SWAMP
Surface Water Ambient Monitoring Program

TOXICITY IN CALIFORNIA WATERS: LAHONTAN REGION

Marie Stillway

Dan Markiewicz

Brian Anderson

Bryn Phillips

Swee Teh

August 2012

California Water Boards

www.waterboards.ca.gov/swamp

ACKNOWLEDGEMENTS

The authors thank Tom Suk of the Lahontan Regional Board. We are grateful for the services provided by the field crews, laboratory and data management staff who participated in this project. Funding was provided by the Surface Water Ambient Monitoring Program.

TABLE OF CONTENTS TOC

Acknowledgements i

Table of Contents ii

Tables and Figures iii

Executive Summary. 1

Introduction 2

Scope and Methodology 4

Regional Toxicity 6

Toxicity by Species. 8

Relationships between Land Use and Toxicity 10

Geographical Patterns in Toxicity 13

Susan River 13

Lake Tahoe Basin. 13

Carson and Walker River Watersheds 13

Owens River Watershed 13

Causes of Toxicity 16

Water 16

Sediment. 16

Ecological Impacts Associated with Toxic Waters 18

Monitoring Recommendations 19

Urban Toxicity 19

TABLE OF CONTENTS TOC

List of Tables

Table 1. Source programs, water and sediment toxicity test counts and test dates for Lahontan regional toxicity data included in this report 2

Table 2. Data conditions used to determine toxicity categories for any given sample collection site. 5

Table 3. Species-specific maximum levels of toxicity observed at sites tested with *C. dubia*, *P. promelas* and *L. minor* water toxicity tests and *H. azteca* sediment toxicity tests 7

List of Figures

Figure 1. Magnitude of toxicity of freshwater samples in the Lahontan Region of California using the most sensitive species (test endpoint 6

Figure 2. Magnitude of toxicity in sediment samples in the Lahontan Region of California based on 10-day *H. azteca* survival 7

Figure 3. Magnitude of toxicity to aquatic plant species in water samples from the Lahontan Region of California 8

Figure 4. Magnitude of toxicity to invertebrate and fish species in water samples from the Lahontan Region of California 9

Figure 5. Magnitude of water toxicity at sites in the Lahontan Region of California based on the most sensitive species (test endpoint) in water samples collected at each site 11

Figure 6. Magnitude of sediment toxicity at sites collected in the Lahontan Region of California based on 10-day survival of *H. azteca* in sediment samples collected at each site 12

Figure 7. Magnitude of water toxicity at sites from the Susan River based on the most sensitive species (test endpoint) in water samples collected at each site 14

TABLE OF CONTENTS TOC

Figure 8. Magnitude of sediment toxicity at sites in the Tahoe Basin of California based on 10-day *H. azteca* survival in sediment samples collected at each site 15

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.

Due to the limited available data, few conclusions can be drawn about toxicity in surface waters and sediments of the Lahontan Region. However, even with the limited number of samples, some toxicity was observed due to herbicides and insecticides, which warrants further study.

Although there were only a few instances of toxicity seen in freshwater and sediment sites in the Lahontan Region, the limited number of samples collected indicate a relatively high frequency of toxicity. There were no instances of *high* water toxicity. *Moderate* toxicity was observed only in *Lemna minor* species (50%); *some* toxicity was observed only in *Pimephales promelas* species (25%), and *Ceriodaphnia dubia* did not exhibit any toxicity. Toxicity to *Hyalella azteca* was seen intermittently with *some* toxicity occurring in 17% of sediment samples.

Water and sediment toxicity was elevated in agricultural, urban and mixed agricultural-urban areas compared to the surrounding undeveloped land. Water toxicity to *L. minor* was attributed to the synergistic effects of the herbicide Transline® and the surfactants nonylphenol and nonylphenol ethoxylate in Transline® formulations. Sediment toxicity to *H. azteca* was attributed to the pyrethroid pesticides bifenthrin and permethrin.

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 Lahontan Region (Region 6). Source programs, test counts and sample date ranges are outlined in Table 1.

The Lahontan Region includes over 700 lakes, 3,170 miles of streams and 1,581 square miles of ground water basins. There are a number of major watersheds in the Lahontan Basin, including Susan River/Honey Lake, Truckee, Carson, Owens and Walker River watersheds (LRWQCB, 1995).

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

Toxicity Test Type	Program	Test Count	Sample Date Range
Water Column	Other SWAMP	144	5/29/03 – 8/25/04
Sediment	Statewide Urban Pyrethroid Monitoring	6	10/30/06
	Stream Pollution Trends (SPoT)	9	9/17/08 – 9/23/08

The diverse topography, geology, and climates within the Lahontan Region make for unique water quality problems which differ greatly when compared to other, more populated regions of California. The natural quality of most high elevation waters in the Lahontan Region, which are derived from snowmelt, is assumed to be very good or excellent, whereas many desert waters have poor water quality due to elevated concentrations of naturally occurring salts and minerals from volcanic, geothermic and evaporative sources (LRWQCB, 1995). Moreover, consumptive municipal and agricultural water use is relatively low in most parts of the Lahontan Region when compared to other parts of California, due to the low resident population and the agricultural emphasis on livestock grazing rather than row crops. Where the majority of water quality problems elsewhere in California can be attributed to pesticides (Anderson et al., 2011), water quality problems in the Lahontan Region are largely related to non-point sources, including erosion from construction, timber harvesting, livestock grazing, stormwater, acid drainage from inactive mines, and individual wastewater disposal systems (LRWQCB, 1995). These non-point sources have led to the development of Total Maximum Daily Loads (TMDLs) based on reducing nutrients, metals, and sediment loadings to Lahontan waterbodies, and little toxicity testing has been utilized within the region.

Very little quantitative information is available on most waterbodies in this region. Four sites on the Susan River were selected for ambient surface water monitoring, and twelve sites were located throughout the Region for sediment toxicity. These combined sixteen sites comprise the second-fewest number of stations evaluated within a region, and made strong associations between observed regional toxicity with land use practices difficult. Because of the large size of the Lahontan Region, the large number of waterbodies in it, the difficulties of sampling in remote terrain and severe weather, coupled with ongoing funding constraints, detailed monitoring data are available for only a few of the Region's waters (LRWQCB, 1995). Two SWAMP studies provide additional information on sediment toxicity in the Lahontan Region. These are SWAMP's Stream Pollution Trends monitoring program (SPoT) which monitors a number of creeks and rivers in the Lahontan Region, and a study of sediment toxicity associated with pyrethroid pesticides in urban streams (Holmes et al., 2008).

