Summary of Toxicity in California Waters: 2001 - 2009

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1 Assessment Questions

This document presents a summary assessment of toxicity in California watersheds and coastal waters using data from SWAMP and partner programs. The following questions are addressed:

1. Where has toxicity been observed in California waters?
2. What is the magnitude of observed toxicity?
3. How do the results of toxicity measurements compare among waters draining urban, agricultural, and other land cover areas?
4. What chemicals have been implicated as causing toxicity?
5. What are the ecological implications of aquatic toxicity?
6. How are test results affected by the statistical methods applied, particularly with respect to use of the Test of Significant Toxicity that US EPA recently released?

2 Background

The word "toxicity" is used here to indicate a statistically significant adverse impact on standard aquatic test organisms in laboratory exposures. A number of different species, including crustaceans, algae, fish, and mollusks, have been used, following widely accepted test protocols with strict quality assurance. Toxicity test organisms are surrogates for aquatic species found in the environment. Toxicity tests are especially useful in water quality monitoring because they can detect the effects of all chemicals (whether measured or not) and respond to pollutant mixtures. These results may or may not have any relationship to human health.

The test organisms have been chosen because they are relatively sensitive to toxic chemicals. Toxicity detected by these organisms might not acutely impact other types of organisms. Endpoints are the measured effects on test species (e.g., fish, crustaceans, etc.). All endpoints measured lethality (as % survival), except for cell counts for the algal population growth endpoint.

3 Findings

Information is presented here to answer the key assessment questions. Additional information, documentation, program information, data sources and literature cited are available from the authors and will be presented in a larger interpretive report available by early 2011.

Where has toxicity been observed in California waters?

The attached maps (Figures 1 – 8) show locations of sites sampled for toxicity by SWAMP and partner programs. All sites presented in this document are color coded using the categorization process described in Figure 11, which considers the available toxicity test endpoints in both water and sediment. Relative to the 303(d) impaired waterbody listing process, a site coded "green" would not be listed for toxicity. Sites coded "yellow" to "red" may be listed if the number of toxic samples met the criteria outlined in the State Water Board's Listing and Delisting Policy.

Toxicity has been observed in all Regions. Streams in upper watersheds and mountainous areas tend to produce fewer toxic samples, while samples from downstream sites in the valleys and along the coasts tend to be more toxic. These lower watershed sites drain larger areas with greater levels of human activity. Consistent sediment toxicity has been observed in many bay and harbor sites. In most years since 1991, for example, annual surveys of San Francisco Bay have shown at least moderate sediment toxicity at a majority of sites throughout the Bay.

Figures 1 – 8. See maps at the end of this document.

Table 1. Summary of information presented in attached maps (Figures 1 through 8)

Figure No.	*Spatial Coverage*	*Results Presented (water, sediment, or both)*
1	Statewide	Both
2	Statewide	Sediment
3	Statewide	Water
4	Northern CA	Both
5	Central CA	Both
6	Southern CA	Both
7	Statewide	Water (summary by Region)
8	Statewide	Sediment (summary by Region)

What is the magnitude of observed toxicity?

Of the 992 sites in this assessment, 473 (48%) had at least one sample in which toxicity was measured in either water or sediment with at least one endpoint (e.g., lethality in one of the test species). Of these, 129 (13% of the total) were classified as high toxicity sites, meaning that the average result for the most sensitive species in all samples from the site was more toxic than the high toxicity threshold for that species (see Figures 7 and 8).

Different Regional Boards use different monitoring designs based on water quality priorities. The North Coast (Region 1) and Lahontan (Region 6) Regions, for example, tend to focus on sedimentation and habitat degradation, so the number of sites in these Regions for which there were toxicity data for this assessment was relatively low (12 sites in each). The greatest number of sites (298) was in the Central Valley Region (Region 5), which has many lowland waterbodies where pollution from toxic chemicals is a concern. Many Regions have conducted non-SWAMP toxicity studies; however, those data are not yet available in CEDEN so they have not been included in this assessment. The percentage of sites with at least one toxic sample ranged from 17% in the Lahontan Region (Region 6) to over 50% in the San Francisco Bay (Region 2), Central Coast (Region 3), Central Valley (Region 5), and Santa Ana Regions (Region 8)(see Figures 7 and 8).

How do the results of toxicity measurements compare among waters draining urban, agricultural, and other land cover areas?

Samples from sites in agricultural and urban areas had significantly higher toxicity than sites in less developed areas (Figure 9), and had a greater magnitude of toxicity (Figure 10). The differences in toxicity between undeveloped and urban areas was highly statistically significant ($p < 0.0005$); and the same is true for the difference between undeveloped and agricultural areas. A subset of the sites assessed (536 out of 992) for this report were mapped and categorized for land cover using geographic information system (GIS) analysis. For each site, an area 1 km upstream (including tributaries) and 500 m on either side of the stream was mapped. If land cover within those areas was greater than 10% “developed” (National Land Cover Dataset classification), they were designated as urban. This is based on the widely supported impervious surface area model that shows decreased ecological condition in streams draining lands with greater than 10% impervious surface area. Sites with greater than 25% agricultural land cover were classified as agricultural sites. Sites were classified as “undeveloped” if they had both less than 10% urban and less than 25% agricultural land cover. Sites were classified as “ag-urban” if they had both greater than 10% urban and 25% agricultural land cover.

Figure 9. Toxicity distribution for samples collected from sites in urban, agricultural, and less developed areas. Lower values represent lower levels of survival, and indicate higher toxicity. Data are for the most sensitive test species at each site. Solid lines, from top to bottom, represent the 90th, 75th, 50th (median), 25th and 10th percentiles of the distribution. Dotted lines are the mean result.

