CLEAN

Central Coast Long-term Environmental Assessment Network

REGIONAL MONITORING PROGRAM

Lead Agency:

Annual Report 2008–2009

January 31, 2010

City of Watsonville
P.O. Box 50000 • Watsonville • California • 95077-5000 • 831.768.3100

2008–2009 Annual Report

Central Coast Long-term Environmental Assessment Network

Submitted to:

California Water Board
Central Coast Region
895 Aerovista Place, Suite 101
San Luis Obispo, CA 93401

Submitted by:

CCLEAN
P.O. Box 8346
Santa Cruz, CA 95061

January 31, 2010

Table of Contents

List of Figures

List of Tables

Central Coast Long-term Environmental Assessment Network

2008-2009 Annual Report

1.0 Executive Summary

The 2008-2009 Central Coast Long-term Environmental Assessment Network (CCLEAN) annual report incorporates the results from 2008-2009 with historic data. Major findings are as follows:

- Nearshore waters of Monterey Bay continue to be impaired due to polychlorinated biphenyl (PCB) concentrations that exceed the Ocean Plan objective for the protection of human health. PCBs in Monterey Bay do not exhibit consistent trends over time. Although there have been samples of nearshore water that have approached or exceeded the Ocean Plan objectives for the pesticide Dieldrin and polynuclear aromatic hydrocarbons (PAHs), there are not consistent patterns of exceedances for these two persistent organic pollutants (POPs) that would warrant special concern. Statistical analyses indicated that, at the current sampling frequency and number of sites, a minimum of 6.3 and probably 11–12 years would be required to detect a significant trend in PCB concentrations below the Ocean Plan objective.
  Recommendation: Sampling of nearshore waters should continue to document the effects on ocean waters caused by discharges from land.
- DDT concentrations in sediments at CCLEAN sites have been stable, except for large increases measured at two sites in 2006. All DDT measurements in sediment samples from historic CCLEAN sites have exceeded the National Oceanic and Atmospheric Administration, Effects Range Low (NOAA ERL; Long et al. 1998; Long et al, 2000), although these DDT concentrations have had no obvious ecological effects. Four new sites sampled near the mouths of the Salinas and Pajaro rivers had much lower concentrations of DDTs than sites along the 80-meter contour and while the sites near the Pajaro River exhibited distributions of DDT homologues similar to deeper sites, shallow nearshore sites are not as useful as deeper sites for measuring trends and effects of POPs.
  Recommendation: The four sites near the Salinas and Pajaro rivers should be moved back to historic sites on the 80-meter contour.
- Mussels along the shore of Monterey Bay contain high concentrations of POPs, primarily Dieldrin. Dieldrin concentrations exceeding the California Office of Environmental Health Hazard Assessment (OEHHA) human health alert level have been frequently measured at Laguna Creek and The Hook although samples from March 2009 contained the lowest concentrations of Dieldrin measured at each site and all sites were below the OEHHA alert level.
  Recommendation: Mussel sampling should continue unchanged.
- There have been no bacterial impairments to the water contact recreation beneficial use associated with discharges from any of the CCLEAN wastewater treatment plants. No

exceedances of Ocean Plan objectives were noted at any near-discharge sampling sites. Statistical analyses detected no differences between near-field and far-field samples.

Recommendation: The CCLEAN participants have previously asserted their desire to continue monitoring receiving water bacteria, even in the absence of demonstrable effects of their discharges on beneficial uses. The results from the ongoing study of fecal pathogens by CCLEAN in collaboration with University of California at Davis and California Department of Fish and Game could inform future recommendations for more meaningful indicators of potential risks from pathogens.

- Except for PBDEs and PFCs, concentrations of most POPs in wastewater remain lower than those previously measured in rivers. While resulting loads have often been much higher from rivers, wastewater loads are similar to river loads in some years with low river discharges. Exceedances of a maximum NPDES permitted effluent limits have been very rare. The percentage of PBDE homologues in total polybrominated diphenyl ethers (PBDEs) is different for wastewater and river discharges, suggesting different sources or effects of wastewater treatment. The percentages of different perfluorinated compounds (PFC) compounds in total PFCs was generally similar between wastewater discharges and the Pajaro River, except for March 2009 when only one PFC compound was detected in the river. The proportions of different PFC compounds in CCLEAN wastewater discharges is similar to those reported for 21 European wastewater discharges. PFCs were not detected in ocean water or mussels and only two PFCs were detected in sediments at one 80-meter contour site and only one PFC was detected in the other 80-meter contour site.

  Recommendation: Wastewater monitoring should continue as it is currently conducted. Analysis of dioxins/furans and PFCs began in October 2008 and several years of data for those contaminants should be evaluated before considering revisions to wastewater sampling. If PFCs continue to be undetectable in ocean water and mussels, elimination of their measurement can be considered.

2.0 Program Background

The complexity of environmental issues affecting nearshore marine waters today have led to general agreement that their protection is only possible by implementing regional approaches to monitoring and resource management. Nearshore marine waters are affected by point-source discharges, storm runoff, rivers, discharges from ships, and aerial deposition. At the same time, many marine resources are diminishing under pressure from increasing usage. In the late 1990s, multiple agencies in the Monterey Bay area began working toward implementation of a regional approach to monitoring watersheds and marine waters.

CCLEAN is a long-term monitoring program that has been designed by program participants through a commitment to environmental stewardship in order to fulfill several regulatory objectives. CCLEAN is currently funded by the City of Santa Cruz, the City of Watsonville, Dynegy, Moss Landing, Monterey Regional Water Pollution Control Agency (MRWPCA), and Carmel Area Wastewater District (CAWD), under the direction of the California Regional Water Quality Control Board, Central Coast Region (Water Board). CCLEAN fulfills a significant component of the subscribing agencies' compliance to their NPDES monitoring commitments, with an emphasis on receiving water monitoring. In addition, it represents a significant portion of their contributions to their communities' efforts at sustainability of their coastal environments. However, CCLEAN is also the current mechanism by which the Water Board fulfills part of its obligations under a monitoring framework developed to provide an ecosystem-based Water Quality Protection Program for the Monterey Bay National Marine Sanctuary. The monitoring framework evolved to fulfill the Water Board's obligations to the Management Plan for the Sanctuary. The Sanctuary's Management Plan includes a Memorandum of Agreement among eight federal, state, and regional agencies (including the Central Coast Regional Water Quality Control Board). The Water Board's framework for partial fulfillment of this Water Quality Protection Program is the Central Coast Ambient Monitoring Program (CCAMP). This multidisciplinary program includes sampling in watersheds that flow into coastal regions, in estuarine coastal confluences, and at coastal sites. The goal of CCAMP is to "collect, assess, and disseminate scientifically based water quality information to aid decision-makers and the public in maintaining, restoring, and enhancing water quality and associated beneficial uses." CCLEAN provides the initial nearshore component of CCAMP. CCLEAN has been underway since 2001 and its Quality Assurance Project Plan (QAPP) is being revised to incorporate recent program changes, and to retain consistency with the Water Board surface water ambient monitoring program (SWAMP) requirements for data compatibility.

Within the framework of CCAMP, the goal of the CCLEAN program is to assist stakeholders in maintaining, restoring, and enhancing nearshore water and sediment quality to support associated beneficial uses in the Central Coast Region, including recreation, wildlife habitat and biological communities. The program's objective is to use high-quality data to address the following questions and objectives:

- What are the major sources of contaminants to nearshore waters?
- What are the effects of wastewater discharges in nearshore waters?
- Do nearshore waters and sediments comply with California Ocean Plan?
- What are the status and long-term trends in the quality of nearshore waters, sediments, and associated beneficial uses?
- Develop a long-term database on trends in the quality of nearshore waters, sediments and associated beneficial uses.
- Ensure that the database is compatible with other regional monitoring efforts and regulatory requirements.
- Ensure that data are presented in ways that are understandable and relevant to the needs of stakeholders.

To answer these questions, CCLEAN uses various graphical and statistical approaches, as well as comparisons of data with numeric and narrative objectives, guidelines and alert levels from the California Ocean Plan (State Water Resources Control Board 2005), Central Coast Basin Plan (RWQCB 1997), California State Mussel Watch Program (California State Mussel Watch Program 2003), California Office of Environmental Health Hazard Assessment (Office of Environmental Health Hazard Assessment 2003), and the National Oceanic and Atmospheric Administration (Long et al. 1998; Long et al. 2000).

3.0 Report Organization and Scope

This document incorporates the results from 2008-2009 in focused examinations designed to improve the efficiency of the CCLEAN program and guide management actions to reduce impairments of beneficial uses associated with discharges of persistent organic pollutants (POPs) to the ocean. Graphical and statistical presentations emphasize six POP groups that have either been associated with beneficial use impairments in previous CCLEAN reports or are pollutants of emerging concern that currently are not regulated by NPDES waste discharge permits (Table 1). In Section 4.2 (4.2 What are the major sources of contaminants to nearshore waters?), the report focuses on the first data for perfluorinated compounds reported by CCLEAN. Results are organized according the major program objectives listed in Section 2.

Table 1. POP groups emphasized in this report.

POP Group	Names of Compounds Included
PAHs	Polynuclear aromatic hydrocarbons: Biphenyl, Naphthalene, 1-methylnapthalene, 2-methylnapthalene, 2,6-dimethylnapthalene, 2,3,5-trimethylnapthalene, Acenaphthene, Acenaphthylene, Anthracene, Dibenzothiophene, Fluorene, Phenanthrene, 1-methylphenanthrene, Benz(a)anthracene, Chrysene, Fluoranthene, Pyrene, Benzo(a)pyrene, Benzo(e)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Dibenz(a,h)anthracene, Perylene, Benzo(ghi)perylene, Indeno(1,2,3-cd)pyrene
DDTs	o,p'-DDT, p,p'-DDT = (1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane) o,p'-DDD, p,p'-DDD = (1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethane) o,p'-DDE, p,p'-DDE = (1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene)
Dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4α,5,6,7,8,8α-octahydro-1,4-endo,exo-5,8-dimethanonaphthalene
Chlordanes	trans-Chlordane, cis-Chlordane, trans-Nonachlor, cis-Nonachlor, Oxychlordane, Heptachlor, Heptachlor epoxide
PCBs	Polychlorinated biphenyls: congener numbers = 5, 8, 18, 20, 21, 28, 31, 33, 43, 44, 49, 52, 56, 60, 61, 66, 70, 73, 74, 76, 80, 86, 87, 89, 90, 93, 95, 97, 99, 101, 105, 106, 110, 111, 115, 116, 117, 118, 127, 128, 132, 138, 139, 141, 149, 151, 153, 156, 158, 160, 163, 164, 168, 170, 174, 177, 180, 181, 182, 183, 187, 190, 194, 195, 196, 201, 203
PBDEs[1]	Polybrominated diphenyl ethers: congener numbers = 7, 8, 10, 11, 12, 13, 15, 17, 25, 28, 30, 32, 33, 35, 37, 47, 49, 51, 66, 71, 75, 77, 79, 85, 99, 100, 105, 116, 119, 120, 126, 128, 138, 140, 153, 154, 155, 166, 181, 183, 190, 203, 206, 207, 208, 209
PFCs[1]	Perfluorinated Compounds: PFOA (Perfluorooctanoic acid), PFOS (Perfluorooctane sulfonic acid), PFOSA, (Perfluorooctanesulfonamide), PFDoA (Perfluorododecanoic acid), PFDeA (Perfluorodecanoic acid), PFBA (Perfluorobutyric acid), PFHpA (Perfluoroheptanoic acid), PFNA (Perfluorononanoic acid), PFUnA (Perfluoroundecanoic acid), PFHxS (Perfluorohexane sulfonic acid), PFBuS (Perfluorobutane sulfonic acid), PFHxA (Perfluorinatedhexanoic acid), PFPeA (Perfluoropentanoic acid)

[1] = Currently not regulated by the California Ocean Plan.

Program monitoring activities during 2008-2009 (program year = July 1, 2008 – June 30, 2009) and their relationship to program objectives are shown in Table 2. Sampling sites are shown in

Figure 1 and the dates of sampling are shown in Table 3. All sampling methods have been described in previous CCLEAN reports (CCLEAN 2007). In 2008–2009, most sediment sampling sites were moved to near the mouths of the Salinas and Pajaro rivers, in an effort to more definitively document those rivers as the major sources of contaminated sediments entering Monterey Bay. Also in this year's report, CCLEAN has implemented a more conservative approach to calculating sums of analytes (e.g., PAHs, DDTs, PCBs, etc.), in which individual analytes whose reported values have received the SWAMP QA code of "JA" (i.e., peak detected,

Table 2. Sampling sites, parameters sampled, frequency of sampling, applicable water-quality stressors, and relevant program objectives for CCLEAN during the 2007–2008 program period.

