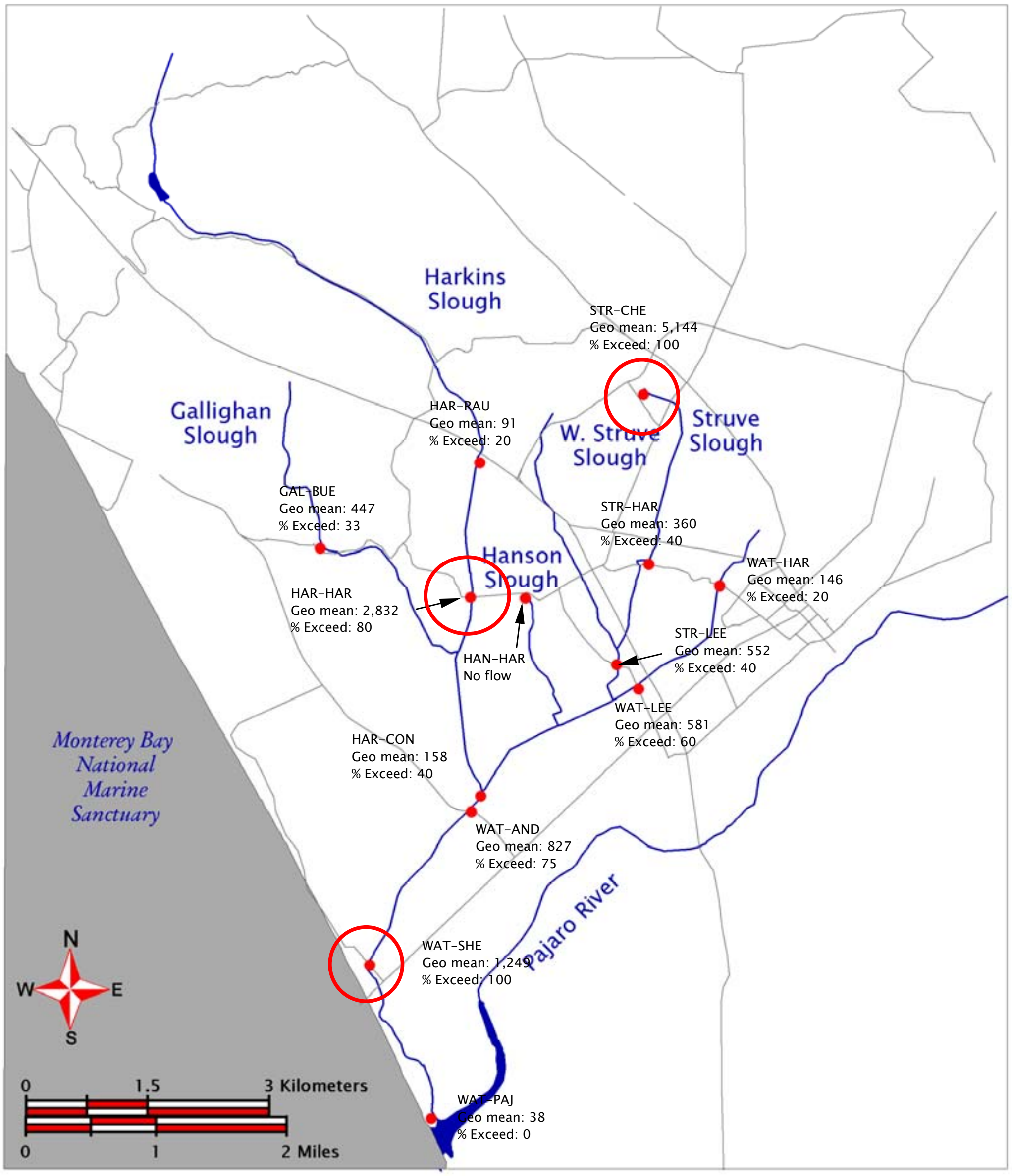



**Figure 7.15** Watsonville Sloughs fecal coliform data collected by CCoWS during summer monitoring campaign. Red circles indicate sites with a geometric mean > 1,000 MPN/100mL. Zero samples were collected at HAN-HAR and only 3 samples were collected at GAL-BUE due to lack of sufficient water at these sites. Only 4 samples were collected at WAT-AND due to a field error.

*Initial Source Tracking & Collaboration with the City of Watsonville*

Since E. coli levels at STR-CHE remained high during the summer monitoring, additional efforts were made, in collaboration with the City of Watsonville, to determine the extent and source of the problem in the Cherry Blossom Drive area. An adaptive, exploratory sampling approach was used. Due to the small drainage area above this site, with only residential and a small municipal airport as the primary land uses, it was hypothesized that human contamination was the source. The City of Watsonville manages the sewer lines of the neighboring houses of the Cherry Blossom/ Loma Prieta Avenue area and took on task of investigating the issue.

On August 14th and 15th, the main sewer lines in the Cherry Blossom Drive area were dye tested. Dye was added to the manhole of the main sewer line at two different locations, and the surrounding drainage area was then observed to see if the dye would surface. If there was a leak in the main sewer line, the dye would likely surface in the nearby area. After several hours of close observation by the City of Watsonville's Collection Systems Manager, there were no traces of dye in the surrounding drainage area.

Many of the neighboring houses were also dye tested to confirm connection to the main sewer line, rather than to an old septic system. The dye tests were performed on August 26th and September 3rd and verified that all of the tested houses were connected to the main sewer lines. Figure 7.16 shows the location of the tested houses.

Samples for fecal coliform and/or *E. coli* were also collected at 9 sites in the Cherry Blossom Drive area throughout August and early September. Not all sites were sampled on each visit. The objective of this sampling was to attempt to isolate the location of the source by detecting differences and increases between sites and by also determining which site consistently had the highest coliform levels. The City of Watsonville analyzed the majority of the samples for total coliform and *E. coli* using the Quanti-tray method with Colilert media.

The locations of the sampling sites are shown in Figure 7.16. STR-CH1, STR-CH2, and STR-CH3 are located upstream of STR-CHE. A lateral sewer line runs beneath Struve Slough between STR-CH2 and STR-CH3. STR-CH2 was only sampled once. For the remainder of the visits, STR-CH2 was either not sampled or was dry. STR-TRB is a small seep that flows into Struve Slough from the right bank immediately upstream of STR-CHE, and STR-PIP is a small pipe that drains into the Slough from the left bank just upstream of STR-CHE. STR-CH4 and STR-CH5 are located downstream of STR-CHE and were only sampled once. The results of this sampling are given in Tables 7.9 and 7.10. On August 5th, the *E. coli* levels at STR-CH3 (189 MPN/100 mL) were lower than levels at STR-CH2 (9,000 MPN/100 mL) indicating a possible source near STR-CH2. However, this pattern was not continuously observed in the subsequent sampling, in part due to lack of flow at STR-CH2 for the remainder of the sampling. With the exception of STR-AIR and STR-CH3, which had *E. coli* levels less than or equal to 300 MPN/100 mL, coliform levels at the other sites varied considerably during the sampling period. The following conclusions are made:

1) There may be a localized source of fecal coliform downstream of STR-CH3.
2) Since fecal coliform levels at individual sites vary from very low to very high there may either be:
    a) an intermittent source, or
    b) variability in the factors that govern the processes linking the source to the sampling site (e.g. hydrology and connectivity) and/or factors that govern the growth and death of coliform such as temperature, light, and nutrients (Gerba, 2000).
3) It is no simple matter to isolate sources even at such small watershed scales using conventional methods such as multiple tube fermentation.

Due to the variability of the data, the location of the source could not be determined from this sampling. Genetic analysis is therefore needed to identify the source. The City of Watsonville collected one sample from STR-CHE on September 10th for genetic analysis. The sample was analyzed by the Source Molecular Corporation using Human Fecal Virus ID. The method detects human fecal viruses by reverse transcriptase polymerase chain reaction (PCR) DNA analytical technology. The sample tested negative for human viruses. As noted in a laboratory report provided by Source Molecular Corporation, although the results were negative, there is still a possibility for fecal contamination. Additional genetic samples were taken from this site and the results are presented in Section 10.1.


**Figure 7.16** Struve Slough and sampling sites in the Cherry Blossom area (Photo: J. Hager May 03).

**Table 7.9** Cherry Blossom *E. coli* Data

| Date | Lab | Method | STR-AIR | STR-CH3 | STR-CH2 | STR-CH1 | STR-PIP | STR-TRB | STR-CHE | STR-CH4 | STR-CH5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 04-Aug-03 | Watsonville | Quanti-tray | | | | 24 | | 1,633 | | 1,095 | 1,540 |
| 05-Aug-03 | Monterey | MTF | 300 | 189 | 9,000 | 16,000 | 1,300 | 1,100 | ≥16,000 | | |
| 18-Aug-03 | Watsonville | Quanti-tray | 2 | | | <10 | | 30 | 1,434 | | |
| 26-Aug-03 | Watsonville | Quanti-tray | | 211 | | <10 | <10 | 1,039 | 4,352 | | |
| 04-Sep-03 | Watsonville | Quanti-tray | | 20 | | <10 | 85 | 1,725 | 1,451 | | |
| 09-Sep-03 | Monterey | MTF | | | | | <20 | 5,000 | 16,000 | | |
| 10-Sep-03 | Watsonville | Quanti-tray | | | | >24,192 | 10 | 17,328 | 15,732 | | |

**Table 7.10** Cherry Blossom Fecal Coliform Data

| Date | Lab | Method | STR-AIR | STR-CH3 | STR-CH2 | STR-CH1 | STR-PIP | STR-TRB | STR-CHE |
|---|---|---|---|---|---|---|---|---|---|
| 05-Aug-03 | Monterey | MTF | 1,700 | 189 | ≥16,000 | ≥16,000 | 1,300 | 1,100 | ≥16,000 |
| 18-Aug-03 | Monterey | MTF | | | | | | | 1,700 |
| 26-Aug-03 | Watsonville | MTF | | 140 | | 110 | 2,400 | 1,300 | 9,000 |
| 09-Sep-03 | Monterey | MTF | | | | | 2,400 | 5,000 | 16,000 |

# 8 Regional Fecal Coliform Levels

This section compares fecal coliform 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 are compared with (1998-2001) CCAMP data in Figure 8.2 and Table 8.1. A schematic describing the whisker plots is given in Figure 8.1. The sites in Figure 8.2 are organized according to approximate hydrologic and geographic provinces. Note that the CCAMP data were collected using a different sampling design, typically involving monthly sampling runs.

The Watsonville data are highly variable, but no more variable than sites throughout the region. The highest levels in the regional data set are from the intensely agricultural and urban areas between Castroville and the City of Salinas. The Watsonville data approach these levels, particularly at HAR-HAR and STR-CHE, but they do not exceed the regional maxima. The lowest levels in the regional data set are from the Salinas main stem and its largest tributaries in the Los Padres National Forest, such as Arroyo Seco and the Nacimiento River. Some of the Watsonville sites approach these low levels, such as the tidal WAT-PAJ site, and at STR-LEE. 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).

We conclude that the Watsonville system is typical of many watersheds with mixed urban and agricultural uses and sluggish waters near the coast, and less intense uses in their headwaters. Given the complexity of coliform-related impairments, research and management strategies should be coordinated at the regional level. The Watsonville system would be a good area for further investigation, given its diversity and representativeness of the region.

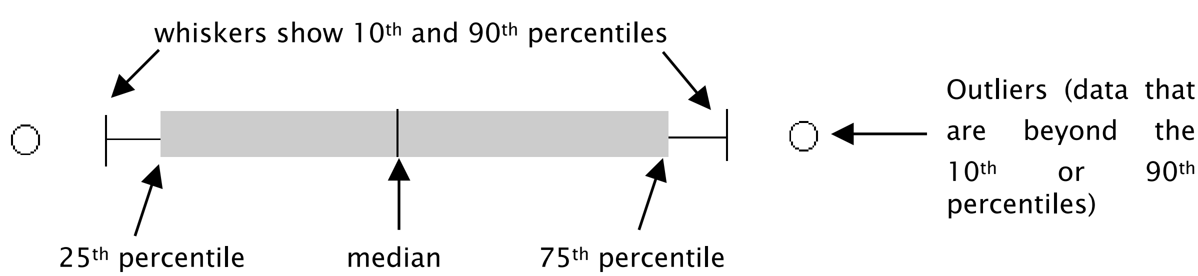



**Figure 8.1** Whisker plot schematic

Table 8.1 CCoWS/CCAMP Site Codes for Regional Comparison

| CCoWS Site ID | CCAMP Site ID | Waterway | Site Description |
|---|---|---|---|
| PAJ-MCG | 305THU | Pajaro River | McGowan Rd/Thurwachter Bridge |
| PAJ-MUR | 305MUR | Pajaro River | Murphy's Creek Rd |
| PAJ-CHI | 305CHI | Pajaro River | Chittenden Rd |
| PAJ-BET | 305PAJ | Pajaro River | Betabel rd |
| MIL-FRA | 305FRA | Miller Canal | Frazier Lake Rd |
| SAW-RIV | 305COR | Salsipuedes Creek | Riverside Rd |
| SBR-156 | 305SAN | San Benito River | Hwy 156 |
| TRE-SOU | 305TRE | Tres Pinos Creek | Southside Rd |
| CND-BLO | 305UVA | Carnadero Creek | Bloomfield Ave |
| LLA-BLO | 305LLA | Llagas Creek | Bloomfield Ave |
| LLA-LUC | 305LUC | Llagas Creek | Lucchessa Ave |
| LLA-HOL | 305HOL | Llagas Creek | Holsclaw Rd |
| LLA-MCR | 305MON | Llagas Creek | Monterey County Rd |
| LLA-OGA | 305OAK | Llagas Creek | Oak Glen Ave |
| LLA-CHE | 305CHE | Llagas Creek | Chesbro Reservoir |
| TES-FAI | 305TES | Tequisquita Slough | Fairview Rd |
| PAC-156 | 305PAC | Pacheco Creek | Hwy 156 |
| CAW-BOL | 306CAR | Carneros Creek | Blohm Rd |
| MCS-MOS | 306MOS | Moro Cojo Slough | Moss Landing Rd |
| OLS-POT | 309POT | Old Salinas River | Potrero Rd (Tide Gates) |
| OLS-MON | 309OLD | Old Salinas River | Monterey Dunes Colony Rd |
| TEM-MOL | 309TDW | Tembladero Slough | Molera Rd |
| TEM-PRE | 309TEM | Tembladero Slough | Preston Rd |
| REC-BOR | 309ALD | Reclamation Ditch | Boronda Rd |
| GAB-BOR | 309GAB | Gabilan Creek | Boronda Rd |
| ALI-AIR | 309ALU | Alisal Creek | Airport Rd |
| ALI-OSR | 309UAL | Alisal Creek | Old Stage Rd |
| SAL-MON | 309SBR | Salinas River | Del Monte Rd |
| SAL-DAV | 309DAV | Salinas River | Davis Rd |
| SAL-CHU | 309SAC | Salinas River | Chualar River Rd |
| SALL-GRE | 309GRN | Salinas River | Greenfield |
| SAL-KIN | 309KNG | Salinas River | King City |
| SAL-BRA | 309USA | Salinas River | Bradley Rd |
| SAL-CAT | 309DSA | Salinas River | along Cattleman Rd |
| SAL-CRE | 309PSO | Salinas River | Creston Rd |
| SAL-H41 | 309SAT | Salinas River | Hwy 41 |
| DRN-DAV | 309SDR | Storm Drain | 300m upstream from Davis Rd |
| QUA-POT | 309QUA | Quail Creek | Potter Rd |
| ARR-THO | 309SET | Arroyo Seco River | Thorne Rd |
| ARR-ELM | 309SEC | Arroyo Seco River | Elm Rd |
| SLC-BIT | 309LOR | San Lorenzo Creek | along Bitterwater Rd |
| ANT-101 | 309SAN | San Antonio River | Hwy 101 |
| NAC-101 | 309NAC | Nacimiento River | Hwy 101 |
| CHO-BIT | 317CHO | Cholame Creek | Bitterwater Rd |
| ATA-H41 | 309ATS | Atascadero Creek | Hwy 41 |