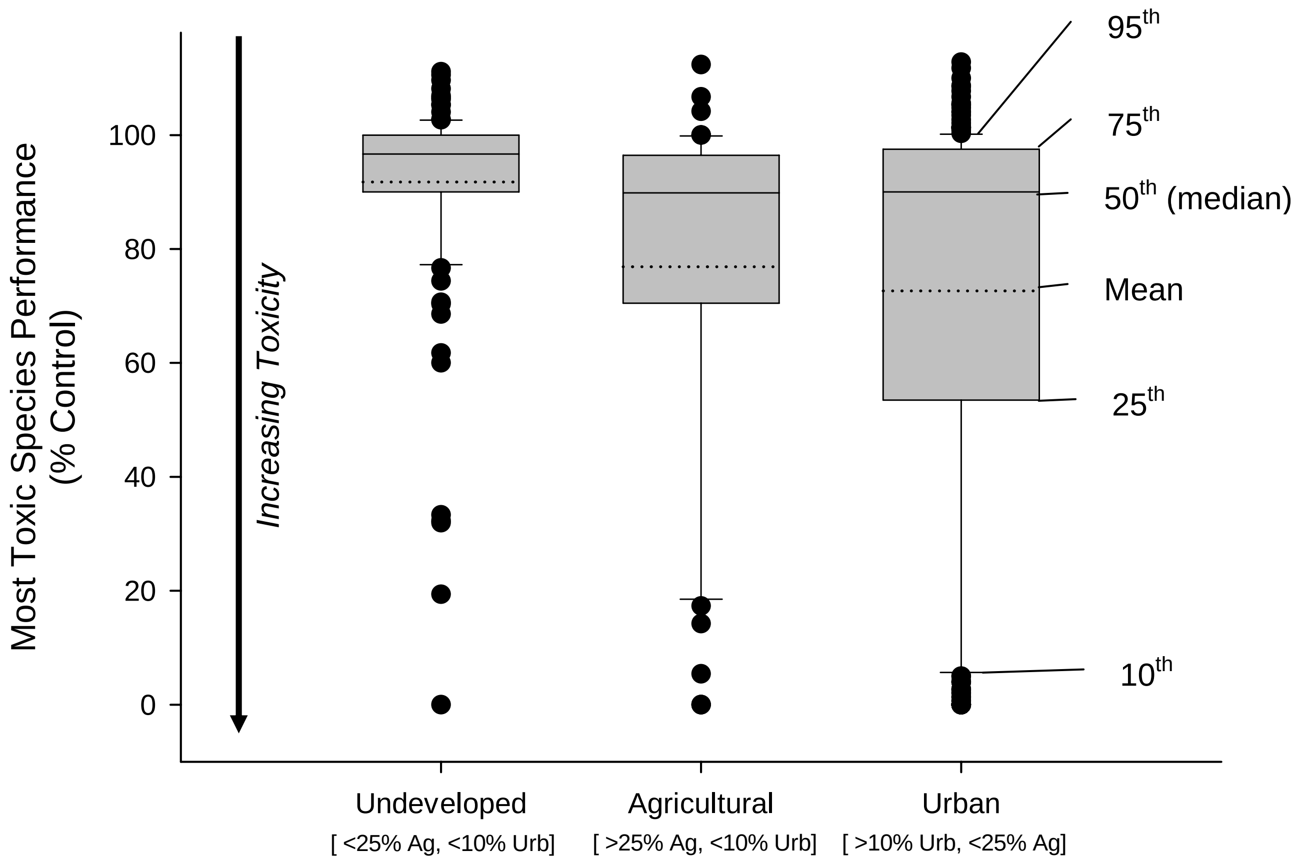
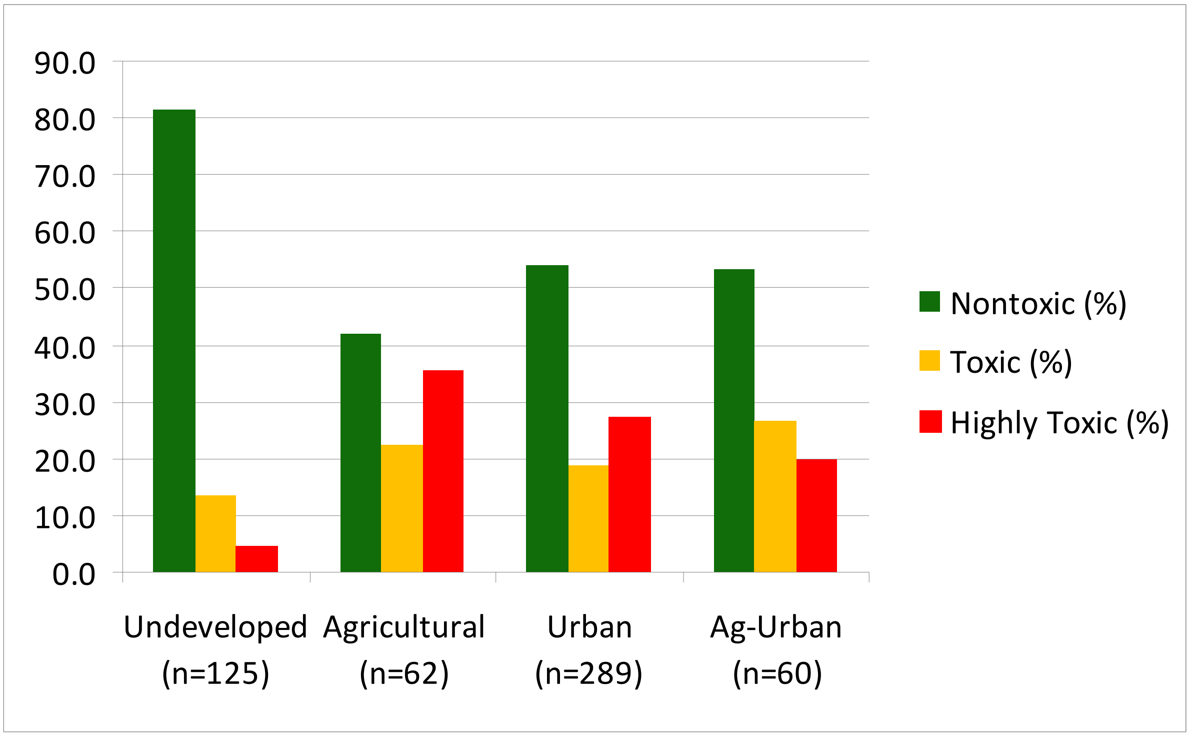


Figure 10. Numbers of sites (as a percentage of all sites in each land-cover category) classified as non-toxic, moderately toxic, or highly toxic, using the coding system shown in Figure 11. Some significant toxicity (yellow) and moderate toxicity (orange) categories are combined here.



What chemicals have been implicated as causing toxicity?

There are thousands of pollutants that can cause biological impacts in waterways, and only about 140 are routinely measured. Ambient water and sediment samples often contain complex mixtures of many pollutants, often with additive effects. Toxicity tests are especially useful in water quality monitoring because they can detect the effects of all chemicals (whether measured or not) and also respond to pollutant mixtures. To find out which chemicals in a sample are causing adverse impacts, toxicity identification evaluations (TIEs) can be used to provide direct experimental evidence.

Table 2 summarizes dozens of studies in which TIEs have identified the causes of toxicity in ambient water and sediment samples from California waterbodies, from 1991 to the present. With the exception of ammonia, all of these ambient TIEs implicated pesticides, primarily organophosphates and, more recently, pyrethroids. It is important to note that pesticides are implicated as causing toxicity in streams draining residential and urban areas as well as agricultural land.

Table 2. Classes of chemicals and specific compounds shown to have caused toxicity in California waterbodies. The third and fourth columns give the numbers of samples in which each of the chemicals listed was implicated in the TIEs conducted by the various studies.

Class	Compound	Water	Sediment
Ammonia	Ammonia	1	-
Carbamate Pesticide	Carbofuran	4	-
Organophosphate Pesticide	Chlorpyrifos	11	4
	Diazinon	13	-
	Ethyl Parathion	1	-
	Malathion	3	-
	Methyl Parathion	3	-
Pyrethroid Pesticide	Bifenthrin	4	8
	Cyfluthrin	3	3
	Cyhalothrin	2	7
	Cypermethrin	-	8
	Esfenvalerate	1	-
	Permethrin	-	1

What are the ecological implications of aquatic toxicity?

A small number of studies have measured chemistry, toxicity, and ecological indicators to investigate relationships between observed toxicity and observed impacts on stream and estuarine ecosystems. In most of these studies, the connection between observed toxicity and ecosystem impacts has been well established. In five journal articles, Anderson, Phillips, and colleagues measured declines in aquatic invertebrate population densities at sites where toxicity was observed in the Salinas and Santa Maria Rivers, downstream of the confluences with pesticide-laden streams draining intensive agriculture. These authors, along with Lao, also observed degradation of marine communities at sites exhibiting sediment toxicity in San Diego Bay, Newport Bay, and the Ballona Creek estuary. Weston observed population declines of the resident amphipod *Hyalella* in Delta and Central Valley waterways where sediment toxicity was observed, often in watersheds dominated by residential land use[1].

[1] Literature cited will be included in the larger interpretive report released in early 2011.

How are test results affected by the statistical methods applied, particularly with respect to use of the EPA Test of Significant Toxicity (TST)?