Sampling Sites	Parameters Sampled at Each Site	Frequency of Sampling	Applicable Water-quality Stressors and Program Objectives
Water Sampling Four wastewater discharges (Santa Cruz, Watsonville, MRWPCA, CAWD) in effluent and one river (Pajaro)	30-day flow proportioned samples using automated pumping equipment, solid-phase-extraction techniques for persistent organic pollutants (POPs).	Twice per year (wet season and dry season)	Sources, loads, trends, effects and permit compliance for: POPs
	Grabs of effluent for ammonia and nitrate, turbidity, temperature, conductivity, pH, urea, orthophosphate, dissolved silica and total suspended solids	Monthly	Sources, loads, trends and permit compliance for: Nutrients
	Evaluate satellite imagery for algal blooms	Periodically	Effects of: Nutrients
30-ft contour sites for Santa Cruz, Watsonville and MRWPCA	Grabs for total and fecal coliform, *enterococcus*	At least monthly	Sources, trends, effects and permit compliance for: Pathogen indicators
Two nearshore background sites	30-day time-integrated samples using automated pumping equipment and solid-phase-extraction techniques for: POPs, nitrate, ammonia, urea, orthophosphate and dissolved silica, total suspended solids, temperature, conductivity, pH, total and fecal coliform, *enterococcus*	Twice per year (wet season and dry season)	California Ocean Plan compliance for: POPs Nutrients Pathogen indicators
Mussel Sampling Five rocky intertidal sites	One composite of 30-40 mussels for POPs, total and fecal coliform, and *enterococcus*	Annually in the wet season	Status, trends, effects and alert level comparisons for: POPs Pathogen indicators
Sediment Sampling Two sites along the 80-meter contour and two sites each immediately offshore the Salinas and Pajaro rivers	POPs, sediment grain size and total organic carbon, benthic infauna	Annually in the fall	Status, trends, effects and alert level comparisons for POPs

but did not meet quantification criteria, result reported represents the estimated maximum possible concentration) are excluded from summed concentrations.

Legend: ⊙ = Effluent & Receiving Water, ✚ = Mussels, ★ = Nearshore Background, • = River, ■ = Sediment

Figure 1. Locations of CCLEAN sampling sites for receiving water, sediment, mussels, and rivers.

Table 3. Dates, volumes and numbers of samples collected for CCLEAN in 2008–2009.

Matrix & Season	Site	Start Date	Ending Date	
Effluent				Number of Liters
Dry	Santa Cruz	August 15, 2008	October 6, 2008	268
	Watsonville	August 15, 2008	September 15, 2008	256
	MRWPCA	August 15, 2008	September 15, 2008	268
	CAWD	August 27, 2008	September 30, 2008	254
Wet	Santa Cruz	February 23, 2009	March 26, 2009	302
	Watsonville	February 24, 2009	March 26, 2009	263
	MRWPCA	February 24, 2009	March 26, 2009	269
	CAWD	February 24, 2008	March 26, 2009	278
River Sampling				Number of Liters
Dry	Pajaro River	August 27, 2008	September 26, 2008	201
Wet	Pajaro River	February 25, 2009	March 27, 2009	408
Nearshore Sampling				Number of Liters
Dry	North	November 7, 2008	December 9, 2008	200
	South	November 7, 2008	December 9, 2008	200
Wet	North	February 20, 2009	March 22, 2009	200
	South	February 20, 2009	March 22, 2009	200
Mussel Sampling				Mussels for POPs/Bacteria
	Scott Creek		March 24, 2009	42/30
	Laguna Creek		March 24, 2009	44/30
	The Hook		March 24, 2009	47/30
	Fanshell Overlook		March 24, 2009	45/30
	Monterey Creek		March 24, 2009	45/30
	Carmel River Beach		March 24, 2009	46/30

4.0 Results for Program Objectives

4.1 What are the status and long-term trends in the quality of nearshore waters, sediments, and associated beneficial uses?

Several elements of the CCLEAN program provide data that enable assessment of both the status and trends in the quality of nearshore waters, sediments and associated beneficial uses (see Table 1). These include sampling of nearshore waters for POPs, nutrients and bacteria; sediments for POPs and benthic infauna; and mussels for POPs and bacteria. Analysis of status involves comparisons with the objectives, guidelines and alert levels described in Section 2. Describing status also documents compliance with the Ocean Plan and other applicable regulatory guidelines, which can also indicate contaminant effects. Analysis of trends involves statistical tests to determine whether measured parameters are changing over time.

The analyses in this section are focused on particular contaminants that previously have been associated in CCLEAN reports either with a status that indicated impairment to beneficial uses or were very close to impairments. These include the following:

- PCBs, PAHs and Dieldrin in nearshore waters (i.e., exceeded 30-day average in California Ocean Plan [Ocean Plan] for the protection of human health)
- DDTs in sediments (i.e., exceeded NOAA ERL)
- Dieldrin in mussels (i.e., exceeded California Office of Environmental Health Hazard Assessment [OEHHA] human health alert level).

All of these impairments were discussed in CCLEAN (2007a). In addition to these previously noted impairments to beneficial uses, this consideration of status and trends also includes analysis of bacteria monitoring in ocean waters by each wastewater treatment plant. The following sections discuss the current status and trends of these contaminants in the associated matrices.

4.1.1 Status and Trends of PCBs, PAHs and Dieldrin in Nearshore Waters

Nearshore waters in Monterey Bay frequently exceed the Ocean Plan objective for 30-day average concentrations of PCBs. (Figure 2). Three out of nine samples from South Monterey Bay and five out of nine samples from North Monterey Bay have exceeded the Ocean Plan objective (i.e., 0.019 ng/L), with the March 2009 sample from North Monterey Bay exceeding this objective by 485%. There have been no consistent differences between sites or between wet-season and dry-season samples.

With the exception of the March 2006 sample from the northern Monterey Bay site, PAHs have been below the Ocean Plan objective for the protection of human health (Figure 3). Both sites exhibited relatively high concentrations of PAHs in March 2006, but displayed no substantial differences between sites or between wet-season and dry-season samples.

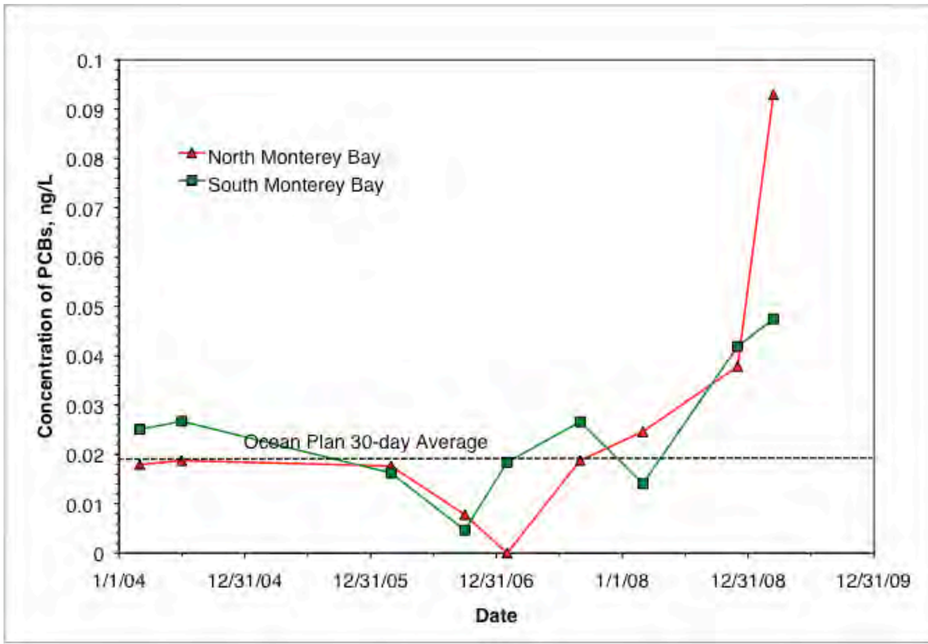

Figure 2. Concentrations of PCBs in nearshore waters at two CCLEAN sites in Monterey Bay.

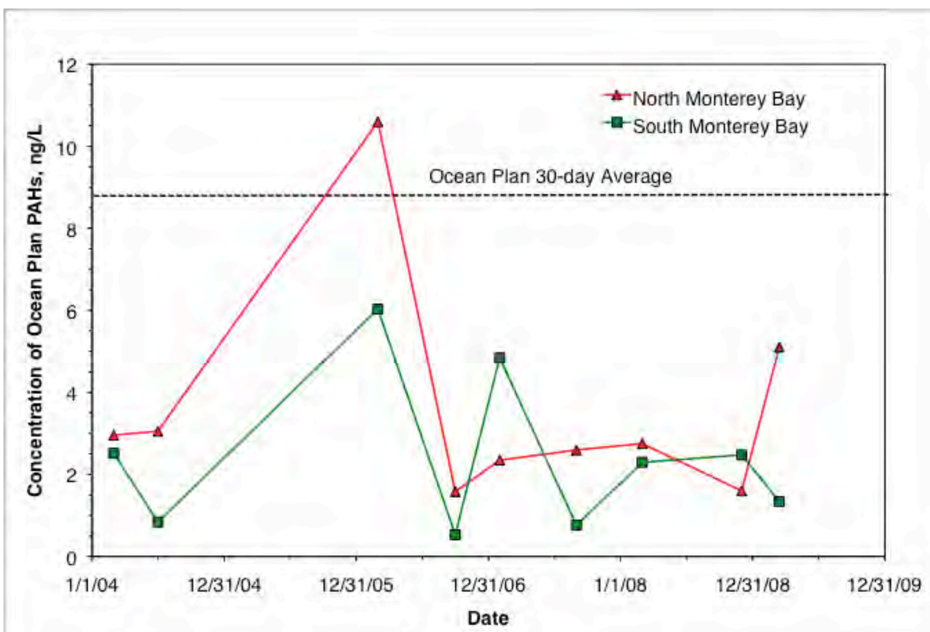

Figure 3. Concentrations of Ocean Plan PAHs in nearshore waters at two CCLEAN sites in Monterey Bay.

After the first sample from the North Monterey Bay site exceeded the Ocean Plan objective for Dieldrin, none of the samples collected since then have exceeded the Ocean Plan (Figure 4). The concentrations have been generally similar between sites, with wet-season samples usually exhibiting higher Dieldrin concentrations than corresponding dry-season samples.

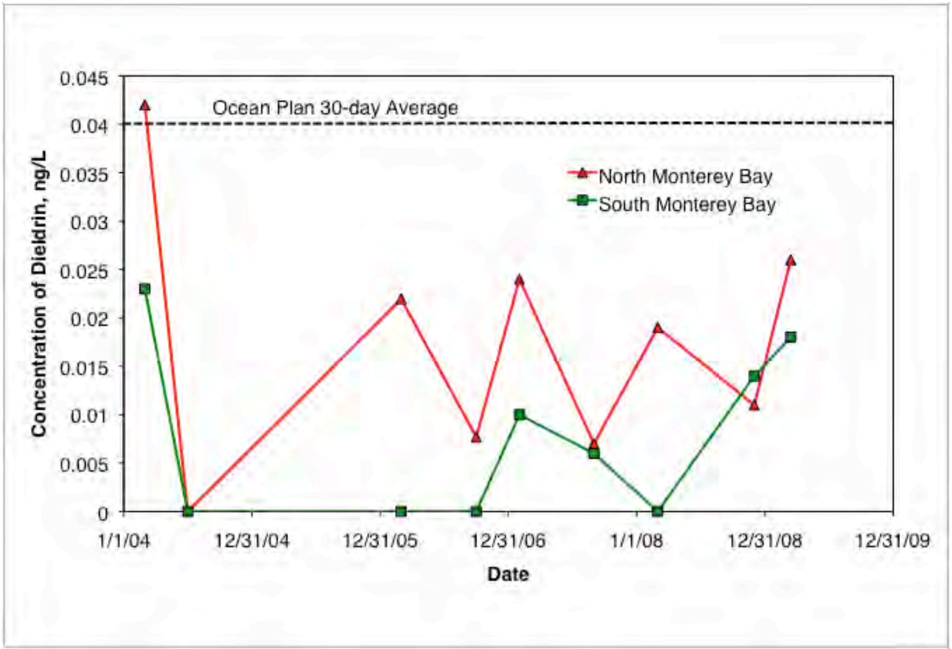

Figure 4. Concentrations of Dieldrin in nearshore waters at two CCLEAN sites in Monterey Bay.

According to State of California policy for designating impaired water bodies (State Water Resources Control Board 2004), Monterey Bay is impaired for PCBs. This policy established statistical criteria for the number of exceedances in the total sample size needed to place a water segment on the 303d list and for 2 – 24 samples, two exceedances are the minimum number needed to designate impairment. In fact, the eight exceedances for PCBs in Monterey Bay would satisfy the criteria for listing even if the sample size were 94.

There were few statistically significant trends in concentrations of PCBs, PAHs or Dieldrin. When wet- and dry-season samples were considered separately, only dry-season Dieldrin exhibited a significant increase over time ($r^2 = 0.76$, $p = 0.0048$). When data for both seasons were combined, only PCBs revealed a significant increase over time ($r^2 = 0.23$, $p = 0.0449$). Because more consistent exceedances of the Ocean Plan were detected for PCBs than either Dieldrin or PAHs, additional analyses were done to determine how many samples would be needed to detect a statistically significant decline in PCBs below the Ocean Plan objective.

