2003 Progress Report

Ecoregion 6 (Southern and Central California Oak and Chaparral Woodlands) Pilot Study for the Development of Nutrient Criteria

Prepared for:
US EPA Region IX Regional Technical Advisory Group
&
CA SWRCB State Regional Board Advisory Group

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1 OVERVIEW AND INTRODUCTION

The purpose of the Southern and Central California Oak and Chaparral Woodlands Pilot Study for the Development of Nutrient Criteria is to test the methods and assumptions for development of nutrient criteria that have been selected for use by the EPA Region IX Regional Technical Advisory Group (RTAG) and the State Technical Regional Technical Advisory Group (STRTAG). The results of the pilot project will be used to evaluate the feasibility of the alternate Work Plan developed in collaboration with the RTAG. The pilot project study area (Ecoregion 6) is illustrated in Figure 1.1. The study area includes areas with Regional Water Quality Control Boards 2, 3, 4, 5, 8, and 9.

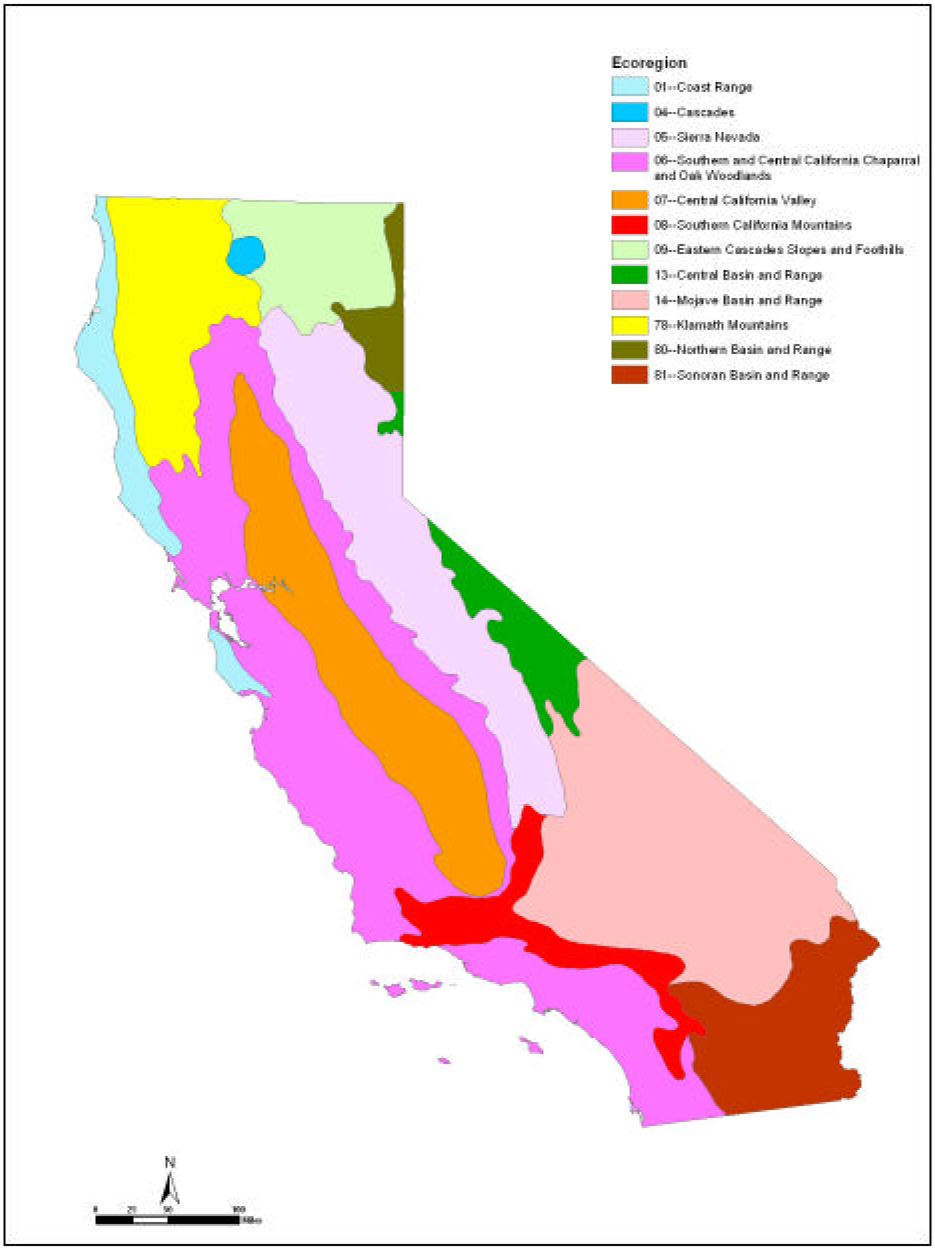


Figure 1-1 Map of Ecoregions across California.

The EPA Region IX Work Plan was developed in collaboration with the RTAG / STRTAG. The USEPA Region IX and California State Water Resources Control Board (SWRCB) nutrient criteria development program is based on an adaptive management process with the RTAG and STRTAG providing key questions for investigation and feedback on findings. A concept white paper was distributed to the RTAG in March 2002 to provide background information on issues and concepts related to the development of nutrient criteria that would need to be addressed in the Work Plan. The RTAG nutrient criteria development workshop held in April 2002 provided the opportunity for discussion and review of the information and concepts presented in the white paper. In addition, it provided a forum for ideas put forward by members of the RTAG. A workshop summary report was distributed to participants and members of the RTAG to ensure that the results of the workshop discussions would be considered in the development of the Work Plan. The draft Work Plan was completed in July 2002 and submitted to the RTAG for review and comment.

As plans were being made to implement the work plan the process took a six-month hiatus due to project funding and contract administration issues. When the issues were resolved in February 2003 the projected project funding had been reduced by 66%. The delay and reduced funding necessitated modifications to the work plan to accommodate a compressed schedule and fewer hours available for the technical support team. The solution was to undertake the Southern California Oak and Chaparral Ecoregion Pilot Study. This adjustment is a minor concession since the original work statement had called for addressing one ecoregion at a time. The major change to the work plan was to consider all waterbodies within the region on a comprehensive watershed basis rather than sequentially evaluating individual waterbody types. These modifications were presented to the RTAG / STRTAG in a background information memorandum and discussed during an April 2003 conference call. Additional information was provided to the RTAG / STRTAG in a project update memorandum that was distributed in June 2003. This report is the result of the tasks undertaken as part of the Pilot Project. The next steps in the adaptive management process will include a workshop to review the results of the pilot project and to develop the key questions that will be addressed in the next phase of the process.

A summary of the process and additional background information on nutrient criteria development has been included as Appendix A.

The key areas of investigation within the pilot project include:

- Evaluate the frequency distribution characteristics of various nutrient related parameters (both causal and response) from minimally impacted water bodies, impacted water bodies achieving Beneficial Uses, and impaired water bodies.
- Analyze the relationship between nutrient causal parameters and nutrient response parameters to identify specific values or ranges where impacts can be identified.
- Develop stratification factors that sort water bodies into "risk" categories that allow for criteria to be tailored to specific response characteristics.
- Assess watershed loading scenarios, transport and loading relationships (i.e., downstream effects), and effects on various response parameters for lakes and reservoirs.
- Refine the decision framework to support nutrient criteria implementation. Consideration of a decision framework to support nutrient criteria. A tiered system that includes co-factors that influence the response of aquatic systems to nutrient inputs allows for the consideration of the effect of confounding factors that can create impairment that closely parallels and can exacerbate the effects of nutrient over enrichment. The RTAG / STRTAG supports the use of a decision

framework that can address the association between nutrients, habitat, flow, and aquatic biota. The proposed decision framework needs to be developed to allow for consideration of the interaction of these factors to translate the application of nutrient criteria to individual water bodies.

- Develop preliminary recommendations for nutrient criteria. The pilot project was initially proposed and described in an April 2003 background information memorandum that was distributed to the RTAG / STRTAG in preparation for a project conference call. The memorandum stated that it would be unlikely that the pilot project would provide the basis for recommendations for nutrient criteria, but that the results would be provided to the RTAG for their consideration.
- Identify key uncertainties and areas requiring further investigation.

1.1 SUMMARY OF REGIONAL BOARD BASIN PLAN NUTRIENT WATER QUALITY OBJECTIVES

USEPA National Nutrient Criteria Program conducted a review of nutrient water quality standards for all states in 2003. The survey is included with this report as Attachment B. The nutrient water quality objectives in the California Basin Plans are most often addressed indirectly through criteria for turbidity. With the exception of Regional Board 4 all evaluated boards (Regional Boards 1-9) provide a numeric measurement of turbidity as their primary nutrient criteria. Within these turbidity values those set by Cal EPA are often used by the Regional Boards as their own accepted criteria. Exceptions include Regional Boards 1 and 7 whose value for unacceptable turbidity has neither units nor specific endpoints. Meanwhile, Regional Board 3 uses values in Jackson Turbidity Units (JTUs), a unit inconsistent and without a conversion to the more common Nephalometric Turbidity Units (NTUs). The most common guideline for the amount of turbidity allowed in a system is any amount that does not hamper the beneficial uses of the site.

While turbidity criteria exist for almost every Regional Board, the inherent inconsistency of turbidity in streams, rivers, and lakes makes it difficult to apply this measurement to any action plan. Recent monitoring guidelines described in MacDonald (1991) state that it is possible to develop a quantifiable link between phosphorus and turbidity. However no established method has yet been developed. Without an established methodology to quantitatively link turbidity to phosphorus enrichment the Regional Boards are left to use turbidity as a qualitative indicator of NPS nutrient enrichment.

Nutrient values in the form of nitrogen criteria exist at four Regional Boards (4, 6, 8, and 9). Three Regional Boards present endpoints for ammonia as a function of pH and temperature and therefore require concurrent information for site-specific conditions (location, time of day, and season of the system being evaluated). The ammonia endpoint is primarily related to a toxicity endpoint (i.e., unionized ammonia) rather than nutrient over enrichment and induced eutrophication. Two Regional Boards provide limits for nitrate and one for nitrite, however these values are essentially a restatement of safe drinking water levels. The fourth (Regional Board 9) presents the nitrogen endpoints as a ratio with measured phosphorus. This last value uses quantitative data for P and a set ratio of N:P=10:1 to determine the level of N. Regional Board 9 is the only board to set values for phosphorus.

The Regional Boards also have site-specific water quality objectives for nutrients that have been established through approved TMDLs. Approved TMDLs for both EPA Regions IX and X are summarized in Section 5 of this report.

The state nutrient criteria survey underscores the need for more rigorous framework and set of nutrient related water quality objectives for most states including California. The goal of the RTAG and

STRTAG is to provide a more rigorous framework for nutrient criteria in California. This pilot project is the first step in meeting that objective.

1.2 OVERVIEW OF PILOT PROJECT APPROACH

The Work Plan pilot project is consistent with the original strategy that relies on development of nutrient criteria using a weight of evidence approach that takes into account observed data, expert opinion, and simulation model results. The first few months of the project were consumed with the development of the pilot project database. The process and results of the data collection efforts are described in Section 2 of this report. A large synoptic database was created, however there are some key limitations that restricted the evaluation of some of the targeted relationships. Very few of the available datasets included any biological data. Therefore the analysis of response variables remains incomplete. The analysis of the data collected for this report is included in Section 3. Population characteristics and the relationship of various parameters are explored in Section 3. Section 4 includes the results of an integrated modeling framework that includes the use of a watershed-loading model (SWAT), a stream transport model (SPARROW), and a lake / reservoir response model (BATHTUB). The model analysis includes several scenarios to explore conditions that are representative of Ecoregion 6. Section 5 includes summaries of several other potential lines of evidence that will require additional development and consideration including: 1) EPA Region IX TMDL numeric endpoints, 2) information regarding a multi-metric biostimulatory risk exposure index for running waters under development by the Central Coast RWQCB, and 3) a synopsis of studies being conducted in the Malibu Creek watershed. In addition, the principal investigators of the long-term studies will be invited with other regional experts to participate in panel discussions at the next RTAG / STRTAG workshop. Section 6 includes a synthesis of the project results in the form of a summary of findings, preliminary recommendations, and next steps for the development of nutrient criteria for ecoregions within EPA Region IX.

2 DESCRIPTION OF DATABASE

2.1 DATA COLLECTION PROCESS

The process of collecting nutrient related water quality data involved communication via telephone and email. Data, when obtained, were in electronic form. The following statements and questions were used during the phone and email communications:

- Introduction and brief description of the EPA National Nutrient Criteria development effort, including a description of Ecoregion 6 (California Oak and Chaparral). The following description was provided: "The primary distinguishing characteristic of this ecoregion is its Mediterranean climate of hot, dry summers and cool, moist winters, and associated vegetative cover comprising mainly chaparral and oak woodlands; grasslands occur in some lower elevations and patches of pine are found at higher elevations. Most of the region consists of open low mountains or foothills, but these are areas of irregular plains in the south and near the border of the adjacent Central California Valley Ecoregion. Much of this region is grazed by domestic livestock; very little land has been cultivated." A link to a map of Ecoregion 6 was provided.
- The following question was asked: "At the present time, we are trying to collect monitoring data from minimally impacted sites in the ecoregion. We are trying to get data for streams and rivers, lakes and reservoirs, and estuaries. This includes water, soil, GIS, and other watershed type data. Have you collected any data that would be relevant to our project? Also, do you know who might be a good contact for this type of data?"
- Minimally impacted water bodies were defined as follows:
    a. Designated / Beneficial Uses are unimpaired -- that is they are being met.
    b. Watershed indicators / disturbance does not dominate hydrology
    c. Land uses include a large fraction of natural landscape
    d. Flows are not severely depleted
    e. Channel is stable with large reaches with well-developed riparian. Substrate is >60% intact -- does not have to be cobble because cobble is not natural condition everywhere -- the >60% is for natural substrate.
    f. Streams do not have to be pristine but natural features have to be reasonably healthy.

2.2 CONTACT TABLE

A contact list was generated that contained the names of potential data sources. This list contained 238 individuals/agencies. Each contact was placed into one of the following categories: sent data, will send data, provided contact information, call back later or, no data. The definitions for each category are as follows:

Sent data – The contact sent data either in electronic or hardcopy format and Tetra Tech received the data.

No data – The person did not have data or contact information and was not likely to be helpful on this project.

Did not hear back – No response to email or telephonic communication.

Provided contact info. – The contact did not have the requested data but provided the name and contact information for someone who might have the type of data requested.

Other Response – Contacts were unable to provide data due to time constraints, or because the data were confidential; data were for locations outside Ecoregion 6; or, data were already in larger databases that we had received.

A summary of the responses is provided in Table 2-1. These responses could be broken down into two distinct categories (positive and negative). The positive responses (i.e., call back later, provided contact information, sent data, and will send data) totaled approximately 67%, while the negative responses (i.e., no data and not contacted) approximated 33% of the total.

The actual list of contacts, the agency that they represent, and their response is provided in Appendix A to this report.

Table 2-1
Summary of Nutrient Data Contact Responses

Response	Quantity
Sent Data	21
Provided Contact Information	47
No Data	74
Did Not Hear Back	63
Other Response (Unable to provide data; data not in Ecoregion 6; data may be confidential; data already in larger databases)	33

2.3 ISSUES

A number of issues were encountered during the data collection phase, which affected the speed at which data could be acquired or the quality of the data itself:

- Water quality data were not sorted and stored in a central location or database that could facilitate easy retrieval;
- Data was not in an electronic format, (i.e. it was contained in hardcopy data sheets, micro-fiche/film, or reports only);
- Several contacts did not return calls or e-mails in either a timely manner or at all;
- Contacts were busy conducting their normal duties and did not make processing our data requests a high priority;
- Several stations did not have latitude/longitude information;
- Limited supporting data for nutrient water quality samples were available (e.g., few flow, DO, pH, or turbidity measurements were collected with the nutrient data);

- Not many water bodies were defined as minimally impacted, and not much data was associated with these waterbodies;
- Although supporting information was explicitly requested, contacts often sent only the water quality data.

