ECOLOGICAL CONDITION ASSESSMENTS OF CALIFORNIA'S PERENNIAL WADEABLE STREAMS: Highlights from the Surface Water Ambient Monitoring Program's Perennial Streams Assessment (PSA) (2000-2007)

SWAMP
Surface Water Ambient Monitoring Program

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

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October 2011

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

RESOURCES AGENCY CALIFORNIA DEPARTMENT FISH & GAME

CALIFORNIA NPS PROGRAM

CALIFORNIA Water Boards

www.waterboards.ca.gov/swamp

THIS REPORT SHOULD BE CITED AS:

Ode, P.R.[1], T.M. Kincaid[2], T. Fleming[3] and A.C. Rehn 9. 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.

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ACKNOWLEDGEMENTS

This report is the culmination of a five-year collaborative monitoring project involving the California Monitoring and Assessment Program (CMAP), the State Water Resources Control Board Non-Point Source Pollution Control (NPS) and Surface Water Ambient Monitoring Program (SWAMP) and the US EPA's Region IX Office of Water (Terrence Fleming) and Non-Point Source (Sam Ziegler) programs and the California Department of Fish and Game's (CDFG) Aquatic Bioassessment Laboratory. The project was funded under Agreement Number 03-273-250-0 and managed by Melenee Emanuel of the NPS Program.

The assessments presented here are, in part, products of data collected under the EPA's Environmental Monitoring and Assessment Program Western Pilot (WEMAP), which provided financial and technical support to the California Department of Fish and Game under a Cooperative Agreement with the EPA's Office of Research and Development. This report was developed, in part, under Assistance Agreement No. CR82823801 awarded by the U.S. Environmental Protection Agency. It has not been formally reviewed by EPA. The views expressed in this document are solely those of the Aquatic Bioassessment Laboratory and EPA does not endorse any products or commercial services mentioned in this publication.

These analyses were based on methodologies developed by the US EPA's Office of Research and Development (ORD) for its EMAP program. We are especially indebted to Tony Olsen for help developing and interpreting the output. Development of the California Observed/Expected (O/E) predictive model by Chuck Hawkins of Utah State University was funded in part by the Pacific Southwest Region of the USDA Forest Service (Cooperative Agreement #PSW-88-0011CA, Cost Reimbursable Agreement # 03-CR-11052007-100, and Contract # 53-9A63-00-1T52). Will Patterson (California Department of Fish and Game, Information Technology Branch) and the California State University, Chico Geographic Information Center provided assistance with GIS analytical tools. Finally, the project owes much of its success to the efforts of staff at CDFG's Aquatic Bioassessment Laboratory (ABL): James Harrington, Shawn McBride, Jennifer York, Dan Pickard, Doug Post, Brady Richards, John Sandberg, Glenn Sibbald and Joe Slusark. Photograph of heptageniid mayfly on front cover included courtesy of the North American Benthological Society.

Special thanks to Patricia Spindler of the Arizona Department of Environmental Quality and Karen Vargas of the Nevada Department of Wildlife for their detailed and helpful reviews.

LIST OF ACRONYMS LOA

Acronyms - Clarification

ABL - Aquatic Bioassessment Laboratory
1k - 1 kilometer scale
5k - 5 kilometer scale
AG + URB Index - Agricultural + Urban index
AGRIC - Agricultural Land Use
ALU - Aquatic Life Use
ATtILA - Analytical Tools Interface for Landscape Assessments (Arcview)
BMI - Benthic Macro-invertebrate Index
CDFG - California Department of Fish and Game
CDFs - Cumulative Distribution Functions
CMAP - California Monitoring and Assessment Program
CRAM - California Rapid Assessment Methodology
CV - Central Valley
DFG - Department of Fish and Game
EMAP - EPA's Environmental Monitoring and Assessment Program
EMAP-West - Western Environmental Monitoring and Assessment Program (EPA program)
GRTS - Generalized Random Tessellation Stratified (design)
IMPERV - Impervious Surface
LCC - Land cover Cascade
LD - Denial of Landowner Access Log
PPT - Log Mean Monthly Precipitation Values
MMI - Multi metric Index
NHD+ - National Hydrography Database Plus
NLCD - National Land Cover Data set
NPS - Non-Point Source Pollution Control
NT - Non-Target
O/E - Observed/Expected predictive model
OCC - Oregon Climate Center
ORD - US EPA's Office of Research and Development
OTUs - Operational Taxonomic Names
PB - Permanent Barriers
PSA - Perennial Streams Assessment
RCMP - Reference Condition Monitoring Program
RIVPACS - River Invertebrate Prediction and Classification System

LIST OF ACRONYMS LOA

Acronyms - Clarification

RWB - Reachwide Composite Sample (a BMI sample)
RWB - Reach Wide Bethos
SAFIT - Southwest Association of Freshwater Invertebrate Taxonomists
SMC - Stormwater Monitoring Coalition
SWAMP - Surface Water Ambient Monitoring Program
TNS - Target Not Sampled
TRB - Targeted Riffle Sample (a BMI sample)
TRC - Targeted Riffle Composite
TS - Target Sampled
URBAN - Urban Land Use
USGS - United States Geographical Survey
WEMAP - EPA's Environmental Monitoring and Assessment Program Western Pilot
WPCL - CDFG Water Pollution Control Laboratory (in Rancho Cordova)

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EXECUTIVE SUMMARY ES

California's resource agencies have recently intensified the coordination of aquatic resource monitoring among their various programs. To guide efficient coordination, these agencies need tools that can clarify the relationships between land use activities and beneficial uses in different regions of the state. The State Water Resources Control Board (State Water Board) has invested in two such tools that together have the potential to transform the way water quality monitoring programs are organized and provide the foundation for improved monitoring efficiency: probability surveys and biological endpoints.

Since 2000, California has conducted three successive probability surveys of its perennial streams and rivers, each with a focus on biological endpoints. These surveys are now combined and are managed collectively by the Surface Water Ambient Monitoring Program (SWAMP) under its Perennial Streams Assessment (PSA) program. In 2010, SWAMP's Perennial Streams Assessment (PSA) conducted the State Water Board's eleventh continuous year of probability monitoring of perennial, wadeable streams. To date, the program has collected biological data (invertebrates, algae) and associated chemical and habitat data from approximately 850 probabilistic sites statewide. These surveys have produced a wealth of data that can and should be used to inform many decisions made by California's water resource agencies. For example, the assessments in the 2006 California Water Quality Assessment Report (Clean Water Act Section 305(b) Report) were based in large part on data from these surveys. Data from these surveys were also used in the development of the 2010 Integrated Report.

This report highlights some of the most significant results from the first eight years of PSA and demonstrates some ways that these data can go beyond 305(b) and 303(d) applications to improve California's water quality programs. The results presented in this summary represent just a fraction of the potential uses of data generated by these ongoing surveys. As the data set becomes more robust, it will continue to support multiple uses for years to come.

This report is organized around four questions that were used to frame management objectives for the State Water Board's Non-Point Source Program (NPS), a major partner in PSA's development:

1. What is the condition of California's streams?
2. Is stream condition changing over time?
3. What is the relative condition of streams draining agricultural, urban and forested regions?
4. Which stressors have the strongest associations with biological condition?

Future SWAMP reports will highlight the application of PSA data to various State Water Board water quality programs, including links to regional monitoring objectives.

MAJOR SURVEY FINDINGS

What is the condition of California's perennial streams?

- Approximately 50% (+/- 4%) of California's total stream length appears to be in good biological condition. Of the other 50%, approximately 27% is in degraded condition and 23% is in very degraded condition.
- All regions of the state have streams in good biological condition except the Central Valley. All areas of the state have streams with degraded biology, but the percentage of degraded streams is highest in the Central Valley and Chaparral regions (foothills of the Sierra Nevada and Coast Ranges).

Is stream condition changing over time?

- We observed no detectable change in the biological condition of California's perennial streams during the short timeframe of this survey. These results will serve as a baseline for measuring future change in condition.

What is the condition of streams draining different land use types?

- 100% of streams draining agricultural and urban landscapes sampled in this survey had degraded or very degraded biological condition. About 30% of streams draining forested landscapes had degraded biological condition.

Which stressors have the biggest impact on biological condition?

- Benthic invertebrates have strong associations with several stressors that are high priorities for California's water quality programs (esp. nutrients, fine sediments and chloride), making them an effective endpoint for relating stressors to aquatic life beneficial uses.
- Instream habitat condition (fine sediments, embeddedness, habitat complexity) was consistently one of the strongest drivers of the biological condition of California's streams, and had a much stronger influence on biological condition than riparian condition.
- Instream habitat degradation and nutrient stressors were pervasive in agricultural and urban streams, but were also present at a large percentage of forested streams statewide. These stressors were strongly associated with decreased biological integrity.

RECOMMENDATIONS FOR MANAGEMENT

- The California Water Quality Monitoring Council (CWQMC) should leverage Perennial Stream Assessment (PSA) surveys to enhance coordination of monitoring across state agencies and across Water Board programs. The CWQMC should promote partnerships between the State Water Board and other entities to enhance coordination of monitoring across the state.

- Results of the PSA probability-based surveys, in context with reference condition distributions can and should be integrated into a variety of Water Board programs and used for quantitative interpretation of regional narrative objectives for a variety of potential stressors (e.g.: nutrients, fine sediment, water chemistry, etc.).

- The Water Boards need additional regulatory tools to protect streams. Most of the stream degradation identified by the PSA appears to be related to water quality factors and habitat quality issues that are not addressed well by traditional water quality programs.

- The Healthy Streams Partnership, being led by SWAMP for the California Water Quality Monitoring Council, should form the framework for a coordinated statewide approach to assessing and protecting all the stream resources of the State including non-perennial streams.

- The California Water Quality Monitoring Council should provide a forum for coordinating GIS stewardship activities statewide to improve the accuracy of perennial and non-perennial flow status designations in GIS layers of California's stream network.

- The State Water Board should invest in tools to determine sources and causes of biological impairment.

- The State Water Board should continue to investigate the use of biology-based stressor thresholds as an objective means to set meaningful, regionally-appropriate water quality standards.

- The use of biologically derived stressor thresholds should be expanded to include additional indicator groups such as fish, algae and riparian vegetation.

- The California Department of Fish and Game (CDFG) Water Branch should use information from the Perennial Streams Assessment (PSA) program to support the CDFG's mission in several areas. These include enforcement and compliance monitoring; streambed alteration agreements; instream flow; and FERC re-licensing. PSA information should also be used to measure the success of DFG restoration and protection programs.

- The State Water Board should encourage the evaluation of development impacts on stream networks on a watershed-wide basis. Development in upstream non-perennial streams can have significant impacts in downstream perennial streams.

- The State Water Board should strengthen the protection of non-perennial streams through the Wetlands and Riparian Area Protection Policy by defining beneficial uses related to riparian area water quality functions (e.g. shading).

- Statewide probability-based surveys should be used as a foundation for prioritizing monitoring, remediation, and protection efforts.

- The assessment tools developed by the SWAMP Bioassessment Program should be used to measure the performance and success of restoration and protection programs implemented by the Water Boards, Department of Fish and Game, and others.

SECTION 1
INTRODUCTION

Streams and rivers are one of California's greatest resources, providing critical economic, recreational, cultural and ecological benefits. Accordingly, these waterbodies have been the target of many federal and state protection and remediation programs since the late 1960s (USEPA 1992, 1996, 2002, Karr and Yoder 2004).

The struggle to adequately protect and restore flowing waters with limited financial resources is a challenge faced by water resource agencies worldwide (Karr and Yoder 2004, Novotny et al. 2004, Lindenmayer et al. 2008, Southerland et al. 2008). Many programs met with early success in reducing point source impacts, but much more intractable non-point source (NPS) problems have stymied programs for decades. To guide efficient coordination among California's resource agencies, these agencies need tools that provide a broad overview of relationships between land use activities and beneficial uses (Karr and Yoder 2004, Maxted et al. 2007).

Two major advances in water quality science have the potential to transform the way water quality programs are organized: probability surveys and biological endpoints.

In **probability survey designs**, sampling locations are randomly selected and represent a known proportion of the total resource of interest (e.g., percent of total stream length) with known statistical confidence. These designs permit the inference of resource conditions for large geographic regions with a relatively small investment in sampling (Ringold et al. 1996, Olsen et al. 1999, Stevens and Olsen 2004). Their products establish an objective context for interpreting targeted monitoring data and facilitate inter-regional comparisons, thus providing critical perspective and a sound foundation for monitoring programs (Stevens and Olsen 2004, Southerland et al. 2008). These designs are now used widely throughout the US[4] and serve as the basis for national condition assessments for several major waterbody types (e.g., coastal waters, lakes, streams and rivers, wetlands).

Biological condition indicators (e.g., fish, algae, invertebrates) are increasingly preferred as ecological assessment endpoints because they provide direct measures of the status of aquatic life beneficial uses, which are frequently the ultimate target of protection (Karr and Yoder 2004). In contrast, chemistry or toxicity-based surrogates require indirect inference to relate the data to the ultimate management objectives. Furthermore, biological integrity is often impaired by factors other than chemical contamination (e.g., hydrologic alteration, instream and riparian habitat alteration). Ecological indicators have the added advantage of integrating condition over space and time, thus providing a more comprehensive assessment

4. Approximately two thirds of US states are currently using probability surveys for some aspect of their aquatic resource monitoring and many of these (~15) are using probability surveys to support statewide stream condition estimates (Tony Olsen, personal communication).

than traditional indicators, which reflect conditions at a single point in time (Karr and Chu 1999, Sponseller et al. 2001). Although aquatic life is just one of the many beneficial uses of streams, support of aquatic life use is a key indicator of the overall integrity of flowing water ecosystems and the landscapes they drain (Karr and Yoder 2004).

HISTORY OF CALIFORNIA'S STATEWIDE PROBABILITY SURVEYS

Several regional probability surveys have been conducted in California, but before 2000, no attempt had been made to conduct a status and trends survey of the state's entire stream population. Since 2000, California has conducted three successive probability surveys of its perennial streams and rivers, each with a primary focus on biological endpoints. The US EPA's Environmental Monitoring and Assessment Program (EMAP) provided California with a foundation of four years (2000-2003, approximately 200 sites) of probability-based stream condition data with its Western Pilot Monitoring Program (EMAP-West)[5]. While EMAP-West was nearing completion, two State Water Board programs, the Surface Water Ambient Monitoring Program (SWAMP) and the Non-Point Source Implementation Program (NPS) collaborated with their counterparts in the US EPA Region IX to develop the California Monitoring and Assessment Program (CMAP). CMAP produced four additional years (2004-2007, approximately 200 sites) of data.

In 2008, the SWAMP program built upon these two previous surveys (EMAP and CMAP) to develop its ongoing Perennial Streams Assessment Program (PSA). These surveys are now combined and are managed collectively by the Surface Water Ambient Monitoring Program (SWAMP) under its Perennial Streams Assessment (PSA) program. In 2010, SWAMP's Perennial Streams Assessment (PSA) conducted the State Water Board's 11th continuous year of probability monitoring.[6] To date, the program has collected biological data (invertebrates, algae[7]) and associated chemical and habitat data from ~850 sites statewide.[8]

Over time, the State's probability surveys have evolved to improve assessment accuracy and increase the number of program objectives they can address. The CMAP program added the ability to identify patterns in stressor-biology relationships related to major land use categories. The new PSA program has increased the ability of the surveys to produce regional survey products, has enhanced the suite of stressor variables measured at sites, and has added additional ecological condition indicators (enhanced algal indicators, wetland condition measure using California Rapid Assessment Methodology (CRAM)). The PSA enhancements are expected to continue to improve the overall accuracy and utility of assessments.

5. California continues to collaborate with the EPA's national monitoring surveys, which conduct probabilistic sampling of streams and rivers every few years. The most recent round of sampling for the EPA's National Rivers and Streams Assessment produced data from approximately 45 sites in 2008-2009.
6. In 2009, SWAMP began coordinating with the Stormwater Monitoring Coalition to integrate the SMC's new probability survey with the PSA. The SMC encompasses the boundaries of Regional Water Boards 4, 8 and 9 (referred to as "South Coast" here). The SMC program currently samples approximately 90 sites per year.
7. Although benthic algal assemblages have been collected under all the statewide surveys (either diatoms or diatoms and soft algae), these results are not yet incorporated into the PSA reporting. Current efforts are underway to develop the capacity to produce algae based condition scores.
8. The Department of Fish and Game's Aquatic Bioassessment Laboratory (ABL) has been a primary collaborator on all of these projects, conducting the majority of the field, laboratory and analytical work.

THE NON-POINT SOURCE (NPS) PROGRAM QUESTIONS

During the design phase of the CMAP program, the development group focused on key monitoring objectives for the study. The NPS program identified six questions that defined the overall mission for its NPS activities in California:

- What is the condition of California's streams?
- Is stream condition changing over time?
- What is the condition of streams draining different land use types?
- Which stressors have the biggest impact on biological condition?
- Is the California NPS program investing resources consistent with water quality problems?
- Are NPS investments effective in protecting and restoring water quality?

Probability surveys are essential for objective answers to several of these questions and provide supporting information for others.

This report presents the results of the first eight years of California's probability surveys of the ecological condition of perennial streams (the EMAP and CMAP data, see sites in Figure 1). The report is organized into six sections representing the six questions. This report is focused on the first four questions, which can be addressed directly with PSA survey data. Each section presents the major findings of these surveys with a focus on their implications for California's water quality programs. Methodological detail and additional results are presented in a set of appendices.

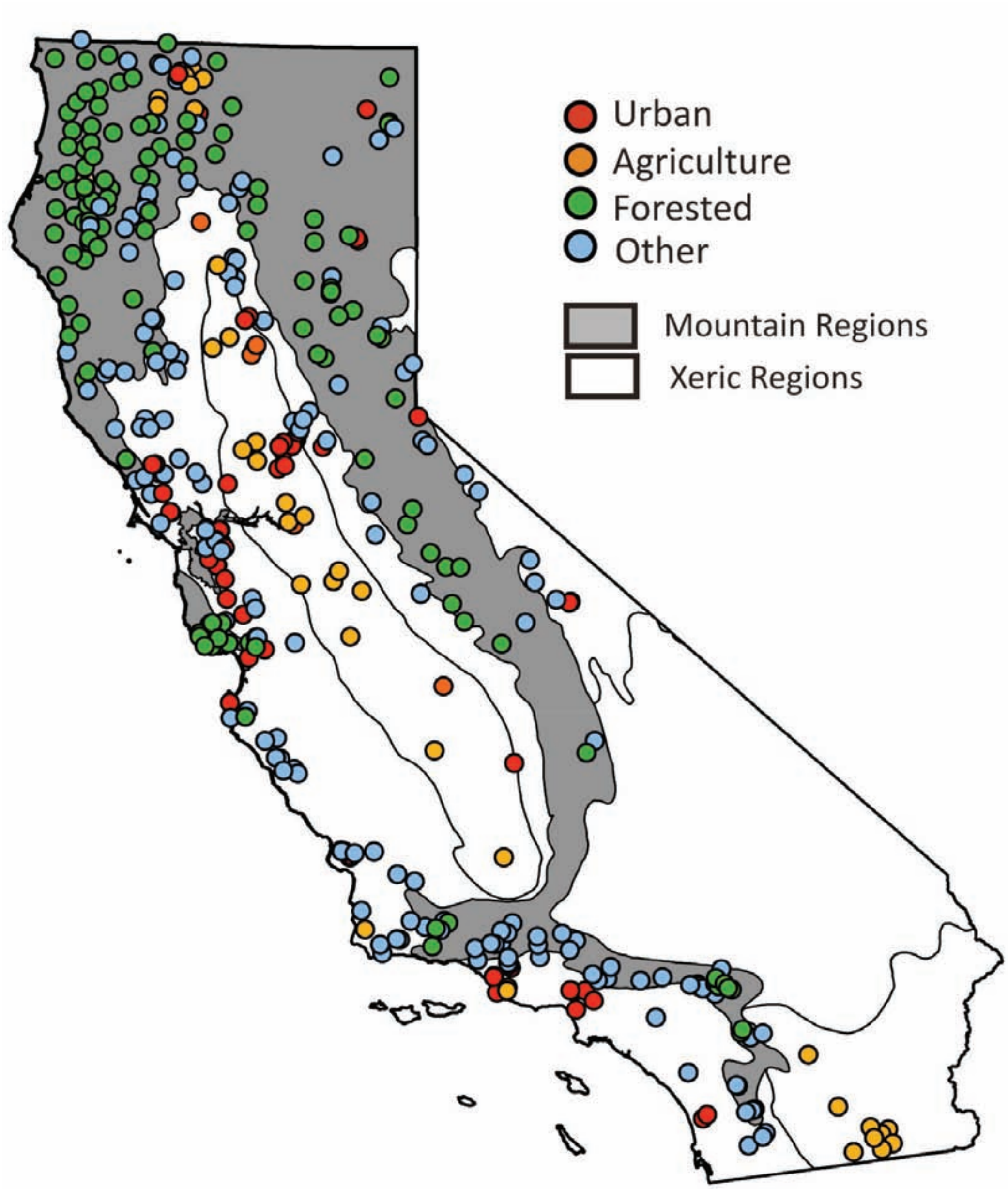


Figure 1. The distribution of sites sampled under Perennial Streams Assessment (PSA) Program between 2000 and 2007, coded by land use designation. Xeric = dry region.

SECTION 2
STATE OF WATER QUALITY
What is the condition of California's streams?

This section is organized in three sub-sections emphasizing different aspects of stream condition: A) Resource extent estimates summarize report findings about the extent and distribution of perennial and non-perennial streams in California, B) Condition assessments summarize biological condition findings and C) Stressor extent summarizes the findings about the prevalence of several stressors that have potential impacts to aquatic life.

A. RESOURCE EXTENT ESTIMATES

The exact sizes of the California's stream network and its perennial and non-perennial components are unknown and challenging to measure. This problem is especially acute in arid regions. However, flow status often has important regulatory implications (e.g., which segments are subject to various regulatory requirements), so there is a clear need for accurate estimates. Probability surveys provide a means to calculate independent, field-based estimates of perennial and non-perennial stream length.

We calculated statewide estimates, regional estimates (based on regional boundaries used in the PSA survey design, Figure 2) and estimates for each of the four land use categories using NHD+ hydrology[9] and reconnaissance data from our surveys Appendix E (Tables E-3 and E-4). Estimates of the percentage of stream length and total stream length represented by different reconnaissance outcomes (whether candidate sites were sampled or not) are presented in Appendix E (Tables E-1, E-2). Percentages for the eight-year averages are presented in Appendix D (Figure D-3).

Statewide Extent Estimates

The total length of California's stream network is defined by NHD+ as 327,963 km. About 15% of this network consists of pipelines, ditches, canals, coastline, and artificial paths or reflects mapping errors (~48,000 km). The remaining network of streams and rivers is approximately 280,000 km.

The majority of California's stream network is non-perennial (~206,000 km, 73%). The total perennial stream length in California is estimated to be 74,000 km (27%). Non-wadeable (i.e., large) rivers comprise

9. NHD+ is an EPA-modified version of the National Hydrography Database (NHD).

about 7,000 km of the perennial length. Thus, there are approximately 67,000 km of perennial, wadeable streams in California (Figure 3, Appendix E)[10]. The results presented in this report are based on the 67,000 km perennial stream network.

Regional Extent Estimates (PSA Regions)

The geographic regions used for SWAMP's PSA surveys are illustrated in Figure 2.[11] As with the statewide results, the total stream length in each region was derived directly from the NHD+ hydrology, but the relative proportions of perennial and non-perennial streams were estimated from the survey. For comparison, values defined by the NHD+ layers are in Appendix D (Table D-3).

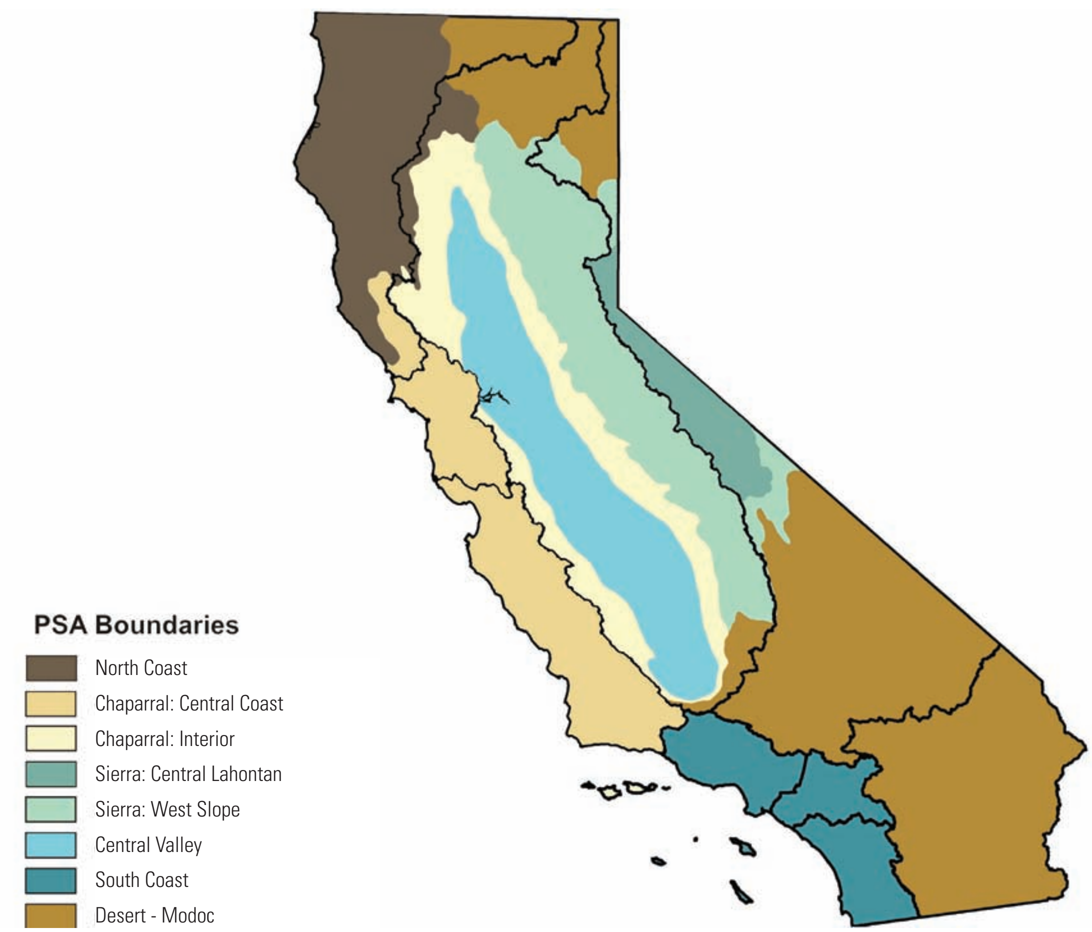


Figure 2. Boundaries of the eight major Perennial Streams Assessment (PSA) subdivisions used in surveys. Black lines correspond to regional water board boundaries. The sub-regions of the Chaparral and Sierra regions were combined for summary analyses in this report.

10. We use the term non-perennial to designate all channels that have water for at least a few days of the year, but less than year-round (this definition includes both "intermittent" and "ephemeral" streams).
11. The PSA boundaries divide the state into reporting regions based primarily on ecological similarity, but the boundary lines were adjusted in some places to coincide with major program boundaries (e.g., South Coast).

The majority (~65%) of the perennial stream length in California drains two PSA regions (North Coast and Sierra Nevada). All regions of the state have a large proportion of non-perennial stream length (Figure 3); at least a third of the total stream length in California and as much as 80-90% of total stream length in arid regions of the state is non-perennial (e.g., Chaparral and Desert-Modoc). The South Coast and Central Valley regions were the only arid regions that had a large proportion of perennial stream length. In the South Coast, this finding reflects a high proportion of perennial stream length in the mountainous portions of the region as well as the facts that: 1) many naturally non-perennial streams in this region are now perennial due to supplemental storm water flows and 2) much non-perennial stream length has been lost as hydrological complexity has been reduced by development. In the Central Valley, this reflects the large amount of supplemental flow from irrigation and the relative abundance of non-wadeable perennial rivers.[12]

Our survey-based estimates of the proportions of perennial and non-perennial streams often contrast strongly with those extracted from the NHD+ data set (Figure 3, Tables D1, D-3). The statewide proportions were similar (34% vs. 27% perennial), but the regional proportions varied greatly. The most extreme cases are the Central Valley and South Coast regions, where surveys found 5 to 6 times as many perennial streams as were coded in the NHD+ (69 and 62% perennial versus 17 and 9% perennial, respectively). A similar but less extreme pattern was seen in the Desert-Modoc regions. In contrast, our surveys estimated that there was 50% more non-perennial stream length in the North Coast region than indicated in the NHD+.

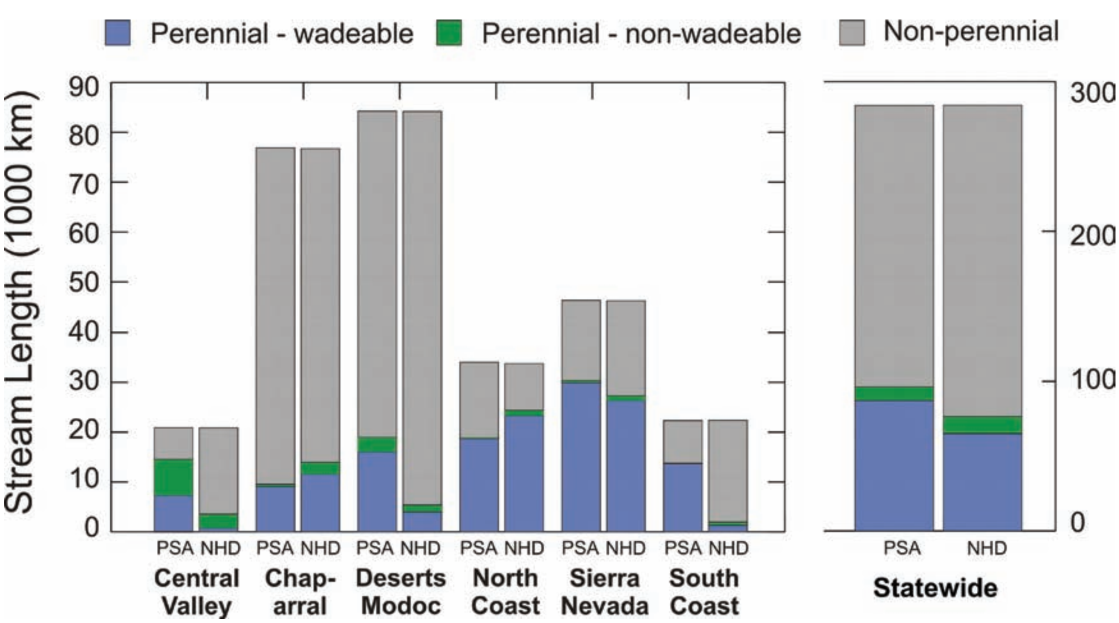


Figure 3. The length and relative proportion of perennial wadeable, perennial non-wadeable and non-perennial streams, in each of the six major Perennial Streams Assessment (PSA) regions. The first bar in each pair represents estimates generated from PSA (this study) and the other bar represents data derived from National Hydrology Database (NHD+). The heights of PSA bars were rescaled to match NHD totals for easier comparisons of flow classes.

