SWAMP
Surface Water Ambient Monitoring Program

TOXICITY IN CALIFORNIA WATERS: NORTH COAST REGION

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EXECUTIVE SUMMARY E

Toxicity testing has been used to assess effluent and surface water quality in California since the mid-1980s. When combined with chemical analyses and other water quality measures, results of toxicity tests provide information regarding the capacity of water bodies to support aquatic life beneficial uses. This report summarizes the findings of monitoring conducted by the Surface Water Ambient Monitoring Program (SWAMP) and associated programs between 2001 and 2010.

As in Anderson et al. (2011), the majority of data presented in this report were obtained from monitoring studies designed to increase understanding of potential biological impacts from human activities. As such, site locations were generally targeted in lower watershed areas, such as tributary confluences or upstream and downstream of potential pollutant sources. Only a minority of sites was chosen probabilistically (i.e., at random). Therefore, these data only characterize the sites monitored and cannot be used to make assumptions about unmonitored areas.

Although there were only a few instances of toxicity seen in sediment collected from sites in the North Coast region, the limited number of samples collected indicate a relatively high frequency of toxicity. Sixty-seven percent (67%) of sites were non-toxic, with 17% of sites exhibiting both some and moderate toxicity. No sediments were highly toxic to *Hyalella azteca*.

Differences in sediment toxicity appear to arise from differences in land use characteristics among the sites tested. All instances of observed toxicity occurred within the urban-dominated areas of the region, and half the samples collected from urban-dominated land use areas exhibited either some or moderate toxicity. Chemical analyses of toxic sediments have identified pyrethroid pesticides as agents of toxicity.

As discussed in Anderson et al. (2011), the principal approach to determine whether observations of toxicity in laboratory toxicity tests are indicative of ecological impacts in receiving waters has been to conduct field bioassessments of macroinvertebrate communities. These studies have included “triad” assessments of chemistry, toxicity and macroinvertebrate communities, the core components of SWAMP. One recommendation for future SWAMP monitoring is to conduct further investigations on the linkages between surface water toxicity and receiving system impacts on biological communities.

SECTION 1 INTRODUCTION

The California State Water Resources Control Board published a statewide summary of surface water toxicity monitoring data from the Surface Water Ambient Monitoring Program (SWAMP) in 2011 (Anderson et al., 2011; http://www.waterboards.ca.gov/water_issues/programs/swamp/reports.shtml). This report reviewed statewide trends in water and sediment toxicity collected as part of routine SWAMP monitoring activities in the nine California water quality control board regions, as well as data from associated programs reported to the California Environmental Data Exchange Network (CEDEN) database. The report also provided information on likely causes and ecological impacts associated with toxicity, and management initiatives that are addressing key contaminants of concern. The current report summarizes a subset of the statewide database that is relevant to the North Coast Region (Region 1).

Very little quantitative information is available on most waterbodies in this region. Twelve sites located throughout the region were selected for sediment toxicity monitoring. These twelve sites comprise the fewest number of stations evaluated within any of the nine regions and therefore semi-detailed monitoring data are available for only a few of the region's waterbodies. Source programs, test count and sample date ranges are outlined in Table 1.

Table 1
Source programs, water and sediment toxicity test counts and test dates for North Coast regional toxicity data included in this report.

Toxicity Test Type	Program	Test Count	Sample Date Range
Water Column	No water column tests		
Sediment	Statewide Urban Pyrethroid Monitoring	6	11/14/06 – 11/15/06
	Stream Pollution Trends (SPoT)	9	10/14/08 – 10/15/08

The North Coast region comprises all of the watershed basins draining into the Pacific Ocean from the California-Oregon state line south to the southern boundary of the watershed of the Estero de San Antonio and Stemple Creek in Marin and Sonoma Counties. The North Coast region encompasses a total area of approximately 19,390 square miles, including 340 miles of scenic coastline, 362 miles of designated Wild and Scenic Rivers, 416 square miles of National Recreation Areas and 1,627 square miles of National Wilderness Areas, as well as urbanized and agricultural areas (Fadness et al., 2008).

While the majority of water quality problems elsewhere in California can be attributed to pesticides (Anderson et al., 2011), water quality problems in the North Coast Region are largely related to non-point sources, including erosion from construction, timber harvesting, livestock grazing, stormwater, and wastewater disposal systems (Fadness et al., 2008). These non-point sources have led to the development of Total Maximum Daily Loads (TMDLs) based on reducing temperature, metals, and sediment loadings to North Coast waterbodies, and due to limited funding available for water quality monitoring and watershed assessment, little toxicity testing has been utilized within the region.

SECTION 2
SCOPE AND METHODOLOGY

This study examined all toxicity data included in the SWAMP and CEDEN databases from toxicity tests whose controls showed acceptable performance according to the Measurement Quality Objectives of the 2008 SWAMP Quality Assurance Project Plan. The attached maps (Figures 3-5) show locations of sites sampled for toxicity by SWAMP and partner programs, and the intensity of toxicity observed in the sediment samples collected at those sites. Sites are color-coded using the categorization process described in Anderson et al. (2011), which combines the results of all toxicity tests performed on samples collected at a site to quantify the magnitude and frequency of toxicity observed there. Toxicity test results reported in the North Coast Region included freshwater sediment samples using the amphipod *Hyalella azteca*. Only survival endpoints are considered in the measures of toxicity reported here; therefore all sites identified as toxic showed a significant decrease in test animal survival in one or more samples.