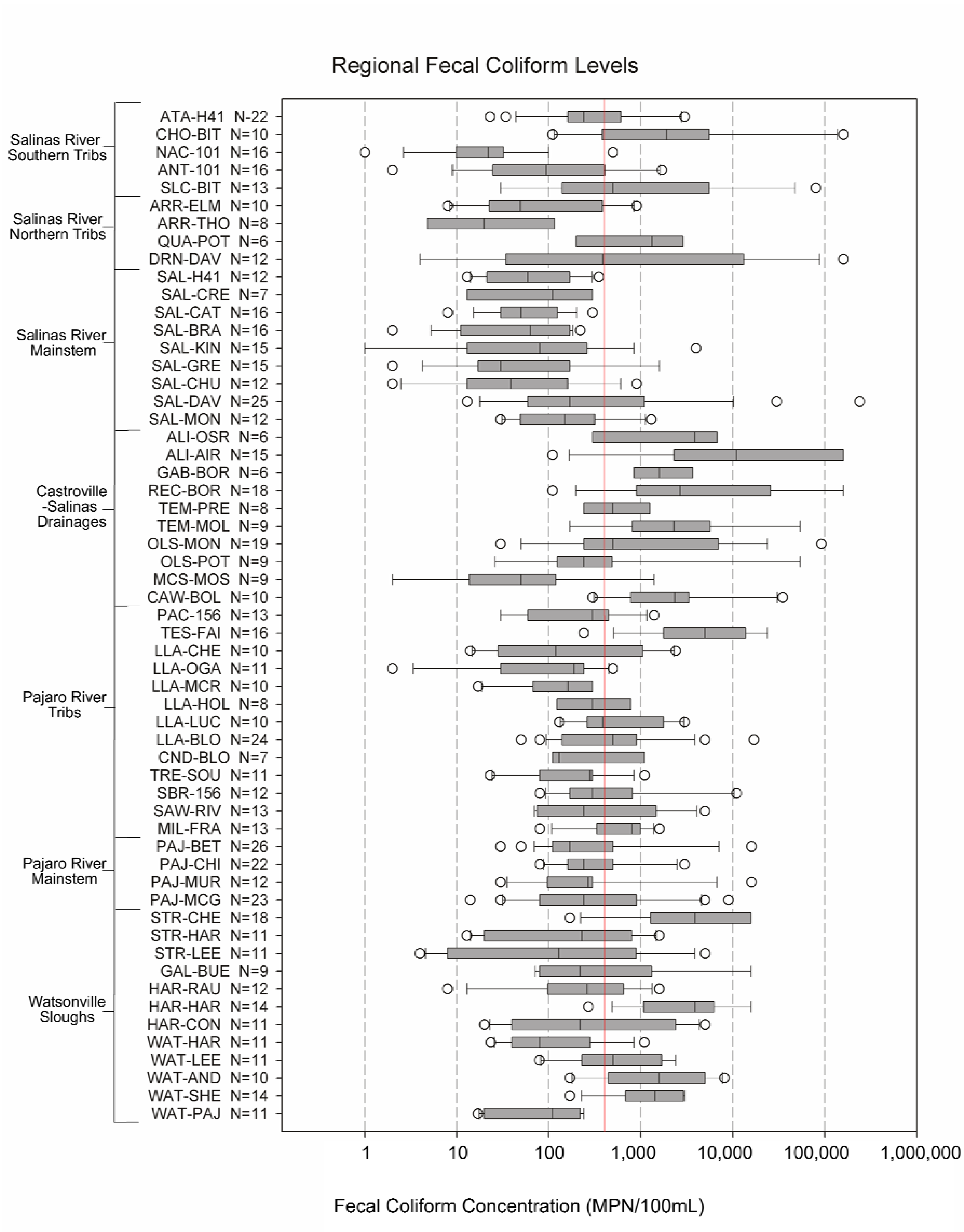



**Figure 8.2** Regional fecal coliform levels (CCAMP and CCoWS data). Red line at 400 MPN/100 mL (Basin Plan REC-1 objective for fecal coliform).

# 9 Problem Statement

The approach for determining the extent of a pathogen problem in Watsonville Sloughs was to sample for total coliform, fecal coliform, and *E. coli* at 13 sites throughout the watershed during both the dry and rainy season. The sampling plan for pathogens was driven by the following question: Are pathogens in exceedance of objectives outlined in the Basin Plan (CCRWQCB, 1994)?

The main beneficial use that was used as a guideline in the study was the REC-1 contact recreation use. The Basin Plan (CCRWQCB, 1994) outlines the water quality objectives pertaining to bacteria for contact recreation as follows:

> Bacteria (REC-1): Fecal coliform concentration, based on a minimum of not less than five samples for any 30-day period, shall not exceed a log mean of 200/100 mL, nor shall more than 10 percent of the total samples during any 30-day period exceed 400/100 mL.

Two monitoring campaigns, each consisting of five sampling runs within a 30-day period, were conducted to determine if the sloughs were in exceedance of the objective described above. The results of the winter and summer exceedance monitoring for coliform showed that with the exception of WAT-PAJ, all sites were in exceedance of the Basin Plan objective for fecal coliform during either the winter monitoring, summer monitoring, or for both. In most cases, fecal coliform exceedance could be explained by *E. coli* levels alone (high *E. coli* levels are generally considered to be a stronger indication of a pathogen problem than high fecal coliform levels).

Although some sites were consistently higher than others, there was considerable variation in the data. For a given site, there was often a wide range in the level of fecal coliform detected. The ranges of the data in winter and summer were similar. The geometric means for *E. coli* during the winter ranged from 9 to 2,784 MPN/100 mL and for summer ranged from 38 to 2,165 MPN/100 mL. The analytical methods used in this study for fecal coliform and *E. coli* are accepted tests for the *indication* of a pathogen presence. Therefore, we conclude:

*Based on fecal coliform and E. coli levels detected during this study, there is a potential pathogen problem throughout most of the Watsonville Sloughs system. A more conclusive statement would require specific genetic testing for known pathogens, or evidence linking community health problems to the Sloughs waters.*

# 10 Preliminary Source Identification

## 10.1 Results of Toxin Biomarker Genetic Analysis

Sites WAT-SHE, HAR-HAR, and STR-CHE (Fig. 10.1) were selected as the primary sampling sites for the genetic source tracking portion of this study based on land use representation and high fecal coliform levels detected during the exceedance monitoring. These 3 sites had the highest geometric means for both fecal coliform and *E. coli* during the first phase of the study.

The first genetic samples were collected on 9 Sep 03 following the dry season exceedance monitoring and the second set of genetic samples were collected on 9 Dec 03. Ideally, the rainy season genetic samples would have been collected immediately following the Feb-Mar 03 exceedance monitoring, however due to contract scheduling constraints, the genetic sampling was delayed until the 2003-2004 rainy season. All sites were sampled for total coliform, fecal coliform, and *E. coli* following November 2003 storms and prior to the genetic sampling in order to confirm that the hot spots identified in the Feb-Mar 03 campaign were consistent in the 2003-2004 rainy season. A total of 16 samples were analyzed by the laboratory group led by Dr. Betty Olson at UC Irvine using the Toxin Gene Biomarker method.

Each sample was serially diluted (3-5 dilutions with 3-5 replicates for each dilution), filtered using a 0.45 μm nitrocellulose membrane, and then placed in mTEC agar plates. DNA for all *E.coli* colonies that developed on a given plate was then extracted. DNA was analyzed using nested PCR, visualized with gel electrophoresis, and then confirmed by various restriction enzymes and Southern Blot hybridization. The occurrence (MPN/100 mL) of each toxin gene biomarker (rabbit-ralG, human-STh, dog-*pap*G allele III, bird-*tsh*, and cow-LTIIa) within each sample was then determined based on positive/negative results for the multiple dilutions and replicates using a MPN calculator.

The results of the analysis are presented in Table 10.1 and Figure 10.2. Although the Basin Plan objective ("…nor shall more than 10% of all samples exceed 400 MPN per 100 mL") refers to percent exceedance and is for fecal coliform, and not specifically for *E. coli* (a member of the fecal coliform group), the objective value serves as an ideal baseline for comparison and is used throughout the following analysis. In many samples, *E. coli* levels alone led to exceedance of 400 MPN/100 mL. *E. coli* from bird sources lead to exceedance of 400 MPN/100 mL in all 16 samples. During the rainy season, *E. coli* dog and cow sources individually lead to exceedance of 400 MPN/100 mL in all 9 samples. *E. coli* from human sources only led to exceedance of 400 MPN/100 mL for fecal coliform during the rainy season at STR-CHE (2 of 3 replicate samples), although the average of the 3 replicates was below 400 MPN/100 mL. *E. coli* from rabbit sources never lead to exceedance of 400 MPN/100 mL.

Figure 10.3 shows percent composition of the 5 biomarkers in samples from each of the 3 sites during both the dry and rainy seasons. The most prevalent of the 5 sources tested were dog, bird, and cow. It is important to note that sources other than the 5 that were tested (rabbit, human, dog, bird, and cow) may have been present in samples and would not have been detected using the Toxin Biomarker method. Other potential sources that may be present in Watsonville Sloughs include: cat, horse, sheep, goat, pig, rodents, and other small mammals such as fox, raccoon, skunk, and opossum. As research on the method continues more toxin biomarkers will likely be developed and future studies may involve analysis to detect prevalence of these other potential sources.

The following sections detail the results from each site:

*Watsonville Slough at Shell Road*

WAT-SHE (Fig. 10.1) was the most ideal location for the genetic analysis, as the site has a large watershed area with multiple land uses/sources that are representative of the entire Watsonville Sloughs system (rural residential, urban, industrial, natural/recreation lands, grazing, and row crop agriculture). WAT-SHE is located at the bottom of the Watsonville Sloughs watershed and theoretically receives all inputs from upstream tributaries and all land uses under normal flow conditions.

At WAT-SHE the most prevalent detectable source of *E. coli* during the dry season was birds with an average of 1,743 MPN/100mL for 3 replicate samples. The next most abundant detectable source of *E. coli* was dogs with an average of 109 MPN/100mL for 3 replicate samples. *E. coli* attributed to human and cow sources had occurrences less than 5 MPN/100mL for the dry season. *E. coli* from rabbit sources was not detected in the dry season samples. 94% of the 5 sources tested were attributed to bird sources and 6% to dog sources (Fig. 10.3).

During the rainy season, the most prevalent detectable source of *E. coli* was cows (i.e. cattle) with an average of occurrence of 5,267 MPN/100mL. *E. coli* sources from dogs and birds were also considerably high with an average occurrence of 2,833 MPN/100ml for dog and 1,967 MPN/100mL for bird. *E. coli* attributed to human and rabbit sources were less than 10 MPN/100mL for the rainy season. 52% of the 5 sources tested were attributed to cows, 28% to dog, and 20% to bird (Fig. 10.3).

*Harkins Slough at Harkins Slough Road*

HAR-HAR (Fig. 10.1) was also selected as an ideal site for genetic analysis because a large portion of the Harkins Slough watershed drains to this site. Harkins Slough comprises almost half of the total area for the Watsonville Sloughs system, and this site is representative of rural residential, grazing, and row crop land uses.

At HAR-HAR the most prevalent detectable source of *E. coli* during the dry season was also birds with an average of 1,420 MPN/100mL for 3 replicate samples. As was the case for WAT-SHE, next most abundant detectable source of *E. coli* was dogs with an average of 1,253 MPN/100mL for 3 replicate samples. *E. coli* attributed to human and cow sources had occurrences less than 25 MPN/100mL for the dry season. *E. coli* from rabbit sources was not detected in the dry season samples. 52% of the 5 sources tested were attributed to birds sources, 47% to dog sources, 1% to human sources, and less than 1% to cow sources (Fig. 10.3).

During the rainy season, the most prevalent detectable source of *E. coli* was cows with an average of occurrence of 8,867 MPN/100mL. *E. coli* sources from birds and dog were also considerably high with an average occurrence of 2,267 MPN/100ml for bird and 1,100 MPN/100mL for dog. *E. coli* attributed to human increased to an average 253 MPN/100 mL for 3 replicate samples, and rabbit sources increased to an average 34 MPN/100mL for the rainy season. 71% of the 5 sources tested were attributed to cows, 18% to bird, 9% to dog, and 2% to human (Fig. 10.3).

*Struve Slough near Cherry Blossom Drive*

STR-CHE (Fig. 10.1) was selected as a site for genetic analysis because it consistently had the highest fecal coliform levels of all of 13 sampling sites. Although the watershed area above this site is small, the major land uses are purely residential and urban, including a portion of the Watsonville Municipal Airport.

At STR-CHE the most prevalent detectable source of *E. coli* during the dry season was also birds with an occurrence of 2,400 MPN/100mL in a single sample. Replicates were not taken during the dry season visit to this site. The next most abundant detectable source of *E. coli* was dogs with 43 MPN/100mL. *E. coli* attributed to human and cow sources was less than 10 MPN/100mL for the dry season. *E. coli* from rabbit sources was not detected in the dry season samples. 98% of the 5 sources tested were attributed to bird sources, 2% to dog sources, less than 1% to human and cow sources (Fig. 10.3).

During the rainy season, the most prevalent detectable sources of *E. coli* were cows and bird both with an average of occurrence of 3,867 MPN/100mL. *E. coli* sources from dogs were also considerably high with an average occurrence of 2,100 MPN/100ml. *E. coli* attributed to humans increased considerably from the dry season to an average 318 MPN/100 mL for 3 replicate samples. Rabbit sources were less than 1 MPN/100mL for the rainy season. 38% of the 5 sources tested were attributed to cows, 38% to bird, 21% to dog, and 3% to human (Fig. 10.3).