12. The Central Valley's vast network of canals and ditches were intentionally excluded from this survey; these results apply to the region's natural channels.

Resource Extent Estimates: Implications

The large proportion of non-perennial stream length across all regions of California has significant implications for water quality monitoring in California. Although these ecosystems are non-perennial, they often support rich biotic communities both in the stream channels and in surrounding riparian zones. In addition, these streams collectively drain large areas of land, which can result in concentrated seasonal impacts from point and non-point pollution sources to downstream perennial flows. This issue is especially acute in arid regions of the state (e.g., Chaparral, South Coast, Desert-Modoc).

Despite the fact that non-perennial streams often comprise the majority of stream length and fall under the jurisdiction of the Water Boards under the Porter-Cologne Act, very few of California's monitoring resources are currently invested in non-perennial systems. Clearly, these habitats are strong candidates for increased monitoring and protection efforts.

B. CONDITION ASSESSMENTS

The primary goal of these surveys was to establish objective estimates of the ecological condition of California's wadeable perennial streams. We used the condition of benthic macroinvertebrate communities (BMI) as our measure of ecological condition. The following estimates summarize: 1) overall statewide condition, and 2) condition within each PSA region. Condition estimates for each of the NPS classes are presented in Section III. Hereafter, all statements about streams refer to wadeable, perennial streams unless otherwise specified.

Statewide Condition Assessments

Half of the stream length in California is in relatively good biological condition, while half has either degraded (~27%) or very degraded (23%) biological condition (Figure 5).[13,14] The overall proportion of stream length in the three condition classes for the eight-year data set (2000-2007) was similar to that reported for the first four years in 2005 (Ode and Rehn 2005) and the first six years (Ode 2007).[15]

Degraded sites were concentrated in urban (San Francisco Bay Area, southern coastal California) and agricultural areas (Imperial Valley, Central Valley, Klamath River). However, all regions contained streams in "good", "degraded", and "very degraded" biological condition (Figure 4).

Since the target status of 20% of total stream length could not be assessed (LD + PB + NS, Table E-1), we have presented the overall condition assessment in two alternative forms. Figure 5a displays the total

13. See Appendix C and Appendix D for an explanation of how impairment thresholds were determined
14. Although the term "impairment" is frequently used in bioassessment, we use the terms "degraded" and "very degraded" throughout this report to avoid confusion with the regulatory meaning of impairment.
15. See Appendix C for effects of scoring adjustments used in this and prior reports.

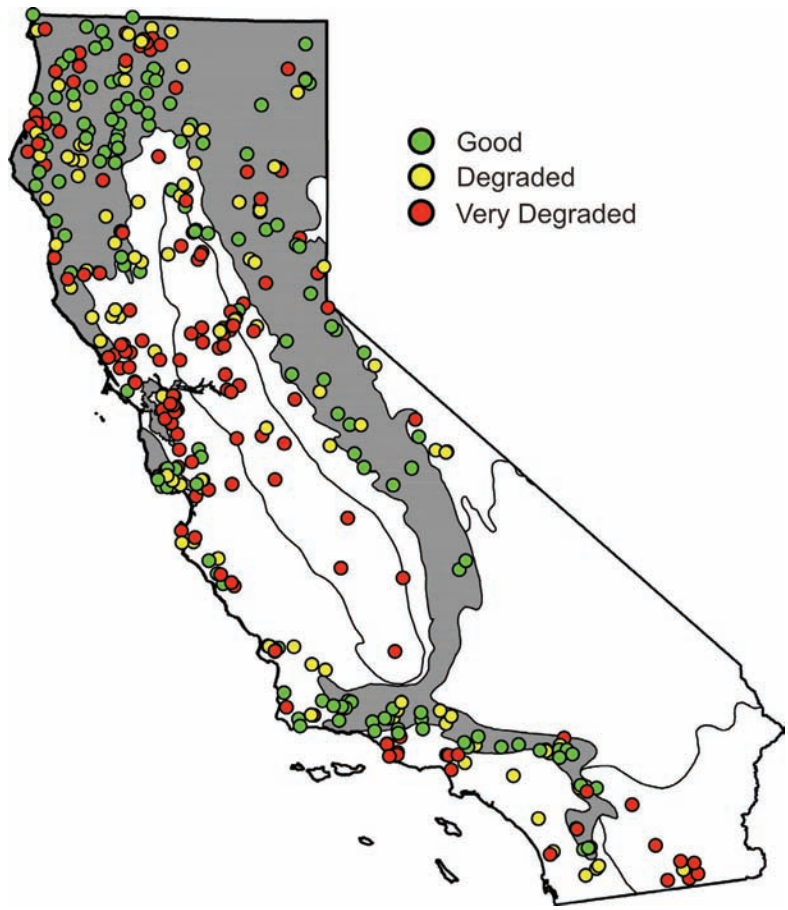


Figure 4. Distribution of survey sites coded by biological condition (green = good, yellow = degraded biology, red = very degraded biology).

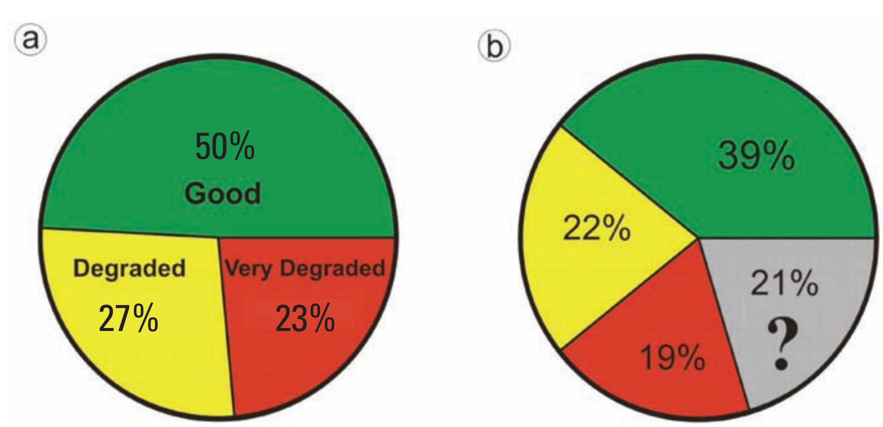


Figure 5. The percent of total stream length in different biological condition classes. Two presentation alternatives: a) with the proportion of unassessed stream length (reconnaissance fate codes LD, PB and NS) extrapolated from the sampled target site data (TS + TNS), b) with unassessed stream length left as a distinct category (adjusted for non-perennial stream length and represented here by a question mark).

stream length, with the unassessed stream length (reconnaissance fate codes LD, PB and NS) extrapolated from the sampled target site data (TS + TNS) while Figure 5b includes the unassessed stream length as a distinct category (represented by a question mark). The former presentation requires the assumption that the unassessed stream length has the same proportion of stream condition as the assessed stream length, while the latter makes no assumptions about this portion of the stream population.

Condition Assessments by PSA Region

As expected, biological condition of streams varied considerably among the PSA regions (Figures 6a, 6b). The heavily forested regions (North Coast and Sierra) had more streams in good condition (~70%) than the state as a whole (~50%), while the Central Valley (0%) and Chaparral (~35%) regions had fewer streams in good biological condition than the statewide average. Streams in the highly urbanized South Coast region were in much better condition than might be expected from the region's high degree of development. However, this is likely a reflection of the high proportion of stream length in higher elevation streams, which tend to drain less developed areas and still support intact invertebrate communities downstream.

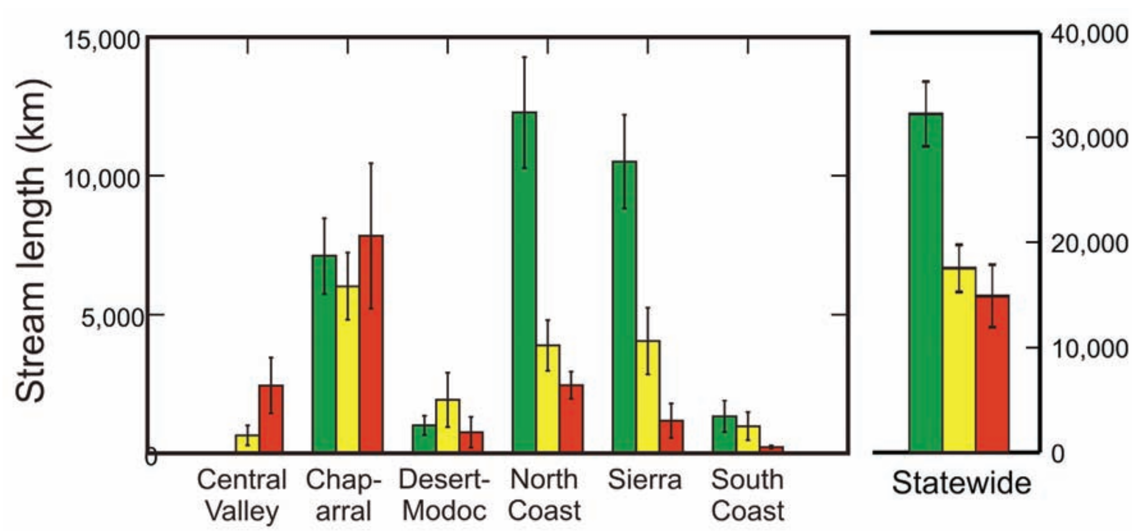


Figure 6a. Total stream length in each biological condition category (green = good, yellow = degraded, red = very degraded) statewide, and for each of the six major Perennial Streams Assessment (PSA) regions.

Condition Assessment Implications

The probability-based condition assessments produced from the EMAP and CMAP surveys are the first objective overviews of the biological condition of streams in California. The range of biological condition scores can now be compared among NPS categories and among major regions of the state. Thus, resource managers now have an objective tool for answering whether data from targeted monitoring sites represent above average, average or below average conditions for that region or land use/land cover category (for further discussion see Figure 10 and related text in the Stressor Extent Implications section). Prior to these surveys, managers relied on best professional judgment or data collected from (typically non-representative) targeted data sets. Accurate information about the expected range of conditions can now be used to help make more informed decisions about resource protection, including more efficient allocation of limited resources to monitoring, protection and remediation (e.g., prioritization of high quality streams).

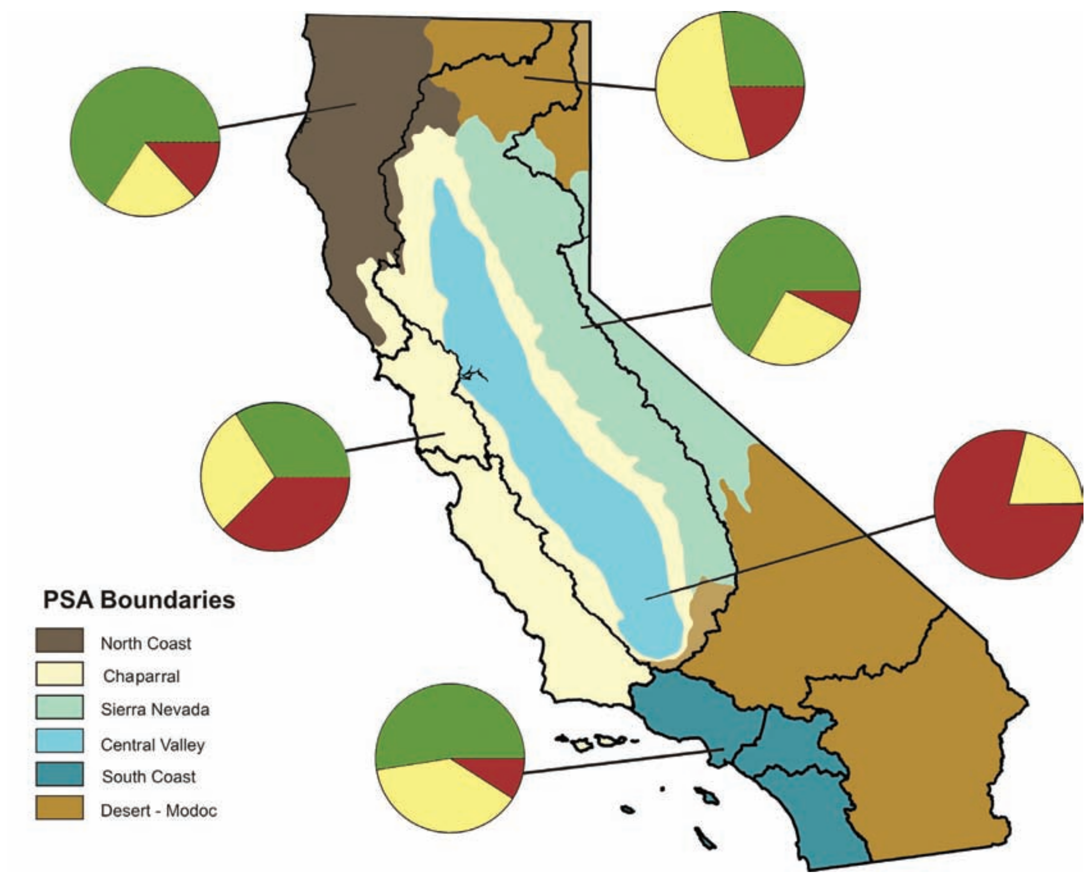


Figure 6b. The biological condition of wadeable perennial streams (pie charts: green = good, yellow = degraded, red = very degraded) in each of the six major Perennial Streams Assessment (PSA) regions in California.

C. STRESSOR EXTENT

Stressor Exceedance Thresholds

Probability surveys offer an objective tool for comparing the prevalence of various potential stressors (land cover, chemistry and habitat) present in California's streams. Chemical data and physical habitat measures were collected along with biological samples and landuse data were calculated from GIS layers during analysis (see Appendix A for methods). Moderate and severe degradation thresholds (listed in Appendix A-Table A-3) were used as the basis of the comparison shown in Figures 7a and 7b.

The majority of California's streams are experiencing instream habitat degradation. Moderate degradation thresholds for instream habitat, fine sediment and bed stability measures were exceeded in 40-65% of California's streams, and severe degradation thresholds for these habitat measures were exceeded in 20-40% of California streams. Riparian disturbances were common (40% of streams exceed moderate thresholds). Although riparian vegetative complexity was still a significant stressor, it was less often impaired than the other habitat measures (~25% of streams exceeded moderate thresholds).

Nutrients (nitrogen and phosphorus) also affected a large proportion of California's streams, exceeding moderate impairment thresholds in approximately 40% of streams and severe thresholds in 15-20% of streams. Chloride levels were also a common stressor, affecting > 50% of streams at moderate levels and >30% of streams at high levels. In contrast, turbidity and suspended solids were only rarely found in exceedance of thresholds.

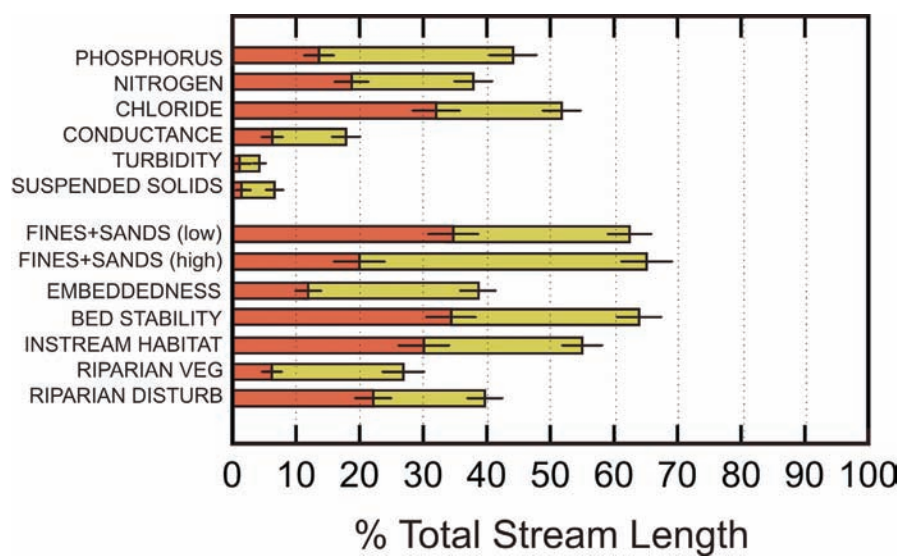


Figure 7a. Percentage of statewide stream length with chemical and habitat assessment values above moderate (yellow) and severe (red) degradation thresholds. Stressors and thresholds are listed in Appendix A, Table A-3. Bars for severe thresholds are plotted on top of bars for moderate thresholds.

Between 5% and 20% of streams exceeded moderate land cover percentages, and about half as many streams exceeded high land cover percentages (Figure 7b). We observed a consistent pattern of higher levels of development (agricultural and/or urban) in near-stream vs. watershed scales (see Appendix A, Figure A-1 for details), presumably reflecting the fact that land development tends to be concentrated in stream valleys (see Appendix E, Figure E-5). For example, whereas only 2% of California's stream length had very high levels (>10%) of impervious surface in the entire upstream watershed, nearly 10% of streams exceeded this level of impervious surface in the region immediately upstream of sampling locations (1k). Interestingly, this pattern was present, but not as strong for agricultural streams as it was for urban streams.

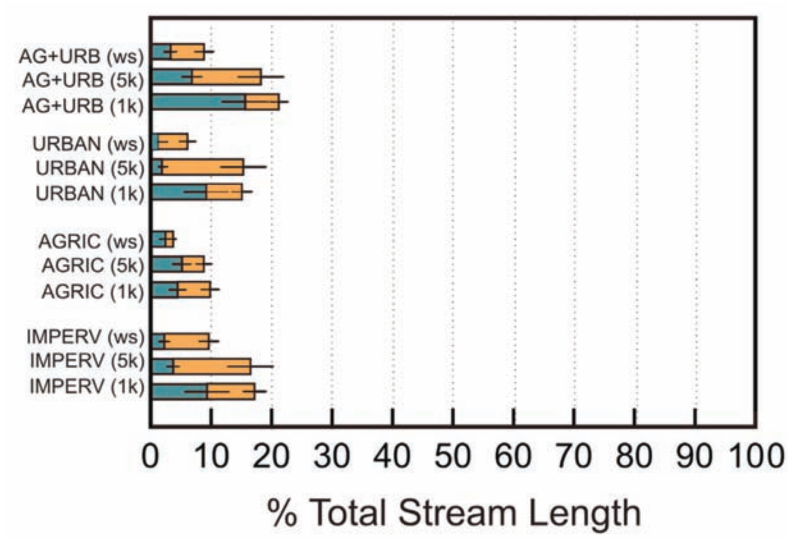


Figure 7b. Percent of total stream length statewide that exceed moderate (orange) and high (blue) land use coverage thresholds. Land use thresholds and variable codes are described in Appendix A, Table A-3. Codes in parentheses refer to the spatial scale at which the land cover was calculated: ws = entire upstream watershed, 5k = 5 kilometer area upstream of site, 1k = 1 kilometer area upstream of site. Variable codes: AG + URB = combination of agricultural and urban land use, URBAN = % urban land use, AGRIC = % agricultural land use, IMPERV = % impervious surface.

Range of Stressor Levels in PSA Regions

SWAMP's PSA surveys are designed to establish an objective picture of statewide and regional stressor extent and overall distributions. Figures 8a, 8b, and 9 illustrate several examples in this section.

With respect to nutrients, nitrogen levels were lowest in the North Coast and Sierra regions, but were generally high elsewhere, with extremely high values in the South Coast region. Phosphorus levels were also lowest in the North Coast and Sierra regions, but generally high in the other regions, particularly in the Central Valley. The prevalence of streambed sediments (% fines and sand) spanned the full range (0-100%) in all regions of the state, but were generally lowest in North Coast and Sierra streams where overall development intensity is lowest[16]. Instream habitat condition scores were also generally highest in North Coast and Sierra streams and lowest in Central Valley and South Coast streams, which tend to have very high levels of total urban and agricultural development. As in the statewide results, this development was concentrated within 1km upstream of sampling locations. Percent of land cover with impervious surface was highest in the Central Valley and Chaparral regions[17]. Additional information on stressor distributions for each PSA region can be found in Appendix E, Figures E-4,5.

16. While these levels are lower than other regions, this does not indicate that these regions do not have significant problems with fine sediment impairment.

17. Values for both urban + agricultural lands and impervious surface were lower in the South Coast region than might be expected based on the overall high degree of urbanization in this region. However, most of the sites in this survey were in the relatively less developed higher elevation regions of the SMC (Figure 1), reflecting the fact that the majority of stream length in the region is in the higher elevations.

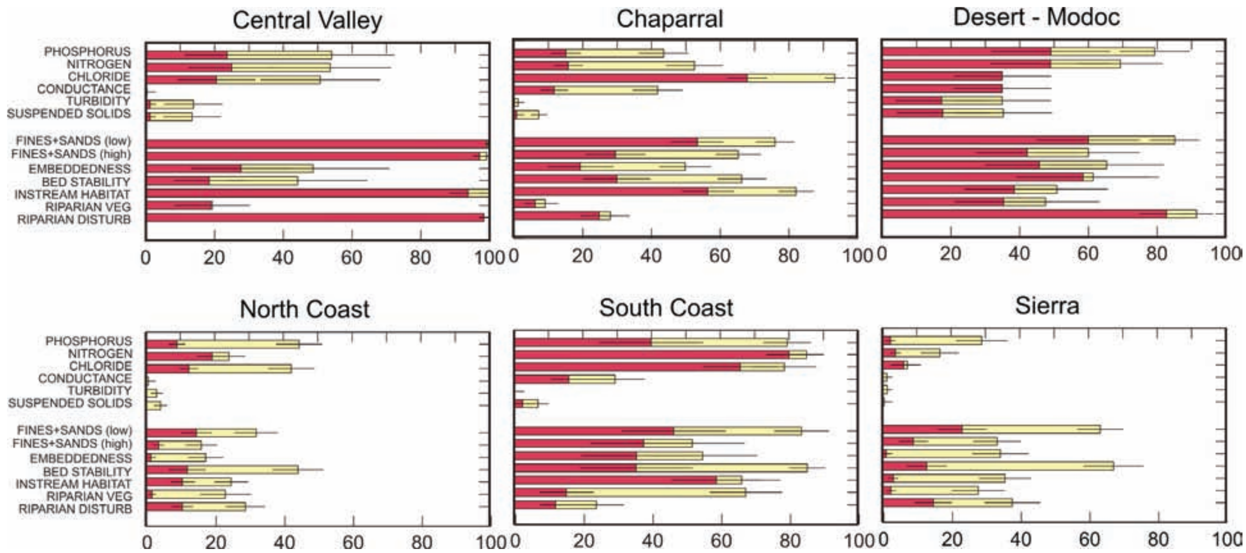


Figure 8a. Percentage of stream length within each Perennial Streams Assessment (PSA) region with chemical contamination or habitat alteration values greater than moderate (yellow) or severe (red) degradation thresholds. Stressor thresholds are listed in Appendix A-Table A-3.

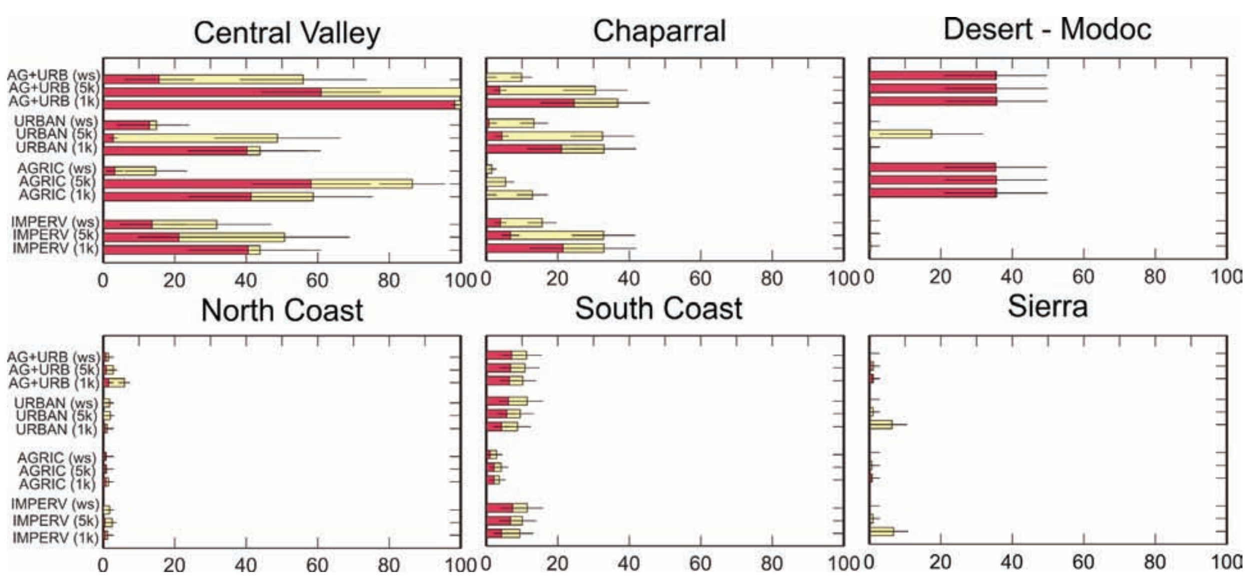


Figure 8b. Percent of stream length in each Perennial Streams Assessment (PSA) region with land use coverage that exceed moderate (yellow) or severe (red) degradation thresholds. Variable codes: AG + URB = combination of agricultural and urban land use, URBAN = % urban land use, AGRIC = % agricultural land use, IMPERV = % impervious surface. Codes in parentheses refer to the spatial scale at which the land cover was calculated: ws = entire upstream watershed, 5k = 5 kilometer area upstream of site, 1k = 1 kilometer area upstream of site. Stressors code definitions and thresholds are also listed in Appendix A-Table A-3.

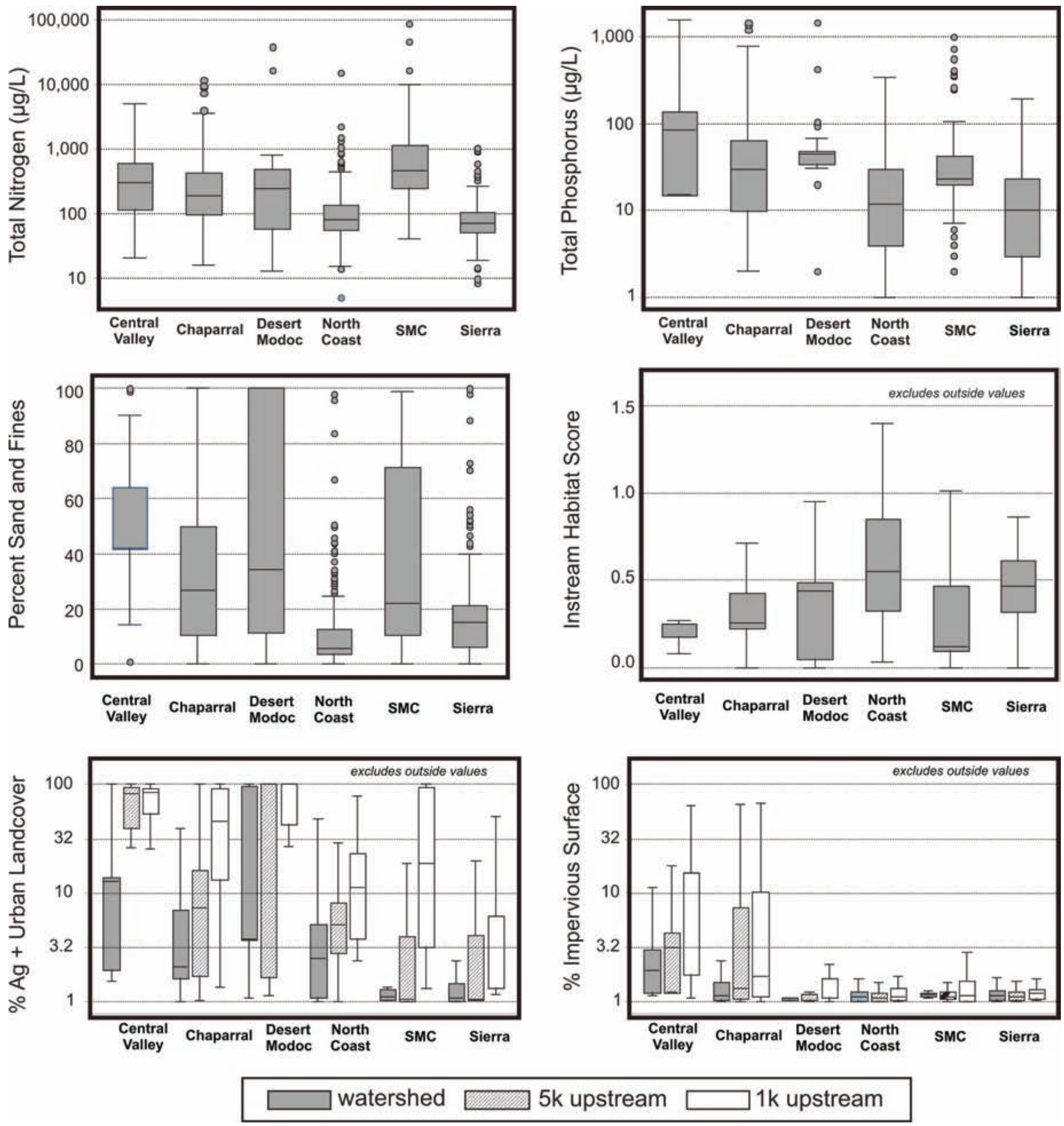


Figure 9. Boxplots depicting the range of selected stressor values for total nitrogen, total phosphorous, percent sand and fines, instream habitat score, percent combine agricultural and urban land cover, and percent impervious surface, observed in the main Perennial Streams Assessment (PSA) regions of California. The "box" in each boxplot encloses 50% of the sample distribution, bounded by the 25th and 75th percentiles. The horizontal bar represents the median value and the "whiskers" represent the upper and lower quartiles of the values, excluding outliers (outside values). Log scales were used on all graphs except the Percent Sand and Fines graph, and the Instream Habitat Score graph. Outside values were not plotted on the lower three graphs for clarity. Agricultural + Urban Land Cover and Impervious Surface graphs present data for three spatial scales: watershed, 5 km upstream, and 1 km upstream from the survey point.