State Water Board staff is developing, for Board consideration, a Policy for Toxicity Assessment and Control to establish new numeric toxicity objectives. The proposed policy includes new numeric objectives for chronic and acute toxicity, a new statistical methodology for determining whether a sample is toxic that is based on the US EPA's Test of Significant Toxicity (TST), and monitoring requirements for wastewater, stormwater and some non-point source discharges. The TST also would be applicable to monitoring conducted by SWAMP so this assessment was conducted using the new methodology.

In toxicity testing of ambient or stormwater samples, a single site sample often is compared to a laboratory control sample. In these tests, the objective is to determine whether a given sample of site water is toxic, as indicated by a significantly different organism response in the site water compared to the control water using a traditional t-test or similar statistic. To demonstrate the TST approach for ambient toxicity programs, SWAMP data from 409 chronic tests for *Ceriodaphnia dubia* (crustacean) and 256 chronic tests for *Pimephales promelas* (fish) were used by the US EPA to compare results of the two statistical approaches. The following data are from the EPA TST Technical Document.

Table 3 summarizes results of *Ceriodaphnia* tests analyzed with the TST test method. The majority (92%) of these comparisons resulted in the same decision using either the TST or the traditional t-test approach. Of the other 8% of samples, approximately 6% (24 tests) would have been declared not toxic using the traditional t-test approach when the TST would declare them toxic. In 2% of the tests (7 tests), samples would have been declared toxic using the traditional t-test approach when the TST would not indicate toxicity.

Table 3. Comparison of results of chronic *Ceriodaphnia* ambient toxicity tests using the TST approach and the traditional (t-test) analysis.

		EPA Test of Significant Toxicity	
		Toxic	Non-Toxic
Traditional (t-test)	Toxic	20%	2%
	Non-Toxic	6%	72%

The two approaches agree 92% of the time (green).

This analysis indicates there is little difference in the assessment of ambient toxicity regardless of which statistical method is applied to the data.

4 Next Steps

The assessment questions addressed in this summary document will be more fully evaluated in a detailed report to be released in early 2011. The data set will be expanded to include additional information from SWAMP and partner programs to more fully address the details and implications of toxicity in California waters. Topics that will be more fully explored in the forthcoming report include: differences between sediment and water toxicity results, specific patterns related to land use and hydrology, additional information on the causes and ecological implications of toxicity, and temporal trends. In addition to the forthcoming statewide report, SWAMP will be producing separate reports for each Regional Board focusing on regional toxicity issues.

5 Caveats

The following points should be kept in mind when considering the information presented here:

1. Most of the data presented here were collected by monitoring studies designed to increase understanding of potential biological impacts from human activities. Site locations were generally targeted in low watershed areas, such as tributary confluences or upstream and downstream of potential pollutant sources. Only a minority of the sites were selected at random; therefore, these data characterize only the sites monitored, and cannot be used to make assumptions about unmonitored areas.
2. These results may underestimate ambient toxicity because most samples were collected as "grabs" by filling a sample bottle or collecting sediment at one point in time. Toxic chemicals often flow downstream in pulses. Studies in which test organisms were caged in-stream often have detected toxicity when grab sample tests have not.
3. This assessment integrates data sets from a number of programs. This integration was made possible by the SWAMP quality assurance conventions and the SWAMP and California Environmental Data Exchange Network (CEDEN) data management system. There are, however, data from a number of other Water Board monitoring programs that have not yet been submitted to CEDEN and were not used in this analysis. Information on data sources is given in Table 3.
4. The different programs often had different monitoring objectives, and there is large variation in the number of samples collected at each site and the number of sites surveyed in each Region.
5. For land use evaluations, only land cover within one kilometer upstream of a site was considered for categorizing the site. As a result, only local effects were assessed. There could be far field effects from other land use types that might cause toxicity at a site, which were not considered here.

6. All sites assessed were located in ambient waters, such as streams or estuaries. None of the data here represent effluent or other waste discharges.

6 Data Quality and Data Sources

Data Quality Objectives for this Assessment

Comparability and data sources for this analysis: This analysis was able to use data collected by SWAMP Regional and Statewide monitoring programs, as well as by partner programs, because SWAMP has a developed systematic structure to document and evaluate data comparability. This structure gives data users the ability to quickly combine data from multiple sources to perform integrated assessments. The SWAMP Quality Assurance Program has instituted standards for data quality and its verification while the SWAMP Data Management Program has developed data formats, transfer protocols, and the California Environmental Data Exchange Network that allow data to be brought together.

Statewide survey: Data were pooled from multiple sources to create the data set used in this statewide survey. The quality objective for data usability and comparability among data batches was defined as follows: data batches were usable for this analysis if toxicity test controls met test acceptability criteria as set by the test protocols. Other quality control and metadata information were not considered germane to the goals of this report. Data from multiple test protocols (indicator organisms) measured at multiple laboratories were integrated into a single data set for analysis.

Threshold development: Thresholds for distinguishing between moderate toxicity and high toxicity were developed using data from multiple laboratories for all toxicity endpoints presented in this analysis. For this purpose, the quality objective for data usability and comparability among data batches was defined as follows: data batches were used only if classified as “SWAMP-Compliant.” Data classified as “SWAMP-Compliant” have been verified as meeting all measurement quality objectives and requirements as defined in the 2002 SWAMP Quality Assurance Management Plan or the 2008 SWAMP Quality Assurance Program Plan.

Data Sources for this Assessment

The sources listed in Table 3 are for the data currently available in CEDEN. Many other studies by the State Board, the Regional Boards, regulated entities, and partner programs have been conducted but are not considered here. Many of those data sets will be entered into CEDEN as time and funding allow.

Table 4. Summary of data sources* and date ranges used for this assessment.

Region	*Project*	*Date Range*	*No. of Sites*	*No. of Samples*
1	SWAMP Monitoring	11/14/2006 - 11/15/2006	3	6
	SWAMP Stream Pollution Trends	10/14/2008 - 10/15/2008	9	9
	Region 1 Total Sampling	11/14/2006 - 10/15/2008	12	15
2	RMP - Status and Trends	7/27/2004 - 8/29/2007	72	220
	SWAMP Monitoring	9/18/2001 - 1/3/2007	58	366
	SWAMP Stream Pollution Trends	6/17/2008 - 8/13/2008	10	10
	Region 2 Total Sampling	9/18/2001 - 8/13/2008	137	596
3	Salinas River Watershed	7/8/2002 - 9/22/2004	45	268
	CCAMP	12/3/2001 - 9/22/2009	123	513
	SWAMP Monitoring	1/6/2007 - 2/5/2007	9	25
	SWAMP Stream Pollution Trends	5/22/2008 - 7/21/2008	11	11
	Region 3 Total Sampling	12/3/2001 - 9/22/2009	152	817
4	SWAMP Monitoring	10/29/2001 - 6/11/2008	169	342
	SWAMP Stream Pollution Trends	5/19/2008 - 5/22/2008	7	7
	Region 4 Total Sampling	10/29/2001 - 6/11/2009	176	349
5	Ag Waiver RWQCB5	3/26/2003 - 11/28/2007	155	1190
	East San Joaquin Water Quality Coalition	7/31/2004 - 9/25/2007	26	1246
	San Joaquin Water Quality Coalition	8/24/2004 - 9/25/2007	24	1074
	SWAMP Monitoring	10/19/2001 - 3/29/2007	76	951
	SWAMP Stream Pollution Trends	4/28/2008 - 8/20/2008	31	31
	Region 5 Total Sampling	10/9/2001 - 8/20/2008	298	4492
6	SWAMP Monitoring	10/30/2006	3	6
	SWAMP Stream Pollution Trends	9/17/2008 - 9/23/2008	9	9
	Region 6 Total Sampling	10/30/2006 - 9/23/2008	12	15
7	SWAMP Monitoring	5/6/2002 - 10/29/2008	25	235
	SWAMP Stream Pollution Trends	10/28/2008 - 10/29/2008	3	3
	Region 7 Total Sampling	5/6/2002 - 10/29/2008	25	238
8	SWAMP Monitoring	8/7/2001 - 1/7/2007	97	135
	SWAMP Stream Pollution Trends	5/20/2008 - 6/4/2008	5	5
	Region 8 Total Sampling	8/7/2001 - 6/4/2008	99	134
9	SWAMP Monitoring	3/12/2002 - 5/14/2009	85	344
	SWAMP Stream Pollution Trends	5/21/2008 - 5/22/2008	7	7
	Region 9 Total Sampling	3/12/2002 - 5/14/2009	85	351
Grand Total		***8/7/2001 - 9/22/2009***	***992***	***7007***