Watsonville Sloughs Pathogen TMDL Genetic Sampling Sites

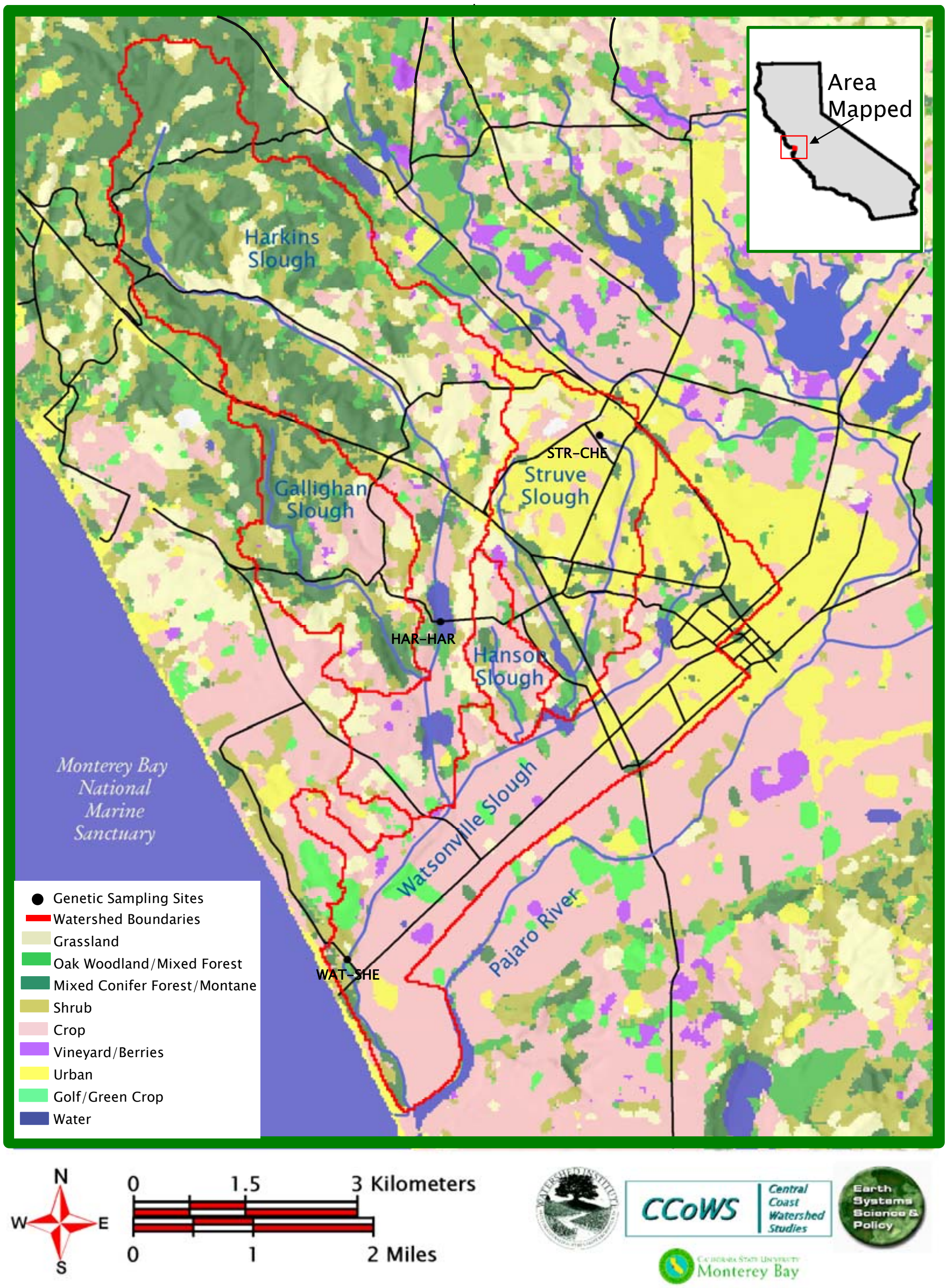



**Figure 10.1** Map showing watershed boundaries and genetic sampling sites.

**Table 10.1** Summary of Biomarker PCR Analysis (*E. Coli* MPN/100mL)

| PCR Summary | Rabbits | | Humans | | Dogs | | Birds | | Cows | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Summer | Winter | Summer | Winter | Summer | Winter | Summer | Winter | Summer | Winter |
| STR A | 0 | 0.36 | 9.3 | 93 | 43 | 1,500 | 2,400 | 4,600 | 0.36 | 4,600 |
| STR B | | 0.3 | | 430 | | 2,400 | | 4,600 | | 4,600 |
| STR C | | 0.74 | | 430 | | 2,400 | | 2,400 | | 2,400 |
| **Avg** | **0** | **0** | **9** | **318** | **43** | **2,100** | **2,400** | **3,867** | **0** | **3,867** |
| WAT A | 0 | 9.2 | 1.5 | 7.4 | 43 | 2,400 | 2,400 | 2,400 | 0.92 | 2,400 |
| WAT B | 0 | 7.4 | 0.74 | 7.4 | 43 | 1,500 | 2,400 | 1,100 | 0.36 | 11,000 |
| WAT C | 0 | 3.6 | 3 | 15 | 240 | 4,600 | 430 | 2,400 | 3.6 | 2,400 |
| **Avg** | **0** | **7** | **2** | **10** | **109** | **2,833** | **1,743** | **1,967** | **2** | **5,267** |
| HAR A | 0 | 74 | 23 | 200 | 430 | 1,100 | 930 | 1,100 | 3 | 11,000 |
| HAR B | 0 | 23 | 15 | 280 | 930 | 1,100 | 930 | 4,600 | 9.2 | 11,000 |
| HAR C | 0 | 3.6 | 3 | 280 | 2,400 | 1,100 | 2,400 | 1,100 | 3.6 | 4,600 |
| **Avg** | **0** | **34** | **14** | **253** | **1,253** | **1,100** | **1,420** | **2,267** | **5** | **8,867** |

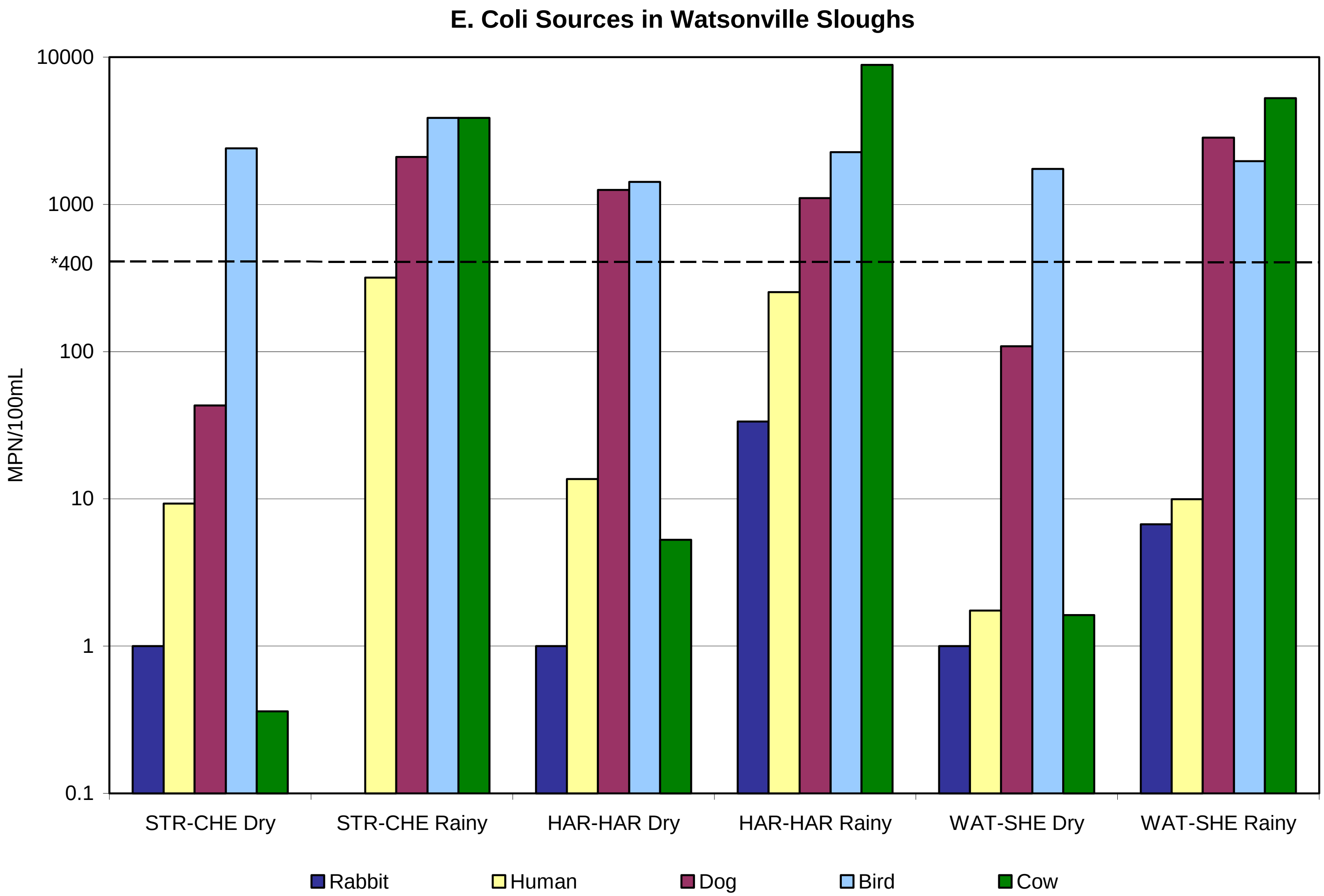



**Figure 10.2** Results of Biomarker PCR analysis showing sources of *E. coli* at 3 sites in Watsonville Sloughs. Dotted line represents 400 MPN/100 mL comparison value.

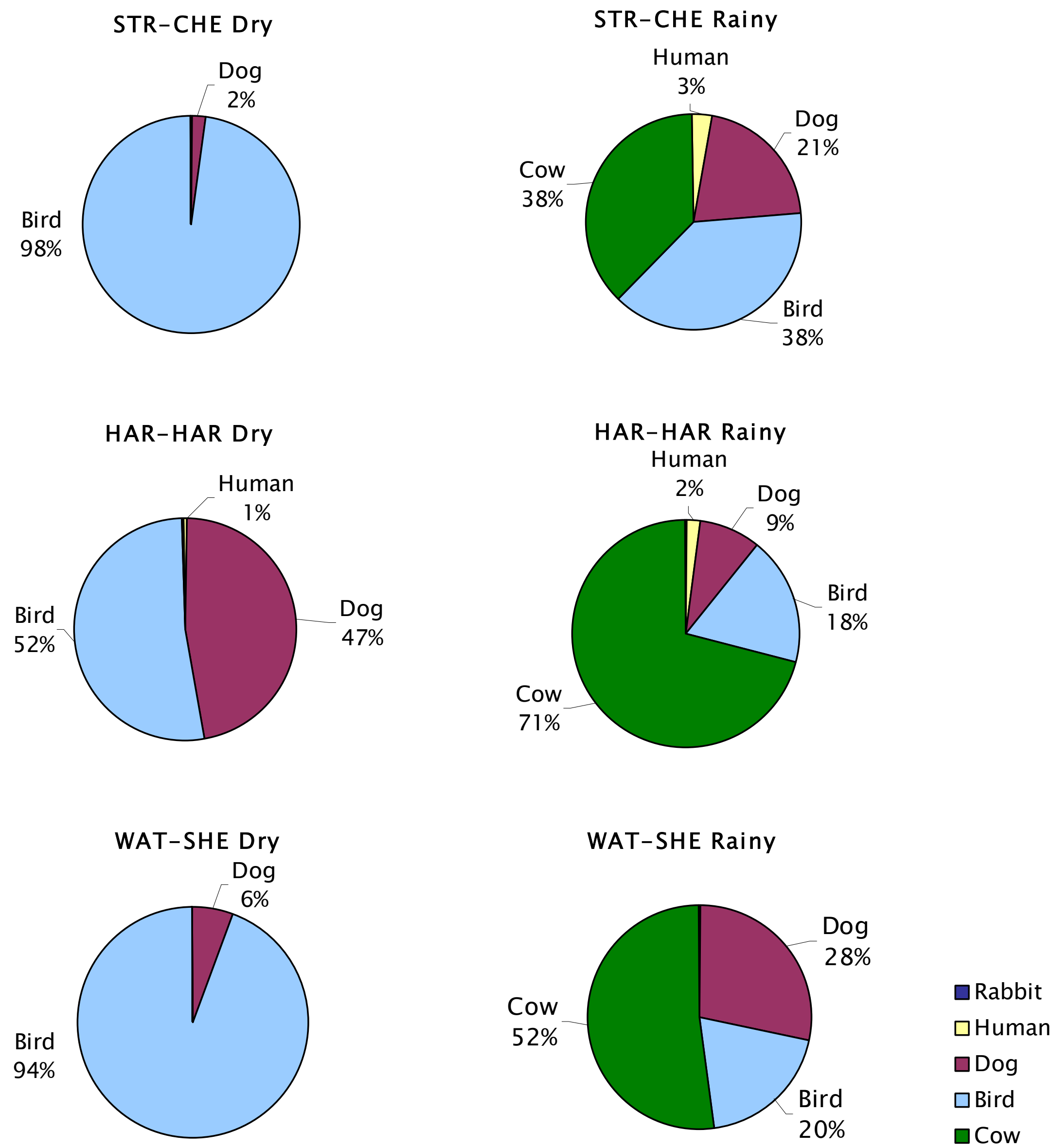



**Figure 10.3** Percent composition of 5 *E. coli* biomarkers in water samples from 3 sites in Watsonville Sloughs. Note other *E. coli* sources may have been present in sample. The charts above only show percent composition for the 5 biomarkers that were screened.

# 11 Critical Conditions and Seasonal Variation

## 11.1 Critical conditions

Moe (2002) lists five critical conditions for transmission of infectious agents through water:

1. Source (e.g. human waste)
2. Transmission through water (e.g. streamflow)
3. Survival and possibly growth of the infectious agent
4. Infectious dose (i.e. virulence)
5. Host susceptibility

In the present study, transmission is assured by streamflow and the fact that contact recreation is a defined beneficial use of Watsonville Slough. We exclude issues of dose and susceptibility from our discussion. Thus, the conditions that are necessary for pathogen impairment as indicated for Watsonville Sloughs *may* include one or more of:

- Significant sources of human fecal matter
  - Despite lower indicator levels than for other biomarkers, human fecal matter is the most commonly cited source of waterborne infection (Moe, 2002)
- Significant sources of cow fecal matter
  - High indicator levels were measured, and cow fecal matter is known to contain the pathogenic *E. coli* strain O157:H7 (Rosen, 2000)
- Significant sources of dog fecal matter
  - Less likely, given lower indicator levels, and infrequently cited infection risk (Rosen, 2000)
- Significant sources of bird fecal matter
  - Unlikely. Although there were high indicator levels, bird fecal is less commonly cited as a source of infection (Rusin et al., 2000)
- Growth-promoting waterbody conditions (see Gerba, 2000)
  - Sluggish, relatively deep water
  - High nutrient levels
  - High turbidity / suspended sediments (low light)
  - Warm temperatures
  - Few predators (invertebrates etc)

## 11.2 Seasonal variation

The exceedance data and the genetic data differ with respect to indications of seasonal variation. Based on the exceedance monitoring data, there is no clear pattern of seasonal variation. Between summer and winter sampling periods, several sites increased and several decreased in fecal coliform levels - and these differences did not follow any clear spatial pattern. Looking at the *E. coli* data, there is a slight suggestion that levels were lower in winter at urban sites, and higher at other sites. However, two sites contradict this apparent trend (WAT-SHE and STR-CHE).