In order to summarize the magnitude of toxicity at each site, the data went through a number of steps.

1. Standardize the statistical analyses: When data were submitted to the SWAMP/CEDEN databases, reporting laboratories evaluated the potential toxicity of samples using a variety of statistical protocols. In order to standardize the analysis of the entire data set, all control – sample comparisons were re-analyzed using the proposed EPA Test of Significant Toxicity (Anderson et al., 2011; Denton et al., 2011; US EPA, 2010).

2. Calculate the High Toxicity Threshold: The High Toxicity Threshold is determined for each species' endpoint from the entire dataset summarized in the Statewide Report (Anderson et al., 2011). This threshold is the average of two numbers, both expressed as a percentage of the control performance. The first number is the data point for the 99th percentile of Percent Minimum Significant Difference (PMSD), representing the lower end of test sensitivity across the distribution of PMSDs in the Statewide Report. The second value is the data point for the 75th percentile of Organism Performance Distribution of all toxic samples, representing an organism's response on the more toxic end of the distribution. This average serves as a reasonable threshold for highly toxic samples.

3. Determine the Toxicity Category for each site: The magnitude and frequency of toxicity at each sample collection site was categorized (Table 2) according to Anderson et al. (2011) and Bay et al. (2007) as "non-toxic", "some toxicity", "moderately toxic", or "highly toxic". Throughout this document the terms some, moderate and highly will be italicized when in reference to these categories.

Table 2
Data conditions used to determine toxicity categories for any given sample collection site.

Category	Conditions for Categorization
Non-toxic	No sample is ever toxic to any test species
Some Toxicity	At least one sample is toxic to one or more species, and all of the species' responses fall above their species-specific High Toxicity Threshold
Moderate Toxicity	At least one sample is toxic to one or more species and at least one of the species' responses falls below their species-specific High Toxicity Threshold
High Toxicity	At least one sample is toxic to one or more species and the mean response of the most sensitive species falls below its respective High Toxicity Threshold

SECTION 3
REGIONAL TOXICITY

Although there were only a few instances of toxicity seen in sediment sites in the North Coast Region between 2001 and 2010 (Figure 1), the limited number of samples collected indicate a relatively high frequency of toxicity. Sixty seven percent (67%) of sediment samples were non-toxic, with 17% of sites showing *some* and *moderate* toxicity, each. None of the sites tested within this region were *highly* toxic (Table 3).

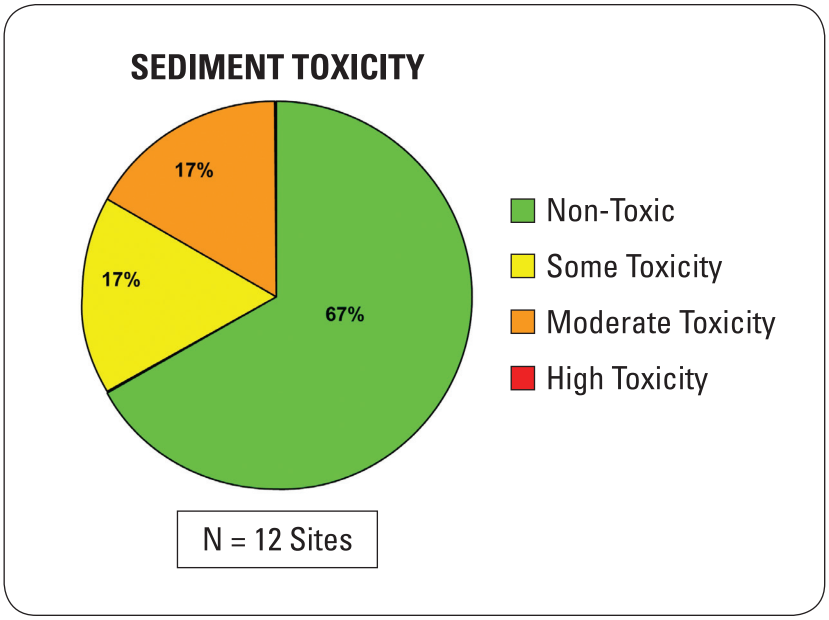

Figure 1. Magnitude of toxicity in sediment samples in the North Coast Region of California based on 10-day *H. azteca* survival.

Table 3
Maximum levels of toxicity observed at sites tested with *H. azteca*.

Number of Sites	Maximum Toxicity Level Observed			
	Non-Toxic	Some Toxicity	Moderately Toxic	Highly Toxic
12	8	2	2	0

SECTION 4
RELATIONSHIPS BETWEEN LAND USE AND TOXICITY

Land use was quantified as described in Anderson et al. (2011), around stream, canal and ditch sites at which samples were collected for testing in sediment toxicity tests. Using ArcGIS, polygons were drawn to circumscribe the area within one kilometer of each site that was upstream of the site, in the same catchment, and within 500 meters of a waterway draining to the site. Land use was categorized according to the National Land Cover Database. All "developed" land types in the land cover database were collectively categorized as "urban". "Cultivated crops" and "hay/pasture" were categorized together as "agricultural". All other land types were categorized as "other" for the purpose of this analysis. Percentages of each land use type were quantified in the buffers surrounding the sample collection sites. Urban land category represents sites with nearby upstream land use of greater than 10% urban and less than 25% agricultural areas. Agricultural land category represents sites with nearby upstream land use of greater than 25% agricultural and less than 10% urban areas.