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 (QAPrP). The attached maps (Figures 5-8) show locations of sites sampled for toxicity by SWAMP and partner programs, and the intensity of toxicity observed in the water and 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. At sites where both water and sediment toxicity data were collected, two toxicity categories were calculated to separately summarize the degree of toxicity in water and in sediment.

Toxicity test results reported in the Lahontan region included freshwater exposures of the cladoceran *Ceriodaphnia dubia*, the fathead minnow *Pimephales promelas*, and the vascular freshwater plant *Lemna minor* (duckweed). Sediment samples were tested using the amphipod *Hyalella azteca*. Only survival endpoints and duckweed growth are considered in the measures of toxicity reported here; therefore all sites identified as toxic showed a significant decrease in test animal survival or duckweed growth 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; U.S. 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 the 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, moderately 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 toxicity 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	One or more samples are toxic to one or more species, and the mean of one or more species' response(s) falls above their respective "high toxicity threshold"
High Toxicity	One or more samples are toxic to one or more species, and the mean of one or more species' response(s) falls below their respective "high toxicity threshold"

SECTION 3
REGIONAL TOXICITY

Although there were only a few instances of toxicity seen in freshwater and sediment sites in the Lahontan Region between 2001 and 2010 (Figures 1 and 2), the limited number of samples collected indicate a relatively high frequency of toxicity. Freshwater toxicity tests included exposures of fish, invertebrates and duckweed, while sediment toxicity tests were performed using the amphipod *Hyalella azteca*. Water column toxicity was more common than sediment toxicity. Fifty percent (50%) of sampling sites showed *moderate* water toxicity, with 25% of sites showing *some* toxicity, and 25% of sites showing no toxicity. The majority of sediment sites were non toxic (83%), with 17% showing *some* toxicity. None of the sites tested within this region were *highly* toxic (Table 3).

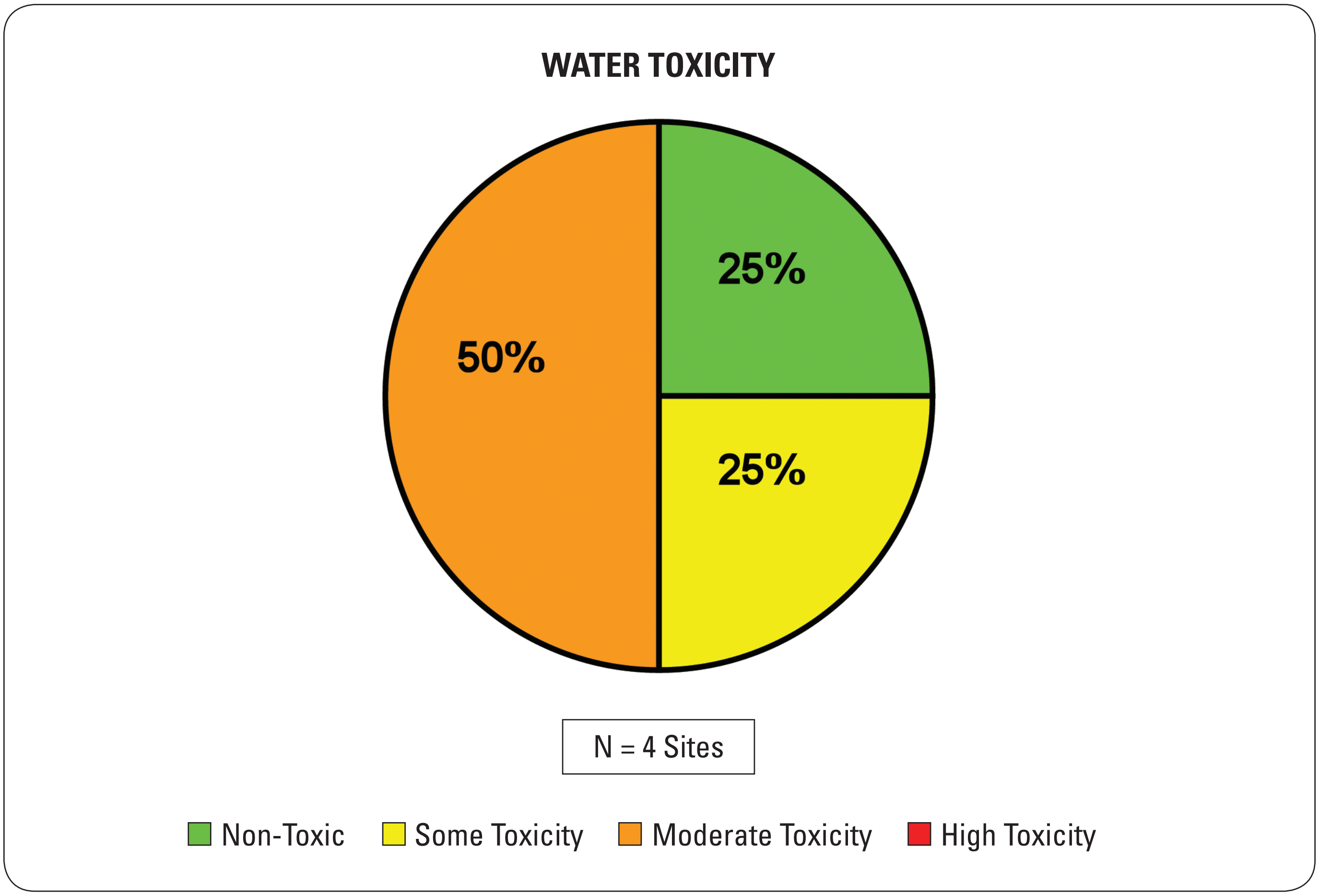

Figure 1. Magnitude of toxicity in freshwater samples in the Lahontan Region of California, based on the most sensitive species (test endpoint).