The genetic data follow a clearer temporal pattern. Mean biomarker MPNs increased from summer to winter in almost all cases. Based on these data, a preliminary conclusion may be reached that impairment is more likely during winter. The highest indications of human and cow fecal matter were obtained from the winter genetic samples. The processes leading to these observations may include entrainment of transient human waste, cattle waste, and inadequately composted manure within surface runoff; as well as entrainment of sewer or septic system leakage in surface and shallow sub-surface runoff.

The broader conclusion, however, is that coliform data exhibit so much spatial, temporal, and genetic variability that further study is required. This is despite the endeavors of the present study, which involved 21 sampling sites; 163 exceedance samples and 32 exploratory samples analyzed for fecal coliform and *E. coli* MPNs; and 18 genetic samples analyzed for five biomarkers each.

We recommend further study targeting:

- detailed microbial ecology and physical water conditions,
- specific pathogen groups (e.g. particular strains of *E. coli* or *Streptococcus*),
- specific waterways (e.g. Harkins Slough),
- short time scales (e.g. twice daily for a week).

# 12 Literature Cited


American Public Health Association, American Water Works Association, Water Environment Federation, 1998. Standard methods for the examination of water and wastewater (20th edition). Washington, DC: American Public Health Association.

Applied Science and Engineering Inc., 1999. Pajaro River Watershed water quality management plan, final. Prepared for the Association of Monterey Bay Area Governments.

Auer, M.T., and S.L. Niehaus, 1993. Modeling fecal coliform bacteria-I. Field and laboratory determination of loss kinetics. Wat. Res. 27(4): 693-701.

Barcina, I., J.M. Gonzalez, J. Iriberri, and L. Egea, 1989. Effect of visible light on progressive dormancy of Escherichia coli cells during the survival process in natural fresh water. Applied and Environmental Microbiology 55(1): 246-251

Bowie, G.L., W.B. Mills, D.B. Porcella, C.L. Campbell, J.R. Pagenkopf, G.L. Rupp, K.M. Johnson, P.W.H. Chan, S.A. Gherini, Tetra Tech, and C.E. Chamberlain, 1985. Rates, constants, and kinetics formulations in surface water quality monitoring (2nd edition). Environmental Research Laboratory, USEPA.

Busch, J., 2002. Watching the Watsonville wetlands: an armchair guide to the Watsonville Slough system. Freedom, CA: Watsonville Wetland Watch, 80 pp.

California Irrigation Management Information System, 2003. http://www.cimis.water.ca.gov

California Regional Water Quality Control Board Central Coast Region, 1994. Basin plan. State Water Resources Control Board.

Central Coast Ambient Monitoring Program, 2003. http://www.ccamp.org/

Central Monterey Bay wetlands Project, 2001. Watsonville Sloughs Watershed water quality data report June 2000 – June 2001. Prepared by Coastal Watershed Council.

Evison, L.M., 1988. Comparative studies on the survival of indicator organisms and pathogens in fresh and sea water. Wat. Sci. Tech. 20(11/12):309-315.

Gerba C., 2000. Environmentally transmitted pathogens. In Maier, R.M., I.L. Pepper, C.P. Gerba, Environmental Microbiology 491-503. San Diego, CA: Academic Press.

Gonzalez, J.M., J. Iriberri, L. Egea, and I. Barcina, 1992. Characterization of culturability, protistan grazing, and death of enteric bacteria in aquatic ecosystems. Applied and Environmental Microbiology 58:998-1004.

Hager, J. and F.G.R. Watson, 2003. Watsonville Sloughs pathogen and sediment TMDL: quality assurance project plan and field sampling plan. Watershed Institute Publication No. WI-2002-13. Prepared for the Central Coast Regional Water Quality Control Board. Available online: http://science.csumb.edu/~ccows/2002/watsonville/CCoWS_WatsonvilleQAPP_030604.pdf

Hanes, N.B., G.A. Rohlich, and W.B. Sarles, 1966. Effect of temperature on the survival of indicator bacteria in water. J. N. Engl. Wat. Wks Ass. 80:6-18.

Hunt, J.W., B.S. Anderson, B.M. Phillips, R.S. Tjeerdema, H.M. Puckett, and V. deVlaming, 1999. Patterns of aquatic toxicity in an agriculturally dominated coastal watershed in California. Agriculture, Ecosystems, and Environment 75: 75-91.

Hurst, C.J., R.L. Crawford, G.R. Knudsen, M.J. McInerney, and L.D. Stetzenbach, 2002. Manual of environmental microbiology (2nd edition). Washington, DC: ASM Press.

Kittrell F.W. and S.A. Furfari, 1963. Observations on coliform bacteria in streams. J. Wat. Pollut. Control Fed. 35:1361-1385.

Lantrip B.M., 1983. The decay of enteric bacteria in an estuary. John Hopkins University; PhD Dissertation; Baltimore, MD.

LeChavallier, M.W., C.D. Cawthon, and R.G. Lee, 1988. Factors promoting survival of bacteria in chlorinated water supplies. Applied and Environmental Microbiology 54(3): 649-654.

Leclerc, H., D.A.A. Mossel, S.C. Edberg, and C.B. Struijk, 2001. Advances in the bacteriology of the coliform group: their suitability as markers of microbial water safety. Annu. Rev. Mircobiol. 55:201-234.

Los Huertos, M., L.E. Gentry, and C. Shennan, 2001. Land use and stream nitrogen concentrations in agricultural watershed along the central coast of California. The Scientific World 1:8 pp.

McFeters, G.A., and D.G. Stuart, 1972. Survival of coliform bacteria in natural waters: field and laboratory studies with membrane-filter chambers. Applied Microbiology 24(5): 805-811.

Moe, C.L., 2002. Water transmission of infectious agents. In Hurst, C.J., R.L. Crawford, G.R. Knudsen, M.J. McInerney, and L.D. Stetzenbach, Manual of Environmental Microbiology (2nd edition) 184-204. Washington, DC: ASM Press.

National Climatic Data Center, 2003. http://www.ncdc.noaa.gov/oa/ncdc.html

Newman, W. B., F.G.R. Watson, J. Casagrande, and B. Feikert, 2003. Land use history and mapping in California's central coast region. Watershed Institute Publication No. WI-2003-03. Prepared for the Central Coast Regional Water Quality Control Board, 86 pp. Available online: http://science.csumb.edu/~ccows/2003/region3_lulc/LandUseMappingRegion3_030219.pdf

Oliver, J., 1997. Comprehensive watershed management solutions to nonpoint source pollution in the Salinas Valley and Pajaro River Basin. Watershed Institute report. Prepared for the Central Coast Regional Water Quality Control Board, 56 pp.

Pajaro Valley Water Management Agency, 2002. Harkins Slough diversion project NPDES permit no. 96-4 annual monitoring report, draft.

Questa Engineering Corporation, 1995. Water resources management plan for Watsonville Slough System Santa Cruz County. Prepared for the Association of Monterey Bay Area Governments.

Rosen, B.H., 2000. Waterborne pathogens in agricultural watersheds. USDA Watershed Science Institute publication, 62 pp.

Rusin, P., C.E. Enriquez, D. Johnson, C.P. Gerba, 2000. Environmentally transmitted pathogens. In Maier, R.M., I.L. Pepper, C.P. Gerba, Environmental Microbiology 447-490. San Diego, CA: Academic Press.

State Water Resources Control Board, 2004. State Mussel Watch Program and Toxic Substance Monitoring Program. http://www.swrcb.ca.gov/programs/smw/

Swanson Hydrology and Geomorphology, 2003. Watsonville Sloughs Watershed conservation and enhancement plan. Prepared for the Santa Cruz County Planning Department.

Watson, F.G.R. and J.M. Rahman, 2003. Tarsier: a practical software framework for model development, testing and deployment. Environmental Modelling and Software, 19:245-260.

Western Regional Climate Center, 2003. http://www.wrcc.dri.edu/index.html

Wilkinson, J., A. Jenkins, M. Wyer, and K. Kay, 1995. Modelling faecal coliform dynamics in streams and rivers. Wat. Res. 29(3): 847-855.

## Appendix A- Fecal Coliform Data From Previous Studies

| SC County Env. Health Site Code | DATE | LOCATION | Fecal Coliform (CFU/100 mL) |
|---|---|---|---|
| O010 | 20 Mar 90 | PAJARO DUNES BEACH | |
| O010 | 29 Sep 92 | PAJARO DUNES BEACH | 0.1 |
| O010 | 01 Dec 92 | PAJARO DUNES BEACH | 0.1 |
| O010 | 15 Dec 92 | PAJARO DUNES BEACH | 140 |
| O010 | 23 Nov 93 | PAJARO DUNES BEACH | 1 |
| O010 | 31 Jan 94 | PAJARO DUNES BEACH | 0.1 |
| O010 | 28 Feb 94 | PAJARO DUNES BEACH | 0.1 |
| O010 | 29 Mar 94 | PAJARO DUNES BEACH | 8 |
| O010 | 24 May 94 | PAJARO DUNES BEACH | 0.1 |
| O010 | 16 Aug 94 | PAJARO DUNES BEACH | 0.1 |
| O010 | 13 Sep 94 | PAJARO DUNES BEACH | 0.1 |
| O010 | 14 Oct 94 | PAJARO DUNES BEACH | 12 |
| O010 | 17 Nov 94 | PAJARO DUNES BEACH | 20 |
| O010 | 13 Dec 94 | PAJARO DUNES BEACH | 4 |
| O010 | 11 Jan 95 | PAJARO DUNES BEACH | 804 |
| O010 | 06 Feb 95 | PAJARO DUNES BEACH | 3.9 |
| O010 | 14 Mar 95 | PAJARO DUNES BEACH | 2990 |
| O010 | 21 Mar 95 | PAJARO DUNES BEACH | 520 |
| O010 | 28 Mar 95 | PAJARO DUNES BEACH | 100 |
| O010 | 30 Mar 95 | PAJARO DUNES BEACH | 40 |
| O010 | 04 Apr 95 | PAJARO DUNES BEACH | 64 |
| O010 | 02 May 95 | PAJARO DUNES BEACH | 96 |
| O010 | 06 Jun 95 | PAJARO DUNES BEACH | 3.9 |
| O010 | 06 Jul 95 | PAJARO DUNES BEACH | 3.9 |
| O010 | 01 Aug 95 | PAJARO DUNES BEACH | 3.9 |
| O010 | 31 Aug 95 | PAJARO DUNES BEACH | 8 |
| O010 | 26 Sep 95 | PAJARO DUNES BEACH | 0.9 |
| O010 | 24 Oct 95 | PAJARO DUNES BEACH | 12 |
| O010 | 18 Dec 95 | PAJARO DUNES BEACH | 1470 |
| O010 | 21 Dec 95 | PAJARO DUNES BEACH | 80 |
| O010 | 18 Jan 96 | PAJARO DUNES BEACH | 530 |
| O010 | 10 Jun 96 | PAJARO DUNES BEACH | 4 |
| O010 | 09 Jul 96 | PAJARO DUNES BEACH | 3 |

| SC County Env. Health Site Code | DATE | LOCATION | Fecal Coliform (CFU/100 mL) |
|---|---|---|---|
| O010 | 06 Aug 96 | PAJARO DUNES BEACH | 3 |
| O010 | 07 Jan 97 | PAJARO DUNES BEACH | 60 |
| O010 | 18 Feb 97 | PAJARO DUNES BEACH | 28 |
| O010 | 11 Mar 97 | PAJARO DUNES BEACH | 0.9 |
| O010 | 22 Apr 97 | PAJARO DUNES BEACH | 0.9 |
| O010 | 04 Jun 97 | PAJARO DUNES BEACH | 0.9 |
| O010 | 17 Jun 97 | PAJARO DUNES BEACH | 0.9 |
| O010 | 23 Jul 97 | PAJARO DUNES BEACH | 4 |
| O010 | 15 Sep 97 | PAJARO DUNES BEACH | 8 |
| O010 | 28 Oct 97 | PAJARO DUNES BEACH | 4 |
| O010 | 11 Dec 97 | PAJARO DUNES BEACH | 108 |
| O010 | 05 Jan 98 | PAJARO DUNES BEACH | 0.9 |
| O010 | 17 Apr 98 | PAJARO DUNES BEACH | 2000 |
| O010 | 30 Jun 98 | PAJARO DUNES BEACH | 0.9 |
| O010 | 25 Aug 98 | PAJARO DUNES BEACH | 0.9 |
| O010 | 22 Sep 98 | PAJARO DUNES BEACH | 4 |
| O010 | 26 Apr 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 05 May 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 11 May 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 18 May 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 25 May 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 01 Jun 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 08 Jun 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 14 Jun 99 | PAJARO DUNES BEACH | 8 |
| O010 | 23 Jun 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 30 Jun 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 06 Jul 99 | PAJARO DUNES BEACH | 0.0004 |
| O010 | 02 Aug 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 09 Aug 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 16 Aug 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 23 Aug 99 | PAJARO DUNES BEACH | 8 |
| O010 | 30 Aug 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 07 Sep 99 | PAJARO DUNES BEACH | 4 |
| O010 | 14 Sep 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 27 Sep 99 | PAJARO DUNES BEACH | 148 |
| O010 | 06 Oct 99 | PAJARO DUNES BEACH | 4 |
| O010 | 12 Oct 99 | PAJARO DUNES BEACH | 0.9 |

| SC County Env. Health Site Code | DATE | LOCATION | Fecal Coliform (CFU/100 mL) |
|---|---|---|---|
| O010 | 19 Oct 99 | PAJARO DUNES BEACH | 2 |
| O010 | 25 Oct 99 | PAJARO DUNES BEACH | 16 |
| O010 | 27 Oct 99 | PAJARO DUNES BEACH | 16 |
| O010 | 18 Nov 99 | PAJARO DUNES BEACH | 196 |
| O010 | 23 Nov 99 | PAJARO DUNES BEACH | 4 |
| O010 | 01 Dec 99 | PAJARO DUNES BEACH | 0.9 |
| O010 | 08 Dec 99 | PAJARO DUNES BEACH | 24 |
| O010 | 05 Jan 00 | PAJARO DUNES BEACH | 4 |
| O010 | 23 Feb 00 | PAJARO DUNES BEACH | 592 |
| O010 | 27 Feb 00 | PAJARO DUNES BEACH | 560 |
| O010 | 02 Mar 00 | PAJARO DUNES BEACH | 52 |
| O010 | 06 Mar 00 | PAJARO DUNES BEACH | 32 |
| O010 | 22 Mar 00 | PAJARO DUNES BEACH | 16 |
| O010 | 03 Apr 00 | PAJARO DUNES BEACH | 2 |
| O010 | 10 Apr 00 | PAJARO DUNES BEACH | 2 |
| O010 | 11 Apr 00 | PAJARO DUNES BEACH | 2 |
| O010 | 26 Apr 00 | PAJARO DUNES BEACH | 4 |
| O010 | 02 May 00 | PAJARO DUNES BEACH | 2 |
| O010 | 09 May 00 | PAJARO DUNES BEACH | 20 |
| O010 | 17 May 00 | PAJARO DUNES BEACH | 2 |
| O010 | 23 May 00 | PAJARO DUNES BEACH | 2 |
| O010 | 31 May 00 | PAJARO DUNES BEACH | 2 |
| O010 | 27 Jun 00 | PAJARO DUNES BEACH | 4 |
| O010 | 05 Jul 00 | PAJARO DUNES BEACH | 2 |
| O010 | 11 Jul 00 | PAJARO DUNES BEACH | 2 |
| O010 | 18 Jul 00 | PAJARO DUNES BEACH | 2 |
| O010 | 23 Oct 00 | PAJARO DUNES BEACH | 20 |
| O010 | 21 Nov 00 | PAJARO DUNES BEACH | 3.9 |
| O010 | 26 Mar 01 | PAJARO DUNES BEACH | 5 |
| P1 | 12 Dec 79 | WATSONVILLE S @ PAJARO R | 179 |
| P1 | 22 Apr 80 | WATSONVILLE S @ PAJARO R | 1820 |
| P1 | 19 Dec 89 | WATSONVILLE S @ PAJARO R | 0.1 |
| P1 | 19 Dec 89 | WATSONVILLE S @ PAJARO R | 0.1 |
| P1 | 10 Apr 90 | WATSONVILLE S @ PAJARO R | 420 |
| P1 | 10 Apr 90 | WATSONVILLE S @ PAJARO R | 420 |
| P1 | 17 Apr 90 | WATSONVILLE S @ PAJARO R | 460 |
| P1 | 17 Apr 90 | WATSONVILLE S @ PAJARO R | 460 |