*There are data from a number of other Water Board monitoring programs (e.g., NPDES wastewater and stormwater receiving water monitoring) that have not yet been submitted to CEDEN and were not used in this analysis.

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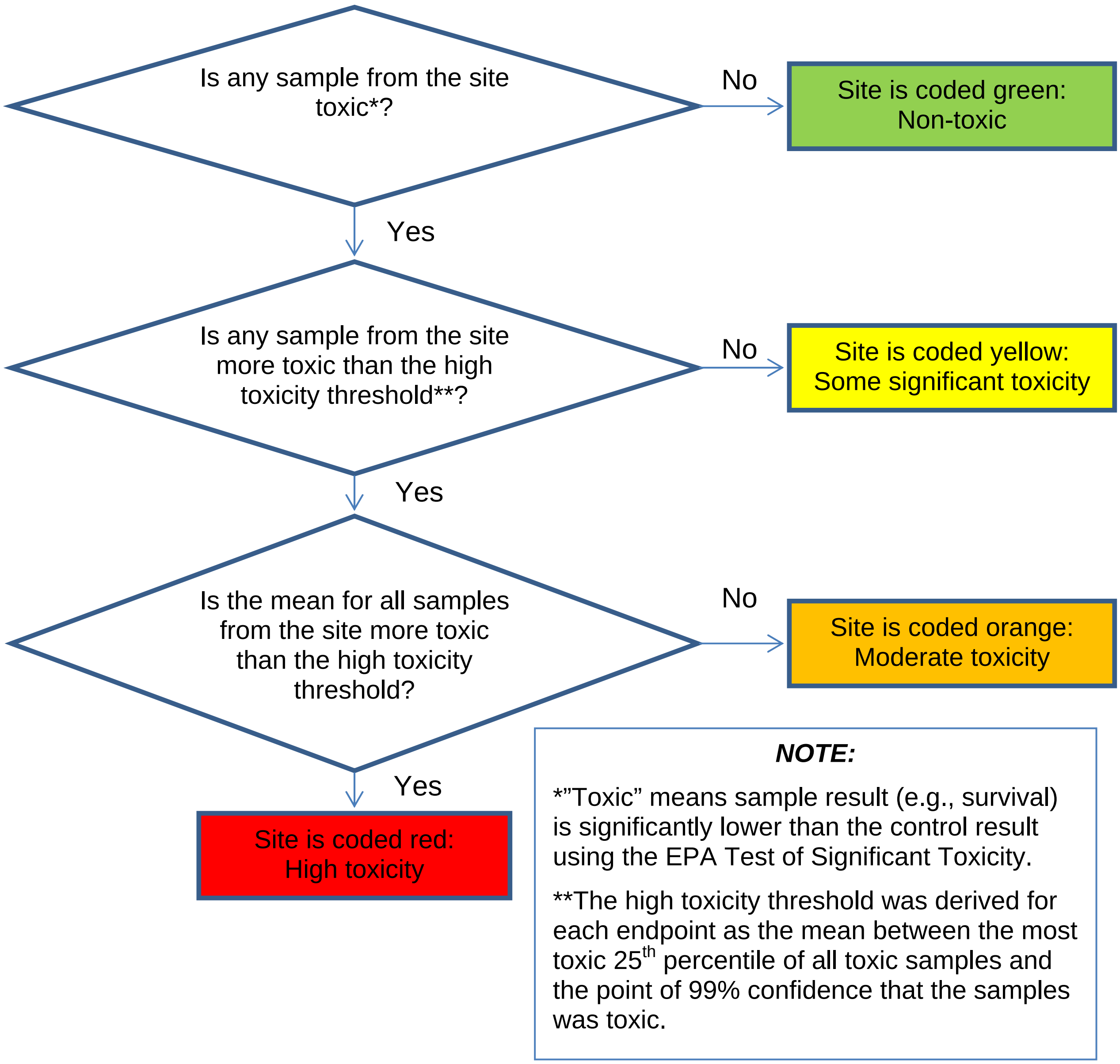
Figure 11. Site categorization process

The process used to characterize the magnitude of toxicity at each site was designed to take into consideration the widely varying number of samples and test endpoints (such as fish or crustacean survival) among sites. If any toxic samples were measured for a site, the site was categorized based on the most sensitive endpoint. This process considers both individual sample results and the mean results for sites with multiple samples. Relative to the impaired waterbody listing process, a site coded "green" would not be listed for toxicity. Sites coded "yellow" to "red" would be listed if the number of toxic samples met the criteria outlined in the State Water Board's Listing and De-listing Policy.



