Surface Water Ambient Monitoring Program

INITIAL TRENDS IN CHEMICAL CONTAMINATION, TOXICITY AND LAND USE IN CALIFORNIA WATERSHEDS

STREAM POLLUTION TRENDS (SPoT) MONITORING PROGRAM

SECOND REPORT

FIELD YEARS 2009-2010

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MARCH 2013

California Water Boards
www.waterboards.ca.gov/swamp

THIS REPORT SHOULD BE CITED AS:

Anderson BS, Phillips BM, Siegler K, Voorhees, J. 2012. Initial Trends in Chemical Contamination, Toxicity and Land Use in California Watersheds: Stream Pollution Trends (SPoT) Monitoring Program. Second Technical Report - Field Years 2009-2010. California State Water Resources Control Board, Sacramento, CA. 92 pp (with appendices).

ACKNOWLEDGEMENTS

The Surface Water Ambient Monitoring Program's Stream Pollution Trends monitoring program was designed to address statewide water quality information needs by a SWAMP Roundtable committee of monitoring coordinators and program partners. Committee members included:

Terry Fleming (U.S. Environmental Protection Agency),

Michael Lyons (Los Angeles Regional Water Quality Control Board),

Chris Sommers (EOA, Inc.),

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Lilian Busse (San Diego Regional Water Quality Control Board)

Jeff Geraci (Colorado River Basin Regional Water Quality Control Board)

Kevin Lunde (San Francisco Regional Water Quality Control Board)

Karen Worcester (Central Coast Regional Water Quality Control Board)

The assessment questions, objectives, design, indicators, and methods were reviewed by the SPoT Scientific Review Committee: Michelle Hladik (U.S. Geological Survey), Debra Denton (U.S. EPA) and Lester McKee (San Francisco Estuary Institute). We thank all committee members and members of the SWAMP Roundtable for their considerable insights and support.

Trace metals were analyzed by the California State University team at the Marine Pollution Studies Laboratory, Moss Landing Marine Laboratories (Autumn Bonnema, Steve Martenuk). Trace organics were analyzed by the California Department of Fish and Game Water Pollution Control Laboratory at Rancho Cordova (Dave Crane, Patricia Bucknell, Gail Cho), and the Institute for Integrated Research on Materials, Environment and Society at Long Beach State University (Rich Gossett).

Data were managed by the SWAMP Data Management Team at Moss Landing Marine Laboratories. Data management and transfer to the California Environmental Data Exchange Network (CEDEN) were supervised by Mark Pranger. Marco Sigala and Cassandra Lamerdin provided additional assistance with SWAMP bioassessment data. Rusty Fairey and Marco Sigala managed SWAMP contracts at the San Jose State University Foundation.

Raphael Mazor (Southern California Coastal Water Research Project) also provided bioassessment data collected for the southern California Stormwater Monitoring Council monitoring program, and we are grateful for his assistance. Dave Paradies (Central Coast Regional Water Quality Control Board) helped identify SWAMP and SMC bioassessment sites appropriate for comparison to SPoT sites.

Kelly Moran (TDC Environmental) provided data and helpful discussions on urban use of pyrethroid pesticides.

John Hunt provided helpful comments on earlier drafts of this report.

Watershed delineations and land cover data extractions were conducted by the Geographic Information Center at California State University, Chico. This work was directed by Dr. Pete Ode, California Department of Fish and Game. We are grateful to Dr. Ode and the GIC for their high quality work and for the efficiency with which these analyses were conducted.

Quality assurance and quality control were directed by the SWAMP QA Team, with special thanks to Beverly van Buuren, Amara Vandervort, and Matthew Gomes. Data quality for this report was reviewed and documented by Stacy Swenson.

Program management and report production for the SWAMP program are led by Karen Larsen, Rich Breuer, Lori Webber, Toni Marshall, and Dawit Tadesse and we are grateful for their commitment and support.

Special thanks to SWAMP Round Table participants, whose vision for the SWAMP program have been essential to the success of this project.

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List of Acronyms

BMI	Benthic Macroinvertebrate
BOG	Bioassessment Oversight Group that directs the SWAMP bioaccumulation monitoring program
CDPR	California Department of Pesticide Regulation
CEDEN	California Environmental Data Exchange Network
DDT	Dichlorodiphenyltrichloroethane, synthetic organochlorine pesticide known for its persistent toxicity and banned in the United States in 1972
DFW	California Department of Fish and Wildlife
EPT	Ephemeroptera/Plecoptera/Trichoptera Index
GIC	The Geographic Information Center at California State University, Chico
IBI	Index of Biological Integrity
LC50	Median Lethal Concentration
MPSL	Marine Pollution Studies Laboratory, consisting of the toxicology laboratory at Granite Canyon, and the logistics, data management, and trace metal analytical laboratory at Moss Landing
NAWQA	National Water Quality Assessment, a program of the US Geological Survey
NLCD	National Land Cover Dataset
PAH	Polycyclic aromatic hydrocarbons, a suite of organic pollutants produced through combustion of fossil fuels
PBDE	Polybrominated diphenyl ethers, which are widely employed as flame-retardants. In 2006 the State of California began prohibiting the manufacture, distribution, and processing of pentaBDE and octaBDE products.
PCB	Polychlorinated biphenyls, a group of industrial compounds widely used for their insulating properties. PCB production was banned in the United States in 1979.
PEC	Probable Effect Concentration. An empirically derived sediment quality objective that sets a concentration above which toxicity is expected to occur (Macdonald, 2000).
PSA	Perennial Streams Assessment. The SWAMP statewide program measuring ecological indicators at probabilistically selected sites in California streams.
RMC	Regional Monitoring Coalition
SRC	Scientific Review Committee
SPoT	Stream Pollution Trends Monitoring Program
SQO	Sediment Quality Objectives
SWAMP	Surface Water Ambient Monitoring Program
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TU	Toxic Unit
WPCL	California Department of Fish and Wildlife's Water Pollution Control Lab

EXECUTIVE SUMMARY

The Stream Pollution Trends (SPoT) program is a statewide monitoring effort focused on the Surface Water Ambient Monitoring Program (SWAMP) priority of assessing the levels to which aquatic life beneficial uses are supported in California streams. The program has three primary goals:

1. Determine long-term trends in stream contaminant concentrations and effects statewide.
2. Relate water quality indicators to land-use characteristics and management effort.
3. Establish a network of sites throughout the state to serve as a backbone for collaboration with local, regional, and federal monitoring.

The SPoT program is specifically designed to fill critical information needs for state, regional and local resource management programs, including Clean Water Act §303d impaired waters listing, CWA §305b condition assessment, total maximum daily load (TMDL) assessment and allocation, non-point source program water quality assessment, stormwater and agricultural runoff management, pesticide registration and labeling, and local land use planning.

This report summarizes results of the 2009 and 2010 annual surveys and emphasizes identifying chemicals of concern and the watershed land uses associated with their presence in California streams. These data are compared to those of the 2008 SPoT sampling year, allowing a preliminary assessment of emerging trends. The results indicate detections of pyrethroid pesticides in sediment increased from 55% of the statewide samples in 2008 to 85% in 2010. Concentrations of several other classes of organic chemicals in sediment decreased or remained unchanged. Metals in sediments were unchanged between 2008 and 2010. The percentage of sediments that were toxic to amphipods remained relatively consistent among the three sampling years. The percentage of highly toxic samples increased from 6% to 67% when toxicity tests were conducted at a colder temperature that more closely matched the average surface water temperature in SPoT watersheds. This suggests that toxicity was caused by pyrethroid pesticides at these stations. The results also demonstrate that, on a statewide basis, levels of most measured pollutants in stream sediment increased as urban land cover in their watersheds increased. Industrial compounds, some metals, and many pesticides were found at higher concentrations in urban watersheds than in agricultural or "open" watersheds statewide. Conditions at the five SPoT reference sites remained unchanged with low contamination and no toxicity observed.

A preliminary assessment of the relationship between SPoT indicators of water quality and indicators of ecological degradation measured in statewide and regional macroinvertebrate bioassessment programs indicated significant correlations between amphipod survival in laboratory toxicity tests and increased abundance of amphipods and other crustacea in associated samples. There was not a statistically significant correlation between amphipod survival and the Index of Biological Integrity in these samples. Identification of these stations provides a foundation for future collaborations that link SPoT with other state and regional monitoring programs.

As part of long-term monitoring of trends in contaminants and toxicity in California watersheds, the SPoT program will emphasize evaluating changing trends in specific contaminant classes as new regulations are implemented. In the near future this includes changes in pyrethroid concentrations in urban watersheds that are anticipated to coincide with California Department of Pesticide Regulation management actions targeting these pesticides. In addition, the program is adding emerging contaminants of concern to the SPoT analyses as these are identified (e.g., fipronil).The data presented here describe the baseline condition for the SPoT long-term trends assessment. They also demonstrate a significant relationship between land use and stream pollution, and provide data directly relevant to a number of agency water quality protection programs.

SECTION 1
INTRODUCTION

SPoT IN THE SWAMP ASSESSMENT FRAMEWORK

Clean freshwater is California's most precious natural resource. It flows through streams that drain watersheds subject to constantly changing levels of human activity. Understanding the connections between these human activities, the changing landscape, and the quality of our waters is essential for the preservation of aquatic life, human health, and the prosperity of California's economy. As the population grows, foothills are converted to residential and agricultural use, agricultural lands are converted through urban and suburban development, and regulatory programs and conservation practices are implemented to maintain and restore stream condition in this ever changing environment.

The Stream Pollution Trends (SPoT) program is designed to improve our understanding of watersheds and water quality by monitoring changes in both over time, evaluating impacts of development, and assessing the effectiveness of regulatory programs and conservation efforts at a watershed scale. The overall goal of this long-term trends assessment program is to detect meaningful change in the concentrations of stream-borne contaminants and their biological effects in large watersheds at time scales appropriate to management decision making.

The three specific program goals are to:

1. Determine long-term trends in stream contaminant concentrations and effects statewide.
2. Relate water quality indicators to land-use characteristics and management effort.
3. Establish a network of sites throughout the state to serve as a backbone for collaboration with local, regional, and federal monitoring.

SPoT sampling locations were selected to provide a statewide network of sites at the drainage points of large watersheds to support collaboration with watershed-based monitoring programs throughout the state. To establish this network, SPoT staff met with Regional Board monitoring coordinators and stormwater agencies to develop a coordinated monitoring design. The Southern California Stormwater Monitoring Coalition participated in site selection for the southern California SPoT sites. A representative from the Bay Area Stormwater Management Agencies Association served on the SWAMP committee that designed the program, and all SPoT sites in the San Francisco Bay Region are aligned with monitoring sites for the Municipal Regional Stormwater NPDES Permit (CRWQCB-SFR, 2011). SPoT sites in the Central Coast and Central Valley Regions are shared by the Cooperative Monitoring Program for Agriculture and Irrigated Lands Program, respectively (Appendix 1). In most cases, the SPoT assessments of sediment toxicity and chemistry complement water column measurements made by cooperating programs.

The SPoT program indicators are measured in stream sediment because this matrix best accommodates program goals. Most trace metal and organic pollutants that enter streams adhere to suspended sediment particles and organic matter, and this sediment-associated phase is the major pathway for contaminant loading in streams and downstream waterways (Karickhoff 1984, DiToro et al. 1991, Foster and Charlesworth 1996). In addition, sediment measurements are appropriate for long-term trend monitoring because pollutants that accumulate in depositional sediment on the stream bed are much more stable over time (~months to years) than dissolved or suspended pollutants that move downstream in pulses that are highly variable over short time scales (~hours). SPoT surveys are timed to collect sediment from recent stream bed deposits during base flow periods after the high water season when most sediment and pollutant transport takes place.

The SPoT program complements the other three SWAMP statewide monitoring programs: the Perennial Streams Assessment (PSA), the Reference Condition Management Program (RCMP), and the bioaccumulation monitoring program of the Bioaccumulation Oversight Group (BOG). The PSA measures ecological endpoints related to macroinvertebrate and algal communities, and uses a probabilistic design to assess aquatic health in perennial, wadeable streams statewide. PSA and RCMP provide a baseline assessment of high quality streams, and provides direct evidence of aquatic life condition statewide. The BOG program measures contaminant concentration in sport fish collected on a rotating basis from streams, lakes and coastal waters.

SPoT complements the PSA by focusing on the magnitude of pollution in streams, using toxicological endpoints to establish causal connections between these chemicals and biological impacts, and by analyzing land cover as part of a watershed-scale evaluation of the sources of pollutants affecting aquatic life. The PSA contributes to the attainment of SPoT goals by assessing the overall health of wadeable perennial streams, and by testing assumptions about the status of reaches upstream of the intensive land uses that might be found associated with pollutants measured by SPoT. SPoT complements the BOG by identifying watershed sources for contaminants measured in fish from downstream water ways. The BOG complements SPoT by providing perspectives on the fate and human health aspects of pollutants in streams, particularly as related to their uptake in fish tissue and risk associated with human consumption. PSA, RCMP, BOG, and SPoT together provide freshwater data similar to those used in other programs to develop sediment quality objectives (SQOs) in marine and estuarine habitats. Co-location of sites or addition of specific indicators across the PSA, BOG, and SPoT programs could allow for development of freshwater SQOs for California in the near future (SWAMP 2010).

SPoT was specifically designed to provide data directly useful for regulatory programs and conservation initiatives. SPoT data can be incorporated directly into Clean Water Act § 303[d] listing of impaired waters, as well as into the statewide status assessments required by § 305[b]. Eight SPoT sites are located in priority watersheds for the US EPA Measure W program (also known as the Watershed Improvement Measure (WIM) or SP-12). The focus on causes and sources of pollutants in watersheds feeds directly into Total Maximum Daily Load program efforts to quantify pollutant loadings and understand sources and activities that contribute to those loadings. By coordinating with local and regional programs, SPoT provides statewide context for local results, and provides information useful for local management and land use planning activities. SPoT is also specifically designed to assist with the watershed-scale effectiveness evaluation of management actions implemented to improve water quality, such as pesticide reduction or irrigation management on farms, and installation of stormwater treatment devices or low impact development in urban areas. Use of SPoT data for watershed scale evaluations of management practice effectiveness is currently limited by the lack of a comprehensive and standardized reporting system for practice implementation, as will be discussed further in this report.

SECTION 2
METHODS

MONITORING OBJECTIVES AND DESIGN

Program methods were selected to meet the following monitoring objectives:

1. Determine concentrations of a suitable suite of contaminants in depositional sediment collected near the base of large California watersheds;
2. Determine whether these depositional sediments are toxic to representative organisms;
3. Quantify ancillary parameters such as land cover and impervious surface area, available from the National Land Cover Dataset and other public sources;
4. Analyze data to evaluate relationships between contaminant concentrations, toxicity, and land cover metrics;
5. Conduct trends analyses to detect the direction, magnitude, and significance of change in the above parameters over time.

The monitoring design was based on the US Geological Survey's National Water Quality Assessment (USGS – NAWQA: http://water.usgs.gov/nawqa/). The NAWQA program is designed to increase understanding of water-quality conditions, of whether conditions are getting better or worse over time, and how natural features and human activities affect those conditions. The NAWQA integrator site concept provided the basis for the SPoT monitoring design. NAWQA integrator sites are established near the base (discharge point) of larger, relatively heterogeneous drainage basins with complex combinations of environmental settings. Sediments collected from depositional areas at integrator sites provide a composite record of pollutants mobilized from throughout the watershed. While many hydrologic, engineering, and environmental variables affect the ability of this record to adequately characterize all pollutant-related activities, sediment samples collected from such areas are considered to be a relatively good and logistically feasible means of assessing large watersheds for long-term trends.

SPoT employs a targeted monitoring design to enable trend detection on a site-specific basis. To serve their purpose as integrator sites, SPoT sites were located at the base of large watersheds containing a variety of land uses. Because depositional sediment is needed for sample collection, sites were targeted in locations with slow water flow and appropriate micro-morphology, to allow deposition and accumulation. SPoT and NAWQA use integrator sites because both programs focus on understanding causes and sources of water quality impairment. The connection with land use is a major part of the assessment, and targeted sites allow greater discretion to adjust to significant land cover variation in low watershed areas. One of the three main goals of SPoT was to form a statewide network of sites that provides statewide context for the findings of local and regional programs. A targeted approach allowed the SPoT program flexibility to link to established sites from other Regional Water Board monitoring programs that preceded SWAMP.

SITE SELECTION AND SURVEY TIMING

In 2008, 92 sites were surveyed to census about half of the nearly 200 major hydrologic units (8-digit HUCs) in California. SPoT program funding was greatly reduced in 2009 and only 23 sites were sampled. Full funding was restored in 2010, and 95 stations were surveyed. Site locations were re-evaluated and some of the 2008 sites were relocated for better watershed representation for the 2010 sampling season (Figure 1).