| SC County Env. Health Site Code | DATE | LOCATION | Fecal Coliform (CFU/100 mL) |
|---|---|---|---|
| P1 | 24 Apr 90 | WATSONVILLE S @ PAJARO R | 110 |
| P1 | 24 Apr 90 | WATSONVILLE S @ PAJARO R | 110 |
| P1 | 01 May 90 | WATSONVILLE S @ PAJARO R | 0.1 |
| P1 | 01 May 90 | WATSONVILLE S @ PAJARO R | 0.1 |
| P1 | 23 Dec 91 | WATSONVILLE S @ PAJARO R | 60 |
| P1 | 23 Dec 91 | WATSONVILLE S @ PAJARO R | 60 |
| P1 | 27 Feb 00 | WATSONVILLE S @ PAJARO R | 140 |
| P1 | 27 Feb 00 | WATSONVILLE S @ PAJARO R | 140 |
| P1 | 02 Mar 00 | WATSONVILLE S @ PAJARO R | 80 |
| P1 | 02 Mar 00 | WATSONVILLE S @ PAJARO R | 80 |
| P1 | 06 Mar 00 | WATSONVILLE S @ PAJARO R | 240 |
| P1 | 06 Mar 00 | WATSONVILLE S @ PAJARO R | 240 |
| P1 | 02 May 00 | WATSONVILLE S @ PAJARO R | 480 |
| P1 | 02 May 00 | WATSONVILLE S @ PAJARO R | 480 |
| P1 | 12 Dec 79 | WATSONVILLE S @ PAJARO R | 179 |
| P1 | 22 Apr 80 | WATSONVILLE S @ PAJARO R | 1820 |
| P101 | 21 Dec 87 | WATSONVILLE S @ BEACH RD | 20 |
| P101 | 01 Feb 88 | WATSONVILLE S @ BEACH RD | 40 |
| P101 | 13 Jun 89 | WATSONVILLE S @ BEACH RD | 10 |
| P101 | 11 Jul 94 | WATSONVILLE S @ BEACH RD | 840 |
| P101 | 12 Sep 94 | WATSONVILLE S @ BEACH RD | 320 |
| P101 | 13 Oct 94 | WATSONVILLE S @ BEACH RD | 80 |
| P101 | 22 Nov 94 | WATSONVILLE S @ BEACH RD | 20 |
| P101 | 12 Dec 94 | WATSONVILLE S @ BEACH RD | 860 |
| P101 | 06 Feb 95 | WATSONVILLE S @ BEACH RD | 140 |
| P101 | 03 Apr 95 | WATSONVILLE S @ BEACH RD | 240 |
| P101 | 01 May 95 | WATSONVILLE S @ BEACH RD | 700 |
| P101 | 05 Jun 95 | WATSONVILLE S @ BEACH RD | 320 |
| P101 | 05 Jul 95 | WATSONVILLE S @ BEACH RD | 640 |
| P101 | 31 Jul 95 | WATSONVILLE S @ BEACH RD | 140 |
| P101 | 30 Aug 95 | WATSONVILLE S @ BEACH RD | 140 |
| P101 | 25 Sep 95 | WATSONVILLE S @ BEACH RD | 80 |
| P101 | 23 Oct 95 | WATSONVILLE S @ BEACH RD | 120 |
| P101 | 20 Nov 95 | WATSONVILLE S @ BEACH RD | 80 |
| P101 | 17 Dec 95 | WATSONVILLE S @ BEACH RD | 200 |
| P101 | 17 Jan 96 | WATSONVILLE S @ BEACH RD | 850 |
| P101 | 10 Jun 96 | WATSONVILLE S @ BEACH RD | 160 |

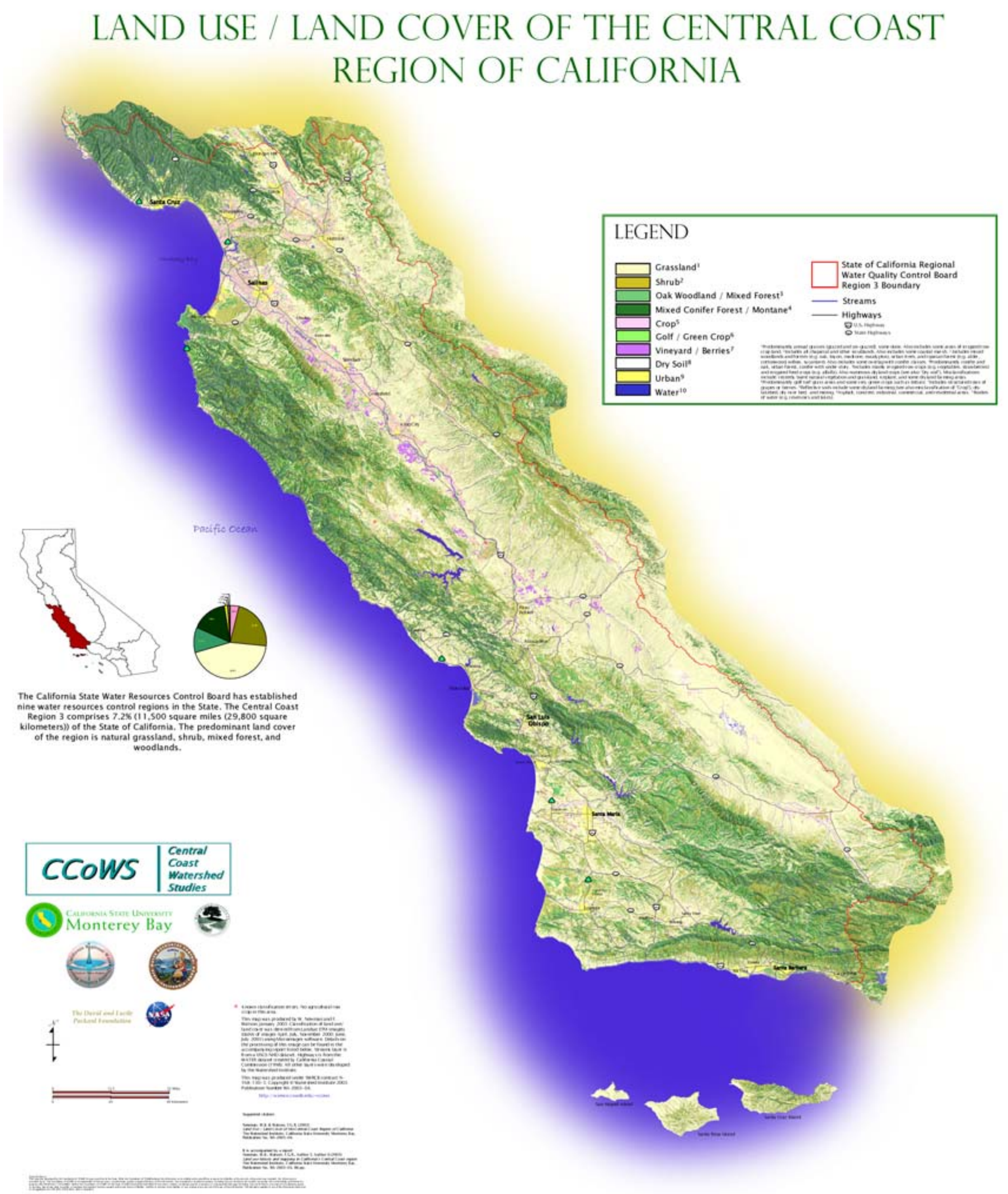
| SC County Env. Health Site Code | DATE | LOCATION | Fecal Coliform (CFU/100 mL) |
|---|---|---|---|
| P101 | 09 Jul 96 | WATSONVILLE S @ BEACH RD | 140 |
| P101 | 06 Aug 96 | WATSONVILLE S @ BEACH RD | 120 |
| P101 | 07 Jan 97 | WATSONVILLE S @ BEACH RD | 80 |
| P101 | 18 Feb 97 | WATSONVILLE S @ BEACH RD | 5500 |
| P101 | 11 Mar 97 | WATSONVILLE S @ BEACH RD | 180 |
| P101 | 22 Apr 97 | WATSONVILLE S @ BEACH RD | 2420 |
| P101 | 04 Jun 97 | WATSONVILLE S @ BEACH RD | 700 |
| P101 | 23 Jul 97 | WATSONVILLE S @ BEACH RD | 160 |
| P101 | 28 Oct 97 | WATSONVILLE S @ BEACH RD | 40 |
| P101 | 11 Dec 97 | WATSONVILLE S @ BEACH RD | 110 |
| P1041 | 16 Jun 76 | WATS SLOUGH @ SAN ANDREAS | 2100 |
| P1042 | 23 May 77 | WATS S ABOVE HARKINS S | 380 |
| P1042 | 27 Apr 78 | WATS S ABOVE HARKINS S | 800 |
| P1042 | 22 Apr 80 | WATS S ABOVE HARKINS S | 1540 |
| P1042 | 24 Sep 80 | WATS S ABOVE HARKINS S | 4040 |
| P1042 | 18 May 81 | WATS S ABOVE HARKINS S | 1936 |
| P1042 | 01 Oct 81 | WATS S ABOVE HARKINS S | 2510 |
| P1042 | 11 May 82 | WATS S ABOVE HARKINS S | 2130 |
| P1042 | 28 Sep 82 | WATS S ABOVE HARKINS S | 130 |
| P1042 | 06 Apr 84 | WATS S ABOVE HARKINS S | 5060 |
| P1051 | 22 Nov 94 | WATSONVILLE S @ LEE RD | 900 |
| P1051 | 12 Dec 94 | WATSONVILLE S @ LEE RD | 900 |
| P1051 | 06 Feb 95 | WATSONVILLE S @ LEE RD | 460 |
| P1051 | 01 May 95 | WATSONVILLE S @ LEE RD | 1200 |
| P1051 | 05 Jun 95 | WATSONVILLE S @ LEE RD | 1260 |
| P1051 | 31 Jul 95 | WATSONVILLE S @ LEE RD | 80 |
| P1051 | 25 Sep 95 | WATSONVILLE S @ LEE RD | 260 |
| P1051 | 23 Oct 95 | WATSONVILLE S @ LEE RD | 550 |
| P1051 | 20 Nov 95 | WATSONVILLE S @ LEE RD | 60 |
| P1051 | 17 Dec 95 | WATSONVILLE S @ LEE RD | 45 |
| P1051 | 17 Jan 96 | WATSONVILLE S @ LEE RD | 1500 |
| P1051 | 10 Jun 96 | WATSONVILLE S @ LEE RD | 361 |
| P1051 | 06 Aug 96 | WATSONVILLE S @ LEE RD | 580 |
| P1051 | 07 Jan 97 | WATSONVILLE S @ LEE RD | 50 |
| P1051 | 11 Mar 97 | WATSONVILLE S @ LEE RD | 30 |
| P1051 | 22 Apr 97 | WATSONVILLE S @ LEE RD | 100 |
| P1051 | 04 Jun 97 | WATSONVILLE S @ LEE RD | 130 |

| SC County Env. Health Site Code | DATE | LOCATION | Fecal Coliform (CFU/100 mL) |
|---|---|---|---|
| P1051 | 23 Jul 97 | WATSONVILLE S @ LEE RD | 100 |
| P1051 | 15 Sep 97 | WATSONVILLE S @ LEE RD | 80 |
| P1051 | 28 Oct 97 | WATSONVILLE S @ LEE RD | 340 |
| P1051 | 25 Nov 97 | WATSONVILLE S @ LEE RD | 140 |
| P1051 | 25 Jan 98 | WATSONVILLE S @ LEE RD | 72 |
| P1051 | 25 Mar 98 | WATSONVILLE S @ LEE RD | 1380 |
| P1051 | 26 Apr 98 | WATSONVILLE S @ LEE RD | 230 |
| P1051 | 01 Jul 98 | WATSONVILLE S @ LEE RD | 350 |
| P1051 | 25 Aug 98 | WATSONVILLE S @ LEE RD | 284 |
| P10521 | 11 Feb 92 | STRUVE S @ LEE RD | 380 |
| P10521 | 25 Feb 92 | STRUVE S @ LEE RD | 80 |
| P10521 | 11 Jul 94 | STRUVE S @ LEE RD | 80 |
| P10521 | 12 Sep 94 | STRUVE S @ LEE RD | 280 |
| P10521 | 13 Oct 94 | STRUVE S @ LEE RD | 20 |
| P10521 | 22 Nov 94 | STRUVE S @ LEE RD | 540 |
| P10521 | 12 Dec 94 | STRUVE S @ LEE RD | 820 |
| P10521 | 06 Feb 95 | STRUVE S @ LEE RD | 0.1 |
| P10521 | 03 Apr 95 | STRUVE S @ LEE RD | 40 |
| P10521 | 01 May 95 | STRUVE S @ LEE RD | 1000 |
| P10521 | 05 Jun 95 | STRUVE S @ LEE RD | 380 |
| P10521 | 05 Jul 95 | STRUVE S @ LEE RD | 420 |
| P10521 | 31 Jul 95 | STRUVE S @ LEE RD | 100 |
| P10521 | 30 Aug 95 | STRUVE S @ LEE RD | 540 |
| P10521 | 06 Aug 96 | STRUVE S @ LEE RD | 207 |
| P10521 | 07 Jan 97 | STRUVE S @ LEE RD | 400 |
| P10521 | 11 Mar 97 | STRUVE S @ LEE RD | 0.9 |
| P10521 | 22 Apr 97 | STRUVE S @ LEE RD | 40 |
| P10521 | 04 Jun 97 | STRUVE S @ LEE RD | 470 |
| P10521 | 23 Jul 97 | STRUVE S @ LEE RD | 820 |
| P10524 | 11 Apr 89 | STRUVE S @ LANDIS | 80 |
| P10525 | 04 Apr 89 | STRUVE S @ CHRISTIAN SCHOOL | 250 |
| P10526 | 04 Apr 89 | STRUVE S BELOW GREEN VALLEY RD | 700 |
| P10526 | 11 Apr 89 | STRUVE S BELOW GREEN VALLEY RD | 180 |
| P10526 | 13 Mar 90 | STRUVE S BELOW GREEN VALLEY RD | 520 |
| P10526D | 11 Apr 89 | STRUVE S BELOW GR VLY RD-DITCH | 200 |
| P10528 | 06 Mar 90 | STRUVE S BELOW AIRPORT B | 220 |
| P10528 | 13 Mar 90 | STRUVE S BELOW AIRPORT B | 350 |