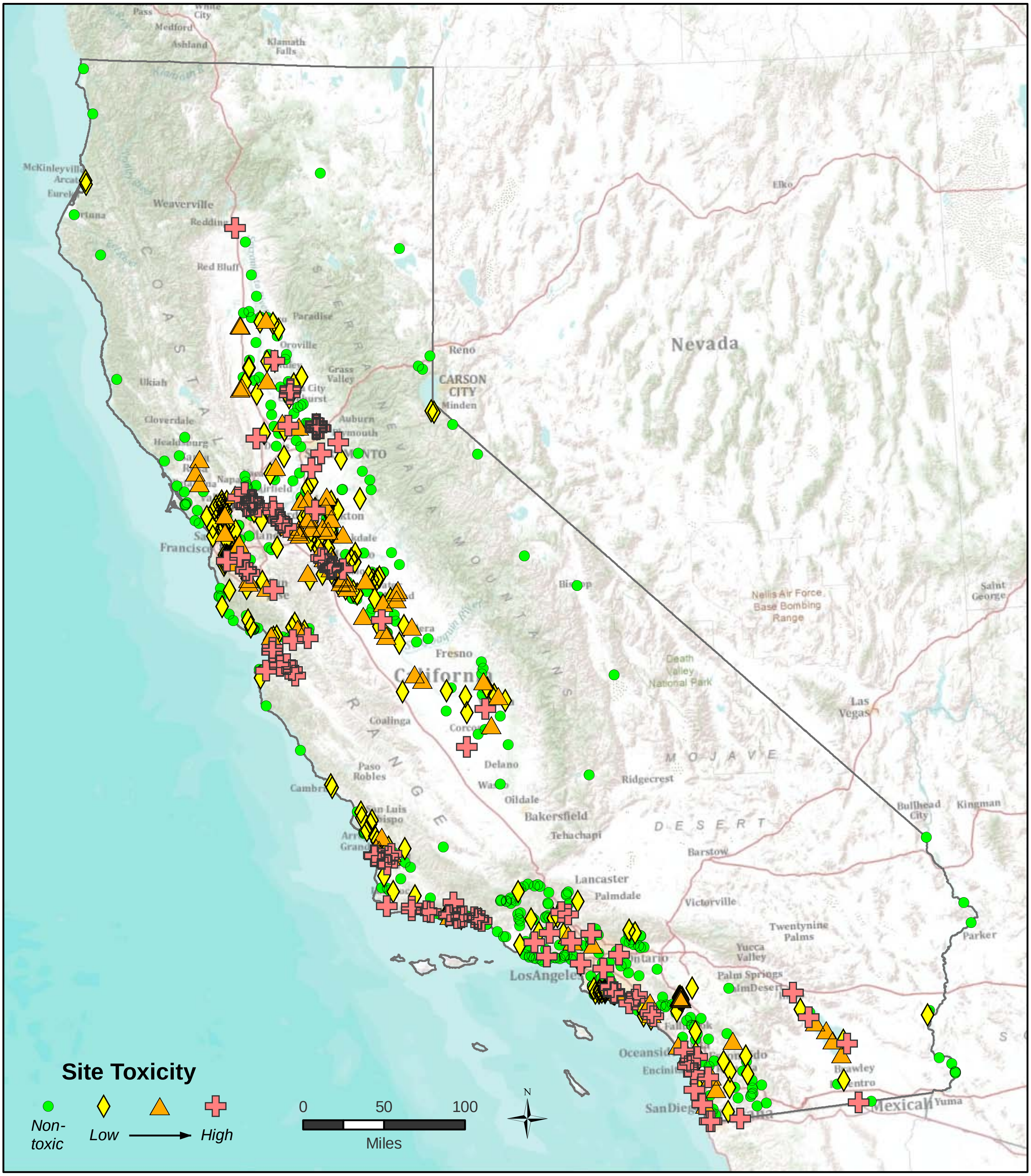


Figure 1. Magnitude of toxicity at all California sites assessed, based on the most sensitive species (test endpoint) in either water or sediment samples at each site.

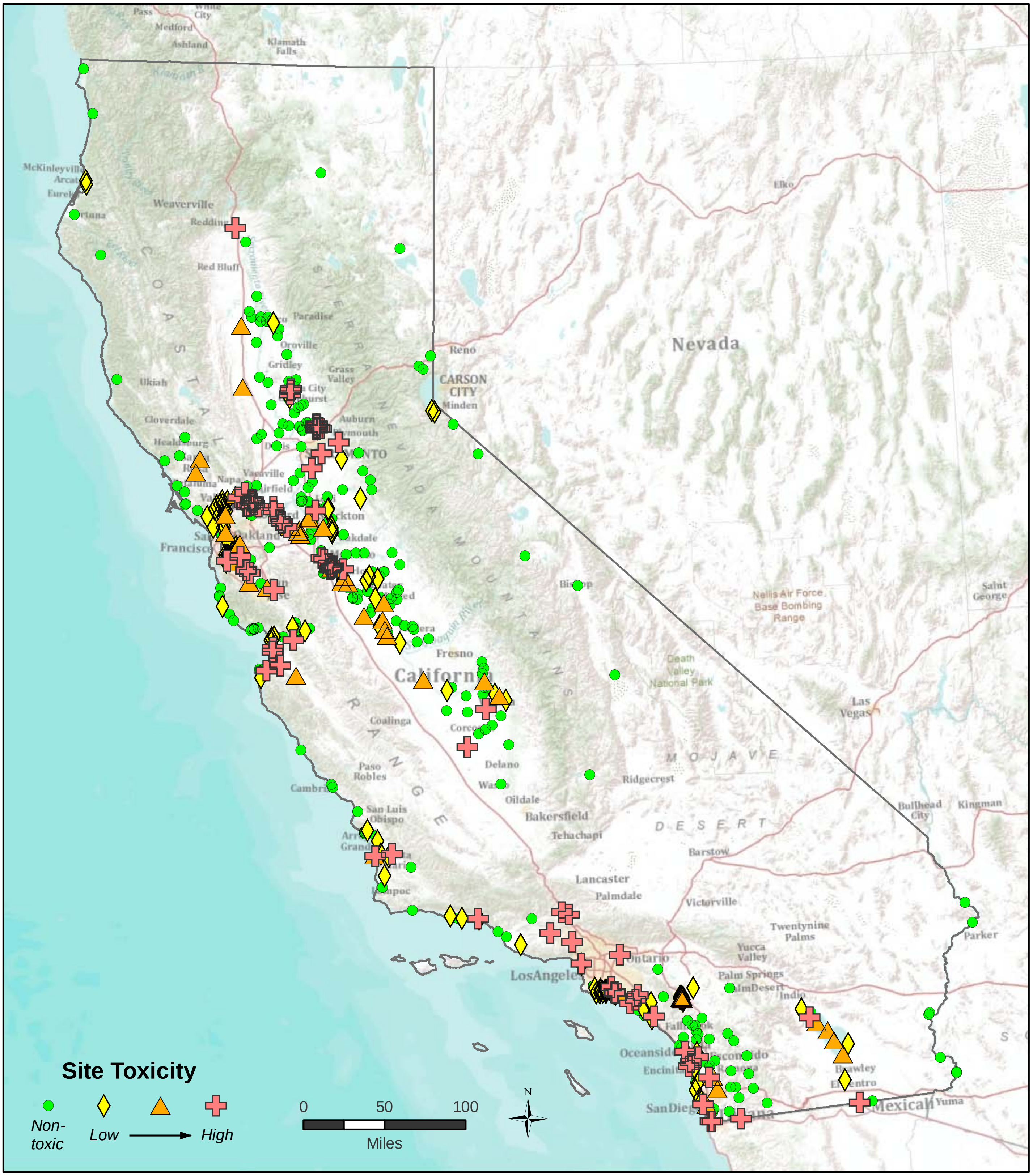


Figure 2. Magnitude of sediment toxicity at all California sites assessed, based on the most sensitive species (test endpoint) in sediment samples collected at each site.