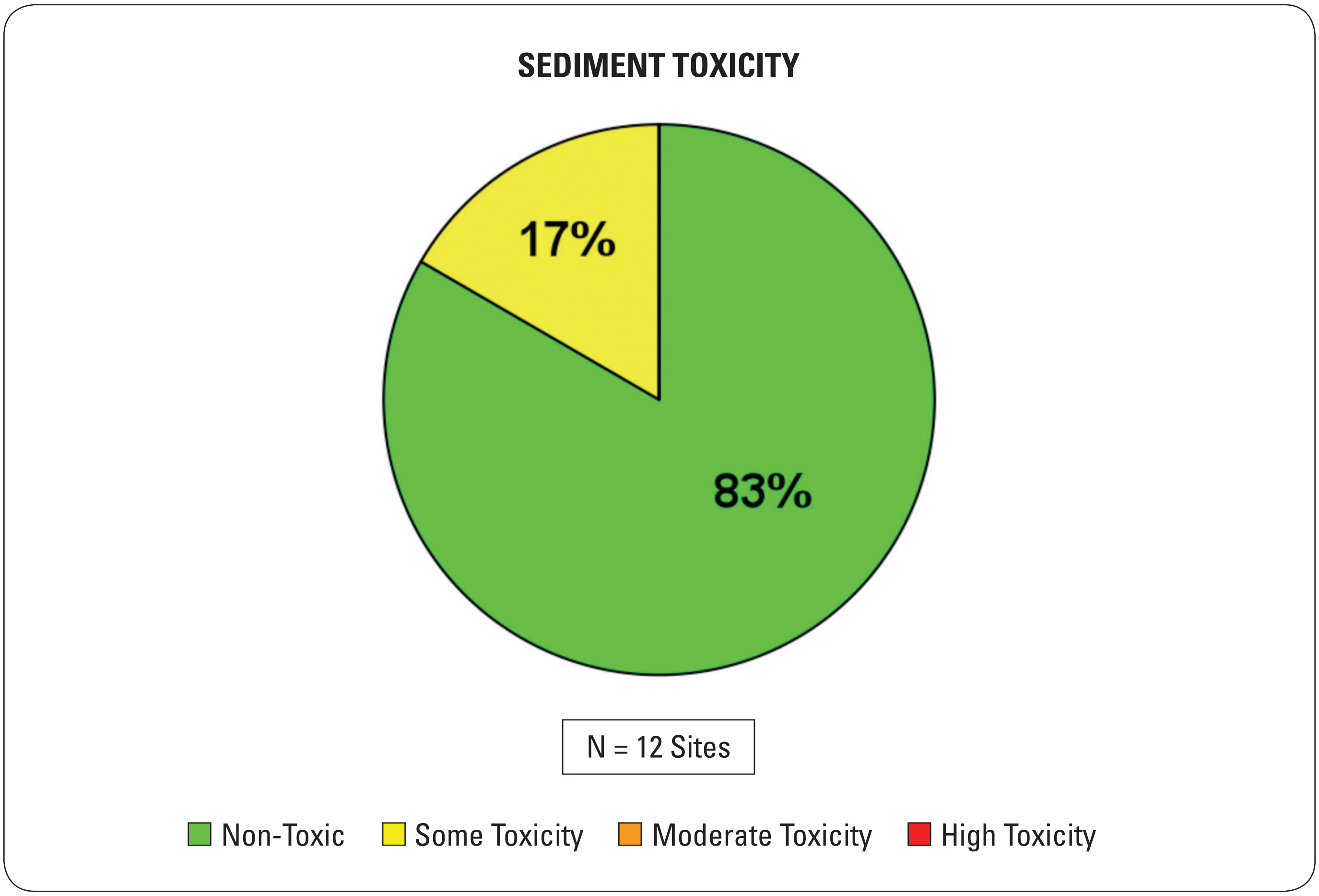

Figure 2. Magnitude of toxicity in sediment samples in the Lahontan Region of California based on 10-day *H. azteca* survival.

Table 3
Species-specific maximum levels of toxicity observed at sites tested with *P. promelas*, *C. dubia* and *L. minor* water column toxicity tests and *H. azteca* sediment toxicity tests.

Toxicity Test Type Species	Program Number of Sites	Maximum Toxicity Level Observed			
		Non-Toxic	Some Toxicity	Moderately Toxic	Highly Toxic
P. promelas	4	3	1	0	0
C. dubia	4	4	0	0	0
L. minor	4	2	0	2	0
H. azteca	12	10	2	0	0

TOXICITY BY SPECIES

The fathead minnow *P. promelas*, the cladoceran *C. dubia*, and the duckweed *L. minor* were used to test the toxicity of freshwater samples to examine potential for ecological impacts of contaminants across a range of trophic levels. Freshwater toxicity is summarized by individual species in Figures 3 and 4.

There were no instances of *high* water toxicity in samples collected in the Lahontan Region between 2001 and 2010. *Moderate* toxicity was observed only in *L. minor* species (50%). *Some* toxicity was observed only in *P. promelas* (25%), and *C. dubia* did not exhibit any toxicity.

Toxicity to *H. azteca* was seen intermittently, with *some* toxicity occurring in 17% of sediment samples.