Stressor Extent Implications

The stressor extent data provided by probability surveys establish critical perspective for state and regional programs like SWAMP and the NPS Program. Accurate information about distribution pattern of stressors is essential because it establishes the background condition for each stressor. This information can then be used to accurately place targeted data in the context of the global pattern within a region of interest.

Targeted monitoring data sets tend to be strongly biased toward problem areas (Stein and Bernstein 2007, Rehn and Ode 2009). As a result, exclusive focus on targeted data tends to give an inaccurate view of background conditions. Regional distributions estimated from probability surveys allow objective comparisons of the importance of different stressors within and among regions, and thus provide objective tools for prioritizing resource allocation to reduce stressors.

When data from SWAMP's Reference Condition Monitoring Program (RCMP) become available in 2011, California will be able to generate statewide and regional distributions of stressor values at reference sites (least disturbed conditions). The combination of reference distributions (from RCMP) and probability distributions (from PSA) for stressors will provide valuable perspective for water quality managers. This information can also be used to define objective management thresholds that are tailored to the region of interest (e.g., a regional board or ecoregion).

For example, a significant challenge in monitoring programs (e.g., pre- and post-project monitoring, stormwater permit monitoring) is that projects rarely are evaluated from a perspective larger than the project itself. A framework provided by the overall and reference distributions would give monitoring programs the ability to distinguish between relatively small differences and regionally significant differences between pre- and post-project conditions (e.g., A-B or C-D vs. A-C or A-D, Figure 10).

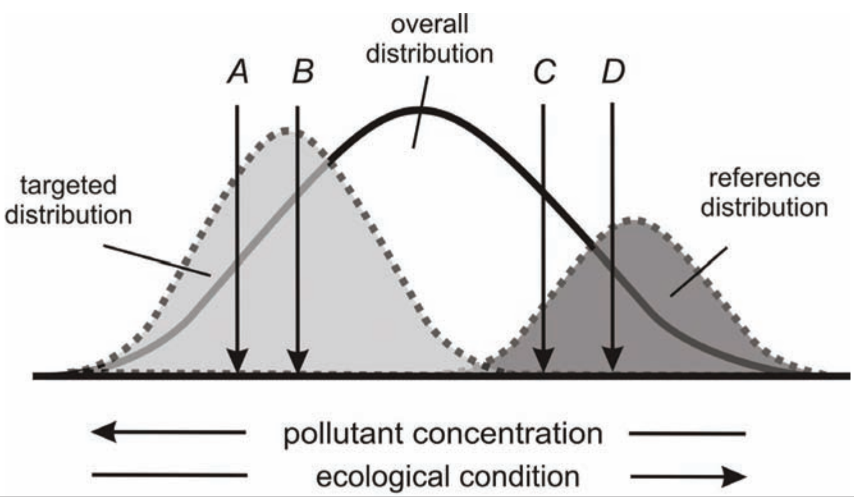


Figure 10. Theoretical distributions of monitoring variables across all sites (e.g., from PSA probability surveys) and across reference sites (e.g., from SWAMP's RCMP). Letters (A-D) refer to hypothetical site values discussed in the text.

SECTION 3
TRENDS IN WATER QUALITY
Is stream condition getting better or worse?

STATEWIDE TRENDS

The condition of California's streams was very consistent over the eight-year period reported here, with 50% of stream length rated as being in good biological condition and the remaining stream length split approximately evenly between somewhat degraded and very degraded biological condition (Figure 11). The overall EMAP results (2000-2003) were nearly identical to those of the CMAP project (2004-2007). As the PSA program accumulates data, SWAMP will be able to look at statewide trends in stressor variables, and regional trends in condition and stressors.

The rolling window averages of four year blocks of data consisted of approximately two hundred sites/block, with a margin of error of approximately 6%. This level of precision allows us to detect a change of approximately 12 percentage points in any of the condition categories within four years. In the absence of a significant driver of change (strong increases or decreases in stresses to California's stream population), changes of this magnitude are unlikely to occur in timeframes of a decade or two.

To enhance our ability to detect trends in biological integrity and biology-associated stressors, SWAMP will also consider collecting biological data from targeted sites under its Stream Pollution Trends (SPoT) monitoring program.

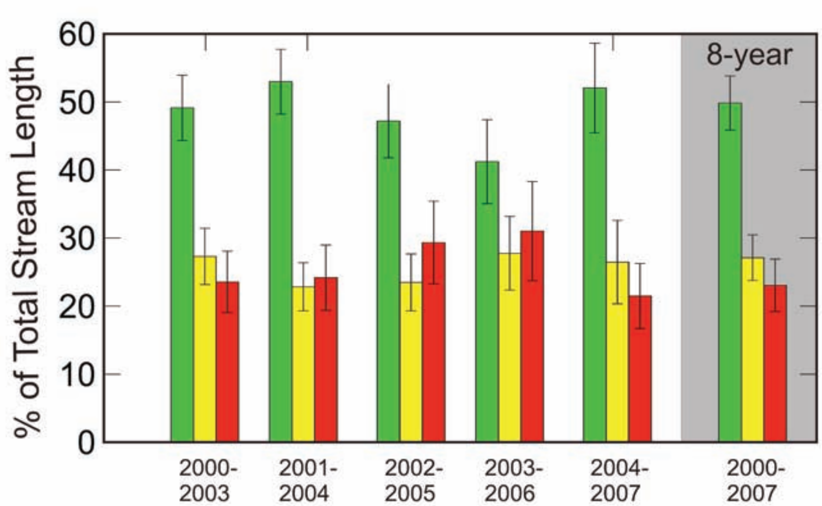


Figure 11. Percent of statewide stream length (± 1se) in each of three biological condition categories for 6 different assessment timeframes. Green = good, yellow = degraded, red = very degraded, biological condition (see methods for explanation). Each set of bars represents a four year rolling average.

SECTION 4
ASSOCIATIONS WITH LAND USES
What is the extent of degradation associated with major Non-Point Source (NPS) classes?

This section follows the organization of Section 2. Here, the results are presented for urban, agricultural, forested and "other" land cover classes: A) resource extent estimates, B) biological condition estimates, and C) stressor extent estimates.

A. NON-POINT SOURCE (NPS) RESOURCE EXTENT ESTIMATES

The CMAP program focused on four non-point source categories of land use/land cover: 1) urban, 2) agricultural, 3) forested[18] and 4) "other". We assigned sites to NPS categories based on percentages of these land cover classes in the drainage upstream of each site.[19] Sites with greater than 50% agricultural land cover at local or watershed scales were designated as agricultural sites. Sites with greater than 25% urban land cover at local or watershed scales were designated as urban sites. Sites with greater than 75% forested land cover at local or watershed scales were designated as forest sites and sites not meeting any of these criteria were designated as "other". Of the 280,000 km of streams in the state, most of the stream length fell in our "other" (~137,000 km) or "forested" (115,000 km) categories. The remaining stream length was strongly associated with either agricultural (~26,000 km) or urban land uses (4,000 km).[20]

The ratio of perennial to non-perennial streams varied considerably among the land use categories, but perennial stream length was smaller than the total non-target stream length in all NPS groups (Figure 12, Appendix E, Table E-1). Urban streams had the highest proportion of perennial stream length (66%), followed by forested streams, about a third of which were perennial. Agricultural regions were mostly comprised of non-perennial streams.

Relationship Between Land cover and Biological Condition

Sites meeting our working definition of agricultural had dramatically different distributions of condition scores than the forested and "other" classes (Figure 13). Nearly all the stream length in urban and agricultural watersheds had very degraded biological, but the proportion of very degraded streams was higher in urban streams (~90%) than agricultural streams (~70%). In contrast, approximately 70% of the

18. The CMAP program uses the term "forested" because its focus is on the condition of streams that drain forested landscapes rather than the specific impacts of forestry or timber harvest land uses.
19. See Appendix B, "Recalculation of Land use Assignments" for details of the assignment criteria.
20. These estimates are strongly affected by the thresholds used to define inclusion in the category. See methods section for a detailed explanation.

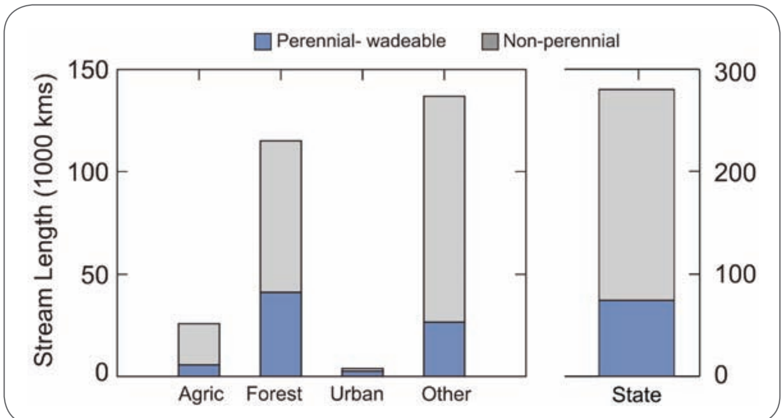


Figure 12. Statewide extent estimates of California's perennial and non-perennial stream length, broken out by California Monitoring Assessment Program (CMAP) land cover class. Non-wadeable rivers are included in the perennial group.

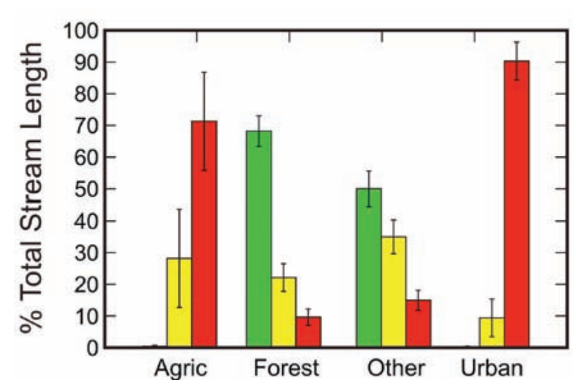


Figure 13. The biological condition of California's wadeable perennial stream length broken out by land cover (use) class. Green = good, yellow = degraded, red = very degraded, biological condition.

stream length in forested watersheds was in good biological condition, somewhat better than streams in the state as a whole.

Relationships Between Stressors and Land cover

The prevalence of the physical and chemical stressors varied considerably among the NPS land cover classes (Figure 14). In general, fewer forested streams had high levels of stressors than urban or agricultural streams, but even forested regions had many streams with high stressor levels.

Chemical threshold exceedances were common in agricultural streams: nearly 60% had high phosphorus and nitrogen concentrations, approximately 50% had very high chloride concentrations, and approximately 40% had very high specific conductance. Turbidity and suspended sediment exceedances were not as prevalent, with high thresholds exceeded in only 20% of agricultural streams. Urban streams had similar nutrient concentrations to agricultural streams. In contrast, very high chloride thresholds exceedances were much higher (> 80%) in urban streams than in agricultural streams, but conductance, turbidity and suspended sediments exceedances were far less frequent (< 5%). While fewer forested streams exceeded threshold values for chemical stressors, nutrients and chloride levels were a problem in 20 – 40% of forested streams.

Habitat degradation was widespread in both urban and agricultural streams, with high levels of habitat impairment scores in the majority of agricultural and urban streams (except for riparian vegetation, which was generally good in urban systems). Physical habitat degradation was less extensive in forested streams than in urban and agriculture dominated landscapes, but most of the habitat variables indicated at least moderate degradation in 40-50% of forested streams.

Stressor Extent

Boxplots of common stressors in the NPS land cover categories (Figure 15) further illustrate the different distributions of stressors in agricultural, urban and forested streams (see also Appendix E- Figures E-7 and E-8). Nutrients and fine sediments were very high and instream habitat condition scores were generally low in agricultural and urban regions. The range of these values generally indicated slightly greater degradation in agricultural than urban streams, but these differences were generally minor. The distributions of stressor values in different NPS classes are equivalent to the hypothetical distributions presented in Figure 10 and therefore give essential perspective to various monitoring programs by describing the current range of stressor values in streams draining agricultural, urban and forested regions.

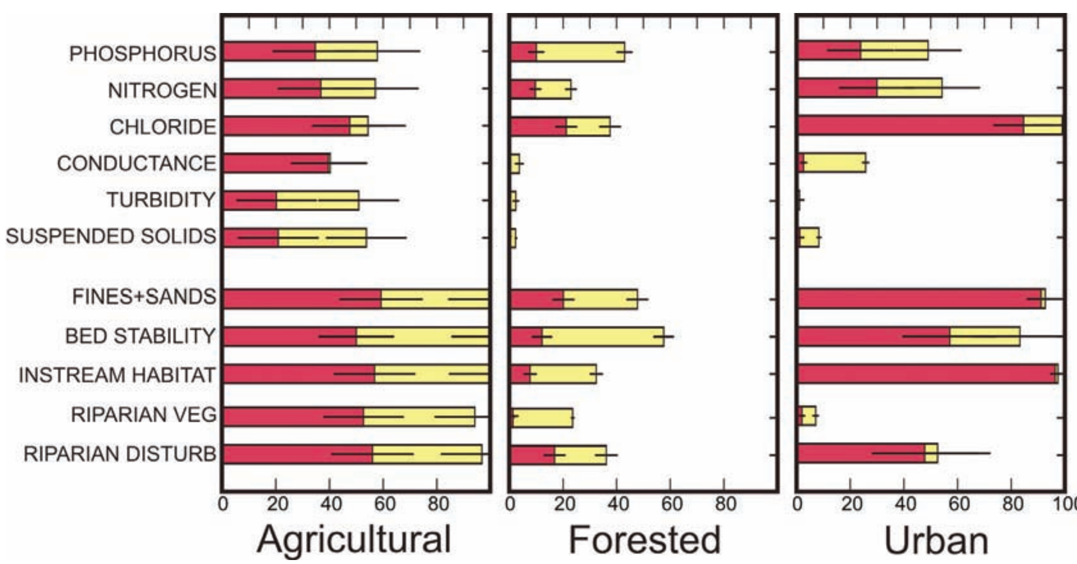


Figure 14. Percentage of California's stream length in each of three major land cover classes that exceeded degradation thresholds for chemical and physical habitat stressors. Red bars represent severe degradation thresholds and yellow bars represent moderate degradation thresholds. Threshold values are presented in Appendix A, Table A-3.

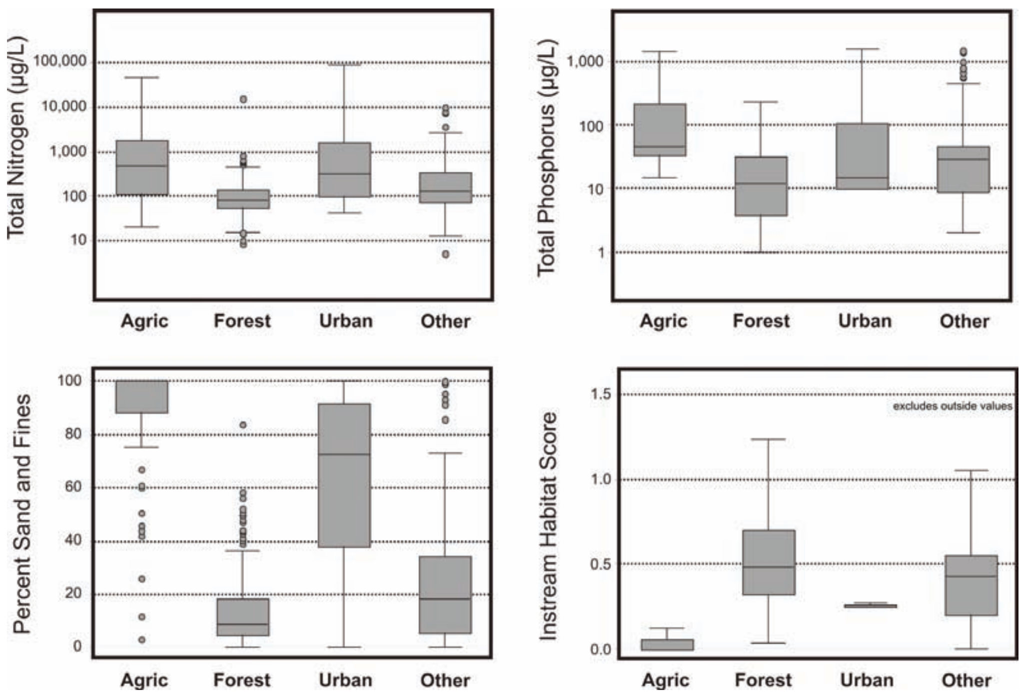


Figure 15. Distribution of chemical and physical habitat variables in each of the four Non-Point Source (NPS) land cover classes for total nitrogen, total phosphorous, percent sand and fines, and instream habitat score. Note the use of a log scale on some of the plots and that outside values (dots) were removed from the instream habitat plot for clarity.

SECTION 5
LAND USE AND THREATS TO WATER QUALITY
Which land use categories pose the biggest threats to aquatic life condition?

Threat is a combination of the extent of stressor in the environment and the magnitude of risk associated with that stressor. One of the most valuable contributions of probability surveys to state monitoring programs is that they provide objective tools for estimating extent and risk.

In Section III, we presented information about stressor extent. Here, we present three different ways of evaluating threat with data from our probability surveys: 1) relative risk and attributable risk estimates, 2) continuous risk relationships and 3) biology-based stressor thresholds.

RELATIVE RISK ASSESSMENTS AND ATTRIBUTABLE RISK (STATEWIDE, PSA, NPS)

The concepts of relative risk and attributable risk were adapted from the field of human epidemiology (Van Sickle and Paulsen 2008), which identifies human health patterns with similar statistical methodologies to those used in these surveys. In a bioassessment context, relative risk is defined as the increased risk of biological impairment that is associated with the presence of a particular stressor. Attributable risk integrates this relative risk with the prevalence of the stressor in the population of interest (in this case, California's wadeable stream population). Attributable risk can be thought of as a relative impact factor for comparing stressors. The methods for calculating both relative risk and attributable risk are described briefly in Appendix B.

Side by side comparisons of stressor extent, relative risk and attributable risk estimates can provide considerable insight about stressors (Figure 16). Some variables have both high prevalence (extent) and high relative risk and therefore have very high impact to overall biological condition (= attributable risk). Examples include several related measures of instream habitat degradation (fine sediments, bed stability, instream habitat condition) and chloride. In contrast, other variables have low prevalence and low risk (e.g., turbidity, suspended sediment, and riparian vegetative complexity), and therefore have a low overall impact to biological condition statewide. In between these extremes, many stressors have either moderate levels of both extent and risk (e.g., embeddedness) or high levels of one factor, but low levels of another (e.g., local development, riparian disturbance, nutrient levels). These combinations all result in moderate levels of impact to overall biological condition (as measured by attributable risk).

As we noted in Section I-C, proximity of land cover to sampling locations had a large impact on all measures of stressor impact. Developed land cover tended to occur near streams (i.e., in the 1k and 5k regions near the sampling location) more frequently than in the upstream watershed. Furthermore, presence of development posed greater risk to biological integrity when it was near streams than when more distantly distributed throughout the watershed. These patterns were reflected in attributable risk estimates and were stronger for urban land cover (and impervious surface) than for agricultural land cover.

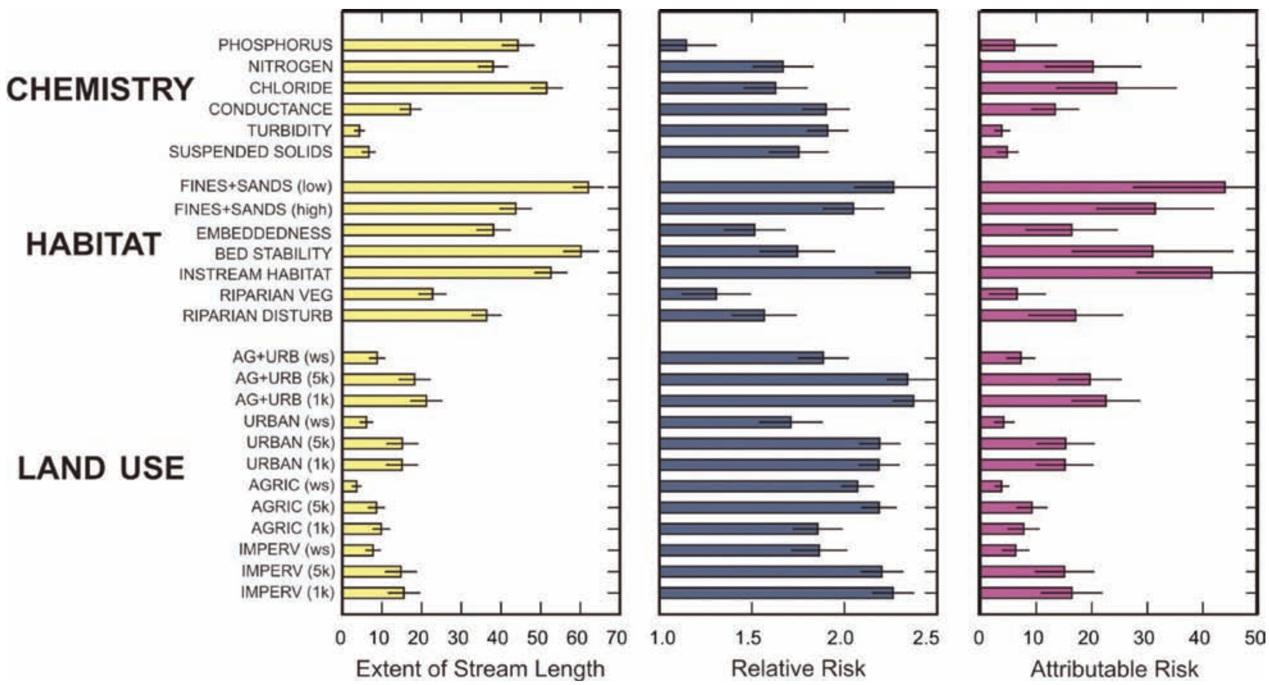


Figure 16. Stressor extent, relative risk and attributable risk estimates for chemical, habitat and land use variables. All three variables are based on the moderate threshold levels presented in Appendix A, Table A-3. Variable codes: AG + URB = combination of agricultural and urban land use, URBAN = % urban land use, AGRIC = % agricultural land use, IMPERV = % impervious surface.
Codes in parentheses refer to the spatial scale at which the land cover was calculated: ws = entire upstream watershed, 5k = 5 kilometer area upstream of site, 1k = 1 kilometer area upstream of site.

Continuous Risk Plots (statewide examples)

The analyses for calculating extent, relative risk and attributable risk estimates all require single thresholds for classifying sites into most disturbed and least disturbed categories (Appendix A, Table A-3). This classification is performed both for the stressors and the biological responses. Although we use these thresholds to facilitate reporting, it is often of interest to see how our extent and risk estimates vary with different thresholds. For variables like biological condition or nutrient concentration, we can visualize the relationships between extent and varying thresholds by plotting cumulative distribution functions (CDFs), which show the percentage of a population (in this case perennial stream length) above or below any threshold value. Example CDFs are shown for statewide biological condition and condition x NPS class in Appendix C (Figures C-1 and C-2).

We can produce equivalent figures for relative risk (Figure 17), making it easier to see how risk of biological impairment varies with stressor intensity. Although this information would be extremely valuable for resource management, the methodology is more complicated than for CDFs of extent or condition because risk calculations require a minimum number of observations in each cell. However, stressors that have well-distributed stressor data may be amenable to this approach.

For example, % fines and sand and embeddedness have fairly continuous relationships with biological risk, increasing evenly with increasing stressor levels (Figure 17). In contrast, nitrogen concentration appears to have a threshold response, in which relative risk has a strong response to increasing nitrogen levels up to about 500 µg/L, but plateaus at higher concentrations. These differences can have significant implications for appropriate remediation strategies.

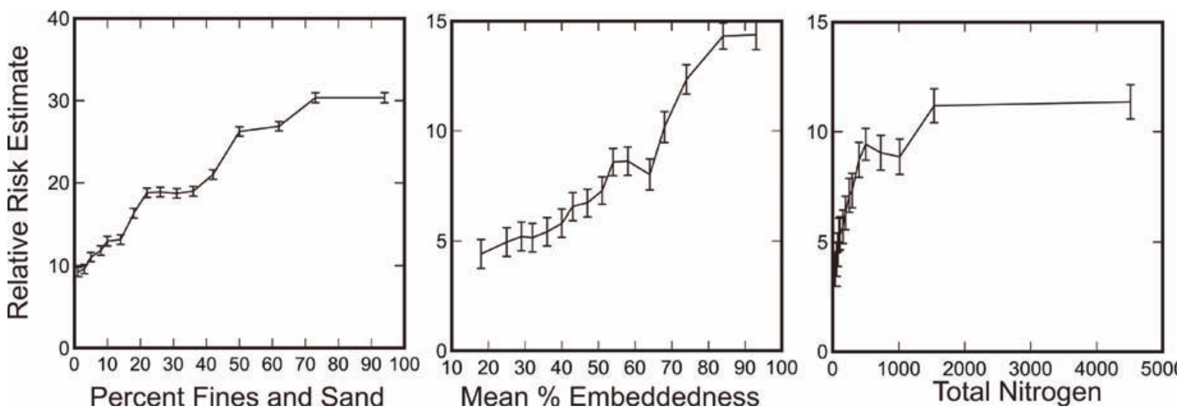


Figure 17. Continuous risk threshold plots showing the relationship between relative risk and stressor intensity for three example stressors.

Biology-based Stressor Thresholds

We also developed a third approach for evaluating threats to biological condition based on statistical properties of the association between biological condition and stressor intensity. Because biological condition is seldom the result of any single variable, univariate stressor response relationships (such as those shown in Figures 18-21) are usually characterized by a large amount of variability. However, these simple regressions can provide valuable insights into biological integrity.

We found that biological indicators demonstrate clear thresholds of response to many stressor variables, in which sites with intact biological condition (i.e., green dots in Figures 18-21) are rarely, if ever observed beyond a certain stressor level. We used this relationship to identify quantitative "biology-based stressor thresholds" (Appendix E, Tables E-3 and E-4). Here, we present examples of this approach for two common stressors (nitrogen concentration and fine sediments), both for the overall statewide distributions and for each of the major PSA regions. Scatterplots for additional stressors are presented in Appendix E (Figures E-8, E-9).

We established preliminary thresholds at the 90th percentile of the good condition (green) distribution (represented in Figures 18-21 by blue dashed lines). Depending on the intended application, threshold values could easily be adjusted to more or less conservative percentiles (e.g., 85%, 95%, see Appendix E). Such thresholds can help validate or adjust existing management targets, which rarely if ever incorporate biological condition measures. Although there may be multiple reasons for using lower thresholds, higher thresholds will clearly not support aquatic life uses. Furthermore, relating stressor thresholds to biological endpoints will be especially valuable for variables that have non-zero reference values (e.g., nutrients, sediments, chloride, conductance, etc.).

Probability survey data can also help identify regionally appropriate biology-based thresholds. There are strong regional differences in the distribution of stressor values at sites with intact biological assemblages in both the nitrogen example (Figure 19) and the percent fines and sand example (Figure 21). In the latter case, the value for % fine sediments at the 90th percentile of the good biology scores was much lower (~10% fine sediments) for North Coast streams than it was for South Coast streams (~70% fine sediments), whereas the value for Chaparral sites (~40% fine sediments) was close to the state average (Figure 20).

Implications and Other Considerations

It is critical that water quality programs begin including direct measures of biological condition in their toolbox. Although all the tools for investigating threats to biological condition discussed in this section have limitations (e.g., measurements have significant amounts of uncertainty, stressors are not independent of each other, methods rely on association between stressors and biological condition but can't establish causation), they provide consistent insights.
For example:

- Biological condition is strongly influenced by instream habitat condition, nutrient levels and chloride levels
- Land use, especially near-stream land use, greatly affects biological condition
- Biology-based stressor thresholds are a valuable tool for validating upper limits for stressors. Biologically-validated stressor thresholds will be especially valuable for variables that have non-zero reference values (e.g., nutrients, fine sediments, chloride, conductance, etc.).
- Stressor prevalence, magnitude and impact all vary considerably from region to region

Beyond Univariate Analyses

Although much can be done with single variable approaches, it is well-documented that biological condition usually responds to multiple co-occuring and interactive stressors. The biplots of nitrogen concentration and fine sediments as a function of % impervious surface provide a simple example of this concept (Figure 22). There are numerous multivariate techniques for evaluating the relative strengths and interactions of these factors. These analyses will be the subject of upcoming reports.

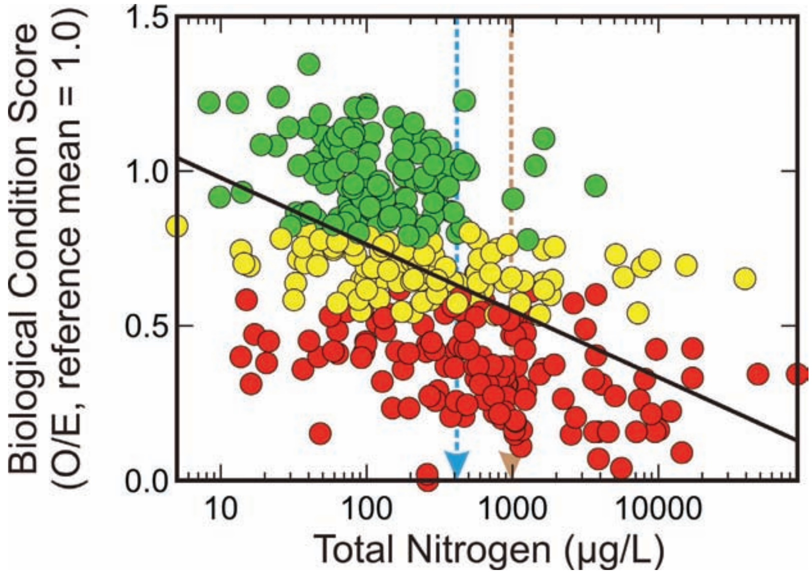


Figure 18. Statewide relationship between total nitrogen concentration and biological condition scores. Green dots represent sites in good condition and yellow and red dots represent sites with degraded and very degraded biological condition, respectively. The blue dotted line represents a 90th percentile threshold (see text) and the brown line indicates a common nitrogen impairment threshold.