A number of factors were considered when selecting SPoT sites (Hunt et al., 2012). The most important factors included location in a large watershed with heterogeneous land cover, in most cases on the order of an 8-digit hydrologic unit code (8-digit HUC = sub-basin = USGS cataloging unit); location at or near the base of a watershed, defined as the confluence with either an ocean, lake, or another stream of equal or greater stream order; and location where site-specific conditions are appropriate for the indicators selected (e.g., depositional areas, sufficient flow, appropriate channel morphology, substrate). Availability of previous data on sediment contaminant concentrations, biological impacts, or other relevant water quality data was also an important consideration, particularly if sites could be co-located with key sites from cooperative programs.

During sample collection at most SPoT sites, fine sediment particles were found in thin layers throughout the channel. Some sites were dominated by deep deposits of fine sediment. At many sites, however, there were fewer locations where fine sediment accumulated in layers thick enough to allow efficient sample collection (> 2 cm). To put the availability of depositional areas into context, consider that Hall et al. (2010) mapped fine sediment distributions at 99 transects in three California streams, each designated as agricultural, urban or residential. They estimated that an average of 17% of the stream bed was characterized as "depositional". SPoT results should not be construed as a characterization of the entire stream in which study sites were located. Rather they are intended as relative indicators of the annual pollutant mobilization and transport within target watersheds, which is a useful matrix for evaluating annual trends.

The SPoT reference sites provide information on temporal trends in contamination and toxicity in the absence of significant contaminant-related land use change (Figure 1). Five large watersheds with relatively low levels of human activity were selected, representing the north coast, San Francisco Bay Area, Sierra foothills, Coast Range, and southern California inland areas. Sites in these watersheds were selected based on the criteria outlined above. Two reference sites are USGS NAWQA sites in the San Joaquin and Santa Ana River study units: Tuolumne River at Old La Grange bridge 535STC210 (San Joaquin) and San Jacinto River Reference Site 802SJCREF (Santa Ana).

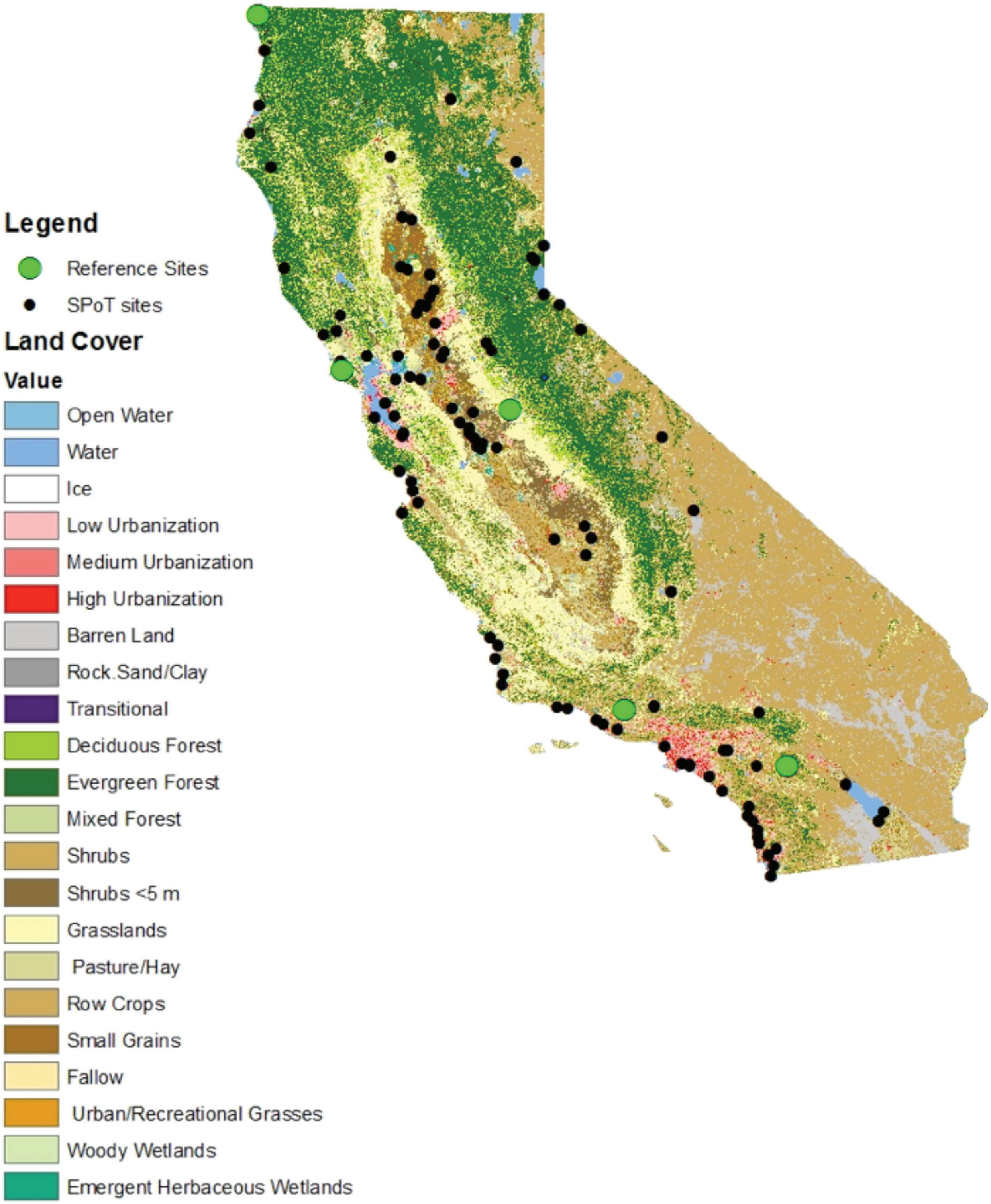

Figure 1. 2010 SPoT sites (black circles), reference sites (green circles), and land use categories.

SPoT surveys are timed so that sediment is collected from recent stream bed deposits during base flow periods after the high flow season, when most sediment and pollutant transport and loading take place. In general, surveys began in coastal southern California in late spring, ran through coastal central California in early summer, the Central Valley in mid-summer, the eastern Sierra in late summer, and ended at the North Coast and Colorado River Basins in the fall. This timing has been consistent among sampling years to minimize intra-annual variation as a factor affecting long term trends.

Maps of all SPoT sites with associated site names and location information are provided in the appendices of the first SPoT report (Hunt et al., 2012) and at the end of this report. Digital copies of the first SPoT report are available on line at: http://www.swrcb.ca.gov/water_issues/programs/swamp/reports.shtml#spot.

INDICATORS AND MEASUREMENT PARAMETERS

SPoT indicators were selected to measure contaminants previously demonstrated to be of concern in California streams, as well as assess toxicity to a benthic crustacean representing a resident genus. Indicators were chosen based on criteria outlined in the SPoT 2008 Report (Hunt et al., 2012). Based on these criteria, the following sediment indicators were selected:

1. Toxicity – 10-day growth and survival test with the representative freshwater amphipod *Hyalella azteca*, to estimate biological effects of contaminants;
2. Organic Contaminants - organophosphate, organochlorine, and pyrethroid pesticides, and polychlorinated biphenyls (PCBs);
3. Metal Contaminants - Ag, Al, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Zn;
4. Total organic carbon (TOC), sediment grain size, and total phosphorus;
5. Tier 2 Contaminants – a subset of sediments was also measured for polycyclic aromatic hydrocarbons (PAHs) and polybrominated diphenyl ethers (PBDEs).

ANALYTICAL CHEMISTRY, TOXICITY TESTING, FIELD METHODS, AND DATA STORAGE

All chemical analyses and toxicity tests were performed by SWAMP laboratories: the California Department of Fish and Wildlife (DFW) Water Pollution Control Laboratory (trace organics), the Marine Pollution Studies Laboratory at Moss Landing (MPSL, trace metals), and the UC Davis MPSL at Granite Canyon (toxicity). All methods and quality assurance/quality control (QA/QC) requirements are listed in the SPoT Quality Assurance Project Plan (SPoT, 2010). The results of QA/QC measurements for the 2009-2010 surveys are provided in Appendix 3.

All data collected for this study are maintained in the SWAMP database, which is managed by the data management team at Moss Landing Marine Laboratories (http://swamp.mpsl.mlml.calstate.edu/).

The complete dataset includes QA data (quality control samples and blind duplicates) and additional ancillary information (specific location information, and site and collection descriptions). The complete dataset from this study is also available on the web at http://www.ceden.org/. Data for the SPoT program can be accessed from the CEDEN query system, http://www.ceden.us/AdvancedQueryTool.

GEOGRAPHIC INFORMATION SYSTEM ANALYSES

Anthropogenic contaminant concentrations in streams are influenced by the mobilization of pollutants in their watersheds. The analyses described here evaluate the strength of relationships between human activity in watersheds, as indicated by land cover, and pollutant concentrations in recently deposited stream sediment. Watershed delineations and land cover data extractions were conducted by the Geographic Information Center (GIC) at California State University, Chico (http://www.gic.csuchico.edu/index.html). The entire drainage area specific to each SPoT site was delineated using automated scripts based on digital elevation models. Each delineation file was reviewed by GIC and SPoT program staff for accuracy. Reviews included comparisons to National Hydrologic Dataset catchments, and Google Earth® images of drainage areas as kml files. Drainage areas near the site were delineated with 1 km and 5 km radius buffers to create the 1K and 5K drainage areas for analysis (along with analyses of the entire watershed area draining to each site; Figure 2). Semi-circular buffers were used because engineered drainage structures and other low-watershed features made more precise delineation impossible within the scope of this analysis.

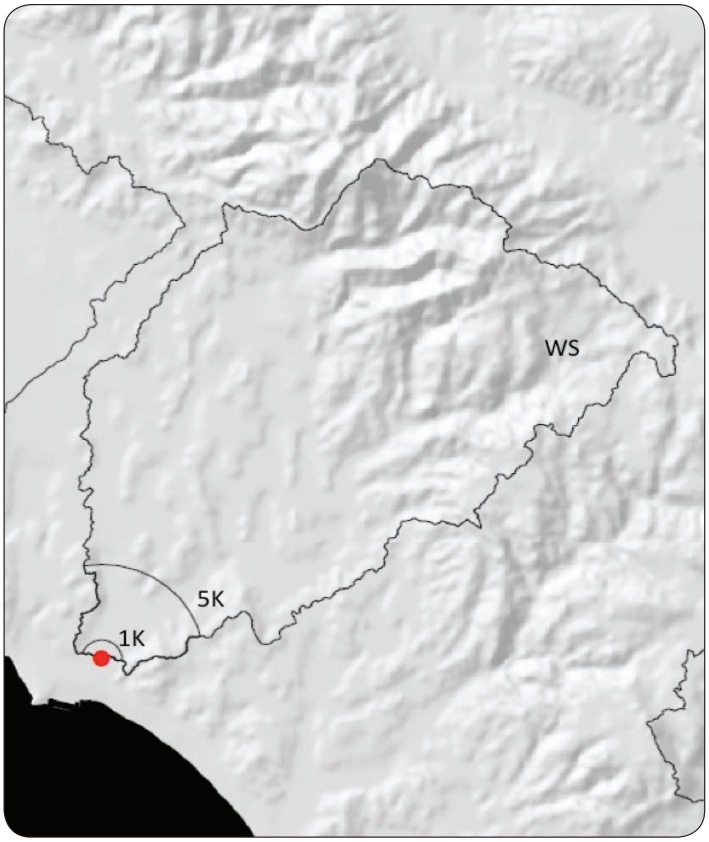

Figure 2. A depiction of watershed delineation. The red dot designates the site at the bottom of the watershed (WS, larger polygon). The semi-circular smaller areas are watershed areas 1 km (1K) and 5 km (5K) from the site.

Drainage area shapefiles were used to extract land cover grids from the National Land Cover Dataset (NLCD, depicted with different colors in Figure 1). The following NLCD categories were used in the analyses relating land cover to water quality. “Developed, Open Space” (NLCD 21) included areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses, such as large-lot single-family housing units, parks, and golf courses. “Urban” (NLCD 22, 23, 24) included low, medium, and high intensity developed areas. “Agricultural” land cover was represented by Pasture (NLCD 81) and Cultivated Crops (NLCD 82).

In correlation analyses, pollutant concentrations were compared to continuous percent land cover data as % urban, % developed open space, % pasture, and % cultivated crops. For analyses based on comparisons among watersheds types, watershed areas were characterized as “urban” if they had greater than 10% urban cover (NLCD categories 22 + 23 + 24). This characterization is in line with studies indicating stream degradation where impervious surface cover exceeds 10% (Schueler, 1994). Watershed areas were characterized as “agricultural” if they had greater than 10% cultivated crop cover (NLCD 82). Watersheds that did not meet these criteria were labeled as “open”.

Impervious surface area data were obtained from the National Land Cover Dataset (Imperv_nlc; NLCD2006 Percent Developed Imperviousness).

STATISTICAL ANALYSES

Toxicity of sediment samples was determined using the U.S. EPA’s test of significant toxicity-TST (U.S. EPA, 2010). For any given year, sites that were not toxic were coded green, sites that were significantly toxic were coded yellow, and sites that were toxic and had percent survival lower than the high toxicity threshold for *Hyalella azteca* (38.6%) were coded red (Anderson et al., 2011). Toxicity results from multiple years were summarized using the following criteria: sites with no toxic samples were coded green for non toxic, sites with at least one toxic samples was coded yellow for some toxicity, sites with at least one sample below the high toxicity threshold were coded orange for moderate toxicity, and sites with an average survival less than the high toxicity threshold were coded red for high toxicity (see Table 3).

Because of the large number of sites and analytes, chemicals were grouped into classes for most statistical analyses. Total DDTs, Total PCBs, PBDEs, and Total PAHs were summed, where appropriate, in each analyte class, in accordance with previous studies evaluating sediment quality guidelines, (Macdonald, 2000). All detected pyrethroids were summed together where indicated, and pyrethroids were also summed as carbon normalized toxic units (Amweg et al., 2005). For many analyses, eight relatively toxic trace metals (As, Cd, Cr, Cu, Pb, Hg, Ag, Zn; Mahler et al., 2006) were summed to provide an overall characterization of measured metal levels in sediment. Trace metals were also interpreted as the sum of four metals commonly released into the environment by human activity, and less affected by geologic abundance in California (Cd, Cu, Pb, Zn; (Topping and Kuwabara, 2003; Mahler et al., 2006; Bonifacio et al., 2010)). An aliquot of each sediment sample was also sieved to 63 um so that trace metal concentrations could be measured in both sieved (fine grained) and unsieved (whole) sediment. The sieved versus un-sieved metal comparison was included at the recommendation of the SPoT SRC because trace metals bind preferentially to smaller sediment size fractions, particularly clays, and concentrations measured on sieved sediment can be compared across watersheds with less variability related to differences in grains sizes among samples. Concentrations in unsieved sediments are the total metal concentrations and can be compared to thresholds for biological effects.

Multivariate Spearman rank correlations were used for all statistical evaluations of relationships between toxicity, pollutants, and land cover. All analyses were done using IBM SPSS Statistics Package (IBM Corporation, 2011).

Tables in the Results section provide probability (p) values indicating the strength of relationship among variables in the multiple correlations. These p values have not been adjusted to account for the number of simultaneous comparisons made (e.g., Bonferroni adjustment). There is debate in the statistical literature about the value of adjusting alpha values to account for inference based on many simultaneous tests (Perneger, 1998). Alpha adjustments were not made here because we are not interested in whether all null hypotheses are true simultaneously, but rather which relationship are of greatest interest in exploring connections between land use and stream pollution.

SECTION 3
RESULTS

GOAL 1 – LONG TERM TRENDS IN TOXICITY AND CHEMICAL CONCENTRATIONS

Reference Site Conditions – Toxicity and Chemistry

All references samples were nontoxic in all years except for the Smith River (103SMHSAR) tested in 2010 (Table 1). The range of Total Organic Carbon (TOC) and percent fine grained sediments at the reference sites were similar to those in the statewide monitoring sites. Concentrations of organic contaminants were generally lower than the other monitoring sites, except for pyrethroids in Lagunitas Creek in 2008 (201LAG125), and pyrethroids in Sespe Creek in 2010 (403STCSSP). The range of both sieved and unsieved metals in reference site sediments were also similar to the larger data set. The distribution of the sum of eight metals (As, Cd, Cr, Cu, Pb, Hg, Ag, and Zn) is often determined by geological abundance. All reference sites were located relatively short distances downstream of mountainous areas within their watersheds. The Lagunitas Creek reference site watershed contains serpentine outcroppings of the Franciscan formation, and the other reference site watersheds had moderate to high levels of historic mining activity.

Total phosphorus concentrations were lower in reference site sediments than in sediments from the non-reference sites (data not shown). Phosphorus can be geologically abundant in certain areas, and can also be elevated by urban and agricultural fertilizer applications or soil disturbance associated with land development.