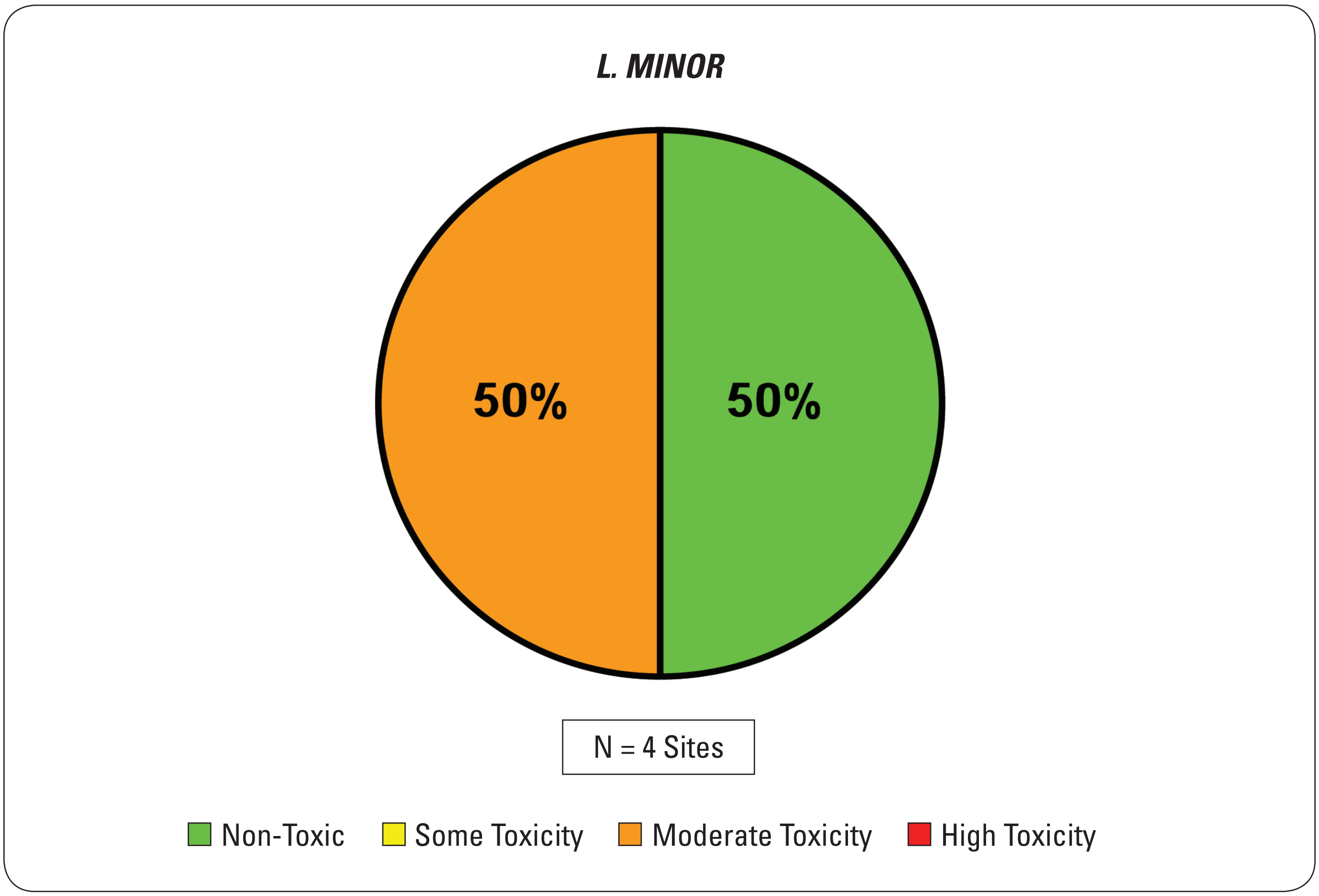

Figure 3. Magnitude of toxicity to aquatic plant species in water samples from the Lahontan Region of California.

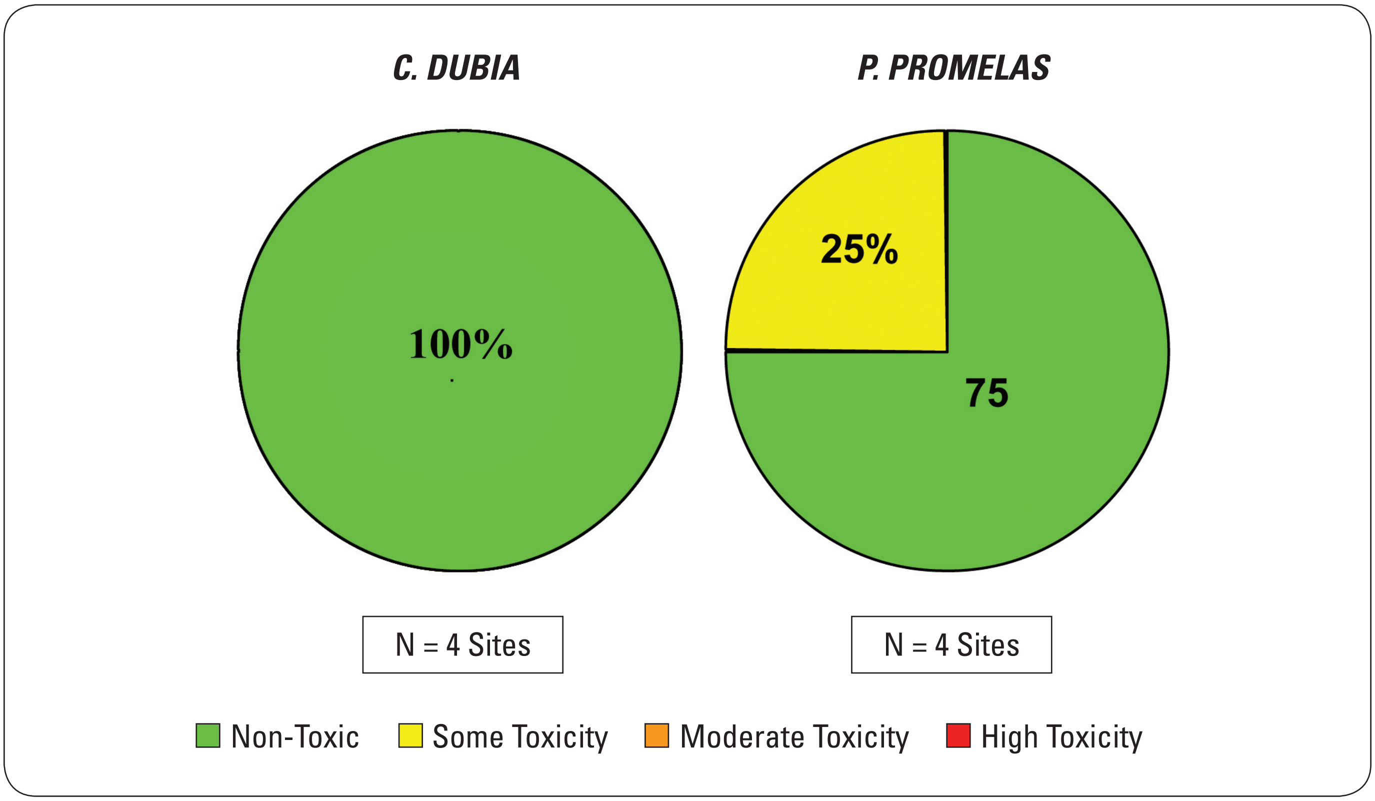

Figure 4. Magnitude of toxicity to invertebrate and fish species in water samples from the Lahontan Region of California.

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 water column or 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.

Water and sediment toxicity in the Lahontan Region was elevated in agricultural, urban, and mixed agricultural-urban areas compared to the surrounding undeveloped land (Figures 5 and 6). Greater *H. azteca* sediment toxicity in urban areas has been reported previously by Holmes et al. (2008), some of whose data was incorporated into the data set analyzed in the current report. Although it was not possible to use the Lahontan regional data set to examine associations between toxicity and agriculture due to a lack of toxicity data, these associations are well established in other parts of California (Anderson et al. 2011; de Vlaming et al., 2000; Weston et al., 2005).