2.4 PRELIMINARY DATA SCREENING

The data that were received from the various source agencies were screened for consistency prior to being included in the EPA Region IX Nutrient Database. This screening process selected data that met the following criteria:

- Data must have latitude/longitude coordinates or a description of the sample site that allowed us to locate it on a regional map;
- Data must have either a numerical value or a non-detect value for requested parameters. Data where concentrations or values (except flow) were listed as 0.0 were excluded

3 EMPIRICAL DATA ANALYSIS

3.1 DATA OBTAINED

Usable data was obtained from 712 unclassified stations and 79 minimally impacted stations over Ecoregion 6 distributed as shown in Figure 1. The main sources of the data are identified in Table 1. Important sources of data were the Regional Boards (2, 3, 4, 5, and 9) the USGS, the Central Coast Ambient Monitoring Program, and the Army Corps of Engineers. Although other sources of data no doubt exist within the ecoregion, we still feel confident that we have a fair representation of stations over this area, and that individual sub-regions are not under- or over-weighted. Future data collection may address some other remaining sources of data.

Data on the following nutrient parameters were obtained with sufficient frequency to be used in the analysis that follows: NH_3, NO_2, NO_3, TKN, PO_4, and TP. All data were converted to represent the constituent in units of mg of nitrogen per liter or mg of phosphorus per liter. Thus, when data were reported for total nitrate in mg/l, this was multiplied by 14/62 to convert to units of nitrate as nitrogen in mg/l. This was done to obtain consistency across data sets from different sources.

3.2 DATA LIMITATIONS

Even though a large quantity of data was collected through the effort described earlier, we must still point out some limitations that reflect this approach. These are likely to be significant in any nutrient-related data collection over a large region, and must be considered in future evaluations of nutrient criteria that are based on existing datasets from multiple sources.

Few stations had sufficient co-located information on biology. A small number of stations did report values of chlorophyll a, dissolved oxygen, secchi depth, and turbidity, but these data were insufficient to carry out a region-wide analysis. This finding is similar to what was observed in our earlier pilot study (Tetra Tech, 2000). Data on other metrics that characterize algal or benthic communities, such as diversity or percentage of diatoms, was even more rare, and it is unlikely that such data will exist except in small, localized research studies that limit their wider applicability in nutrient criteria development.

No information on watershed characteristics. Descriptions of stations (watershed, land use, residence times, etc.) were requested during data collection, but almost no sites had enough characterization information available. To a certain degree, this shortcoming can be addressed for stream stations in the future by the availability of high resolution digital elevation data, that can be used to calculate the watershed for each station in the database, and in conjunction with land cover and soil characteristics maps can be used to define the land use characteristics for each station. This was done in a preliminary manner for all the stations in the database, but will be the subject of more detailed analysis in the coming year. For lake stations, key nutrient-related parameters such as the depth and residence time must be obtained on a site-by-site basis.

Uneven data density. Because the sampling conducted by different entities has different objectives, some stations are found to have substantially more data than other stations. If a population of all available data is pooled, there is the potential for the population to be biased by the existence of some stations with a large number of contributing datapoints. This is likely to be a feature of datasets across regions that combine data from multiple sampling programs with multiple objectives.

The same set of parameters was not measured. Although we have identified NH_3, NO_2, NO_3, TKN, PO_4, and TP as the parameters that are most widely reported, not all of these constituents are measured as often or as uniformly. For example, a subset of stations may have a lot of data on NH_3, but less information on the other constituents. This is again a consequence of there being multiple objectives underlying the data collection.

Data do not cover the same time period. All available data from stations within Ecoregion 6 was requested from the individuals/agencies contacted. For some stations the data record goes back several decades, but more commonly the data record single stations exists for a finite duration, and different stations may have been monitored over different time periods. For example, one station in the database may contain data from data from 1975 to 1985, another station may contain data from 1990 to the present. When data from such stations are pooled, there may be unknown influences such as weather or changing land use that are not easy to account for in a database of several hundred stations.

Limited Number of stations identified as minimally impacted. One of the requests made of the contacts was for a list of stations that could be classified as minimally impacted, as defined earlier. These stations could be used as a comparison against the general population of stations. However, this effort did not yield a large number of stations. In part this may be because there are few minimally impacted stations in Ecoregion 6, and in part it may be because agencies/individuals do not have the basis to perform this characterization.

Not using the same methods. It was assumed for the purpose of this study that the data provided to us used commonly accepted methods for analyzing various nutrient constituents. It is possible that there are systematic differences across agencies that use slightly different methods. However, such an analysis was beyond the scope of this work.

Some of the limitations identified following the data collection have been addressed in the data screening procedures defined below. However, other limitations are fundamental to the data collection process, and must be considered as regulatory or policy decisions are based on them.

3.3 SCREENING OF DATA

Before any analysis, the data were subject to the following transformations:

- Data records reporting values below the minimum detection limit (MDL) for a constituent were replaced by the MDL for that constituent as reported by the source collecting the data.
- Data records prior to 1980 were not considered in the analysis because of possible confounding effects because of the use of different methods and/or changing conditions in the water body.
- Data records that reported concentrations in excess of 50 mg/l for a single constituent were treated as outliers and discarded from the analysis. This resulted in the removal of about 20 data points.
- In the original dataset, the number of data points per station is highly uneven, with some stations reporting thousands of measurements, and some stations reporting less than 10 measurements. To account for this unevenness in the data, we used one data point per nutrient metric per station per month. Although this cannot completely correct for the bias in the uneven data collection, it does prevents undue weight being given to a small number of stations. The number of monthly data points for different stations is mapped in Figure 2. The map shows that there are a large number of stations with sufficient data in the Central Coast. A handful of stations in the San Francisco Bay area and the Los Angeles area seem to be well characterized with a large number of data points.

3.4 CLASSIFICATION OF STATIONS

Stations were first classified as to whether they fell in a stream or lake because this information was not always provided with the source data. This was done by comparing the station coordinates with a GIS layer of water bodies in California. The site description associated with each station, where available, was also used for verification. As a result of this process, of the general population of streams, 101 stations could not be classified, 28 stations fell in bays, 98 stations were in lakes, and 484 stations fell in streams. Of the minimally impacted stations, 2 stations were not classified, 5 were in lakes, and 71 were in streams.

Stations that were classified by the data providers as being minimally impacted were considered separately in the analysis. The remaining stations were classified into three categories: unimpaired (i.e., meeting all designated uses), impaired by nutrients, and impaired by factors other than nutrients. This was based on a GIS mapping of the station coordinates over maps of impaired and unimpaired waters obtained from California and US EPA sources. Points that were <1 mile from the water body were considered to lie within the water body to account for errors in geographic positioning of various geographic data sources. This classification is shown in maps in Figure 3 through 6, where the station locations are overlaid on 1) a land use map of the state of California, and 2) a map identifying water bodies as unimpaired or impaired (by nutrients or non-nutrient factors). The minimally impacted stations are also shown on these maps.

The numbers of minimally impacted, impaired, and unimpaired stations, for each water body type are as follows:

Water Body Type	Stream	Lake	Bay
Minimally Impacted	71	5	-
Unimpaired	218	75	21
Impaired (nutrients)	81	2	-
Impaired (non-nutrients)	185	21	8

3.5 BOX PLOTS OF DATA

Utilizing the data screened as described above, and using only the stations in lakes and streams that have been categorized as minimally impacted, impaired, and unimpaired stations, results in a subset of nearly 22,000 data points with NH_3, NO_2, NO_3, TKN, PO_4, or TP data. To present these data in a way that aids comprehension, values for each nutrient constituent in each category of water body were represented by box plots. These plots are useful because they show key features of the distributions that have earlier been considered important in nutrient criteria development, i.e., the 25th percentile, the median, and the 75th percentile of the data.

Data are shown in Figures 7-18 for NO_3, NO_2, NH_3, TKN, PO_4 and TP for either lakes or streams with stations being classified as minimally impacted, unimpaired, impaired by nutrients, and impaired by agents other than nutrients. These data are also summarized in Tables 2 through 5. The main findings from this analysis are as follows:

- The data are highly variable for all categories of water bodies and for all nutrient constituents, spanning several orders of magnitude in many cases. Given the variety of natural and anthropogenic sources of nutrients, and the role of runoff in transport, this result is not surprising. From the standpoint of nutrient criteria development, this result is important because it provides a basis to relate the unimpaired and minimally impacted station variability into the criteria. Figure 19 shows the variation in standard deviations across different classifications of streams. Unimpaired water bodies have lower standard deviations of nitrate and TP, but standard deviations of TKN and PO_4 do not differ significantly.
- If we believe than nutrients concentrations can be directly related to impairment, we expect a to see a pattern in these plots, with the lowest concentrations in minimally impacted water bodies, higher nutrient concentrations in unimpaired water bodies, and still higher concentrations corresponding to impaired water bodies. For streams, this relationship was found to be strong for the case of NO_3 and PO_4, somewhat significant for TKN and NH_3, but was not seen for the other two constituents, TP and NO_2. For lakes, the dataset we were working with was much smaller, and the trends were harder to discern. There appeared to be an effect of nitrate concentrations on impairment, albeit weaker than what was observed for streams. The behavior with respect to phosphorus was counterintuitive, with lower concentrations being seen impaired water bodies.
- The seasonal effect of nutrients, particularly during the growing season was also considered in these analyses. Data were plotted separately for the months of June through September during which temperatures are expected to be warm, and algal growth likely to be significant. The results of these analyses are presented alternately with the whole-year analysis in Figures 8, 10, 12, 14, 16, and 18. These results amplify the findings of the whole year plots, especially for NO_3, where the difference between the minimally impacted and impaired stations is greater. For the other parameters the results are supportive of the whole year analysis. These results demonstrate that it may be possible to focus the criteria on nutrient concentrations during the warm, growing months of the year.
- Data summaries for all waterbody types, presented in Tables 2-5, can be used to supplement the box plots to identify the median and upper and lower quartile of constituent concentrations for impaired and unimpaired water bodies. Thus, over June through September, median concentrations of nitrates in streams vary from 0.08 mg/l for minimally impacted water bodies, to 0.3 mg/l for water bodies that are unimpaired and meet their designated uses, and increase to 5.43 mg/l in nutrient-impaired water bodies. Likewise, PO_4 concentrations increase from 0.02 mg/l in minimally impacted water bodies to 0.08 mg/l in unimpaired water bodies, increasing to 0.25 mg/l in nutrient impaired water bodies. In contrast, median TP levels in minimally impaired streams are almost as high as in nutrient-impaired streams (0.14 mg/l vs. 0.12 mg/l). Section 4 explores some of the reasons underlying high TP concentrations in small, first-order streams.
- The N-P ratio provides one basis for suggesting that nitrogen species may be more strongly correlated to impairment. When the molar ratio of nitrogen: phosphorus is greater than 16, the expected ratio of these elements in algal biomass, a water body is thought to be phosphorus limited, and when this ratio is less than 16, a water body may become. Co-located nitrogen and total phosphorus values (same station, date, and time) were plotted in Figure 20 to determine which element is most likely to be limiting. Most of the stream stations in Ecoregion 6 appear to be nitrogen limited as indicated by the Redfield ratio, although the lake stations appear to be limited by both nutrients. This finding may explain why we see a strong relationship between impairment and nitrate levels in streams in Ecoregion 6.

3.6 NUTRIENT LAND-USE RELATIONSHIPS

It is well understood that the presence of developed land in a watershed can lead to increased nutrient levels in downstream water bodies, as a result of various anthropogenic point and non-point sources. To understand nutrient levels in the absence of anthropogenic inputs, we are also interested in the distribution of values for stations where the percentage of developed land is low. To evaluate the effects of land use on nutrient concentrations, we performed a preliminary analysis where we looked at the proportion of different land uses with the CALWATER watersheds in which each of the study stations fell. The relationship between percentage of developed land (either percent of agricultural land or percent of urban land) and nutrient concentrations are shown in Figure 21 for streams and in Figure 22 for lakes. Although the relationships are noisy in all cases, more can be inferred from the stream plots because of the larger number of datapoints. In most instances it can be seen that higher levels of developed land, nutrient concentrations are high. Interestingly, however, when the percentage of developed land is low, nutrient concentrations can be both high are low. The general relation is strongest for NO_3 data. This is indicative of a) possible inaccuracy in the analysis, because the land use in the CALWATER watershed for a station may not represent the land use in its entire watershed, or b) the effect of background sources of nutrients. In future work with these data, this question will be considered in greater detail by using the calculated watershed for each station in Ecoregion 6. For the urban land use, it appears that there is a decrease in some nutrient concentrations at high percentages of urban land. This is an interesting finding although possibly not important from the viewpoint of nutrient criteria development.

3.7 STREAM LEVEL AND NUTRIENT CONCENTRATION

Streams in EPA's RF1 database are characterized by level from 1 through 8; streams at the highest level (Level 8) are small streams with no tributaries, which feed into lower level streams. At the other extreme, Level 1 streams are expected to be large streams/rivers than drain into oceans. As we move from Level 8 to Level 1 streams we expect increases in catchment area and flow. As discussed in Section 4, the progression to larger streams is expected to reduce nutrient concentrations because of removal processes in streams. The relationship between nutrient chemistry and stream levels for unimpaired streams is shown in Figure 23. Based on the existing dataset there do not appear to be strong relationships between stream level and concentrations of NO_3, TKN, and TP. The pool of data for the minimally impacted stations was not large enough to perform a robust analysis, although such an analysis is recommended for future work.

3.8 CHLOROPHYLL A AND NUTRIENTS

In general, chlorophyll a values were relatively sparse in the data collected for Ecoregion 6 and insufficient for a region-wide analysis. An exception, however, is the dataset obtained from Regional Board 3, which does contain a large number of co-located measurements of nutrient chemistry and chlorophyll a concentrations. These data were used to study the nature of the relationship between chlorophyll a and nutrients as shown in Figures 24 and 25. The data show a correlation between TKN and chlorophyll a, and somewhat weaker correlations for NO_3 and PO_4. TP data were insufficient to draw any conclusions. This association of chlorophyll a with TKN is in line with our finding earlier that most streams in Ecoregion 6 are nitrogen limited. Where sufficient data are available, chlorophyll target concentrations can be used to determine a corresponding range of nutrient concentrations that can be used to guide criteria development. At present these data are limited to a small part of the Ecoregion and cannot be extrapolated to the entire area. Future data collection of this nature over more stations is strongly recommended.

3.9 ASSESSMENT OF SUBSETS OF DATA

To evaluate the spatial relationships of nutrient constituents over Ecoregion 6, medians of key parameters were plotted on a map of the region. Plots of NO_3, TKN, PO_4, and TP are shown in Figure 26 through 29. These maps permit a different assessment of the same data that have been discussed in earlier sections. By far the largest number of stations with usable parameters are in the coastal regions of Ecoregion 6. In particular, it appears that the Central Coast Region south of Monterey Bay has low concentrations of all four constituents that have been mapped, whereas the areas further south such as those near San Luis Obispo, Santa Barbara, and Los Angeles, all high consistently higher concentrations of all four nutrients. The Monterey Bay area has high concentrations of nutrients, especially NO_3 and TKN. The area south of San Francisco Bay has high concentrations of TKN, but relatively low concentrations of the phosphorus species. The coastal areas north of San Francisco Bay have low concentrations of TKN, TP, and PO_4. Despite a large number of stations overall, it seems we still have insufficient data to characterize nutrient concentrations in the northern part of Ecoregion 6. This will be a focus of future data collection.