STATEWIDE CONDITIONS – TOXICITY AND CHEMISTRY

Sediment Characteristics: Grain Size and TOC

Sediment collection for SPoT emphasizes collecting fine-grained depositional sediments, as many contaminants associate with the smaller size fraction (< 63 µm), which accumulate in low energy depositional areas. Fine sediment particles can be found throughout the channel at many sites in thin layers covering other dominant substrate, including sand, cobble, boulders, concrete, and woody debris. Fine sediments form deeper layers in pockets and larger depressions where micro-hydrological and geomorphic conditions favor deposition. These deeper depositional areas were targeted for sample collection because they allowed the most effective collection of fine material. In some sampling areas, fine sediments formed large and deep deposits across the channel.

While field teams were trained to collect the finest-grained material available, a number of samples were composed primarily of grains larger than 63 um (Figure 3). None of these samples contained substantial

Table 1
Toxicity and chemistry trends at references sites. Green indicates non toxic and yellow indicates toxic. ND indicates non-detect (detection limits listed in Appendix 3).

Station	Year	Survival (% of Control)	TOC (%)	Fines (%)	Sum DDT (ng/g)	Sum Pyrethroids (ng/g)	Sum PCB (ng/g)	Sum of 8 Metals (µg/g)	Sum of 8 Metals (<63 µm) (µg/g)
103SMHSAR	2008	95	4.17	72.8	ND	ND	ND	405	472
	2009	95		14.3	ND	ND	ND	511	581
	2010	73	3.14	44.8	ND	0.145	ND	388	697
201LAG125	2008	100	1.27	34.0	ND	10.6	0.312	255	364
	2009	91		46.9	ND	ND	ND	312	422
	2010	99	1.97	45.2	ND	0.103	ND	263	205
403STCSSP	2008	104	1.26	87.1	1.49	ND	2.71	166	175
	2010	104	1.78	62.1	ND	7.41	ND	120	143
535STC210	2008	97	0.51	5.90	5.65	ND	ND	241	450
	2010	96	5.34	37.6	ND	ND	ND	286	370
802SJCREF	2008	95	1.8	91.2	1.69	ND	0.713	177	214
	2009	100		39.1	ND	ND	ND	102	210
	2010	101	0.49	34.0	ND	ND	ND	68.0	97.8

amounts of coarse sand or larger particles, but grains larger than 63 um made up the larger fraction in half of the samples from 2009 and a third of the samples from 2010.

Field teams were also trained to avoid or remove conspicuous debris, including leaves and other large organic material. TOC content cannot be readily determined in the field, and the sampling protocol has no set criterion for TOC concentration. Measured TOC in 2009 and 2010 ranged from 0.42% to 10.78% of the total sediment mass, with a median of approximately 2% (Figure 3). These results do not demonstrate any significant trend in either grain size or TOC in SPoT sediments over the initial three years of the program. This suggests that the observed trends in sediment contamination discussed below are unrelated to changes in these parameters.

Toxicity Trends

While this report emphasizes data collected between 2009 and 2010, the following discussion includes toxicity results from 2008 through the 2011 sampling season to provide a four year depiction of statewide toxicity trends. The incidence of sediment toxicity has remained relatively stable between 2008 and 2011 (Table 2). The percentage of toxic and highly toxic samples increased in 2009, but this may reflect the reduced sample size during that year.

Significant toxicity was observed in 30% of the sediment samples collected in 2009 and 21% of the samples collected in 2010 (Table 2). Approximately 8.5% of the samples from both years were identified as highly toxic. Highly toxic samples were collected from agricultural watersheds in the Central Valley's Tulare basin, at sites on the central coast, in urban areas of southern California, and in the Tijuana River (watershed partly extending to Mexico). Other toxic samples were collected from a wide range of watershed types, including those along the north coast, the Sierra Nevada and urban and agricultural areas across the state. In some cases, high toxicity was observed at the same sites over multiple years in specific regions. Site-specific trends in contamination and toxicity are discussed below.

Table 3 depicts a four-year running average of toxicity in the SPoT program. Sixty-six percent of the stations tested to date have not had a single toxic sample, whereas 34% have had at least some toxicity. As the program progresses it is expected that these figures could depict greater toxicity because as cumulative sampling progresses, the chance for detecting toxicity at any one site increases. The long term trend can be illustrated by tracking a running average of four years of data (i.e., two report cycles).

Note that the three color grading system is used when there is only one sample per site (e.g., for the year-by-year results presented in Table 3), and the four color system is used when multiple samples per site are evaluated (Table 3). The scheme for grading site toxicity when multiple samples have been collected is described in the SWAMP report summarizing toxicity in California waters (Anderson et al., 2011).

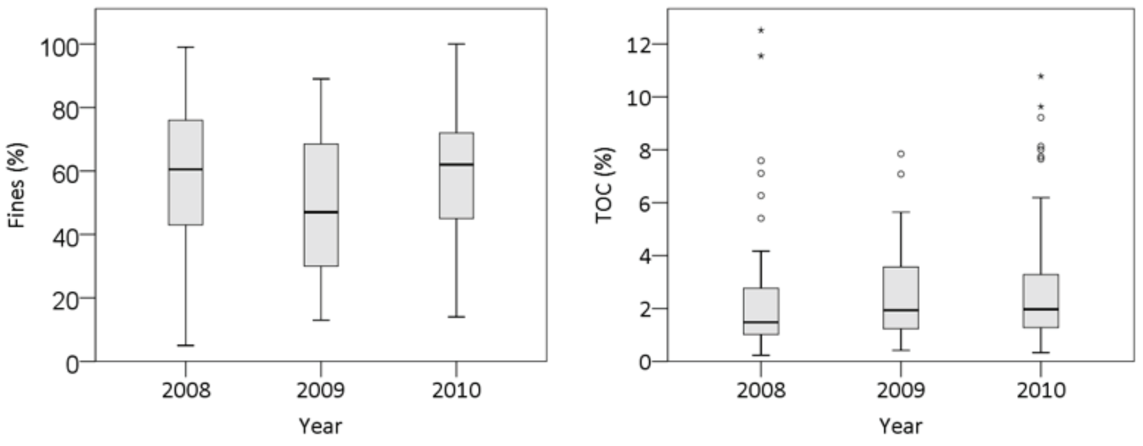

Figure 3. Three-year trends for percent fines and total organic carbon. Boxes represent first and third quartiles, line represents median, and t-bars represent 95% confidence limits. Additional points are outliers.

Table 2
SPoT sediment toxicity trends in tests conducted at 23 °C from 2008-2011.

Number of Sites Tested	2008	2009	2010	2011
	92	23	95	100
% Non-toxic	79	70	79	83
% Toxic	14	21	13	12
% Highly Toxic	7	9	8	5
% Toxic + % Highly Toxic	21	30	21	17

Table 3
Four-year average of toxicity in the SPoT Program.

Category	Percent of Sites	Description
Non-toxic	66	No samples are significantly toxic
Some Toxicity	23	Some toxic samples, but none lower than 38.6% survival
Moderate Toxicity	4	At least one sample below 38.6% survival
High Toxicity	7	Mean % survival of all samples less than 38.6%

Chemistry Trends

Sediment Organic Chemicals

The three year trends for the principal organic chemical constituents analyzed in SPoT sediments are presented in Table 4. Although this table depicts trends between 2008 and 2010, the 2009 SPoT program year only surveyed 23 stations, compared to 92 and 95 stations in 2008 and 2010, respectively. Sampling a smaller number of targeted stations likely influenced the 2009 results and this should be considered when evaluating trends over the initial three years of the project. Increases in the average concentrations of some organic chemicals may not be reflective of statewide trends. Of the general classes of organic chemicals measured, pyrethroid pesticides demonstrated an increasing trend in detections and concentrations in sediments. Both the average and range of total pyrethroid concentrations increased in 2010. In addition, the number of samples having at least one pyrethroid detected increased from 2008 to 2010 (Table 4). Since many of the pyrethroid detections occurred in sediments collected from SPoT sites in urbanized watersheds, trends in urban pyrethroid use are instructive.

Bifenthrin was the most commonly detected pyrethroid in the 2008 and 2010 SPoT samples. There are two possible explanations for the increased detections of bifenthrin in these samples. One is that of all the pyrethroids, bifenthrin is the most stable in aquatic environments. At 20° C, bifenthrin has an aerobic half-life in sediment ranging from 12 to 16 months. The half-life range is 25-65 months at 4° C, and anaerobic half lives are much longer (Gan et al., 2005). Statewide pyrethroid use reported to the California Department of Pesticide Regulation did not increase between 2008 and 2010. The total pounds of active ingredients including bifenthrin, cyfluthrin, cypermethrin, L-cyhalothrin, and permethrin was 622,172 in 2008 and 582,581 in 2010.

Table 4
Three-year trends for detections of representative total chemical classes.

Sum of Chemical Class	Year	Percentage Detections	Average Detection	Minimum	Maximum
Pyrethroids (ng/g)	2008	55	16.9	0.516	113
	2009	52	12.8	1.36	48.5
	2010	81	30.4	0.084	1010
DDT (ng/g)	2008	73	31.8	0.361	365
	2009	78	77.8	0.456	420
	2010	33	12.1	1.00	43.8
Organophosphates (ng/g)	2008	12	25.9	5.2	116
	2009	4	59.2	59.2	59.2
	2010	0	NA	NA	NA
PCB (ng/g)	2008	49	15.6	0.113	125
	2009	39	13.0	0.581	31.6
	2010	10	17.05	2.10	36.3
PAH (ng/g)	2008	100	757	18.5	3567
	2009	100	1457	44.5	5535
	2010	93	293	1.70	4966
PBDE (ng/g)	2008	88	18.7	0.586	121
	2009	78	10.38	3.81	21.9
	2010	78	18.7	0.272	106
Metals 8 (µg/g)	2008	100	241	68.0	872
	2009	100	226	87.4	511
	2010	96	202	40.5	616

The chlorinated compounds DDT and PCBs saw a general decline over the three years. Detections and concentrations of PAHs, PBDEs and the sum of 8 metals remained constant. Note that PAHs and PBDEs were only measured in SPoT samples from Tier II sites, mostly in urban watersheds. Detections and concentrations of organophosphate pesticides in sediment also decreased between 2008 and 2010. For example, chlorpyrifos was detected in 12% of SPoT sites in 2008 and only 1 out of 23 sites sampled in 2009. No chlorpyrifos was detected in the 95 SPoT sites sampled in 2010. Analysis of chlorpyrifos sales through the Department of Pesticide Regulation showed relatively consistent sales during this period (1.9 million lbs. active ingredient in 2008, 1.6 million lbs. in 2009 and 1.9 million lbs. in 2010; http://www.cdpr.ca.gov/docs/mill/nopdsold.html).

Sediment Metals

Trace metals were measured in both whole sediments and sediments sieved to less than 63 um (Figure 4). Because trace metals bind preferentially to smaller sediment size fractions, particularly clays, it has been suggested that sieving sediments allows a better comparison of metal concentrations across watersheds by reducing the effects of grain size differences. Concentrations of metals in unsieved sediments give a measure of the total metal concentrations and these can be compared to published guideline values as an indication of the potential for biological effects. Relative differences of metals in sieved and unsieved samples were compared to determine the benefit of this additional analysis to the SPoT program in detecting long term trends.

State wide, concentrations of the two metal sums did not change over the three year sampling period. Similarly, the mean concentrations of mercury in sediments were largely unchanged over the sampling period (Figure 4). Mercury bioaccumulates in higher trophic level organisms and has been identified as one of the primary contaminants of concern in coastal sport fish tissues monitored by SWAMP's Bioassessment Oversight Group (BOG) (http://www.swrcb.ca.gov/water_issues/programs/swamp/coast_study.shtml). Mercury in sediment demonstrated high statewide variability, and specific sites in highly urbanized regions had the highest concentrations (discussed below).

Results of sieved and unsieved metals analyses were compared among years. Summary statistics (means, standard deviations, and coefficients of variation) were compared for 23 samples that were analyzed in all three years. The average coefficients of variation presented in Table 5 represent the mean of individual coefficients of variation calculated from three years of samples (2008, 2009 and 2010). The variability among the three years for the sums of 4 and 8 metals was slightly higher in sieved samples versus unsieved samples. When the single metals copper and zinc were compared, the bulk samples were slightly more variable than the sieved samples. Because of the high variability observed between years or among years, and because of the high variability in results between sites, it was determined that sieved metals do not provide additional information beyond the results of the bulk metals analysis.

Table 5

Average coefficients of variation among three years of results (n = 23), of sieved and unsieved metals for two metal sums, copper and zinc. *8 metals = As, Cd, Cr, Cu, Pb, Hg, Ag, Zn; **4 metals =Cd, Cu, Pb, Zn

Year	Bulk	Sieved
Sum 8 Metals*	21%	24%
Sum 4 Metals**	23%	25%
Copper	26%	23%
Zinc	32%	25%

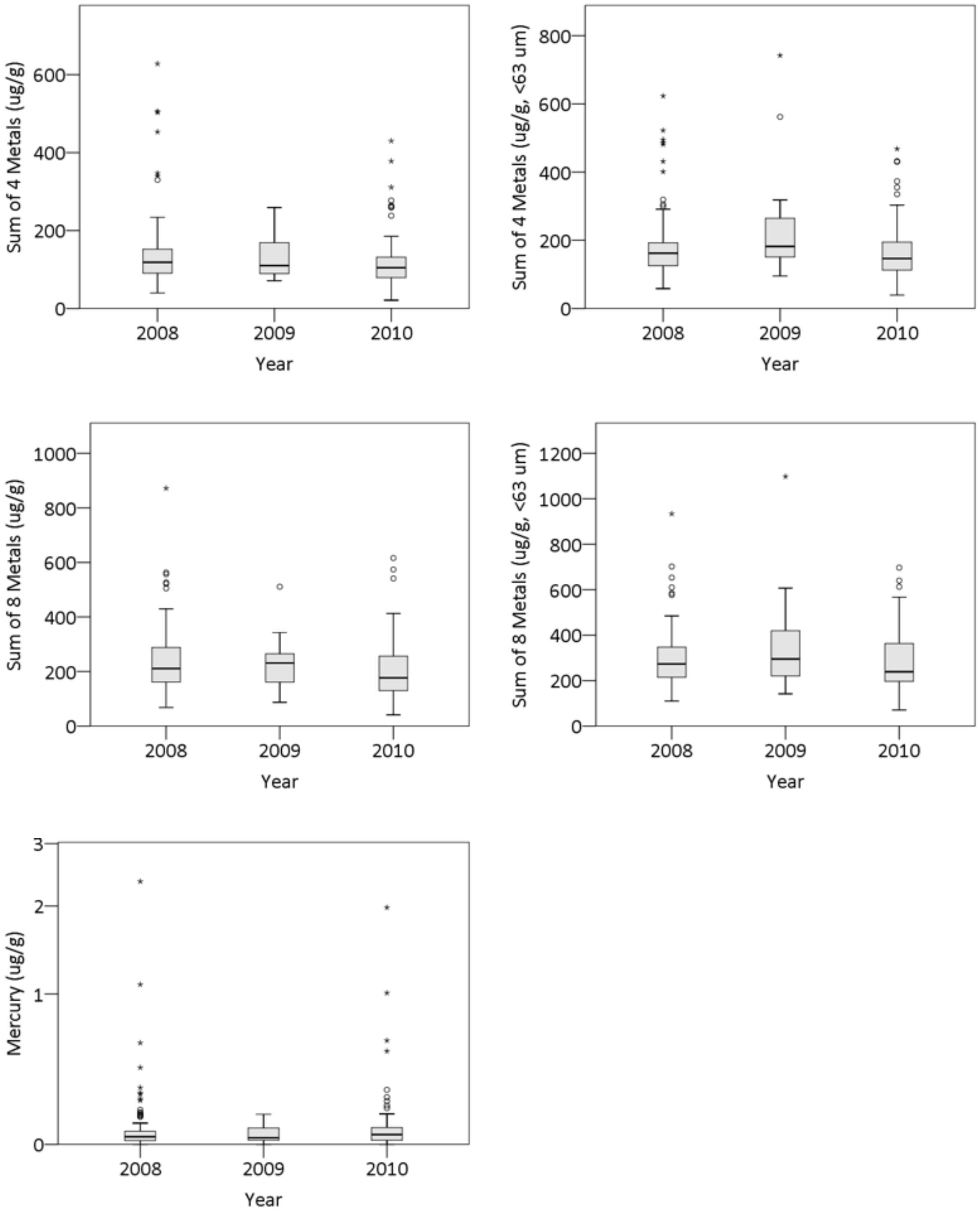

Figure 4. Three-year trends for four- (Cd, Cu, Pb, Zn) and eight- (As, Cd, Cr, Cu, Pb, Hg, Ag, and Zn) metal summations, and mercury (Hg) alone. Boxes represent first and third quartiles, line represents median, and t-bars represent 95% confidence limits. Additional points are outliers.