In duckweed freshwater toxicity tests, frond growth was impacted in sites from the Susan River with agricultural and agricultural-urban dominated uses, and fathead minnow survival was impacted at a Susan River site which was mostly urban influenced. In *H. azteca* sediment tests, survival was impacted at sites with urban influence, showing *moderate* toxicity in the vicinity of South Lake Tahoe.

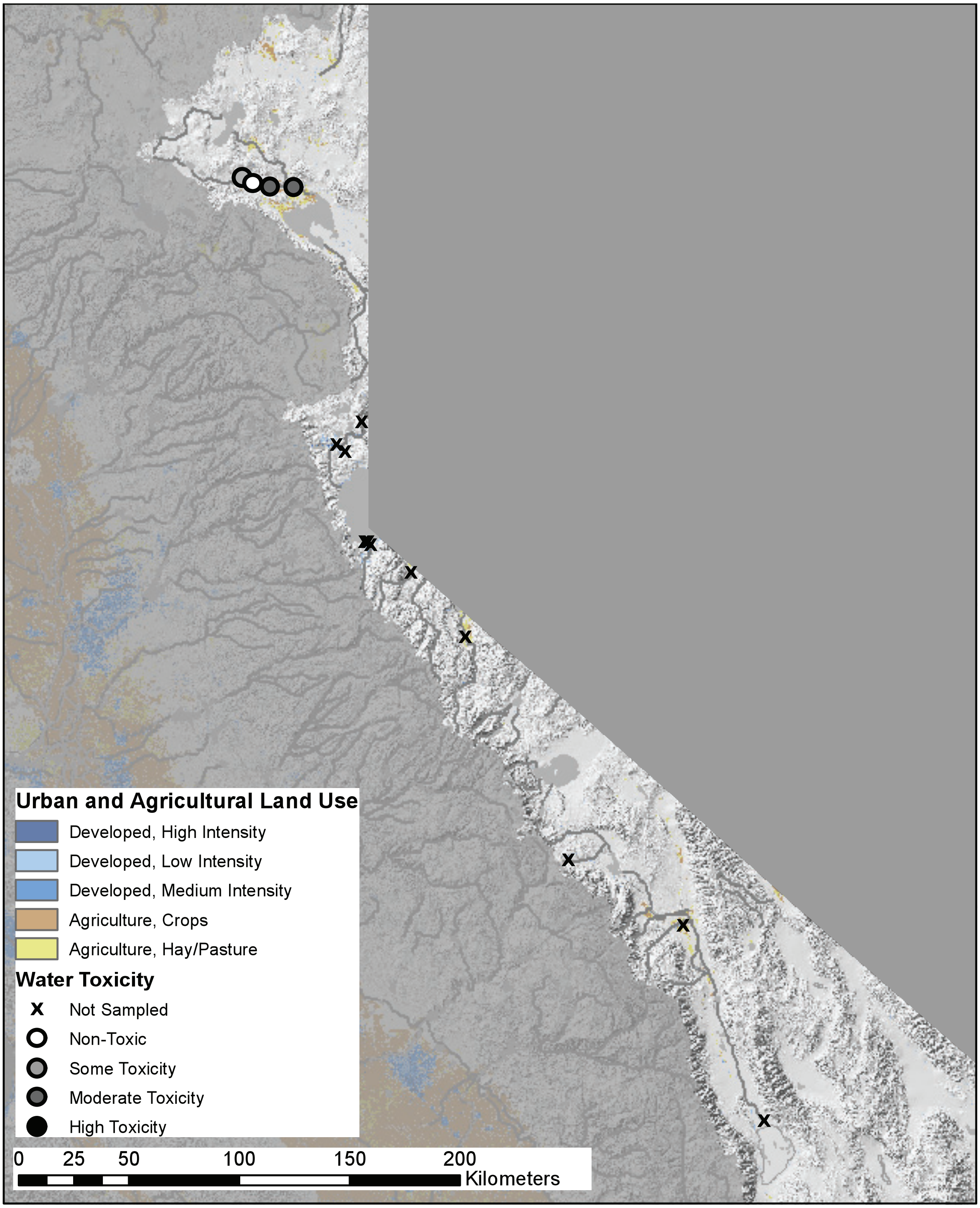

Figure 5. Magnitude of water toxicity at sites in the Lahontan Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