Table 3-1 Major sources of data in Ecoregion 6

Agency	Number of Stations
USGS	216
RWQCB 4	179
RWQCB 3	151
Central Coast Ambient Monitoring Program	134
RWQCB 5	55
Corps of Engineers	50
Orange County	25
Orange County PFRD	25
Department of Water Resources	24
UCLA	18
RWQCB 9	12
RWQCB 2	6
Monterey County	6
Heal the Bay	2

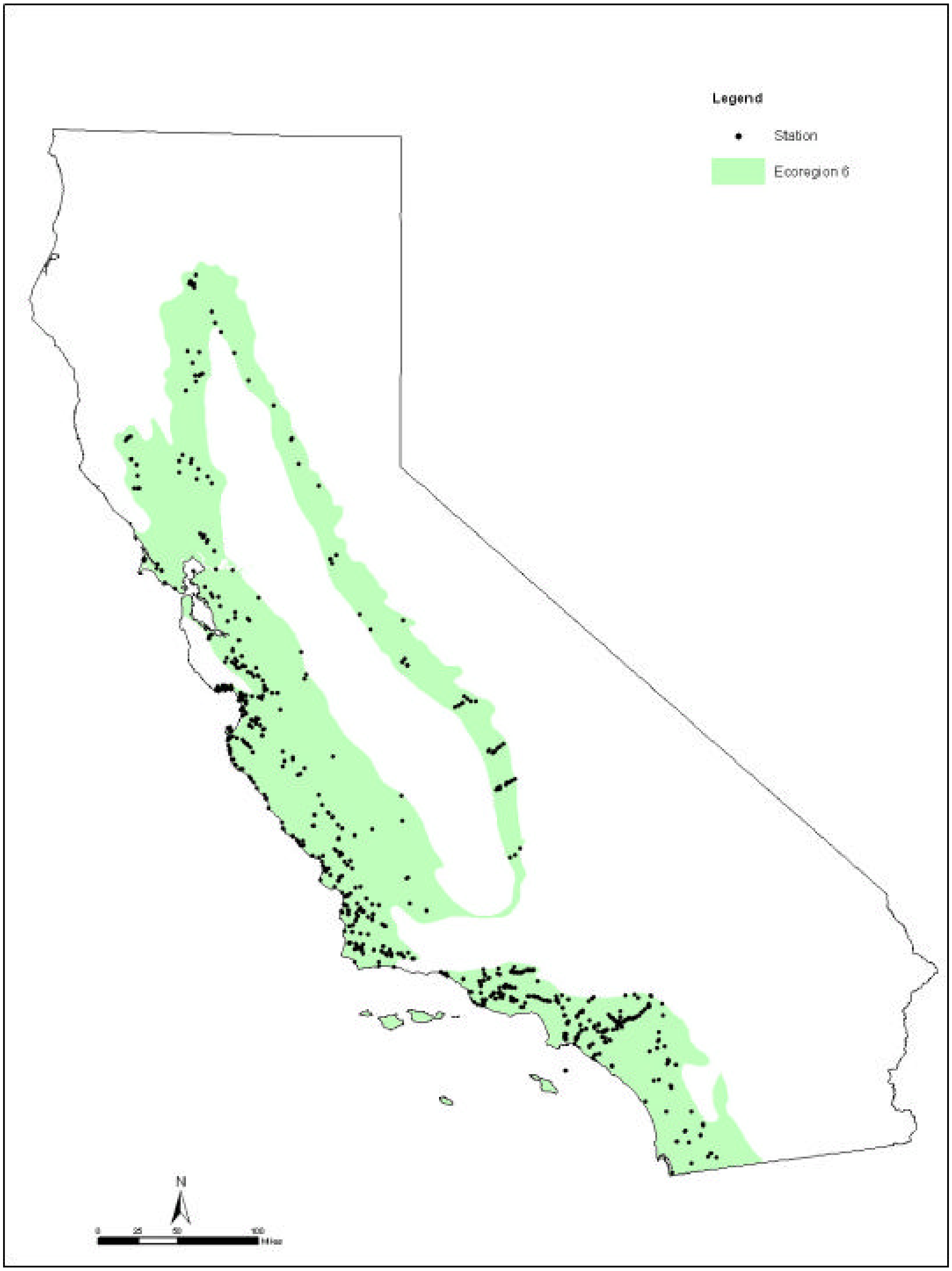


Figure 3-1. Distribution of stations with nutrient data in Ecoregion 6

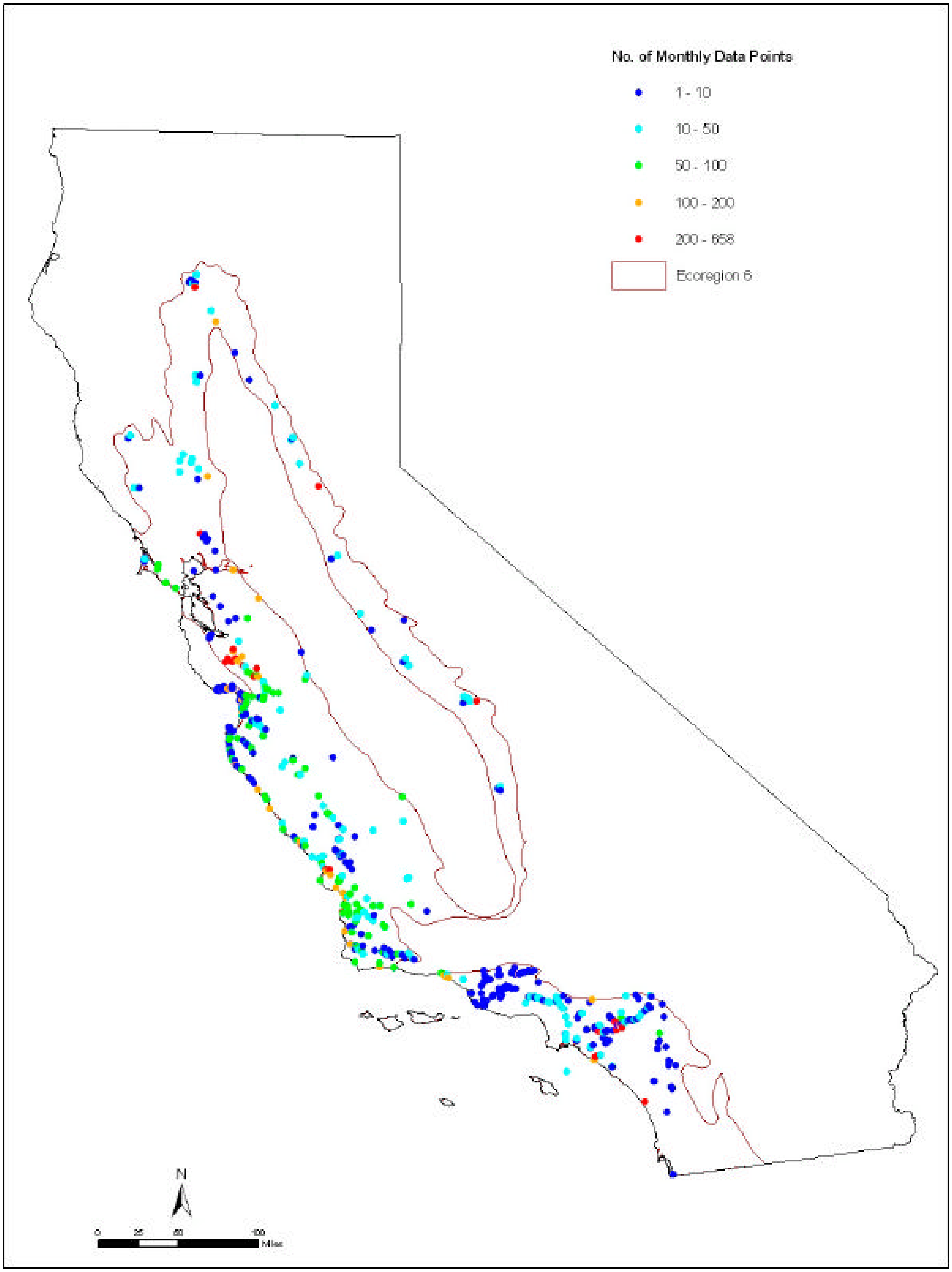


Figure 3-2. Number of monthly data points with nutrient data in different stations of Ecoregion 6

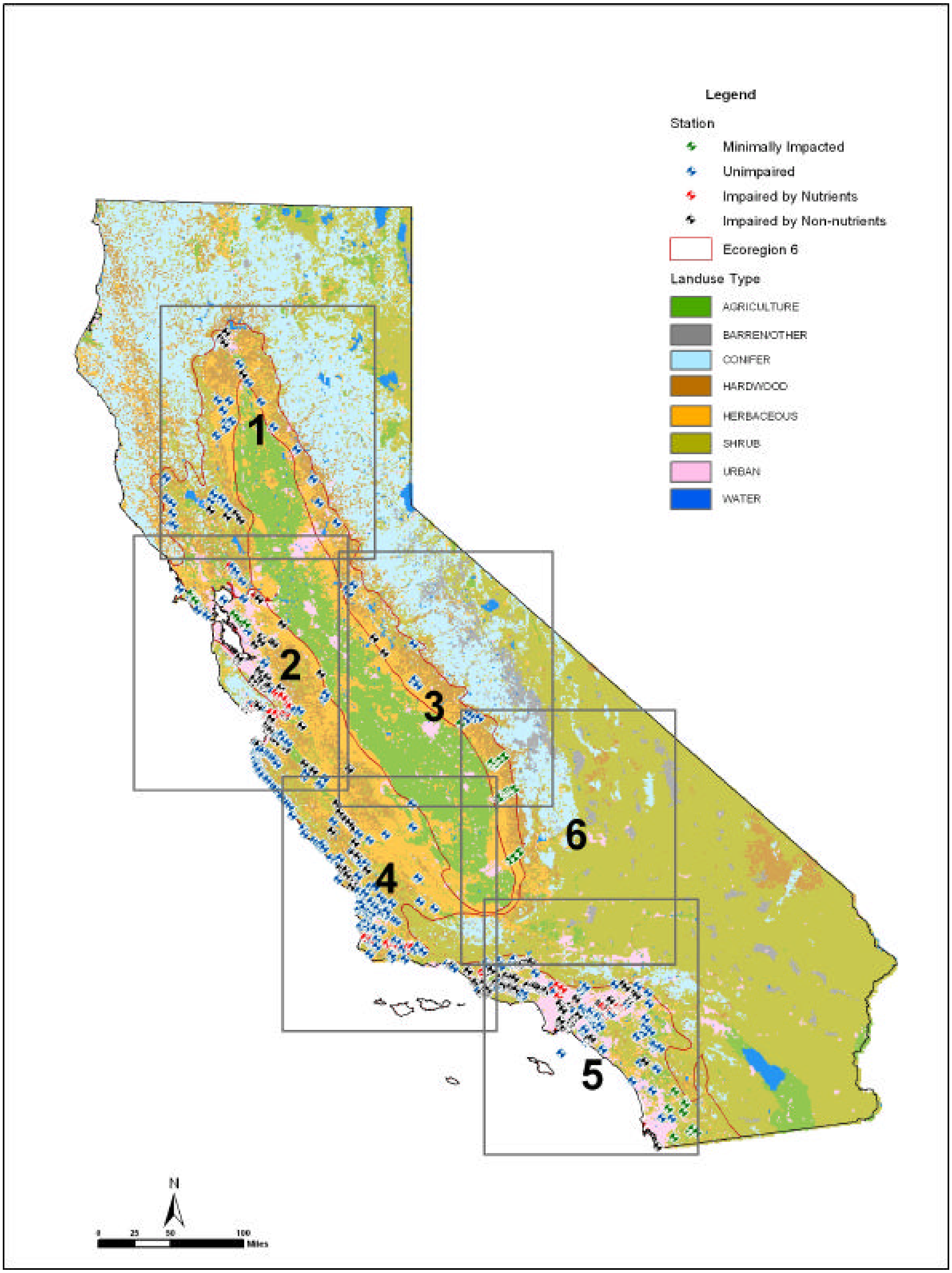


Figure 3-3. Stations classified as minimally impacted, unimpaired, impaired by nutrients, and impaired by non-nutrients across Ecoregion 6, overlaid on a map of land use.

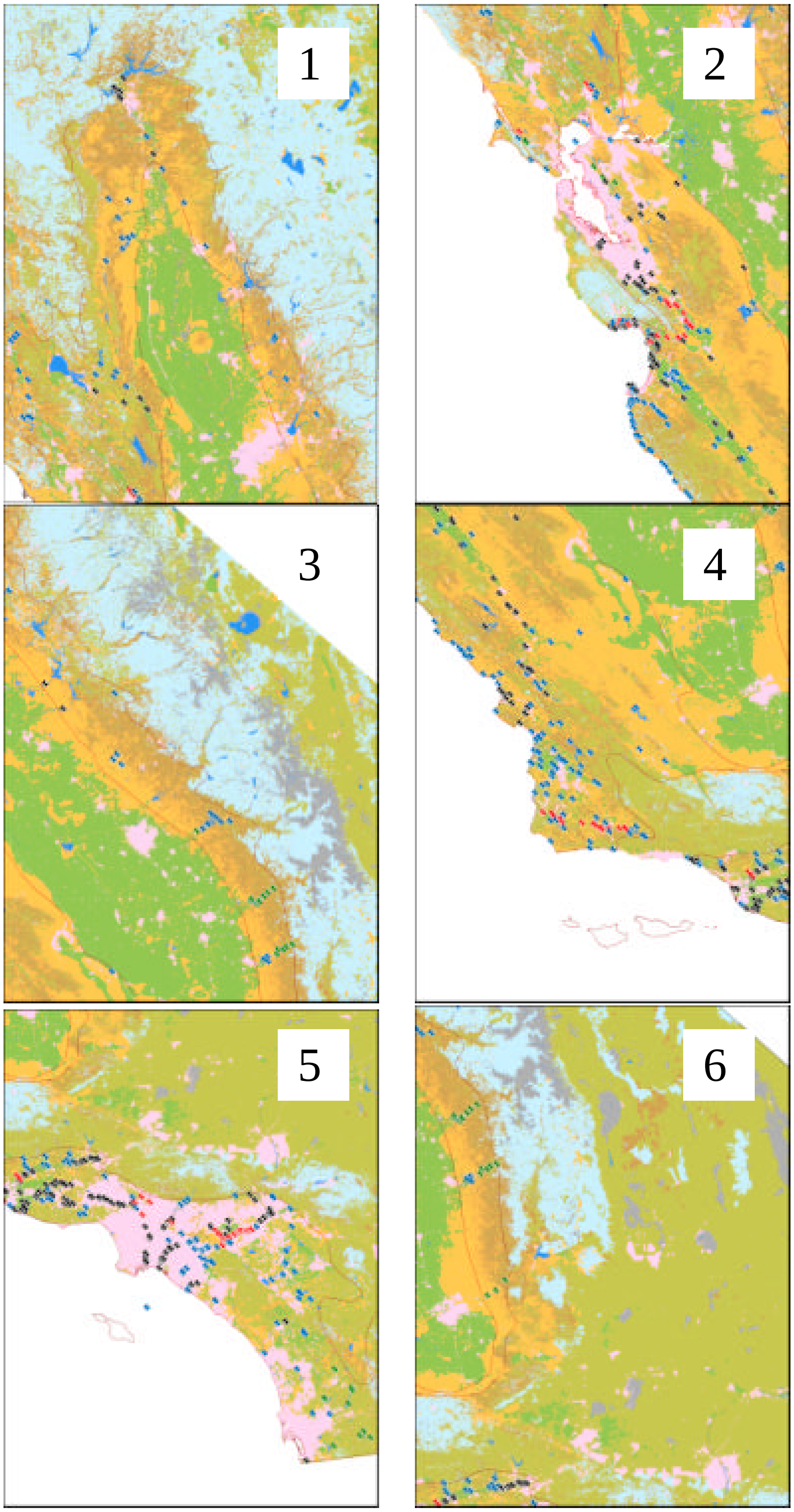


Figure 3-4. Stations classified as minimally impacted, unimpaired, impaired by nutrients-2-0, and impaired by non-nutrients across Ecoregion 6. Same as map in Figure 3-3 but focused on different parts of Ecoregion 6. The colors associated with the symbols and the land use coverages are shown in Figure 3-3. The map numbers correspond to the areas shown in Figure 3-3.