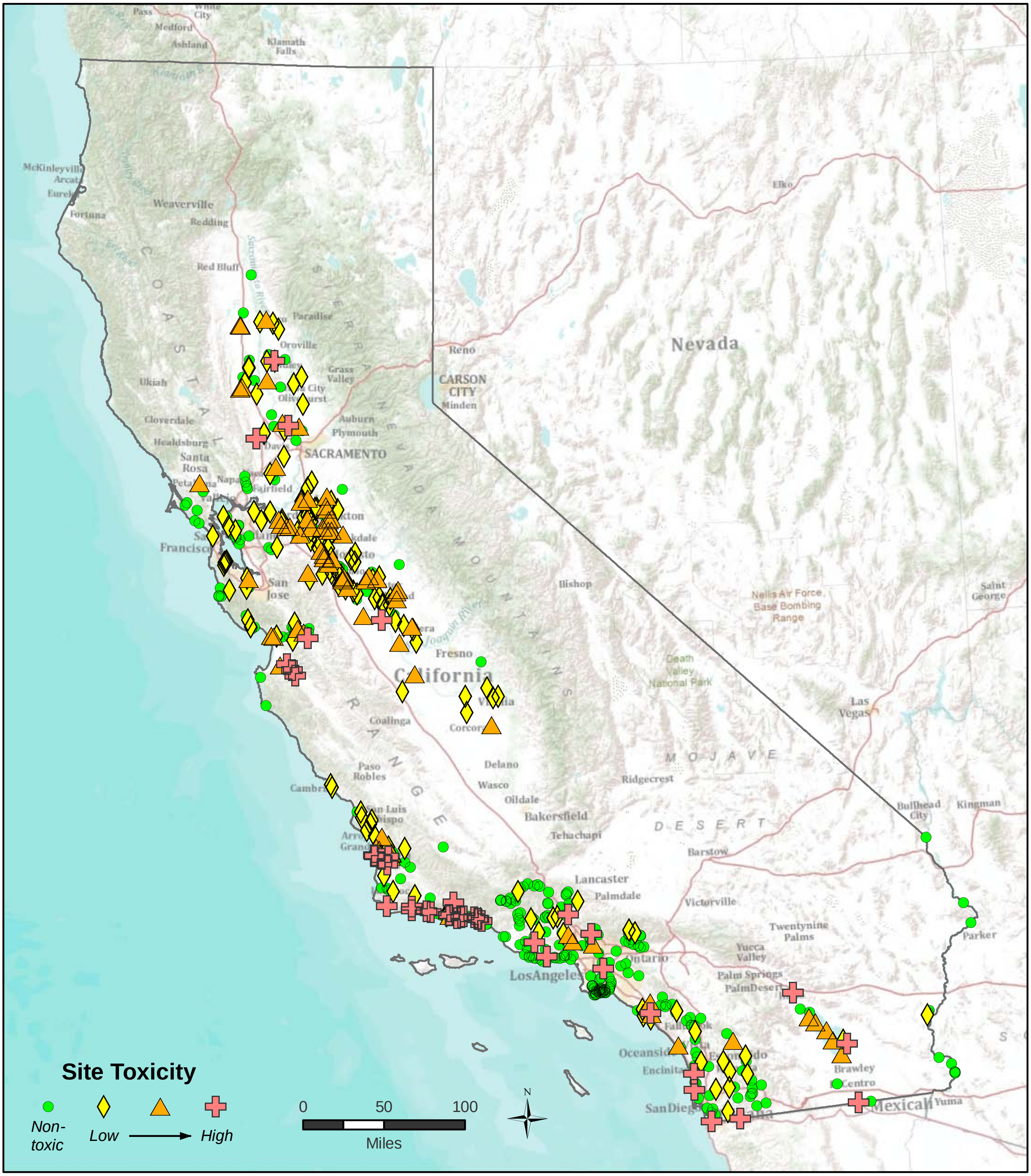


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Figure 3. Magnitude of water column toxicity at all California sites assessed, based on the most sensitive species (test endpoint) in water samples collected at each site.

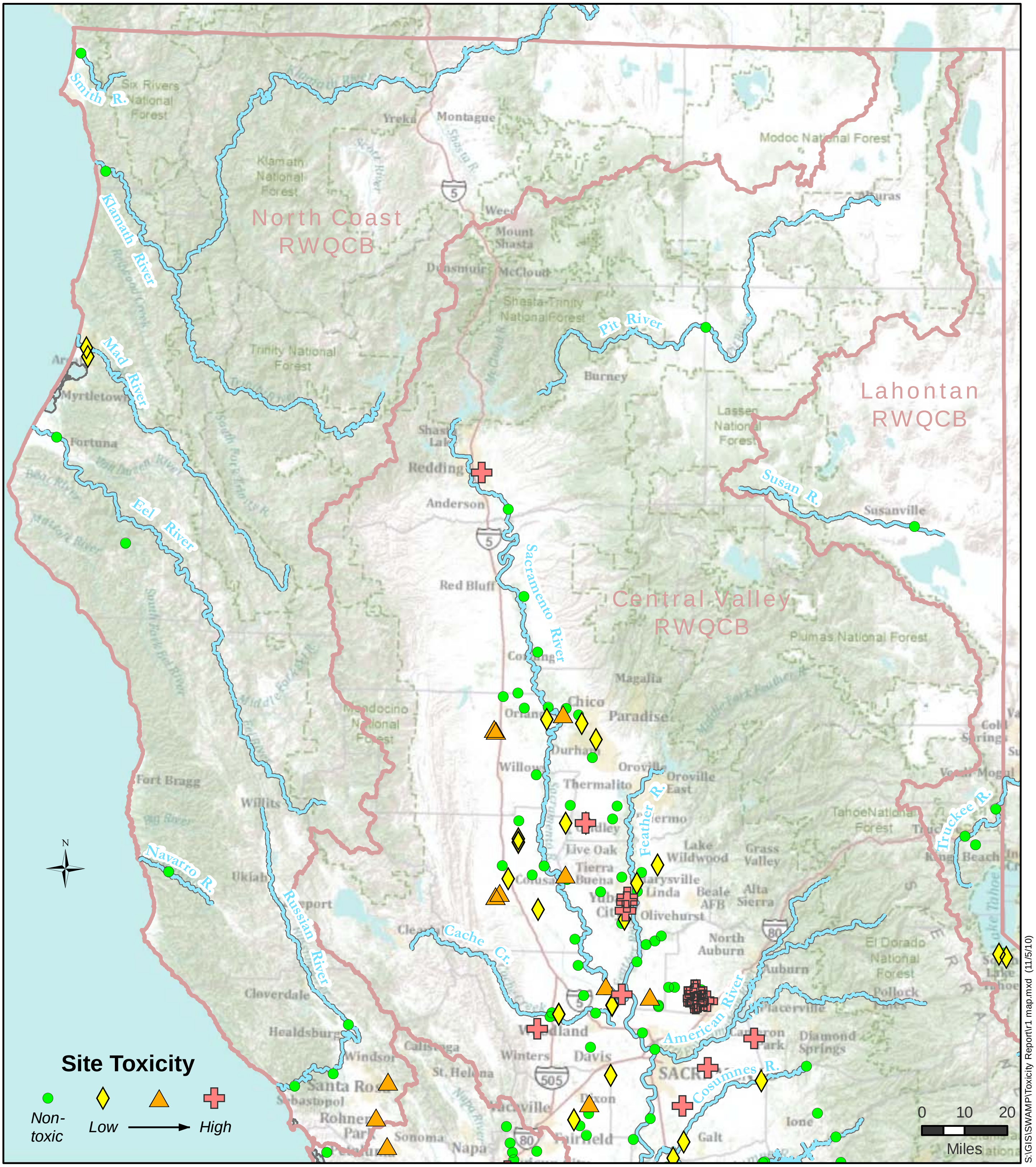

Figure 4. Magnitude of toxicity at sites in northern California, based on the most sensitive species (test endpoint) in either water or sediment samples at each site.