Chemical Concentrations Related to Toxicity and Guideline Thresholds

The relationships between amphipod mortality and sediment chemical concentrations were investigated for the 2008-2010 sampling years using Spearman Rank correlations, and by comparing amphipod survival with individual chemical threshold values. Where possible, median lethal concentrations (LC50s) were used to evaluate chemistry data. Various other sediment quality guidelines were used when LC50s were not available. Several new pesticide LC50s were used to re-evaluate the 2008 data set. Sediment quality guidelines included probable effect concentrations and median effect concentrations. Fifty guideline and LC50 values were used to evaluate several chemical classes including pyrethroid pesticides, organochlorine pesticides, organophosphate pesticides, PAHs, PCBs, and metals.

Correlation results show that amphipod survival was related to a number of organic chemical classes in 2008. The strongest (negative) correlations were between amphipod survival and sum pyrethroid pesticides, sum PCBs and sum DDTs (Table 6). Note: a negative correlation in this case indicates that as a chemical concentration increases amphipod survival decreases. There were no significant correlations between amphipod survival and chemical classes in the 2009 dataset, likely because of the small sample size. In 2010, amphipod survival was significantly negatively correlated with pyrethroids, sum PCBs and sum DDTs.

Table 6
Results of Spearman rank correlations between amphipod survival and concentrations of various analyte groups (2008-2010). Shaded cells indicate a significant negative correlation between survival and chemical concentration ($\alpha < 0.05$).

Analyte Group	2008		2009		2010	
	Probability	N	Probability	N	Probability	N
Sum Pyrethroids	0.000	92	0.768	23	0.000	95
Sum DDT	0.009	92	0.281	23	0.021	94
Sum PAH	0.040	28	0.397	6	0.294	49
Sum PCB	0.000	92	0.649	23	0.029	94
Sum Metals 8	0.062	92	0.637	23	0.169	95
Sum Metals 8 (<63 µm)	0.102	92	0.387	23	0.424	95
Sum Metals 4	0.048	92	0.604	23	0.124	95
Sum Metals 4 (<63 µm)	0.062	92	0.809	23	0.469	95
Percent Fines (<63 µm)	0.038	92	0.476	23	0.281	95

Of the fifty chemical thresholds evaluated, guideline values were exceeded for total chlordane and several metals, and LC50 values were exceeded for most pyrethroids and the organophosphate pesticide chlorpyrifos. The total chlordane probable effects concentration (PEC) was exceeded fourteen times between 2008 and 2010, but never by more than a factor of three. Only one sample from 2008 was highly toxic. It should be noted that the PEC for chlordane may not be a reliable indicator of the potential for acute toxicity to amphipods. Recent dose-response experiments have shown that chlordane is essentially not toxic to the marine amphipod *Eohaustorius estuarius* at concentrations found in surficial sediments (Phillips et al., 2011). Trace metal concentrations exceeded PECs at many sites, but it is unlikely these concentrations contributed to observed toxicity to *Hyalella azteca* because the concentrations did not exceed LC50s derived from dose-response experiments. Nickel and chromium most often exceeded the PEC. As with chlordane, the nickel PEC may not be a reliable indicator of toxicity to amphipods. For example, the nickel PEC is 48.6 mg/kg (Macdonald, 2000) but the nickel LC50 derived from recent sediment spiking experiments was found to be 521 mg/kg (Liber et al., 2011). Thus, while many samples exceeded the PEC for nickel, none exceeded the LC50. As laboratory dose response data become available for more contaminants, these will be used as the primary values for assessing the potential for toxicity to *H. azteca*. Both nickel and chromium are geologically abundant, particularly in areas of serpentine soils, such as those common in the Franciscan formation of the central and northern coast ranges (Bonifacio et al., 2010). Both are also used in various industrial applications, so natural sources cannot be assumed for all elevated samples. It should be noted that the comparison of sediment metal concentrations to published guideline values and other effect thresholds emphasize toxicity to invertebrates. In the case of laboratory dose-response experiments, these usually involve standard test species. These comparisons do not consider possible effects on other stream communities, such as algal communities. These may be more sensitive to sediment metal concentrations.

Pesticide LC50s were exceeded in 13% of the samples collected in 2008, 9% in 2009, and 20% in 2010. Most of the elevated concentrations were for bifenthrin, and nearly half of the samples with an exceeded LC50 for pesticides were considered highly toxic. To better evaluate the contribution of pyrethroids to observed toxicity, concentrations were converted to toxic units (TUs) by dividing the measured concentration by the LC50 and summing across all pyrethroids. Approximately 50% mortality would be expected at one TU. Previous research has demonstrated that significant toxicity is observed when the TUs are greater than one (Weston et al., 2005). In the current data set, the proportion of toxic and highly toxic samples increases beyond 0.5 TUs. All samples were toxic at greater than 2.5 TUs (Figure 5). Although correlation analysis from 2008 and 2010 demonstrated relationships between a number of chemical classes and toxicity, only concentrations of pyrethroid pesticides and chlorpyrifos exceeded toxicity threshold values.

Further Diagnosing the Contribution of Pyrethroids to Toxicity

The standard U.S. EPA protocol for *Hyalella azteca* specifies the test be conducted at 23 °C. It has long been recognized that some pyrethroid pesticides are more toxic at colder temperatures (Coats et al., 1989), and this characteristic has been used as a TIE tool to diagnose pyrethroid-associated

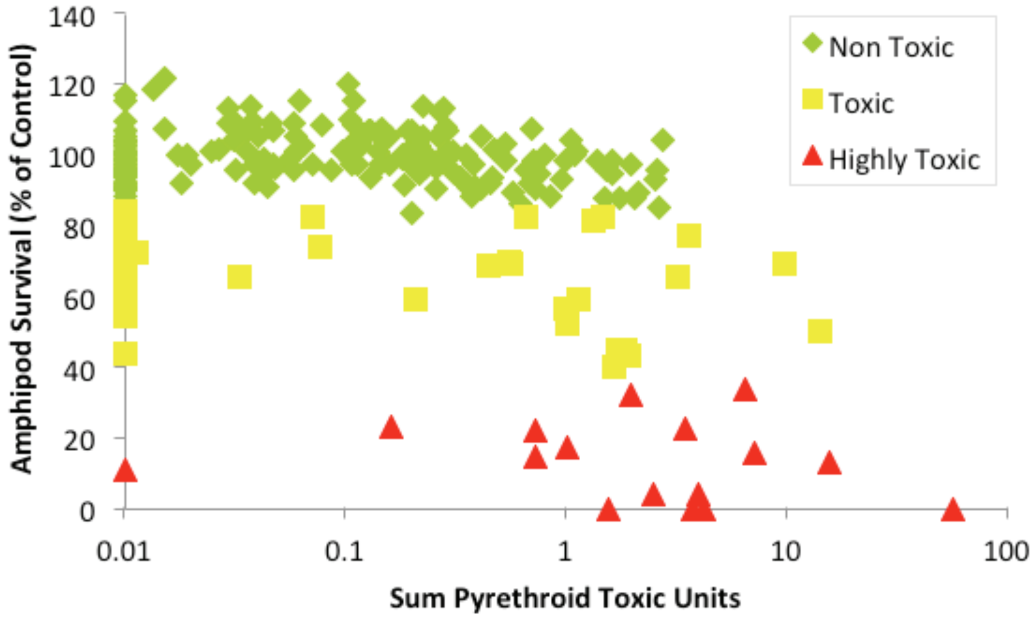

Figure 5. 2008-2010 toxicity data plotted against the sum of pyrethroid toxic units.

toxicity (Anderson et al., 2008). In a SWAMP statewide study of urban creek toxicity, Holmes et al. used this attribute to help identify pyrethroids as the likely cause of toxicity to *H. azteca* (Holmes et al., 2008). Increasing toxicity with decreasing temperature has been demonstrated specifically with *H. azteca* in more recent studies (Weston et al., 2009), and also with chironomids (Harwood et al., 2009). Harwood et al. (2009) showed this is due to slower metabolic breakdown of pyrethroids at lower temperatures. Temperature effects were evaluated using a subset of SPoT stations starting in 2010 (n = 15 samples). Tests were conducted at the standard 23°C and also at 15°C, to help diagnose toxicity due to pyrethroids. In addition, the 15°C test temperature assesses toxicity at a more environmentally relevant temperature for California surface waters (Table 7). Thirty-three additional low temperature comparisons were conducted as part of the SPoT variability study, also in 2010.

Table 7
Average surface water temperature in SPoT watersheds for each Regional Water Quality Control Board in California. Data present day-time water temperatures sampled at water depths less than 0.1 m. Data represent samples collected in all months.

Region	1	2	3	4	5	6	7	8	9	Statewide Average
Average Temperature (°C)	14.2	14.3	16.5	17.7	15.8	9.7	20.7	14.7	18.5	15.8
N	120	123	69	75	797	214	33	49	103	

Tests of samples from the SPoT base stations demonstrate that significantly more samples were toxic when tested at 15°C, and the magnitude of toxicity was much greater at the lower test temperature (Table 8). Seven percent of the samples were highly toxic when tested at 23°C, while 67% were highly toxic when tested at 15°C. Pyrethroid pesticides were detected in all of these samples, and all of the toxic samples contained greater than 0.5 toxic units of total pyrethroids. Toxic units based on organic carbon corrected LC50s are also presented to provide a better estimation of bioavailable sediment associated pyrethroid concentrations. The results of the variability study stations (described below) are less striking. These stations were located in primarily open space and agriculturally dominated areas and were generally not toxic with low concentrations of pyrethroids. Three sites contained concentrations of pyrethroids with toxic unit values greater than 0.5. These stations all had significantly greater toxicity when tested at 15°C. The results indicate that pyrethroid pesticides likely played a role in the increased incidence of toxicity in these samples. Two temperature testing has been expanded in the SPoT program and results for the 2011 sampling year are comparable to those presented here.

Table 8

Comparison of percent survival in 2010 samples tested at 23° C and 15° C. Data are from base stations (A) and variability study stations (B). The pyrethroid toxic units (TU) presented are based on LC50s for both dry-weight and organic carbon-normalized concentrations. See methods for details.

(A) Base Stations	23° C Survival (% of Control)	15° C Survival (% of Control)	Sum Pyrethroid TU*	OC-Corrected Sum Pyrethroid TU*
204SLE030	86	22	0.62	0.16
205GUA020	97	10	1.97	0.76
207LAU020	96	22	1.53	1.94
404BLNAxx	69	3	9.78	2.59
405SGRA2x	69	1	0.56	0.81
412LARWxx	95	21	1.63	0.82
504BCHROS	115	96	0.11	0.08
551LKI040	105	105	0.22	0.22
558PKC005	85	8	2.65	1.89
801CCPT12	77	18	3.59	2.92
801SARVRx	83	35	1.45	2.16
801SDCxxx	16	1	7.12	8.01
904ESCOxx	88	65	1.49	1.21
906LPLPC6	93	40	2.53	2.45
907SDRWAR	88	85	2.03	1.51
% Non-toxic	66	13		
% Toxic	27	20		
% Highly Toxic	7	67		

(B) Variability Study Stations	23° C Survival (% of Control)	15° C Survival (% of Control)	Sum Pyrethroid TU*	OC-Corrected Sum Pyrethroid TU*
504BCHROS	104	92	0.11	0.18
504BCHROS	109	110	0.03	0.11
504BCHBID	96	84	0.23	0.36
504BCHBID	109	104	0.05	0.13
504BCHBID	114	91	0.04	0.10
504BCHNOR	99	42	1.62	1.34
504BCHNOR	107	104	0.02	0.10
504BCHNOR	120	84	0.10	0.14
504BCHRIV	95	99	0.22	0.38
504BCHRIV	107	79	0.70	0.54
504BCHRIV	114	75	0.22	0.42
551LKI040	103	95	0.22	0.19
551LKI040	107	101	0.15	0.13
551LKI041	103	96	0.06	0.15
551LKI041	108	108	0.28	0.27
551LKI041	113	110	0.03	0.14
551LKI043	99	88	0.23	0.44
551LKI043	105	100	0.26	0.32
551LKI043	113	89	0.28	0.16
551LKI044	101	103	0.30	0.22
551LKI044	105	92	0.41	0.27
551LKI044	109	87	0.06	0.16
558PKC001	101	99	0.19	0.39
558PKC001	107	97	0.29	0.30
558PKC001	112	107	0.27	0.39
558PKC003	74	100	0.08	0.12
558PKC003	101	101	0.04	0.23
558PKC003	107	104	0.05	0.18
558PKC005	50	0	14.26	16.97
558PKC005	100	93	0.22	0.43
558PKC010	99	96	0.04	0.22
558PKC010	107	92	0.04	0.15
558PKC010	107	104	0.13	0.67

These data also suggest that the potential for surface water toxicity is likely underestimated in SPoT watersheds based on assessing toxicity at the standard protocol temperature (23°C). Average surface water temperatures in the SPoT watersheds were evaluated by compiling all surface water temperature data from years 2001-2010 for each of the hydrologic units where SPoT stations are located (Table 7). Samples represent day-time temperatures measured at depths less than 0.1m as part of SWAMP routine monitoring, which is conducted during all months of the year (Cassandra Lamerdin, Moss Landing Marine Laboratories, personal communication). Based on these screening criteria, the average statewide surface water temperature for all regions was 15.8°C, considerably lower than the standard test temperature (23°C). Average temperatures ranged from a low of 9.7°C in Region 6 to a high of 20.7°C in Region 7.

Evaluation of Spatial and Temporal Variability Associated with SPoT Base Stations

The SPoT program is designed to assess one-hundred sites yearly to determine long-term trends in toxicity and chemical contamination. As described above, this design is based upon that used by the USGS NAWQA program. SPoT stations are located near the base of major watersheds, and sampling is conducted once per year after the rainy season. Based on recommendations from the SPoT SRC, additional testing has been conducted at selected SPoT sites to assess the temporal and spatial variability of toxicity and contamination. Results of these additional assessments were analyzed to determine the extent to which a once-per-year summer sampling event at single SPoT stations provided adequate spatial and temporal representation of the watershed for the determination of long-term trends in contamination and toxicity. Three Region 5 sites were selected for the initial phase of this study: Big Chico Creek, the South Fork of the Kings River, and Packwood Creek. These SPoT sites are in largely agricultural watersheds but also receive substantial urban stormwater runoff. Additional sites from urban-dominated watersheds were assessed in 2011. For each of the SPoT sites in this study, three additional stations were monitored upstream. These were located within a few kilometers of the base station in order to provide adequate spatial representation. All stations plus the base station were sampled three times per year to represent the summer, winter and spring seasons.

Toxicity was estimated using 10-day amphipod survival tests, and contamination was characterized by measurement of pyrethroid pesticides. Pyrethroids were selected because of their pervasive use in urban and agricultural watersheds and increasing importance in driving sediment toxicity in California watersheds. Toxicity was also tested at two temperatures as described above. The toxicity and chemistry data were analyzed by first conducting a two-factor analysis of variance (without replication) on the spatial and temporal data within the 2010 sampling season. The results of these analyses determined if there were significant differences among the seasons within the year, or among the stations within the watershed. The results from the three base station samples conducted within 2010 were then compared to the base station results from other years using an F-Ratio test to determine if seasonal variability was significantly greater than annual variability.

There were no significant differences among the stations for toxicity at either temperature or for bifenthrin, the pyrethroid pesticide detected. Total organic carbon (TOC) was significantly different at the stations in the Packwood Creek watershed (Table 9). There were significant seasonal differences for toxicity at 23°C for Big Chico Creek and Lower Kings River. If the amphipod survival results are more variable among years than they are within a year, then it is assumed that yearly sampling is adequate to characterize long-term trends. Results of the F-Ratio tests indicate that annual variability was greater than seasonal variability at all three sites. These results indicate that in most instances, a single baseline sample was representative of sediment toxicity at proximate stations and in different seasons.

Table 9
Probability values for statistical comparisons among stations, seasons and years at variability sites.
Shading represents significant differences ($p<0.05$).