Differences in sediment toxicity appear to arise from differences in land use characteristics among the sites tested (Table 4). Among the sets of sites that were sampled for testing with *H. azteca*, the average percentage of urban land in 1 kilometer upstream buffers was 31%, the average percentage of agricultural land was 17%, and average percentage of undeveloped (other) land was 52%. All instances of observed toxicity occurred within urban-dominated areas of the Region, and half of the samples collected from urban-dominated land use areas exhibited either *some* or *moderate* toxicity.

In *H. azteca* sediment tests, urban sediments showed lower survival than sediments from all other types of sites (Figure 2: Wilcoxon Rank Sum Test), however these differences were not statistically significant. Sediments showed *some* toxicity in the vicinity of urban-dominated areas of McKinleyville and Arcata, and *moderate* toxicity in the high-density residential areas of Rohnert Park and Santa Rosa. Greater *H. azteca* sediment toxicity in urban areas has been reported previously by Weston et al. (2005) and Holmes et al. (2008), some of whose data was incorporated into the data set analyzed in the current report.

Table 4
***H. azteca* sediment toxicity and land use at sites in the North Coast Region of California.**

Site	Station Name	Toxicity Category	*H. azteca* 10-day Survival (as % of control)	Land Use Category
103SMHSAR	Smith River at Sarina Road	Non-Toxic	95.0	Agricultural
105KLAMKK	Klamath River at Kamp Klamath	Non-Toxic	95.1	Urban
109MAD101	Mad River upstream Hwy 101	Some Toxicity	83.2	Urban
110SUP089	Jane's Creek Meadows	Some Toxicity	74.4	Urban
111EELFRN	Eel River at Fernbridge	Non-Toxic	89.7	Agricultural
111EELMYR	Eel River - South Fork at Meyers Flat	Non-Toxic	100.1	Other
113NAVDMC	Navarro River at Dimmick Campground	Non-Toxic	84.2	Urban
114LAGMIR	Laguna de Santa Rosa at Mirabel	Non-Toxic	96.1	Urban
114RRAXRV	Russian River at Alexander RV Park	Non-Toxic	89.5	Agricultural
114RRDSDM	Russian River downstream Duncan Mills	Non-Toxic	96.1	Urban
114SUP035	Hinebaugh Creek @ Donna	Moderate Toxicity	53.6	Urban
114SUP090	Ducker Creek	Moderate Toxicity	52.0	Urban

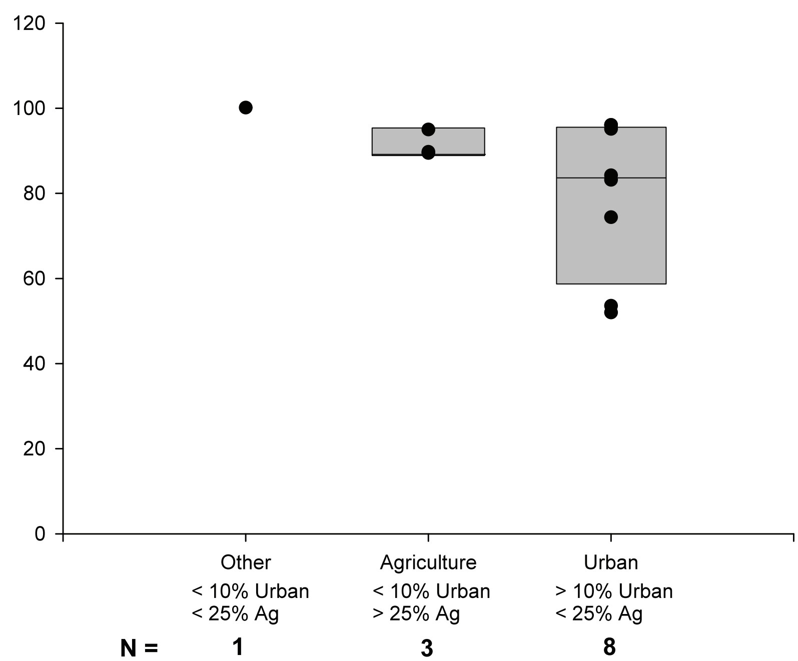

Figure 2. Toxicity distribution for samples collected from sites in urban, agricultural, and less developed areas. Lower values represent lower levels of amphipod survival, and indicate higher toxicity. Solid lines, from top to bottom, represent the 75th, 50th (median), and 25th percentiles of the distribution.

SECTION 5
GEOGRAPHICAL PATTERNS IN TOXICITY

NORTH COAST REGION

(Figures 3 -5)

The majority of sediment samples collected throughout the Region was non-toxic. Two sites from the Humboldt Bay Watershed Management Area (WMA) exhibited *some* toxicity: Mad River upstream of Hwy 101 (109MAD101) and the urban creek Jane's Creek Meadows (110SUP0889). Two urban creek sites from the Russian/Bodega WMA exhibited *moderate* toxicity: Hinebaugh Creek at Donna (114SUP035) and Ducker Creek (114SUP090).

The Surface Water Ambient Monitoring Program's Stream Pollution Trends Monitoring Program (SPoT) monitored nine waterbodies for sediment toxicity (*H. azteca*) and contaminants in the North Coast Region in 2008. Of these, two stations were toxic, the Mad River (109MAD101) and the Navarro River (113NAVDMC), though toxicity at both stations was of low magnitude. SPoT monitored eight of these nine sites in 2010, and five out of the eight sites were significantly toxic to amphipods. Toxicity was observed in the Smith River (103MHSAR), Mad River (109MAD101), two sites on the Eel River (111EELFRN, 111EELMYR), and the Navarro River (113NAVDIM). A much higher magnitude of toxicity was observed in the 2010 North Coast regional SPoT samples relative to 2008. Although pyrethroid pesticides were detected in three of the eight samples, only one of these samples was toxic, and no chemicals were detected at high enough concentrations to explain the observed toxicity.