The ability to detect a trend is limited by the amount of variation among samples and the rate of change in the trend (Nicholson et al. 1997). Such trend detection is important because it allows us to efficiently collect observations to determine whether a particular impairment is getting better or worse to determine, for example, whether management actions have been effective at reducing the observed impairment. A simple approximation for the amount of time necessary for PCB concentrations to decline below the Ocean Plan objective involves dividing the slope of the increase by the difference between the 2008-2009 mean concentrations and the objective. As the rate of increase has been 0.0057 ng/L per year (Figure 5), a minimum of 6.3 years would be required for the mean to drop below the objective, assuming the same rate of change for increases and decreases. Nicholson's 1997 publication includes a table that estimates the number of years needed to detect a significant trend, based upon the slope of the trend line and variation in the data. This method indicates 11–12 years would be needed to detect a significant trend with a significance level of 0.05 and power of 90%.

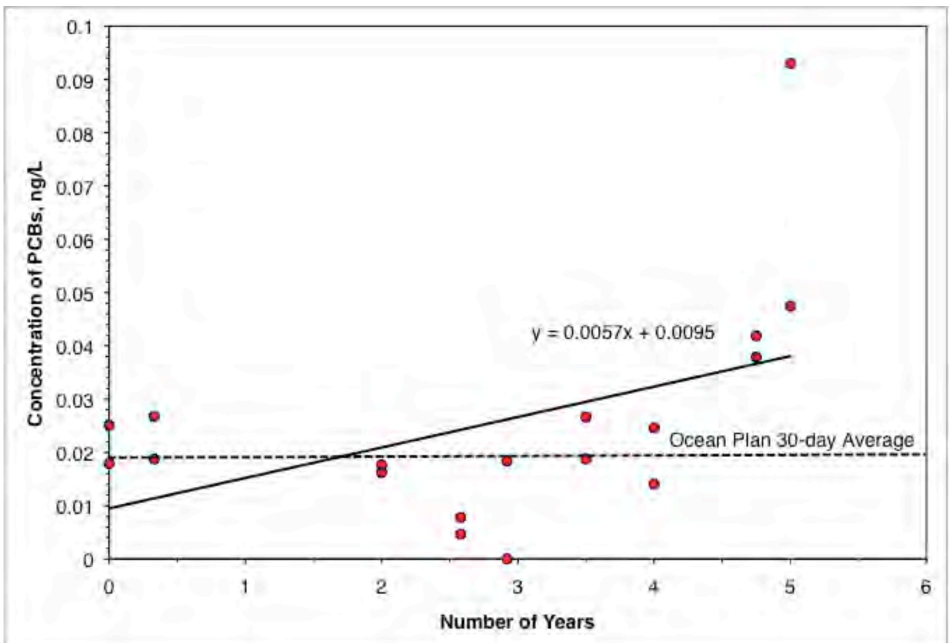

Figure 5. The trendline of PCBs in ocean waters at two CCLEAN nearshore sites compared with the Ocean Plan objective.

4.1.1.2 Conclusions

Nearshore waters of Monterey Bay continue to be impaired due to PCB concentrations that exceed the Ocean Plan objective for the protection of human health, with the 2008–2009 concentrations being the highest reported by CCLEAN for ocean waters. Monterey Bay should be considered for listing as impaired due to PCBs in the next revision of the Central Coast Region 303(d) list. Although there have been samples of nearshore water that have approached or exceeded the Ocean Plan objectives for PAHs and Dieldrin, there are not consistent patterns of exceedances for these two POPs that would warrant special concern.

Statistical analyses indicated that, at the current sampling frequency and number of sites, a minimum of 6.3 and probably 11–12 years would be required to detect a significant trend in PCBs concentrations below the Ocean Plan objective.

4.1.1.3. Recommendations

Sampling of nearshore waters should continue in order to document the effects on ocean waters caused by discharges from land.

4.1.2 Status, Trends and Effects of DDTs in Sediments

DDTs in sediments at sites along the 80-meter contour have consistently exceeded the concentration above which 10% of samples nationwide exhibited toxicity in 1,513 laboratory bioassays in an analysis conducted by the National Oceanic and Atmospheric Administration (Long et al. 2000) (Figure 6). Nevertheless, no ecological effects have been associated with high DDT concentrations in CCLEAN samples. DDT concentrations have historically been similar among CCLEAN sites and have not varied substantially among years, except for very unexplained high concentrations measured at sites SedRef 02 and SedDep 01 in 2006. These two sites are the two historic CCLEAN sediment sites that have been retained in the redesigned sediment-sampling element of the program.

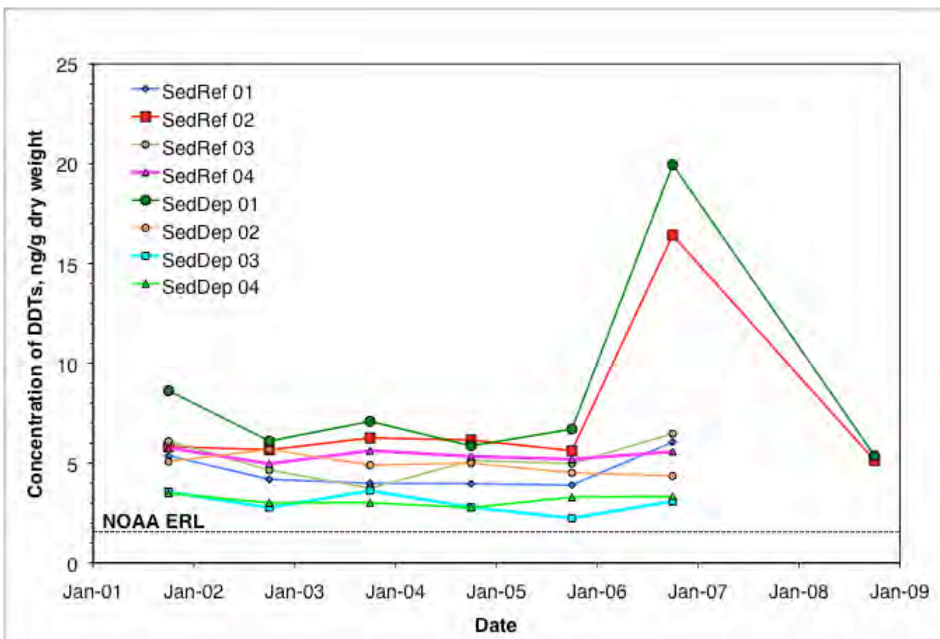

Figure 6. DDTs measured in sediments from historic CCLEAN sites in Monterey Bay.

Comparisons of DDT concentrations between SedRef 01, SedDep 02 and Source 01, Source 02, Source 03, and Source 04 do not document the Salinas and Pajaro rivers as the sources of DDTs flowing into Monterey Bay. DDT concentrations were uniformly lower at the four sites near the Salinas and Pajaro rivers than at the two retained sites along the 80-meter contour (Figure 7). There were also substantial differences in grains size distributions and total organic carbon (TOC) concentrations between the 80-meter contour sites and the near-river sites (Figure 8 and Figure 9). Because contaminants in sediments adsorb to fine particles and organic matter, there are often higher concentrations of contaminants in sediments with smaller particle sizes and greater concentrations of total organic carbon (TOC). DDT is known to vary according to TOC concentrations, however DDT concentrations normalized to TOC were still substantially higher at the two 80-meter contour sites than at the near-river sites (Figure 10).

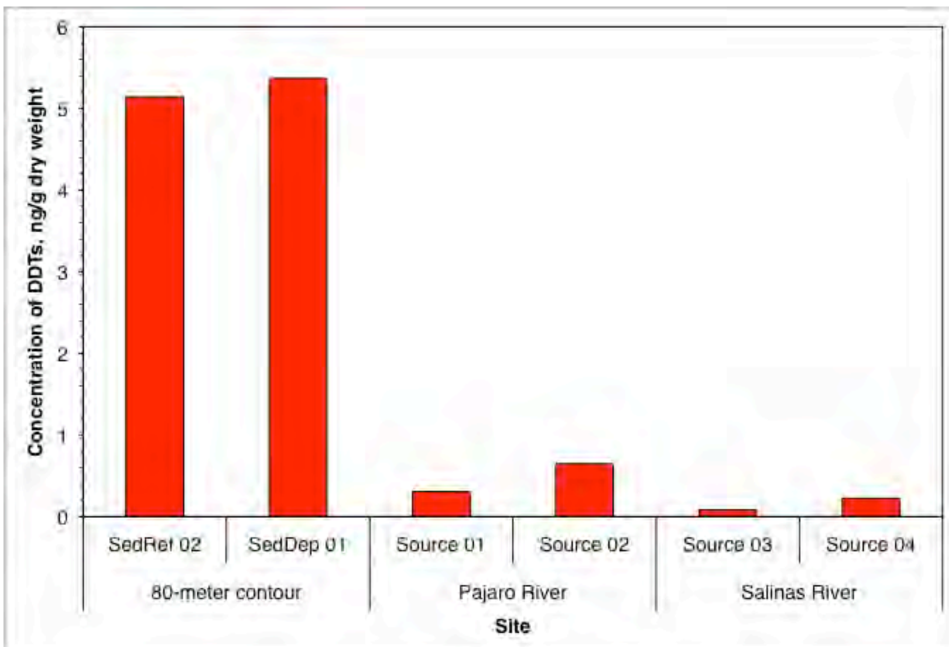

Figure 7. Concentrations of DDTs in sediments sampled at six sites in October 2008.

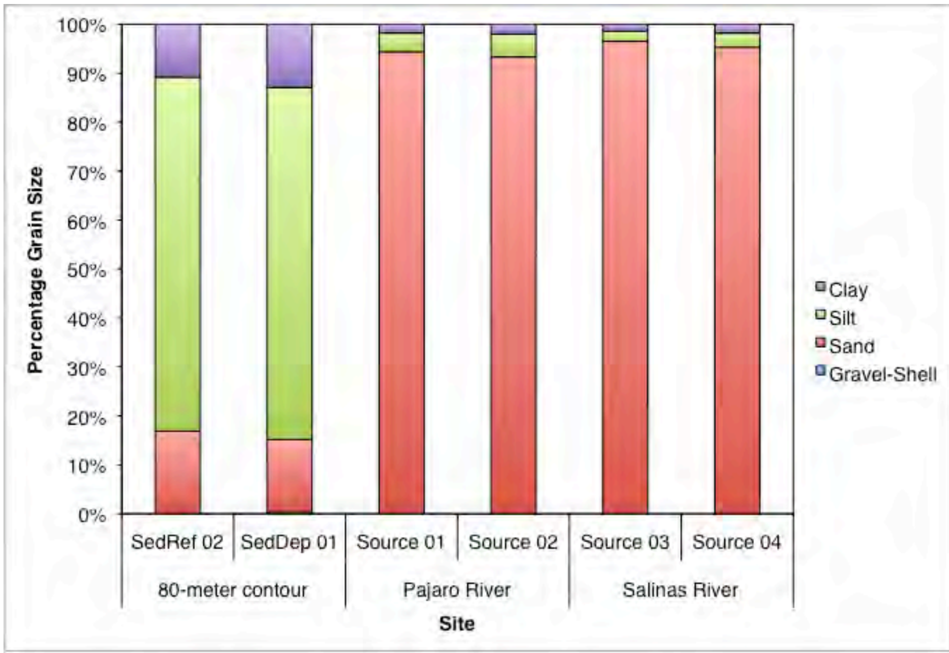

Figure 8. Grain size distribution in sediments sampled at six sites in October 2008.

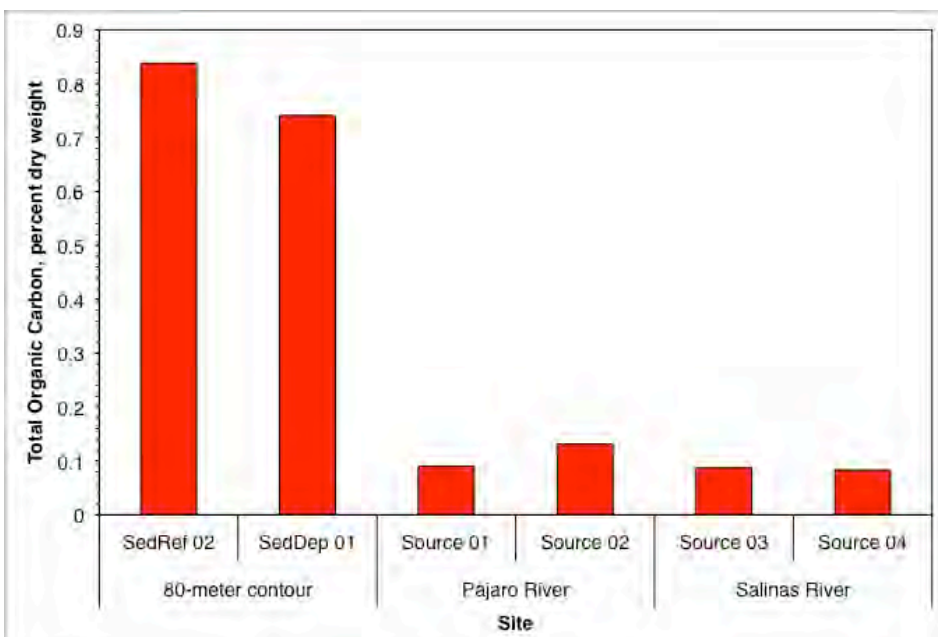

Figure 9. Total Organic Carbon in sediments sampled at six sites in October 2008.