Station Name	Significant Difference Among			F-Ratio Test (one tail)
	Parameter	Stations	Seasons	Ho: Annual ≥ Seasonal
Big Chico Creek	23° Toxicity	0.295	<0.001	0.487
	15° Toxicity	0.481	0.340	0.057
	TOC	0.312	0.303	
	Bifenthrin	0.717	0.344	
Lower Kings River	23° Toxicity	0.386	0.002	0.949
	15° Toxicity	0.236	0.534	0.794
	TOC	0.393	0.871	
	Bifenthrin	0.721	0.542	
Packwood Creek	23° Toxicity	0.297	0.834	0.108
	15° Toxicity	0.052	0.478	0.370
	TOC	0.010	0.060	
	Bifenthrin	0.302	0.413	

Conclusions regarding the representativeness of the current once per year sampling depend on the spatial and seasonal variability of toxicity and chemistry at these sites. The current results suggest once per year sampling adequately represent highly variable indicators in particular watersheds, particularly for sites with less overall variability. No definitive conclusions regarding the SPoT sampling design can be made based on the limited number of sites and samples used for the current comparison. Additional variability samples were collected in 2011 and 2012. These were collected from two sites in highly urban watersheds (Coyote Creek and San Diego Creek). Analysis of data from repeated sampling of the same sites will help to better assess how well the current design characterizes trends in sediment contamination and toxicity. The additional temporal and spatial sampling in these two watersheds is also intended to allow for a more comprehensive assessment of the effectiveness of the newly implemented California Department of Pesticide Regulation's use restrictions for pyrethroid pesticides in urban environments. Results of these additional variability studies will be presented in the 2011-2012 SPoT report.

Regional Trends

The majority of toxicity data from SPoT stations sampled statewide from 2008 through 2010 demonstrated variable results over time. The specific sites that were highly toxic in every sampling year (when tested at 23°C) included: the Tembladero Slough and Santa Maria River stations in Region 3, San Diego Creek in Region 8, and the Tijuana River in Region 9. No SPoT sites from Region 1, 2, 6 or 7 were consistently categorized as highly toxic (i.e., during all three sampling years). As noted above, the number of sites demonstrating high toxicity increased when tests were conducted at 15°C, and this was likely due to the presence of pyrethroid pesticides. Sites for which high toxicity was observed in 15°C tests included: San Leandro Creek and Guadalupe Creek in Region 2, Ballona Creek and the San Gabriel and Los Angeles Rivers in Region 4, Packwood Creek in Region 5, and Chino Creek, San Diego Creek and the Santa Ana River in Region 8. As testing with two temperatures expanded to more sites in 2011 and 2012 the number of sites demonstrating consistently high toxicity increased when tested at 15°C. These data will be incorporated into the characterization of statewide and site-specific trends for the 2011-2012 SPoT report.

Individual regional trends in chemical contamination generally followed the statewide trends (Table 10). Average DDT concentrations in sediment decreased between 2008 and 2010 in all regions. Average PCBs in sediment were largely not detected in Regions 1, 3, 5, 6 and 7, and decreased in Regions 2 and 8. Average PCBs in sediment were basically unchanged in Regions 4 and 9, two of the most urbanized regions in the state. Average pyrethroid pesticide concentrations in sediments increased between 2008 and 2010 in Regions 1, 4, 5, 6, 7, 8, and 9, but were almost unchanged in Regions 2 and 3. The largest increase in average pyrethroid concentrations in sediment occurred in Region 4, and this was due to very large increases at two stations: Bouquet Creek and Ballona Creek. The highest SPoT total pyrethroid concentrations in the state in 2010 were measured in sediments from Bouquet Creek, Ballona Creek (both in Region 4), and the Tijuana River (Region 9). The high total pyrethroid concentrations at these sites were due to bifenthrin.

Region 1 – North Coast

Nine sites were sampled in 2008 and eight sites were sampled in 2010. One of the Russian River sites (114RRAXRV) was removed from the list. Information on specific SPoT sites is provided in Appendix 2. The incidence of sediment toxicity in Region 1 increased from 22% to 63% (Figure 6). While no samples were highly toxic, there was an increase of toxic samples. Two samples were collected in 2009, and were not toxic. No Region 1 samples were tested at 15°C. The percentage of pyrethroid detections increased from 22% to 38%, but the increase in the average sum measurement was fairly low. Chlorinated chemicals were not detected in 2010, and PAHs and PBDEs were not measured in 2008. The average concentration of the sum of anthropogenic metals decreased slightly between 2008 and 2010.

Region 2 – San Francisco Bay

Ten sites were sampled in 2008 and 11 sites were sampled in 2010. Sonoma Creek (206SON010) was added to the list. Sediment toxicity in Region 2 streams decreased between 2008 and 2010, but one highly toxic sample was collected in 2010 (Kirker Creek – 207KIR020, Figures 6 and 7). Three samples were collected in 2009. Two of these samples were significantly toxic, as they were in 2008. Three non toxic samples were also tested at 15°C., and were highly toxic at the lower temperature. All of these samples had greater than 0.5 TU of total pyrethroids. Overall, the percentage of pyrethroid and PAH detections and the average sum concentrations did not change significantly between 2008 and 2010, whereas detections and concentrations of DDT and PCBs decreased. Detections and concentrations of PBDE also decreased, but to a lesser extent. The average concentration of the sum of anthropogenic metals decreased between 2008 and 2010. Two sites in Region 2 had the highest sediment mercury concentrations measured in the SPoT program. These were Walker Creek Ranch (Hg = 1.01 – 2.36 µg/g) and Guadalupe Creek (1.09 – 1.98 µg/g).

Region 3 – Central Coast

The same 11 sites were sampled in 2008 and 2010. Incidence of toxicity was reduced by half during this period, but the number of highly toxic samples remained the same (Tembladero Slough – 309TDWxxx and Santa Maria River – 312SMAxxx, Figures 7 and 8). Three samples were collected in 2009, including the Santa Maria River, which was highly toxic. Two other samples that were toxic in 2008 were not toxic in 2010. No Region 3 samples were tested at 15°C. The number of pyrethroid detections increased, but the average sum was lower. The numbers of detections and concentrations of DDT were decreased, and PCBs were not detected in 2010. The concentrations of PAHs and PBDEs decreased, but the number of detections did not change. Metals were detected in every sample, but their concentrations were lower in 2010.

Region 4 – Los Angeles

Seven sites were sampled in 2008 and eight sites were sampled in 2010 (Figure 8). The Los Angeles River (412LAWRxx) was added to the list. The incidence of toxicity in Region 4 increased between 2008 and 2010, particularly with the addition of Bouquet Canyon Creek (403STCBQT), which was highly toxic and contained the highest concentration of pyrethroids measured in the program. Ballona Creek (405BLNAxx) and San Gabriel River (405SGRA2x) were also moderately toxic in 2010. Two Region 4 samples were collected in 2009, but only Ballona Creek was toxic. Three sites were tested at 15°C (Ballona Creek, San Gabriel River and Los Angeles River – 412LARWxx). All three sites became highly toxic when tested at the colder temperature. The Los Angeles River was not toxic when tested at 23°C. All three sites contained greater than 0.5 toxic units of pyrethroids. Pyrethroids were detected in all of the 2010 samples, whereas they were only detected in about half of the samples from 2008. The average sum concentration also increased approximately five-fold. Detections of DDT and PCBs decreased, but only the concentrations of DDT were lower in 2010. PBDEs were detected in every sample in 2008 and 2010, but their concentrations were lower in 2010. Metals were detected in every sample, but their concentrations were lower in 2010.

Region 5 – Central Valley

Thirty-one sites were sampled in 2008 and 34 sites were sampled in 2010. The Mokelumne River at Highway 49 (532CAL004) was removed from the list, but Harding Drain (535STC501), Marsh Creek

(541MERECY), Del Puerto Creek (541STC516), and Mokelumne River at New Hope Road (544SAC002) were added (Figures 6-8). Considering the high number of samples collected in Region 5, the incidence of toxicity remained fairly constant. Marsh Creek and Orestimba Creek (541STC019) were both highly toxic, although Orestimba Creek was not toxic in 2008. Only four Region 5 samples were collected in 2009, and none of these were significantly toxic. Three sites were tested at 15°C and as part of the variability study: Big Chico Creek (504BCHROS), Lower Kings River (551LKI040), and Packwood Creek (558PKC005). All three of these sites were not toxic at 23°C, but Packwood Creek became highly toxic when tested at the lower temperature. This station also contained 2.65 toxic units of pyrethroids. Detections of pyrethroids increased from 42% of the samples to 76% of the samples, and the average total concentration increased three-fold. Detections and concentrations of all other contaminant classes decreased between 2008 and 2010.

Region 6 – Lahontan

Nine samples were collected in 2008 and ten samples were collected in 2010 (Figures 6 and 8). Deep Creek (628DEPSED) was added to the list. Pyrethroids were detected in half of the samples in 2008 and 2010, and the average total concentration increased in 2010. Detections and concentrations of DDT and PCBs went to zero in 2010, and those of PBDEs were reduced by half. PAHs and metals were detected in every sample, but total concentrations were lower in 2010.

Region 7 – Colorado River Basin

Three samples were collected in 2008 and 2009, but only two samples were collected in 2010. Region 7 is the only region to have a complete set of samples for the 2009 season. Only the New River was significantly toxic in all three years (723NROTWM). No samples in Region 7 were highly toxic (Figure 8). Pyrethroids were detected in both the Alamo and New River samples in all three samples years, and the average total concentration increased four-fold. A previous SWAMP study implicated pyrethroids as the cause of water column toxicity in the New River (Phillips et al., 2007). DDT and metals were detected in all of the samples, but concentrations were lower in 2010. PCBs were not detected in any samples and PBDEs were not measured. PAHs were not measured in 2008, but were detected in all 2010 samples.

Region 8 – Santa Ana

Five samples were collected in 2008, two in 2009, and four in 2010. One highly toxic sample from 2008 (845SGRDRE) was removed from the list, as was one of the San Jacinto River stations (802SJRGxx). Two stations were added in 2010 (Chino Creek – 801CCPT12, and Santa Ana River – 801SARVRx), and both were moderately toxic (Figure 8). Two sites were sampled in all three years, San Jacinto River reference (802SJCREF) and San Diego Creek (801SDCxxx). The reference site has not been toxic, but the San Diego Creek site was highly toxic every year. Detections of pyrethroids were similar from year to year, but the average total concentration increased in 2010. Detections and concentrations of DDT and PCBs decreased between 2008 and 2010, and although PAHs, PBDEs, and metals were detected in every sample, the concentrations of these contaminants also decreased between 2008 and 2010.

Region 9 – San Diego

Seven sites were sampled in 2008 and 2010, and a subset of three of these sites was sampled in 2009. Agua Hedionda Creek (904CBAHC6) and Forrester Creek (907SDFRC2) were removed from the list after 2008, and were replaced by San Dieguito River (905SDSDQ9) and the San Diego River (907SDRWAR). All of the Region 9 sites were non-toxic except for the Tijuana River (911TJHRxx), which was sampled in 2008 and 2010 and was highly toxic (Figure 8). Pyrethroids were detected in all of the samples collected in Region 9, and the average total concentration increased almost five-fold between 2008 and 2010. Detections of DDT, PCBs and PAHs all decreased, as did concentrations of DDT and PAHs. Detections of PBDEs increased, but average concentrations were similar. Metals were detected in all samples, and concentrations decreased slightly between 2008 and 2010.

Table 10
Summary of toxicity and chemistry results organized by Water Quality Control Board Region.

Region		Toxicity			Pyrethroids		DDT		PCB		PAH		PBDE		Metals 4	
		2008	2010		2008	2010	2008	2010	2008	2010	2008	2010	2008	2010	2008	2010
1	% Toxic	22	63	% Detections	22	38	22	0	11	0		100		100	100	100
	% Highly Toxic	0	0	Average Sum	2.18	1.67	0.52	0	0.16	0		120		3.62	91.3	85.6
2	% Toxic	50	18	% Detections	89	82	80	50	100	20	100	100	100	88	100	100
	% Highly Toxic	0	9	Average Sum	25.6	24.6	26.4	5.72	33.0	4.19	1286	1132	34.1	19.4	248	190
3	% Toxic	36	18	% Detections	64	82	100	64	73	0	100	100	75	75	100	100
	% Highly Toxic	18	18	Average Sum	26.9	15.2	87.9	8.29	5.55	0	765	108	7.97	1.83	121	99.7
4	% Toxic	29	38	% Detections	43	100	100	25	100	75		100	100	100	100	100
	% Highly Toxic	0	13	Average Sum	33	184	32.1	5.23	15.9	15.1		151	121	65.5	158	131
5	% Toxic	6	9	% Detections	42	76	74	32	23	0	100	83	80	50	100	100
	% Highly Toxic	3	6	Average Sum	2.98	8.42	12.4	3.05	0.69	0	459	82.2	3.08	2.01	123	108
6	% Toxic	0	0	% Detections	44	50	11	0	11	0	100	100	100	50	100	100
	% Highly Toxic	0	0	Average Sum	3.44	8.69	0.16	0	0.05	0	172	29.0	1.36	0.59	120	95.6
7	% Toxic	33	50	% Detections	67	100	100	100	0	0		100			100	100
	% Highly Toxic	0	0	Average Sum	5.71	25.8	43.2	23.0	0	0		119			144	107
8	% Toxic	40	75	% Detections	80	75	100	75	100	25	100	100	100	100	100	100
	% Highly Toxic	40	25	Average Sum	46.8	79.6	22.6	3.83	25.0	1.25	426	152	12.1	8.06	224	108
9	% Toxic	14	14	% Detections	100	100	100	29	86	57	100	80	75	100	100	100
	% Highly Toxic	14	14	Average Sum	16.2	79.9	6.09	2.47	7.35	7.76	1035	310	6.98	5.68	185	160

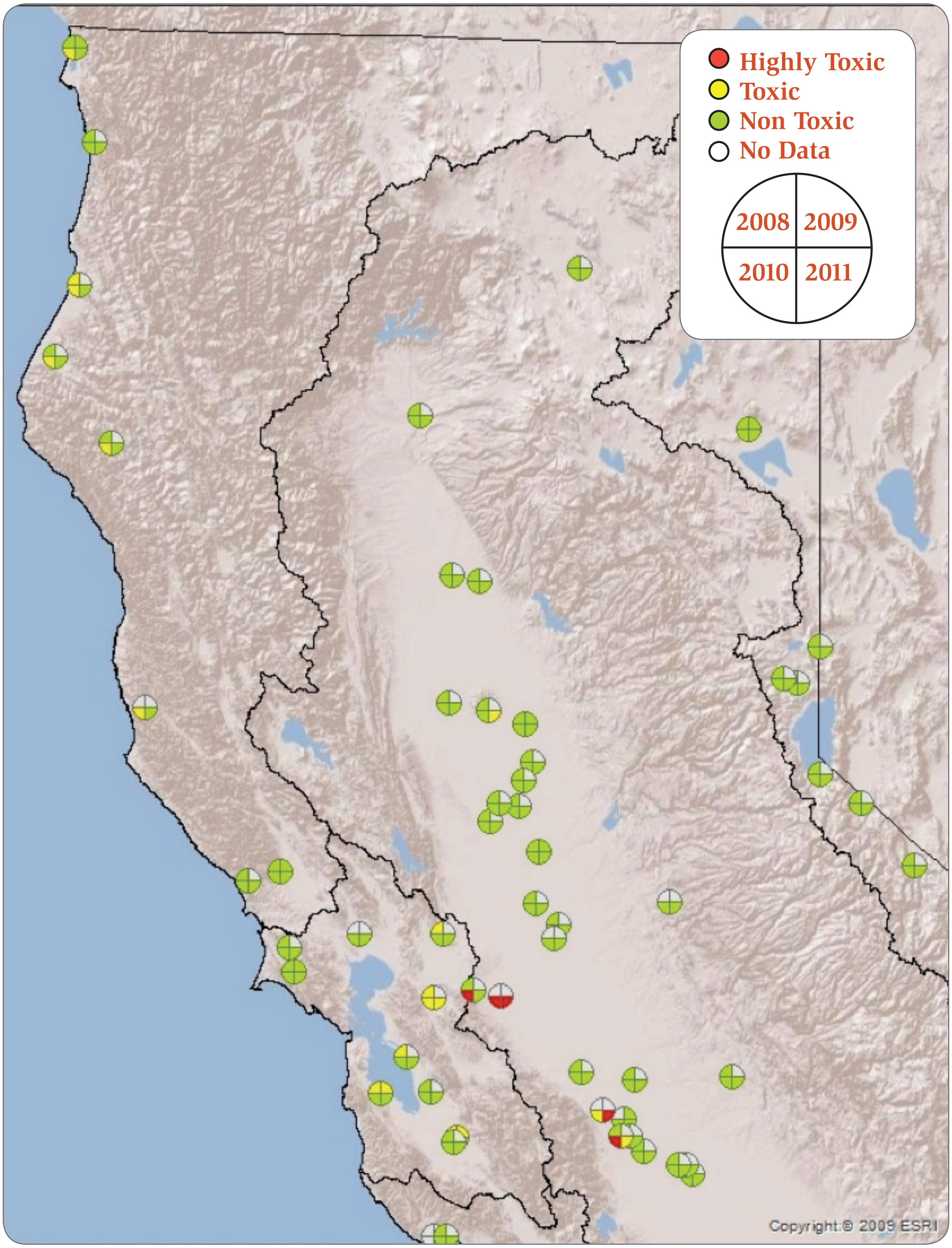

Figure 6. Regional toxicity trends in Northern California.