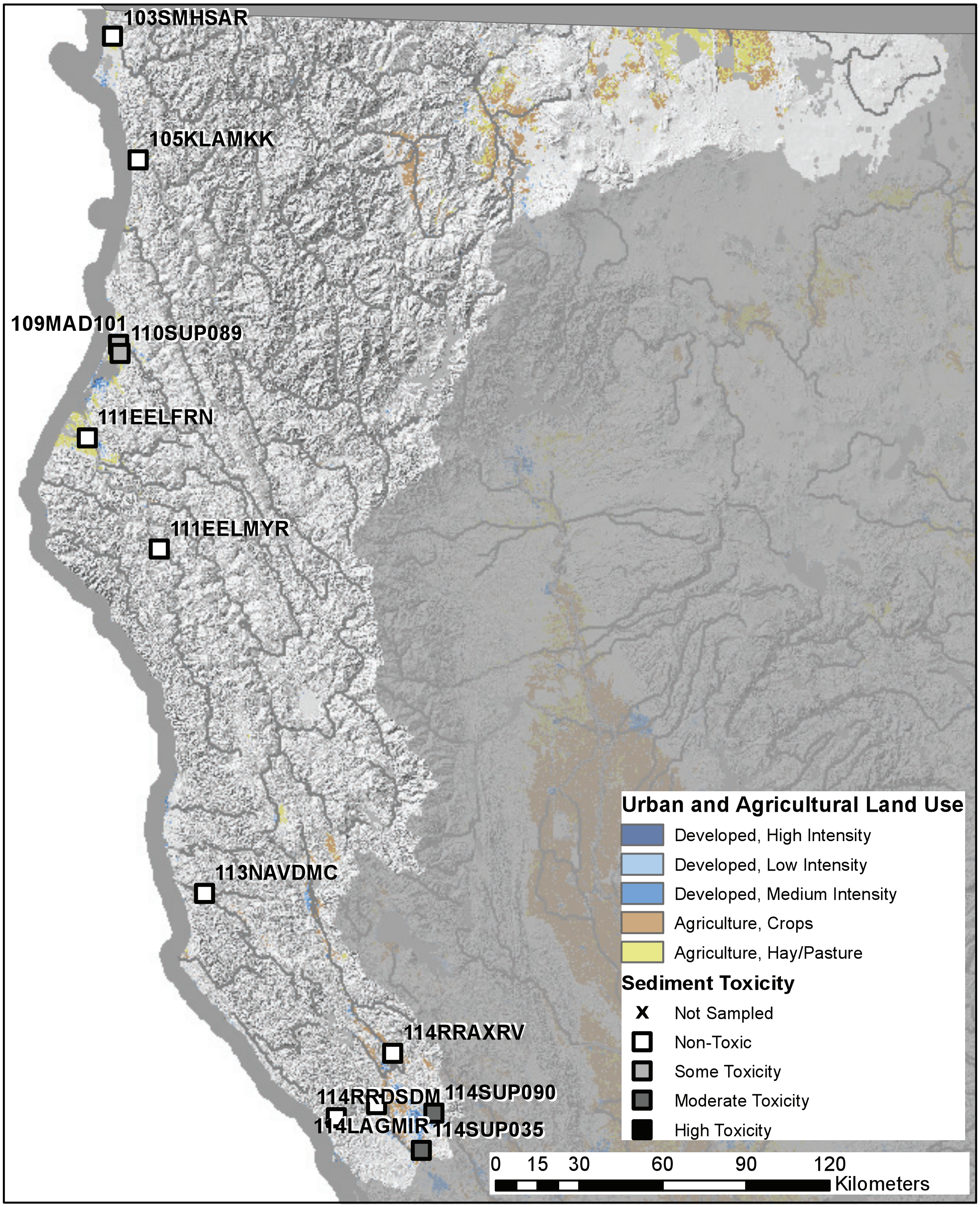

Figure 3. Magnitude of sediment toxicity at sites in the North Coast Region of California based on the 10-d survival of *H. azteca* in sediment samples collected at each site.