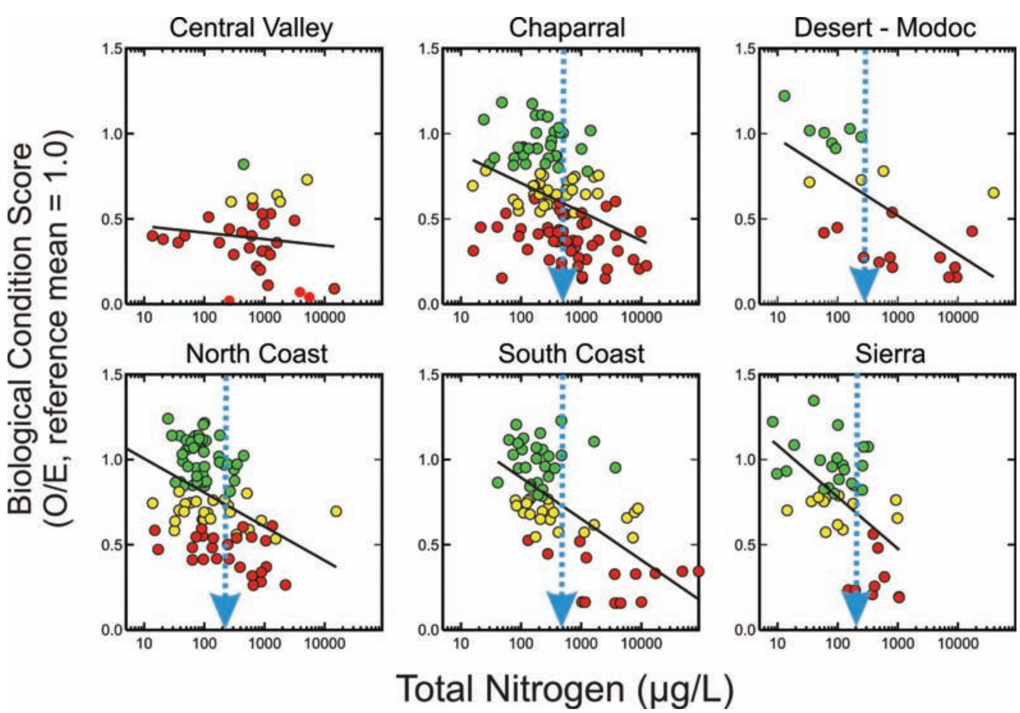


Figure 19. Relationship between biological condition scores and total nitrogen concentration in each Perennial Streams Assessment (PSA) Region. Green dots represent sites in good biological condition and yellow and red dots represent sites with degraded and very degraded biological condition, respectively.

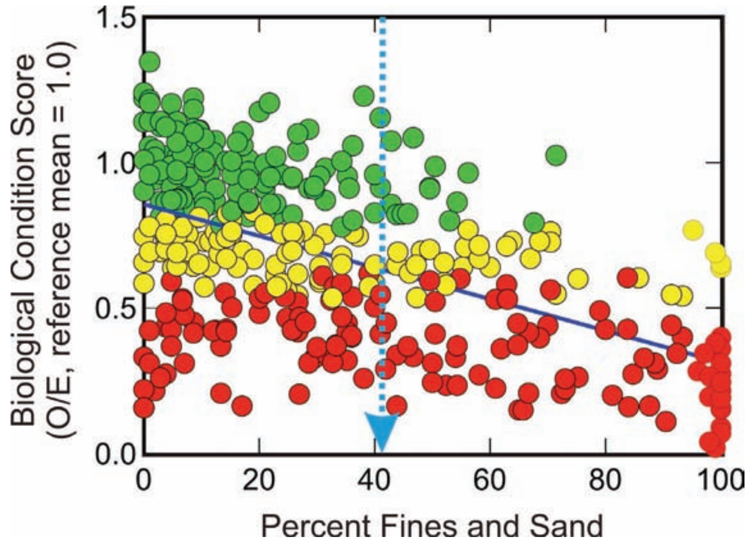


Figure 20. Statewide relationship between the percentage of fine sediments in sampling reaches and biological condition scores. Green dots represent sites in good biological condition and yellow and red dots represent sites with degraded and very degraded biological condition, respectively. The blue dotted line represents a 90th percentile threshold (see text).

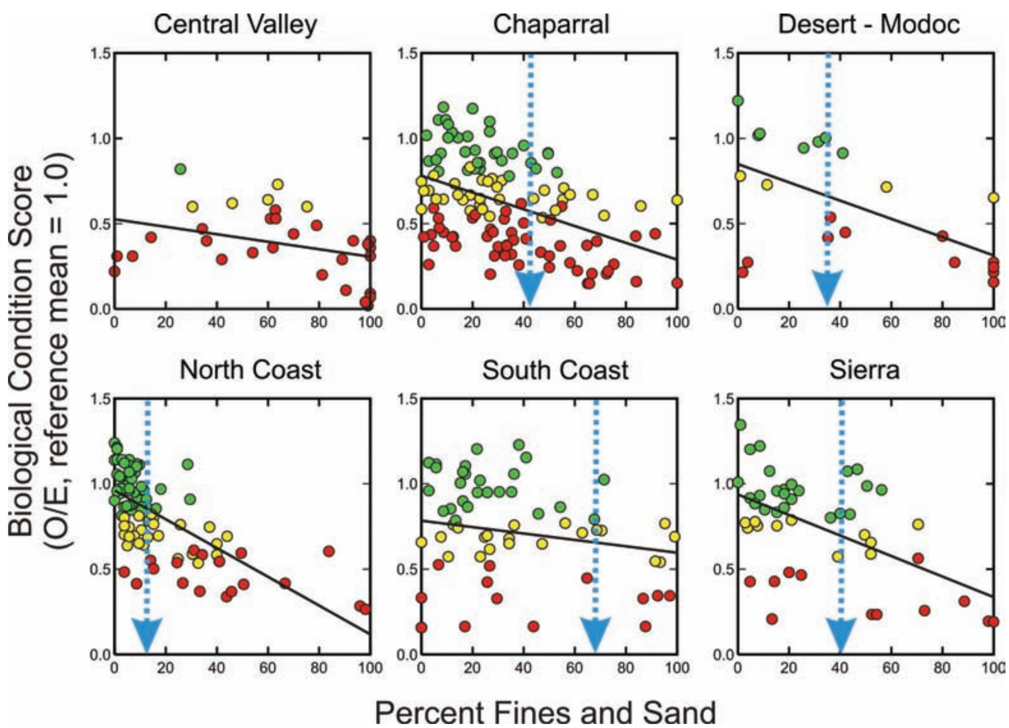


Figure 21. Scatterplots of biological condition scores in each of the six Perennial Streams Assessment (PSA) regions, as a function of the percent of fine sediments in the sampling reach. Green dots represent sites in good biological condition and yellow and red dots represent sites with degraded and very degraded biological condition, respectively. The blue dotted lines represents the 90th percentile threshold (see text).

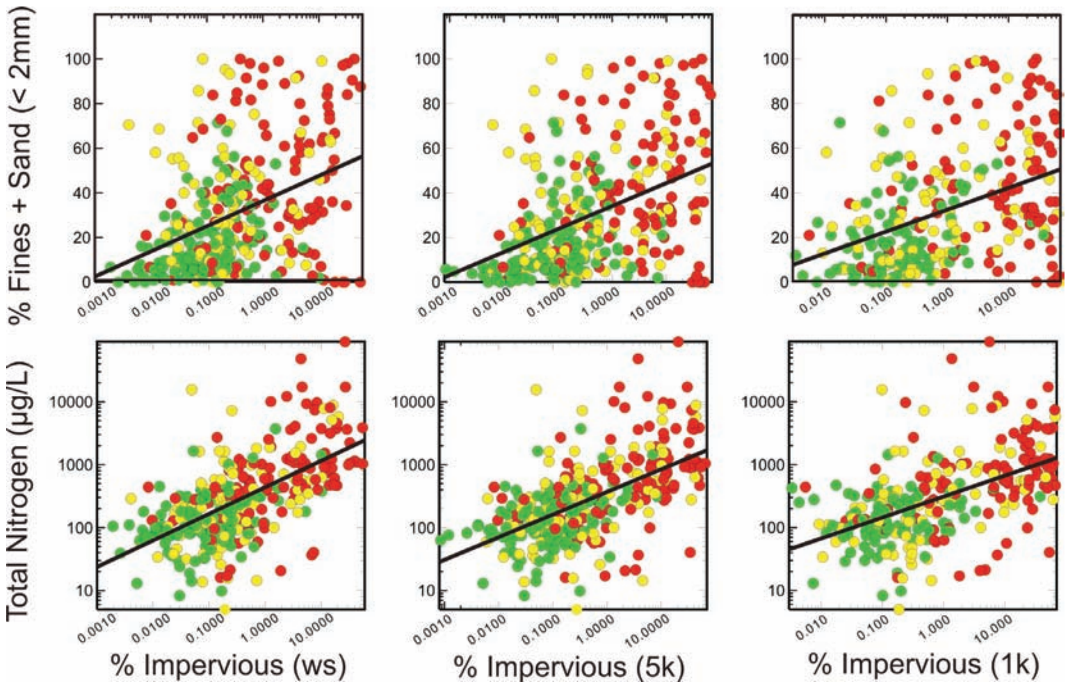


Figure 22. Bi-plots of relationships between two stressors (nitrogen concentration and proportion of fine sediments) and impervious surface at three spatial scales. Codes in parentheses refer to the spatial scale for analysis: ws = entire upstream watershed, 5k = 5 kilometer area upstream of site, 1k = 1 kilometer area upstream of site. Colored dots represent sites in good biological condition (green), degraded condition (yellow) or very degraded condition (red).

SECTION 6
RESOURCE INVESTMENTS AND LAND USE
Are California Non-Point Source (NPS) Program investments consistent with water quality problems?

Sections I – IV provide many examples of ways that probability data can give the NPS Program and water quality programs tools for interpreting data from or about their programs and help inform better management decisions. To make full use of this information, monitoring programs should use this information to evaluate their patterns of resource allocation. When the CMAP program was initiated, the development team recognized that probability survey results could give perspective on several key management questions, including: “Where is the program investing its resources (staff and fiscal)?”, “How do these allocations compare to the patterns of pollution, land use and aquatic life condition observed in probability surveys?” The SWAMP and NPS Programs will be reporting the results of these analyses separately.

ARE NON-POINT SOURCE (NPS) PROGRAM INVESTMENTS EFFECTIVE IN PROTECTING AND RESTORING WATER QUALITY?

Probability survey data can be used to inform on the effectiveness of assessments programs because they produce objective scales against which to measure change (see Figure 10). The effectiveness of many current and past NPS investments can be evaluated against the regional distributions of relevant stressor variables or condition indicators to determine the magnitude of changes of interest. As in Section V, these assessments will be reported separately.

SECTION 7
RECOMMENDATIONS FOR MANAGEMENT

- The California Water Quality Monitoring Council (CWQMC) should leverage Perennial Stream Assessment (PSA) surveys to enhance coordination of monitoring across state agencies and across Water Board programs. The CWQMC should promote partnerships between the State Water Board and other entities to enhance coordination of monitoring across the state. The Monitoring Council can facilitate this coordination in two ways:
  - By identifying ways to integrate use of PSA products into existing water quality programs;
  - By identifying mechanisms for sharing the costs of the PSA surveys among agencies that use its products.

Water Board programs already implementing bioassessment tools include: Storm Water (e.g., construction general permit), TMDL, Non-Point Source Program and NPDES permitting. Other Water Board programs which would find value and benefit from application of bioassessment tools include: Water Quality Certifications in Wetland and FERC relicensing Programs, Irrigated Lands Regulatory Program and many Regional Board programs. The Stormwater Monitoring Coalition (SMC) in southern coastal California, the San Francisco Bay Area's Regional Monitoring Coalition, the US Forest Service, the Garcia River Watershed and the Tahoe Regional Planning Agency are excellent examples of effective existing partnerships.

- Results of the PSA probability-based surveys, in context with reference condition distributions can and should be integrated into a variety of Water Board programs and used for quantitative interpretation of regional narrative objectives for a variety of potential stressors (e.g.: nutrients, fine sediment, water chemistry, etc.). This will lead to greater consistency in the use and interpretation of biological data.

- The Water Boards need additional regulatory tools to protect streams. Most of the stream degradation identified by the PSA appears to be related to water quality factors and habitat quality issues that are not addressed well by traditional water quality programs. Elements of the *Wetlands and Riparian Area Protection Policy* currently under development, including the definition of water quality objectives for riparian areas, will be instrumental to protecting stream health. The development of biological objectives will provide programs with a quantitative regulatory tool to protect stream resources and will provide greater consistency in the used and interpretation of biological data. With biological objectives, benthic macroinvertebrate assemblages can be used to identify high quality waters deserving of protection as part of the state's Anti-degradation Policy. Roughly half of the state's perennial wadeable streams are in good biological condition and would benefit from enhanced protection.

- The Healthy Streams Partnership, being led by SWAMP for the California Water Quality Monitoring Council, should form the framework for a coordinated statewide approach to assessing and protecting all the stream resources of the State including non-perennial streams. Non-perennial streams comprise the majority of California's stream length and are a critical link between stressors in watersheds and ecological integrity for both perennial and non-perennial stream resources. Bioassessment tools comparable to those being implemented on perennial streams are needed to monitor and assess the condition of non-perennial streams. The SWAMP currently does not have the resources to address non-perennial streams. Coordination with the Wetlands and Riparian Area Protection Policy and the California Wetland Monitoring Workgroup's Wetland and Riparian Area Monitoring Program will be essential to this goal.

- The California Water Quality Monitoring Council should provide a forum for coordinating GIS stewardship activities statewide to improve the accuracy of perennial and non-perennial flow status designations in GIS layers of California's stream network. Accurate base maps are essential to the protection of the State's aquatic resources. Inconsistencies between map and field observations underscore the need for local stewardship to update base maps, specifically with respect to flow status. This should be well-coordinated with the California Wetland Monitoring Workgroup's Wetland and Riparian Area Monitoring Program and their effort to develop a standardized base map of California's wetlands and aquatic resources, which will be maintained by the California Department of Fish and Game.

- The State Water Board should invest in tools to determine sources and causes of biological impairment. The PSA surveys reinforce the need to pay particular attention to sources of instream habitat and nutrient impairment, which were strongly associated with biological degradation across all regions and land cover types.

- The State Water Board should continue to investigate the use of biology-based stressor thresholds as an objective means to set meaningful, regionally-appropriate water quality standards. Biologically-validated stressor thresholds can be especially valuable for variables that have non-zero reference values (e.g., nutrients, fine sediments, chloride, conductance, etc.). The State Water Board should identify candidate water quality analytes that would benefit from biology-based threshold analyses.

  Constituents that are currently collected along with biological data could be analyzed immediately with data in the SWAMP-CEDEN databases. Other constituents of interest should be added to statewide biological monitoring programs (e.g., SWAMP, SMC, RMC).

- The use of biologically derived stressor thresholds should be expanded to include additional indicator groups such as fish, algae and riparian vegetation. Multiple lines of evidence could be developed by each indicator group, to add weight and precision to the biologically derived threshold value.

- The California Department of Fish and Game (CDFG) Water Branch should use information from the Perennial Streams Assessment (PSA) program to support the CDFG's mission in several areas. These include enforcement and compliance monitoring; streambed alteration agreements; instream flow; and FERC re-licensing. PSA information should also be used to measure the success of DFG restoration and protection programs.

- The State Water Board should encourage the evaluation of development impacts on stream networks on a watershed-wide basis. Development in upstream non-perennial streams can have significant impacts in downstream perennial streams. This is consistent with the requirements of the recent Clean Water Act Section 404 compensatory mitigation rule which calls for using a watershed approach to make regulatory decisions affecting aquatic resources. The State Water Board's Wetlands and Riparian Area Protection Policy should be used to support these evaluations.

- The State Water Board should strengthen the protection of non-perennial streams through the Wetlands and Riparian Area Protection Policy by defining beneficial uses related to riparian area water quality functions (e.g. shading). While non-perennial streams are protected under Porter Cologne, the level of protection provided to these streams under Clean Water Act authority may vary.

- Statewide probability-based surveys should be used as a foundation for prioritizing monitoring, remediation, and protection efforts.

- The assessment tools developed by the SWAMP Bioassessment Program should be used to measure the performance and success of restoration and protection programs implemented by the Water Boards, Department of Fish and Game, and others.

SECTION 8
FUTURE DIRECTIONS
Integrating PSA-SMC designs, Enhancing Program Linkages

Over time, the state's probability surveys have evolved to improve assessment accuracy and increase the number of program objectives they can address. The CMAP program added the ability to identify patterns in stressor-biology relationships related to major land use categories. The new PSA program has increased the ability of the surveys to produce regional survey products, enhanced the suite of stressor variables measured at sites and added additional ecological condition indicators (e.g., enhanced algal indicators, California Rapid Assessment Methodology for wetlands—CRAM). The PSA enhancements are expected to continue to improve the overall accuracy and utility of assessments.

A parallel program has been developed by a coalition of stormwater monitoring entities in southern coastal California. The Stormwater Monitoring Coalition (SMC) just completed its second year of implementing a probability survey in the area encompassed by Regional Water Boards 4, 8 and 9 (referred to as "South Coast" in this report). The SMC program is using a compatible sampling design and similar suite of indicators to PSA, so the SMC data can be rolled into the overall PSA survey analyses. The SMC program is collecting data from approximately 90 sites/ year, greatly enhancing the PSA program's 72 sites/ year. Similar (but smaller scale) partnerships are being developed with the US Forest Service in the Sierra Nevada, The Nature Conservancy in the Garcia River watershed and the Tahoe Regional Planning Agency.

SWAMP is now actively seeking opportunities to more closely link products from its PSA and Reference Condition Monitoring Program (RCMP) to the objectives of State Water Board programs and other state agencies, via the Water Quality Monitoring Council.

Since the PSA program is ongoing, we expect to revisit the analyses presented here as the program refines its techniques for assessing and reporting these data. To follow revisions and updates, please visit the SWAMP website (http://www.swrcb.ca.gov/water_issues/programs/swamp).

CONCLUDING REMARKS CR

The protection of the ecological condition of flowing waters is one of the highest priorities under the Clean Water Act and this objective is increasingly adopted as a primary foundation for monitoring programs at both state and federal levels. This refocused attention on the condition of aquatic life has been coupled with major advances in the science of landscape ecology (Allan and Johnson 1997, Allan 2004, Hansen et al. 2005, Burcher et al. 2007), which provides insight into the relationship between anthropogenic activities in watersheds and the condition of aquatic resources in those landscapes.

The recent surge of interest in applied stream ecology/ landscape ecology has produced a large body of studies that have investigated the landscape factors that control aquatic life use (ALU) condition (Roy et al. 2003a, Allan 2004, Brown and Veras 2005, Burcher and Benfield 2006, Booth et al. 2007), mechanisms by which they affect ALU (Townsend and Hildrew 1994, Roy et al. 2003b, Burcher et al. 2007) and spatial scales at which these variables act (Townsend et al. 2003, Feld and Herring 2007). In a recent synthesis by Burcher and others (2007), the authors argue that since natural and anthropogenic influences (e.g., agricultural or urban development, wildfires) occurring in the watershed do not directly affect biota but rather influence biota through a series of intermediate factors (e.g., changes in discharge, eutrophication, fine sediment deposition), protection of ecological condition requires an understanding of these intermediate pathways. This Land cover Cascade (LCC) provides a conceptual framework for organizing the relationships among the multitude of landscape factors affecting ALU in streams.

Probability surveys and biological endpoints are powerful tools for monitoring programs committed to protecting ALU because they provide an objective means of identifying the relationships among pathway elements in the LCC. Coupled with frameworks like the LCC, probability surveys provide an efficient mechanism for organizing monitoring data into information that should be used to prioritize protection and remediation efforts. The unique nature of these probability data sets makes them an extremely valuable resource that can be repeatedly mined to address a wide variety of water quality management objectives.

APPENDIX A
METHODS

STUDY DESIGN/SITE SELECTION

This report combines results from two large probability surveys (Table A-1) that comprise the first eight years of the PSA surveys: the EMAP-West study (2000 to 2003) and the CMAP study (2004-2007). All surveys were based on a generalized random tessellation stratified (GRTS) design, which uses a reverse hierarchical ordering scheme to generate a relatively even distribution of sites throughout the stream network in the study area (Stevens and Olsen 2004).

EMAP-West - There was no stratification in the EMAP-West design, but site selection weights were adjusted so that Strahler stream order categories (1st, 2nd, 3rd, and 4th+) were sampled in approximately equal proportions throughout the state. We combined four separate survey designs for this analysis (see Ode and Rehn 2005 for more detail). Three of these were modifications of the main EMAP sample frame: 1) the California statewide sites that were part of the larger EMAP design, 2) the southern coastal California special interest sites, and 3) the northern coastal California special interest sites. A separate GRTS survey was created in 2003 to increase the representation of sites in the central coast region. In each of the designs, the US EPA's RF3 hydrology layer was used as the sample frame, excluding modified channels and canals when these classes were coded in the RF3. A list of potential sampling locations was generated randomly from the RF3 hydrology layer as described by Stevens and Olsen (2004).

CMAP - The CMAP design was based closely on the original EMAP design, but was modified to enable stream condition assessments based on land use categories (agricultural, urban, forested and other). The US EPA's RF3 hydrology layer was again used as the sample frame, excluding modified channels and canals when this information was coded in the RF3. In the last two years of CMAP (2006 and 2007), we added a supplemental set of sites using a sample frame consisting of modified channels eliminated in the previous designs (EMAP and CMAP). The Canals design was added to determine whether inclusion of modified canals would be appropriate and practical for our statewide probability surveys.

We used the USGS/US EPA's National Land cover Data (NLCD 2001) to assign sites to one of four land use/land cover classes (urban, agricultural, forested and other), using the coding defined in Table 2. We reprocessed the original 30 m resolution NLCD grids to a lower resolution (300 m) grid needed for the sample draw. Analysts at the EPA's ORD then used this grid to assign a preliminary land cover class to each of the sites in the sample draw (based simply on the value of the land cover pixel at the site coordinates) and delivered the list of potential sampling sites to the ABL field crew.

SITE EVALUATION

Once the list of potential sampling coordinates was generated for each region, we conducted a multi-phase process to screen for sites meeting the definition of the target population (perennial, natural channels). We first conducted an initial screen of the site list to eliminate sites that were obviously not part of the targeted population (channelized streams, non-perennial streams, etc). Field crews then split up the remaining sites by county and visited county Tax Assessor's offices (or consulted online tax assessor data) to identify land ownership for each site. For sites that fell on public lands, we contacted officials to obtain permission to sample and obtain sampling permits where necessary. For sites on private land we contacted owners by letter requesting permission to visit the site. When access permission was granted, field crews performed on-site reconnaissance to identify sites that were part of the target population.

There were many reasons why potential sites were rejected during the reconnaissance phase. In the arid southwest, much of the stream length coded as perennial on USGS quadrant maps, on the 1:100,000 RF3 stream layer, and on subsequent NHD and NHD+ layers digitized from them, is not perennial. Conversely, many stream segments coded as non-perennial are perennial. Earlier analyses indicated that approximately 50% of stream length coded as perennial in the southern coastal region was actually non-perennial (Rehn and Ode 2004). Underground pipelines, canals and aqueducts frequently cannot be distinguished from streams in NHD, and these were rejected as non-target during reconnaissance. In addition, some perennial sites were inaccessible due to physical barriers (e.g., access was too dangerous or required > 1 day backpacking trips). Private ownership further confounded site selection. When landowners denied access to a site, it was impossible to determine its target status; these sites were categorized as "status unknown".

EMAP - Sites meeting the target criteria were selected for sampling in the order they appeared on the original list to assure random site selection. Site reconnaissance continued until a pool of approximately 60 target sites each was identified and sampled from the northern coast, the southern coast and statewide. An additional 30 sites were sampled from the central coast region using a separate design. During the reconnaissance process, we evaluated 1140 sites, keeping careful records of each site's target status, and if applicable, reasons why sites were eliminated from the target pool for use in later analyses. We sampled over 200 study reaches throughout California between April and September of 2000 through 2003, sampling southern sites at the beginning of the sampling season and progressing north later in the year.

CMAP - Site reconnaissance was identical to that for the EMAP study, except that we added an additional step to help balance the number of sampled sites in the four land cover classes. Sites were selected in the order they appeared on the original random list, but once the goal was reached for each class (e.g., 13 sites of each land cover class per year) all subsequent sites belonging to that class were skipped. Between 2006 and 2007, we sampled 20 randomly selected sites in constructed channels for the supplemental canal survey.

FIELD METHODS

Once target sites were identified and sampling permission was obtained, we sampled sites according to standard EMAP West field methods (Peck et al. 2006). A sampling reach was defined as forty times the average stream width at the center of the reach, with a minimum reach length of 150m. We collected two BMI samples from each reach: 1) a reachwide composite sample (RWB) consisting of 11 square foot samples taken from equally spaced locations throughout the reach and 2) a targeted riffle sample (TRB) consisting of 8 one ft^2 samples taken from fast water habitat units within the reach (Hawkins et al. 2001). Fish and algae samples were collected according to Peck and others (2006) but are not reported here. Algae data from this project are being incorporated into SWAMP's ongoing statewide development of algal assemblages as a second biological condition indicator to complement benthic macroinvertebrate data. Fish data will also be evaluated for their potential as biological indicators for California, but this development is currently a lower priority for SWAMP. Water chemistry samples were collected from the mid-point of each reach and analyzed using WEMAP protocols (Klemm and Lazorchak 1994). Field crews recorded physical habitat data using EPA qualitative methods (Barbour et al. 1999) and quantitative methods (Kaufmann et al. 1999).

LAB METHODS

All BMI samples were processed at CDFG's Aquatic Bioassessment Laboratory. A 600 organism subsample from each BMI sample was identified according to SAFIT Level II standard taxonomic effort levels (www.swrcb.ca.gov/water_issues/programs/swamp/docs/safit/ste_list.pdf). All taxonomic data were entered into an MS Access database (CalEDAS) that allowed us to produce standardized taxa lists at different standard effort levels. Five percent of taxa were re-identified for quality assurance and archived vials of all samples are housed at the Chico facility.

CALCULATING BIOLOGICAL CONDITION SCORES

We calculated biological condition scores for all sites using recently developed predictive models based on the River Invertebrate Prediction and Classification System (RIVPACS, Wright et al.1984). Like multimetric approaches (Kerans and Karr 1994, Ode et al. 2005, Rehn and Ode 2005), predictive modeling techniques establish thresholds of ecological impairment based on a characterization of the biotic assemblages expected to occur under minimal human disturbance (Wright et al. 1984, 1989, 2000). However, predictive models compare assemblages at test sites to an expected taxonomic composition rather than expected metric values. Taxon-based models have seen widespread use since the first BMI models were created in Great Britain in the late 1970s (Norris and Georges 1993, Hawkins et al. 2000, Van Sickle et al. 2005) and have been promoted in the US (Hawkins et al. 2000, Hawkins and Carlisle 2001) as an alternative to the multimetric approach initially endorsed by the US EPA (Barbour et al. 1999). For this analysis, we employed California

Observed/ Expected (O/E) models (C. Hawkins unpublished) that can be used to score sites throughout the state. To apply the CA O/E models, we prepared separate files of taxa and predictor variables for each of the 3 sub-models.

Benthic Invertebrate Taxonomic Data - Taxonomic lists generated from ABL's taxonomic database (CalEDAS) were modified for compatibility with the formats used in the O/E models by: 1) eliminating ambiguous taxa, 2) subsampling 300 organism counts from the original 500 count samples, 3) converting the final taxonomic names to the operational taxonomic names (OTUs) used in the models (e.g., converting chironomid midges to subfamily), and 4) cross-tabulating the taxonomic list into a taxon by site matrix. Steps 2 and 4 were performed with software developed by Dave Roberts ("subsample.exe" and "matrify.exe" available through the Western Center for Monitoring and Assessment of Freshwater Ecosystems).

Central Valley IBI – The O/E models used in this study do not represent some regions of the state very well, most notably the Central Valley. To improve the accuracy of our assessments in this region, we scored sites with an alternate biological index, the Central Valley IBI (Rehn et al. 2008). The Central Valley IBI is a multi-metric index (MMI) that converts the list of organisms occurring at a site into a numeric score on a scale of 1-100. For our analyses, we converted MMI scores to the 0-1 scale of O/E models by dividing site scores by the 80th percentile of the MMI reference distribution. This adjustment was applied to all Central Valley sites.

HABITAT VARIABLES

We determined the values of six map-based predictor variables for each site: 1 and 2) geographic coordinates (latitude and longitude) were obtained from the original study design file, 3) watershed area was calculated by delineating upstream watershed boundaries for each site in using automated GIS scripts and manual delineation where necessary, 4) log mean "normal" precipitation was estimated by overlaying sites on a GIS grid of mean monthly precipitation (1961-1990) obtained from the Oregon Climate Center (OCC, www.ocs.orst.edu/prism), 5) mean "normal" temperature was estimated from mean monthly temperature grids (1961-1990) also obtained from the OCC, 6) percent sedimentary geology was estimated from an unpublished GIS geology classification of the western United States derived by John Olson, (Utah State University) from a generalized geologic map of the coterminous US (Reed and Bush, pubs.usgs.gov/atlas/geologic).

Once predictor variables were determined for each site, we used precipitation and temperature data to assign each site to one of the three submodels based on the following criteria: 1) sites with mean monthly temperatures (Tmean) less than 9.9°C were assigned to Class 3, 2) sites with temperatures greater than 9.9°C were assigned to Class 2 if they had log mean monthly precipitation values (logPPT) less than 2.952, and to Class 1 if logPPT was greater than 2.952. The three sub-models required different sets of predictor variables: Class 1 used latitude, log watershed area, and mean temperature; Class 2 used longitude, percent sedimentary geology and mean precipitation; Class 3 used log watershed area and mean temperature. The site files were uploaded to the web interface containing the California models at the Western Center for

Monitoring and Assessment of Freshwater Ecosystems (http://129.123.10.240/WMCPortal/DesktopDefault.aspx?tabindex=2&tabid=27).