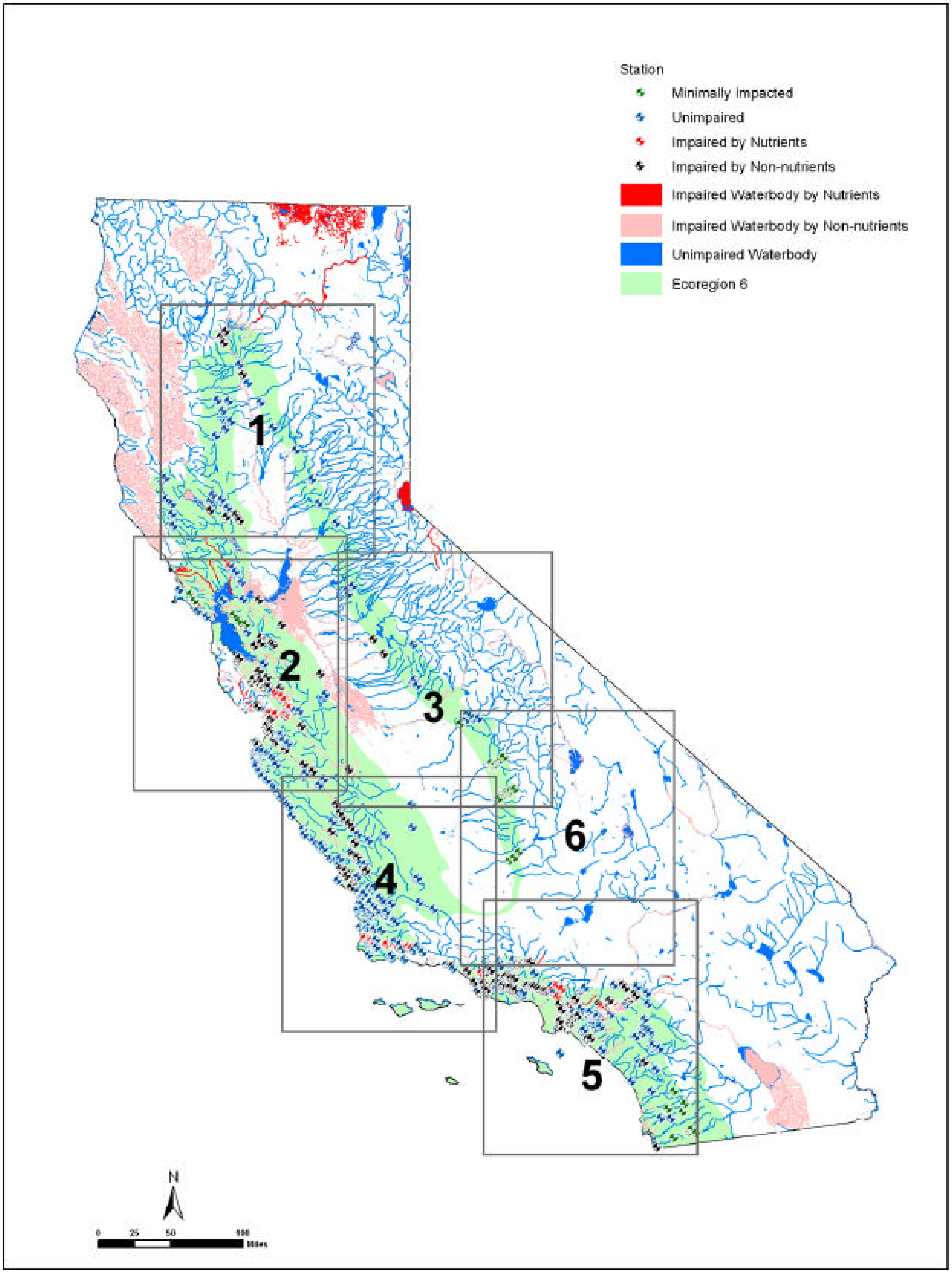


Figure 3-5. Stations classified as minimally impacted, unimpaired, impaired by nutrients, and impaired by non nutrients across Ecoregion 6, overlaid on a map of identifying water bodies as unimpaired and impaired by nutrients and non-nutrients.

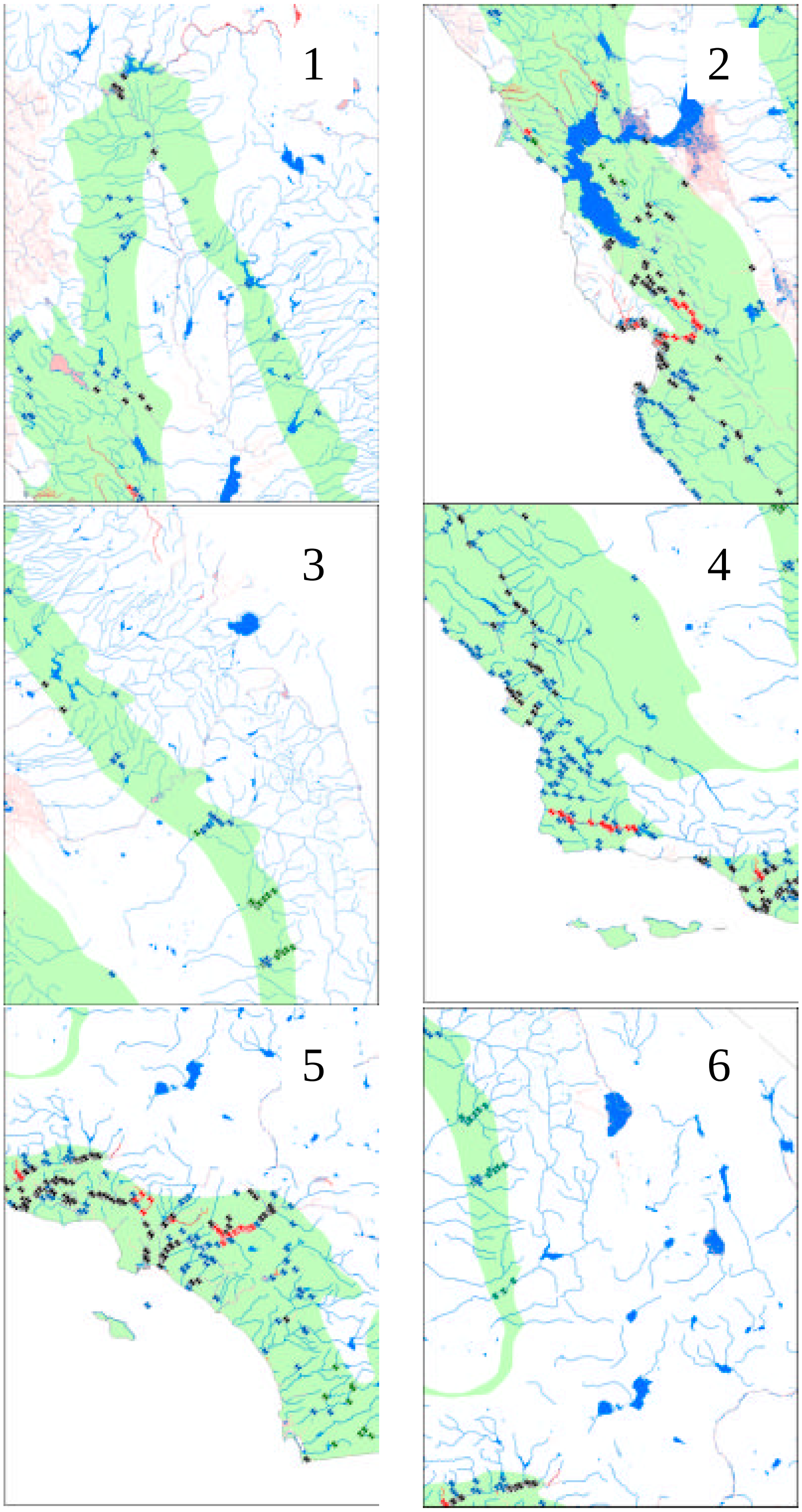
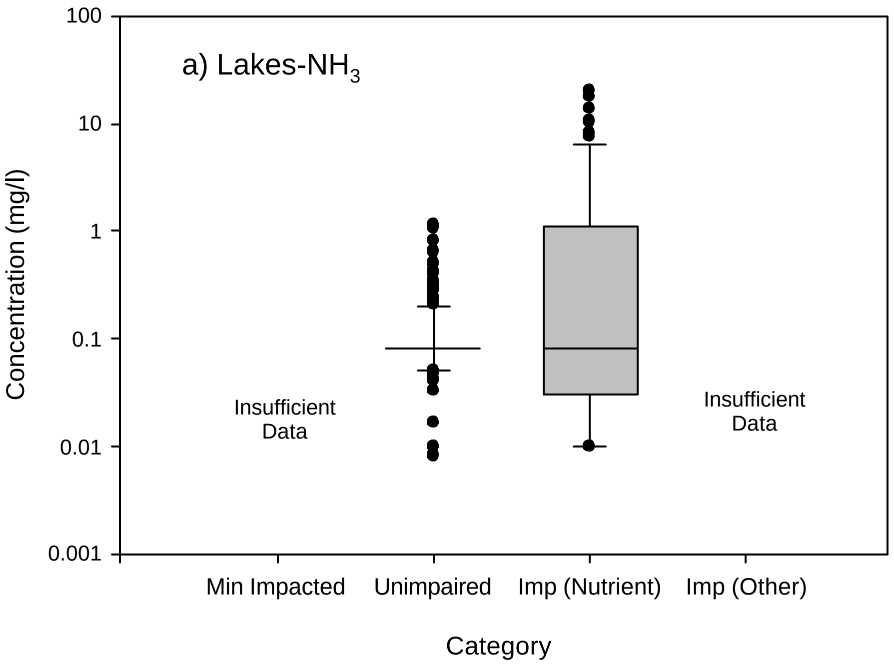


Figure 3-6. Stations classified as minimally impacted, unimpaired, impaired by nutrients, and impaired by non nutrients across Ecoregion 6, overlaid on a map identifying unimpaired and impaired water bodies. Same as map in Figure 3-5 but focused on different parts of Ecoregion 6. The colors associated with the symbols and the water bodies are shown in Figure 3-5. The map numbers correspond to the areas shown in Figure 3-3.



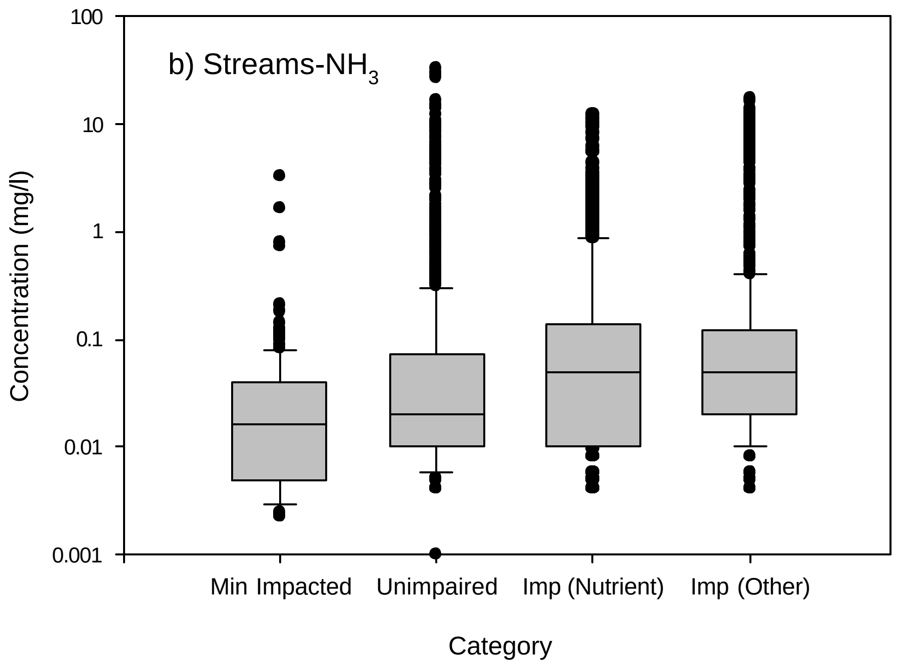
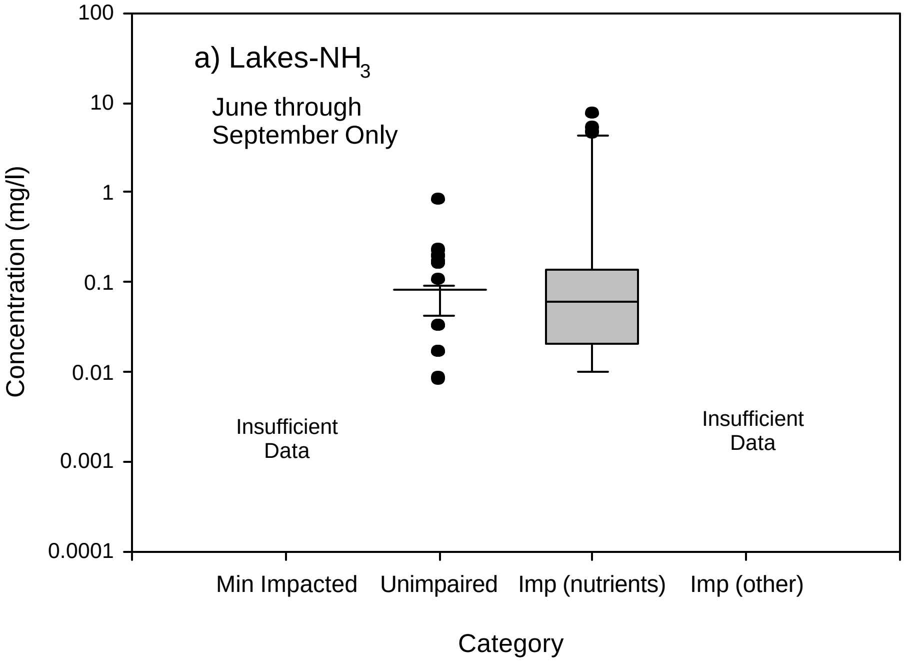


Figure 3-7. NH_3 levels across the whole year in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-