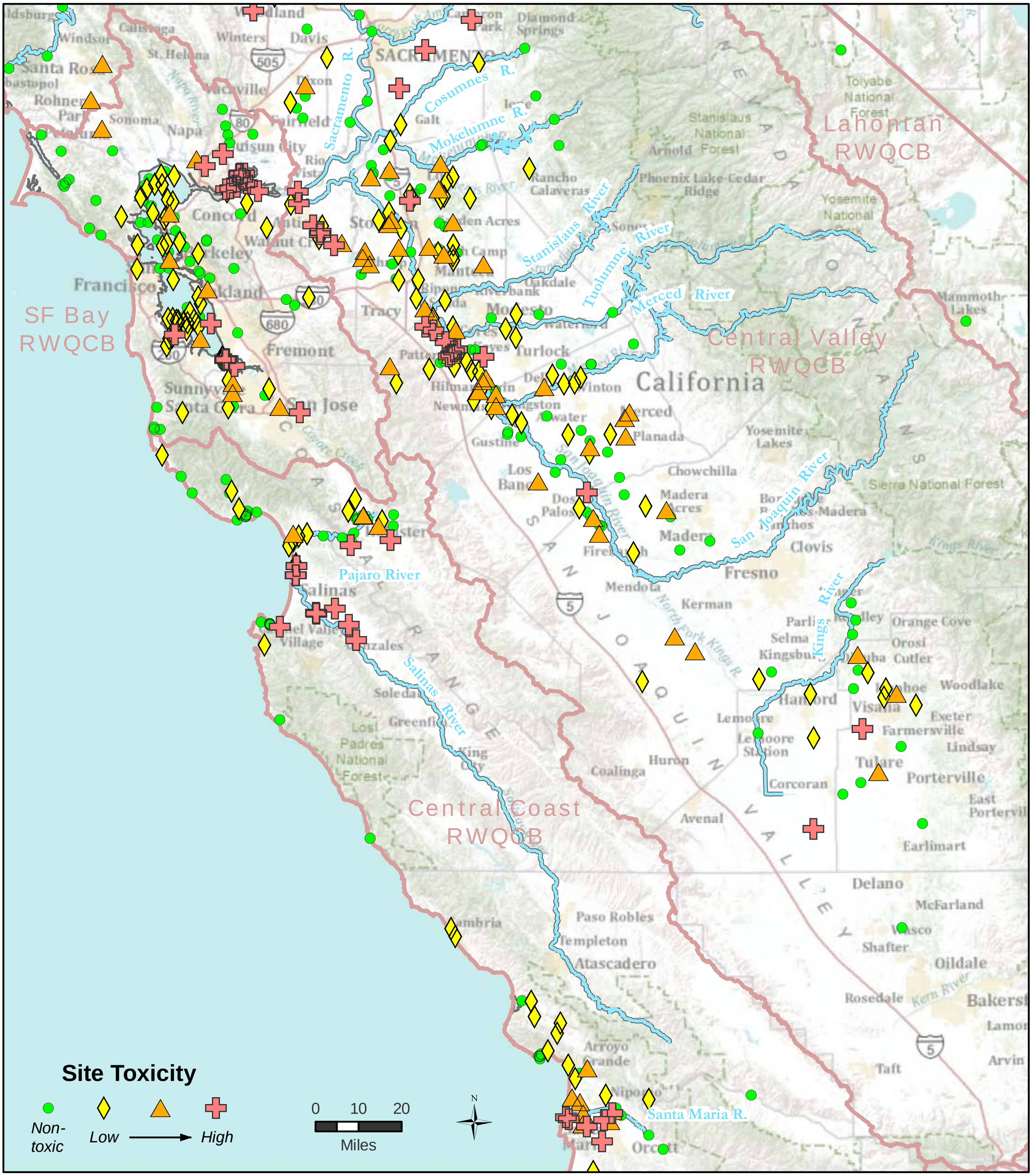

Figure 5. Magnitude of toxicity at sites in central California, based on the most sensitive species (test endpoint) in either water or sediment samples at each site.

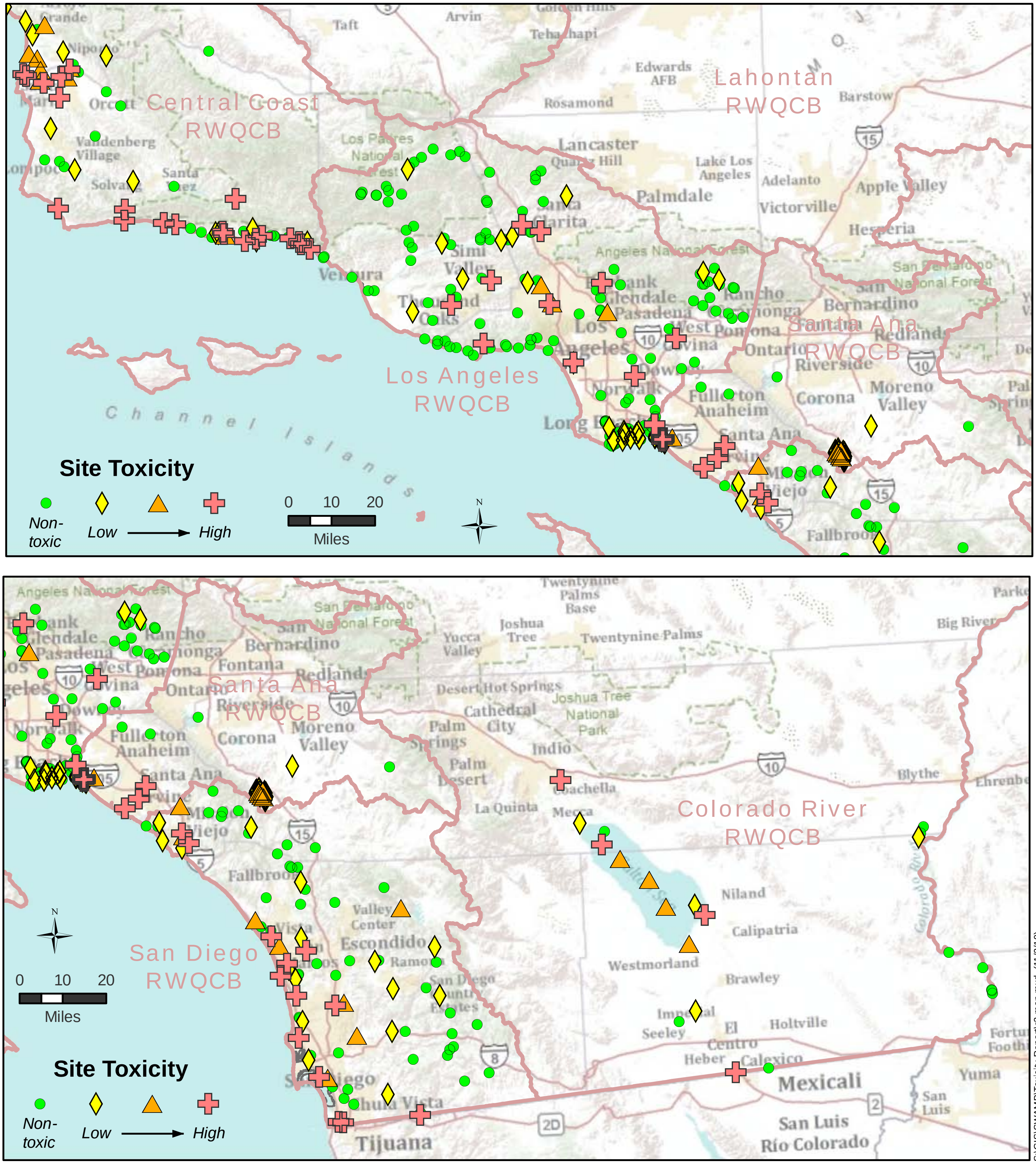

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Figure 6. Magnitude of toxicity at sites in southern California, based on the most sensitive species (test endpoint) in either water or sediment samples at each site.