We calculated O/E scores for all sites using versions of the O/E models in which chironomid midges (Diptera: Chironomidae) were reported at the subfamily level (= OTU2). Unless otherwise specified, we report O/E ratios using submodels that include only common taxa (probability of capture > 0.5) since these tend to be more stable (Hawkins, personal communication) than models that include all taxa (probability of capture >0.0).

RECALCULATION OF LAND USE ASSIGNMENTS

The original assignment of land use categories to CMAP sites during the initial sample draw was used as a quick way to screen potential sites. However, since this preliminary assignment of sites was relatively coarse (based only on the land use class present in a 300 m pixel overlapping the site), we went through a more intensive GIS process to assign sites to land use classes based on land use percentages in upstream drainages of each site.

We used the newly released national land cover data set (NLCD 2001) for site assignments, converting the NLCD land use codes (Table A-2) to one of the four land use categories according to the values in Table A-3, applying these re-assignments to both EMAP and CMAP data. We calculated land use percentages for the four categories at each of three spatial scales (Figure A-1): 1) the entire upstream drainage, 2) a portion of the upstream watershed within 5km of the site (5k_buffer) and 3) a portion of the upstream watershed within 1 km of the site (1k_buffer). The upstream watershed boundaries were delineated for EMAP sites by manually clipping them from existing CalWater v. 2.2 shapefile boundaries. Boundaries for CMAP sites were delineated from 30m DEM data (from the National Elevation Database) using automated scripts developed by the CSU Chico Geographic Information Center. Creation of the local watershed clips was performed with automated scripts developed by Will Patterson (CDFG, Biological Data Branch).

Once watersheds and local clip files were created, we used the ArcView 3.x extension ATtILA (Ebert and Wade 2004) to calculate land use percentages for each of the four land use/ land cover categories at each of the three spatial scales. All sites were then assigned to one of the land use categories using the following decision criteria: 1) if a site had greater than 25% urban land use at any of the three spatial scales it was assigned to the "urban" land use class, 2) if a site had greater than 50% agricultural land use at any of the three spatial scales it was assigned to the "agriculture" land use class, 3) if a site had greater than 75% forested land cover at any of the three spatial scales it was assigned to the "forested" land cover class, 4) sites that did not meet any of these criteria were assigned to the "other" category. In the few cases where sites met more than one of the criteria, sites were assigned to multiple categories (Table 3).[21]

21. The land use thresholds used to define membership in the main land use classes were intentionally set at high levels to ensure that watersheds had a high influence of the nominal land use/land cover. Influence of urban and agricultural land uses are known to affect biotic condition at levels below these thresholds, so conclusions based on these thresholds should be conservative (Wang et al. 1997).

CHEMISTRY DATA

All chemical analyses for the EMAP dataset, except those measurements collected in situ were performed by laboratories managed by the EMAP program. Field samples were shipped to EMAP directly. All chemical analyses for CMAP were performed by the CDFG Water Pollution Control Laboratory in Rancho Cordova (WPCL) following the same methods used by EMAP. Where necessary, we converted analytical units used in CMAP to those used in EMAP for all combined assessments.

PROBABILITY SURVEY ASSESSMENTS

Because all the sites sampled in these studies were selected probabilistically, we can estimate the proportion of total stream length that each site represents and the amount of error in that estimated length. This relationship serves as the basis for a set of products generated by this kind of probability survey: 1) population estimates based on the reconnaissance data, 2) condition estimates (and their underlying cumulative distribution frequency plots) of the target population, 3) stressor extent estimates of the percent stream length with stressor values greater than set thresholds, and 4) relative risk estimates of the increased risk of biological impairment associated with stressor levels in exceedance of the thresholds used in the stressor extent estimates. We produced these products for several different temporal ranges: 1) annual estimates, 2) five sets of four-year rolling averages (2000-2003, 2001-2004, 2002-2005, 2003-2006, 2004-2007), and 3) one overall eight-year combined estimate.

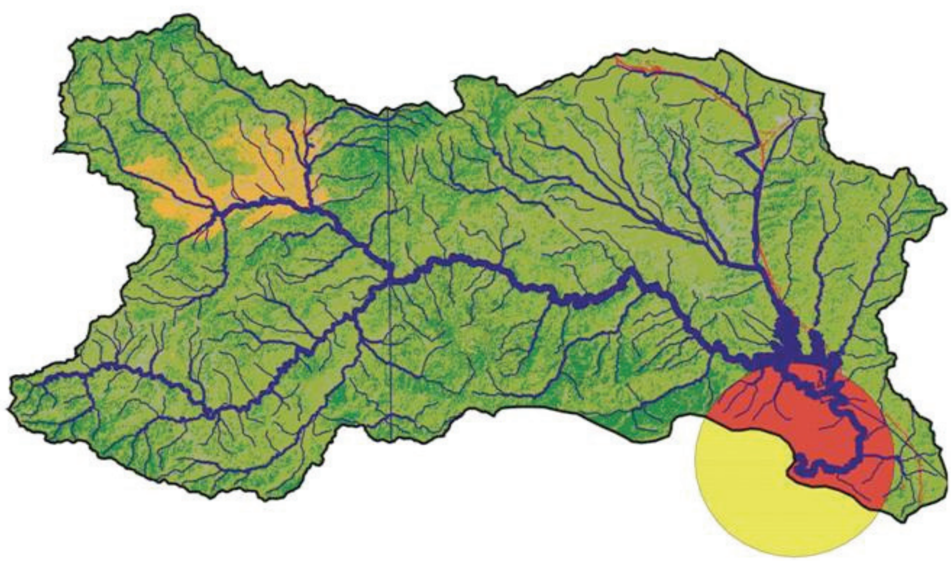


Figure A-1. Example watershed showing a 1 km surrounding a survey point. The percent of land used for agriculture, urban and other uses was calculated upstream of each survey point (area in red) for three spatial scales: 1 km, 5 km and watershed scale.

To address the NPS classes, we also produced combined estimates for the major products (resource estimates, condition estimates, stressor extent estimates and relative risk estimates) for each of the four land cover/land use classes defined in the CMAP program (agricultural, urban, forested and other).

Combining Multiple Surveys and Re-assignment of Weights

All probabilistic survey analyses were derived using the "psurvey.analysis" scripts developed in the R programming language (Version 2.4.1, www.r-project.org) by the EPA's Office of Research and Development in Corvallis, Oregon (see US EPA's ORD website, http://www.epa.gov/nheerl/arm/analysispages/monitanalysisinfo.htm, for more detailed discussion). The analysis package was used to combine the 6 design models and adjust site weights to reflect their percent contribution to the target population. The presence of the CMAP land use stratification element required us to assign all EMAP sites (including those in the reconnaissance set) to one of the four CMAP land use classes, greatly complicating the weight adjustment step.

Population (Resource Extent) Estimates

We used data from the reconnaissance effort to estimate the total stream length in the following categories: 1) the sampled target population (all perennial wadeable streams, TS + TNS), 2) the non-target population (NT), 3) stream length not sampled due to denial of landowner access (LD), and 4) stream length not sampled due to the presence of physical barriers to sampling (PB).

Most of the non-target stream length was comprised of dry channels or otherwise non-perennial streams, but a small percentage consisted of pipelines or constructed channels that were erroneously coded as natural stream channels in current NHD+ hydrology. Two common fates of prospective sites in the reconnaissance effort (landowner denial, LD and permanent barriers, PB) represented approximately 20% of total stream length (approximately 84,000 km), for which we could not determine flow status. For our extrapolated estimates of perennial and non-perennial stream length, we added a portion of the unknown length (LD, PB and NS) to the perennial and non-perennial estimates based on their respective proportions (e.g., 21 and 79%, respectively for the statewide estimates) in the known population.

Condition Assessments

Adjusted sites weights were used in conjunction with the O/E scores calculated for each sampled target site to estimate the percentage of stream miles in three ecological condition categories: "Good", "Degraded" and "Very Degraded"[22]. We used thresholds of 1.5 and 3 standard deviations below the mean reference O/E score (the score expected in the reference state) to set the boundaries between "Good" and "Degraded" , and

22. In prior reports, we used the terms "Impaired" and "Very Impaired" to refer to biological conditions outside those expected under reference condition, with no intention of implying any regulatory meaning. We have adopted the new terminology to avoid confusion with the regulatory meaning of "impairment".

between "Degraded" and "Very Degraded", respectively. We used separate thresholds (listed in Appendix A, Table A-3) for each of the three submodels based on the mean and standard deviations of the submodels.[23]

Assignment of Stressor Thresholds for Stressor Extent and Relative Risk Estimates

We calculated stressor extent and relative risk estimates using two sets of thresholds (most disturbed and least disturbed) to identify the proportion of stream length associated with exceedance of these thresholds and increased risk associated with this exceedance (Table 3).[24] These thresholds are identical to those used in the EMAP West analyses (Stoddard et al. 2005) where the stressors overlap. Land use thresholds were the same as those used for land use assignments and thresholds for the remaining stressors (Chloride, total suspended solids, turbidity and Percent Fines & Sand) were assigned by the authors based on the distribution of stressor values in the combined dataset.[25]

Stressor Extent

For our stressor extent and relative risk estimates, we evaluated fourteen local and watershed scale attributes that had the potential to affect biological condition of the sampling sites. There are three attribute categories: 1) ambient water chemistry, 2) land use, 3) local physical habitat (instream and riparian). Land use variables were based on the three spatial scales used to assign sites to land use/ land cover classes (watershed, 5k buffer, 1k buffer). We evaluated three land cover measures (% agricultural, % urban, % un-natural (AG + URB). Most of the 14 stressor variables can be directly or indirectly altered as a result of human activity and have been known to have harmful effects on stream biota (Stoddard et al. 2005). Physical habitat variables in particular were selected to reflect a range of instream and riparian impacts likely to affect benthic macroinvertebrate condition (Kaufmann et al. 1999).

Relative Risk and Attributable Risk

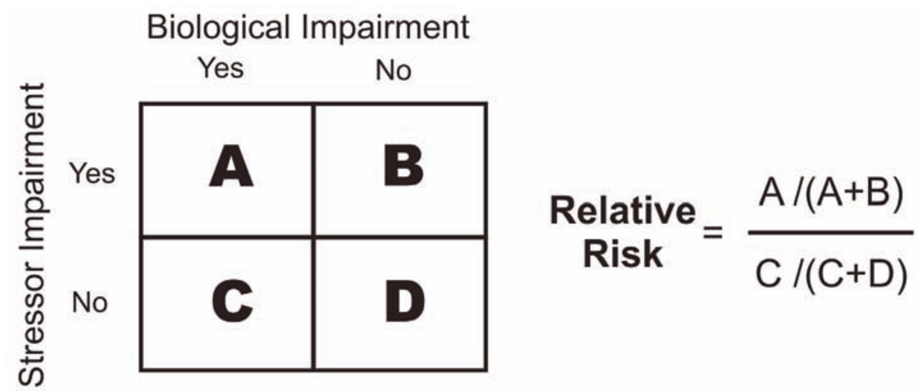
Relative risk and population attributable risk are measures adapted for biological surveys from the field of human epidemiology (Van Sickle and Paulsen 2008). Relative risk is the increased risk of biological impairment associated with the presence of high levels of a given stressor, whereas attributable risk combines relative risk and stressor extent into a single impact factor.

23. In previous reports, we used the average standard deviation for the three sub-models (0.15). The correction in the current version resulted in slightly higher estimates of overall impairment.

24. Note that several of the EMAP thresholds differ for the two major ecoregion groupings (mountain and xeric) used in the analyses. All stressors and their thresholds are presented in Table 3.

25. Since chemical concentrations vary diurnally and seasonally, the stressor extent and relative risk estimates for these analytes should be interpreted carefully. Sampling was performed during index periods that were defined to represent periods of stable base flow. Chemical concentrations are therefore likely to have higher peaks at some point in a year than we measured. Thus, our stressor extent estimates are likely underestimates for highly variable measures.

Relative risk estimates were generated using the relative risk function developed for the probability survey scripts in the psurvey.analysis package (Van Sickle et al. 2006). The function calculates relative risk as the ratio of two ratios:



Two sets of relative risk estimates were calculated for both the statewide and land use results using the upper and lower impairment thresholds defined in Table B-3.

Population attributable risk is the percent reduction in the extent of poor biological condition that would result from the removal of a stressor. Attributable risk was calculated using the same 2 x 2 table used to calculate relative risk, but also incorporated stressor extent estimates following methodology described by Van Sickle and Paulsen (2008). R scripts for the attributable risk analysis were developed by T. Kincaid and are part of the psurvey package.

Table A-1
Number of Sites Surveyed Each Year Under the EPA's Environmental Monitoring Assessment Program (EMAP) and California's Monitoring and Assessment Program (CMAP) programs, Listed by Land Use Assignment.

Project	Sampling Year	Total	Agricultural	Urban	Forest	Other	Urban/Forest	Urban/Agirculture	Agriculture/Forest	Comments
EMAP	2000	31	0	0	17	13	0	1	0	First year of project, ~50% normal sampling effort
	2001	67	2	2	30	33	0	0	0	Normal sampling year
	2002	65	4	5	29	27	0	0	0	Normal sampling year
	2003	28	0	4	6	18	0	0	0	All but 3 sites in Central Coast supplemental project area; ~25 additional EMAP targeted reference sites (don't contribute to condition assessments)
CMAP	2004	51	5	11	11	23	0	0	1	Normal sampling year
	2005	51	7	10	12	21	1	0	0	Normal sampling year
	2006	50	8	11	13	15	1	2	0	Includes 9 sites from supplemental canal design (not included in primary assessments)
	2007	50	11	21	5	10	0	3	0	Includes 11 sites from supplemental canal design (not included in primary assessments)
TOTAL		393	37	64	123	160	2	6	1	Total Agriculture = 44 sites, Total Urban = 72 sites, Total Forest = 126 sites

Table A-2
A Conversion Of The Coding Scheme For The 2001 National Land Cover Dataset (NLCD) To The California Perennial Streams Assessment (PSA) Land Cover Categories.

NLCD 2001 Land cover Coding Scheme			
NLCD Code	**NLCD Definition**	**PSA Land Cover Class**	**ATtILA Custom Codes**
11	Open Water	Not assigned	Water/ No Data
12	Perennial Ice/ Snow	Not assigned	Water/ No Data
21	Developed, Open Space (e.g., lawns, parks, roadside vegetation)	Code 21 (assigned conditionally)	Urban/ Recreational Grasses
22	Developed, Low Intensity	URBAN	Low Density Residential
23	Developed, Medium Intensity	URBAN	High Density Residential
24	Developed, High Intensity	URBAN	Commercial/ Industrial
31	Barren Land	OTHER	Natural Barren
41	Deciduous Forest	FOREST	Forest
42	Evergreen Forest	FOREST	Forest
43	Mixed Forest	FOREST	Forest
52	Shrub/ Scrub	OTHER	Shrublands
71	Grasslands/ Herbaceous	OTHER	Natural Grasslands
81	Pasture/ Hay	AGRICULTURE	Pasture
82	Cultivated Crops	AGRICULTURE	Row Crops
90	Woody Wetlands	OTHER	Wetlands
95	Emergent Herbaceous Wetlands	OTHER	Wetlands

Other = other natural landscapes, ATtILA = Analytical Tools Interface for Landscape Assessments.

Table A-3
Stressor Thresholds Used For Calculating Stressor Extent and Relative Risk Estimates.

Stressor Type	Variable Name	Stressor Description; Units	Severe Threshold Xeric	Moderate Threshold Xeric	Severe Threshold Mountain	Moderate Threhsold Mountain
Water Chemistry	Cl^-	*chloride; µg/L*	> 245	< 100	> 245	< 100
	NTL	*total nitrogen; µg/L*	**> 600**	**≤ 200**	**> 200**	**≤ 125**
	PTL	*total phosphorus; µg/L*	**> 175**	**≤ 40**	**> 40**	**≤ 10**
	COND	*specific conductance; µS/cm*	**> 1000**	**≤ 500**	**> 1000**	**≤ 500**
	TSS	*total suspended solids; mg/L*	> 50	≤ 15	> 50	≤ 15
	TURB	*turbidity; ntu*	> 20	≤ 5	> 20	≤ 5
	CHL a	*chlorophyll a; mg/m2*	200	150	200	150
	AFDM	*algal biomass, (ash free dry mass); g/m2*	> 20	< 10	> 20	<10
Land use (@3 scales: 1k, 5k, ws)	*U_INDEX*	***Ag + Urb; Unnatural Index = % agricultural + % urban***	> 40	< 10	> 40	< 10
	URB	*percent urban land uses (NLCD 2001 codes 21, 22, 23, 24)*	> 25	< 5	> 25	< 5
	AG	*percent agricultural land uses (NLCD 2001 codes 81, 82)*	> 50	< 10	> 50	< 10
	IMPERV	*percent impervious surface (from NLCD 2001)*	> 10	< 2	> 10	< 2
Biological Condition	*OE_MMI_adj*	*OE_RWB, but replaced OE score with Central Valley MMI score for CV sites; scores adjusted to correct for RWB/TRC bias* Model 1: mean = 1.03, sd = 0 .13; Model 2: mean = 1.02, sd = 0.16; Model 3: mean = 1.02, sd = 0.15	< 3sd below mean of reference	>1.5 sd below mean of reference	< 3sd below mean of reference	>1.5 sd below mean of reference
Physical Habitat	LRBS	**Bed Stability**; EMAP streambed stability (Phil Kaufmann); both high and low values are considered impaired (represent high levels of fining and winnowing)	**< -1.7 or > 0.3**	**≥ -0.9 and ≤ -0.1**	**< -1.3 or > 0.6**	**≥ -0.7 and ≤ 0.1**
	PCT_SAFN	**Percent Fines + Sand (< 2.0 mm)**; two thresholds defined — low	> 25	< 10	> 25	< 10
		high	> 40	< 20	> 40	< 20
	XEMBED	**Mean Embeddedness** of substrates by fine particles (EMAP method)	75	50	75	50
	W1_HALL	**Riparian Disturb**; EMAP composite riparian disturbance index	**> 0.9**	**≤ 0.7**	**> 0.95**	**≤ 0.35**
	XCMGW	EMAP composite **riparian vegetation** complexity index	**< 0.132**	**≥ 0.270**	**< 0.23**	**≥ 0.67**
	XFC_NAT	EMAP composite **habitat complexity** index	**< 0.32**	**≥ 0.60**	**< 0.14**	**≥ 0.33**

Thresholds in were derived using a Pearson Correlation Matrix of relationships among the major stressor variables. Thresholds in bold were used for the EPA's Western EMAP condition assessments, while thresholds in italics were assigned by the authors as described in the text. OE: Observed/Expected, TRC: Targeted Riffle Composite, RWB: Reach-wide Benthos, MMI: Multi-metric Index (ie: Index of Biotic Integrity).

Table A-4
Pearson Correlation Matrix of Relationships Among the Major Stressor Variables.

	Impervious Surface_1km	Impervious Surface_5km	Impervious Surface_ws	Agricultural_1km	Agricultural_5km	Agricultural_ws	Urban_1km	Urban_5km	Urban_ws	Agricultural+Urban Index_1km	Agricultural+Urban Index_5km	Agricultural+Urban Index_ws	Algal Biomass	Chlorophyll a	Total Nitrogen	Total Phosphorus	Chloride	Specific Conductance	Total Suspended Solids	Turbidity	Mean Embeddedness	Percent Fines & Sand	Bed Stability	Habitat Complexity Index	Riparian Vegetation Complexity Index	Riparian Disturbed Index
Riparian Disturbed Index	0.52	0.49	0.30	0.33	0.37	0.19	0.54	0.50	0.32	0.63	0.60	0.36	0.05	0.19	0.24	0.28	0.21	0.22	0.25	0.29	0.38	0.39	-0.32	-0.23	-0.25	1.00
Riparian Vegetation Index	-0.19	-0.17	-0.12	-0.24	-0.27	-0.27	-0.15	-0.16	-0.14	-0.25	-0.29	-0.24	0.00	-0.11	-0.14	-0.01	-0.13	-0.20	-0.21	-0.21	-0.12	-0.15	0.15	0.35	1.00	
Habitat Complexity Index	-0.24	-0.17	-0.14	-0.19	-0.20	-0.17	-0.24	-0.18	-0.14	-0.30	-0.26	-0.20	0.02	-0.12	-0.11	-0.10	-0.12	-0.20	-0.10	-0.13	-0.13	-0.25	0.16	1.00		
Bed Stability	-0.13	-0.15	-0.14	-0.35	-0.35	-0.36	-0.19	-0.15	-0.15	-0.35	-0.33	-0.29	-0.15	0.01	-0.22	-0.17	-0.22	-0.26	-0.17	-0.14	-0.82	-0.81	1.00			
Percent Fines & Sand	0.29	0.35	0.40	0.35	0.41	0.37	0.34	0.35	0.39	0.48	0.52	0.51	0.13	0.03	0.28	0.24	0.33	0.40	0.16	0.15	0.90	1.00				
Mean Embeddedness	0.19	0.25	0.28	0.30	0.33	0.31	0.25	0.26	0.28	0.38	0.40	0.38	0.10	-0.01	0.21	0.18	0.27	0.34	0.14	0.14	1.00					
Turbidity	0.16	0.07	0.07	0.20	0.24	0.08	0.23	0.08	0.06	0.30	0.21	0.09	-0.04	-0.04	0.03	0.24	0.09	0.12	0.92	1.00						
Total Suspended Solids	0.13	0.05	0.05	0.24	0.28	0.12	0.20	0.05	0.04	0.30	0.21	0.09	-0.01	-0.03	0.12	0.28	0.15	0.18	1.00							
Specific Conductance	0.15	0.21	0.24	0.29	0.30	0.37	0.15	0.21	0.23	0.29	0.34	0.37	0.11	0.21	0.59	0.27	0.77	1.00								
Chloride	0.16	0.25	0.26	0.15	0.18	0.22	0.15	0.24	0.25	0.22	0.30	0.32	0.10	0.21	0.35	0.41	1.00									
Total Phosphorus	0.16	0.17	0.26	0.10	0.13	0.05	0.20	0.17	0.25	0.22	0.21	0.23	0.03	0.11	0.14	1.00										
Total Nitrogen	0.09	0.22	0.35	0.44	0.42	0.46	0.08	0.20	0.31	0.32	0.41	0.48	0.05	0.13	1.00											
Chlorophyll a	0.22	0.18	0.09	0.12	0.08	0.09	0.18	0.21	0.08	0.22	0.21	0.11	0.49	1.00												
Algal Biomass	0.02	-0.03	-0.05	0.03	0.04	0.05	0.02	-0.01	-0.06	0.03	0.02	-0.02	1.00													
Agricultural+Urban Index_ws	0.48	0.71	0.87	0.34	0.39	0.54	0.47	0.72	0.89	0.59	0.79	1.00														
Agricultural+Urban Index_5km	0.64	0.78	0.65	0.57	0.65	0.51	0.59	0.80	0.66	0.81	1.00															
Agricultural+Urban Index_1km	0.77	0.62	0.47	0.56	0.55	0.41	0.82	0.63	0.46	1.00																
Urban_ws	0.53	0.80	0.97	0.06	0.06	0.09	0.52	0.81	1.00																	
Urban_5km	0.79	0.98	0.79	0.06	0.06	0.07	0.72	1.00																		
Urban_1km	0.94	0.71	0.51	0.00	0.06	0.07	1.00																			
Agricultural_ws	0.06	0.08	0.11	0.62	0.75	1.00																				
Agricultural_ws_5km	0.05	0.06	0.07	0.88	1.00																					
Agricultural_ws_1km	-0.01	0.05	0.07	1.00																						
Impervious Surface_ws	0.52	0.79	1.00																							
Impervious Surface_5km	0.79	1.00																								
Impervious Surface_1km	1.00																									

Highlighted cells indicate Pearson "r" values: less than -0.5 (blue); between 0.5 and 0.7 (yellow); and 0.7 and greater (orange). AG = agricultural, IMPERV = impervious surface, ws = watershed scale, 5k = 5 kilometer scale, 1k = 1 kilometer scale. See Table A-3 for "variable Name.

APPENDIX B
EFFECTS OF SCORING ADJUSTMENTS ON ASSESSMENT RESULTS

INFLUENCE OF CANAL DESIGN ON OVERALL ASSESSMENTS

The addition of the data from the 2006-2007 Canal Survey had minimal impact on the overall assessment (Figure 8). However, two primary factors led us to determine that inclusion of the canal design was too problematic for use in these assessments: 1) extreme problems with obtaining access permission have the potential to introduce large amounts of unpredictable bias into the assessments, and 2) management of canals to eliminate habitat (i.e., dredging) and biological organisms make measurement of biological condition unrealistic, if not meaningless. Therefore, implementation of the canal design was halted in mid-2007 and all further analyses in this report were performed without the data from the canal design.

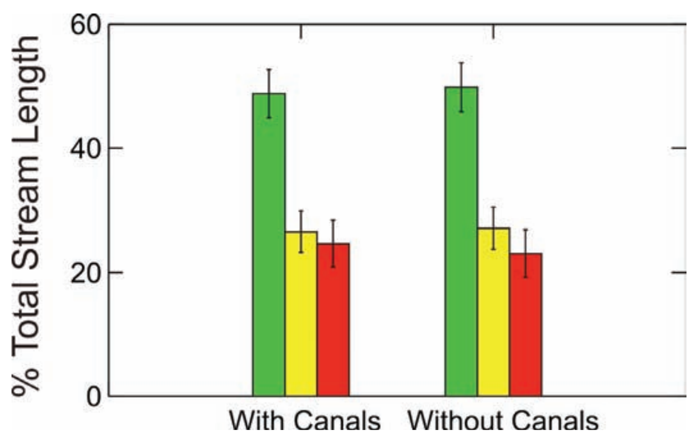


Figure B-1 Overall (eight-year) condition estimates produced with data from canal design included or excluded. Green = good biological condition, yellow = degraded biological condition, red = very degraded biological condition (see text for additional explanation).

CHANGES TO BMI SCORING METHODS

There were three significant differences between the scoring methods used in the previous two condition assessments (Ode and Rehn 2005, Ode 2007) and this report:

1. Since California's water quality programs (SWAMP) have moved toward a reachwide sampling approach as the standard field method in most cases, we used reachwide samples for scoring sites in all analyses in this report. In previous reports we based our analyses on scores calculated from the targeted riffle samples (since the models were based on TRB data), but we used RWB samples in the handful of cases where TRB data were unavailable or had low counts (<275 organisms after subsampling and elimination of ambiguous taxa).
2. We replaced O/E scores for all Central Valley sites with the newly developed Central Valley IBI (Rehn et al. 2009).
3. Since the O/E models (developed with TRC data) have a slight tendency to underscore RWB samples (Rehn et al. 2007), we added 0.04 to all RWB scores to correct for the bias. Since the magnitude of the RWB<TRB bias did not differ among submodels (Ode unpublished data), we used the same correction factor for all models.

We evaluated the effects of these changes by comparing the overall condition scores produced under various permutations of these changes (different versions are listed in Table B-1).

The impact of various scoring systems on overall (eight-year) condition estimates is presented in Figure B-2. The transition to RWB based BMI scores ("OE_TRC_RWB" vs. "OE_RWB") slightly lowered overall condition estimates, but the RWB correction ("OE_RWB" vs. "OE_RWB_adj") eliminated this issue. The replacement of OE scores with MMI scores at Central Valley sites ("OE_MMI_adj" vs. "OE_RWB_adj") slightly raised the average condition scores.

Table B-1
Five Versions of the Benthic Invertebrate Scoring Index Used To Quantify the Effects of Adjustments.

Biological Indicator Version	Description	Comments
OE_TRC_RWB	O/E Score (Chironomidae to subfamily, p= 0.5 threshold); used TRC method as default, substituting RWB when TRC not available; this is the scoring measure used in previous assessments	This is the scoring method used for previous statewide condition assessments
OE_RWB	O/E Score (Chironomidae to subfamily, p= 0.5 threshold); RWB used exclusively (no TRC data)	This version demonstrates the impact of switching from a primarily TRC method to RWB statewide
OE_MMI	O/E Score (Chironomidae to subfamily, p= 0.5 threshold); Same as OE_RWB, but Central Valley MMI used at Central Valley sites	This version demonstrates the impact of scoring CV sites with the new CV MMI
OE_RWB_adj	O/E Score (Chironomidae to subfamily, p= 0.5 threshold); Same as OE_RWB, but adjusted RWB scores (+0.04) to account for RWB < TRC bias	This version demonstrates the impact of adjusting RWB scores to account for RWB < TRC bias
OE_MMI_adj*	O/E Score (Chironomidae to subfamily, p= 0.5 threshold) Same as OE_RWB, but replaced O/E score with Central Valley MMI score for CV sites; scores adjusted to correct for RWB/TRC bias	Includes both the CV IBI and scoring bias corrections. *This scoring method is used in all subsequent analyses in this report

These indices were used to quantify the effects of adjustmentsto the scoring system between previous condition assessments and those presented in this report. Biological Indicator version: O/E = observed/expected; TRC = Targeted Riffle Composite; RWB = Reachwide Benthos; MMI = Multi-metric Index; CV = Central Valley

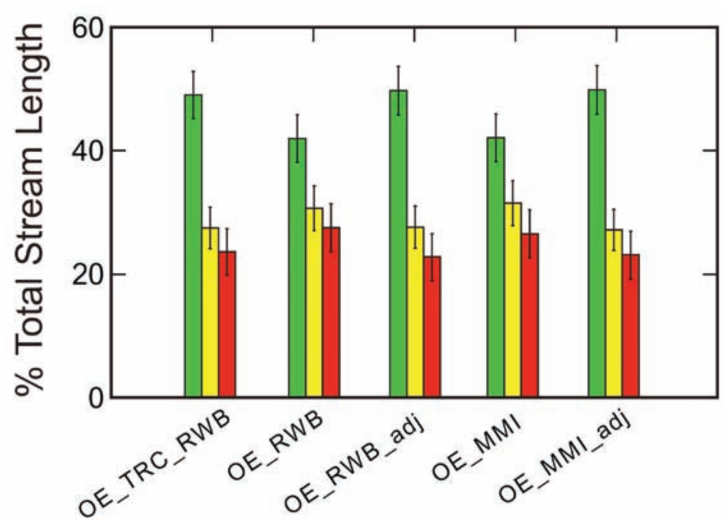


Figure B-2. Overall (eight-year) condition assessments based on five different versions of the biological scoring index. Green = good, yellow = degraded, red = very degraded, biological condition. O/E = observed/expected; TRC = Targeted Riffle Composite; RWB = Reachwide Benthos; MMI = Multi-metric Index; such as Biological Condition Score.