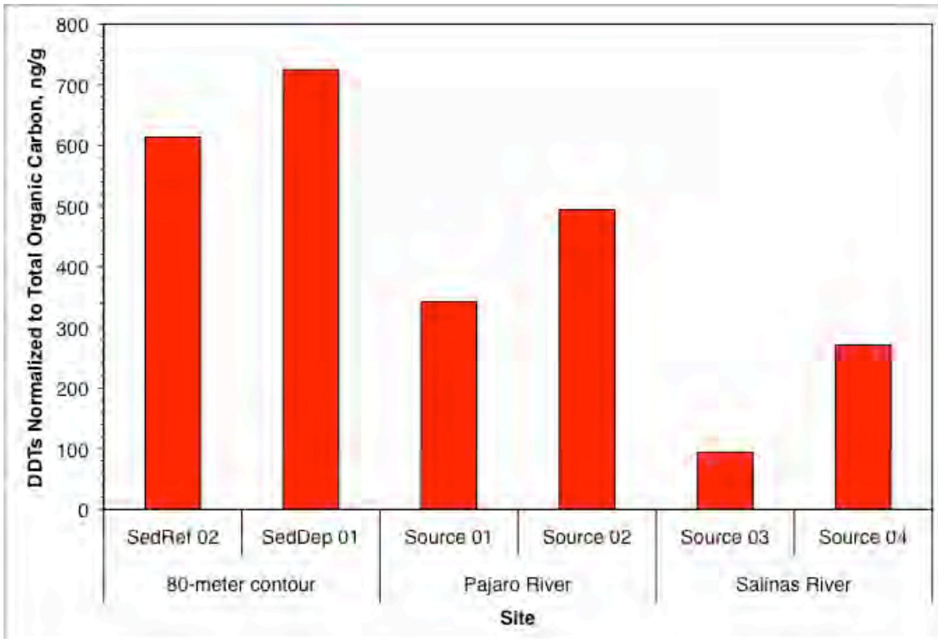

Figure 10. Concentrations of DDTs in sediments sampled at six sites in October 2008 normalized to TOC.

Although bulk and normalized DDT concentrations were very different between the 80-meter contour sites and the near-river sites, the mean percentage contributions of individual DDT homologues to total DDTs were similar between the 80-meter contour sites and the Pajaro River sites (Figure 11). Only these two areas had DDT homologues detected. DDT degrades into DDE and DDD and higher concentrations of DDT homologues is indicative of fresher, less degraded sources, suggesting that in 2008 less degraded DDTs were being discharged from the Pajaro River than from the Salinas River.

4.1.2.1 Conclusions

DDT concentrations in sediments at historic CCLEAN sites have been stable, except for large increases measured at two sites 2006. All DDT measurements at historic CCLEAN sites have exceeded the NOAA ERL. Although these DDT concentrations have had no obvious ecological effects, they are of concern and require continued measurement because of the documented distribution of DDTs from Monterey Bay onto the continental shelf and slope (Hartwell 2008). The low concentrations of DDTs at the four near-river sites probably would not be associated with detectable effects on the benthic community. The very low TOC and DDTs in sediments from these four sites suggest that inshore sites with very low sediment TOC, even those near the mouths of rivers, are not better than the 80-meter contour sites for measuring the effects of contaminated sediments washing off the land.

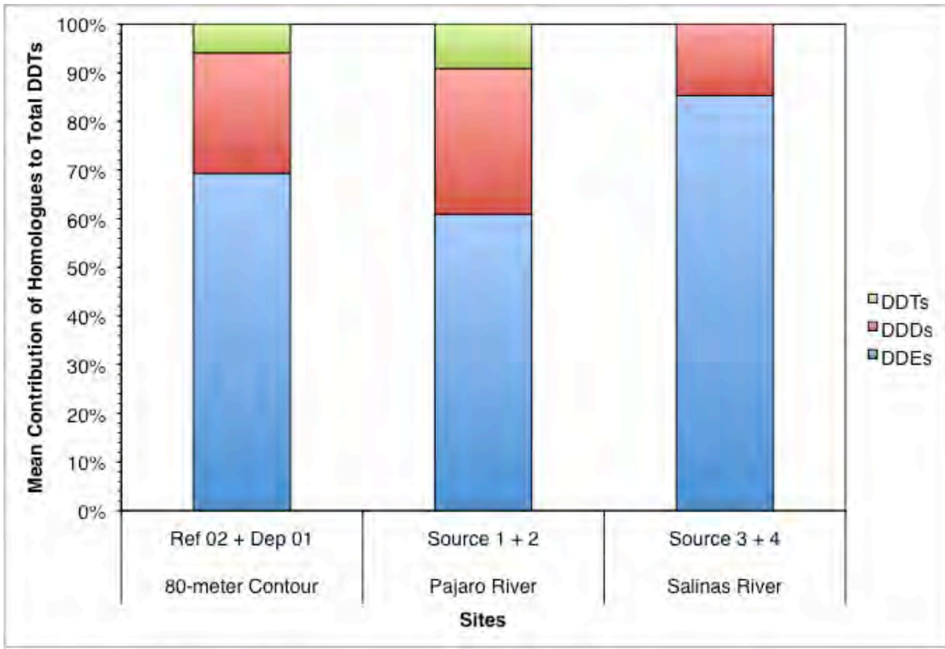

Figure 11. Mean percentage contribution to total DDTs by each of three homologues averaged over two sites in three areas.

4.1.2.2 Recommendations

The four sites that were located off the Salinas and Pajaro rivers in 2008 should be moved back to the 80-meter contour. It is recommended that they be re-established at historic sites SedRef 03, SedRef 04, SedDep 02 and SedDep 03.

4.1.3 Status and Trends of Dieldrin in Mussels

March 2009 marks the first CCLEAN mussel measurements for which none of the sites exceeded the OEHHA human health alert level for Dieldrin (Figure 12). Moreover, the March 2009 measurements were the lowest wet-season concentrations recorded for every site. None of the overall downward trends was statistically significant, although Carmel River Beach was marginally non-significant ($r^2 = 0.43$, $p = 0.079$). Previous analyses have shown that concentrations of Dieldrin in mussels are correlated with rainfall and river discharges (CCLEAN 2007; Hardin et al. 2007). Consequently, these declines in Dieldrin concentrations could be associated with the low rainfall amounts received by the region in the winter of 2008–2009. Future sampling will determine whether the low Dieldrin concentrations in March 2009 represent true attenuation of terrestrial sources or a temporary dip.

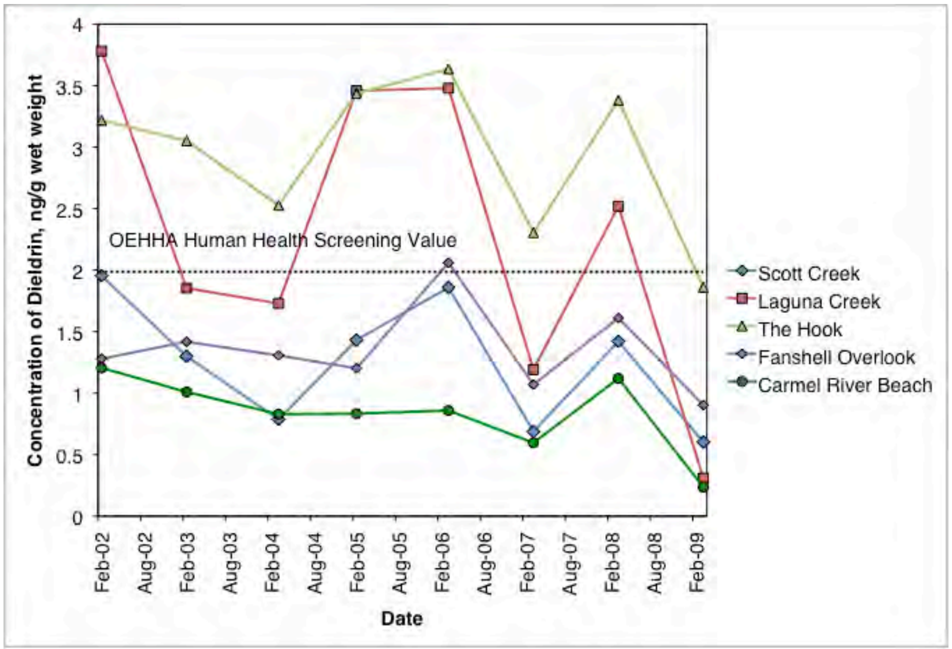

Figure 12. Dieldrin measured in mussels during the wet season from five CCLEAN sites in the Monterey Bay area.

4.1.3.1 Conclusions

Mussels along the chore of Monterey Bay contain high concentrations of POPs, primarily Dieldrin. Dieldrin concentrations exceeding the OEHHA human health alert level have been frequently measured at two locations. These high Dieldrin concentrations constitute an impairment of the shellfish collection beneficial use and are a potential risk to humans and wildlife that consume mussels.

4.1.3.2 Recommendations

Mussel sampling should continue unchanged. The mussel data collected have been very valuable in documenting impairments of beneficial uses, as well as supporting assessments of contaminant sources.

4.1.4 Status, Trends and Effects of Bacteria in Receiving Waters

The Ocean Plan limits the bacterial concentrations in ocean waters designated for use in water-contact recreation. These objectives are as follow:

30-day Geometric Mean:
i. Total coliform density shall not exceed 1,000 per 100 ml;
ii. Fecal coliform density shall not exceed 200 per 100 ml; and
iii. Enterococcus density shall not exceed 35 per 100ml.
Single Sample Maximum:
i. Total coliform density shall not exceed 10,000 per 100 ml;
ii. Fecal coliform density shall not exceed 400 per 100ml;

iii. Enterococcus density shall not exceed 104 per 100 ml; and
iv. Total coliform density shall not exceed 1,000 per 100 ml when the fecal coliform/total coliform ratio exceeds 0.1.

Receiving water data collected by the City of Santa Cruz, City of Watsonville and MRWPCA from July 2008 through June 2009 were compared with these objectives to assess the status of ocean waters for water contact recreation and the potential effects of wastewater on bacterial concentrations. CAWD is required to sample receiving water bacteria only if the total coliform concentration in their wastewater exceeds 2,400 MPN/100ml three or more times in a 30-day period, which has not occurred during the existence of the CCLEAN program. Because only Santa Cruz samples bacteria in receiving waters more than once per month, 30-day geometric means could not be calculated for most data and geometric means were, instead, calculated over the entire year.

There are no indications that the wastewater discharges are causing impairments to water contact recreation due to bacterial concentrations. Only the Ocean Plan *Enterococcus* single sample objective for water contact recreation was exceeded at the far-field receiving water monitoring station associated with the Santa Cruz discharge (Table 4). Moreover, in all cases except the geometric means for total and fecal coliform and the single sample maximum for total coliform at Watsonville, the sites nearest the discharges had lower values than the sites farther from the discharges. Fecal coliform concentrations at the station nearest the Watsonville discharge also were significantly greater than at the station farthest from the discharge. Nevertheless, the site nearest the Watsonville discharge is directly influenced by the Pajaro River, so these differences between the near-discharge station and the station farthest from the discharge cannot be ascribed to the discharge.

There were few temporal trends in bacteria concentrations near the CCLEAN wastewater discharges. Bacteria concentrations near each discharge tended to be greatest during the winter and spring months and lower in the summer and fall months (Figure 10, Figure 11 and Figure 12). Statistical analysis of log-transformed bacteria concentrations from 2003 to 2009 found significant increases over time only for total coliform at both Santa Cruz stations, although time accounted for less than 10% of the variation at these sites (Station A: $r^2 = 0.09$ $p = <0.0001$; Station G: $r^2 = 0.08$ $p = 0.0002$).