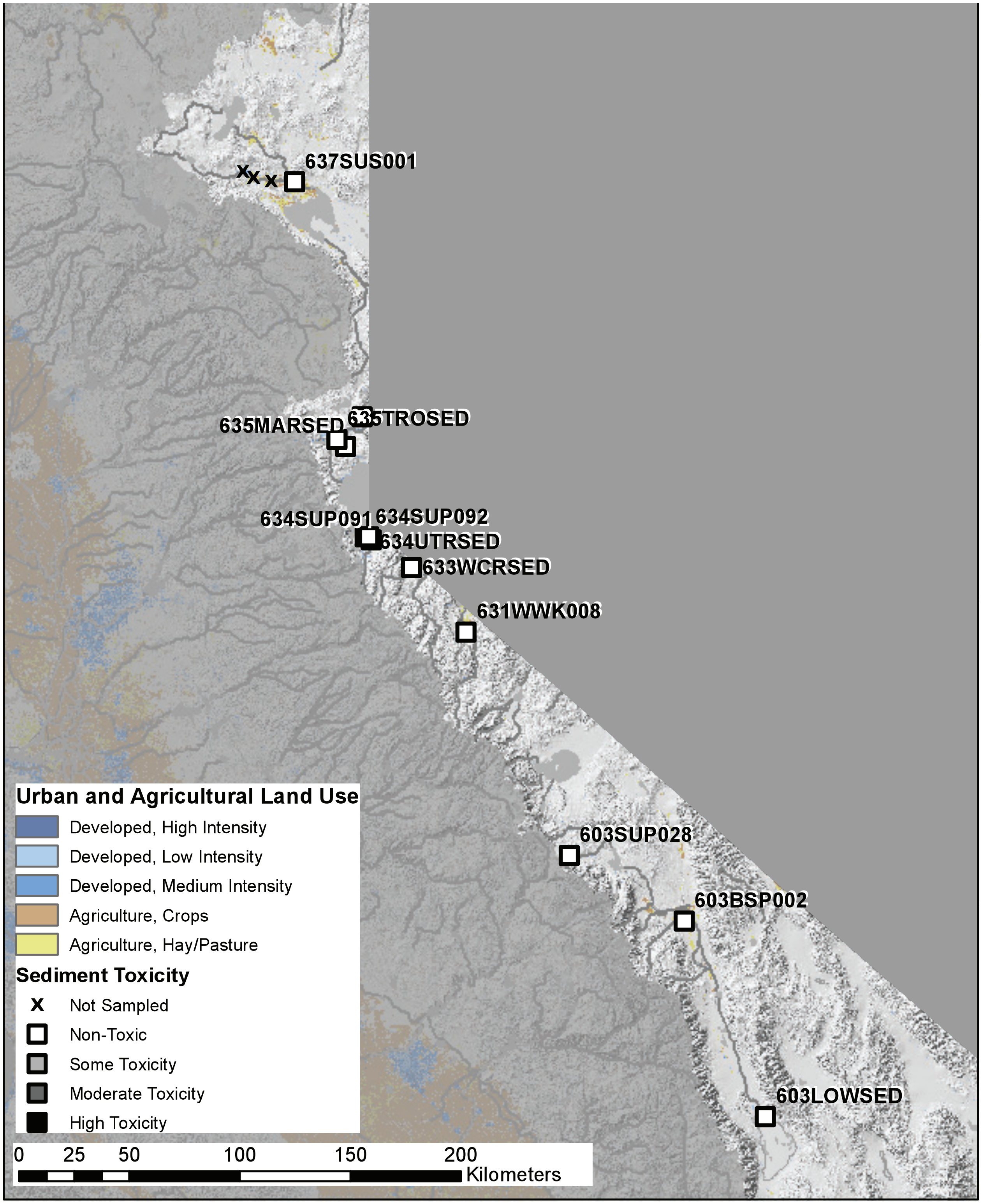

Figure 6. Magnitude of sediment toxicity at sites in the Lahontan Region of California based on the 10-d survival of *H. azteca* in sediment samples collected at each site.

SECTION 5
GEOGRAPHICAL PATTERNS IN TOXICITY

Notably, there were few toxic events. However, toxicity was observed in the Susan River and in the Lake Tahoe Basin, and are discussed below.

SUSAN RIVER

Mild to *moderate* water toxicity was seen throughout the agricultural and urban-agricultural areas of Susan River, up and downstream of Susanville in the Honey Lake watershed (Figure 7). Susan River at McGowen Lane (637SUS012) was non-toxic to all freshwater species. Susan River at Hobo Camp (637SUS013) exhibited *some* toxicity to the fathead minnow. Susan River at Leavitt Lane (637SUS011) and Susan River near Litchfield (637SUS001) were *moderately* toxic to duckweed. However, a sediment sample collected at the Susan River near Litchfield site (637SUS001) was non-toxic to *H. azteca*.

LAKE TAHOE BASIN

Sediment samples throughout the Truckee River watershed showed either no or *moderate* toxicity (Figure 8). Sites located north of Lake Tahoe such as the Lower Truckee River near the state line (635TRKSED), Trout Creek near mouth (635TROSED), Martis Creek near mouth (635MARSED), as well as the southern site Upper Truckee River near the inlet to Lake Tahoe (634UTRSED) were non-toxic to *H. azteca*. In contrast, sediments collected south of Lake Tahoe such as at the Tahoe Keys at Venice 2 (634SUP092) and the Truckee River Swale (634SUP091) were *moderately* toxic.

CARSON AND WALKER RIVER WATERSHEDS

Sediments from the West Fork of the Carson River at Paynesville (633WCRSED) and West Carson River at Topaz (631WWK008) were both non-toxic.

OWENS RIVER WATERSHED

Sediments collected from Mammoth Creek at Minaret (603SUP028), Bishop Creek at East Line St. (603BSP002) and the Lower Owens River near mouth (603LOWSED) were all non-toxic.