APPENDIX C
CUMULATIVE DISTRIBUTION FUNCTIONS

We have used a suite of graphical approaches (e.g., pie charts, bar charts and boxplots) throughout this report to summarize data and emphasize key points. However, probability datasets lend themselves to a richer way of displaying the distribution data underlying these graphics called cumulative distribution functions (CDFs). The following figures present example CDFs that illustrate some of the kinds of information that can be read from these graphs.

CDFs are simply plots of a given variable (typically displayed on the x-axis) against the cumulative total of variable values (y-axis). In the example in Figure C-1, the cumulative total stream length represented by sampling sites is plotted as a function of biological condition scores. Each solid dot represents a single site and the vertical distance between dots represents the contribution of that site to the total stream length in the population (i.e., California perennial streams). The open dots represent the upper and lower 95% confidence limits around the solid dots.

Because all sites were selected randomly, we can use the CDF relationship to create bar charts and pie charts (or read this information directly from the graphs). The colored dotted lines in the lower graphic in Figure C-1 represent the two biological impairment thresholds used in our analyses. The yellow and red bars represent the moderate and severe biological impairment thresholds, respectively. The horizontal arrows indicate the corresponding percentages of stream length having poorer biological condition scores than these thresholds (i.e., 51 and 24%, the numbers in the pie charts in Figure 5). A key advantage of CDFs is that they allow the reader to quickly see the effect of changing thresholds on the final assessment results thus providing transparency and conveying much information in a compact form.

Figure C-2 illustrates another feature of CDFs -- the ability to quickly compare different distribution patterns. The arrows in the figure indicate the % of stream length corresponding to the very degraded biological condition threshold for each of the four NPS categories; the information in this figure is the basis of the bar chart in Figure 13.

These figures represent two examples, but CDFs could be generated for any of the relationships presented in this report. CDFs could be made for any combination of stressor variable and at any spatial or land use/land cover grouping.

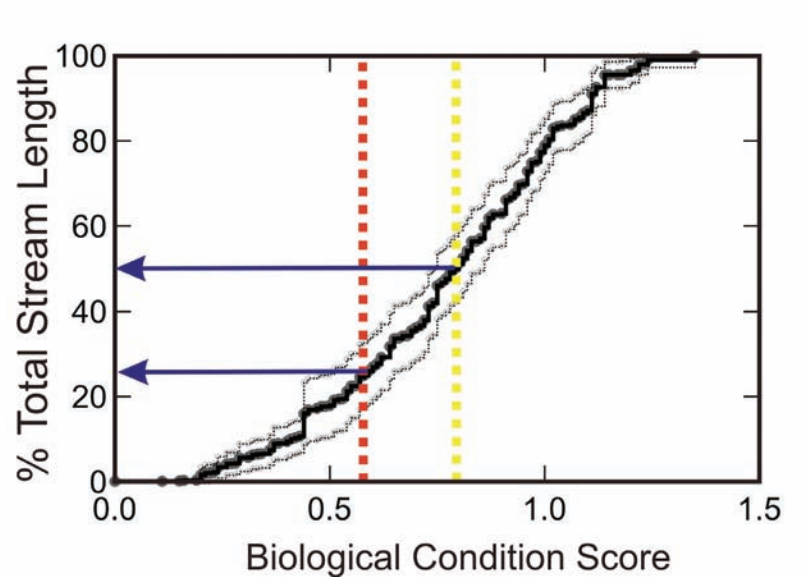


Figure C-1. Cumulative distribution graph of biological condition scores with upper and lower 95% confidence limits, and biological condition thresholds, representing eight-years of stream surveys. The heavy black line composed of points indicates the biological condition score from each site. The dotted gray lines represent the upper and lower 95% confidence limits of the scores. The yellow line indicates a threshold point, below which biological condition scores are degraded. The red line indicates the threshold point below which biological condition scores are very degraded. Each threshold corresponds to a specific percent of stream length (indicated by the blue arrows).

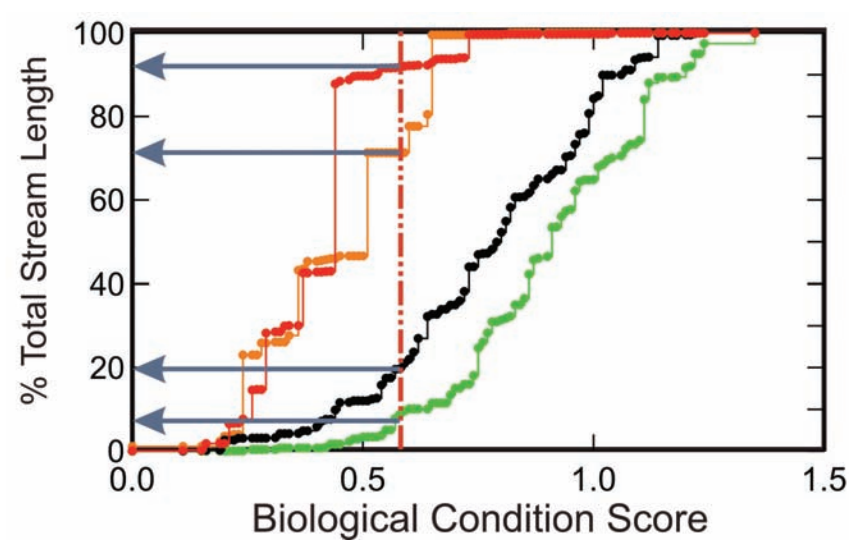


Figure C-2. Overall cumulative distribution of biological condition scores for each of four land cover classes, derived from eight years of stream surveys. Each point on the lines, represents a biological condition score for a stream running through a particular land use area: Red = urban sites, Orange = agricultural sites, Green = forested sites, and Black = other sites. The red line indicates a biological condition score threshold demarcating the point below which sites are in very degraded condition. The corresponding percent of stream length falling below this threshold is indicated on the y-axis (see gray arrows).

APPENDIX D
RESOURCE EXTENT ESTIMATES AND RECONNAISSANCE FATES

RESOURCE EXTENT ESTIMATES

The exact sizes of California's stream network and its perennial and non-perennial components are unknown and challenging to measure. Like most states and federal agencies, California's resource agencies rely on GIS layers that were originally digitized from USGS topographic maps. The resolution and accuracy of these layers varies considerably throughout the state due to changes in cartographic technologies over time and the large number of subjective decisions involved in delineating streams and assigning flow status. This problem is especially acute in arid regions. However, flow status often has important regulatory implications (e.g., which segments are subject to various regulatory requirements), so there is a clear need for accurate estimates. Probability surveys provide a means to calculate independent, field-based estimates of the relative proportion of perennial and non-perennial stream length.

We calculated statewide estimates, regional estimates and estimates for each of the four land use categories using NHD+ hydrology[26] and reconnaissance data from our surveys. Estimates of the percentage of stream length and total stream length represented by different reconnaissance fates are presented in Appendix E (Tables E-1, E-2) and percentages are presented for the eight-year averages in Figure D-3.

Statewide Extent Estimates

The total length of California's hydrography network (including streams, canals, pipelines, etc.) is defined by NHD+ as 339,541 km. Approximately 284,000 km of this was designated as either a perennial or non-perennial stream. Based on this survey, approximately 92,000 km (~34%) is perennial streams. Approximately 6,200 km of the perennial population is non-wadeable rivers, thus the total perennial, wadeable stream length in California is estimated to be approximately 85,000 km. The vast majority of the remaining non-target stream length (~180,000 km) is non-perennial (Table D-1, Appendix E)[27]. The remainder of non-target NHD+ stream length (~56,000 km) consisted of pipelines, ditches, canals, coastline, artificial paths or reflects mapping errors. In this section, we use the total perennial and non-perennial stream length estimated from this survey as the basis for our regional and land use length

26. NHD+ is a modified version of the National Hydrography Database (NHD).

27. We use the term non-perennial to designate all channels that have water for at least a few days of the year, but less than year-round (this definition includes both "intermittent" and "ephemeral" streams).

estimates. Non-perennial length was calculated from the reconnaissance fate data (Appendix E, Table E-1) as the sum of known non-perennial streams (NT-NP) plus a percentage of the stream length in the landowner denial (LD) and physical barrier(PB) categories proportional to the percentage of NP stream length in the rest of the population (Total – NT_Other, PB and LD). Perennial stream length was the sum of targeted stream length (TS + TNS), non-wadeable streams, and a percentage of the LD and PB length proportional to total P streams.

REGIONAL EXTENT ESTIMATES (PSA REGIONS)

The geographic regions used for SWAMP's PSA surveys are illustrated in Figure D-1.[28] As with the statewide results, the total stream length in each region was derived directly from the NHD+ hydrology, but the relative proportions of perennial and non-perennial streams were estimated from the survey (Table D-1). For comparison, values defined by the NHD + layers are listed in Table D-3.

A similar but less extreme pattern was seen in the Desert-Modoc regions. In contrast, our surveys estimated that there was 50% more non-perennial stream length in the North Coast region than indicated in the NHD + (28% vs. 45% NP).

Non-Point Source (NPS) Extent Estimates

The CMAP program focused on four non-point source categories of land use/land cover: 1) urban, 2) agricultural, 3) forested[29] and 4) "other". We assigned sites to NPS categories based on percentages of these land cover classes in the drainage upstream of each site.[30] Of the 280,000 km of streams in the state, most of the stream length fell in our "other" (~137,000 km) or "forested" (115,000 km) categories. The remaining stream length was strongly associated with either agricultural (~26,000 km) or urban land uses (4,000 km).[31]

The ratio of perennial to non-perennial streams varied considerably among the land use categories, but perennial stream length was smaller than the total non-target stream length in all NPS groups (Figure D-2, Table D-2). Urban streams had the highest proportion of perennial stream length (66%), followed by forested streams, about a third of which were perennial. Agricultural regions were mostly comprised of non-perennial streams.

28. The PSA boundaries sub-divide the state into reporting regions based primarily on ecological similarity, but the boundary lines were adjusted in some places to coincide with major program boundaries (e.g., SMC).
29. The CMAP program used the term "forested" because its focus was on the condition of streams that drain forested landscapes rather than the specific impacts of forestry or timber harvest land uses.
30. See Appendix A, "Recalculation of Land use Assignments" for a detailed explanation of the assignment criteria.
31. These estimates are strongly affected by the thresholds used to define inclusion in the category. See methods section for a detailed explanation.

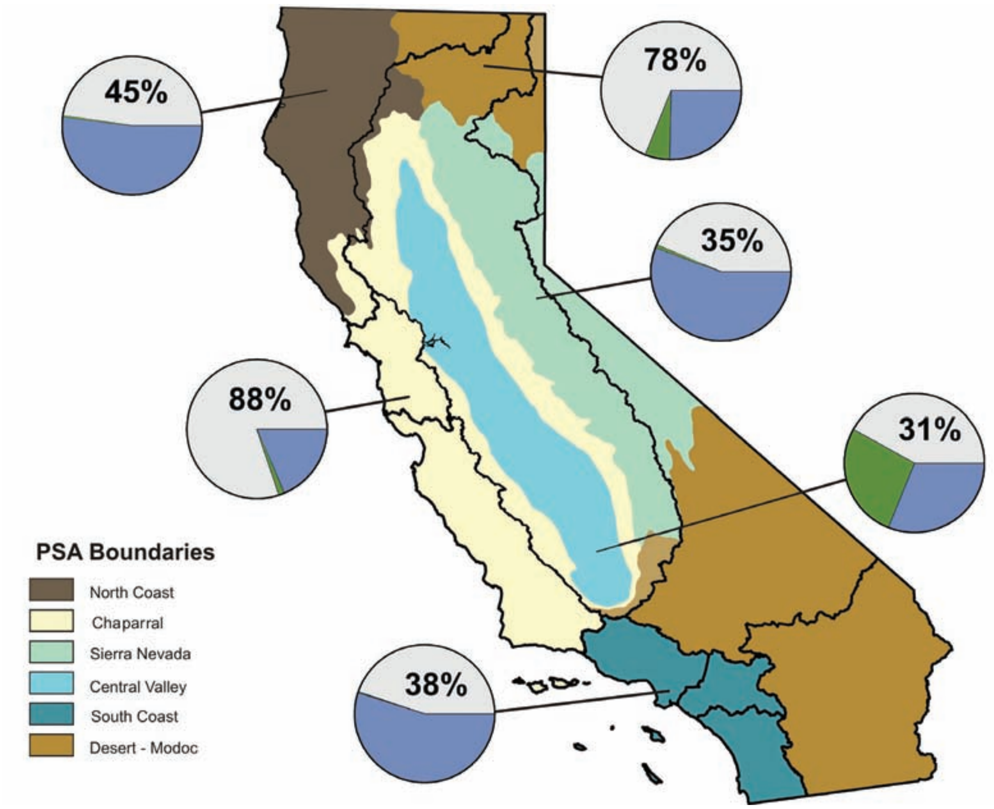


Figure D-1. Map of major Perennial Streams Assessment (PSA) regions with pie charts showing the relative proportion of perennial-wadeable (blue), perennial-non-wadeable (green) and non-perennial (gray) streams in each region. Thick black lines indicate Regional Water Board boundaries.

Table D-1
Extent Estimates of California's Perennial and Non-Perennial Stream length, by PSA Region.

Category		Central Valley	Chaparral	Deserts Modoc	North Coast	Sierra Nevada	South Coast	Statewide
Non-Perennial Streams	%	31	88	78	45	35	38	66
	km	4,127	71,096	61,693	16,406	14,648	7,557	179,860
Perennial Streams	%	69	12	22	55	65	62	34
	km	9,382	10,094	17,905	20,017	27,166	12,148	92,379
Total	%	5	30	29	13	15	7	100
	km	13,509	81,190	79,598	36,423	41,814	19,705	272,239

Total statewide stream length was defined in NHD+, whereas the perennial and non-perennial components were estimated from survey reconnaissance data.

Table D-2
Extent Estimates for Perennial and Non-Perennial Stream Length in Californiaa and in Each Non-Point Source (NPS) Category.

Category		Agricultural	Urban	Forested	Other
Perennial Streams	%	22	66	36	19
	km	5,672	2,591	41,191	26,605
Non-Perennial Streams	%	78	34	64	81
	km	20,215	1,339	73,850	110,256
Total	%	9	1.5	41	49
		25,887	3,930	115,042	136,861

Perennial streams include both wadeable and non-wadeable stream segments. The total stream length does not include approximately 32,000 km of miscoded linework in NHD+ (conveyances, map errors, buried pipelines, etc.).

Reconnaissance Fates

To prepare for each season's field work, survey field crews evaluate a list of candidate sampling sites for inclusion in the sampling pool. The primary reasons for site rejection are that a site isn't a wadeable, perennial stream (non-target), it is deemed too dangerous to access (physical barrier) or because access permission was not obtained (landowner denial). These reconnaissance "fates" differ among regions of the state and among different land use classes, often providing insights into the issues unique to these groups of streams. They also suggest avenues for improving the efficiency and effectiveness of the surveys.

Statewide

Approximately 63% of the total statewide stream length was non-target (Figure E-1). Of the stream length not classified as non-target, a significant proportion of California's total stream length could not be confirmed as either part of the target stream population or non-target, either because of denial of access by landowners (~14%) or physical barriers to sampling (~7%).

Non-Point Source (NPS) Land Cover Categories

There were marked differences in the issues involved in selecting the sampling sites for the four land use/ land cover categories (Figure D-1). Agricultural sites were frequently non-perennial or otherwise non-target, and were more likely than other categories to be denied access by landowners. In contrast, urban streams were subject to very little landowner denial, mostly a reflection of the high percentage of public ownership in urban regions. Forested streams had a higher proportion of stream length that was physically inaccessible, but were otherwise similar to the statewide averages.

PSA Regions

The reconnaissance fates of candidate sites in the PSA regions strongly reflected the predominant NPS classes in each region (Figure D-2). The South Coast region, which has a high proportion of urban and other publicly owned lands, had a high success rate, with relatively few barriers to sampling access. Streams in the North Coast and Sierra regions (with high proportions of forested lands) had both high permission denial rates and physical barriers (steep, remote canyons) to access. The Chaparral regions were very similar to statewide averages, as might be expected given their mixed land uses.

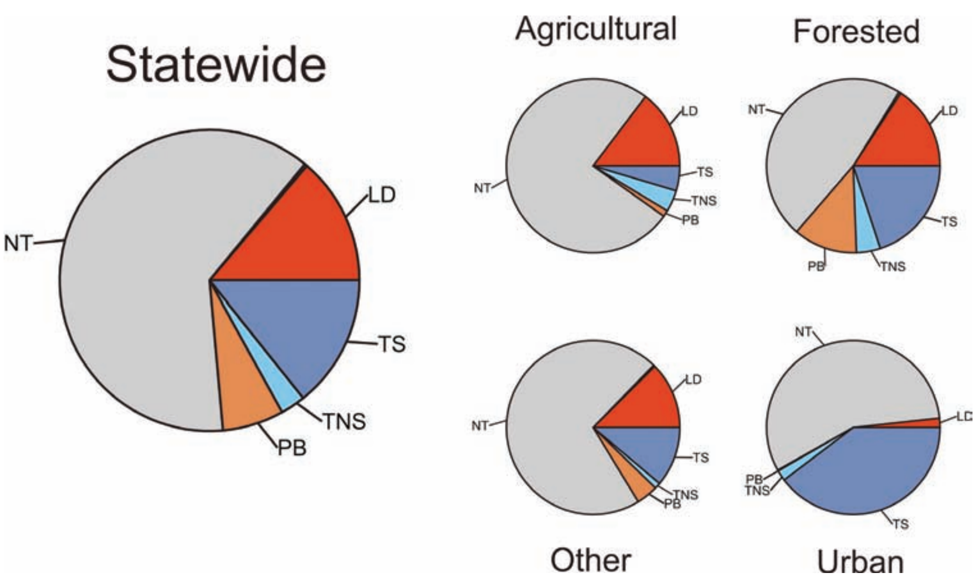


Figure D-2. Estimates (All Years: 2000-2007) of the percentage of total stream length falling into one of five reconnaissance fate classes: LD = landowner denial, NT = non-target, PB = physical barrier, TNS = target, not sampled, TS = target sampled. Results are shown for all sites for each of the four land cover/ land use classes. (Percentages and total stream length estimates are listed in Appendix E, Table E-1.)

Resource Extent Estimates: Implications

The large proportion of non-perennial stream length across all regions of California has significant implications for water quality monitoring in the state. Although these ecosystems are non-perennial, they often support rich biotic communities both in the stream channels and in surrounding riparian zones. In addition, these streams collectively drain large areas of land, which can result in concentrated seasonal impacts to downstream perennial flows. This issue is especially acute in dry regions of the state (e.g., Chaparral, South Coast, Desert-Modoc).

Despite the fact that non-perennial streams often comprise the majority of stream length and fall under the jurisdiction water boards under the Porter-Cologne Act, very few of California's monitoring resources are currently invested in non-perennial systems. Clearly, these habitats would benefit from increased attention.

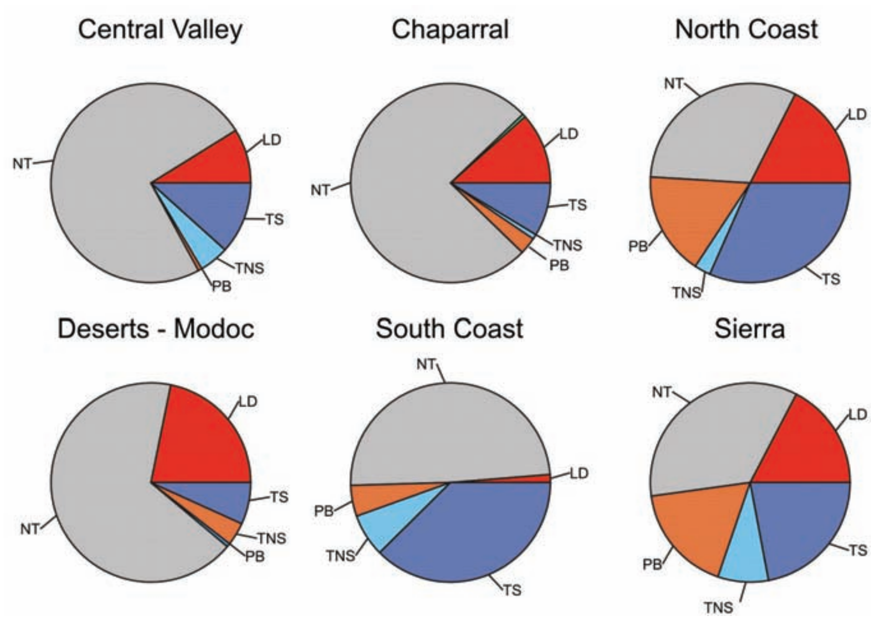


Figure D-3. Estimates of the percentage of total stream length falling into one of five reconnaissance fate classes: LD = landowner denial, NT = non-target, PB = physical barrier, TNS = target, not sampled, TS = target sampled. Results are shown for the six Perennial Streams Assessment (PSA) regions of California. (Percentages and total stream length estimates are listed in Appendix E, Table E-2.)

On a practical level, the large proportion of non-target stream length added significant labor costs to the reconnaissance efforts and contributes to the overall error in our condition estimates, and stressor extent estimates and risk assessments. The significant proportion of stream length that we were unable to assign to either the target or non-target populations (due primarily to landowner denials) further reduced the proportion of the resource that we were able to assess. These factors were most prominent in forested regions (North Coast and Sierra Nevada). It is likely that some of this unassessed population is dominated by non-target stream channels (i.e., mostly dry, non-perennial streams), but this uncertainty also contributes to the overall variability in our assessments. These factors illustrate the need for stream layers that accurately reflect the location of perennial and non-perennial channels in the state and the need to improve landowner participation rates.

NHD+ TABLES: FCODES AND STRAHLER ORDER

The following tables describe the distribution of California's stream network. FCODES, which designate different channel types, are defined in NHD + documentation: http://nhd.usgs.gov/NHDinGEO_FCodes_by_layer.pdf.

Table D-3
Extent Estimates (in kilometers) of Stream Length Falling Under Specific National Hydrography Database Plus (NHD+) Codes, Within Each of the Major Perennial Streams Assessment (PSA) Regions.

NHD+ Flow Code	Central Valley (km)	Chaparral (km)	Deserts Modoc (km)	North Coast (km)	Sierra Nevada (km)	South Coast (km)	California Totals (km)
33400	47	78	82	21	17	93	338
33600	25,819	3,523	4,604	58	1,489	936	36,430
33601	172	130	233		0	27	562
34305		0		1	0		1
34306		0	5	0	7		13
41100		0	10	1	9		19
42800		0			1		1
42801	148	194	209	5	200	34	791
42802		0	2		0		2
42803	221	560	745	27	217	693	2,463
42804	1	0			0		1
42807		11			0		11
42809		7	2		50	1	60
42811		0			13		13
42813	5	9	3		0	2	19
43100		0	2	1	0		4
46003	17,299	62,780	78,818	9,369	18,930	20,403	207,598
46006	3,559	13,951	5,386	24,372	27,279	1,977	76,525
47800		0	87	27	156		270
48700		0	0	0	1		1
55800	2,363	2,646	3,115	822	1,874	636	11,456
56600	6	1,952		135	0	872	2,965
% Non-Perennial (NP= 46003)	83%	82%	94%	28%	41%	91%	73%
% Perennial (P=46006)	17%	18%	6%	72%	59%	9%	27%
Total P+NP	20,858	76,730	84,204	33,714	33,133	22,380	284,123
Total NHD+	49,639	85,840	93,303	34,841	50,243	25,675	339,541

Stream length values are presented in kilometers (km). Codes in red text indicate natural perennial and non-perennial channels.

Table D-4
Extent Estimates (in kilometers) of River Length for Medium and Large Rivers (4th order or greater) In Each of the Major Perennial Streams Assessment (PSA) Regions.

Strahler Order	Central Valley (km)	Chaparral (km)	Deserts Modoc (km)	North Coast (km)	Sierra Nevada (km)	South Coast (km)	California Totals (km)
null	30,109	11,934	32,794	1,049	4,990	4,630	85,507
1	8,452	45,555	37,795	20,956	27,482	12,947	153,186
2	3,805	14,110	13,050	6,074	8,966	4,140	50,145
3	2,465	7,323	5,832	3,431	4,938	2,234	26,223
4	1,836	3,980	2,031	1,784	2,377	1,071	13,078
5	1,003	1,985	1,081	880	1,319	530	6,798
6	1,220	902	721	384	171	123	3,521
7	718	38		283			1,039
8+	32	12					44
Large Rivers	4,808	6,918	3,833	3,331	3,867	1,723	24,480

Some line segments in NHD+ are disarticulated (canals, pipelines, coastline and some headwater streams, etc.). These segments are listed as "null".

APPENDIX E
SUPPLEMENTAL RESULTS

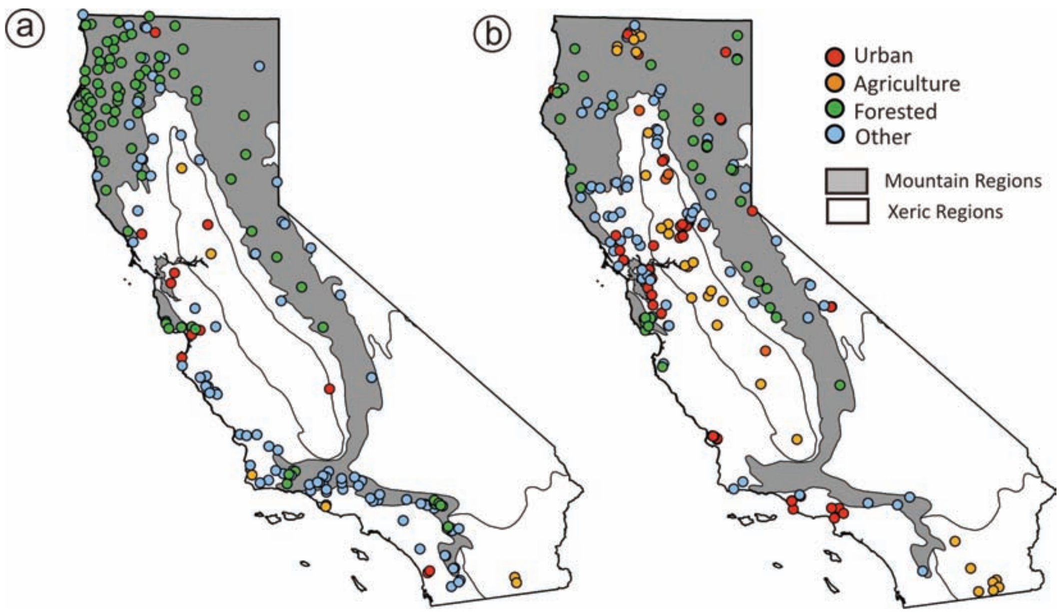


Figure E-1. Distribution of sites used in condition assessments coded by final land use designation: a) Environmental Monitoring Assessment Program (EMAP) sites and b) California Monitoring Assessment Program (CMAP) sites.

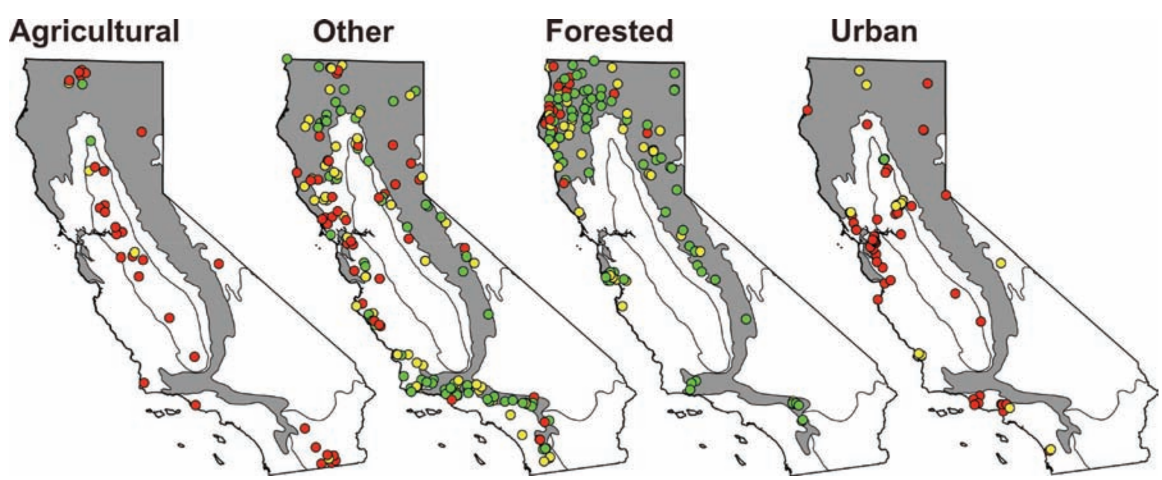


Figure E-2. Distribution of site scores in each of four Non-Point Source (NPS) categories. Green = good, yellow = degraded, red = very degraded.

Table E-1
Extent Estimates (in km and %) of Stream Resources Removed From The Random Sampling Process Due to Inaccessibility (or other confounding factors), Correlated With Specific Land Uses.