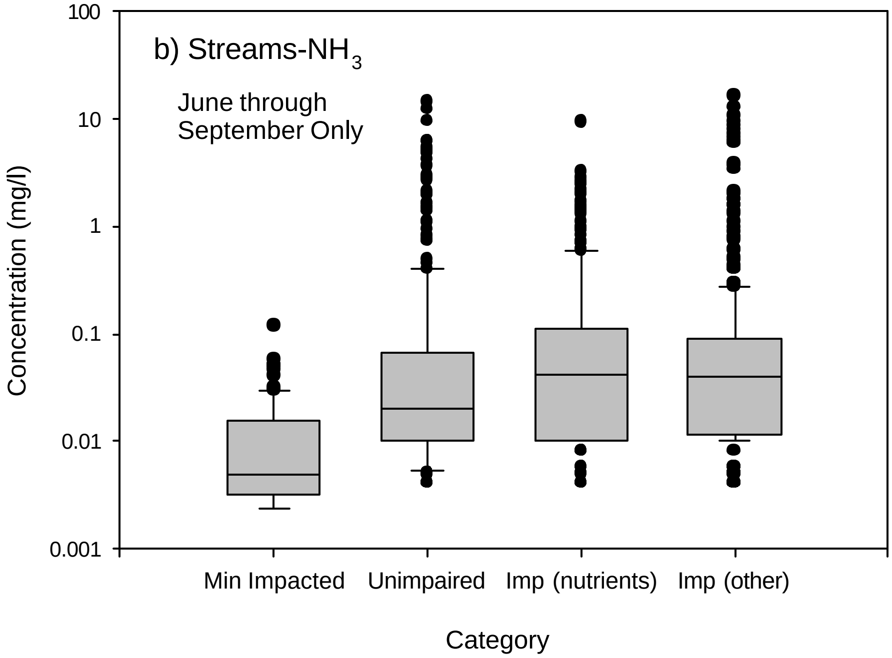
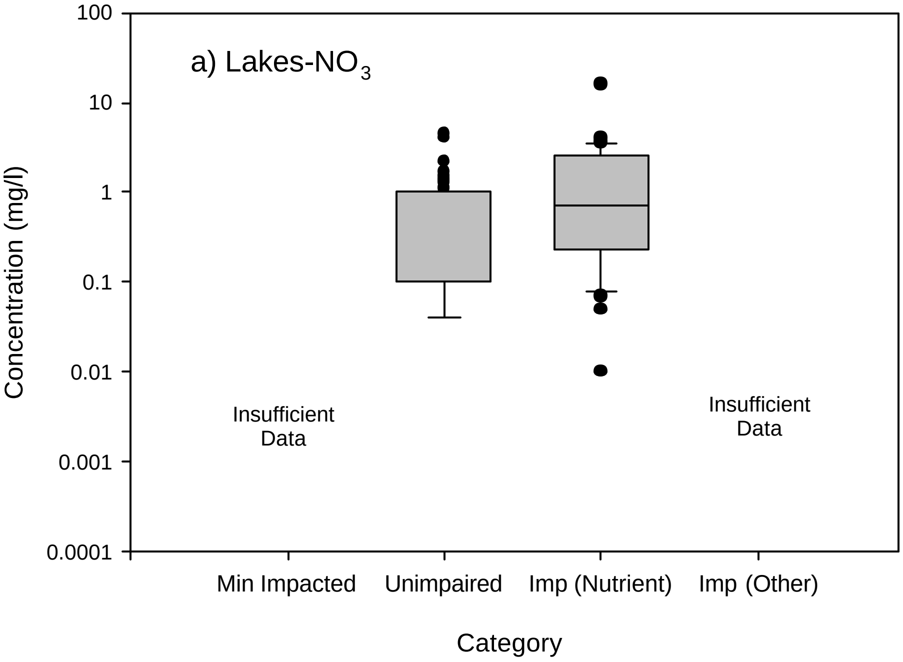


Figure 3-8. NH_3 levels from June to September in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10^{th} and 90^{th} confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.



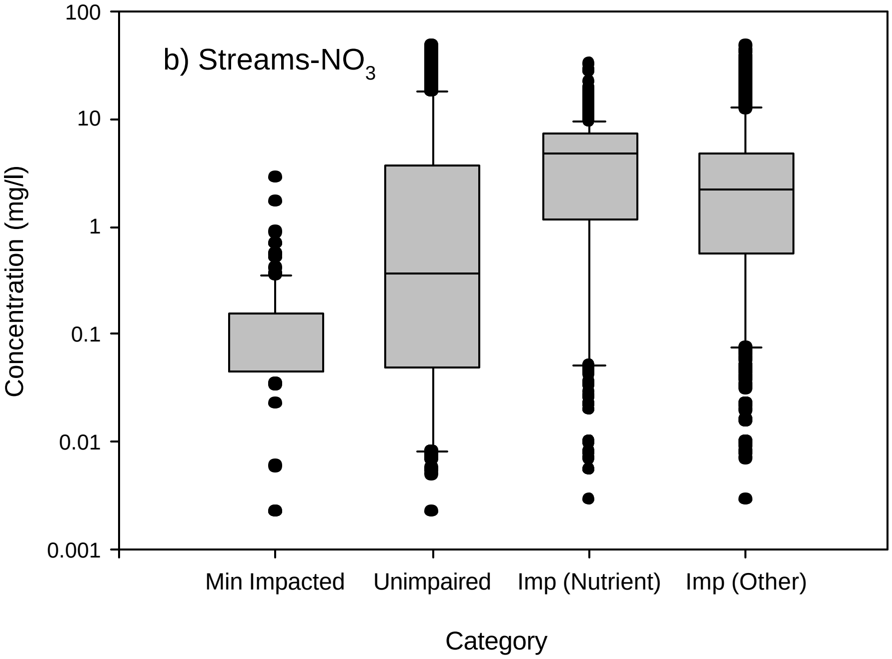
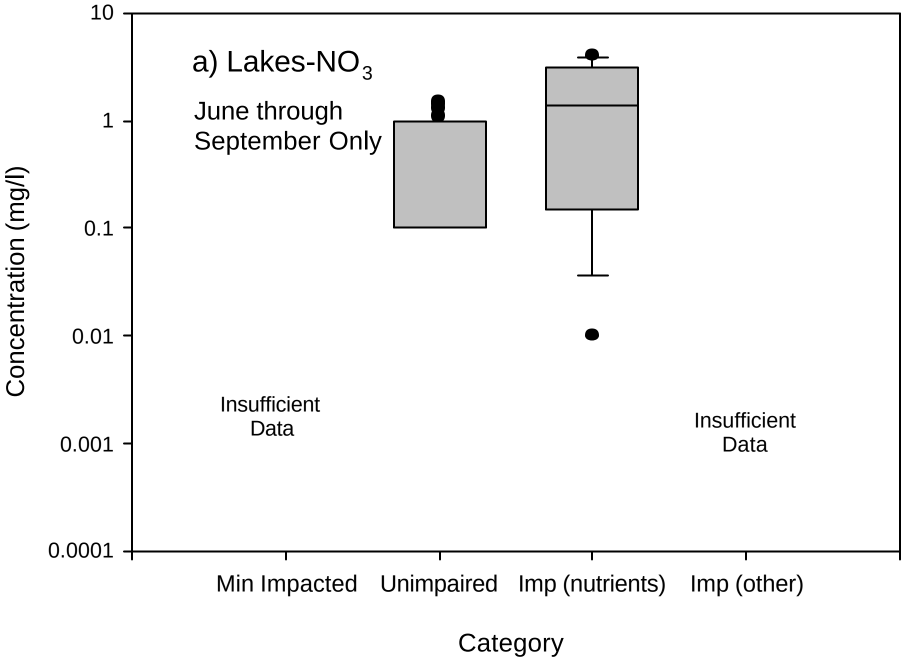


Figure 3-9. NO_3 levels across the whole year in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.



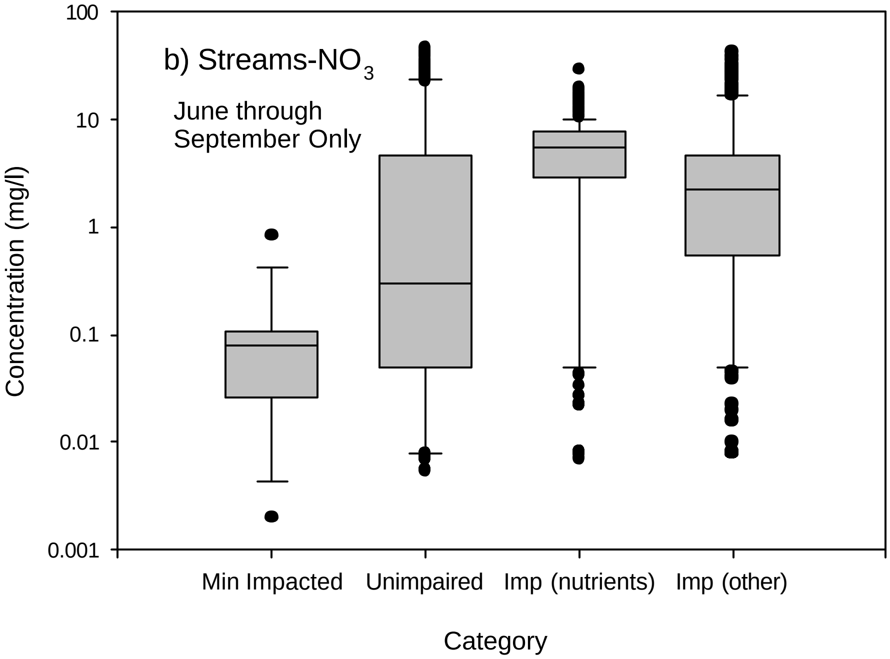
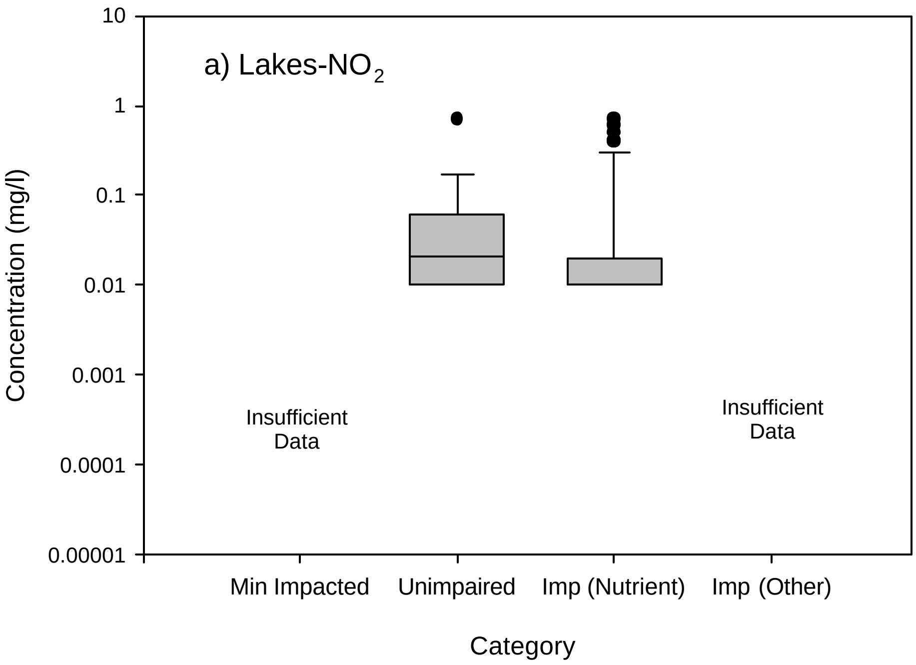


Figure 3-10. NO_3 levels from June to September in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.



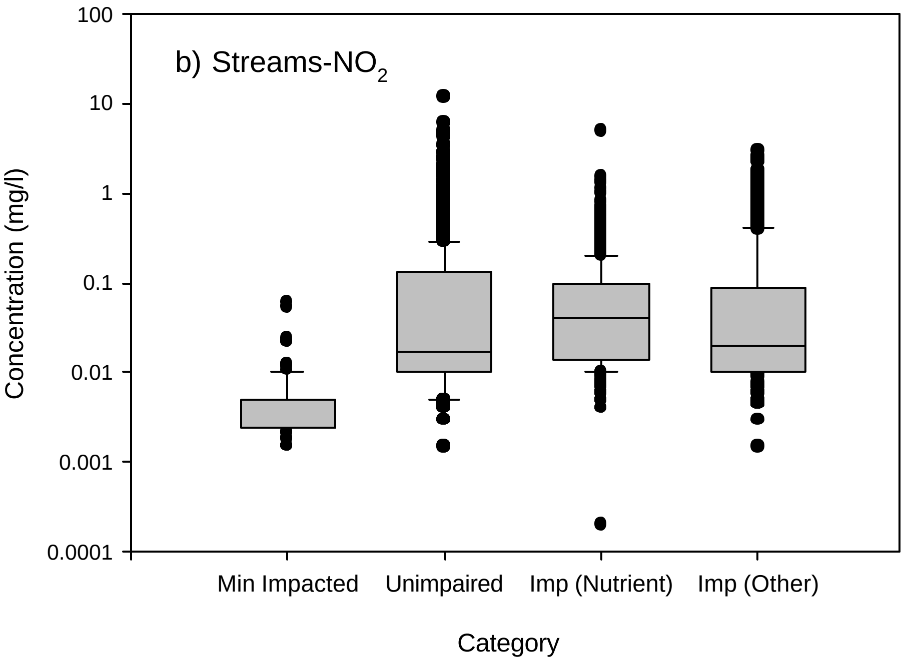


Figure 3-11. NO$_2$ levels across the whole year in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.

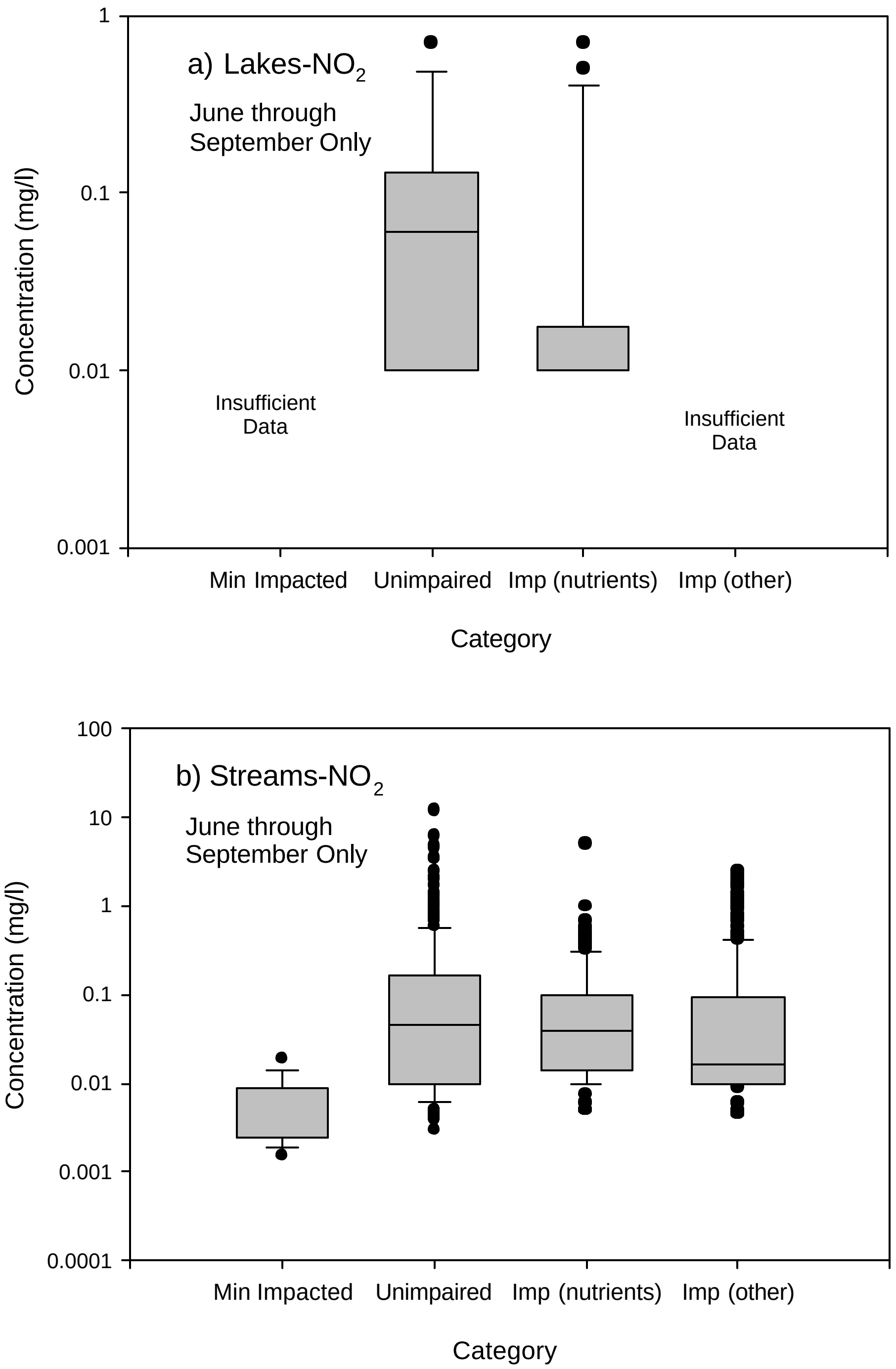


Figure 3-12. NO_2 levels over June through September in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.