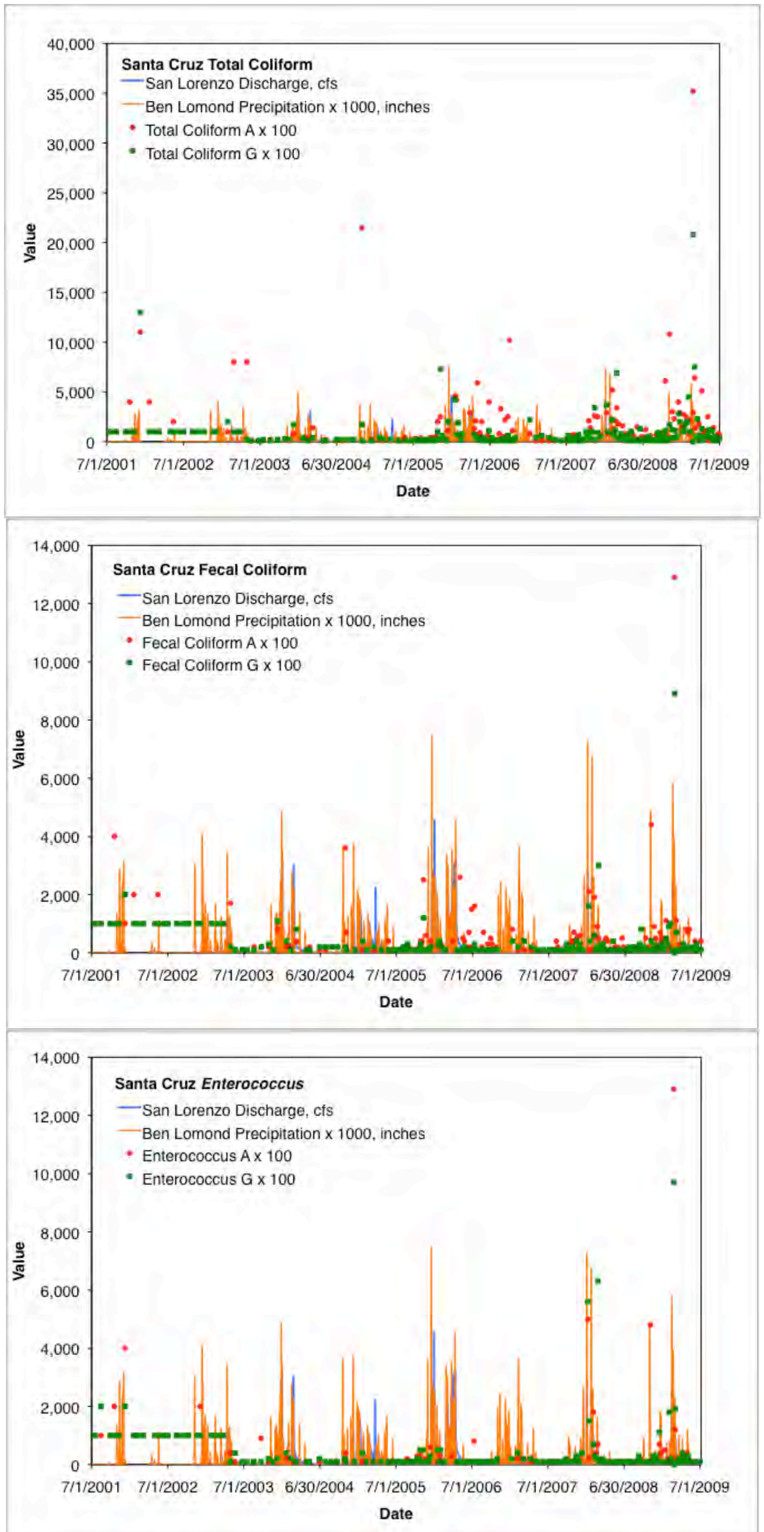

Figure 10. Receiving water bacteria measured at two stations near and far from the Santa Cruz wastewater discharge between July 2001 and June 2009, compared with local rainfall and flows from the San Lorenzo River. Values are scaled to fit on the same graph.

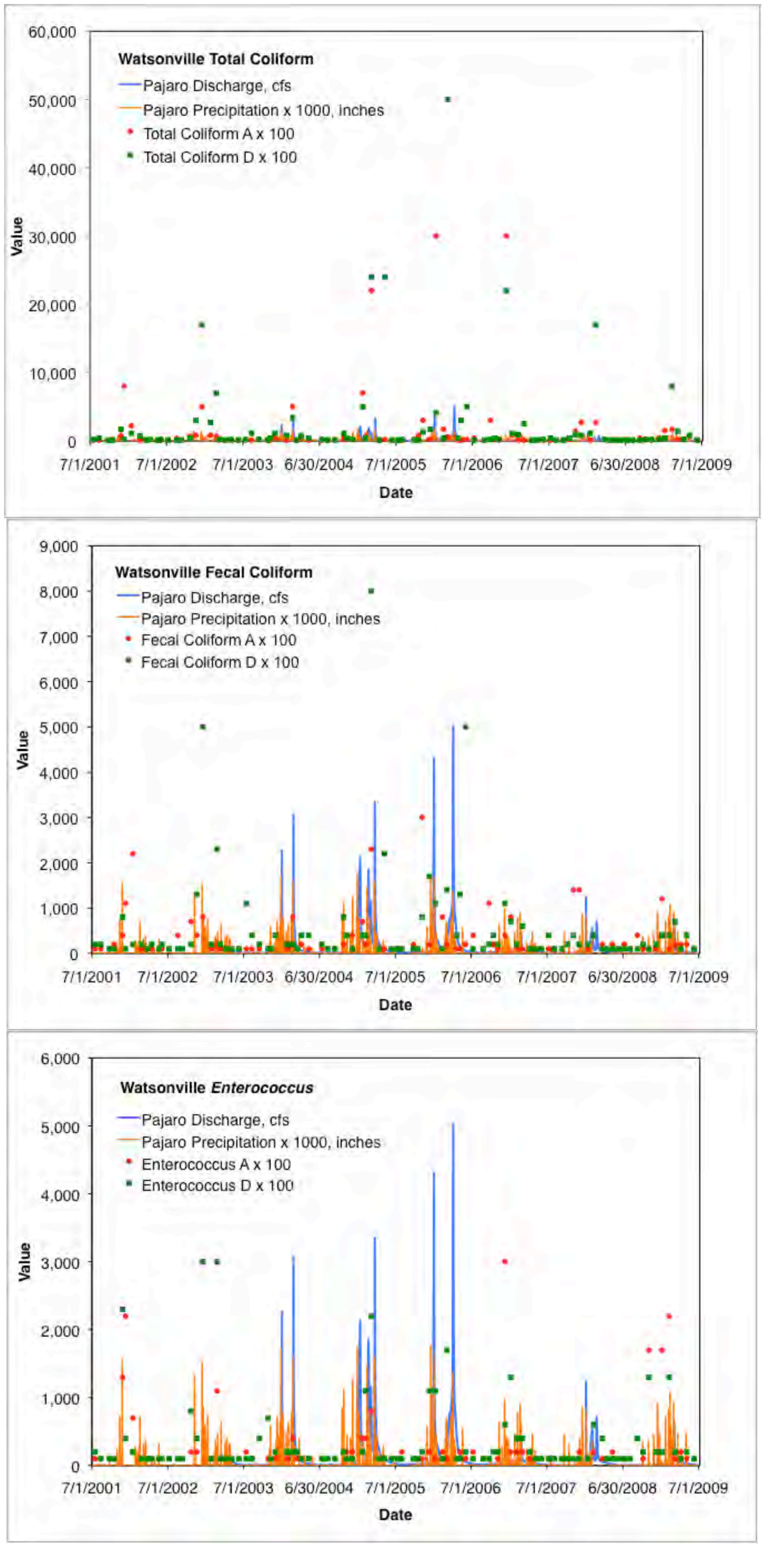

Figure 11. Receiving water bacteria measured at two stations near and far from the Watsonville wastewater discharge between July 2001 and June 2009, compared with local rainfall and flows from the Pajaro River. Values are scaled to fit on the same graph.

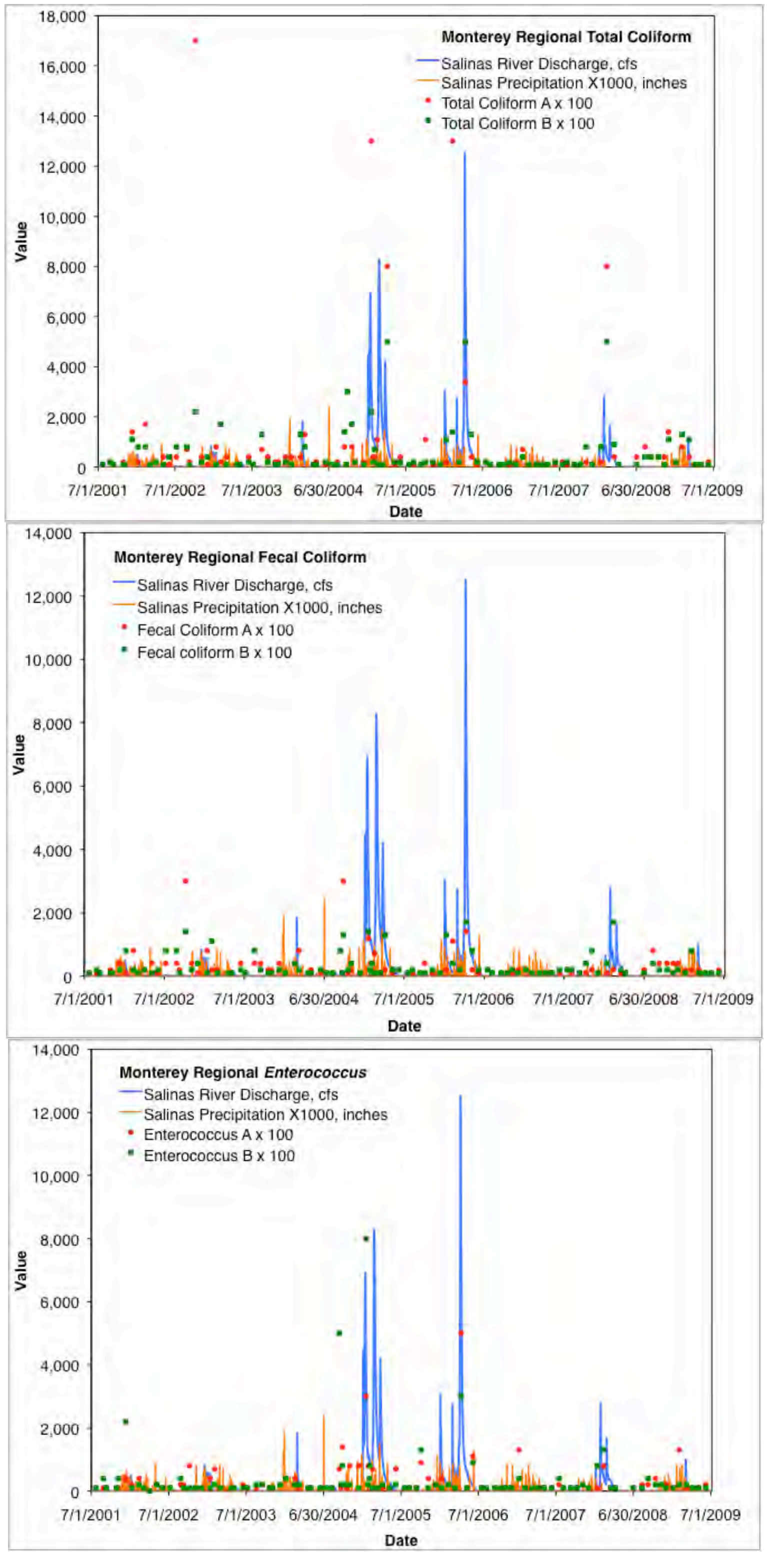

Figure 12. Receiving water bacteria measured at two stations near and far from the MRWPCA wastewater discharge between July 2001 and June 2009, compared with local rainfall and flows from the Salinas River. Values are scaled to fit on the same graph.

In addition to comparing bacteria data with Ocean Plan objectives, statistical procedures were used to evaluate the possible effects of wastewater discharges on bacterial concentrations in the ocean. Paired t-tests were performed to see if there were significant differences in bacteria concentrations between the station nearest to and a station farther from each respective wastewater discharge. It should be noted that the receiving water monitoring sites for the City of Santa Cruz are not located in relation to the wastewater discharge, but are situated along the shore to reflect actual bacterial exposures by swimmers and surfers, so these statistical tests may be less informative about the direct effects of the Santa Cruz discharge on receiving water bacteria concentrations. These paired t-tests found no significant differences between the near- and far-field sites for the 2008–2009 program year (Table 5).

Table 4. Geometric means and single sample maxima for indicator bacteria in receiving waters adjacent to ocean outfalls for three CCLEAN wastewater dischargers from July 2008 through June 2009.

			MPN/100 ml	
Agency	**Site**	**Total Coliform**	**Fecal Coliform**	**Enterococcus**
			Geometric Means	
Santa Cruz	A (far)	8.72	2.13	1.63
	G (near)	5.67	1.75	1.56
Watsonville	A (far)	2.96	1.74	2.61
	D (near)	3.02	1.87	2.30
MRWPCA	D (far)	3.52	2.52	1.86
	B (near)	2.77	1.59	1.41
			Single Sample Maxima	
Santa Cruz	A (far)	352	129	129
	G (near)	208	89	97
Watsonville	A (far)	17	12	22
	D (near)	80	7	13
MRWPCA	D (far)	14	8	13
	B (near)	13	8	4

Table 5. Results of paired t-tests for differences in bacteria concentrations between near-field and far-field sites adjacent to each wastewater discharge sampled from July 2008 through June 2009.