| SC County Env. Health Site Code | DATE | LOCATION | Fecal Coliform (CFU/100 mL) |
|---|---|---|---|
| P10528 | 20 Mar 90 | STRUVE S BELOW AIRPORT B | 1760 |
| P10528 | 27 Mar 90 | STRUVE S BELOW AIRPORT B | 390 |
| P10529 | 04 Apr 89 | STRUVE S @ AIRPORT B | 700 |
| P10530 | 04 Apr 89 | STRUVE S @ AIRPORT B | 1950 |
| P10531 | 11 Apr 89 | STRUVE S @ AIRPORT B | 11750 |
| P10532 | 18 Apr 89 | STRUVE S @ AIRPORT B | 800 |
| P10533 | 25 Apr 89 | STRUVE S @ AIRPORT B | 7500 |
| P10534 | 02 May 89 | STRUVE S @ AIRPORT B | 140 |
| P1065 | 16 Jun 76 | HARKINS S @ HARKINS S RD BRIDG | 870 |
| P1065 | 06 Feb 90 | HARKINS S @ HARKINS S RD BRIDG | 260 |
| P1065 | 25 Feb 92 | HARKINS S @ HARKINS S RD BRIDG | 0.1 |
| P1065 | 11 Jul 94 | HARKINS S @ HARKINS S RD BRIDG | 640 |
| P1065 | 12 Sep 94 | HARKINS S @ HARKINS S RD BRIDG | 380 |
| P1065 | 13 Oct 94 | HARKINS S @ HARKINS S RD BRIDG | 40 |
| P1065 | 22 Nov 94 | HARKINS S @ HARKINS S RD BRIDG | 380 |
| P1065 | 12 Dec 94 | HARKINS S @ HARKINS S RD BRIDG | 1120 |
| P1065 | 01 May 95 | HARKINS S @ HARKINS S RD BRIDG | 650 |
| P1065 | 31 Jul 95 | HARKINS S @ HARKINS S RD BRIDG | 200 |
| P1065 | 30 Aug 95 | HARKINS S @ HARKINS S RD BRIDG | 420 |
| P1065 | 25 Sep 95 | HARKINS S @ HARKINS S RD BRIDG | 40 |
| P1065 | 23 Oct 95 | HARKINS S @ HARKINS S RD BRIDG | 980 |
| P1065 | 20 Nov 95 | HARKINS S @ HARKINS S RD BRIDG | 220 |
| P1065 | 17 Dec 95 | HARKINS S @ HARKINS S RD BRIDG | 1350 |
| P1065 | 17 Jan 96 | HARKINS S @ HARKINS S RD BRIDG | 16050 |
| P1065 | 10 Jun 96 | HARKINS S @ HARKINS S RD BRIDG | 19 |
| P1065 | 06 Aug 96 | HARKINS S @ HARKINS S RD BRIDG | 680 |
| HS0 | 21 Dec 87 | HARKIN'S SLOUGH | 0.1 |
| HS0 | 07 Jan 97 | HARKIN'S SLOUGH | 20 |
| HS0 | 15 Sep 97 | HARKIN'S SLOUGH | 340 |
| P1040 | 23 May 77 | HARKINS SLOUGH @ WATS S | 460 |
| P1040 | 12 Dec 79 | HARKINS SLOUGH @ WATS S | 283 |
| P1040 | 22 Apr 80 | HARKINS SLOUGH @ WATS S | 40 |
| P1040 | 24 Sep 80 | HARKINS SLOUGH @ WATS S | 550 |
| P1040 | 18 May 81 | HARKINS SLOUGH @ WATS S | 11800 |
| P1040 | 01 Oct 81 | HARKINS SLOUGH @ WATS S | 300 |
| P1040 | 11 May 82 | HARKINS SLOUGH @ WATS S | 673 |
| P1040 | 28 Sep 82 | HARKINS SLOUGH @ WATS S | 50 |

| SC County Env. Health Site Code | DATE | LOCATION | Fecal Coliform (CFU/100 mL) |
|---|---|---|---|
| P1040 | 06 Apr 84 | HARKINS SLOUGH @ WATS S | 430 |
| PVWMA Site Code | Date | Location | Fecal Coliform (MPN/100 ml) |
| HAR-EFF | 09 Jan 02 | Harkins Slough Diversion Effluent | 1,100 |
| HAR-EFF | 06 Feb 02 | Harkins Slough Diversion Effluent | 1,400 |
| HAR-EFF | 13 Mar 02 | Harkins Slough Diversion Effluent | 2,200 |
| HAR-EFF | 10 Apr 02 | Harkins Slough Diversion Effluent | 20 |
| HAR-EFF | 08 May 02 | Harkins Slough Diversion Effluent | 33 |
| HAR-CON | 09 Jan 02 | Harkins Slough 25' upstream of confluence | 500 |
| HAR-CON | 06 Feb 02 | Harkins Slough 25' upstream of confluence | 500 |
| HAR-CON | 13 Mar 02 | Harkins Slough 25' upstream of confluence | 800 |
| HAR-CON | 10 Apr 02 | Harkins Slough 25' upstream of confluence | <20 |
| WAT-HSU | 09 Jan 02 | Watsonville Slough 50' upstream of pump station | 300 |
| WAT-HSU | 06 Feb 02 | Watsonville Slough 50' upstream of pump station | 800 |
| WAT-HSU | 13 Mar 02 | Watsonville Slough 50' upstream of pump station | 300 |
| WAT-HSU | 10 Apr 02 | Watsonville Slough 50' upstream of pump station | 50 |
| WAT-HSD | 09 Jan 02 | Watsonville Slough 50' downstream of pump station | 240 |
| WAT-HSD | 06 Feb 02 | Watsonville Slough 50' downstream of pump station | 1,300 |
| WAT-HSD | 13 Mar 02 | Watsonville Slough 50' downstream of pump station | 800 |
| WAT-HSD | 10 Apr 02 | Watsonville Slough 50' downstream of pump station | 110 |

# Appendix B-Region 3 Land Use Land Cover Map



# Appendix C-CCoWS Data

| Site Code | Date | Discharge (m3/s) | Stage (m) | Stage Inverted (m) | Total Coliform (MPN/100mL) | Fecal Coliform (MPN/100mL) | *E. coli* (MPN/100mL) |
|---|---|---|---|---|---|---|---|
| GAL-BUE | 18-Feb-03 | 0.004 | | | 1,600 | 220 | 170 |
| GAL-BUE | 27-Feb-03 | 0.016 | | | 1,600 | 1,600 | 1,600 |
| GAL-BUE | 13-Mar-03 | 0.006 | 0.215 | | | | |
| GAL-BUE | 14-Mar-03 | 0.015 | 0.24 | | 16,000 | 300 | 300 |
| GAL-BUE | 15-Mar-03 | 0.066 | 0.41 | | | | |
| GAL-BUE | 15-Mar-03 | | 0.345 | | | | |
| GAL-BUE | 18-Mar-03 | | 0.235 | | 800 | 80 | 20 |
| GAL-BUE | 20-Mar-03 | 0.010 | 0.24 | | 110 | 80 | 80 |
| GAL-BUE | 13-Apr-03 | 0.018 | 0.32 | | | | |
| GAL-BUE | 13-Apr-03 | 0.038 | 0.35 | | | | |
| GAL-BUE | 19-Jun-03 | 0.001 | 0.23 | | 800 | 70 | 70 |
| GAL-BUE | 26-Jun-03 | 0.000 | 0.23 | | 16,000 | 16,000 | 700 |
| GAL-BUE | 01-Jul-03 | 0.001 | 0.22 | | 1,600 | 80 | 14 |
| GAL-BUE | 08-Jul-03 | 0.000 | 0.2 | | | | |
| GAL-BUE | 13-Jul-03 | 0.000 | | | | | |
| GAL-BUE | 16-Jul-03 | 0.000 | | | | | |
| HAN-HAR | 27-Feb-03 | 0.003 | | | 1,600 | 1,600 | 1,600 |
| HAN-HAR | 15-Mar-03 | 0.010 | | | | | |
| HAN-HAR | 13-Apr-03 | 0.004 | | | | | |
| HAN-HAR | 13-Apr-03 | 0.003 | | | | | |
| HAN-HAR | 19-Jun-03 | 0.000 | | | | | |
| HAN-HAR | 26-Jun-03 | 0.000 | | | | | |
| HAN-HAR | 01-Jul-03 | 0.000 | | | | | |
| HAN-HAR | 08-Jul-03 | 0.000 | | | | | |
| HAN-HAR | 13-Jul-03 | 0.000 | | | | | |
| HAN-HAR | 16-Jul-03 | 0.000 | | | | | |
| HAR-916 | 17-Apr-03 | | | | 900 | 50 | |
| HAR-916 | 06-May-03 | | | | 2,005 | | 254 |
| HAR-BUE | 17-Apr-03 | | | | 3,000 | 230 | |
| HAR-BUE | 06-May-03 | | | | 2,005 | | 478 |
| HAR-CON | 18-Feb-03 | | | | 1,600 | 1,600 | 1,600 |
| HAR-CON | 27-Feb-03 | | | | 16,000 | 220 | 220 |
| HAR-CON | 14-Mar-03 | | | | 3,000 | 2,400 | 800 |

| Site Code | Date | Discharge (m3/s) | Stage (m) | Stage Inverted (m) | Total Coliform (MPN/100mL) | Fecal Coliform (MPN/100mL) | *E. coli* (MPN/100mL) |
|---|---|---|---|---|---|---|---|
| HAR-CON | 18-Mar-03 | | | | 9,000 | 5,000 | 5,000 |
| HAR-CON | 20-Mar-03 | | | | 5,000 | 130 | 130 |
| HAR-CON | 19-Jun-03 | | | | 9,000 | 40 | 20 |
| HAR-CON | 26-Jun-03 | | | | 3,000 | 1,300 | 20 |
| HAR-CON | 01-Jul-03 | | | | 16,000 | 2,400 | 2,400 |
| HAR-CON | 08-Jul-03 | | | | 5,000 | 40 | 40 |
| HAR-CON | 16-Jul-03 | | | | 16,000 | 20 | 20 |
| HAR-H1U | 17-Apr-03 | | | | 2,400 | 2,400 | |
| HAR-H1U | 06-May-03 | | | | 1,652 | | 150 |
| HAR-HAR | 18-Feb-03 | | | 0.42 | 1,600 | 900 | 900 |
| HAR-HAR | 27-Feb-03 | | | 0.57 | 1,600 | 1,600 | 1,600 |
| HAR-HAR | 13-Mar-03 | | 0.95 | | | | |
| HAR-HAR | 14-Mar-03 | | 0.065 | | 3,500 | 1,100 | 1,100 |
| HAR-HAR | 15-Mar-03 | | 0.08 | | | | |
| HAR-HAR | 18-Mar-03 | | 0.105 | | 2,400 | 1,000 | 420 |
| HAR-HAR | 20-Mar-03 | | 0.115 | | 9,000 | 5,000 | 5,000 |
| HAR-HAR | 19-Jun-03 | | -0.17 | | 5,000 | 270 | 120 |
| HAR-HAR | 26-Jun-03 | | -0.18 | | 5,000 | 5,000 | 800 |
| HAR-HAR | 01-Jul-03 | | -0.13 | | 5,000 | 3,000 | 2,400 |
| HAR-HAR | 08-Jul-03 | | -0.24 | | 9,000 | 5,000 | 1,700 |
| HAR-HAR | 13-Jul-03 | | -0.23 | | | | |
| HAR-HAR | 16-Jul-03 | | -0.27 | | 16,000 | 9,000 | 2,200 |
| HAR-HAR | 05-Aug-03 | | -0.36 | | 9,000 | 5,667 | 2,167 |
| HAR-HAR | 09-Sep-03 | | | | 16,000 | 16,000 | 16,000 |
| HAR-PEA | 17-Apr-03 | | | | 2,400 | 170 | |
| HAR-PEA | 06-May-03 | | | | 2,005 | | 75 |
| HAR-RAU | 18-Feb-03 | | | 1.75 | 1,600 | 500 | 300 |
| HAR-RAU | 27-Feb-03 | 0.103 | | 1.63 | 1,600 | 1,600 | 1,600 |
| HAR-RAU | 13-Mar-03 | 0.019 | 0.2 | | | | |
| HAR-RAU | 14-Mar-03 | 0.019 | 0.245 | | 5,000 | 400 | 367 |
| HAR-RAU | 15-Mar-03 | 1.432 | 0.605 | | | | |
| HAR-RAU | 15-Mar-03 | | 0.6 | | | | |
| HAR-RAU | 15-Mar-03 | | 0.535 | | | | |
| HAR-RAU | 18-Mar-03 | 0.009 | 0.26 | | 1,100 | 500 | 500 |
| HAR-RAU | 20-Mar-03 | 0.021 | 0.235 | | 5,000 | 700 | 700 |
| HAR-RAU | 13-Apr-03 | 0.037 | 0.47 | | | | |