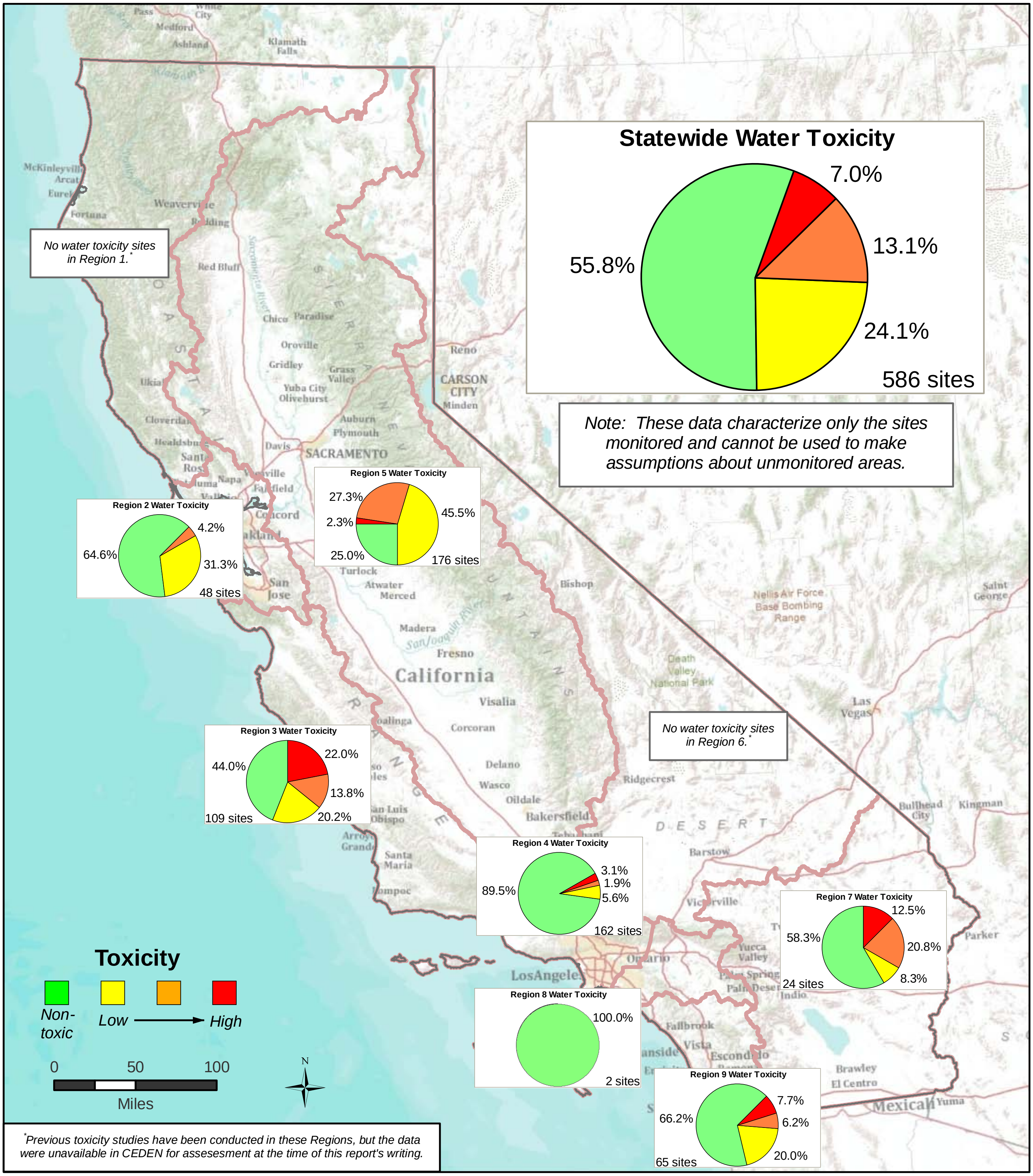

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Figure 7. Magnitude of toxicity in water statewide and by Regional Water Board. Color coding is as shown in Figure 11.

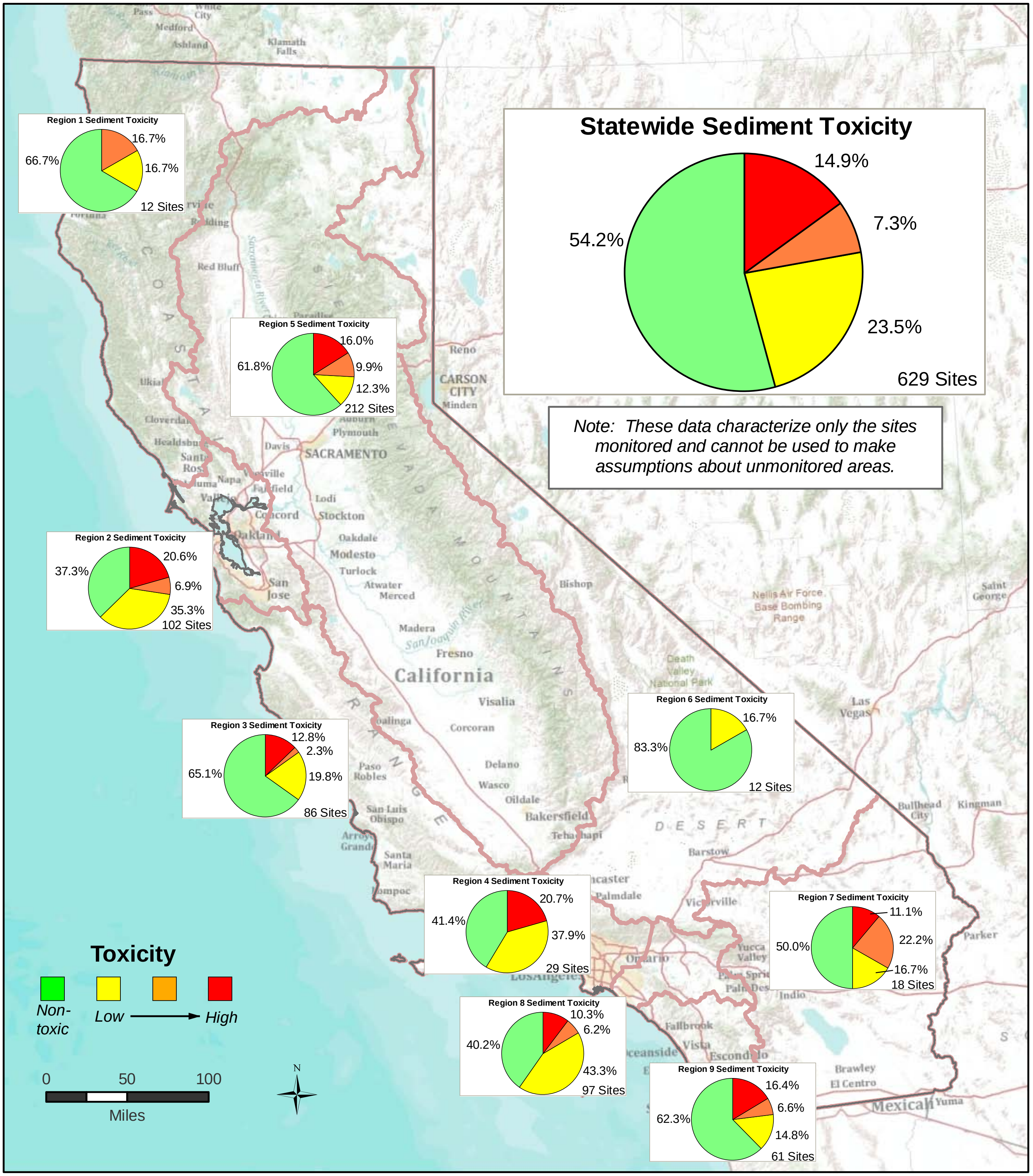

Figure 8. Magnitude of toxicity in sediment statewide and by Regional Water Board. Color coding is as shown in Figure 11.