	Probability		
Agency	Total Coliform	Fecal Coliform	Enterococcus
Santa Cruz	0.9944	0.9723	0.8232
Watsonville	0.1902	0.5348	0.9211
MRWPCA	0.5685	0.8878	0.8610

4.1.4.1 Conclusions

There have been no bacterial impairments to the water contact recreation beneficial use associated with discharges from any of the CCLEAN wastewater treatment plants. Only the Ocean Plan *Enterococcus* single sample objective for water contact recreation was exceeded once at the farfield receiving water monitoring station adjacent to the Santa Cruz discharge. Statistical analyses detected no differences between near-field and far-field samples.

4.1.4.2 Recommendations

The CCLEAN participants have previously asserted their desire to continue monitoring receiving water bacteria, even in the absence of demonstrable effects of their discharges on beneficial uses. The results from the ongoing study of fecal pathogens by CCLEAN in collaboration with University of California at Davis and California Department of Fish and Game could inform future recommendations for more meaningful indicators of potential risks from pathogens.

4.2 What are the major sources of contaminants to nearshore waters?

4.2.1 Loads of POPs

CCLEAN continues to measure POPs in wastewater and the Pajaro River. POP concentrations in wastewater are usually much below limits established in each discharger's NPDES permit (Table 6). Only one permit exceedance was noted in 2008–2009 and that was for Dieldrin in wet-season sample from Carmel. Carmel also had lower PBDE concentrations than the other wastewater discharges, but higher PFC concentrations (Table 7). Wet-season concentrations of POPs were much higher in the Pajaro River than in most of the wastewater discharges, except for PBDEs and PFCs, which had consistently higher concentrations in wastewater.

CCLEAN has previously documented that discharges from rivers contain the greatest loads of contaminants to ocean waters from the sources measured in the Monterey Bay area (CCLEAN 2007). For some most POPs, cumulative loads from rivers constitute

Table 6. Concentrations of regulated (Ocean Plan) pollutants in CCLEAN lab blanks, equipment blanks, wastewater discharges (with NPDES permit limits for each discharger) and the Pajaro River.

Source & Date	PAHs, ng/L	PCBs, ng/L	DDTs, ng/L	Chlordanes, ng/L	HCHs, ng/L	Endosulfans, ng/L	Dieldrin, ng/L	Dioxins/Furans, TEQs
Lab Blank								
Sep-08	0	0.000941	0	0	0	0	0	0.00000186
Mar-09	0.0499	0.000336	0	0	0	0.006	0	0.00000743
Equip. Blank								
Sep-08	0.9268	0.01298	0	0.006	0	0	0	0.00000314
Mar-09	0.646	0.0147	0	0.009	0	0	0	0.000009
Santa Cruz								
Permit	1200	2.66	23.8	3.2	560	1260	5.6	0.000546
Sep-08	10.227	0.2625	0.104	0.212	0	0.069	0.091	0.000015
Mar-09	4.273	0.2936	0.199	0.61	0	0.09	0.538	0.000059
Watsonville								
Permit	748	1.62	14.45	1.96	340	770	3.4	0.000332
Sep-08	9.196	0.6790	0.538	0.32	0	0.186	0.144	0.000021
Mar-09	9.14	0.8391	0.546	0.673	0	0.413	0.644	0.000071
MRWPCA								
Permit	1284.8	2.774	24.82	3.358	292	1314	5.84	0.0005694
Sep-08	8.868	0.2529	0	0.306	0.468	0.189	0.163	0.0000097
Mar-09	11.713	0.3617	0.902	0.397	0	0.483	0.529	0.000078
Carmel								
Permit	1073.6	2.318	20.74	2.806	488	1098	0.88	0.0004758
Sep-08	42.688	0.2659	0.078	0.836	1.259	0.205	0.529	0.0000185
Mar-09	27.89	0.2925	0.423	0.982	0.856	0.292	1.97*	0.000036
Pajaro River								
Sep-08	8.941	0.0549	0.676	0.067	0	0.031	0.131	NA
Mar-09	33.757	0.2418	25.337	0.929	0	0.648	1.35	NA

* = Exceeds NPDES permit limit
NA = Not analyzed

Table 7. Concentrations of unregulated pollutants in CCLEAN lab blanks, equipment blanks and wastewater discharges.

Source & Date	PBDEs, ng/L	PFCs, ng/L
Lab Blank		
Sep-08	0	0
Mar-09	0.0334	0
Equip. Blank		
Sep-08	0.1166	NA
Mar-09	0.1048	NA
Santa Cruz		
Sep-08	8.817	52.13
Mar-09	8.968	95.21
Watsonville		
Sep-08	14.933	51.87
Mar-09	15.523	35.64
MRWPCA		
Sep-08	13.745	55.59
Mar-09	20.465	37.92
Carmel		
Sep-08	1.811	402.18
Mar-09	6.847	157.91
Pajaro River		
Sep-08	0.3030	2.9
Mar-09	1.0407	33.24

NA = Not analyzed

most of the total mass of contaminant discharged into ocean waters. While cumulative loads of PAHs, DDTs, Dieldrin and PCBs from rivers have varied substantially through time, mostly in response to storm flows, wastewater loads have been consistently low (Figures 13, 14, 15 and 16). In years with lower river discharges (e.g., 2002–2003 and 2006–2007) loads of many POPs from rivers and wastewater are similar.

Loads of some POPs have been higher from wastewater than from rivers. CCLEAN began measuring the PBDEs, used primarily as flame retardant in cushions, mattresses and plastic electronics cases, in the 2006–2007 program year. Loads from wastewater were more than twice those from rivers (CCLEAN 2007). Continued sampling in the Pajaro provides a reference for continued comparison between river and wastewater loads of PBDEs that suggests wastewater still exceeds rivers (Figure 17).

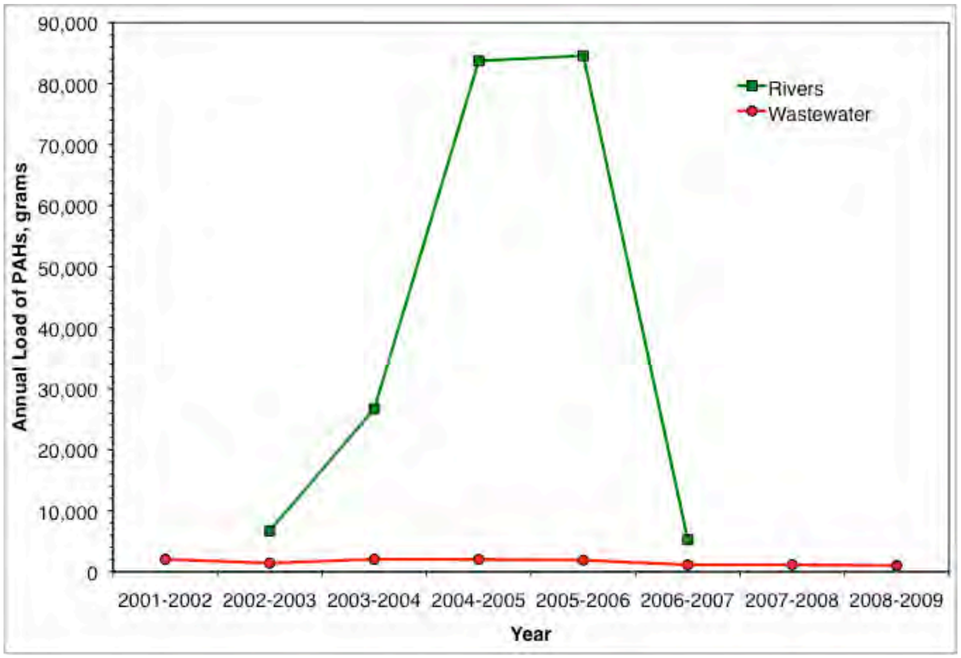

Figure 13. Cumulative loads of PAHs discharged by rivers and wastewater into the ocean in the Monterey Bay area. Sampling of all rivers but the San Lorenzo and Pajaro ceased in 2007.

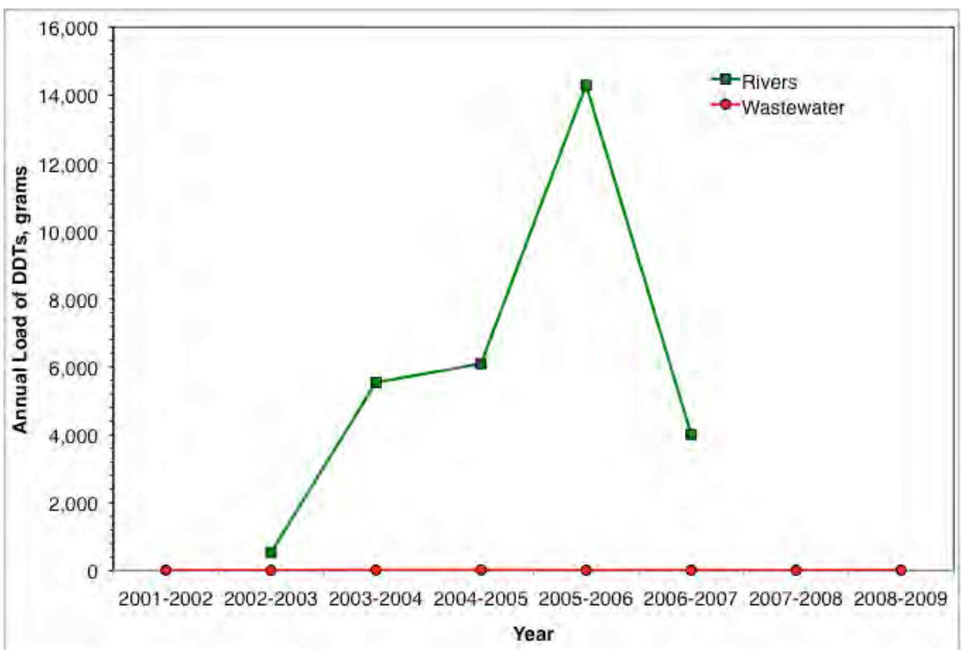

Figure 14. Cumulative loads of DDTs discharged by rivers and wastewater into the ocean in the Monterey Bay area. Sampling of all rivers but the San Lorenzo and Pajaro ceased in 2007.

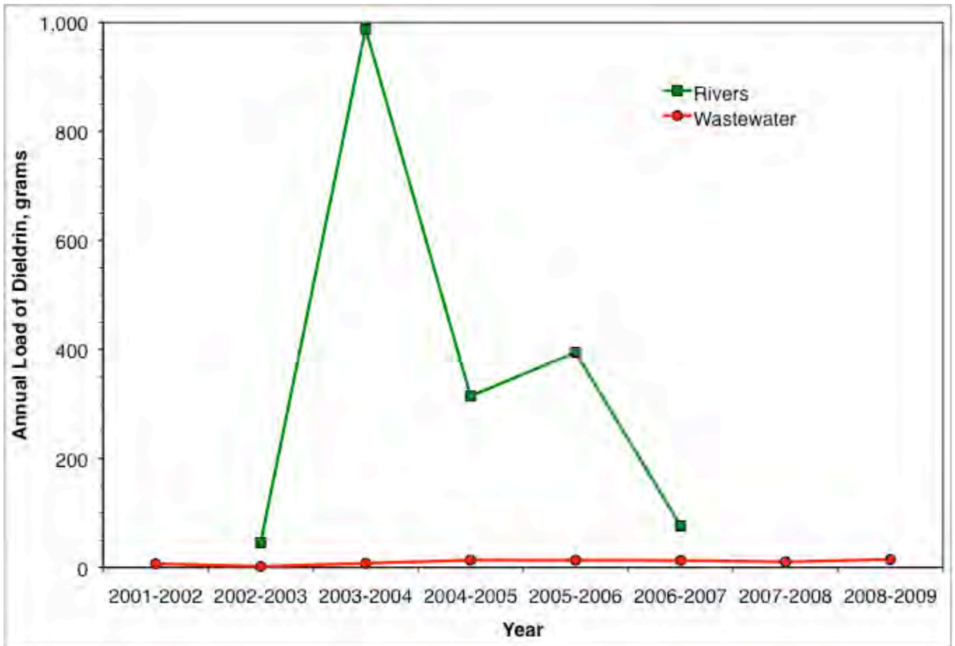

Figure 15. Cumulative loads of Dieldrin discharged by rivers and wastewater into the ocean in the Monterey Bay area. Sampling of all rivers but the San Lorenzo and Pajaro ceased in 2007.