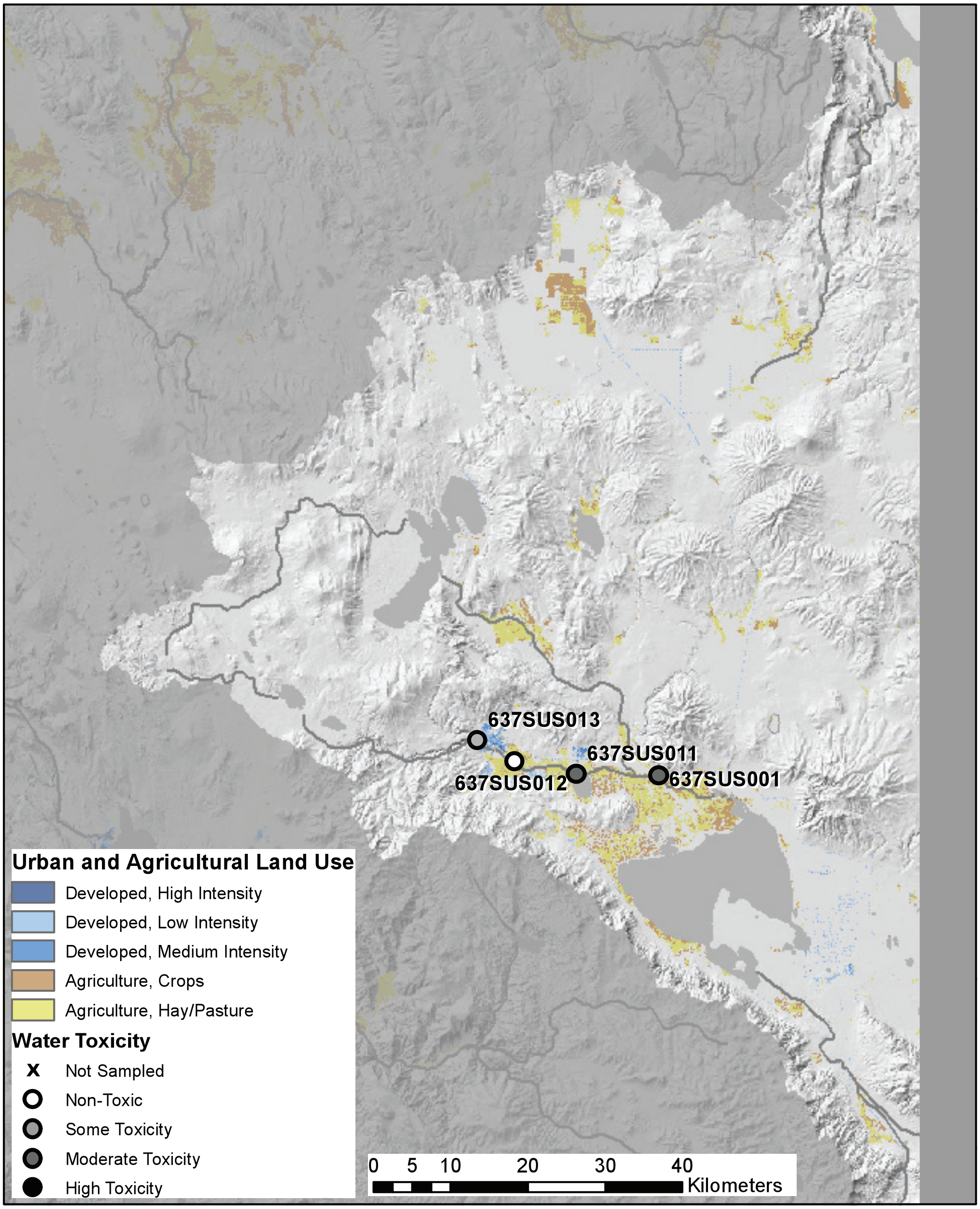

Figure 7. Magnitude of water toxicity at sites from the Susan River based on the most sensitive species (test endpoint) in water samples collected at each site.

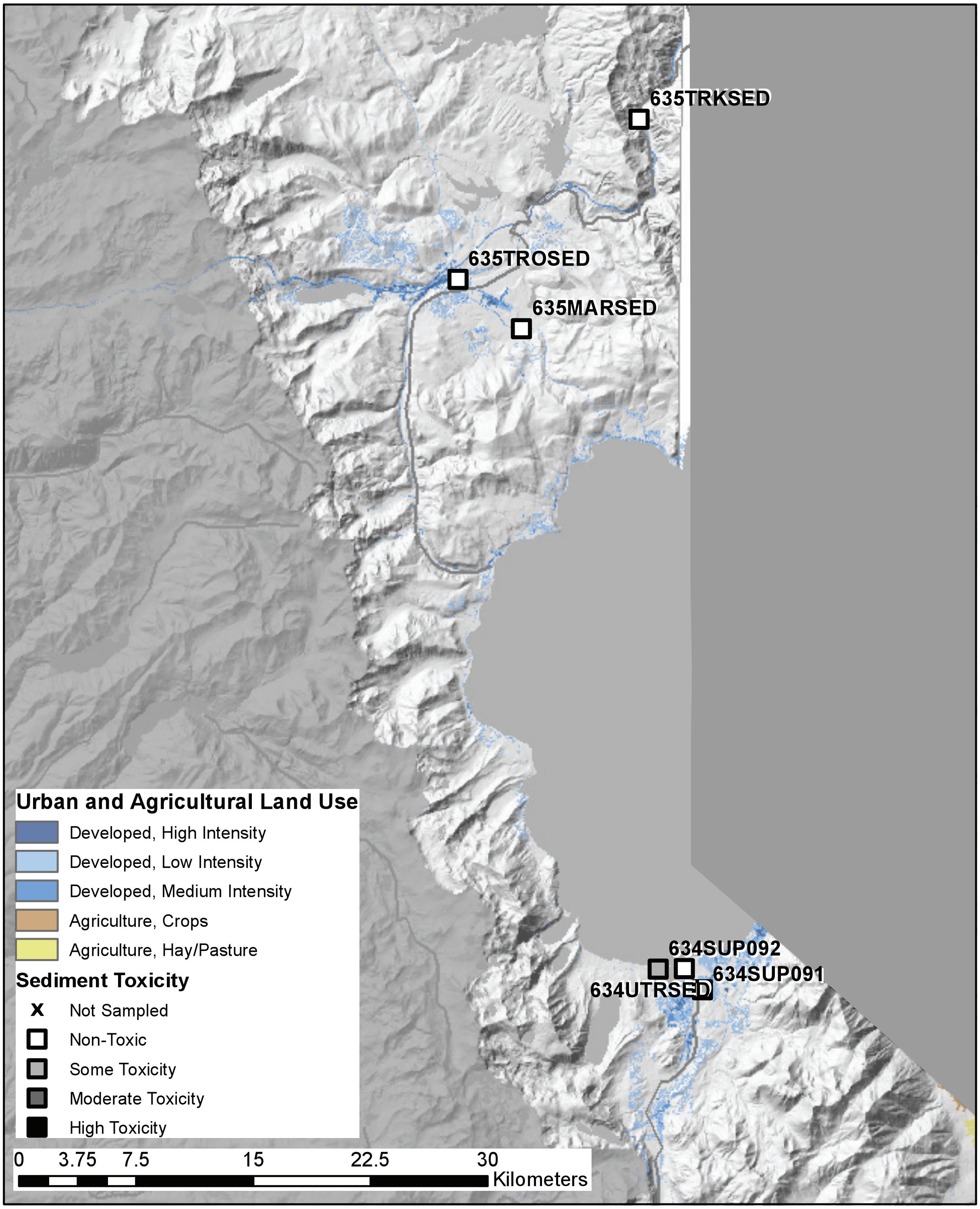

Figure 8. Magnitude of sediment toxicity at sites in the Tahoe Basin of California based on the 10-d survival of *H. azteca* in sediment samples collected at each site.

SECTION 6
CAUSES OF TOXICITY

Although the majority of samples collected in the Lahontan Region were non-toxic, the few instances of observed toxicity can be attributed to herbicides and insecticides.

WATER

Water toxicity exhibited in the Susan River was investigated by Fong et al. (2004), who determined that duckweed toxicity was caused by the synergistic effects of the herbicide Transline® and the surfactants nonylphenol and nonylphenol ethoxylate in Transline® formulations. Transline® is used for vegetation control in right-of-ways in Lassen County, and both Susan River sites (at Leavitt Lane; 637SUS011 and near Litchfield; 637SUS001) are located adjacent to roadways. In addition, the temporal pattern of toxicity in this study matched typical Transline® application (July to September), and toxicity was not exhibited by any other species at the time this duckweed toxicity occurred.