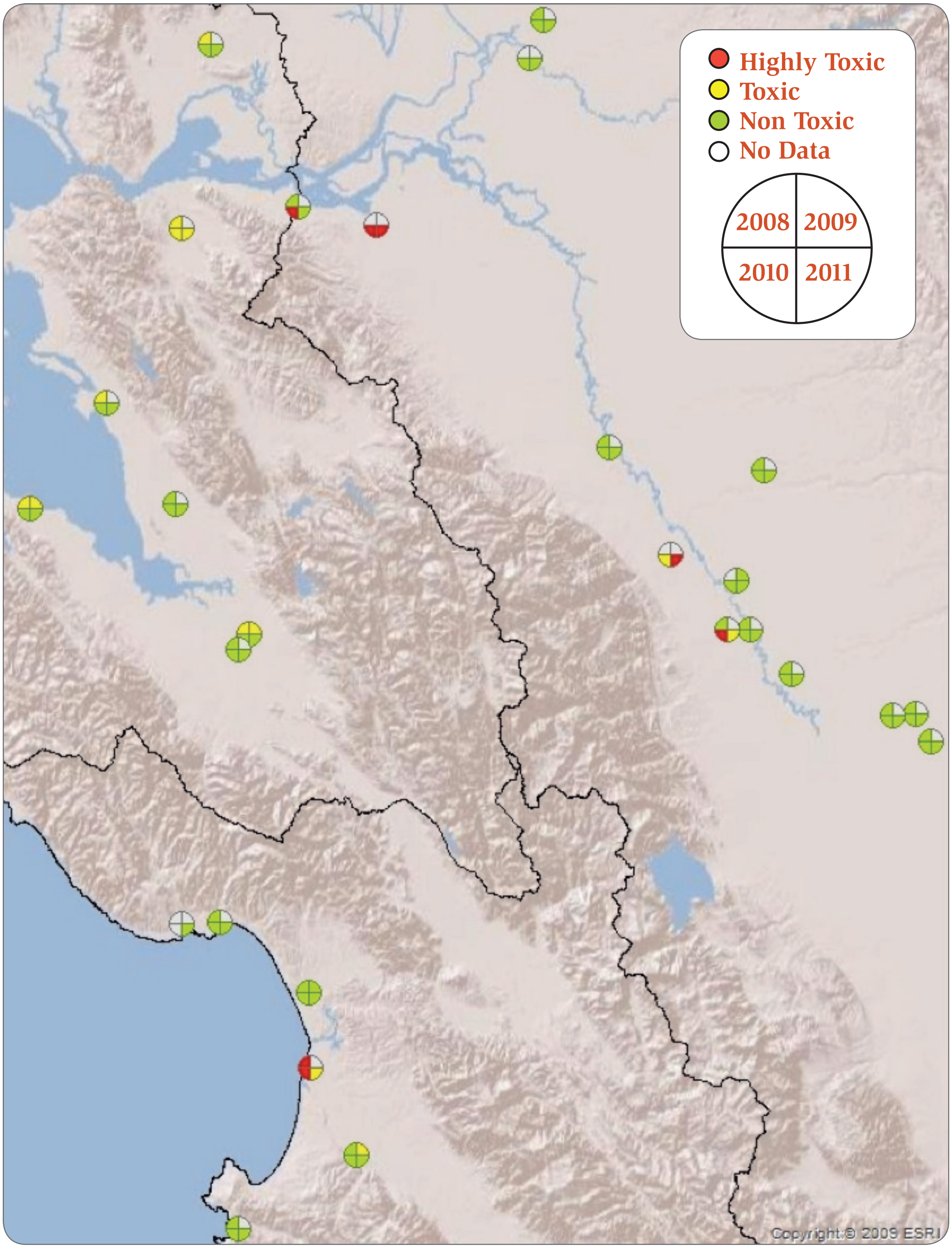

Figure 7. Regional toxicity trends in Central California.

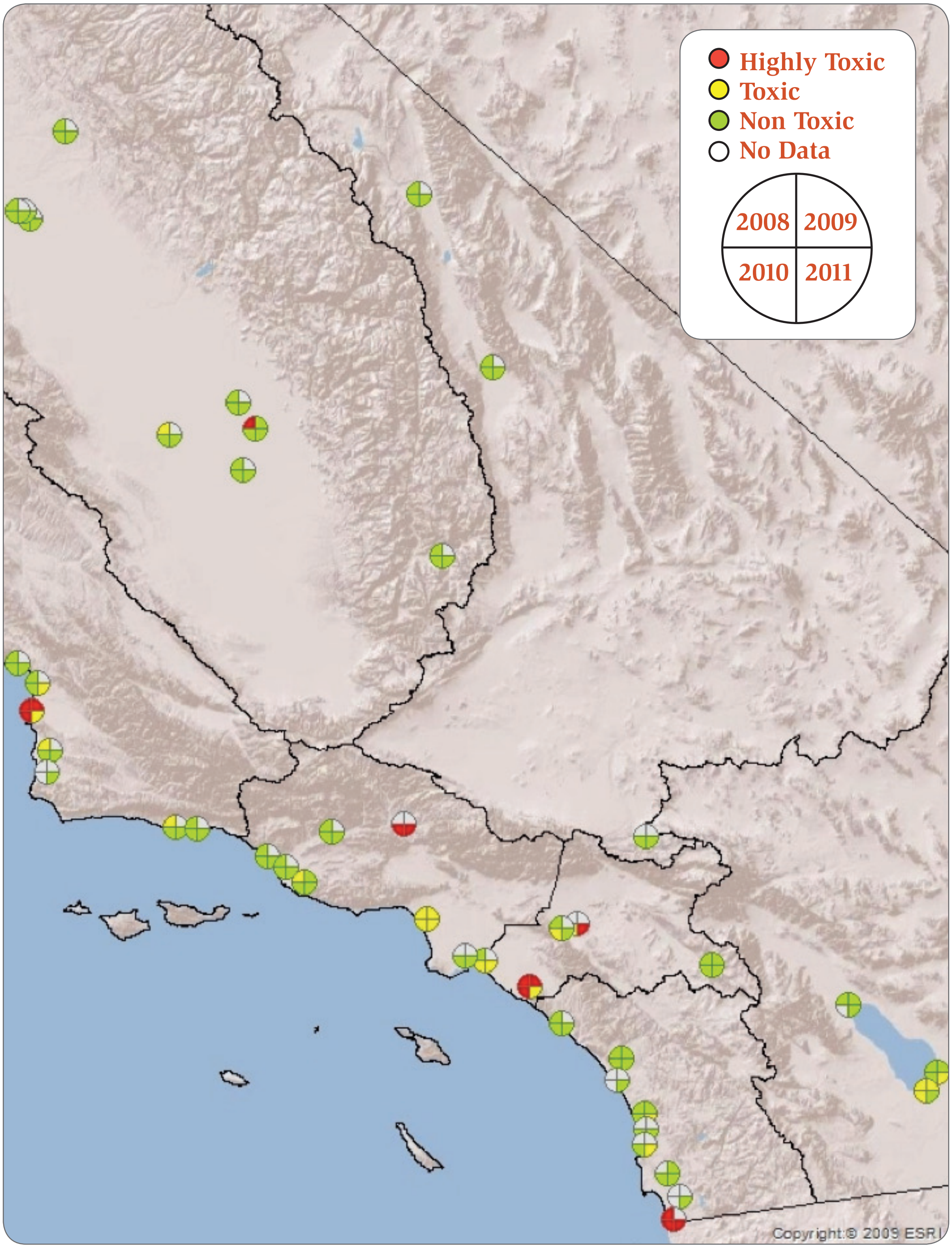

Figure 8. Regional toxicity trends in Southern California.

GOAL 2 – RELATIONSHIPS BETWEEN WATER QUALITY INDICATORS AND LAND USE

The SPoT program is designed to detect long-term changes in watershed contaminants and toxicity as they relate to changes in land use. Land use information is obtained from the National Land Cover Database (NLCD). The 2001 version of the NLCD was used for the 2008 SPoT report, and the 2006 version of the NLCD was used for the current report. Changes in land use for all of the SPoT watersheds were characterized for 3 different scales: 1 kilometer upstream of the sampling site, 5 k upstream, and the entire watershed above the site. To assess overall changes in land use, the average urban land use and agricultural land use (row crop and pasture) were calculated. Land use data presented in Table 11 shows that at the 1k scale, the average urban land use in all SPoT watersheds increased from 28% to 29% between 2008 and 2010, but decreased by one percent at the watershed scale. During this same period, agriculture land use increased at the 5K scale by 1%. Thus, changes in state wide land use between the 2001 and 2006 NLCD were minimal.

Table 11
Relative changes in urban and agricultural land use between 2008 and 2010.
Numbers indicate the percentage of urban and agricultural land cover at each watershed scale.

SPoT WS Year	NLCD Year	Urban			Agriculture		
		1k	5k	Watershed	1k	5k	Watershed
2008	2001	28	23	10	23	26	8
2010	2006	29	23	9	23	27	8

Correlations

Correlations between land cover and toxicity and chemistry indicators for SPoT watersheds from 2008-2010 are presented in Table 12. The vast majority of significant correlations for both sediment toxicity and chemical contaminants in SPoT watersheds were with urban land cover (i.e., the greater the percentage of urban land cover, the greater the in-stream sediment toxicity). There were significant correlations between urbanization and these indicators at all three watershed scales. Amphipod survival was negatively correlated with urban land cover in 2008 and 2010, and was also negatively correlated with developed open space land cover. In 2008, amphipod survival was negatively correlated with agricultural land cover (as Cropland) only at the watershed scale. In 2010, amphipod survival was negatively correlated with agriculture land cover at all three watershed scales.

Contaminant concentrations were most highly correlated with urban land cover during all three years. In 2008, urban land cover at all three scales was highly correlated with all of the classes of organic contaminants. Weaker relationships were observed in the 2009 dataset because of the smaller sample size. DDT was highly correlated with urban land cover in 2008, but was more strongly correlated with agriculture land cover at all three watershed scales in 2010. Sediment metals were significantly correlated

Table 12

Results of correlation analyses between sediment chemical contaminant concentrations, toxicity (% amphipod survival) and percentage of land cover in four categories using nonparametric multivariate Spearman's α test. Shaded probability cells indicate statistically significant negative relationships between toxicity and % land cover for each category, or statistically significant positive relationships between chemical variables and % land cover ($\alpha < 0.05$).

2008 Variable (n= 92)	Urban			Developed Open Space			Pasture			Crop		
	1K	5K	Watershed	1K	5K	Watershed	1K	5K	Watershed	1K	5K	Watershed
Survival (% of Control)	0.016	<0.001	0.053	0.940	0.081	0.037	0.227	0.583	0.066	0.334	0.101	0.029
Sum Pyrethroids	<0.001	<0.001	<0.001	0.516	0.005	<0.001	0.431	0.203	0.088	0.343	0.182	0.292
Sum DDT	0.004	<0.001	<0.001	0.648	0.013	<0.001	0.936	0.461	0.313	0.095	0.067	0.004
Sum PAH	0.012	0.014	0.046	0.593	0.127	0.043	0.016	0.002	<0.001	0.042	0.008	0.001
Sum PBDE	<0.001	<0.001	0.001	0.977	0.141	0.007	0.103	0.014	0.024	0.053	0.047	0.034
Sum PCB	<0.001	<0.001	<0.001	0.059	<0.001	<0.001	0.205	0.030	0.003	0.034	0.006	0.038
Sum Metals 8	0.025	0.067	0.205	0.961	0.824	0.204	0.042	0.122	0.274	0.673	0.654	0.544
Sum Metals 8, <63 um	0.003	0.029	0.186	0.374	0.146	0.050	0.033	0.136	0.194	0.584	0.971	0.537
Sum Metals 4	0.001	0.001	<0.001	0.898	0.630	0.043	0.007	0.093	0.230	0.333	0.595	0.221
Sum Metals 4, <63 um	<0.001	<0.001	<0.001	0.163	0.042	0.003	0.002	0.058	0.039	0.444	0.316	0.089
2009 Variable (n= 23)												
Survival (% of Control)	0.239	0.572	0.735	0.343	0.566	0.865	0.636	0.581	0.982	0.205	0.379	0.783
Sum Pyrethroids	0.268	0.093	0.056	0.397	0.458	0.239	0.258	0.911	0.362	0.476	0.456	0.356
Sum DDT	0.823	0.190	0.149	0.427	0.706	0.334	0.743	0.524	0.231	0.684	0.346	0.013
Sum PAH	0.072	0.042	0.787	0.208	0.544	0.872	0.158	0.140	0.208	0.158	0.158	0.872
Sum PBDE	0.104	0.032	0.213	1.000	0.284	0.500	0.016	0.069	0.284	0.459	0.459	0.559
Sum PCB	0.014	<0.001	0.066	0.343	0.007	0.062	0.055	0.048	0.129	0.546	0.086	0.561
Sum Metals 8	0.094	0.115	0.768	0.433	0.109	0.538	0.231	0.145	0.048	0.511	0.215	0.125
Sum Metals 8, <63 um	0.260	0.268	0.691	0.686	0.405	0.672	0.789	0.189	0.008	0.778	0.914	0.081
Sum Metals 4, <63 um	0.330	0.110	0.491	0.986	0.371	0.321	0.143	0.085	0.049	0.842	0.835	0.568

2008 Variable (n= 92)	Urban			Developed Open Space			Pasture			Crop		
	1K	5K	Watershed	1K	5K	Watershed	1K	5K	Watershed	1K	5K	Watershed
2010 Variable (n= 95)												
Survival (% of Control)	0.043	<0.001	0.006	0.472	0.002	<0.001	0.227	0.252	0.002	0.015	0.028	0.015
Sum Pyrethroids	<0.001	<0.001	<0.001	0.218	<0.001	<0.001	0.049	0.265	0.139	0.677	0.467	0.591
Sum DDT	0.694	0.101	0.032	0.239	0.960	0.210	0.638	0.098	0.042	0.004	0.004	0.002
Sum PAH	0.005	0.001	0.006	0.197	0.166	0.006	0.777	0.057	0.110	0.186	0.010	0.031
Sum PBDE	0.055	0.002	0.018	0.974	0.900	0.033	0.602	0.041	0.014	0.122	0.100	0.011
Sum PCB	<0.001	<0.001	<0.001	0.246	0.001	<0.001	0.539	0.060	0.110	0.013	0.012	0.037
Sum Metals 8	0.105	0.058	0.278	0.457	0.783	0.243	0.027	0.097	0.353	0.694	0.804	0.978
Sum Metals 8, <63 um	0.099	0.158	0.680	0.337	0.492	0.357	0.119	0.649	0.773	0.466	0.470	0.833
Sum Metals 4	0.001	<0.001	<0.001	0.477	0.173	0.011	0.007	0.068	0.410	0.777	0.628	0.712
Sum Metals 4, <63 um	<0.001	<0.001	0.003	0.270	0.074	0.037	0.034	0.399	0.421	0.734	0.675	0.227

with urban land uses in all three sampling years. However, stronger correlations were observed for the four metals associated with anthropogenic inputs (Cd, Cu, Pb, Zn; Table 12). Weaker correlations were observed for the eight metals that include constituents that have substantial geologic sources (Ni, Hg, Cr), and therefore would not necessarily be associated with urbanized landscapes. Correlations between the eight metals and urban land cover decreased between 2008 and 2010. Metals were sometimes correlated with developed open space and with pasture land on the 1 km scale in 2008 and 2010, but were not strongly correlated with agriculture land cover (Crop Land) in any of the three sampling years.

Impervious Surfaces

Percentage of watershed area covered by impervious surfaces at all three scales were negatively correlated with amphipod survival and positively correlated with sediment concentrations of most classes of contaminants (Table 13). Sum DDT did not correlate with impervious surface at the 1 and 5 km scales, but did correlate at the whole watershed scale. The sum of 8 metals, whether sieved or unsieved, only correlated with impervious surface at the 1 km scale. These results were very similar to the 2010 correlation results for urban land cover (Table 12).

Trends Related to Land Use

For the purposes of relating trends in chemical concentrations to land use, the watersheds were categorized based on the land use at 1km, 5km, and watershed scales as described above. As described above, the number of detections and the average concentrations of pyrethroid pesticides increased between 2008 and 2010, and the concentrations of this chemical class significantly correlated with urban land use at all watershed scales (Figure 9). Because pyrethroids are hydrophobic and are often detected near their sources, viewing their concentrations in relation to land use at the 1 km scale is striking. Overall concentrations in the urban watersheds were higher than the agricultural watersheds, but concentrations in both types of watersheds at the 1 km scale showed a significant increase.