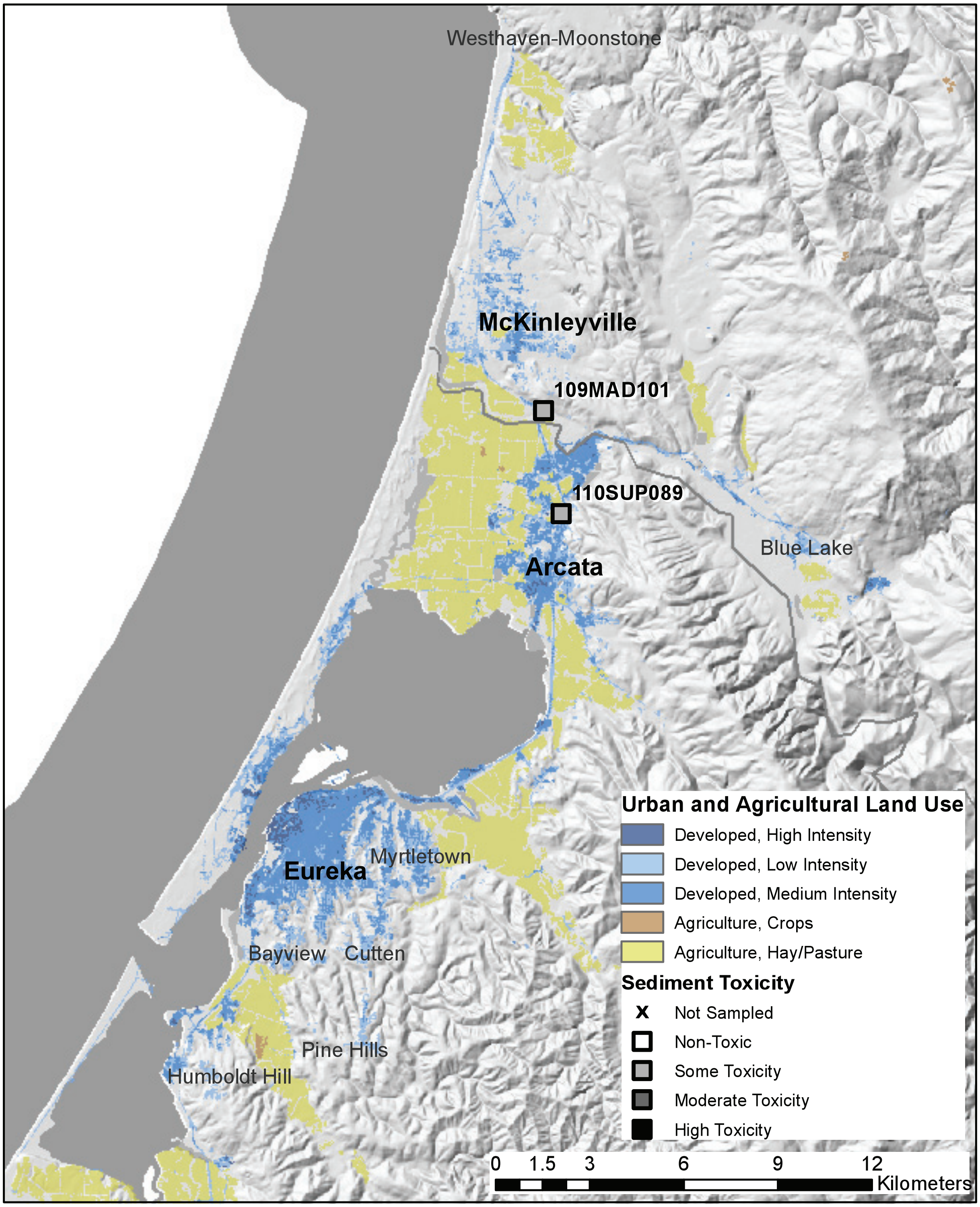

Figure 4. Magnitude of sediment toxicity at sites in the Humboldt Bay WMA of California based on the 10-d survival of *H. azteca* in sediment samples collected at each site.