| Site Code | Date | Discharge (m3/s) | Stage (m) | Stage Inverted (m) | Total Coliform (MPN/100mL) | Fecal Coliform (MPN/100mL) | *E. coli* (MPN/100mL) |
|---|---|---|---|---|---|---|---|
| HAR-RAU | 13-Apr-03 | 0.030 | 0.48 | | | | |
| HAR-RAU | 17-Apr-03 | | | | 2,400 | 170 | |
| HAR-RAU | 06-May-03 | | 0.23 | | 1,652 | | 178 |
| HAR-RAU | 19-Jun-03 | | 0.15 | | 220 | 130 | 130 |
| HAR-RAU | 26-Jun-03 | | 0.16 | | 1,100 | 40 | 40 |
| HAR-RAU | 01-Jul-03 | | 0.15 | | 1,600 | 900 | 900 |
| HAR-RAU | 08-Jul-03 | | 0.16 | | 130 | 8 | 4 |
| HAR-RAU | 13-Jul-03 | | 0.16 | | | | |
| HAR-RAU | 16-Jul-03 | | 0.125 | | 1,300 | 170 | 170 |
| STR-AIR | 17-Apr-03 | | | | 5,000 | 220 | |
| STR-AIR | 05-Aug-03 | | | | 16,000 | 1,700 | 300 |
| STR-AIR | 18-Aug-03 | | | | 4,838 | | 2 |
| STR-CH1 | 17-Apr-03 | | | | 5,900 | 300 | |
| STR-CH1 | 06-May-03 | | | | 12,980 | | 310 |
| STR-CH1 | 04-Aug-03 | | | | 2,599 | | 24 |
| STR-CH1 | 05-Aug-03 | | | | 16,000 | 16,000 | 16,000 |
| STR-CH1 | 18-Aug-03 | | | | 4,352 | | 10 |
| STR-CH1 | 26-Aug-03 | | | | | 110 | 10 |
| STR-CH1 | 04-Sep-03 | | | | | | 10 |
| STR-CH2 | 05-Aug-03 | | | | 16,000 | 16,000 | 9,000 |
| STR-CH2 | 26-Aug-03 | 0.000 | | | | | |
| STR-CH2 | 04-Sep-03 | 0.000 | | | | | |
| STR-CH3 | 05-Aug-03 | | | | 16,000 | 189 | 189 |
| STR-CH3 | 26-Aug-03 | | | | | 140 | 211 |
| STR-CH3 | 04-Sep-03 | | | | | | 20 |
| STR-CH4 | 04-Aug-03 | | | | 9,676 | | 1,095 |
| STR-CH5 | 04-Aug-03 | | | | 9,676 | | 1,540 |
| STR-CHE | 18-Feb-03 | 0.001 | | | 1,600 | 1,600 | 1,600 |
| STR-CHE | 27-Feb-03 | 0.004 | | | 16,000 | 16,000 | 16,000 |
| STR-CHE | 14-Mar-03 | 0.001 | 0.1 | | 90,000 | 16,000 | 16,000 |
| STR-CHE | 15-Mar-03 | 0.064 | 0.17 | | | | |
| STR-CHE | 15-Mar-03 | | 0.14 | | | | |
| STR-CHE | 18-Mar-03 | 0.003 | 0.1 | | 9,000 | 170 | 170 |
| STR-CHE | 20-Mar-03 | 0.001 | 0.1 | | 5,000 | 2,400 | 2,400 |
| STR-CHE | 13-Apr-03 | 0.046 | 0.18 | | | | |
| STR-CHE | 13-Apr-03 | 0.014 | | | | | |

| Site Code | Date | Discharge (m3/s) | Stage (m) | Stage Inverted (m) | Total Coliform (MPN/100mL) | Fecal Coliform (MPN/100mL) | *E. coli* (MPN/100mL) |
|---|---|---|---|---|---|---|---|
| STR-CHE | 17-Apr-03 | | | | 14,667 | 667 | |
| STR-CHE | 06-May-03 | | | | 3,227 | | 100 |
| STR-CHE | 19-Jun-03 | 0.006 | 0.1 | | 16,000 | 3,000 | 3,000 |
| STR-CHE | 26-Jun-03 | | 0.09 | | 16,000 | 5,000 | 300 |
| STR-CHE | 01-Jul-03 | 0.002 | 0.1 | | 16,000 | 16,000 | 8,135 |
| STR-CHE | 08-Jul-03 | 0.003 | 0.1 | | 3,000 | 3,000 | 1,300 |
| STR-CHE | 13-Jul-03 | 0.001 | | | | | |
| STR-CHE | 16-Jul-03 | 0.001 | 0.1 | | 16,000 | 5,000 | 5,000 |
| STR-CHE | 05-Aug-03 | | 0.1 | | 16,000 | 16,000 | 16,000 |
| STR-CHE | 18-Aug-03 | | | | 15,402 | | 1,434 |
| STR-CHE | 18-Aug-03 | | 0.09 | | 16,000 | 1,700 | 500 |
| STR-CHE | 26-Aug-03 | | 0.09 | | | 9,000 | 4,352 |
| STR-CHE | 04-Sep-03 | | | | | | 1,447 |
| STR-CHE | 04-Sep-03 | | | | | | 1,467 |
| STR-CHE | 09-Sep-03 | | 0.09 | | 16,000 | 16,000 | 16,000 |
| STR-HAR | 18-Feb-03 | | | 1.12 | 1,600 | 13 | 8 |
| STR-HAR | 27-Feb-03 | | | 1.12 | 1,600 | 1,600 | 1,600 |
| STR-HAR | 14-Mar-03 | | | 1.2 | 70 | 20 | 20 |
| STR-HAR | 15-Mar-03 | | | 1.11 | | | |
| STR-HAR | 18-Mar-03 | | | 1.08 | 140 | 40 | 40 |
| STR-HAR | 20-Mar-03 | | | 1.09 | 40 | 20 | 20 |
| STR-HAR | 19-Jun-03 | | | 1.3 | 2,400 | 800 | 800 |
| STR-HAR | 26-Jun-03 | | | 1.35 | 3,000 | 230 | 230 |
| STR-HAR | 01-Jul-03 | | | | 5,000 | 300 | 130 |
| STR-HAR | 08-Jul-03 | | | | 1,600 | 500 | 500 |
| STR-HAR | 16-Jul-03 | | | | 16,000 | 220 | 170 |
| STR-LEE | 18-Feb-03 | | | 0.21 | 240 | 4 | 4 |
| STR-LEE | 27-Feb-03 | | | 0.17 | 240 | 8 | 4 |
| STR-LEE | 14-Mar-03 | | | 0.25 | 50 | 8 | 8 |
| STR-LEE | 15-Mar-03 | | | 0.17 | | | |
| STR-LEE | 18-Mar-03 | | | 0.12 | 80 | 20 | 20 |
| STR-LEE | 20-Mar-03 | | | 0.14 | 270 | 20 | 20 |
| STR-LEE | 19-Jun-03 | | | 0.32 | 5,201 | 1,367 | 260 |
| STR-LEE | 26-Jun-03 | | | 0.36 | 9,000 | 5,000 | 3,000 |
| STR-LEE | 01-Jul-03 | | | | 5,000 | 340 | 340 |
| STR-LEE | 08-Jul-03 | | | | 9,000 | 130 | 130 |

| Site Code | Date | Discharge (m3/s) | Stage (m) | Stage Inverted (m) | Total Coliform (MPN/100mL) | Fecal Coliform (MPN/100mL) | *E. coli* (MPN/100mL) |
|---|---|---|---|---|---|---|---|
| STR-LEE | 16-Jul-03 | | | 0.35 | 3,000 | 170 | 170 |
| STR-PIP | 26-Jun-03 | | | | 16,000 | 16,000 | 9,000 |
| STR-PIP | 01-Jul-03 | | | | 3,000 | 20 | 20 |
| STR-PIP | 16-Jul-03 | | | | 16,000 | 300 | 70 |
| STR-PIP | 05-Aug-03 | | | | 16,000 | 1,300 | 1,300 |
| STR-PIP | 26-Aug-03 | | | | | 2,400 | 10 |
| STR-PIP | 04-Sep-03 | | | | | | 85 |
| STR-PIP | 09-Sep-03 | | | | 16,000 | 2,400 | 20 |
| STR-TRB | 08-Jul-03 | | | | 800 | 300 | 300 |
| STR-TRB | 04-Aug-03 | | | | 9,676 | | 1,633 |
| STR-TRB | 05-Aug-03 | | | | 5,000 | 1,100 | 1,100 |
| STR-TRB | 18-Aug-03 | | | | 4,838 | | 30 |
| STR-TRB | 26-Aug-03 | | | | | 1,300 | 1,039 |
| STR-TRB | 04-Sep-03 | | | | | | 1,725 |
| STR-TRB | 09-Sep-03 | | | | 9,000 | 5,000 | 5,000 |
| WAT-AND | 18-Feb-03 | | 0.465 | | 1,600 | 1,600 | 1,600 |
| WAT-AND | 27-Feb-03 | | 0.57 | | 1,600 | 1,600 | 1,600 |
| WAT-AND | 14-Mar-03 | | 0.73 | | 16,000 | 5,000 | 3,000 |
| WAT-AND | 15-Mar-03 | | 0.77 | | | | |
| WAT-AND | 18-Mar-03 | | 0.87 | | 22,000 | 5,000 | 3,000 |
| WAT-AND | 20-Mar-03 | | 0.56 | | 7,000 | 300 | 300 |
| WAT-AND | 13-Apr-03 | | 0.25 | | | | |
| WAT-AND | 19-Jun-03 | | 0.31 | | 16,000 | 500 | 500 |
| WAT-AND | 26-Jun-03 | | 0.23 | | 16,000 | 8,150 | 400 |
| WAT-AND | 01-Jul-03 | | 0.232 | | 16,000 | 675 | 675 |
| WAT-AND | 08-Jul-03 | | 0.23 | | 16,000 | 170 | 170 |
| WAT-AND | 13-Jul-03 | | 0.26 | | | | |
| WAT-AND | 16-Jul-03 | | 0.26 | | | | |
| WAT-HAR | 18-Feb-03 | | | | 280 | 37 | 22 |
| WAT-HAR | 27-Feb-03 | | | | 1,600 | 170 | 110 |
| WAT-HAR | 14-Mar-03 | | | | 300 | 80 | 80 |
| WAT-HAR | 18-Mar-03 | | | | 800 | 40 | 40 |
| WAT-HAR | 20-Mar-03 | | | | 367 | 23 | 23 |
| WAT-HAR | 19-Jun-03 | | | | 9,000 | 80 | 20 |
| WAT-HAR | 26-Jun-03 | | | | 1,776 | 1,108 | 153 |
| WAT-HAR | 01-Jul-03 | | | | 1,600 | 50 | 50 |

| Site Code | Date | Discharge (m3/s) | Stage (m) | Stage Inverted (m) | Total Coliform (MPN/100mL) | Fecal Coliform (MPN/100mL) | *E. coli* (MPN/100mL) |
|---|---|---|---|---|---|---|---|
| WAT-HAR | 08-Jul-03 | | | | 500 | 50 | 50 |
| WAT-HAR | 16-Jul-03 | | | | 1,700 | 300 | 300 |
| WAT-LEE | 18-Feb-03 | 0.052 | | | 1,600 | 80 | 80 |
| WAT-LEE | 27-Feb-03 | 0.113 | | | 16,000 | 300 | 300 |
| WAT-LEE | 13-Mar-03 | | 0.35 | | | | |
| WAT-LEE | 14-Mar-03 | 0.011 | 0.035 | | 1,600 | 1,600 | 500 |
| WAT-LEE | 15-Mar-03 | 0.197 | 0.275 | | | | |
| WAT-LEE | 15-Mar-03 | | 0.255 | | | | |
| WAT-LEE | 15-Mar-03 | | 0.175 | | | | |
| WAT-LEE | 18-Mar-03 | 0.055 | 0.105 | | 16,000 | 95 | 390 |
| WAT-LEE | 20-Mar-03 | 0.043 | 0.08 | | 16,000 | 1,700 | 1,700 |
| WAT-LEE | 13-Apr-03 | 0.291 | 0.33 | | | | |
| WAT-LEE | 13-Apr-03 | 0.142 | 0.24 | | | | |
| WAT-LEE | 19-Jun-03 | 0.002 | -0.08 | | 16,000 | 300 | 170 |
| WAT-LEE | 26-Jun-03 | 0.001 | -0.09 | | 16,000 | 2,400 | 170 |
| WAT-LEE | 01-Jul-03 | 0.003 | -0.08 | | 1,600 | 500 | 500 |
| WAT-LEE | 08-Jul-03 | 0.004 | -0.06 | | 16,000 | 230 | 230 |
| WAT-LEE | 13-Jul-03 | | -0.06 | | | | |
| WAT-LEE | 16-Jul-03 | 0.002 | -0.085 | | 16,000 | 800 | 800 |
| WAT-PAJ | 18-Feb-03 | | 0.719328 | | 130 | 130 | 80 |
| WAT-PAJ | 27-Feb-03 | | 1.00584 | | 1,600 | 220 | 140 |
| WAT-PAJ | 14-Mar-03 | | 0.77724 | | 240 | 240 | 130 |
| WAT-PAJ | 15-Mar-03 | | 1.2192 | | | | |
| WAT-PAJ | 18-Mar-03 | | 0.86868 | | 1,133 | 143 | 143 |
| WAT-PAJ | 20-Mar-03 | | 0.786384 | | 900 | 240 | 240 |
| WAT-PAJ | 19-Jun-03 | | 0.36576 | | 80 | 20 | 20 |
| WAT-PAJ | 26-Jun-03 | | 0.27432 | | 40 | 20 | 20 |
| WAT-PAJ | 01-Jul-03 | | 0.359664 | | 1,100 | 110 | 110 |
| WAT-PAJ | 08-Jul-03 | | 0.237744 | | 22 | 22 | 22 |
| WAT-PAJ | 13-Jul-03 | | 0.3048 | | | | |
| WAT-PAJ | 16-Jul-03 | | 0.079248 | | 77 | 77 | 77 |
| WAT-SHE | 18-Feb-03 | | | | 1,600 | 300 | 300 |
| WAT-SHE | 27-Feb-03 | | | 1.15 | 1,600 | 1,600 | 1,600 |
| WAT-SHE | 14-Mar-03 | | | 1.04 | 9,000 | 1,700 | 1,700 |
| WAT-SHE | 15-Mar-03 | | | 0.88 | | | |
| WAT-SHE | 18-Mar-03 | | | 0.83 | 500 | 500 | 300 |

| Site Code | Date | Discharge (m3/s) | Stage (m) | Stage Inverted (m) | Total Coliform (MPN/100mL) | Fecal Coliform (MPN/100mL) | *E. coli* (MPN/100mL) |
|---|---|---|---|---|---|---|---|
| WAT-SHE | 20-Mar-03 | | | 1.14 | 9,000 | 170 | 170 |
| WAT-SHE | 19-Jun-03 | | | 10 | 5,000 | 800 | 500 |
| WAT-SHE | 26-Jun-03 | | | 12 | 5,000 | 1,300 | 1,300 |
| WAT-SHE | 01-Jul-03 | | | 10 | 5,000 | 3,000 | 2,400 |
| WAT-SHE | 08-Jul-03 | | | | 1,600 | 750 | 750 |
| WAT-SHE | 16-Jul-03 | | | 12.5 | 2,400 | 1,300 | 1,300 |
| WAT-SHE | 05-Aug-03 | | | | 4,600 | 2,900 | 2,633 |
| WAT-SHE | 09-Sep-03 | | | | 16,000 | 2,400 | 2,400 |

# Appendix D-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. The evaluation sheets are included below. In general, the quality assurance evaluations were satisfactory.

All fecal coliform and *E. coli* field blanks resulted in values less than or equal to 2 MPN/100 mL, with one exception of 40 MPN/100 mL at WAT-PAJ. Results of interlaboratory comparisons, which involved duplicate samples being sent to an additional laboratory, resulted in percent differences that ranged from 0 to 5,826%. Excluding this one extreme, the average % difference of duplicates analyzed by the two laboratories was 43%. These results are not unexpected due to the natural variability of coliform bacteria and also due to the high range of the upper and lower 95% confidence limits of the test. For instance, the 95% confidence limits for a coliform value of 1,600 MPN/100 mL range from 600 to 5,300 MPN/100 mL. However, the extreme relative percent difference of 5,826% cannot be attributed solely to variation and limitations in the method itself. For that specific interlaboratory comparison, one of the laboratories reported an *E. coli* value of 270 MPN/100 mL (not exceeding the Basin Plan standard), where as the other reported 16,000 MPN/100 mL (exceeding the Basin Plan standard). Both laboratories were state certified and performed the analysis using the same method. The large difference in the results may likely be due to a combination of errors, which could include environmental variability, human error, and limitations in the analytical method. Once again, this highlights the importance of collecting many samples and not drawing conclusions from a single sample alone. The likelihood that a single sample will bias results and conclusions diminishes as the number of samples increases. The sampling plan for this project involved sampling 5 times within a 30-day period, and single site exceedance of the Basin Plan objective was based on the geometric mean of the data.