The chlorinated compounds DDT and PCBs were also significantly correlated with urban land use. Figure 10 depicts the reduction of these compounds in urban watersheds at the watershed scale. The sum of 4 metals had more significant correlations with urban land use than the sum of 8 metals. The four-metal sum is reflective of the total concentrations of the more toxic divalent cations (Cd, Cu, Pb and Zn). Figure 11 shows the relative concentration ranges of metals in all three land use categories at the watershed scale. Although concentrations of metals did not vary state wide, concentration in urban watersheds decreased during the three year sampling period.

Table 13

Correlations between sediment chemical contaminant concentrations, toxicity (% amphipod survival) and impervious surface cover within the watersheds generated using nonparametric multivariate Spearman’s αtest. Shaded probability cells indicate statistically significant negative relationships between amphipod survival and land cover, or statistically significant positive relationships between chemical concentrations and land cover ($\alpha < 0.05$).”

2010 Variable	1 km	5 km	Watershed
Survival (% of Control)	0.028	<0.001	0.003
Sum Pyrethroids	<0.001	<0.001	<0.001
Sum DDT	0.725	0.129	0.022
Sum PAH	0.007	0.001	0.001
Sum PCB	0.013	0.001	0.004
Sum PBDE	<0.001	<0.001	<0.001
Sum Metals 8	0.056	0.069	0.250
Sum Metals 8, <63 um	0.041	0.173	0.723
Sum Metals 4	<0.001	<0.001	<0.001
Sum Metals 4, <63 um	<0.001	<0.001	0.003

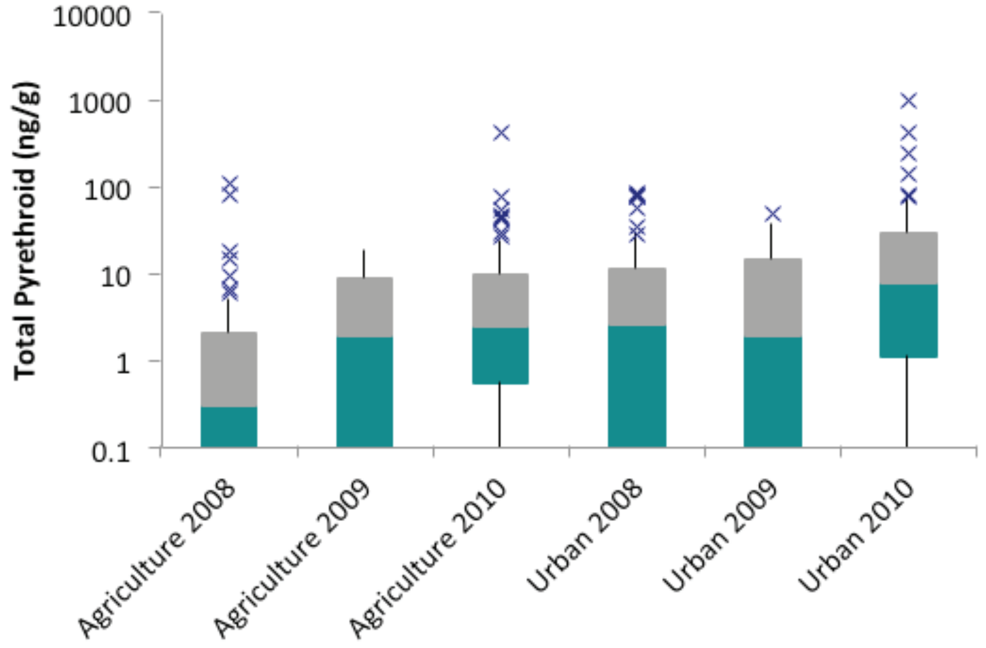

Figure 9. Changes in total pyrethroid concentrations in agricultural and urban watersheds at the 1 km scale. Boxes represent first and third quartiles, line represents median, and t-bars represent 95% confidence limits. Additional points are outliers.

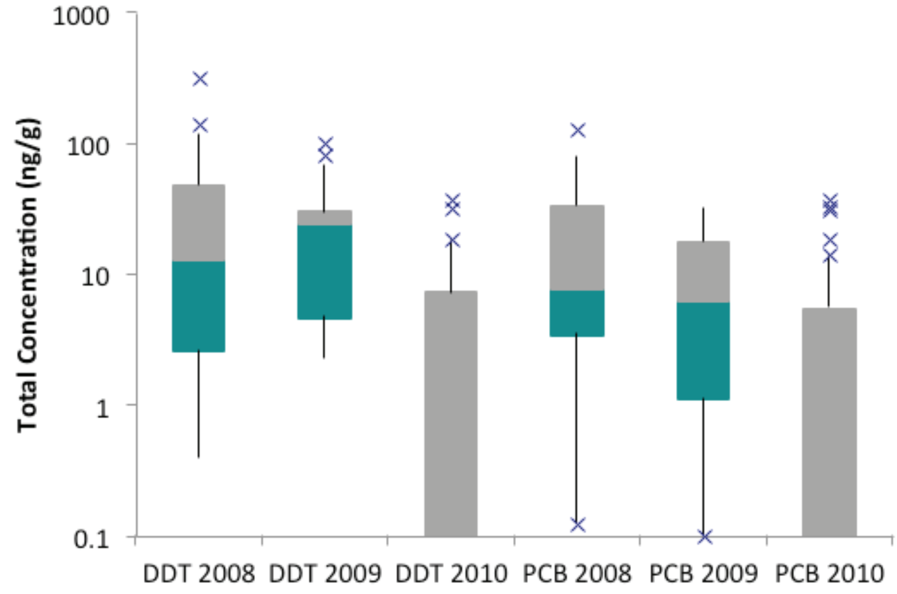

Figure 10. Changes in total DDT and PCB concentrations in urban watersheds at the 1 km scale. Boxes represent first and third quartiles, line represents median, and t-bars represent 95% confidence limits. Additional points are outliers.

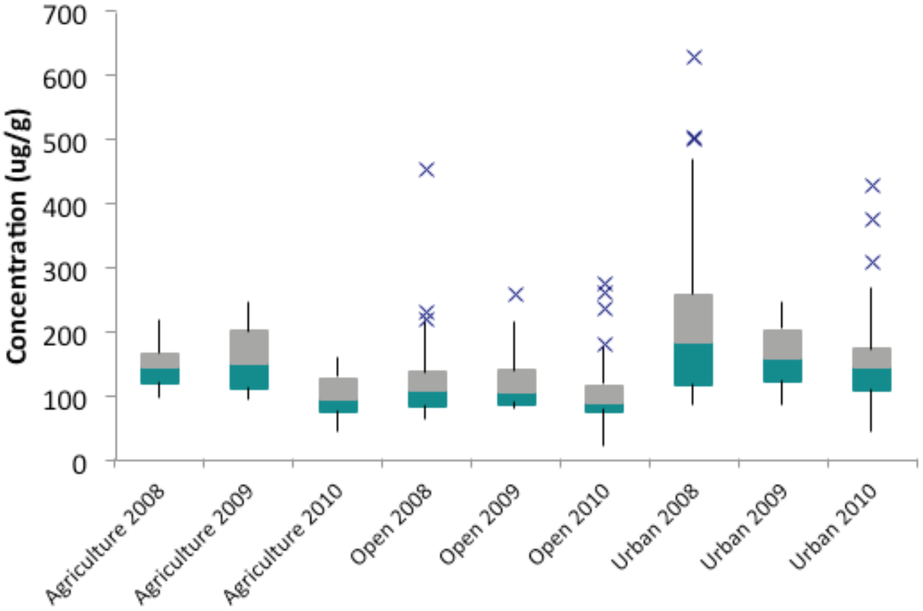

Figure 11. Changes in the sum of 4 metals concentrations (Cd, Cu, Pb and Zn) in all watershed types at the watershed scale. Boxes represent first and third quartiles, line represents median, and t-bars represent 95% confidence limits. Additional points are outliers.

GOAL 3 – COLLABORATION WITH OTHER PROGRAMS

SPoT complements the other SWAMP statewide monitoring programs: the Perennial Streams Assessment (PSA) program, the southern California Stormwater Monitoring Council (SMC), the San Francisco Bay area Regional Monitoring Coalition (RMC), and the bioaccumulation monitoring program of the Bioaccumulation Oversight Group (BOG). The PSA measures ecological endpoints related to wadeable streams statewide, and uses a probabilistic design to assess aquatic health. The PSA provides a baseline assessment of macroinvertebrate and algal communities in high quality streams, and provides direct evidence of aquatic life condition statewide. The SMC and RMC provide bioassessment data similar to the PSA, as well as toxicity and chemical contamination data. The BOG program measures contaminant concentrations in sport fish collected on a rotating basis from streams, lakes and coastal waters. SPoT complements the PSA by focusing on the magnitude of pollution in streams, using toxicological endpoints to establish causal connections between these chemicals and biological impacts, and by analyzing land cover as part of a watershed-scale evaluation of the sources of pollutants affecting aquatic life. The PSA contributes to the attainment of SPoT goals by assessing the overall health of wadeable perennial streams, and by testing assumptions about the status of reaches upstream of the intensive land uses that might be found associated with pollutants measured by SPoT. SPoT complements the BOG by identifying watershed sources for contaminants measured in fish from downstream waterways. The BOG complements SPoT by providing perspectives on the fate and human health aspects of pollutants in streams, particularly as related to their uptake in fish tissue and risk associated with human consumption. PSA, BOG, and SPoT together provide freshwater data similar to those used in other programs to develop sediment quality objectives (SQOs) in marine and estuarine habitats. Co-location of sites or addition of specific indicators across the PSA, BOG, and SPoT programs could allow for development of freshwater SQOs for California.

Relationships between SPoT Indicators and Stream Ecology

SPoT measures sediment toxicity to amphipods and chemical concentrations as indicators of stream water quality. Numerous studies have linked low amphipod survival in laboratory toxicity tests with ecological degradation as indicated by impacted benthic macroinvertebrate (BMI) communities in California watersheds (reviewed in Anderson et al., 2011). The relationship between laboratory sediment toxicity test results, chemical contamination and macroinvertebrate community structure in SPoT watersheds was investigated for the current report to develop connections between the indicators of water quality impairment measured by SPoT and indicators of ecological impairment measured by the various programs conducting bioassessment monitoring in these watersheds.

An abbreviated data set was assembled from the SWAMP Bioassessment Reporting Module with the assistance of the SWAMP Data Management Team. Additional southern California data were provided through the cooperation of the southern California Stormwater Monitoring Council (SMC data compiled by Raphael Mazor, Southern California Coastal Water Research Project). To identify spatially appropriate data, coordinates from SPoT stations and stations from the SWAMP and SMC bioassessment programs were compared to determine which stations were reasonably proximate to the SPoT stations. While a number of the bioassessment samples were collected from the same coordinates as the SPoT stations, bioassessment samples that were collected within 15km upstream of the SPoT stations were included in order to provide a minimally sufficient dataset for correlation analysis. Data from eighteen stations were extracted from the SWAMP Reporting Module, and data from an additional eight SMC stations were provided by that program. Samples were compiled from 2008, 2009, and 2010, to correspond with the first three SPoT sampling years. Bioassessment data from each year were matched with the toxicity and chemistry data from the appropriate SPoT sampling year. The SWAMP stations represented samples from southern, central and northern California, and the SMC stations were all from southern California. Correlations were conducted between toxicity and chemistry results and individual Index of Biological Integrity (IBI) scores calculated for each sample. The Northern California IBI calculator was applied to samples from northern California stations and to one northern station in the Santa Cruz area of the central coast region. The southern California IBI calculator was applied to the remaining central California and SMC samples. In addition to the IBI, several additional macroinvertebrate metrics were included in the correlations. All correlations were conducted using the Spearman Rank procedure described above.

Amphipod survival in laboratory tests was significantly correlated with the number of amphipods in

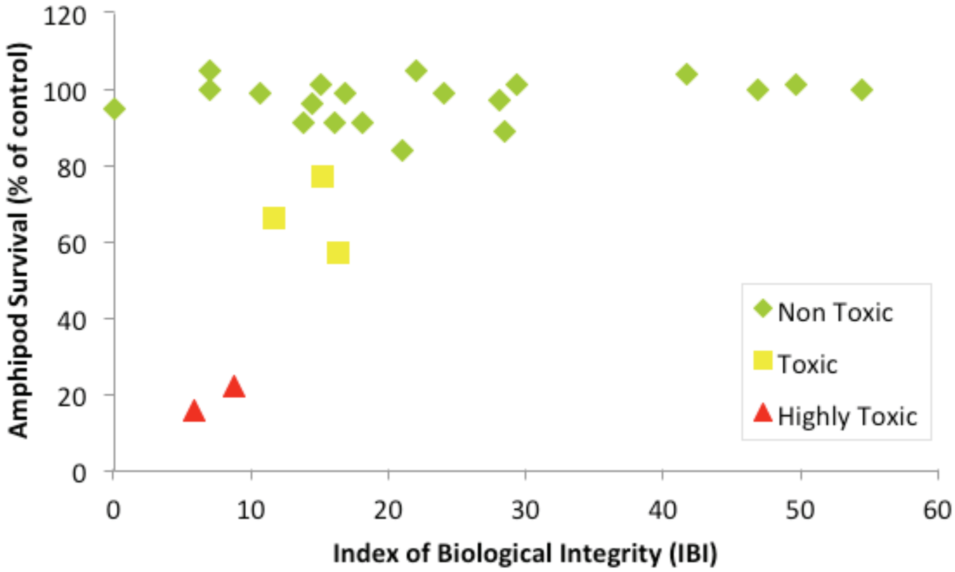

Figure 12. Relationship between amphipod survival in sediment toxicity tests and benthic macroinvertebrate IBI scores. IBI scores were calculated from field bioassessment data from 23 sites assessed during SWAMP and SMC monitoring conducted during 2008, 2009, and 2010, and corresponded to SPoT amphipod sediment toxicity tests conducted at the same or proximate stations during these three years. Amphipod survival is presented as a percentage of the respective control sample survival value.

the field samples and with the number of crustacea (Table 13). Sample sizes for these analyses were limited to 10 and 15, respectively. There was not a strong correlation between amphipod survival in laboratory sediment tests and the IBI at sites sampled within the same sampling year ($p = 0.081$; Table 13). A scatter diagram of these data demonstrate that amphipod survival in 79% of the corresponding SPoT stations were not toxic (Figure 12). IBI scores from the non toxic samples ranged from 0 to 54, but the IBI scores for the toxic and highly toxic samples ranged from 6 to 16. Most of the IBI scores in this dataset were less than or equal to 30, and therefore represent degraded macroinvertebrate communities. This suggests that additional factors beyond those that affect amphipod survival in acute laboratory toxicity tests are influencing macroinvertebrates at these sites. We note that when the northern California IBI calculator was used for the central California stations, amphipod survival in laboratory toxicity tests was significantly correlated with the IBI ($P = 0.043$; data not shown). These data also indicated weak negative correlations between amphipods and crustacea in the field samples and selected contaminants measured in the SPoT sediment samples, including metal concentrations in sediments and PAHs in sediments (crustacea only). The Ephemeroptera/Plecoptera/Trichoptera index indicates the relative densities of mayflies (ephemeroptera), stoneflies (plecoptera), and caddis flies (trichoptera), which represent three insect groups considered to be sensitive indicators of water quality. The EPT index and EPT taxa score were negatively correlated with percent fines in the sediments. Interestingly, while amphipod survival in laboratory tests were significantly correlated with the concentrations of pyrethroid pesticides in the SPoT samples (Table 6, above), none of the BMI metrics were correlated with these pesticides.

Previous California studies have demonstrated significant correlations between sediment and water toxicity in laboratory tests and macroinvertebrate community impacts. These studies have indicated that toxicity observed in urban and agricultural water bodies is linked to declines in a number of BMI metrics and are also correlated with chemical contamination, particularly with pesticide concentrations in water and sediment (Anderson et al., 2003a; Anderson et al., 2003b; Phillips et al., 2004; Weston et al., 2005; Anderson et al., 2006; Phillips et al., 2006; Larry Walker Associates, 2009). Other studies have shown the importance of physical habitat in structuring BMI communities (Hall et al., 2007; Hall et al., 2009; Larry Walker Associates, 2009). It should be noted that the physical habitat data in the SWAMP/PSA and SMC datasets were not compiled in time for this analysis, so correlations between the various BMI metrics and habitat characteristics were not possible at the time of this report. These data are now being compiled. It is likely that these and other stressors interact to influence macroinvertebrate communities. The current analysis represents a preliminary attempt to determine relationships between the SPoT indicators of watershed degradation and ecological impacts measured by the SWAMP/PSA and SMC bioassessment programs. It is anticipated that as SPoT, SWAMP/PSA, and SMC monitoring proceeds, the number of samples available for these correlations will grow. SPoT staff will continue to coordinate with SWAMP and other regional monitoring groups to build on these datasets. This will provide increased statistical power for assessing relationships between SPoT water quality indicators and stream ecological indicators to facilitate identification of the likely stressors causing degradation of California watersheds.