Subpopulation	Category	Number of Data Points	Stream Length (%)	Standard Error (%)	Lower Bound (%)	Upper Bound (%)	Stream Length (km)	Standard Error (km)
Statewide	LD	215	13.9	1.7	10.6	17.2	43,410	5,188
	NT_Boat	77	2.0	0.4	1.3	2.7	6,227	1,151
	NT_NP	485	52.4	2.3	47.8	56.9	163,466	7,247
	NT_Other	148	8.2	1.4	5.5	10.9	25,525	4,330
	PB	83	6.6	1.2	4.3	9.0	20,710	3,739
	TNS	59	2.7	0.5	1.8	3.6	8,443	1,448
	TS	375	14.2	1.1	12.1	16.4	44,465	3,481
	Total	**1442**	**100.0**	**NA**	**NA**	**NA**	**312,245**	**NA**
Agricultural	LD	73	14.7	3.0	8.8	20.6	5,109	1,047
	NT_Boat	23	5.1	1.6	1.8	8.3	1,763	572
	NT_NP	77	48.9	6.2	36.7	61.0	17,008	2,157
	NT_Other	44	21.6	5.1	11.5	31.6	7,502	1,786
	PB	2	1.2	1.0	0.0	3.1	414	345
	TNS	9	4.0	1.7	0.7	7.3	1,406	586
	TS	47	4.6	1.1	2.5	6.8	1,603	381
	Total	**275**	**100.0**	**NA**	**NA**	**NA**	**34,804**	**NA**
Forested	LD	75	16.2	2.6	11.2	21.2	19,045	3,015
	NT_Boat	10	0.8	0.3	0.3	1.3	932	324
	NT_NP	130	45.2	3.7	37.9	52.5	53,077	4,382
	NT_Other	14	1.5	0.6	0.3	2.7	1,753	706
	PB	63	11.9	2.1	7.9	15.9	14,002	2,416
	TNS	24	4.5	1.0	2.5	6.4	5,233	1,168
	TS	153	20.0	2.1	15.9	24.0	23,439	2,422
	Total	**469**	**100.0**	**NA**	**NA**	**NA**	**117,481**	**NA**
Other	LD	59	12.4	2.7	7.1	17.7	19,158	4,180
	NT_Boat	27	2.2	0.6	1.1	3.3	3,374	861

Continued Table E-1

Subpopulation	Category	Number of Data Points	Stream Length (%)	Standard Error (%)	Lower Bound (%)	Upper Bound (%)	Stream Length (km)	Standard Error (km)
Other	NT_NP	208	59.7	3.7	52.4	67.0	92,067	5,762
	NT_Other	46	9.4	2.6	4.4	14.4	14,511	3,946
	PB	17	4.1	1.9	0.4	7.8	6,286	2,920
	TNS	15	1.1	0.4	0.4	1.8	1,690	551
	TS	102	11.1	1.6	7.9	14.3	17,152	2,531
	Total	**474**	**100.0**	**NA**	**NA**	**NA**	**154,239**	**NA**
Urban	LD	8	1.7	0.8	0.2	3.2	98	44
	NT_Boat	17	2.8	1.2	0.5	5.0	158	67
	NT_NP	70	23.0	7.7	7.8	38.2	1,314	443
	NT_Other	44	30.7	10.9	9.5	52.0	1,758	621
	PB	1	0.1	0.1	0.0	0.4	8	7
	TNS	11	2.0	1.0	0.0	4.0	115	59
	TS	73	39.7	10.0	20.1	59.3	2,270	572
	Total	**224**	**100.0**	**NA**	**NA**	**NA**	**5,722**	**NA**

Estimates are for all streams (statewide, 2000-2007) and for the four Non-Point Source (NPS) condition classes. Category codes: LD = landowner denial, NS = not sampled, target status unknown, NT_Boat = non target-not wadeable, NT_NP = non target nonperennial, NT_Other = non-target other, PB = physical barrier, TNS = target, not sampled, TS = target sampled.

Table E-2
Extent Estimates (in km and %) of Stream Resources Removed From The Random Sampling Process Due To Inaccessibility (or other confounding factors), Within Each PSA Region.

Subpopulation	Category	Number of Data Points	Stream Length (%)	Standard Error (%)	Lower Bound (%)	Upper Bound (%)	Stream Length (km)	Standard Error (km)
Central Valley	LD	13	8.9	3.2	2.6	15.1	1,929	694
	NT_Boat	43	20.1	4.8	10.7	29.4	4,364	1,042
	NT_NP	23	16.1	4.3	7.6	24.6	3,497	945
	NT_Other	17	37.9	8.2	21.9	54.0	8,254	1,783
	PB	1	0.6	0.5	0.0	1.7	134	116
	TNS	4	4.8	2.8	0.0	10.3	1,041	611
	TS	23	11.7	4.0	3.8	19.5	2,544	873
	Total	**124**	**100.0**	**NA**	**NA**	**NA**	**21,764**	**NA**
Chaparral	LD	84	11.9	2.0	8.0	15.7	9,919	1,636
	NT_Boat	15	0.8	0.3	0.3	1.3	677	224
	NT_NP	240	72.4	2.6	67.3	77.4	60,370	2,148
	NT_Other	29	2.7	0.6	1.4	4.0	2,239	541
	PB	13	2.8	1.1	0.6	5.0	2,330	935
	TNS	14	0.8	0.3	0.3	1.3	652	219
	TS	121	8.7	1.3	6.2	11.2	7,242	1,076
	Total	**516**	**100.0**	**NA**	**NA**	**NA**	**83,429**	**NA**
Deserts - Modoc	LD	26	21.8	9.6	3.0	40.7	20,487	9,026
	NT_Boat	9	3.5	1.9	0.0	7.2	3,271	1,767
	NT_NP	37	48.4	8.5	31.7	65.0	45,405	7,967
	NT_Other	30	15.2	4.1	7.2	23.3	14,299	3,844
	PB	1	0.6	0.5	0.0	1.5	528	446
	TNS	4	3.8	2.1	0.0	7.9	3,542	1,954
	TS	15	6.8	2.3	2.2	11.3	6,365	2,184
	Total	**122**	**100.0**	**NA**	**NA**	**NA**	**93,896**	**NA**

Continued Table E-2

Subpopulation	Category	Number of Data Points	Stream Length (%)	Standard Error (%)	Lower Bound (%)	Upper Bound (%)	Stream Length (km)	Standard Error (km)
North Coast	LD	57	17.6	2.8	12.2	23.0	6,578	1,034
	NT_Boat	4	0.3	0.2	0.0	0.7	127	71
	NT_NP	75	28.4	3.5	21.5	35.2	10,621	1,311
	NT_Other	11	2.8	0.9	1.1	4.5	1,040	323
	PB	32	16.7	5.6	5.8	27.7	6,266	2,094
	TNS	12	2.6	0.7	1.2	4.1	989	278
	TS	104	31.6	3.5	24.8	38.4	11,842	1,298
	Total	**295**	**100.0**	**NA**	**NA**	**NA**	**37,464**	**NA**
Sierra	LD	32	17.4	5.6	6.4	28.3	8,800	2,843
	NT_Boat	4	0.7	0.4	0.0	1.4	331	187
	NT_NP	27	16.7	5.8	5.3	28.0	8,443	2,925
	NT_Other	10	17.5	7.1	3.5	31.5	8,885	3,617
	PB	20	17.6	4.1	9.5	25.6	8,913	2,087
	TNS	13	8.2	2.4	3.5	12.9	4,151	1,219
	TS	47	22.0	3.8	14.6	29.5	11,176	1,925
	Total	**153**	**100.0**	**NA**	**NA**	**NA**	**50,699**	**NA**
South Coast	LD	3	1.3	0.6	0.1	2.5	324	157
	NT_Boat	2	0.2	0.1	0.0	0.4	49	27
	NT_NP	83	27.8	5.0	18.1	37.5	6,949	1,239
	NT_Other	51	21.2	3.6	14.1	28.2	5,287	894
	PB	16	5.0	1.2	2.8	7.3	1,262	293
	TNS	12	6.9	2.5	2.1	11.8	1,734	622
	TS	65	37.6	7.6	22.6	52.5	9,387	1,908
	Total	**232**	**100.0**	**NA**	**NA**	**NA**	**24,993**	**NA**

Stream length estimates are broken out by PSA region. Refer to Table E-1 for statewide estimates by land use category. Category codes: LD = landowner denial, NS = not sampled – target status unknown, NT_Boat = non-target/not wadeable, NT_NP = non-target non-perennial, NT_Other = non-target other, PB = physical barrier, TNS = target, not sampled, TS = target sampled. N = number of data points in a particular category.

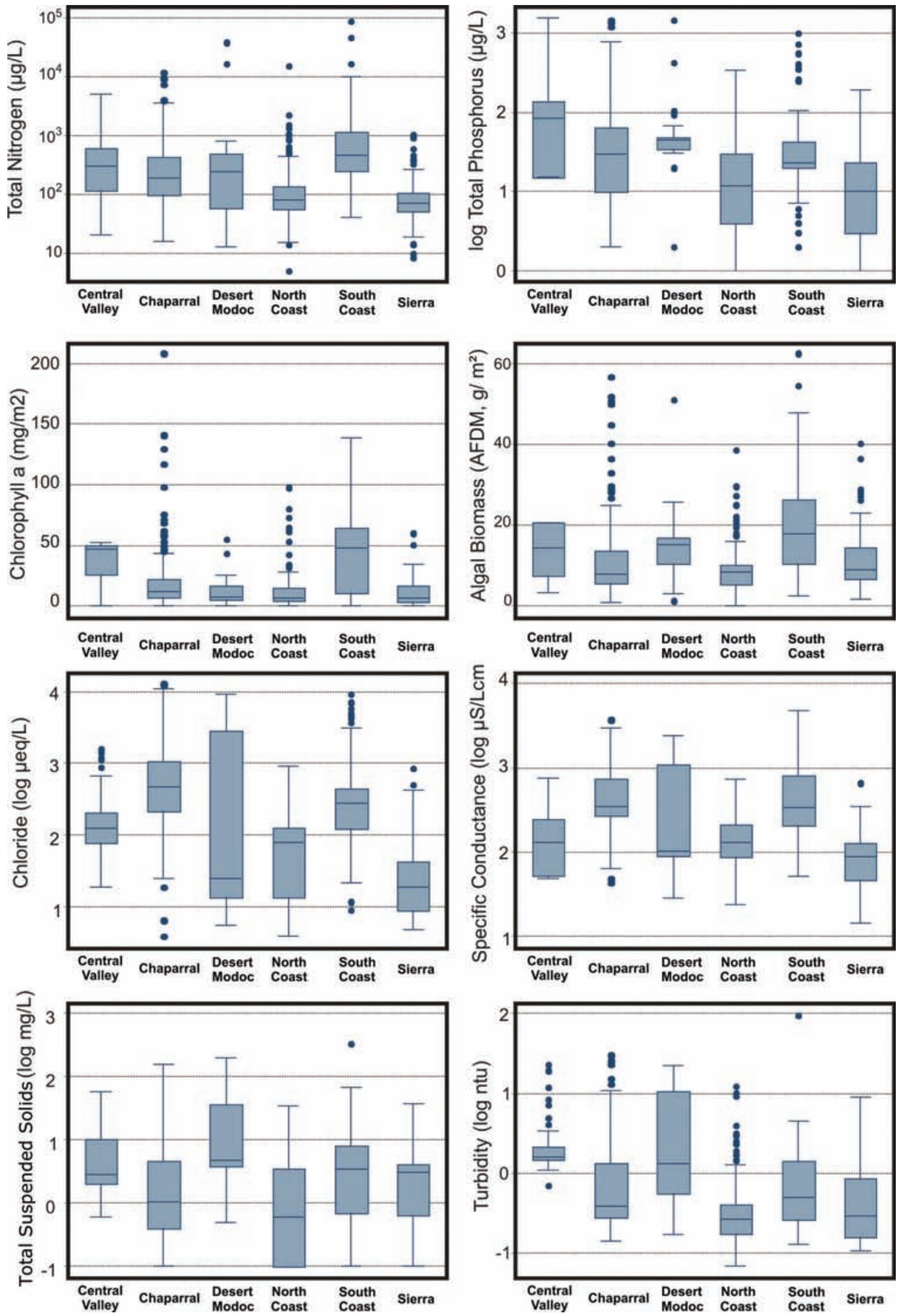


Figure E-3. Stressor distribution boxplots by Perennial Streams Assessment (PSA) Region for chemical variables: total nitrogen, total phosphorous, chlorophyll a, algal biomass, chloride, specific conductance, total dissolved solids and turbidity.

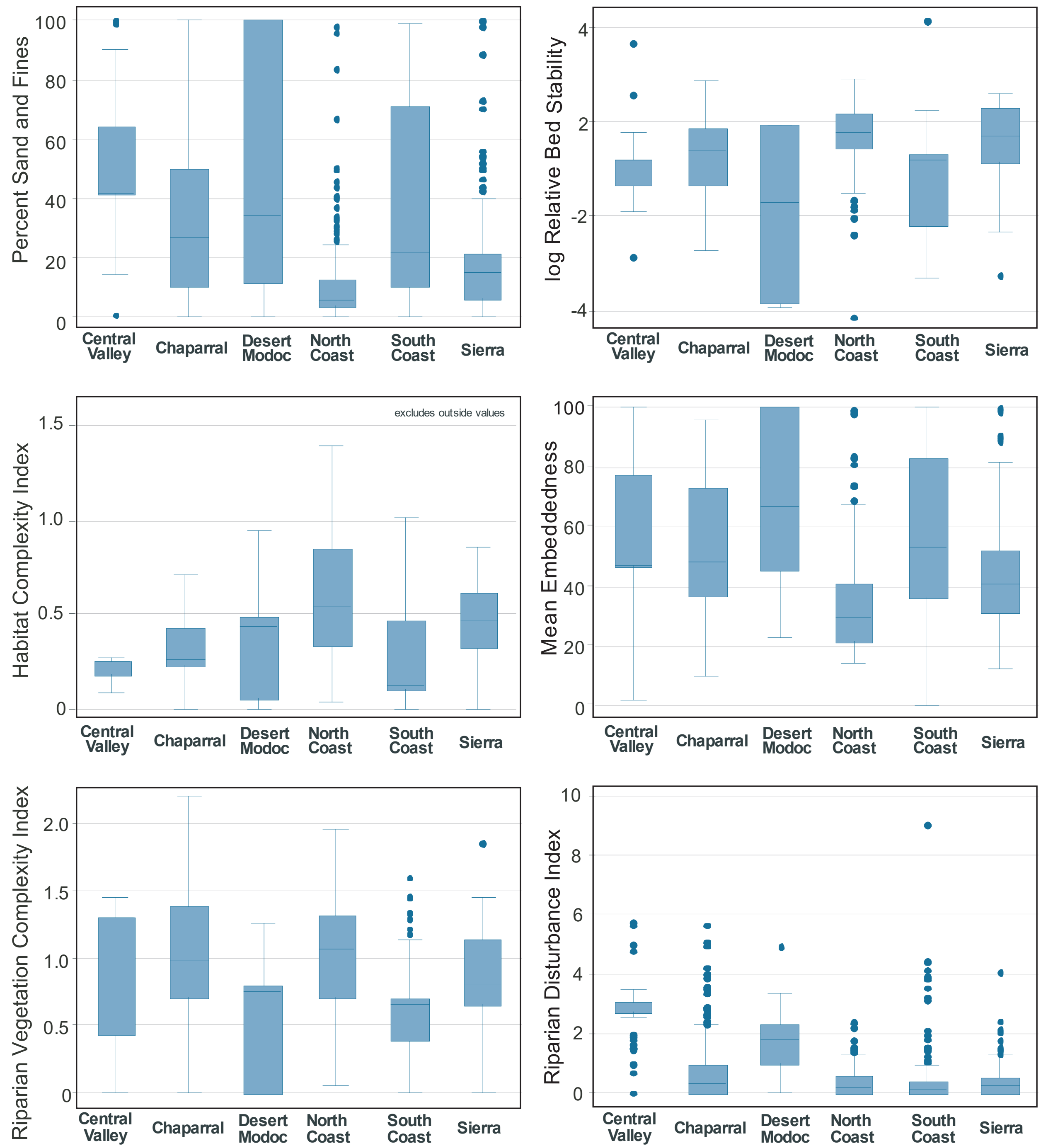


Figure E-4. Stressor distribution boxplots by Perennial Streams Assessment (PSA) region for habitat variables: percent fines plus sand, streambed stability, habitat complexity (EMAP composite), mean embeddedness, riparian vegetation complexity (EMAP composite) and riparian disturbance index (EMAP composite). Definition codes are also listed in Appendix A, Table A-3.

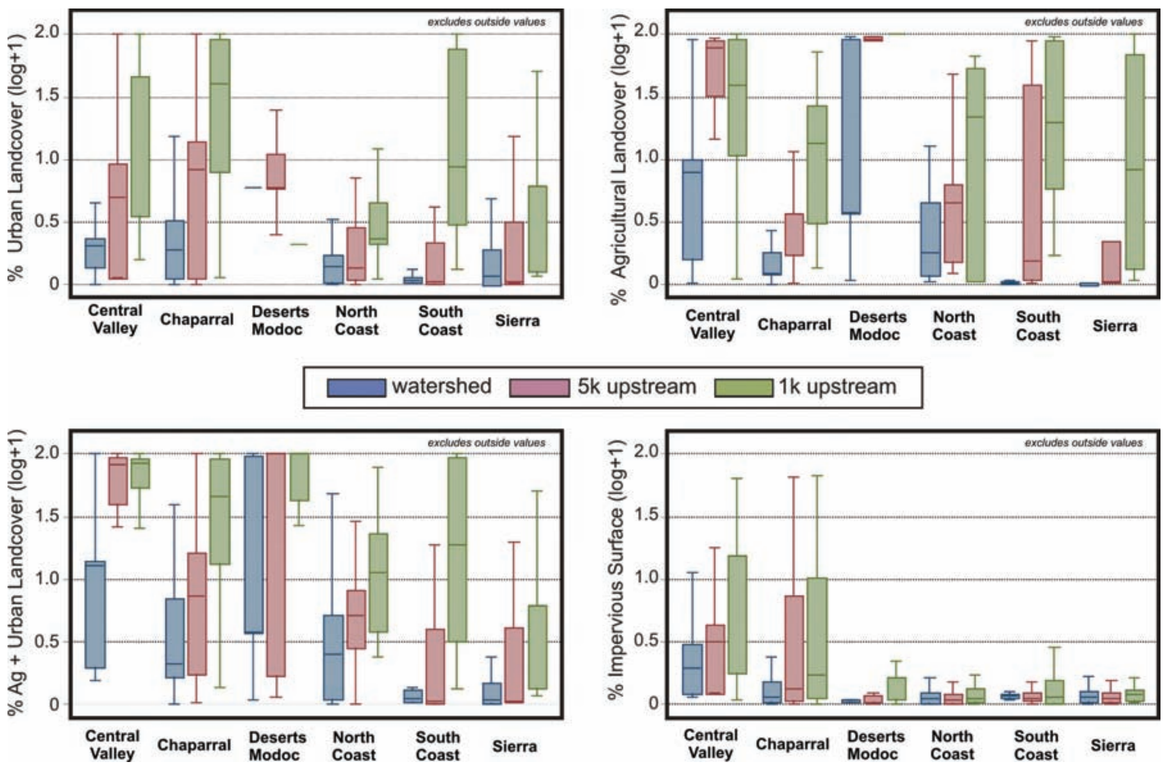


Figure E-5. Stressor distribution boxplots in three distinct spatial scales (ws = watershed, 5k = 5 kilometers, 1k = 1 kilometer), for the land cover variables urban, agricultural, urban + agricultural, and impervious surface, by Perennial Streams Assessment (PSA) region.

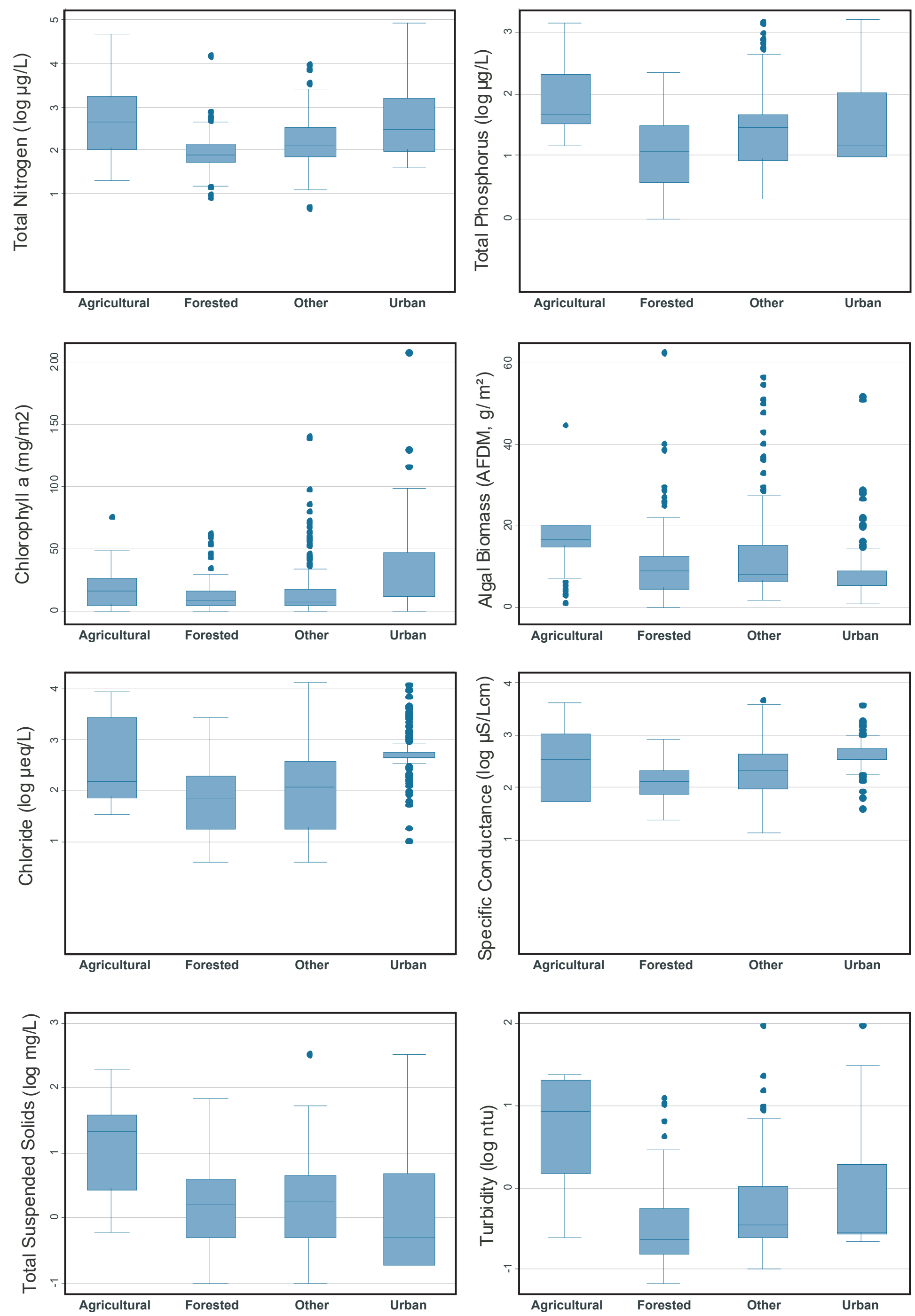


Figure E-6. Stressor distribution boxplots by Non-Point Source (NPS) land cover class for chemical variables: total nitrogen, total phosphorus, chlorophyll a, algal biomass (ash free dry), chloride, specific conductance, total suspended solids, and turbidity. See Table A-3 for additional information.

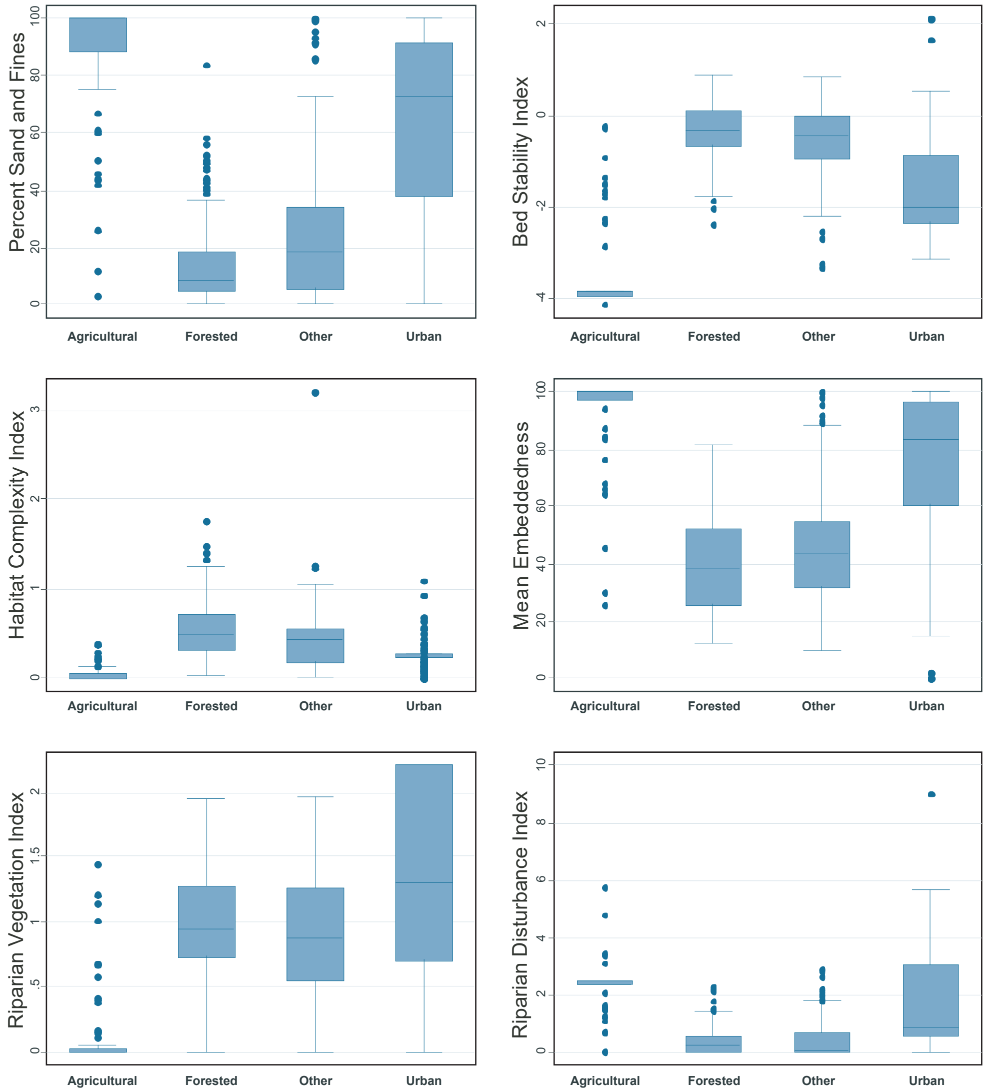


Figure E-7. Stressor distribution boxplots by Non-Point Source (NPS) land cover class for habitat variables: percent fines and sands, bed stability, habitat complexity index (EMAP composite), mean embededness, riparian vegetation index (EMPA composite), riparian disturbance index (EMAP composite).

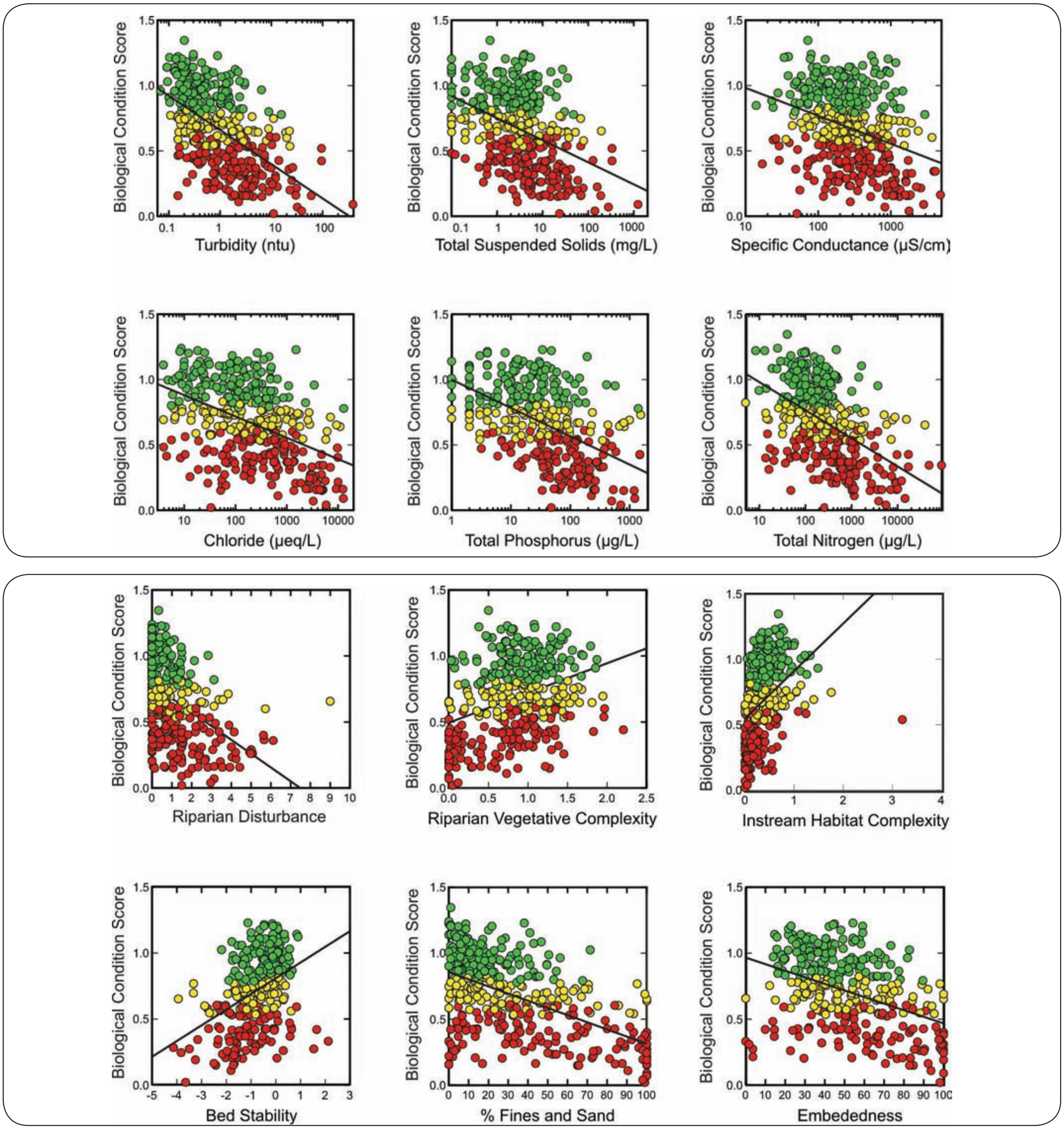


Figure E-8. Relationships between chemical and physical stressor intensity, habitat characteristics, and biological condition scores. Green dots represent sites in good biological condition and yellow and red dots represent sites with degraded and very degraded biological condition, respectively. Chemical stressors: chloride, total phosphorous, and total nitrogen. Physical stressors: turbidity, total suspended solids, specific conductance. Habitat characteristics: riparian disturbance, riparian vegetation, habitat complexity, bed stability, percent fines and sand, mean embededness. See Appendix Table A-3 for additional information.