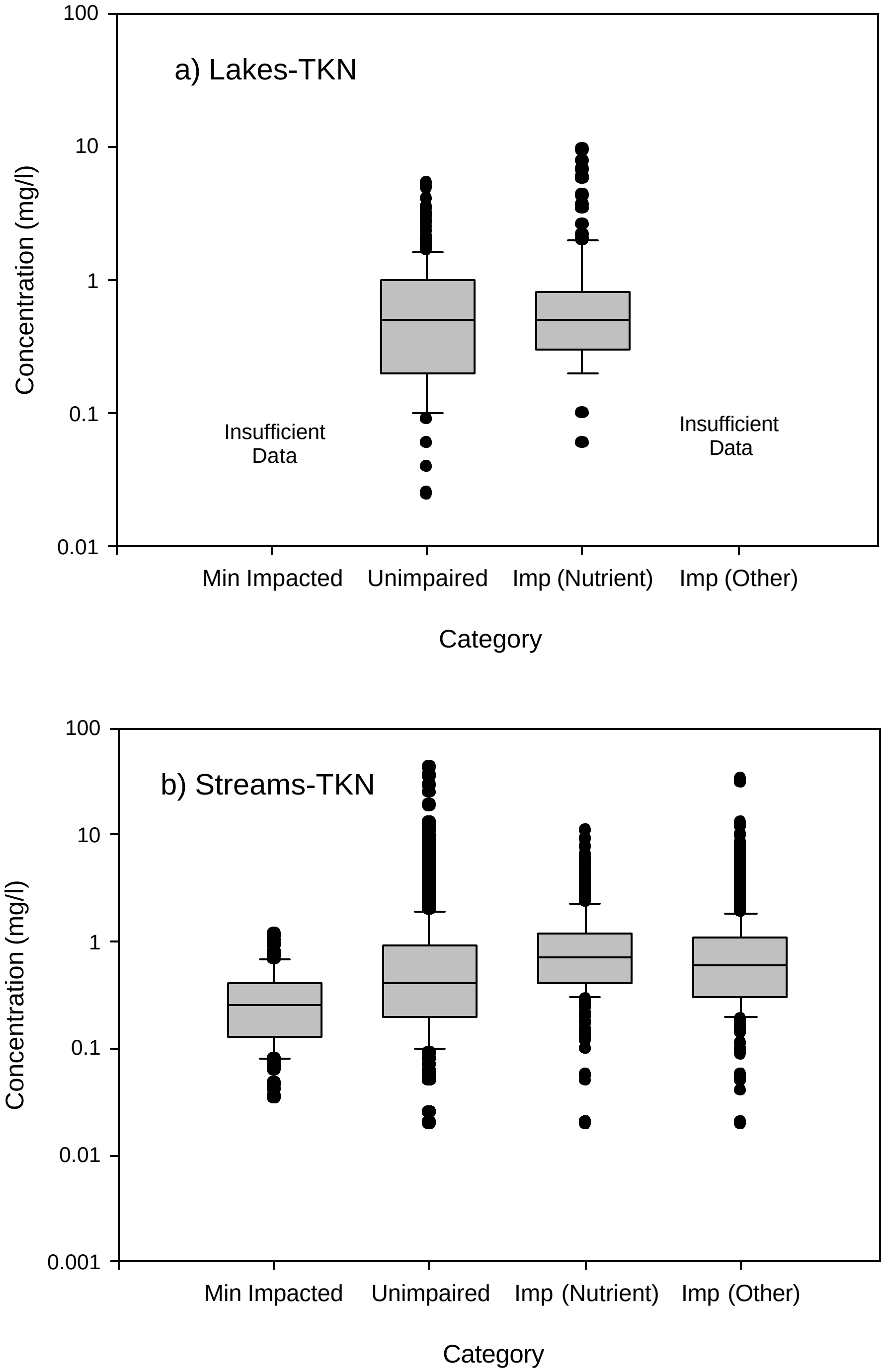
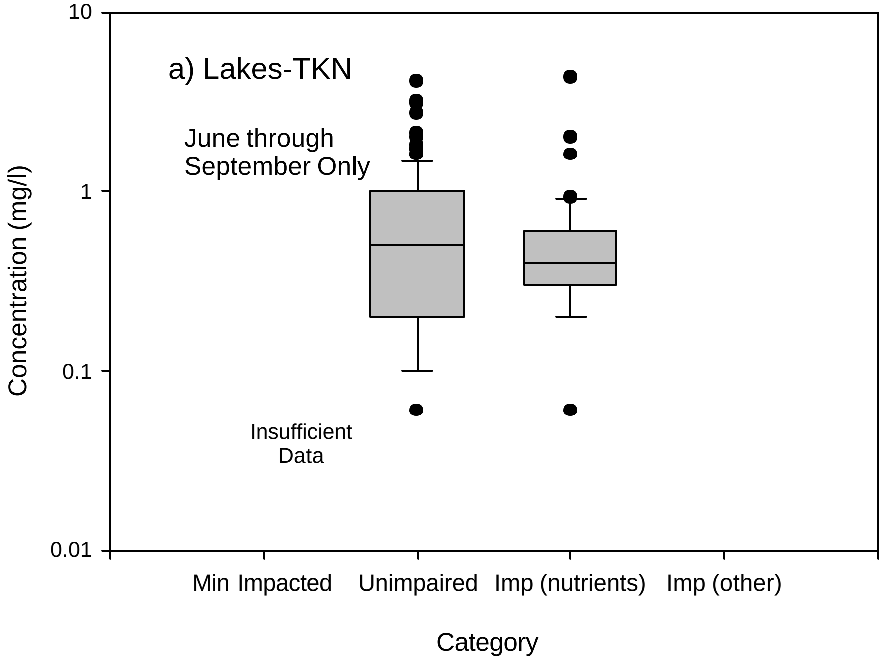


Figure 3-13. TKN levels over the whole year in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.



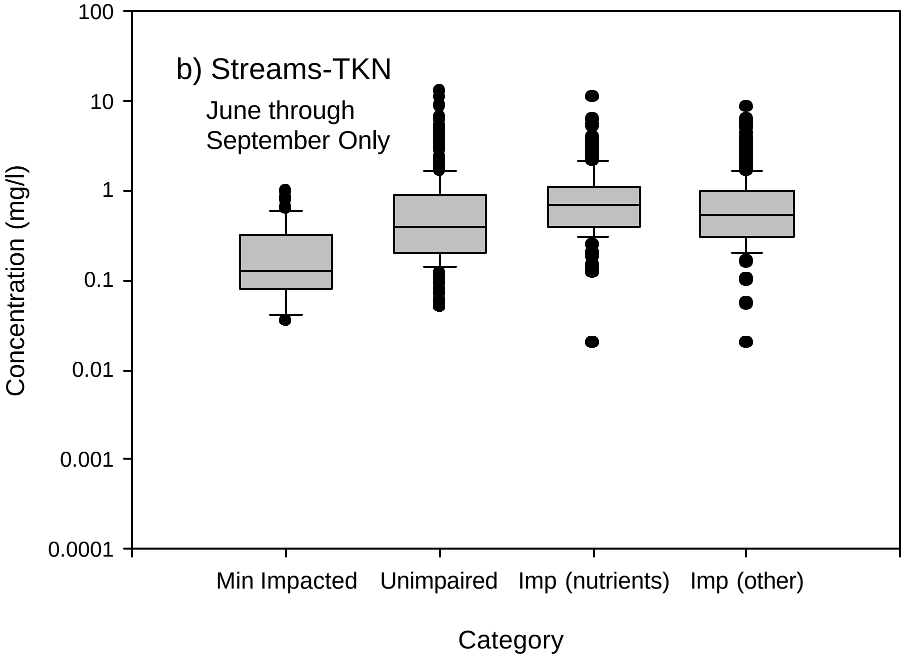


Figure 3-14. TKN levels over June through September in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.

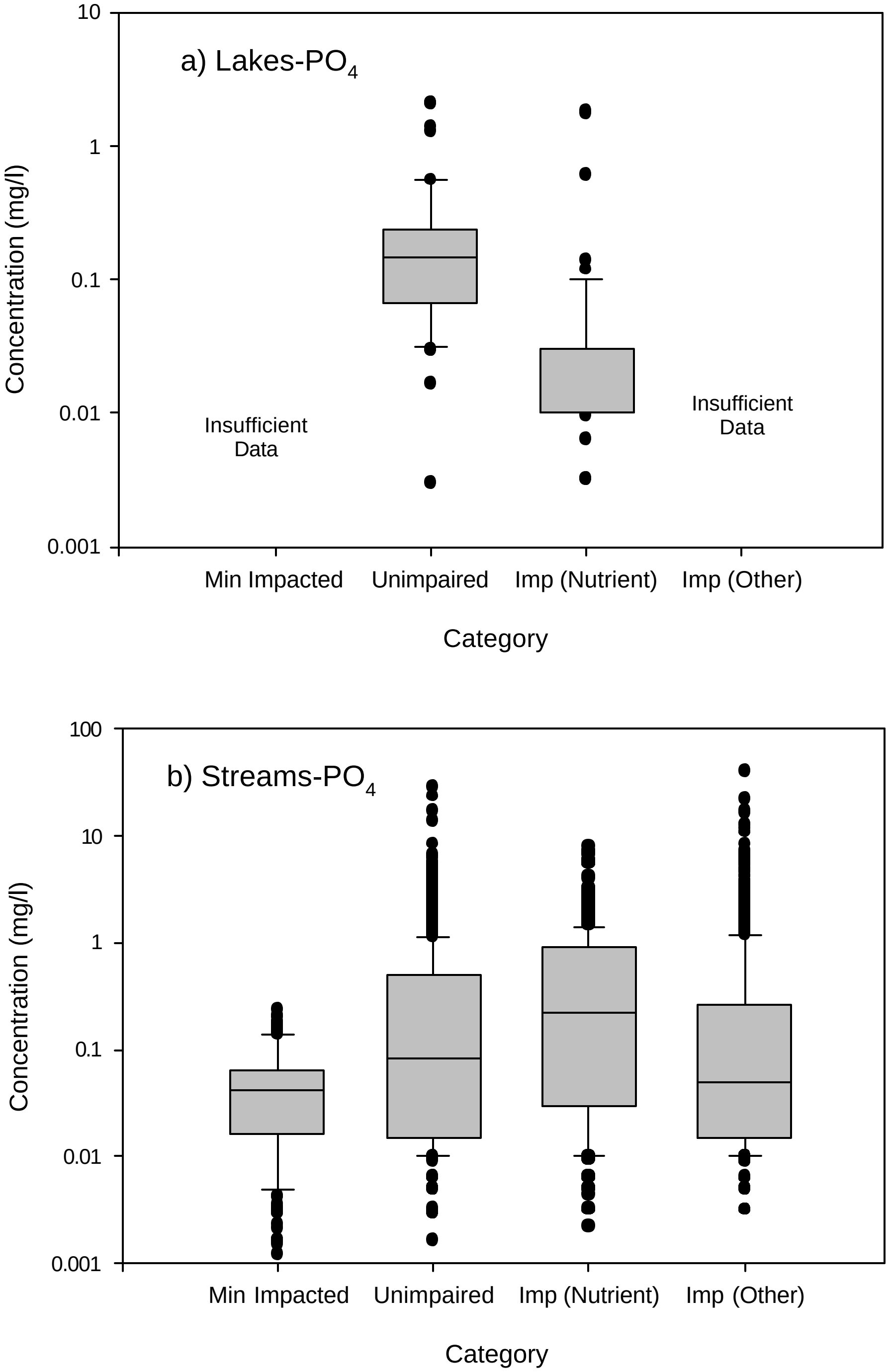
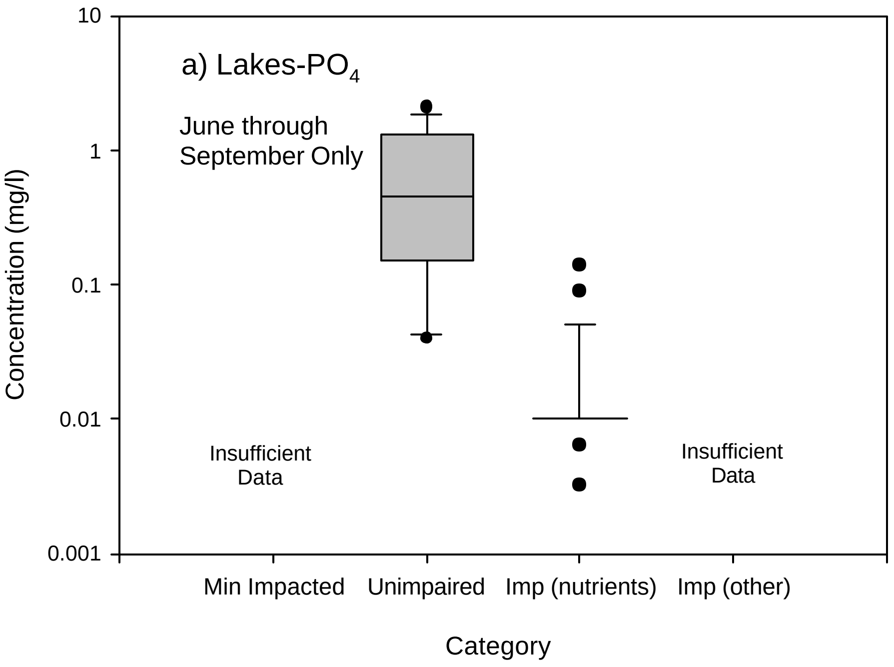


Figure 3-15. PO$_4$ levels across the whole year in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.