Table 14

Results of Spearman Rank correlations between parameters measured by SPoT in samples collected from 2008 – 2010 and benthic macroinvertebrate community metrics measured as part of SWAMP/PSA and SMC monitoring during this same period. Statistically significant correlations are indicated by blue shading (positive correlation) or red shading (negative correlation). *Amphipod survival depicts control-normalized survival of *Hyalella azteca* in SPoT 10d laboratory toxicity tests.

		IBI Score	Sum Individuals	EPT Index (%)	EPT Taxa Score	Amphipoda %	Crustacea %	Chironomidae %	Mollusca %	Oligochaeta%	Shannon Diversity	Simpsons Index	Taxonomic Richness
Amphipod Survival*	Prob.	0.081	0.915	0.711	0.467	0.049	0.006	0.051	0.568	0.520	0.088	0.138	0.587
	N	25	26	17	25	10	15	17	16	18	18	18	18
Pyrethroids	Prob.	0.204	0.086	0.883	0.502	0.216	0.415	0.179	0.557	0.136	0.890	0.964	0.236
	N	25	26	17	25	10	15	17	16	18	18	18	18
DDT	Prob.	0.712	0.681	0.126	0.288	0.275	0.519	0.254	0.754	0.539	0.100	0.261	0.329
	N	25	26	17	25	10	15	17	16	18	18	18	18
PAH	Prob.	0.017	0.082	0.645	0.079	0.895	0.044	0.760	0.350	0.069	0.911	0.823	0.207
	N	10	10	7	9	4	7	7	7	8	8	8	8
PBDE	Prob.	0.840	0.534	0.645	0.409	0.368	0.057	0.036	0.078	0.414	0.257	0.204	0.713
	N	10	10	7	9	4	7	7	7	8	8	8	8
PCB	Prob.	0.443	0.075	0.274	0.454	0.211	0.101	0.598	0.197	0.009	0.223	0.473	0.732
	N	25	26	17	25	10	15	17	16	18	18	18	18
Metals 8	Prob.	0.921	0.995	0.282	0.439	0.032	0.021	0.229	0.118	0.218	0.489	0.913	0.773
	N	25	26	17	25	10	15	17	16	18	18	18	18
Metals 4	Prob.	0.978	0.447	0.293	0.523	0.813	0.286	0.726	0.087	0.059	0.663	0.906	0.829
	N	25	26	17	25	10	15	17	16	18	18	18	18
TOC %	Prob.	0.815	0.095	0.790	0.937	0.960	0.089	0.551	0.565	0.156	0.723	0.958	0.097
	N	25	26	17	25	10	15	17	16	18	18	18	18
Fines %	Prob.	0.675	0.688	0.024	0.016	0.866	0.488	0.350	0.823	0.935	0.005	0.009	0.172
	N	25	26	17	25	10	15	17	16	18	18	18	18

SPoT AND THE INTEGRATED REPORT PROCESS

SPoT was specifically designed to provide data that can inform regulatory programs and conservation initiatives. SPoT data can be incorporated directly into Clean Water Act § 303[d] listing of impaired waters, as well as into the statewide status assessments required by § 305[b]. SPoT data are included in the Integrated Report process and incorporated into the Lines of Evidence (LOE) process used to evaluate sites for inclusion in regional 303(d) lists of degraded water bodies.

The following summary describes how SPoT 2008 data were used in the 2012 Integrated Report cycle (personal communication, Nancy Kapellas, SWRCB, OIMA unit). During data solicitation for the 2012 Integrated Report (IR), the SWAMP Data Management Team sent State Board staff the most current SWAMP data since the last listing cycle (it is intended that data will come from CEDEN for the next assessment cycle). The SPoT data being assessed for the 2012 assessment cycle is from April – October of 2008 (i.e., permanent data). Subsequent SPoT data will be assessed in the next IR assessment cycle (2014). Before the data were assessed, SPoT sample locations were plotted and then associated with specific water bodies. SPoT data are then used to develop specific Lines of Evidence for determination of water body impairment. Approximately half of the pollutants in the SPoT data set are run through the electronic LOE Processor (eLEP). This processor takes data spreadsheets and generates LOEs that are then uploaded into the SWRCB's California Water Quality Assessment (CalWQA) database. The SPoT LOEs to be generated by eLEP are for metals and selected organic pollutants in sediment. The eLEP LOEs have yet to be generated for most of Regions, but, as an example, Region 6 has 127 eLEP generated LOEs from the SPoT data set. The remaining pollutant LOEs are being developed manually by State Board staff, generally because their assessment is too complicated for the eLEP process. The SPoT manually-generated LOEs are for additional pollutants in sediment, including some that require summation (DDT, chlordane, PCBs, etc), as well as sediment toxicity. Statewide, there are about 189 manually generated LOEs from the SPoT data set. The Regional Board staff then review and comment on the manually created LOEs and the State Board staff respond to Regional Board staff comments. The LOEs are then revised, as needed. This process is now taking place for the 2008 SPoT dataset. Regional Board staff will use all the LOEs to make Decision Recommendations in the CalWQA database (anticipated to begin in January 2013), which recommend whether the assessed pollutant should or should not be listed for the water body. The public review process and subsequent list making decisions between State and Regional Board staffs then proceeds.

Eight SPoT sites are located in priority watersheds for the U.S. EPA Measure W program (also known as the Watershed Improvement Measure (WIM) or SP-12). The SPoT focus on causes and sources of pollutants in watersheds feeds directly into Total Maximum Daily Load program efforts to quantify pollutant loadings and understand sources and activities that contribute to those loadings. By coordinating with local and regional programs, SPoT provides statewide context for local results, and provides information useful for local management and land use planning activities. SPoT is also specifically designed to assist with the watershed-scale effectiveness evaluation of management actions implemented to improve water quality, such as pesticide reduction or irrigation management on farms, and installation of stormwater treatment devices or low impact development in urban areas. Use of SPoT data for watershed scale evaluations of management practice effectiveness is currently limited by the lack of a comprehensive and standardized reporting system for practice implementation. This is the subject of on-going efforts at DPR, County Agriculture Commissioner Offices, and the Regional Boards.

SECTION 4 DISCUSSION

This report summarizes results of three years of SPoT monitoring from sites representing approximately one half of California's major watersheds. Sediments deposited at the base of these watersheds tend to integrate contaminants transported from land surfaces throughout the drainage area, and chemical analyses combined with toxicity testing allow an initial assessment of water quality trends in these watersheds and throughout the state. When combined with land use characterizations, SPoT data provide water quality managers with an initial indication of how land use affects water quality.

The short-term trends (three years) indicate increasing detections and concentrations of certain contaminants in many of the state's largest watersheds, and reduced concentrations of other contaminant classes. Increased contamination often coincided with increased sediment toxicity, and toxicity and contamination were particularly correlated with urbanization in these watersheds. The following discussion emphasizes the most obvious trends observed by SPoT from 2008 through 2010 and relates these patterns to the primary goals of the program.

TRENDS IN CHEMICALS OF CONCERN

Although this report describes data for 2008 through 2010, the 2009 SPoT program year monitored only about 25% of the program sites. As such, the 2009 data may not be reflective of statewide trends. Taken together however, the three years of data provide a snapshot of short term trends in contamination and toxicity. The data show a statewide decrease or no change in several classes of organic chemicals, including legacy organic chemicals like DDT and PCBs. Patterns for PBDEs in urban watersheds indicate little change in these chemicals over the three years. Use of these flame retardants is being restricted in California and changes in sediment concentrations of this class of chemicals will be the subject of continued SPoT monitoring in urban watersheds. Concentrations of PAHs and metals in sediments were largely unchanged between 2008 and 2010.

The data also demonstrate that detections and concentrations of the current use pyrethroid pesticides are increasing in California watersheds. While the data do not show an increase in the incidence of sediment toxicity in California watersheds when testing is conducted at the standard protocol temperature (average statewide incidence of toxicity = 27.7% in tests conducted at 23 °C from 2008 - 2010), the incidence of toxicity greatly increased in 2010 at a subset of sites when tests were conducted at a temperature that more closely reflects the ambient temperature in California watersheds (15°C). Higher toxicity at colder temperature is diagnostic of toxicity due to pyrethroid pesticides and the pattern of increasing detections of pyrethroids coupled with increasing toxicity in SPoT samples when tests are conducted at colder temperature suggests that current monitoring may under-estimate the occurrence of pyrethroid-associated toxicity using the standard protocol. It should also be noted that the 10-day test protocol with *H. azteca* represents an acute exposure to sediment contaminants. Previous data have shown the 28-day protocol with this species is more sensitive than the 10-day growth and survival test because it incorporates growth over four weeks (Ingersoll et al., 2005). Because the more photostable pyrethroids (e.g., bifenthrin) may persist for over a year, the potential for chronic impacts of these pesticides on California watersheds are also likely under-estimated by SPoT results. MPSL is comparing the relative sensitivities of the 10-day and 28-day *H. azteca* protocols as part of an effort by the Central Valley Regional Water Quality Control Board to develop sediment quality criteria for bifenthrin. The results of these experiments will be used to determine whether the longer-term protocol is appropriate for future SPoT monitoring.

In a recent summary of SWAMP surface water toxicity testing conducted between 2001 and 2010, Anderson et al. (2011) showed that approximately 45 to 50% of the sites monitored by SWRCB programs demonstrated some water or sediment toxicity. Correlation and TIE studies showed that the majority of toxicity was associated with pesticides, specifically organophosphate and pyrethroid pesticides. The current SPoT results corroborate these findings. Hunt et al. (2012) found that sediment toxicity in SPoT watersheds was highly correlated with pyrethroid concentrations in sediment, and similar correlations were found in 2010 (current report). There has been a steady decline in organophosphate pesticide concentrations detected in SPoT samples, including a statewide decline in the detections of chlorpyrifos. However, chlorpyrifos continues to be associated with sediment toxicity in certain agriculture regions of the state, such as the central coast (Phillips et al., 2012).

Given the evidence that pesticides are associated with ambient toxicity in California waters, certain emerging pesticides will be prioritized for inclusion in the SPoT analyte list as the program's monitoring proceeds. For example, recent regional monitoring has suggested an increase in the detection of the phenylpyrazole insecticide fipronil in urban watersheds (Gan et al., 2005; Holmes et al., 2008). Because of increasing use and the potential for surface water toxicity due to fipronil, this pesticide has been recommended by the SPoT Scientific Review Committee for statewide monitoring starting in 2013. Other important classes of organic chemicals detected in SPoT samples included organochlorine pesticides and PCBs. While pesticides such as DDT continued to be detected in many of the state's watersheds, the concentrations were always below those demonstrated to cause toxicity to *H. azteca*. PCBs were also detected in many of the watersheds, but concentrations were generally lower than guideline thresholds. Organochlorine chemicals (e.g., DDT and PCBs) continue to be of concern in California because of their potential to bioaccumulate and affect wildlife or exceed human health advisory guidelines for fish consumption (Davis et al., 2010). Continued monitoring of organochlorines by SPoT will document trends in this important class of organic chemicals. Concentrations of metals in sediments were relatively stable during the last three years, and selected metal concentrations were lower than toxicity thresholds established for *H. azteca* (Cd, Cu and Zn). Because of differences in sensitivity between *H. azteca* and other resident taxa, and the potential for particular metals to either be toxic to resident macroinvertebrates (Cd, Cu, and Zn) and stream algae, or to bioaccumulate (Hg), metals will continue to be important indicators of watershed contamination as SPoT proceeds

POLLUTANT ASSOCIATIONS WITH LAND COVER

Correlations of SPoT contamination and toxicity data with data from the National Land Cover Database continue to show strong associations between contamination, urbanization and impervious surface cover in California watersheds. This was true for both organic chemicals and metals. One exception was DDT, which was more highly correlated with agriculture land uses in 2010. As was observed by Hunt et al. (2012), there were strong correlations between urban land use and sediment toxicity in California watersheds, and strong correlations were observed at all three watershed scales. Similar relationships were observed between toxicity and measures of impervious surface. Sediment toxicity was also highly correlated with agriculture land uses in the 2010 SPoT dataset.

Hunt et al. (2012) noted two potential confounding factors that are not considered in the interpretation of how data from the NLCD could influence associated watersheds. These are the effects of dams on sediment transport in SPoT watersheds, and the specific contribution of point and non-point source pollution to contamination monitored at SPoT sites. Because the majority of rivers in California have dams, and these impede sediment transport, this likely influences the hydrologic connectivity between upstream sources of contaminants and downstream depositional areas where SPoT stations are located. The influence of dams was considered in the selection of SPoT sites, but the influence of dams was not considered in the GIS analyses of the drainage areas to the sites: land cover in drainage areas was considered equally whether or not a dam was present. Hunt et al. (2012) noted that this likely played a role in land cover influences on a watershed scale, but had less of an impact on the 1 and 5km drainage area scales. In addition, the influence of point source and non-point source discharges on contaminant loading and toxicity at different scales in SPoT watersheds was not considered in the current assessment.

MANAGEMENT ACTIONS AND ANTICIPATED FUTURE TRENDS

California regulatory agencies recognize the role pesticide contamination plays in degradation of state waters and are now implementing plans to address sources of specific current-use pesticides. For example, the U.S. EPA and the California Department of Pesticide Regulation (CDPR) have recently initiated reviews of pyrethroid pesticide registrations and CDPR is currently developing use restrictions for pyrethroid pesticides used by pest control businesses in urban settings (Personal Communication, John Sanders, CDPR). CDPR also plans on following urban restrictions with regulations to address agricultural use of pyrethroids affecting surface water quality. The U.S. EPA also is requiring label changes for pyrethroid products to reduce their impact on surface water quality (http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPP-2008-0331-0021). Incorporation of Low Impact

Development practices on future construction projects are being required throughout the state, and these coincide with revised storm water discharge rules as part of the municipal stormwater (MS4) NPDES permitting. In addition to restrictions on pounds of active ingredients applied per acre and number of applications per crop, use restrictions typically involve recommendations for vegetated buffer zones and setbacks to limit the potential for off-field transport of pesticides in spray drift, irrigation and stormwater runoff. Management actions that incorporate pesticide use restrictions and on-farm practices to reduce and treat runoff will be incorporated into irrigated lands programs on the Central Coast. Based on SPoT coverage of 50 major hydrologic units, the program is positioned to detect changes in pyrethroid contamination in California watersheds as these management actions are implemented. A new collaboration between SPoT and the California Department of Pesticide Regulation (CDPR) is designed to incorporate intensive monitoring of sediment toxicity associated with pyrethroids in 4 urban watersheds starting in 2013. SPoT data provide water resource managers with short and long term readings of how effective use restrictions are in reducing contamination. Addition of emerging contaminants of concern to the SPoT analyte list will allow the program to evolve to address issues related to introduction of new chemicals in California watersheds. Examples include monitoring of fipronil and pyrethroids at Tier II sites in collaboration with CDPR, as well as monitoring of the cyanotoxin microcystin at all SPoT stations in collaboration with California State University Monterey Bay starting in 2013. Results from these collaborations will be discussed in future SPoT reports.

A preliminary assessment of the relationship between water quality indicators measured by SPoT and watershed ecological indicators measured by SWAMP and SMC benthic macroinvertebrate bioassessment programs showed a significant correlation between amphipod survival in laboratory toxicity tests and two stream BMI metrics, the percentage of stream amphipods and crustacea. It is anticipated that as more BMI data are incorporated into the SWAMP and SMC databases, a more detailed assessment of these relationships will be investigated in future SPoT reports. These statistical relationships provide hypotheses for assessing causal relationships between in-stream ecological degradation measured in SWAMP and SMC monitoring and toxicity and chemical stressors measured by SPoT.

SECTION 5
RECOMMENDATIONS

This report summarizes results of three years of statewide monitoring, and these data have been presented to the SPoT Scientific Review Committee and the SWAMP Round Table participants. Based on these discussions, we recommend the following for the 2013 monitoring year:

1) Continue evaluation of SPoT base station representativeness – In addition to continuing the long-term trend monitoring at the SPoT base stations, continue to evaluate spatial variability at the intensively sampled stations. Incorporate site specific data on non-point and point source pollution at these sites to ascertain how these features may affect contamination and toxicity results.
2) Revise the SPoT analyte list to add fipronil and its three primary degradates (fipronil sulfone, fipronil desulfinyl, fipronil sulfide) as emerging chemicals of concern for monitoring at urban (Tier II) watershed stations (in collaboration with CDPR).
3) Discontinue comparison of sieved and unsieved metals, and analyze metals in unsieved sediment only.
4) Consider relative incidence of acute and chronic toxicity at a subset of SPoT stations by comparing results of the 10-day *H. azteca* toxicity test protocol to the 28-day protocol.
5) Develop more comprehensive databases to explore statistical relationships between SPoT chemical and toxicity indicators and SWAMP and SMC ecological indicators.

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SWAMP
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