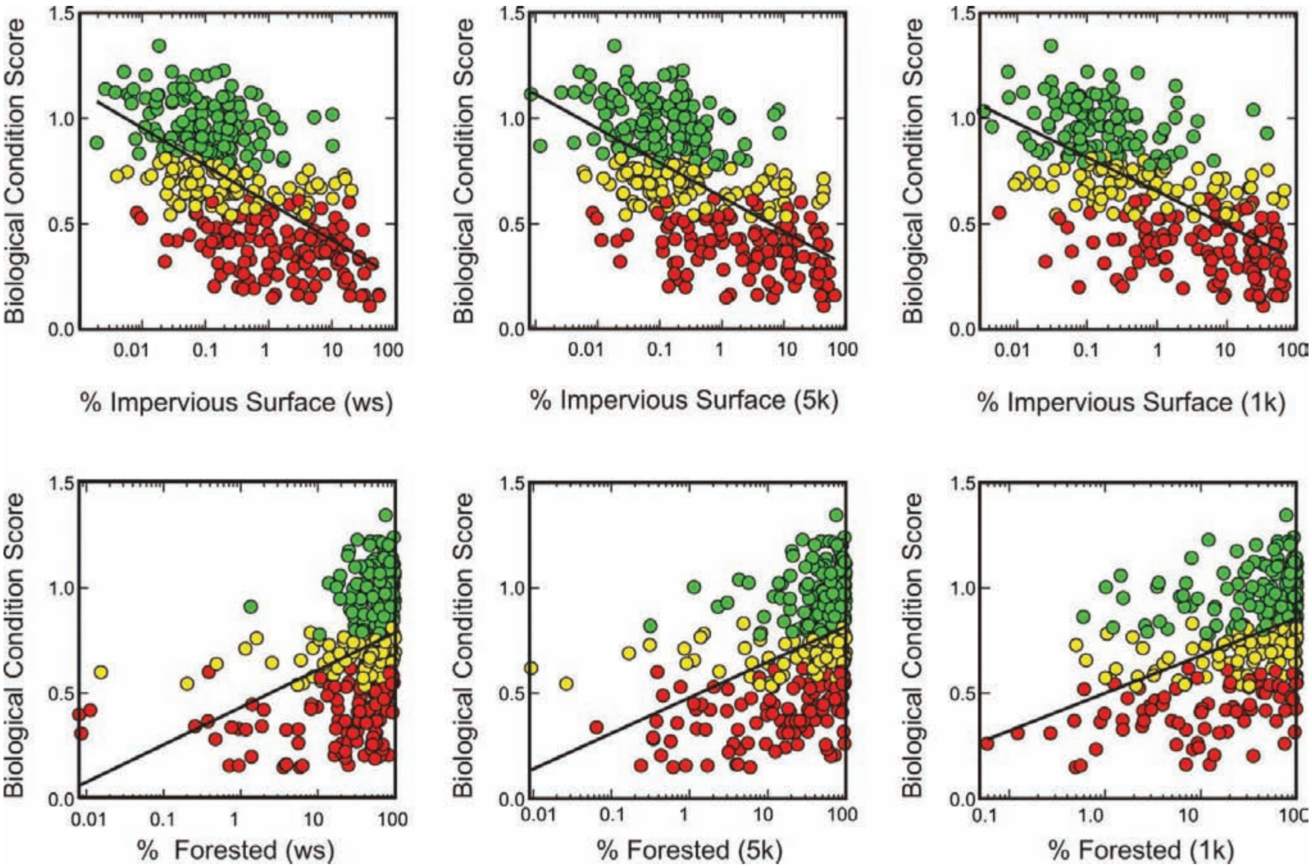


Figure E-9a. Relationship between development impact intensity at three spatial scales (watershed, 5 kilometers, and 1 kilometer) and biological condition scores. Green dots represent sites in good biological condition and yellow and red dots represent sites with degraded and very degraded biological condition, respectively. Condition analysis is presented for agricultural, urban, agricultural + urban, forest, and impervious surface development categories. See Appendix Table A-3 for additional information.

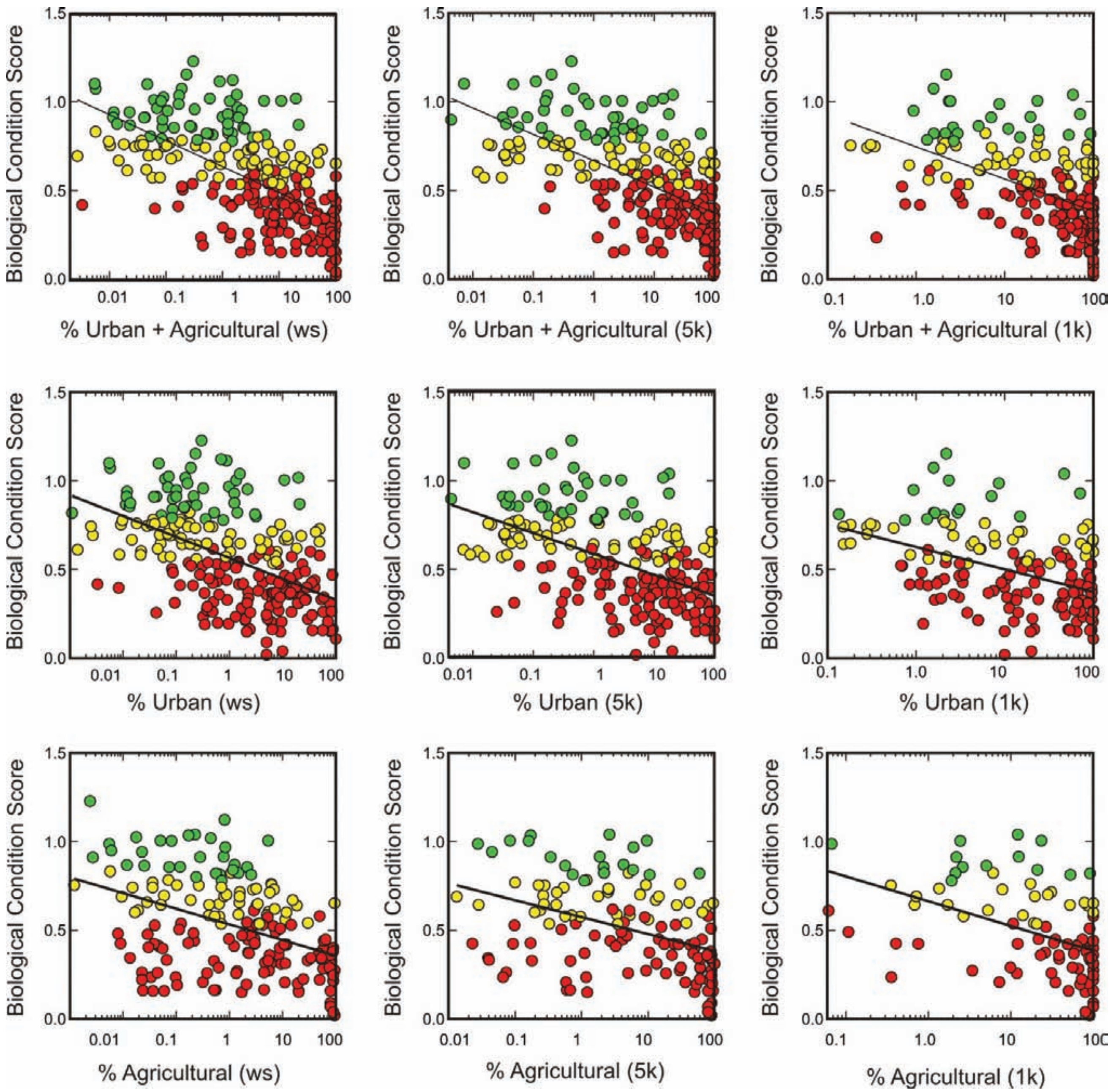


Figure E-9b. Relationship between development impact intensity at three spatial scales (watershed, 5 kilometers, and 1 kilometer) and biological condition scores. Green dots represent sites in good biological condition and yellow and red dots represent sites with degraded and very degraded biological condition, respectively. Condition analysis is presented for agricultural, urban, agricultural + urban, forest, and impervious surface development categories. See Appendix Table A-3 for additional information.

Table E-3
Statewide Results of Biologically Derived Stressor Thresholds for Chemical, Physical, Habitat, and Development Stressors.

	Biology-based stressor threshold demarkation lines.								
Variable (units)	**1%**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
Riparian Disturbance Index			0	0	0.14	0.47	**0.99**	**1.29**	1.5
Riparian Vegetation Complexity Index	0.2	0.45	0.5	0.72	0.96	1.27	**1.39**	**1.53**	1.87
Habitat Complexity Index	0.1	0.14	0.2	0.33	0.49	0.72	**0.88**	**1.13**	1.48
Bed Stability	-2.19	-1.73	-1.35	-0.64	-0.31	0.06	**0.51**	**0.58**	0.9
Percent Fines & Sand (mm)	0	0	1.9	4.76	8.57	20.95	**40**	**46.67**	71.43
Mean Embeddedness (%)	15.75	17.93	18.73	24.73	38.36	51.82	**66.92**	**70.55**	82.76
Turbidity (NTU)	0.09	0.13	0.13	0.18	0.25	0.5	**1.4**	**1.6**	3
Total Suspended Solids (mg/L)	0	0	0.1	0.36	1.1	3.6	**6.4**	**8.5**	20.8
Specific Conductance (µg/cm)	23	38.6	47	73	125	230	**336**	**656**	1460
Chloride (µg/L)	0	4.8	5.9	9.9	42.6	147	**421.4**	**485.14**	3416
Total Phosphorus (µg/L)	0	0	0	2	10	25	**52.25**	**65**	182
Total Nitrogen (µg/L)	0	13	24.8	51	81	133.75	**318**	**393.2**	1433
Chlorophyll a (mg/m2)	0	1.52	3.02	3.79	6.06	14.17	**31.06**	**59.85**	72.98
Algal Biomass * (g/m2)	1.64	2.58	3.03	5.3	8.33	13.64	**26.24**	**28.79**	40.13
Agriculture+Urban Index_ws (%)	0	0	0	0	0	0.1	**1.4**	**1.9**	19.8
Agriculture+Urban Index_5km (%)	0	0	0	0	0	0	**1.4**	**2.5**	14.1
Agriculture+Urban Index_1km (%)	0	0	0	0	0	0	**0**	**7**	19.6
Urban_ws (%)	0	0	0	0	0	0	**0.3**	**1**	19.8
Urban_5km (%)	0	0	0	0	0	0	**0.1**	**1.1**	14.1
Urban_1km (%)	0	0	0	0	0	0	**0**	**1.3**	7.1
Agriculture_ws (%)	0	0	0	0	0	0	**0.3**	**0.8**	0.8
Agriculture_5km (%)	0	0	0	0	0	0	**0**	**0.7**	6
Agriculture_1km (%)	0	0	0	0	0	0	**0**	**2.2**	12.5
Impervious Surface_ws (%)	0	0	0	0.02	0.08	0.23	**0.49**	**0.68**	10.19
Impervious Surface_5km (%)	0	0	0	0.01	0.06	0.2	**0.37**	**0.97**	6.95
Impervious Surface_1km (%)	0	0	0	0	0.05	0.16	**0.49**	**1**	3.33

This table presents a range of biology-based stressor (BBS) threshold demarkation lines which encompass varying percentages of good condition (green) sites. The 90% biology-based stressor threshold demarcation line delineates the point or stressor concentration below which 90% of the good condition (green) sites surveyed occur (see scatter plot Figures 18, 19, 20, 21, E8, E9a and E9b). A BBS threshold can be drawn to include any percentage of the green sites. This table presents BBS threshold concentrations that include 1%, 5%, 10%, 25%, 50%, 75%, 90%, 95% and 99% of good condition sites. Scale codes: ws = watershed scale, 5k = 5 kilometer scale, 1 k = 1 kilometer scale. Appendix Table A-3 gives additional information on variable definitions, and units. Scale codes: ws = watershed scale, 5k = 5 kilometer scale, 1 k = 1 kilometer scale. Land cover codes: AG + URB Index = agricultural + urban index, *Algal biomass measured as ash-free mass (g/m2)

Table E-4
Biologically-Derived Stressor Thresholds For Various Stream Health Indicators
In Each of Six Perennial Streams Assessment (PSA) Regions.

			Biology-based stressor threshold demarkation lines.								
Variable	**n**	**PSA Region**	**1%**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
Riparian Disturbance Index	1	Central Valley	3.13	3.13	3.13	3.13	3.13	3.13	**3.13**	**3.13**	3.13
	35	Chaparral	0	0	0	0	0.14	0.94	**1.08**	**1.45**	1.45
	7	Desert-Modoc	0.33	0.33	0.33	0.85	0.99	0.99	**1.5**	**1.5**	1.5
	50	North Coast	0	0	0	0	0	0.27	**0.55**	**1.06**	1.47
	27	South Coast	0	0	0	0	0.35	0.35	**0.73**	**1.05**	1.95
	24	Sierra Nevada	0	0	0	0	0.24	0.33	**0.79**	**1.29**	2.14
Riparian Vegetation Complexity Index	1	Central Valley	1.01	1.01	1.01	1.01	1.01	1.01	**1.01**	**1.01**	1.01
	35	Chaparral	0.6	0.67	0.67	0.78	0.97	1.22	**1.39**	**1.39**	1.59
	7	Desert-Modoc	0.35	0.35	0.35	0.8	1.14	1.19	**1.19**	**1.19**	1.19
	50	North Coast	0.42	0.49	0.49	0.73	1.08	1.29	**1.53**	**1.87**	1.87
	27	South Coast	0.18	0.2	0.2	0.47	0.66	0.66	**0.84**	**0.99**	1.44
	24	Sierra Nevada	0.03	0.4	0.5	0.69	0.81	1.13	**1.36**	**1.36**	1.85
Habitat Complexity Index	1	Central Valley	0.2	0.2	0.2	0.2	0.2	0.2	**0.2**	**0.2**	0.2
	35	Chaparral	0.13	0.2	0.2	0.24	0.37	0.45	**0.77**	**0.86**	0.86
	7	Desert-Modoc	0.12	0.12	0.12	0.48	0.48	0.95	**1.23**	**1.23**	1.23
	50	North Coast	0.1	0.18	0.23	0.38	0.63	0.85	**0.88**	**0.9**	1.13
	27	South Coast	0.1	0.1	0.1	0.1	0.23	0.54	**0.72**	**0.75**	1.33
	24	Sierra Nevada	0.14	0.14	0.32	0.37	0.5	0.68	**1.26**	**1.48**	1.48
Bed Stability	1	Central Valley	-0.23	-0.23	-0.23	-0.23	-0.23	-0.23	**-0.23**	**-0.23**	-0.23
	35	Chaparral	-1.35	-1.35	-1.35	-0.65	-0.44	-0.16	**-0.02**	**-0.02**	0.27
	7	Desert-Modoc	-1.75	-1.75	-1.75	-1.75	-1.72	-0.56	**-0.56**	**-0.56**	-0.56
	50	North Coast	-1.11	-0.65	-0.55	-0.43	-0.12	0.26	**0.56**	**0.9**	0.9
	27	South Coast	-2.19	-2.19	-2.19	-2.19	-1.61	-0.47	**0.17**	**0.17**	0.22
	24	Sierra Nevada	-1.77	-1.77	-1.48	-1.11	-0.36	0.12	**0.56**	**0.58**	0.58

Continued Table E-4

			Biology-based stressor threshold demarkation lines.								
Variable	**n**	**PSA Region**	**1%**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
Percent Fines & Sand	1	Central Valley	25.71	25.71	25.71	25.71	25.71	25.71	**25.71**	**25.71**	25.71
	35	Chaparral	1.9	1.9	5.71	9.52	20.95	35.58	**42.86**	**49.52**	49.52
	7	Desert-Modoc	0	0	0	8	25.71	34.29	**34.29**	**34.29**	34.29
	50	North Coast	0	0	0.95	2.86	5.71	6.67	**10.48**	**16.19**	29.52
	27	South Coast	2.86	2.86	2.86	13.33	40.95	71.43	**71.43**	**71.43**	71.43
	24	Sierra Nevada	0	0	1	8.57	15.24	20.95	**40**	**46.67**	56.19
Mean Embeddedness	1	Central Valley	45.55	45.55	45.55	45.55	45.55	45.55	**45.55**	**45.55**	45.55
	35	Chaparral	26.73	30.36	30.45	35.27	48.18	67.04	**70.55**	**73.27**	73.27
	7	Desert-Modoc	40.55	40.55	40.55	55.45	66.92	66.92	**66.92**	**66.92**	66.92
	50	North Coast	13.91	15.82	15.82	17.93	24.73	34.64	**41.45**	**47.27**	57.41
	27	South Coast	19.09	19.09	19.09	43.09	73.33	82.76	**82.76**	**82.76**	89.55
	24	Sierra Nevada	19.91	19.91	19.93	35	42.15	51.27	**60.55**	**66.64**	81.73
Turbidity	1	Central Valley	0.7	0.7	0.7	0.7	0.7	0.7	**0.7**	**0.7**	0.7
	35	Chaparral	0.18	0.2	0.21	0.22	1.06	1.4	**2.52**	**2.52**	3
	7	Desert-Modoc	0.17	0.17	0.17	0.17	0.3	1.2	**1.5**	**1.5**	1.5
	50	North Coast	0.09	0.1	0.13	0.13	0.19	0.3	**0.52**	**0.64**	1.49
	27	South Coast	0.13	0.18	0.2	0.2	0.5	0.5	**0.53**	**1.03**	2.23
	24	Sierra Nevada Nevada	0.15	0.15	0.15	0.2	0.23	0.4	**1.6**	**1.6**	6.4
Total Suspended Solids	1	Central Valley	0.6	0.6	0.6	0.6	0.6	0.6	**0.6**	**0.6**	0.6
	35	Chaparral	0	0	0.4	0.5	1.64	7.9	**8.5**	**20.8**	20.8
	7	Desert-Modoc	0.5	0.5	0.5	0.5	3.3	3.9	**5.7**	**5.7**	5.7
	50	North Coast	0	0	0	0.1	0.36	1.9	**4**	**5.68**	8.6
	27	South Coast	0	0	0	0.2	0.7	2.5	**5.9**	**14.76**	35.1
	24	Sierra Nevada Nevada	0.2	0.2	0.4	0.64	2.24	4.1	**5.5**	**6.4**	12.4
Specific Conductance	1	Central Valley	191	191	191	191	191	191	**191**	**191**	191
	35	Chaparral	104	137	137	230	292	350	**744**	**1460**	1460
	7	Desert-Modoc	28	28	28	68	102	279	**279**	**279**	279
	50	North Coast	50	65	73	83	127	181	**281**	**306**	339
	27	South Coast	51	56	139	262	336	545	**919**	**1076**	1353
	24	Sierra Nevada Nevada	23	24	24	41	65	100	**125**	**175**	656

Continued Table E-4

			Biology-based stressor threshold demarkation lines.								
Variable	**n**	**PSA Region**	**1%**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
Chloride	1	Central Valley	245.28	245.28	245.28	245.28	245.28	245.28	**245.28**	**245.28**	245.28
	35	Chaparral	24.92	107.5	119.9	147	262.6	436.6	**485.14**	**3416**	3416
	7	Desert-Modoc	0	0	0	13.16	23.24	89.7	**89.7**	**89.7**	89.7
	50	North Coast	3.9	5.9	5.9	9.9	77	115.9	**169.8**	**280**	389.2
	27	South Coast	9	11.8	47.7	57.12	98.4	265.7	**1079.4**	**1091.6**	1513.3
	24	Sierra Nevada	0	0	4.8	6.8	12.1	33.6	**96.6**	**854.1**	854.1
Total Phosphorus	1	Central Valley	0	0	0	0	0	0	**0**	**0**	0
	35	Chaparral	0	3	4	10	36	53.6	**143**	**182**	182
	7	Desert-Modoc	0	0	0	0	2	30.6	**58.6**	**58.6**	58.6
	50	North Coast	0	0	0	2	6	14	**30**	**35.8**	38
	27	South Coast	2	4	6	19	22	32	**408**	**408**	568
	24	Sierra Nevada	0	0	0	1	4	14	**33.5**	**47.5**	120
Total Nitrogen	1	Central Valley	449.4	449.4	449.4	449.4	449.4	449.4	**449.4**	**449.4**	449.4
	35	Chaparral	0	30	75	77	133.75	221	**446**	**1433**	1433
	7	Desert-Modoc	13	13	13	34.2	60	80.2	**245.9**	**245.9**	245.9
	50	North Coast	0	24.8	29	44	70	91	**215.5**	**349**	349
	27	South Coast	41	83	104	226	364	470	**470**	**470**	3720
	24	Sierra Nevada	0	8.3	14	40.1	81	105	**171**	**171**	320
Chlorophyll a	1	Central Valley	14.37	14.37	14.37	14.37	14.37	14.37	**14.37**	**14.37**	14.37
	35	Chaparral	0	3.02	3.33	4.64	9.09	10.61	**13.64**	**16.67**	42.58
	7	Desert-Modoc	3.03	3.03	3.03	3.03	5.56	5.56	**16.99**	**16.99**	16.99
	50	North Coast	0	1.52	3.03	3.79	6.06	14.39	**27.27**	**42.42**	72.98
	27	South Coast	2.27	4.13	4.13	7.58	29.55	63.64	**63.64**	**63.64**	138.64
	24	Sierra Nevada	0	1.52	2.27	3.03	5.3	17.36	**34.09**	**59.85**	59.85
Algal Biomass	1	Central Valley	10.38	10.38	10.38	10.38	10.38	10.38	**10.38**	**10.38**	10.38
	35	Chaparral	2.65	2.65	3.47	3.92	7.91	13.64	**25**	**25**	56.59
	7	Desert-Modoc	2.88	2.88	2.88	3.26	3.7	9.8	**16.76**	**16.76**	16.76
	50	North Coast	0	1.64	3.03	6.82	8.33	9.09	**12.12**	**24.79**	27.27
	27	South Coast	3.03	4.91	4.91	6.82	24.24	26.24	**26.24**	**28.79**	62.5
	24	Sierra Nevada Nevada	2.27	2.91	2.91	6.82	9	18.18	**28.79**	**40.13**	40.13

Continued Table E-4

			Biology-based stressor threshold demarkation lines.								
Variable	**n**	**PSA Region**	**1%**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
Agriculture+Urban Index_ws	1	Central Valley	0.6	0.6	0.6	0.6	0.6	0.6	**0.6**	**0.6**	0.6
	35	Chaparral	0	0	0	0	0.7	1.4	**5.4**	**19.8**	19.8
	7	Desert-Modoc	0	0	0	0	0.1	0.1	**0.6**	**0.6**	0.6
	50	North Coast	0	0	0	0	0	0	**0.9**	**1.5**	2.5
	27	South Coast	0	0	0	0	0.1	0.1	**0.3**	**0.4**	10.9
	24	Sierra Nevada	0	0	0	0	0	0	**0.1**	**0.3**	1.8
Agriculture+Urban Index_5km	1	Central Valley	59.5	59.5	59.5	59.5	59.5	59.5	**59.5**	**59.5**	59.5
	35	Chaparral	0	0	0	0	0.7	2.1	**9.6**	**14.1**	14.1
	7	Desert-Modoc	0	0	0	0	0.2	0.2	**0.7**	**0.7**	0.7
	50	North Coast	0	0	0	0	0	0	**0**	**0**	3.1
	27	South Coast	0	0	0	0	0	0	**0.4**	**1.1**	6.3
	24	Sierra Nevada	0	0	0	0	0	0	**0**	**0**	6.4
Agriculture+Urban Index_1km	1	Central Valley	92.8	92.8	92.8	92.8	92.8	92.8	**92.8**	**92.8**	92.8
	35	Chaparral	0	0	0	0	0	1.6	**19.6**	**19.6**	23.5
	7	Desert-Modoc	0	0	0	0	0	2.4	**2.4**	**2.4**	2.4
	50	North Coast	0	0	0	0	0	0	**0**	**0**	11
	27	South Coast	0	0	0	0	0	0	**0**	**1.3**	24.1
	24	Sierra Nevada	0	0	0	0	0	0	**0**	**0**	2.9
Urban_ws	1	Central Valley	0	0	0	0	0	0	**0**	**0**	0
	35	Chaparral	0	0	0	0	0	0.2	**1.4**	**19.8**	19.8
	7	Desert-Modoc	0	0	0	0	0	0	**0.1**	**0.1**	0.1
	50	North Coast	0	0	0	0	0	0	**0.1**	**0.7**	0.9
	27	South Coast	0	0	0	0	0.1	0.1	**0.2**	**0.4**	10.8
	24	Sierra Nevada	0	0	0	0	0	0	**0.1**	**0.3**	1
Urban_5km	1	Central Valley	0.3	0.3	0.3	0.3	0.3	0.3	**0.3**	**0.3**	0.3
	35	Chaparral	0	0	0	0	0	0.6	**1.4**	**14.1**	14.1
	7	Desert-Modoc	0	0	0	0	0	0	**0.7**	**0.7**	0.7
	50	North Coast	0	0	0	0	0	0	**0**	**0**	0.1
	27	South Coast	0	0	0	0	0	0	**0.4**	**0.4**	2.9
	24	Sierra Nevada	0	0	0	0	0	0	**0**	**0**	1.3

Continued Table E-4

			Biology-based stressor threshold demarkation lines.								
Variable	**n**	**PSA Region**	**1%**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
Urban_1km	1	Central Valley	1.6	1.6	1.6	1.6	1.6	1.6	**1.6**	**1.6**	1.6
	35	Chaparral	0	0	0	0	0	0	**2**	**7.1**	7.1
	7	Desert-Modoc	0	0	0	0	0	0	**0**	**0**	0
	50	North Coast	0	0	0	0	0	0	**0**	**0**	0
	27	South Coast	0	0	0	0	0	0	**0**	**0.9**	3.1
	24	Sierra Nevada	0	0	0	0	0	0	**0**	**0**	2.9
Agriculture_ws	1	Central Valley	0.6	0.6	0.6	0.6	0.6	0.6	**0.6**	**0.6**	0.6
	35	Chaparral	0	0	0	0	0	0.3	**0.8**	**0.8**	5.4
	7	Desert-Modoc	0	0	0	0	0.1	0.1	**0.4**	**0.4**	0.4
	50	North Coast	0	0	0	0	0	0	**0**	**0.8**	0.8
	27	South Coast	0	0	0	0	0	0	**0**	**0**	1.2
	24	Sierra Nevada	0	0	0	0	0	0	**0**	**0**	0.8
Agriculture_5km	1	Central Valley	59.2	59.2	59.2	59.2	59.2	59.2	**59.2**	**59.2**	59.2
	35	Chaparral	0	0	0	0	0	0.3	**1.9**	**1.9**	9.6
	7	Desert-Modoc	0	0	0	0	0	0.2	**0.2**	**0.2**	0.2
	50	North Coast	0	0	0	0	0	0	**0**	**0**	0
	27	South Coast	0	0	0	0	0	0	**0**	**0.1**	5.9
	24	Sierra Nevada	0	0	0	0	0	0	**0**	**0**	6
Agriculture_1km	1	Central Valley	91.2	91.2	91.2	91.2	91.2	91.2	**91.2**	**91.2**	91.2
	35	Chaparral	0	0	0	0	0	0	**12.5**	**12.5**	23.5
	7	Desert-Modoc	0	0	0	0	0	2.4	**2.4**	**2.4**	2.4
	50	North Coast	0	0	0	0	0	0	**0**	**0**	0
	27	South Coast	0	0	0	0	0	0	**0**	**0**	21
	24	Sierra Nevada	0	0	0	0	0	0	**0**	**0**	0
Impervious Surface_ws	1	Central Valley	0.15	0.15	0.15	0.15	0.15	0.15	**0.15**	**0.15**	0.15
	35	Chaparral	0.01	0.02	0.02	0.03	0.09	0.27	**0.97**	**10.19**	10.19
	7	Desert-Modoc	0	0	0	0	0.01	0.05	**0.38**	**0.38**	0.38
	50	North Coast	0	0	0	0.01	0.04	0.19	**0.23**	**0.52**	0.64
	27	South Coast	0	0	0.01	0.06	0.16	0.16	**0.24**	**0.35**	5.25
	24	Sierra Nevada	0	0	0	0.03	0.11	0.25	**0.3**	**0.49**	0.68

Continued Table E-4

			Biology-based stressor threshold demarkation lines.								
Variable	**n**	**PSA Region**	**1%**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
Impervious Surface_5km	1	Central Valley	0.41	0.41	0.41	0.41	0.41	0.41	**0.41**	**0.41**	0.41
	35	Chaparral	0	0.02	0.02	0.03	0.08	0.37	**0.97**	**6.95**	6.95
	7	Desert-Modoc	0	0	0	0	0.01	0.05	**1.13**	**1.13**	1.13
	50	North Coast	0	0	0	0	0.02	0.09	**0.23**	**0.23**	0.26
	27	South Coast	0	0	0.02	0.08	0.08	0.11	**0.35**	**0.51**	1.27
	24	Sierra Nevada	0	0	0	0.03	0.06	0.22	**0.38**	**0.38**	0.86
Impervious Surface_1km	1	Central Valley	0.29	0.29	0.29	0.29	0.29	0.29	**0.29**	**0.29**	0.29
	35	Chaparral	0	0	0	0.03	0.05	0.49	**1**	**3.33**	3.33
	7	Desert-Modoc	0	0	0	0	0.01	0.11	**0.5**	**0.5**	0.5
	50	North Coast	0	0	0	0	0.01	0.08	**0.23**	**0.31**	0.54
	27	South Coast	0	0	0	0	0.02	0.03	**0.21**	**1.25**	2.18
	24	Sierra Nevada	0	0	0	0.01	0.1	0.22	**0.29**	**1.28**	1.62

IMPERV = impervious surface, ws = watershed scale, 5k = 5 kilometer scale, 1k = 1 kilometer scale.

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