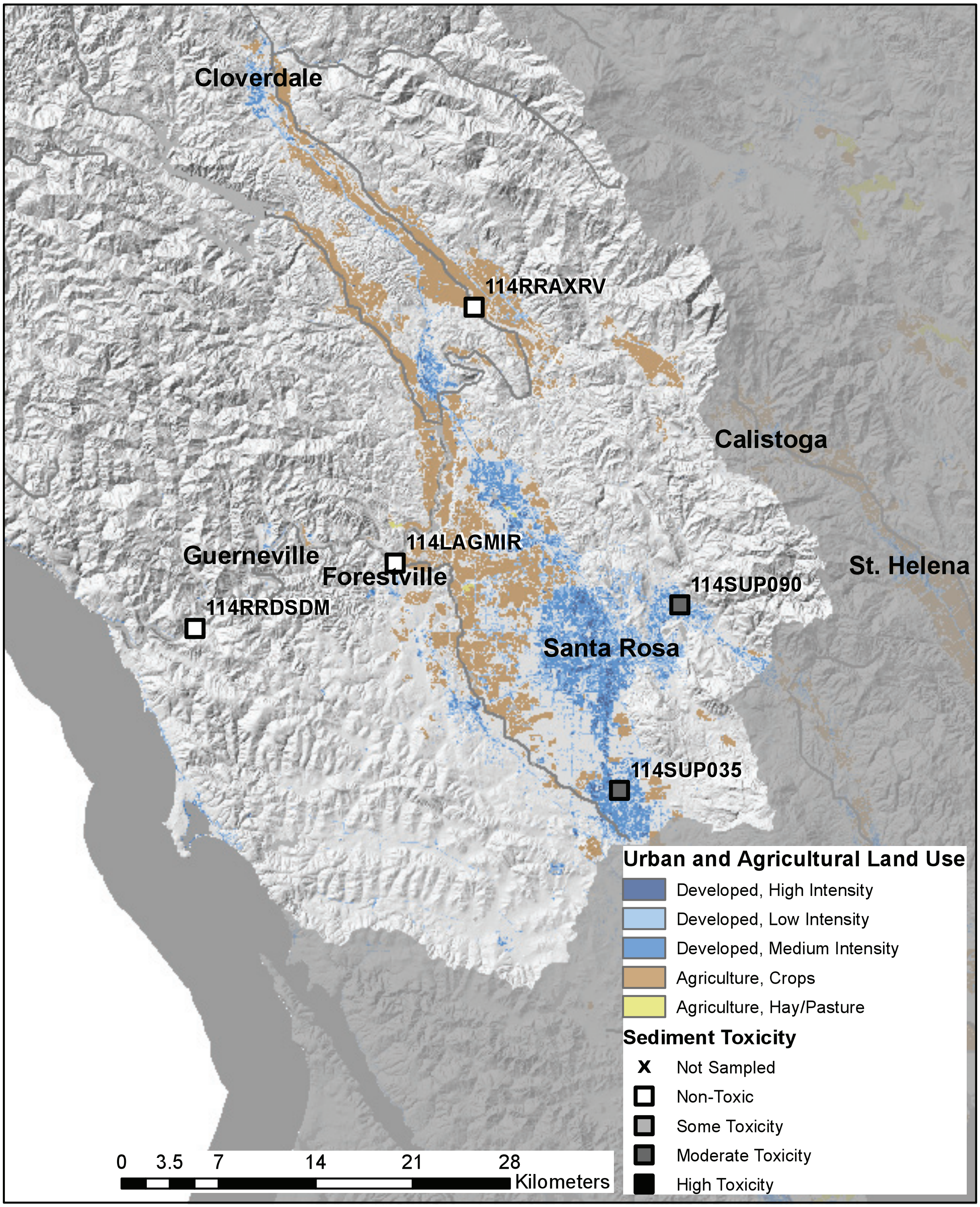

Figure 5. Magnitude of sediment toxicity at sites in the Russian/Bodega WMA of California based on the 10-d survival of *H. azteca* in sediment samples collected at each site.

SECTION 6
CAUSES OF TOXICITY

Sediment toxicity tests using *H. azteca* have been conducted in most regions of California where toxicity has been observed. The majority of chemical analyses of toxic sediments have identified pyrethroid pesticides as agents of toxicity. Other studies have shown sediment toxicity is due to mixtures of organophosphate (OP) and pyrethroid pesticides.

Holmes et al. (2008), identified pyrethroids as the cause of toxicity in their examination of urban-dominated sediments in California, specifically those collected from Hinebaugh Creek (114SUP035) and Ducker Creek (114SUP090). In side-by-side sediment toxicity tests conducted at 23° C and 15° C, these sediments became more toxic at the colder temperature exposure, which is a causal effect typical of pyrethroids (Werner et al., 2010; Weston, 2009). Both sediments contained bifenthrin, as well as cyfluthrin in the Hinebaugh Creek site and permethrin (trace) in the Ducker Creek site.

The Holmes et al. (2008) study provides a more ecologically relevant indicator of pyrethroid toxicity to *H. azteca*, particularly during winter months, where winter temperatures are typically below the 15 °C testing temperature. Sediment toxicity tests conducted at 23 °C can underestimate pyrethroid toxicity because pyrethroids are more toxic at colder temperatures. Since pyrethroids are present year round, this suggests that sediment toxicity due to pyrethroids is greater than previously thought (Anderson et al., 2011).

Recent research has expanded the consideration of the toxicity of urban runoff, particularly in regard to the contamination of urban waterways by pyrethroid pesticides in the densely populated areas of California. Urban pyrethroid sediment toxicity has been identified in the Sacramento area, in runoff from a residential area of Roseville, and in Elk Grove (Amweg et al., 2006; Weston et al., 2005; Weston et al., 2009). Brown et al. (2010) identified pyrethroids as the probable cause for most of the *H. azteca* toxicity in Southern California freshwater wetland sites receiving urban runoff. These sediments contained concentrations of several pyrethroids, such as bifenthrin, permethrin, lambda-cyhalothrin and cyfluthrin exceeding *H. azteca* sediment LC50 values. Pyrethroids have also been detected in toxic concentrations in sediments collected from urban creeks in the East San Francisco Bay (Amweg et al., 2006), and Southern California (Budd et al., 2007).

The prevalence of pyrethroid detections in these urban sediments is not surprising, given that the increased use of pyrethroids as replacements for OPs has been well documented (Amweg et al., 2006; Holmes et al., 2008; Oros and Werner, 2005; Weston et al., 2005, Weston et al., 2009). Concentrations of diazinon have been steadily decreasing in Russian River urban creeks since its 2004 phase out, and bifenthrin was detected in concentrations high enough to cause toxicity to aquatic organisms in sediment from urban creek Foss Creek in Healdsburg (McEnhill, 2006). Pyrethroid pesticides have become the dominant urban-use insecticide in California (Oros and Werner, 2005), utilized for landscape maintenance and structural pest control. Several studies have demonstrated higher concentrations of pyrethroids in sediments located closer to urban storm drain outfalls (Katznelson, 2003; Holmes et al., 2008; Weston et al., 2005), and decreasing downstream. This may account for the differences in the magnitude of toxicity seen in the North Coast Region. Sites Hinebaugh Creek (114SUP035) and Ducker Creek (114SUP090) were located in high-density residential areas and exhibited a higher magnitude of toxicity than sediments collected from the Mad River upstream of Hwy 101 (109MAD101; mainstem) and Jane's Creek Meadows (110SUP089; low-density residential urban creek).