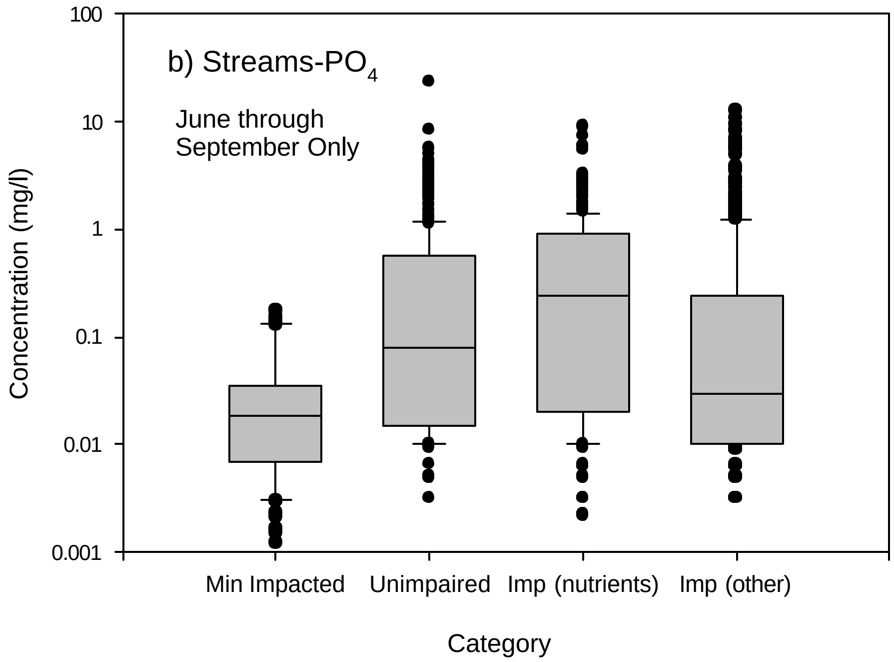


Figure 3-16. PO_4 levels over June through September in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.

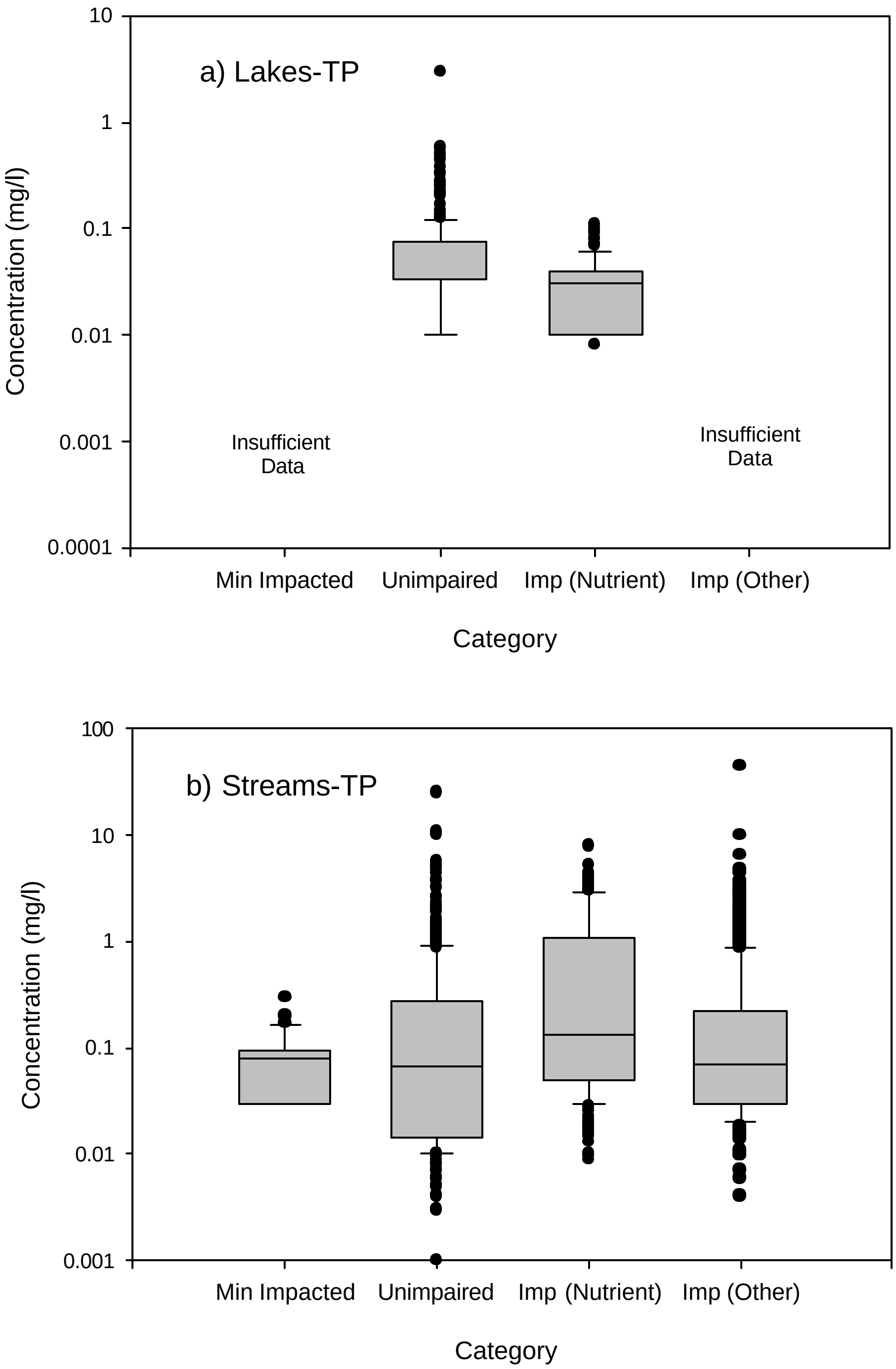
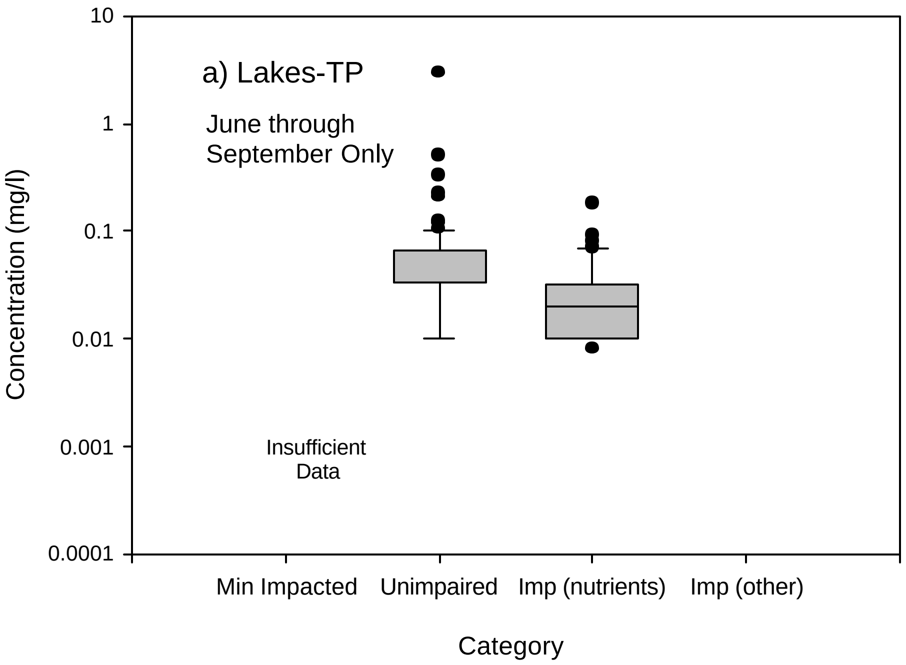


Figure 3-17. TP levels across the whole year in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.



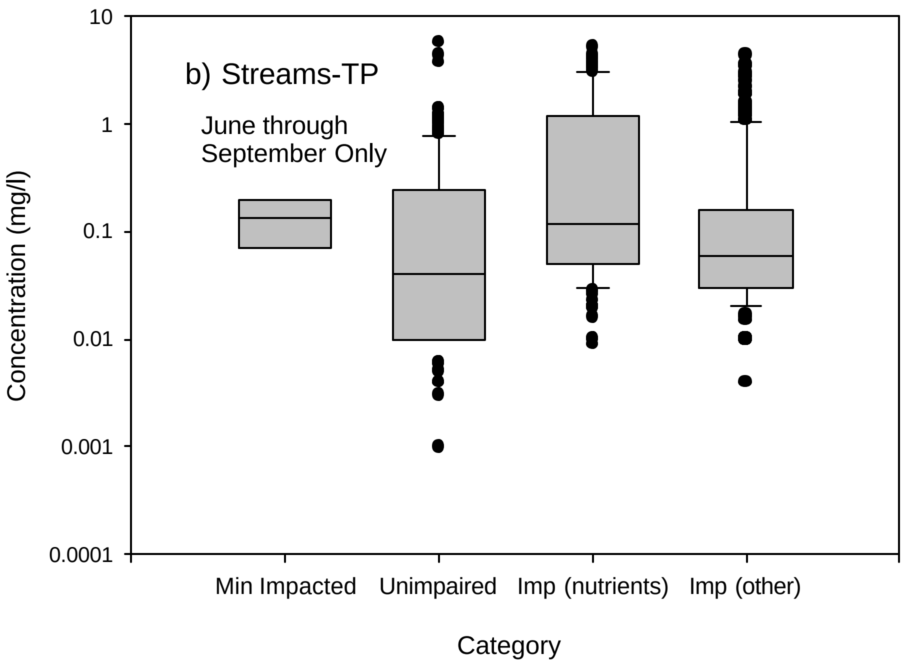


Figure 3-18. TP levels over June through September in lakes and streams, classified as minimally impacted, unimpaired, nutrient impaired, and non-nutrient impaired. The horizontal line in the middle of the each box represents the median, the lines are the 10th and 90th confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.

Table 3-2. Nutrient Concentrations in Lakes (All Year)

Chemical	Stream Type	Median	Average	First Quartile	Second Quartile	Third Quartile	Fourth Quartile	No of Datapoints
NH_3	**Unimpaired**	0.08	0.12	0.08	0.08	0.08	1.15	228
	Impaired (other)	0.08	1.86	0.03	0.08	0.94	20.10	64
NO_2	**Unimpaired**	0.02	0.07	0.01	0.02	0.06	0.70	37
	Impaired (other)	0.01	0.07	0.01	0.01	0.02	0.70	62
NO_3	**Unimpaired**	0.10	0.43	0.10	0.10	1.00	4.52	190
	Impaired (other)	0.70	1.88	0.23	0.70	2.60	15.81	28
TKN	**Unimpaired**	0.50	0.73	0.20	0.50	1.00	5.40	315
	Impaired (other)	0.50	0.96	0.30	0.50	0.80	9.40	107
PO_4	**Unimpaired**	0.15	0.29	0.07	0.15	0.24	2.10	46
	Impaired (other)	0.01	0.10	0.01	0.01	0.03	1.86	55
TP	**Unimpaired**	0.03	0.08	0.03	0.03	0.08	3.00	252
	Impaired (other)	0.03	0.03	0.01	0.03	0.04	0.11	81

Table 3-3. Nutrient Concentrations in Lakes (June through September)

Chemical	Lake Type	Median	Average	First Quartile	Second Quartile	Third Quartile	Fourth Quartile	No of Datapoints
NH_3	**Unimpaired**	0.08	0.09	0.08	0.08	0.08	0.82	81
	Impaired (other)	0.06	0.83	0.02	0.06	0.13	7.60	29
NO_2	**Unimpaired**	0.06	0.13	0.01	0.06	0.12	0.70	9
	Impaired (other)	0.01	0.08	0.01	0.01	0.02	0.70	31
NO_3	**Unimpaired**	0.10	0.49	0.10	0.10	1.00	1.50	81
	Impaired (other)	1.36	1.64	0.18	1.36	2.78	4.00	8
TKN	**Unimpaired**	0.50	0.70	0.20	0.50	1.00	4.10	117
	Impaired (other)	0.40	0.59	0.30	0.40	0.60	4.30	42
PO_4	**Unimpaired**	0.45	0.70	0.19	0.45	1.28	2.10	9
	Impaired (other)	0.01	0.02	0.01	0.01	0.01	0.14	27
TP	**Unimpaired**	0.03	0.08	0.03	0.03	0.07	3.00	109
	Impaired (other)	0.02	0.03	0.01	0.02	0.03	0.18	37

Table 3-4. Nutrient Concentrations in Streams (All Year)

Chemical	Stream Type	Median	Average	First Quartile	Second Quartile	Third Quartile	Fourth Quartile	No of Datapoints
NH_3	Minimally Impacted	0.02	0.05	0.01	0.02	0.04	3.25	261
	Unimpaired	0.02	0.41	0.01	0.02	0.07	32.94	1229
	Impaired (nutrient)	0.05	0.34	0.01	0.05	0.14	12.10	907
	Impaired (other)	0.05	0.47	0.02	0.05	0.12	17.10	1279
NO_2	Minimally Impacted	0.00	0.01	0.00	0.00	0.00	0.06	110
	Unimpaired	0.02	0.15	0.01	0.02	0.13	12.00	1500
	Impaired (nutrient)	0.04	0.09	0.01	0.04	0.10	5.00	861
	Impaired (other)	0.02	0.14	0.01	0.02	0.09	2.95	1160
NO_3	Minimally Impacted	0.05	0.16	0.05	0.05	0.15	2.85	112
	Unimpaired	0.36	4.45	0.05	0.36	3.70	48.09	1301
	Impaired (nutrient)	4.74	5.02	1.17	4.74	7.50	31.84	600
	Impaired (other)	2.2	4.71	0.56	2.20	4.80	48.10	1037
TKN	Minimally Impacted	0.25	0.31	0.13	0.25	0.41	1.20	156
	Unimpaired	0.40	1.01	0.20	0.40	0.93	42.70	1425
	Impaired (nutrient)	0.7	1.06	0.40	0.70	1.20	11.00	868
	Impaired (other)	0.6	0.97	0.30	0.60	1.10	33.00	1486
PO_4	Minimally Impacted	0.04	0.05	0.02	0.04	0.07	0.23	260
	Unimpaired	0.08	0.49	0.02	0.08	0.50	28.73	1671
	Impaired (nutrient)	0.22	0.60	0.03	0.22	0.90	8.10	1056
	Impaired (other)	0.05	0.45	0.02	0.05	0.26	40.00	1793
TP	Minimally Impacted	0.08	0.08	0.03	0.08	0.09	0.30	34
	Unimpaired	0.07	0.36	0.01	0.07	0.27	24.80	633
	Impaired (nutrient)	0.13	0.77	0.05	0.13	1.07	7.94	525
	Impaired (other)	0.07	0.34	0.03	0.07	0.22	45.10	1069

Table 3-5. Nutrient Concentrations in Streams (June through September)

Chemical	Stream Type	Median	Average	First Quartile	Second Quartile	Third Quartile	Fourth Quartile	No of Datapoints
NH_3	**Minimally Impacted**	0.01	0.01	0.00	0.01	0.02	0.12	88
	Unimpaired	0.02	0.38	0.01	0.02	0.07	14.40	331
	Impaired (nutrient)	0.04	0.23	0.01	0.04	0.11	9.30	313
	Impaired (other)	0.04	0.36	0.01	0.04	0.09	16.30	459
NO_2	**Minimally Impacted**	0.00	0.01	0.00	0.00	0.01	0.02	11
	Unimpaired	0.05	0.26	0.01	0.05	0.17	12.00	390
	Impaired (nutrient)	0.04	0.11	0.01	0.04	0.10	5.00	288
	Impaired (other)	0.02	0.15	0.01	0.02	0.09	2.50	415
NO_3	**Minimally Impacted**	0.08	0.13	0.03	0.08	0.10	0.84	11
	Unimpaired	0.30	5.18	0.05	0.30	4.59	45.16	326
	Impaired (nutrient)	5.43	5.69	2.90	5.43	7.75	28.99	185
	Impaired (other)	2.20	5.05	0.58	2.20	4.53	42.45	312
TKN	**Minimally Impacted**	0.13	0.24	0.08	0.13	0.31	0.99	61
	Unimpaired	0.40	0.85	0.20	0.40	0.90	13.00	393
	Impaired (nutrient)	0.70	1.01	0.40	0.70	1.10	11.00	309
	Impaired (other)	0.52	0.81	0.30	0.52	1.00	8.60	537
PO_4	**Minimally Impacted**	0.02	0.04	0.01	0.02	0.04	0.18	88
	Unimpaired	0.08	0.52	0.02	0.08	0.56	23.60	433
	Impaired (nutrient)	0.25	0.66	0.02	0.25	0.90	8.98	354
	Impaired (other)	0.03	0.42	0.01	0.03	0.24	12.55	624
TP	**Minimally Impacted**	0.14	0.14	0.10	0.14	0.17	0.20	2
	Unimpaired	0.04	0.25	0.01	0.04	0.24	5.77	220
	Impaired (nutrient)	0.12	0.82	0.05	0.12	1.17	5.20	197
	Impaired (other)	0.06	0.29	0.03	0.06	0.16	4.42	420