Quality Control Evaluation
Sample collection date: 18 Feb 03
Lab analysis date: 21 Feb 03

Fecal Coliform:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | Fecal Coliform (MPN/100mL) | Standard Deviation | 19.1 |
| WAT-HAR A | 50 | | |
| WAT-HAR B | 23 | Coefficient Of Variance (%) | 52.3 |
| - | - | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank Fecal Coliform (MPN/100mL) | Original Fecal Coliform (MPN/100mL) | Absolute Difference |
| Not collected | | | |

| <u>Inter-Laboratory Comparison</u> (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD Fecal Coliform (MPN/100mL) | BioVir Fecal Coliform (MPN/100mL) | Percent Difference (%) |
| Not collected | | | |

*E. Coli*:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | *E. Coli* (MPN/100mL) | Standard Deviation | 1.4 |
| WAT-HAR A | 21 | | |
| WAT-HAR B | 23 | Coefficient Of Variance (%) | 6.4 |
| - | - | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank *E. Coli* (MPN/100mL) | Original *E. Coli* (MPN/100mL) | Absolute Difference |
| Not collected | | | |

| <u>Inter-Laboratory Comparison</u> (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD *E. Coli* (MPN/100mL) | BioVir *E. Coli* (MPN/100mL) | Percent Difference (%) |
| Not collected | | | |

Quality Assurance Manger:

Julie Hager

Date:
6 Mar 03

Quality Control Evaluation
Sample collection date: 27 Feb 03
Lab analysis date: 28 Feb 03

Fecal Coliform:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | Fecal Coliform (MPN/100mL) | Standard Deviation | 0 |
| HAR-HAR B | ≥1,600 | | |
| HAR-HAR C | ≥1,600 | Coefficient Of Variance (%) | 0 |
| HAR-HAR D | ≥1,600 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank Fecal Coliform (MPN/100mL) | Original Fecal Coliform (MPN/100mL) | Absolute Difference |
| HAR-HAR A | 2 | 0 | 2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD Fecal Coliform (MPN/100mL) | BioVir Fecal Coliform (MPN/100mL) | Percent Difference (%) |
| HAR-HAR | ≥1,600 | ≥1,600 | 0 |
| STR-HAR | ≥1,600 | 1,600 | 0 |

*E. Coli*:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | *E. Coli* (MPN/100mL) | Standard Deviation | 0 |
| HAR-HAR B | ≥1,600 | | |
| HAR-HAR C | ≥1,600 | Coefficient Of Variance (%) | 0 |
| HAR-HAR D | ≥1,600 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank *E. Coli* (MPN/100mL) | Original *E. Coli* (MPN/100mL) | Absolute Difference |
| HAR-HAR A | 2 | 0 | 2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD *E. Coli* (MPN/100mL) | BioVir *E. Coli* (MPN/100mL) | Percent Difference (%) |
| Sample not processed, laboratory error | | | |

Quality Assurance Manger:

Julie Hager
________________________________

Date:
6 Mar 03
__________________

Quality Control Evaluation
Sample collection date: 14 Mar 03
Lab analysis date: 19 Mar 03

Fecal Coliform:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | Fecal Coliform (MPN/100mL) | Standard Deviation | 173 |
| HAR-RAU B | 600 | | |
| HAR-RAU C | 300 | Coefficient Of Variance (%) | 43 |
| HAR-RAU D | 300 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank Fecal Coliform (MPN/100mL) | Original Fecal Coliform (MPN/100mL) | Absolute Difference |
| HAR-RAU A | <2 | 0 | <2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD Fecal Coliform (MPN/100mL) | BioVir Fecal Coliform (MPN/100mL) | Percent Difference (%) |
| Not collected, laboratory closed | | | |

*E. Coli*:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | *E. Coli* (MPN/100mL) | Standard Deviation | 115 |
| HAR-RAU B | 500 | | |
| HAR-RAU C | 300 | Coefficient Of Variance (%) | 31 |
| HAR-RAU D | 300 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank *E. Coli* (MPN/100mL) | Original *E. Coli* (MPN/100mL) | Absolute Difference |
| HAR-RAU A | <2 | 0 | <2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD *E. Coli* (MPN/100mL) | BioVir *E. Coli* (MPN/100mL) | Percent Difference (%) |
| Not collected, laboratory closed | | | |

Quality Assurance Manger:

Julie Hager

Date:
25 Mar 03

Quality Control Evaluation
Sample collection date: 18 Mar 03
Lab analysis date: 24 Mar 03

Fecal Coliform:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | Fecal Coliform (MPN/100mL) | Standard Deviation | 23 |
| WAT-PAJ B | 130 | | |
| WAT-PAJ C | 170 | Coefficient Of Variance (%) | 16 |
| WAT-PAJ D | 130 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank Fecal Coliform (MPN/100mL) | Original Fecal Coliform (MPN/100mL) | Absolute Difference |
| WAT-PAJ A | <2 | 0 | <2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD Fecal Coliform (MPN/100mL) | BioVir Fecal Coliform (MPN/100mL) | Percent Difference (%) |
| WAT-LEE | 700 | 80 | 89 |
| HAR-HAR | 1,300 | 700 | 46 |

*E. Coli*:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | *E. Coli* (MPN/100mL) | Standard Deviation | 23 |
| WAT-PAJ B | 130 | | |
| WAT-PAJ C | 170 | Coefficient Of Variance (%) | 16 |
| WAT-PAJ D | 130 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank *E. Coli* (MPN/100mL) | Original *E. Coli* (MPN/100mL) | Absolute Difference |
| WAT-PAJ A | <2 | 0 | <2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD *E. Coli* (MPN/100mL) | BioVir *E. Coli* (MPN/100mL) | Percent Difference (%) |
| WAT-LEE | 110 | 80 | 27 |
| HAR-HAR | 340 | 500 | 47 |

Quality Assurance Manger:

Julie Hager
_______________________________

Date:
28 Mar 03
________________

Quality Control Evaluation
Sample collection date: 20 Mar 03
Lab analysis date: 25 Mar 03

Fecal Coliform:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | Fecal Coliform (MPN/100mL) | Standard Deviation | 15 |
| WAT-HAR B | 40 | | |
| WAT-HAR C | <20 (10) | Coefficient Of Variance (%) | 65 |
| WAT-HAR D | 20 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank Fecal Coliform (MPN/100mL) | Original Fecal Coliform (MPN/100mL) | Absolute Difference |
| WAT-HAR A | <2 | 0 | <2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD Fecal Coliform (MPN/100mL) | BioVir Fecal Coliform (MPN/100mL) | Percent Difference (%) |
| WAT-HAR | 20 | 13 | 35 |

*E. Coli*:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | *E. Coli* (MPN/100mL) | Standard Deviation | 15 |
| WAT-HAR B | 40 | | |
| WAT-HAR C | <20 (10) | Coefficient Of Variance (%) | 65 |
| WAT-HAR D | 20 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank *E. Coli* (MPN/100mL) | Original *E. Coli* (MPN/100mL) | Absolute Difference |
| WAT-HAR A | <2 | 0 | <2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD *E. Coli* (MPN/100mL) | BioVir *E. Coli* (MPN/100mL) | Percent Difference (%) |
| WAT-HAR | 20 | 13 | 35 |

Quality Assurance Manger:

Julie Hager

Date:
2 Apr 03

Quality Control Evaluation
Sample collection date: 19 Jun 03
Lab analysis date: 20 Jun 03

Fecal Coliform:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | Fecal Coliform (MPN/100mL) | Standard Deviation | 896 |
| STR-LEE B | 800 | | |
| STR-LEE C | 2,400 | Coefficient Of Variance (%) | 66 |
| STR-LEE D | 900 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank Fecal Coliform (MPN/100mL) | Original Fecal Coliform (MPN/100mL) | Absolute Difference |
| STR-LEE A | <2 | 0 | <2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD Fecal Coliform (MPN/100mL) | BioVir Fecal Coliform (MPN/100mL) | Percent Difference (%) |
| Not collected | | | |

*E. Coli*:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | *E. Coli* (MPN/100mL) | Standard Deviation | 240 |
| STR-LEE B | 20 | | |
| STR-LEE C | 500 | Coefficient Of Variance (%) | 92 |
| STR-LEE D | 260 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank *E. Coli* (MPN/100mL) | Original *E. Coli* (MPN/100mL) | Absolute Difference |
| STR-LEE A | <2 | 0 | <2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD *E. Coli* (MPN/100mL) | BioVir *E. Coli* (MPN/100mL) | Percent Difference (%) |
| Not collected | | | |

Quality Assurance Manger:

Julie Hager

Date:
30 Jun 03

Quality Control Evaluation
Sample collection date: 26 Jun 03
Lab analysis date: 1 Jun 03

Fecal Coliform:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | Fecal Coliform (MPN/100mL) | Standard Deviation | 850 |
| WAT-HAR B | 800 | | |
| WAT-HAR C | 1,100 | Coefficient Of Variance (%) | 59 |
| WAT-HAR D | 2,400 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank Fecal Coliform (MPN/100mL) | Original Fecal Coliform (MPN/100mL) | Absolute Difference |
| WAT-HAR A | <2 | 0 | <2 |

| <u>Inter-Laboratory Comparison</u> (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD Fecal Coliform (MPN/100mL) | BioVir Fecal Coliform (MPN/100mL) | Percent Difference (%) |
| WAT-HAR E | 1,433 | 130 | 91 |
| WAT-AND B | 16,000 | 300 | 98 |

*E. Coli*:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | *E. Coli* (MPN/100mL) | Standard Deviation | 121 |
| WAT-HAR B | 300 | | |
| WAT-HAR C | 90 | Coefficient Of Variance (%) | 76 |
| WAT-HAR D | 90 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank *E. Coli* (MPN/100mL) | Original *E. Coli* (MPN/100mL) | Absolute Difference |
| WAT-HAR A | <2 | 0 | <2 |

| <u>Inter-Laboratory Comparison</u> (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD *E. Coli* (MPN/100mL) | BioVir *E. Coli* (MPN/100mL) | Percent Difference (%) |
| WAT-HAR E | 160 | 130 | 19 |
| WAT-AND B | 500 | 300 | 40 |

Quality Assurance Manger:

Julie Hager

Date:
10 Jul 03

Quality Control Evaluation
Sample collection date: 1 Jul 03
Lab analysis date: 3 Jul 03

Fecal Coliform:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | Fecal Coliform (MPN/100mL) | Standard Deviation | 500 |
| WAT-AND B | 800 | | |
| WAT-AND C | 300 | Coefficient Of Variance (%) | 63 |
| WAT-AND D | 1,300 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank Fecal Coliform (MPN/100mL) | Original Fecal Coliform (MPN/100mL) | Absolute Difference |
| WAT-AND A | <2 | 0 | <2 |

| <u>Inter-Laboratory Comparison</u> (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD Fecal Coliform (MPN/100mL) | BioVir Fecal Coliform (MPN/100mL) | Percent Difference (%) |
| WAT-AND E | 800 | 300 | 63 |
| STR-CHE B | 16,000 | 16,000 | 0 |

*E. Coli*:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | *E. Coli* (MPN/100mL) | Standard Deviation | 500 |
| WAT-AND B | 800 | | |
| WAT-AND C | 300 | Coefficient Of Variance (%) | 63 |
| WAT-AND D | 1,300 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank *E. Coli* (MPN/100mL) | Original *E. Coli* (MPN/100mL) | Absolute Difference |
| WAT-AND A | <2 | 0 | <2 |

| <u>Inter-Laboratory Comparison</u> (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD *E. Coli* (MPN/100mL) | BioVir *E. Coli* (MPN/100mL) | Percent Difference (%) |
| WAT-AND E | 800 | 300 | 63 |
| STR-CHE B | 270 | 16,000 | 5,826 |

Quality Assurance Manger:

Julie Hager
____________________________________

Date:
10 Jul 03
____________________

Quality Control Evaluation
Sample collection date: 8 Jul 03
Lab analysis date: 9 Jul 03

Fecal Coliform:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | Fecal Coliform (MPN/100mL) | Standard Deviation | 0 |
| WAT-SHE B | 900 | | |
| WAT-SHE C | 900 | Coefficient Of Variance (%) | 0 |
| WAT-SHE D | 900 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank Fecal Coliform (MPN/100mL) | Original Fecal Coliform (MPN/100mL) | Absolute Difference |
| WAT-SHE A | <2 | 0 | <2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD Fecal Coliform (MPN/100mL) | BioVir Fecal Coliform (MPN/100mL) | Percent Difference (%) |
| WAT-SHE E | 900 | 300 | 67 |

*E. Coli*:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | *E. Coli* (MPN/100mL) | Standard Deviation | 0 |
| WAT-SHE B | 900 | | |
| WAT-SHE C | 900 | Coefficient Of Variance (%) | 0 |
| WAT-SHE D | 900 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank *E. Coli* (MPN/100mL) | Original *E. Coli* (MPN/100mL) | Absolute Difference |
| WAT-SHE A | <2 | 0 | <2 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD *E. Coli* (MPN/100mL) | BioVir *E. Coli* (MPN/100mL) | Percent Difference (%) |
| WAT-SHE E | 900 | 300 | 67 |

Quality Assurance Manger:

Julie Hager

Date:
30 Jul 03

Quality Control Evaluation
Sample collection date: 16 Jul 03
Lab analysis date: 17 Jul 03

Fecal Coliform:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | Fecal Coliform (MPN/100mL) | Standard Deviation | 35 |
| WAT-PAJ B | 110 | | |
| WAT-PAJ C | 80 | Coefficient Of Variance (%) | 46 |
| WAT-PAJ D | 40 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank Fecal Coliform (MPN/100mL) | Original Fecal Coliform (MPN/100mL) | Absolute Difference |
| WAT-PAJ A | 40 | 0 | 40 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD Fecal Coliform (MPN/100mL) | BioVir Fecal Coliform (MPN/100mL) | Percent Difference (%) |
| Not collected | | | |

*E. Coli*:

| Sample Replicates (precision or environmental variability): | | | |
|---|---|---|---|
| Sample ID | *E. Coli* (MPN/100mL) | Standard Deviation | 35 |
| WAT-PAJ B | 110 | | |
| WAT-PAJ C | 80 | Coefficient Of Variance (%) | 46 |
| WAT-PAJ D | 40 | | |

| Field Blank (field method assessment): | | | |
|---|---|---|---|
| Sample ID | Blank *E. Coli* (MPN/100mL) | Original *E. Coli* (MPN/100mL) | Absolute Difference |
| WAT-PAJ A | 40 | 0 | 40 |

| Inter-Laboratory Comparison (laboratory method assessment): | | | |
|---|---|---|---|
| Sample ID | MCHD *E. Coli* (MPN/100mL) | BioVir *E. Coli* (MPN/100mL) | Percent Difference (%) |
| Not collected | | | |

Quality Assurance Manger:

Julie Hager

Date:
30 Jul 03