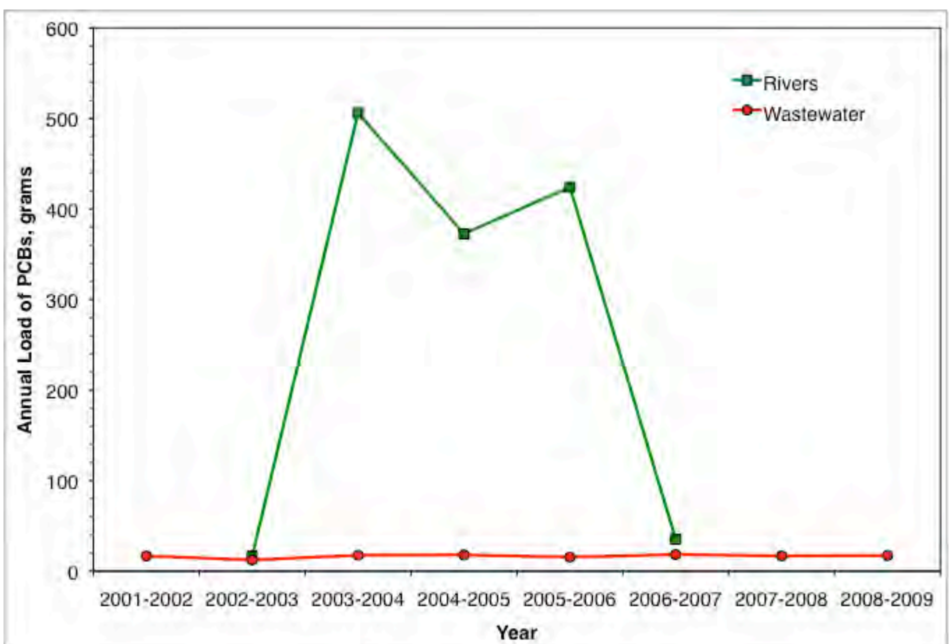

Figure 16. Cumulative loads of PCBs discharged by rivers and wastewater into the ocean in the Monterey Bay area. Sampling of all rivers but the San Lorenzo and Pajaro ceased in 2007.

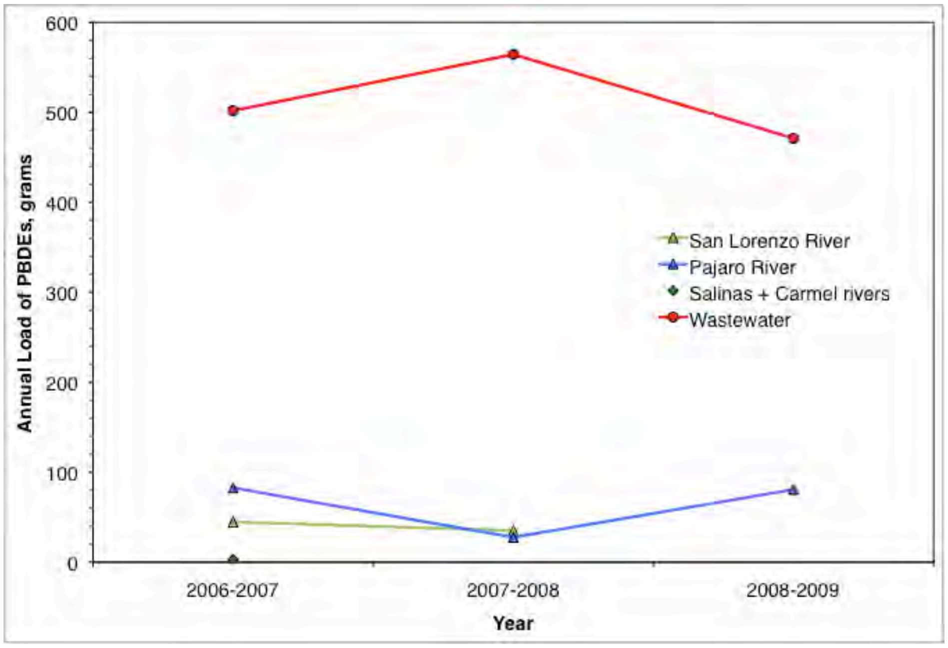

Figure 17. Loads of PBDEs discharged by rivers and wastewater into the ocean in the Monterey Bay area. Sampling of all rivers but the San Lorenzo and Pajaro ceased in 2007.

4.2.2 Characterization of PBDEs and PFCs

Previous analysis of the percentages of different PBDE homologues in total PBDEs from rivers and wastewater suggested very different sources for each (CCLEAN, 2007). Data from 2006–2007 revealed that wastewater had higher percentages of tetraBDEs and pentaBDEs than rivers, whereas rivers had higher percentages of nonaBDEs and decaBDE (CCLEAN 2007). Averages of all samples from 2006–2007 to the present suggest the initial characterization is a consistent pattern (Figure 18). The average percentage of tetraBDEs ranged from 32–39% in wastewater and from 15–16% in the San Lorenzo and Pajaro rivers, whereas the average percentage of decaBDE ranged from 15–23% in wastewater and from 45–55% in rivers. The overall averages also suggest slight differences among wastewater discharges, with MRWPCA and Carmel Area having slightly higher proportions of decaBDE than Santa Cruz or Watsonville.

Whether the differences in percentages of PBDE homologues in rivers and wastewater indicate different sources or effects of wastewater treatment could be clarified when CCLEAN methods are used to sample influent at the Watsonville wastewater treatment facility beginning in January 2010. In the meantime, a rough analysis was performed to assess the similarity in percentages of PBDE homologues if rivers represent the true source and wastewater shows the effects of treatment. The concentrations of nonaBDE and decaBDE homologues in river samples were reduced by 75% and the resulting percentage of PBDE homologues is very similar to wastewater (Figure 19).

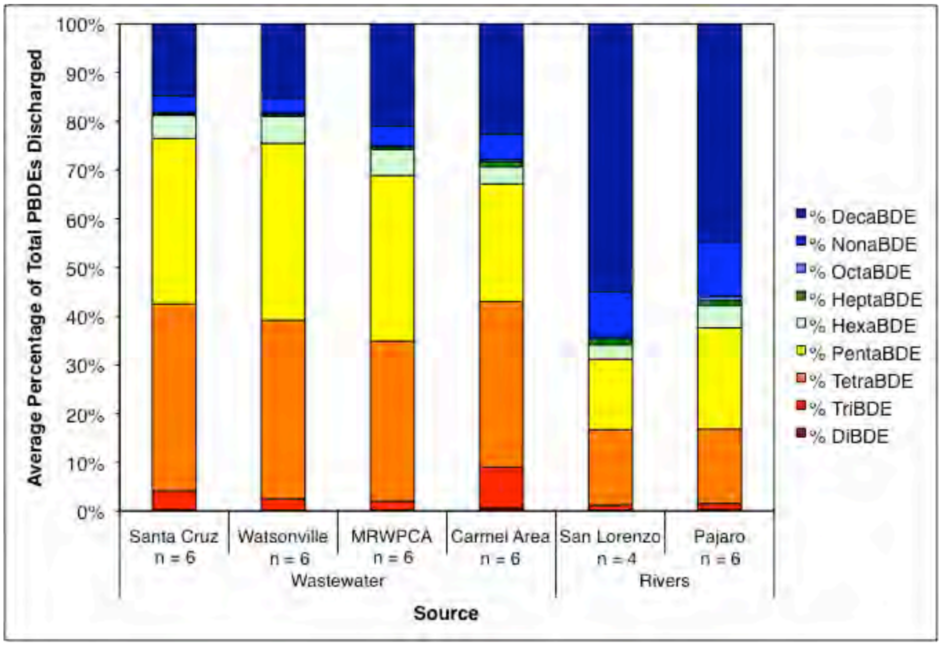

Figure 18. Average percentages of each PBDE homologue present in four wastewater discharges and two rivers. The number of samples is indicated for each source.

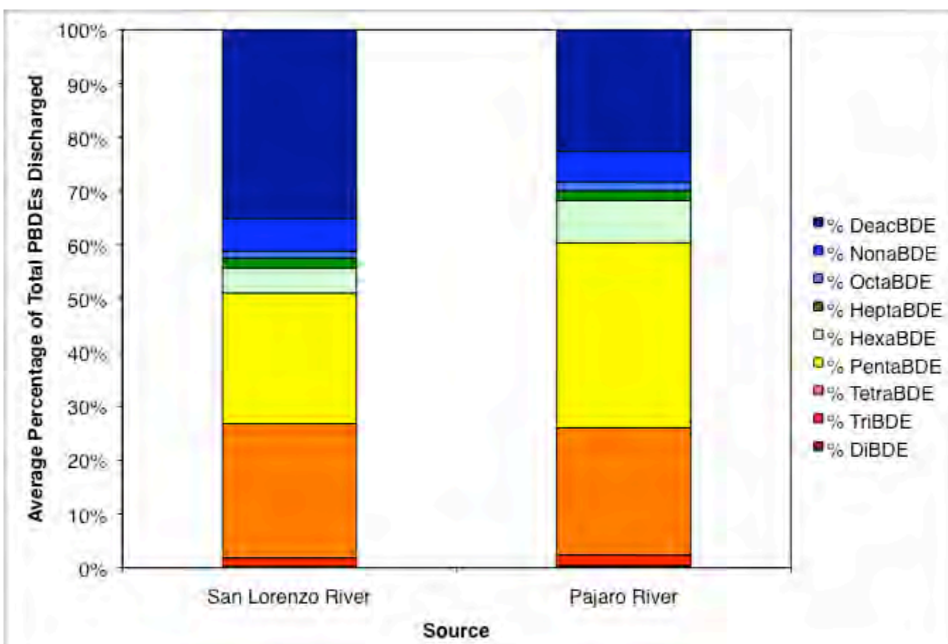

Figure 20. Estimated percentages of each PBDE homologue present in two rivers after reduction of nonaBDE and decaBDE homologues by 75%.

Except for mussels from The Hook, percentages of PBDE homologues in mussels and sediments are roughly between those in wastewater and rivers. (Figure 20). Across all these sites, the percentage of tetraBDEs ranged from 29–43%, which is similar to wastewater but higher than in rivers. Excluding The Hook, the percentage of decaBDE ranged from 27–40%, which is between the ranges for wastewater and rivers. The Hook averaged only 12% decaBDE, which is lower than either wastewater or rivers.

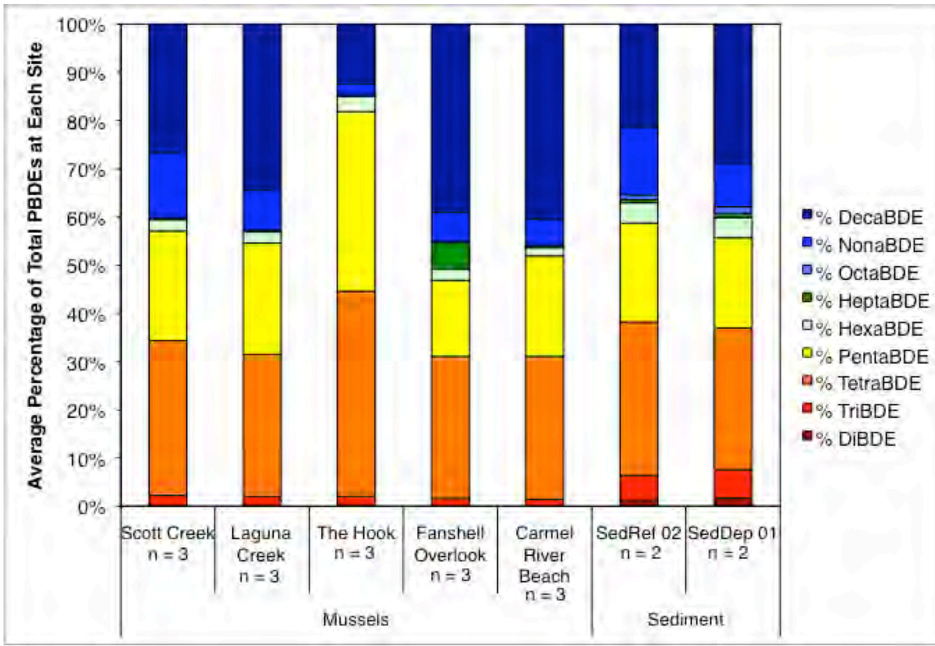

Figure 20. Average percentages of each PBDE homologue present in mussels and sediment at seven sites. The number of samples is indicated for each site.

It is likely that the percentages of PBDE homologues in mussel and sediments are affected both by site-specific biological processes and the relative influence from different sources. Debromination of higher brominated PBDEs, principally decaBDE, can take place both in organisms and in sediments (Stapleton et al. 2004; Tokarz et al. 2008), leading to higher concentrations of the more toxic tetraBDEs and pentaBDEs. DecaBDE is generally not considered to be easily bioaccumulated (Hardy 2002) and many other studies have not detected decaBDE in mussels (de Boer J. et al. 2003). Consequently, the concentrations of decaBDE in the CCLEAN mussel samples are surprising and could suggest greater nearshore influences from river discharges than from wastewater. The greater affinity of higher brominated PBDEs for adsorption to sediment particles (Agency for Toxic Substances and Disease Registry 2004) could also account for relatively higher percentages of decaBDE in rivers than in wastewater.