SECTION 7
ECOLOGICAL IMPACTS ASSOCIATED WITH TOXIC WATERS

Field bioassessments provide information on the ecological health of streams and rivers, and bioassessments of macroinvertebrate communities have been used extensively in California. Throughout the other regions of California, toxicity testing and bioassessment have revealed similar geographical patterns of impaired waterways, with more severely impaired waterways occurring in areas of the most intense urban land uses (Anderson et al., 2011; Ode et al., 2011). In each of these regional reports, field bioassessments were investigated to determine whether relationships between benthic macroinvertebrate communities and contaminants were apparent. In the North Coast Region, no such relationships were identified due to the lack of available contaminant and toxicity testing data.

However, multiple studies have documented urban runoff as a source of benthic community impairment in freshwater streams throughout other regions of California, and the findings of these studies are likely to be broadly applicable wherever benthic communities are exposed to toxic water and sediment. Brown et al. (2010) found that the macroinvertebrate (MI) community in over 85% of the urban wetlands examined in Southern California was at risk due to sediment contamination. Sediment contaminant concentration was found to significantly correlate with decreased MI diversity. Moreover, amphipod sediment toxicity identification evaluations (TIEs) conducted on these sites implicated pyrethroid pesticides as the dominant toxicant responsible for the observed toxicity.

Toxicity studies and TIEs showed that toxicity in the Santa Maria River was caused by mixtures of chlorpyrifos, diazinon, and pyrethroids (Anderson et al., 2006a; Phillips et al., 2006), and stations with the greatest contamination and toxicity also had the lowest macroinvertebrate densities. Subsequent studies in the Santa Maria River Estuary have demonstrated that water and sediment toxicity due to organophosphate and pyrethroid pesticides extend into the estuary (Anderson et al., 2010a; Phillips et al., 2010a). Stations with the greatest contamination in the estuary also had the lowest macroinvertebrate densities, lower numbers of amphipods, and higher numbers of pollution-tolerant species (Anderson et al., 2010a). In addition, when Bacey and Spurlock (2007) examined invertebrate communities in urban streams near Elk Grove and Stockton, they found communities dominated by pollution-tolerant taxa, and detected pesticides at all sites. Generally, given the occurrence of urban sediment toxicity in the North Coast Region, in concert with detections of pyrethroids in contaminated sediments, it is likely that pesticide toxicity plays a role in the impairment of urban benthic communities throughout the region.

It should be noted, however, that other water quality concerns were brought to light with bioassessment monitoring in the North Coast Region. Benthic community impairment can have multiple causes in addition to contaminated water and sediment. Physical habitat often plays a larger role in macroinvertebrate distributions than chemical contaminants (Hall et al., 2007; Weston et al., 2005). For instance, urban and agricultural development on riparian stream corridors often results in altered stream channels, loss of surrounding riparian habitat, and changes in stream flows and hydrologic functions (Herbst, 2009).

Anthropogenic efforts to manage land in the North Coast Region have accelerated natural sediment generation and delivery processes, which in turn compromise the abilities of the waterways to efficiently transport sediment downstream and out of the systems (Fadness et al., 2008). Major land uses such as timber logging, mining, agriculture (including livestock grazing) and construction industries, along with the associated building and use of roads, all contribute to increased erosion in the watershed, leading to excessive sedimentation in streams. In riparian corridors especially, trampling by livestock grazing accelerates the erosion of stream banks and produces channel widening, loss of shade, and in some cases, increased water temperature (Herbst and Kane, 2009). Moreover, sediments from stream bank erosion can decrease benthos diversity by increasing the amount of fine sediments present in stream beds. Fine sediment deposition is one of the most pervasive pollutants affecting water quality in US streams (USEPA, 2002) and is an important factor in the decline of anadromous salamanoid populations in the North Coast Region.

SECTION 8
MONITORING RECOMMENDATIONS

An examination of toxicity monitoring sites with data recorded in the SWAMP/CEDEN databases shows that toxicity sampling in the North Coast Region suffers from significant data gaps. Notably, there were few toxic events. However, if the frequency of toxicity in this limited number of samples is any indication of the potential frequency in a more comprehensive data set, increasing the frequency of ambient monitoring may benefit the North Coast Region's effort to identify additional contaminant concerns.

URBAN TOXICITY

Sediment testing has occurred in only a few North Coast Region cities, and the toxicity of the water column in urban waterways in the North Coast Region is largely unexamined. SWAMP/CEDEN data have shown sediment toxicity exclusively limited to urban areas in the North Coast Region. As demonstrated by several studies throughout other regions of California, urban storm runoff has the potential to negatively impact surface water and sediment quality as well as its benthic communities. Expanded toxicity testing in high-density urbanized areas may be valuable in evaluating the toxicity of urban storm runoff when funding allows.

BIOASSESSMENT

Studies linking water and sediment toxicity to benthic community structure have been notably absent in this region. While inferences can be made from other studies conducted in similar land-use areas throughout California, it may be beneficial to include bioassessments in areas where sediment and/or ambient surface water monitoring occurs. When combined with chemistry, toxicity, and TIE information, bioassessments can indicate linkages between laboratory toxicity and ecosystem impacts.

REFERENCES R

Amweg, E.L., Weston, D.P., You, J., Lydy, M.J., 2006. Pyrethroid insecticides and sediment toxicity in urban creeks from California and Tennessee. Environmental Science and Technology 40, 1700-1706.

Anderson, B.A., Hunt, J.W., Markiewicz, D., Larsen, K., 2011. Toxicity in California Waters. Surface Water Ambient Monitoring Program. California Water Resources Control Board. Sacramento, CA.