It should be noted that Fong et al. (2004) attributed the single event of *P. promelas* toxicity to pathogen-interference rather than by a contaminant(s). Pathogen-related toxicity (PRT) occurs occasionally in fathead minnow tests with ambient samples and is believed to be caused by bacterial pathogens (Kszos et al., 1997; US EPA, 2002). Characteristics of PRT include delayed, unequal mortality among replicates in combination with high among-replicate variability. *P. promelas* toxicity exhibited in Susan River at Hobo Camp (637SUS013) was both delayed and had a coefficient of variation of 38.7% among replicates. Therefore, this instance of toxicity should be interpreted with caution due to the possible presence of a mixture of pathogen(s) and contaminant(s) in this sample.

SEDIMENT

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 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 Truckee Marsh (Tahoe Keys at Venice; 634SUP092) and Truckee River Swale (634SUP091). 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 (Holmes et al., 2008; Werner et al., 2010; Weston, 2009). Both sediments contained bifenthrin, and the Truckee River Swale sediment had the second-highest concentration of permethrin detected in the entire study.

The Holmes et al. study provides a more ecologically relevant indicator of pyrethroid toxicity to *H. azteca*, particularly during winter months and especially in the Lake Tahoe region, where winter temperatures of 4 °C are common. 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 regards to contamination of urban waterways by pyrethroid pesticides in the densely populated areas of Central Valley (Amweg et al., 2006; Weston et al., 2005; Weston et al., 2009). As the population of South Lake Tahoe is estimated to increase (LRWQCB and NDEP, 2010), it is likely that urban pyrethroid use will also increase, and this urban storm runoff has the potential to negatively impact the surrounding waterways.

No toxic sediment samples were reported in the 2008 SPoT data set, but one toxic sample was observed in 2009 (637SUS001) and one toxic sample was observed in 2010 (631WWK008) when tested with *H. azteca*. Both of these samples were statistically toxic with survival results of 86%, but these results were also greater than the test acceptability criterion of 80% survival, indicating the results were probably not biologically significant. Neither of these samples contained significant concentrations of chemicals that could have contributed to the observed results, but pyrethroid pesticides were detected at four SPoT sediment samples in 2008 and five SPoT sediment samples in 2009.

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 throughout 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 agricultural and 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 (BMI) communities and contaminants were apparent. In the Lahontan Region, no such relationships were identified, due to the lack of available contaminant and toxicity testing data.

SECTION 8
MONITORING RECOMMENDATIONS

An examination of toxicity monitoring sites with data recorded in the SWAMP/CEDEN databases shows that toxicity sampling in the Lahontan 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 Lahontan Region's effort to identify additional contaminant concerns. Toxicity, although generally of low magnitude, can be attributed to pesticides and herbicides. Based on these results, we offer the following recommendations:

URBAN TOXICITY

Sediment testing has occurred in only a few Lahontan Region cities, and the toxicity of the water column in urban waterways in the Lahontan Region is largely unexamined. While most of the region's TMDL success can be measured by analytical chemistry alone, toxicity testing in high-density urbanized areas may be valuable in evaluating the toxicity of urban storm runoff. Rapidly expanding communities such as those in the Tahoe Basin and Mammoth Lakes region would all be suitable for the exploration of urban aquatic toxicity when funding allows. Additionally, the inclusion of concurrent bioassessments with toxicity testing would provide data to help managers determine what impact the toxicity of water and sediment has on the surrounding ecological communities.

REFERENCES R

Amweg, E.L., D. Weston, J. You, M. Lydy. 2006. Pyrethroid Insecticides and Sediment Toxicity in Urban Creeks from California and Tennessee. Environ. Sci. Technol. 40, 1700-1706.

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

Bay, S.M., D. Greenstein, D. Young. 2007. Evaluation of methods for measuring sediment toxicity in California bays and estuaries. Technical Report 503. Southern California Coastal Water Research Project. Costa Mesa, CA.

deVlaming, D., D. Markiewicz, K. Goding, A. Morrill, J. Rowan. 2001. Macroinvertebrate Assemblages of the San Joaquin River Watershed. Final Report to the Central Valley Regional Water Quality Control Board. University of California, Davis. Aquatic Toxicology Laboratory. Davis, CA.

Fong, S., V. deVlaming, K. Edgar. 2004. Susan River Toxicity Testing Project 2003-2004. Final Report to the State Water Resources Control Board. University of California, Davis. Aquatic Toxicology Laboratory. Davis, 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., B.S. Anderson, B.M. Phillips, J.W. Hunt, D. Crane, A. Mekebri, G. Blondina, L. Nguyen, V. Connor. 2008. Statewide Investigation of the Role of Pyrethroid Pesticides in Sediment Toxicity in California's Urban Waterways. Environ Sci Technol 42, 7003-7009.

Kszos LA, Stewart AJ, Summer JR. 1997. Evidence that variability in ambient fathead minnow short-term chronic tests is due to pathogenic infection. Environ Toxicol Chem 16:351–356.

California Regional Water Quailty Control Board, Lahontan Region (LRWQCB). 1995. Water Quality Control Plan for the Lahontan Region. South Lake Tahoe, California.

California Regional Water Quality Control Board, Lahontan Region (LRWQCB). 2007. Surface Water Ambient Monitoring Program (SWAMP) at the Lahontan Region: Summary of Results for Years 2000–2005. California Regional Water Quality Control Board, Lahontan Region, South Lake Tahoe, CA. July 2007.

California Regional Water Quality Control Board and Nevada Division of Environmental Protection (LRWQCB and NDEP). 2010. Lake Tahoe Total Maximum Daily Load Final Report. California Regional Water Quality Control Board, Lahontan Region and Nevada Divison of Environmental Protection.

Ode, P.R., T.M. Kincaid, T. Fleming, A.C. Rehn. 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).

Truckee River Watershed Council. 2008. Annual Monitoring Data Report. Submitted to the Sierra Nevada Alliance. Updated September 30, 2008.

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

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., L.A. Deanovic, D. Markewicz, M. Khamphanh, C.K. Reece, M. Stillway, C. Reece. 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., J. You, A. Harwood, M.J. Lydy. 2009. Whole Sediment Toxicity Identification Evaluation Tools for Pyrethroid Insecticides: III. Temperature Manipulation. Environ Toxicol Chem. 28, 173-180.

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.

SWAMP
Surface Water
Ambient Monitoring
Program

For more information, please contact:

Marie Stillway
Aquatic Health Program
University of California, Davis
Department of Anatomy, Physiology and Cell Biology
One Shields Ave
Davis, California

CALIFORNIA
Water Boards

www.waterboards.ca.gov/swamp