In the 2008–2009 program year, CCLEAN began measuring PFCs. PFCs are a complex group of compounds that are characterized by alkyl chains of different lengths on which fluorine is substituted for hydrogen. The PFCs typically measured in environmental monitoring are used either in the manufacture of or as end products to create non-stick cookware, prevent moisture absorption by paper products (e.g., cups, fast-food containers, microwave popcorn bags) and to improve stain resistance in clothing, upholstery and carpeting (Agency for Toxic Substances and Disease Registry 2009). In these PFCs, carboxylate, sulfonate, sulfonamide groups are substituted on one end of the carbon chain (Figure 20).

The molecular structure of these PFCs provides unique physico-chemical properties. The perfluorinated chains are both hydrophobic and oleophobic, whereas the sulfonate and caboxylate head groups are hydrophilic (Higgins and Luthy 2006). have been widely detected in the environment and there are increasing concerns about short-term and long-term toxic effects (Kannan et al. 2005; Oakes et al. 2005; Kannan et al. 2006), although some studies have not detected short-term toxic effects (Ankley et al. 2004; Ankley et al. 2005).

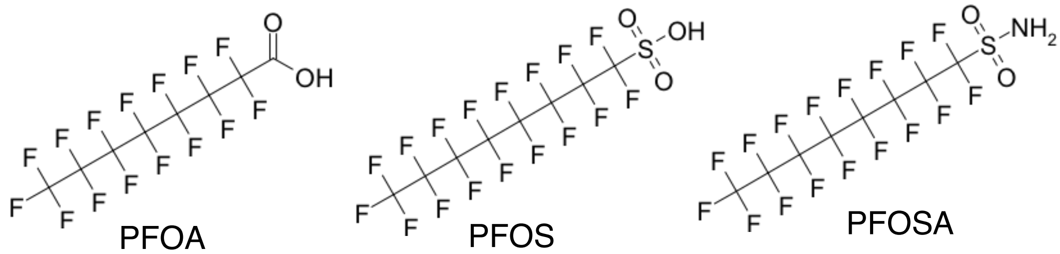

Figure 20. Molecular structure of PFOA, PFOS and PFOSA.

Despite that fact that much higher concentrations of PFCs were measured in wastewater than in the Pajaro River (Table 7), loads from the Pajaro River were greater than from all wastewater discharges combined (Figure 21). The percentage of different PFC compounds in total PFCs were roughly similar across all wastewater sources and the Pajaro River, except for March 2009, when only PFOA was detected in the Pajaro River (Figure 22). The percentage of each PFC compound in CCLEAN wastewater discharges was also similar to the average of 21 European municipal wastewater treatment facilities (Clara et al. 2008), except that there was less PFNA and more PFOS in the European discharges than in the CCLEAN discharges.

Despite being discharged in loads approximately four times greater than for PBDEs, PFCs were not detected in any ocean or mussel sample. Moreover, only sediments from SedDep 01 and SedRef 02 had detectable PFCs: PFBS was detected at SedDep 01 (0.924 ng/g dry weight) and PFOA and PFOS were detected at SedRef 02 at concentrations of 0.154 ng/g and 0.654 ng/g, respectively. These results are enigmatic given the high solubility of PFCs in water and the estimate that surface waters of the world's oceans contain the majority of perfluorooctanoate (Prevedouros et al. 2006), but consistent with both these authors and Higgins and Luthy (2006), who suggested that the only environmental sinks for PFCs are sediment burial or transport to the deep oceans, and that soprtion to sediments is proportional to TOC content, respectively.

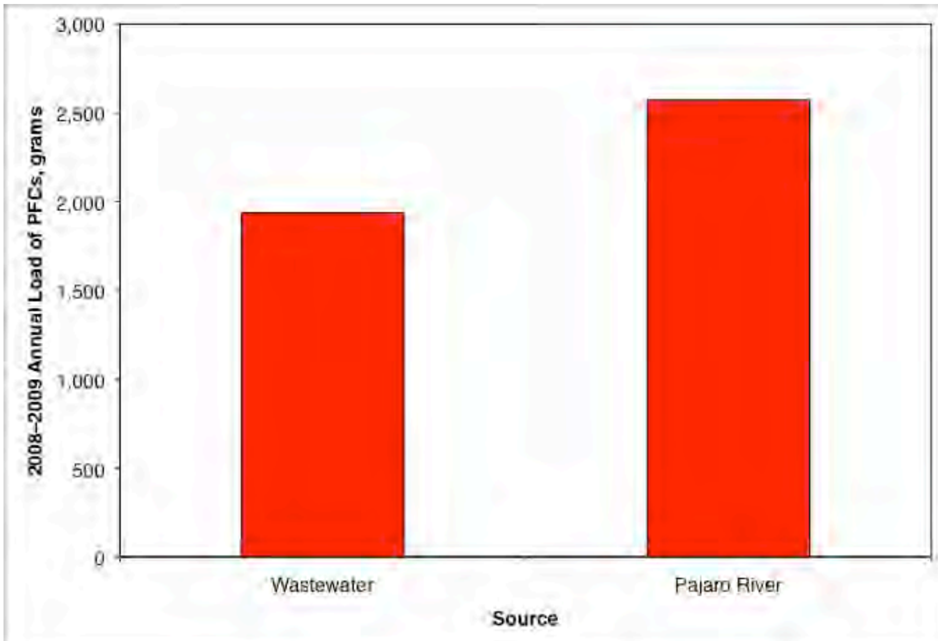

Figure 21. Loads of PFCs from wastewater discharges and the Pajaro River sampled from July 2008 through June 2009.

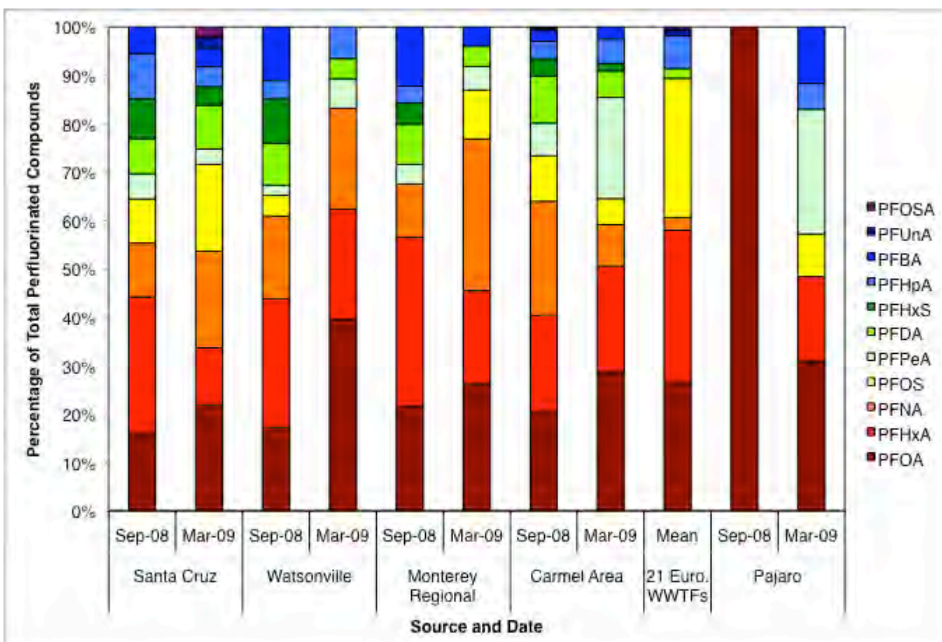

Figure 22. Percentages of each PFC compound present in wastewater and the Pajaro River. The data for the 21 European wastewater treatment facilities are from (Clara et al. 2008).

4.2.3 Recommendations

The wastewater monitoring should continue as it is currently conducted. Analysis of dioxins/furans and PFCs began in October 2008 and several years of data for those contaminants should be evaluated before considering revisions to wastewater sampling. If PFCs continue to be undetectable in ocean water and mussels, elimination of their measurement can be considered.

5.0 References Cited

Agency for Toxic Substances and Disease Registry (2004) Toxicological Profile for Polybrominated Biphenyls and Polybrominated Diphenyl Ethers. U.S. Department of Health and Human Services Public Health Service, Atlanta, GA

Agency for Toxic Substances and Disease Registry (2009) Draft Toxicological Profile for Perfluoroalkyls. U.S Department of Health and Human Services, Atlanta, GA

Ankley GT, D.W. Kuehl, M.D. Kahl, K.M. Jensen, A. Linnum, R. Leino, Villeneuve DA (2005) Reproductive and developmental toxicity and bioconcentration of perfluorooctanesulfonate in a partial life-cycle test with the fathead minnow (Pimephales promelas). Environmental Toxicology and Chemistry 24: 2316-2324

Ankley GT, D.W. Kuehl, M.D.Kahl, K.M. Jensen, B.C. Butterworth, Nichols JW (2004) Partial life-cycle toxicity and bioconcentration modeling of perfluorooctanesulfonate in the northern leopard frog (Rana pipiens). Environmental Toxicology and Chemistry 23: 2745–2755

California State Mussel Watch Program (2003) SMW Program Data 1977-2000. California State Water Resources Control Board

CCLEAN (2007) 2001-2006 Program Overview. Central Coast Long-term Environmental Assessment network, Santa Cruz, CA

Clara M, C. Scheffknecht, S. Scharf, S. Weiss, Gans O (2008) Emissions of perfluorinated alkylated substances (PFAS) from point sources—identification of relevant branches. Water Science & Technology 58: 59–66

de Boer J., P.G. Wester, A. van der Horst, Leonards PE (2003) Polybrominated diphenyl ethers in influents, suspended particulate matter, sediments, sewage treatment plant and effluents and biota from the Netherlands. Environmental Pollution 122: 63-74

Hardin D, Bemis B, Starzel K, Dominik C (2007) Literature Review To Characterize Environmental Contaminants That May Affect The Southern Sea Otter. Monterey Bay National Marine Sanctuary Simon Program, Monterey, CA

Hardy ML (2002) A comparison of the properties of the major commercial PBDPO/PBDE product to those of major PBB and PCB products. Chemosphere 46: 771-728

Hartwell SI (2008) Distribution of DDT and other persistent organic contaminants in Canyons and on the continental shelf off the central California coast. MARINE ENVIRONMENTAL RESEARCH 65: 199-217

Higgins CP, Luthy RG (2006) Sorption of Perfluorinated Surfactants on Sediments. Environmental Science & Technology 40: 7251–7256

Kannan K, Perrotta E, Thomas NJ (2006) Association between Perfluorinated Compounds and Pathological Conditions in Southern Sea Otters. Environmental Science & Technology [Environ. Sci. Technol.] 40: 4943-4948

Kannan K, Yun SH, Evans TJ (2005) Chlorinated, brominated, and perfluorinated contaminants in livers of polar bears from Alaska. Environmental Science & Technology 39: 9057-9063

Long ER, Field LJ, MacDonald DD (1998) Predicting toxicity in marine sediments with numerical sediment quality guidelines. Environmental Toxicology and Chemistry [Environ. Toxicol. Chem.]. 17: 714-727

Long ER, MacDonald DD, Severn CG, Hong CB (2000) Classifying probabilities of acute toxicity in marine sediments with empirically derived sediment quality guidelines. Environmental Toxicology and Chemistry [Environ. Toxicol. Chem.]. 19: 2598-2601

Nicholson MD, R.J. Fryer, Ross CA (1997) Designing Monitoring Programmes for Detecting Temporal Trends in Contaminants in Fish and Shellfish. Mar. Pollut. Bull. 34: 821-826

Oakes KD, P.K. Sibley, J.W. Martin, D.D. MacLean, K.R.Solomon, S.A. Mabury, Kraak GJVD (2005) Short-term exposures of fish to perfluorooctane sulfonate: Acute effects on fatty acyl-CoA oxidase activity, oxidative stress, and circulating sex steroids. Environmental Toxicology and Chemistry 24: 1172-1181

Office of Environmental Health Hazard Assessment (2003) Summary of the Chemicals of Concern Found in Fish: San Francisco Bay Pilot Study, 1994. Pesticide and Environmental Toxicology Section of the Office of Environmental Health Hazard Assessment

Prevedouros K, I.T. Cousins, R.C. Buck, Korzeniowski SH (2006) Sources, Fate and Transport of Perfluorocarboxylates. Envirnomental Science and Technology 40: 32-44

RWQCB (1997) Water Quality Control Plan (Basin Plan). California Regional Water Quality Control Board, Central Coast Region

Stapleton HM, M. Alaee, R.J. Letcher, J.E. Baker (2004) Debromination of the Flame Retardant Decabromodiphenyl Ether by Juvenile Carp (Cyprinus carpio) following Dietary Exposure. Envirnomental Science and Technology 38: 112-119

State Water Resources Control Board (2004) Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List. California State Water Resources Control Board, Sacramento

State Water Resources Control Board (2005) California Ocean Plan. California Environmental Protection Agency, Sacramento, CA

Tokarz JA, M-Y. Ahn, J. Leng, T.R. Filley, Nies L (2008) Reductive Debromination of Polybrominated Diphenyl Ethers in Anaerobic Sediment and a Biomimetic System. Envirnomental Science and Technology 42: 1157-1164