Anderson, B.S., B.M. Phillips, J.W. Hunt, S.L. Clark, J.P. Voorhees, R.S. Tjeerdema, J. Casteline, M. Stewart, D. Crane, A. Mekebri, 2010. Evaluation of methods to determine causes of sediment toxicity in San Diego Bay, California, USA. Ecotoxicol Environ Safety. 73, 534-540.

Bacey, J., Spurlock, F., 2007. Biological assessment of urban and agricultural streams in the California central valley. Environmental Monitoring and Assessment 130, 483-493.

Bay, S., Greenstein, D., Brown, J., 2007. Evaluation of methods for measuring sediment toxicity in California bays and estuaries. Technical Report #503. Southern California Coastal Water Research Project. Westminster, CA.

Brown, J.S., M. Sutula, C. Stransky, J. Rudolph, E. Byron, 2010. Sediment contaminant chemistry and toxicity of freshwater urban wetland in southern California. Journal of the American Water Resources Association. 46, 367-384.

Budd, R., S. Bondarenko, D. Haver, J. Kabashima, and J. Gan. 2007. Occurrence and Bioavailability of Pyrethroids in a Mixed Land Use Watershed. J. Environ. Qual. 36:1006-1012.

Denton D.L., Diamond, J., Zheng, L., 2011. Test of Significant Toxicity: A statistical application for assessing whether an effluent or site water is truly toxic. Environmental Toxicology and Chemistry 30, 1117 – 1126.

Fadness, R.,Kamer,K., Swenson, S. 2008. Summary Report for the North Coast Region (RWQCB-1) for Years 2000-2006. Surface Water Ambient Monitoring Program. Submitted to the California Regional Water Quality Control Board, North Coast Region. Santa Rosa, CA.

Hall, L.W., Killen, W.D., Alden, R.W., 2007. Relationship of farm level pesticide use and physical habitat on benthic community status in a california agricultural stream. Human and Ecological Risk Assessment 13, 843-869.

Herbst, David B. 2009. Trout Creek Restoration Monitoring: Changing Benthic Invertebrate Indicators in a Reconstructed Channel. September, 2009. Sierra Nevada Aquatic Research Laboratory – University of California. Mammoth Lakes, CA.

Herbst, D.B. and J.M. Kane. 2009. Responses of Aquatic Macroinvertebrates to Stream Channel Reconstruction in a Degraded Rangeland Creek in the Sierra Nevada. Ecological Restoration. 27(1) 2009.

Holmes, R.W., Anderson, B.S., Phillips, B.M., Hunt, J.W., Crane, D., Mekebri, A., Blondina, G., Nguyen, L., Connor, V., 2008. Statewide Investigation of the Role of Pyrethroid Pesticides in Sediment Toxicity in California's Urban Waterways. Environ Sci Technol 42, 7003-7009.

Katznelson, Revital. 2003. Russian River First Flush Summary Report, 2002. Clean Water Team, Citizen Monitoring Program of the State Water Resources Control Board, with the North Coast Regional Water Quality Control Board. June 2003. Santa Rosa, CA.

McEnhill, Don Jr. 2006. Russian River Citizens Survey of Pesticides in Urban Creeks 2004-2005. Russian Riverkeeper. Prepared for the State Water Resources Control Board. December 2006. Santa Rosa, CA.

Ode, P.R., Kincaid, T.M., Fleming, T., Rehn, A.C., 2011. Ecological condition assessments of California's perennial wadeable streams: highlights from the Surface Water Ambient Monitoring Program's perennial streams assessment (PSA) (2000-2007). A collaboration between the State Water Resources Control Board's Non-Point Source Pollution Control Program (NPS Program), Surface Water Ambient Monitoring Program (SWAMP), California Department of Fish and Game Aquatic Bioassessment Laboratory, and the U.S. Environmental Protection Agency.

Oros, D.R., I. Werner. Pyrethroid Insecticides: An Analysis of Use Patterns, Distributions, Potential Toxicity and Fate in the Sacramento-San Joaquin Delta and Central Valley. Rep. Oakland, CA: San Francisco Estuary Institute, 2005. Print. White Paper for the Interagency Ecological Program SFEI Contribution. 415.

Phillips, B.M., B.A. Anderson, J.W. Hunt, K. Siegler, J.P. Voorhees, K. McNeill, 2010a. Santa Maria River Watershed and Oso Flaco Creek Watershed TMDL Monitoring Study – Final Report. Central Coast Regional Water Quality Control Board, San Luis Obispo, CA.

U.S. EPA, 2010. National Pollutant Discharge Elimination System Test of Significant Toxicity Technical Document. EPA 833-R-10-004. Office of Wastewater Management. Washington DC.

USEPA, 2002. Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. Fourth Edition. EPA 821-R-02-013. Office of Water. Washington, D.C.

Werner, I., Deanovic, L.A., Markiewicz, D., Khamphanh, M., Reece, C.K., Stillway, M., Reece, C., 2010. Monitoring acute and chronic water column toxicity in the northern Sacramento-San Joaquin Estuary, California, USA, using the euryhaline amphipod, Hyalella azteca: 2006 to 2007. Environmental Toxicology and Chemistry 29, 2190-2199.

Weston, D.P., Holmes, R.W., Lydy, M.J., 2009. Residential runoff as a source of pyrethroid pesticides to urban creeks. Environmental Pollution 157, 287-294.

Weston, D.P., R.W. Holmes, J. You, M.J. Lydy, 2005. Aquatic toxicity due to residential use of pyrethroid insecticides. Environmental Science & Technology. 39, 9778-9784.

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