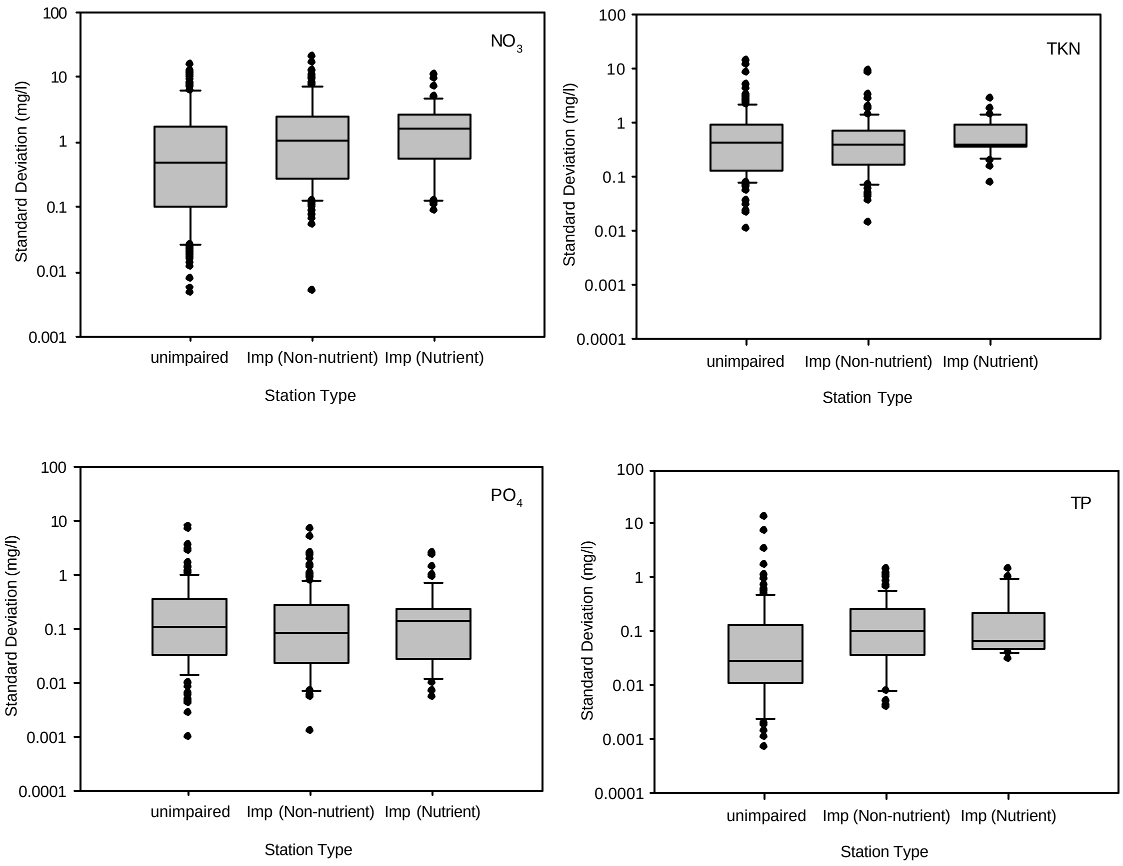


Figure 3-19. Standard deviations of NO_3, TKN, PO_4 and TP across different types of streams in Ecoregion 6. The horizontal line in the middle of the each box represents the median, the lines are the 10^{th} and 90^{th} confidence intervals and the black circles are the outliers. Note the log-scale on the y-axis of the plots.

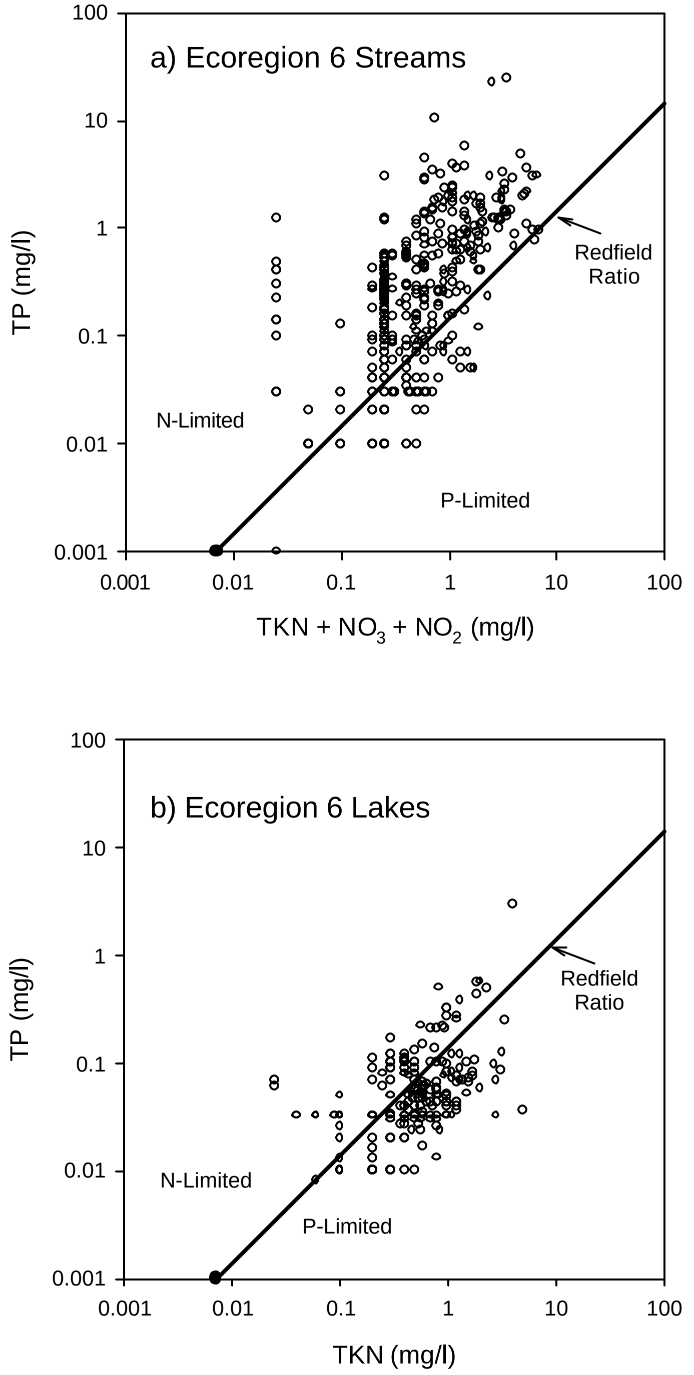


Figure 3-20. Co-located (same station, date, time) measurements of total nitrogen (sum of TKN, NO_3, and NO_2) and total phosphorus in Ecoregion 6 streams and lakes.

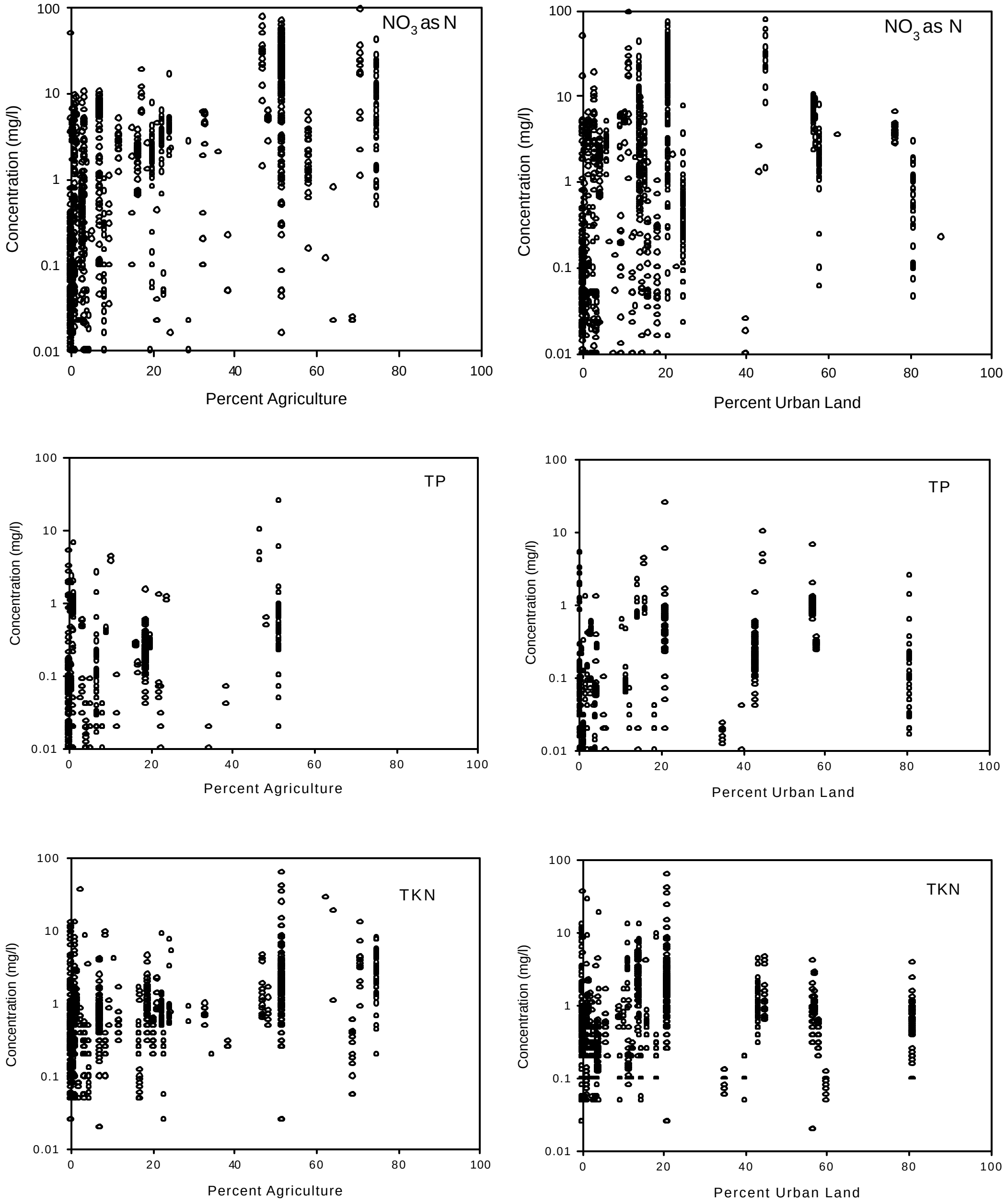


Figure 3-21. NO$_3$, TP, and TKN measurements related to land use in the CALWATER watershed of the corresponding station for stream stations.

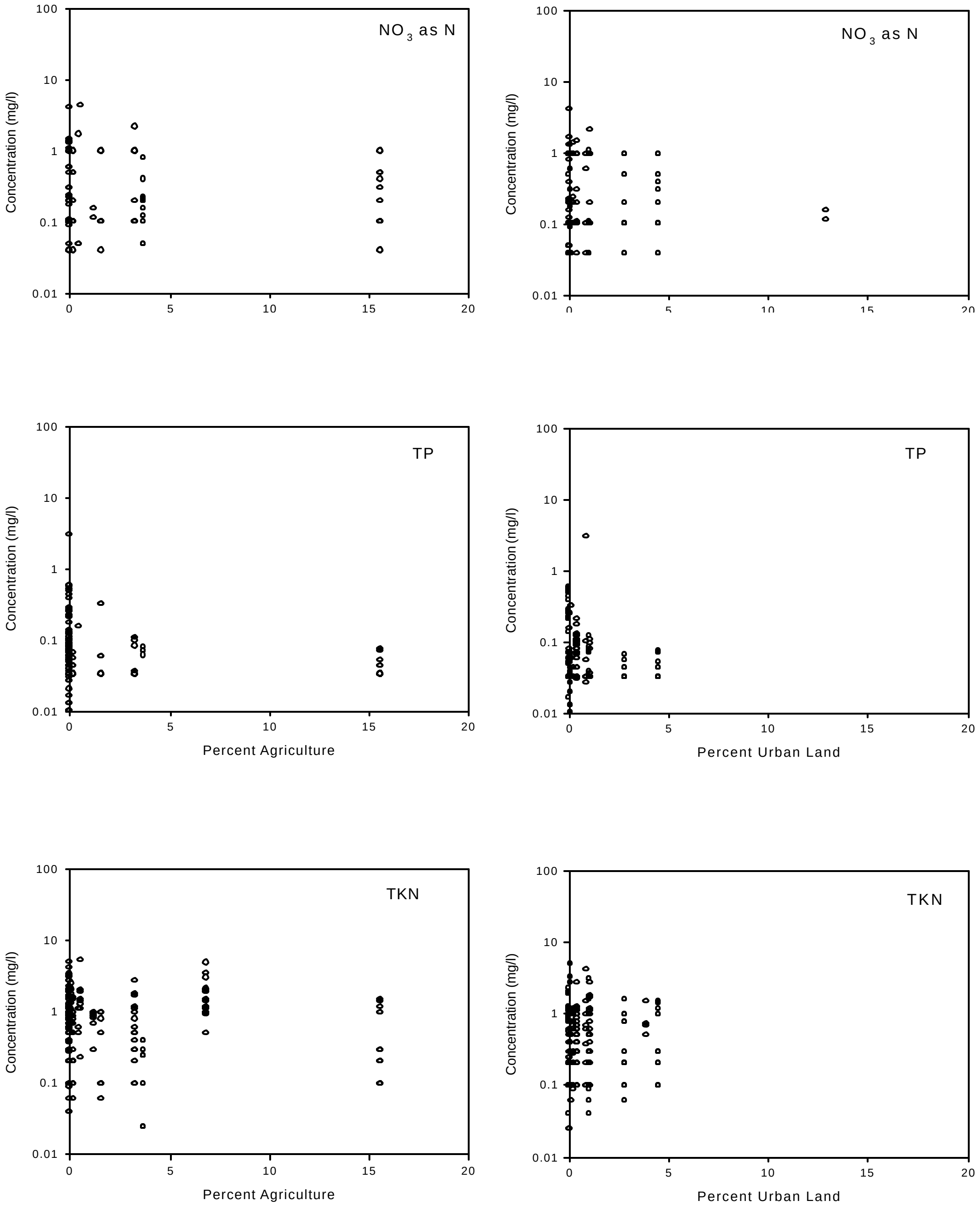


Figure 3-22. NO$_3$, TP, and TKN measurements related to land use in the CALWATER watershed of the corresponding station for lake stations.

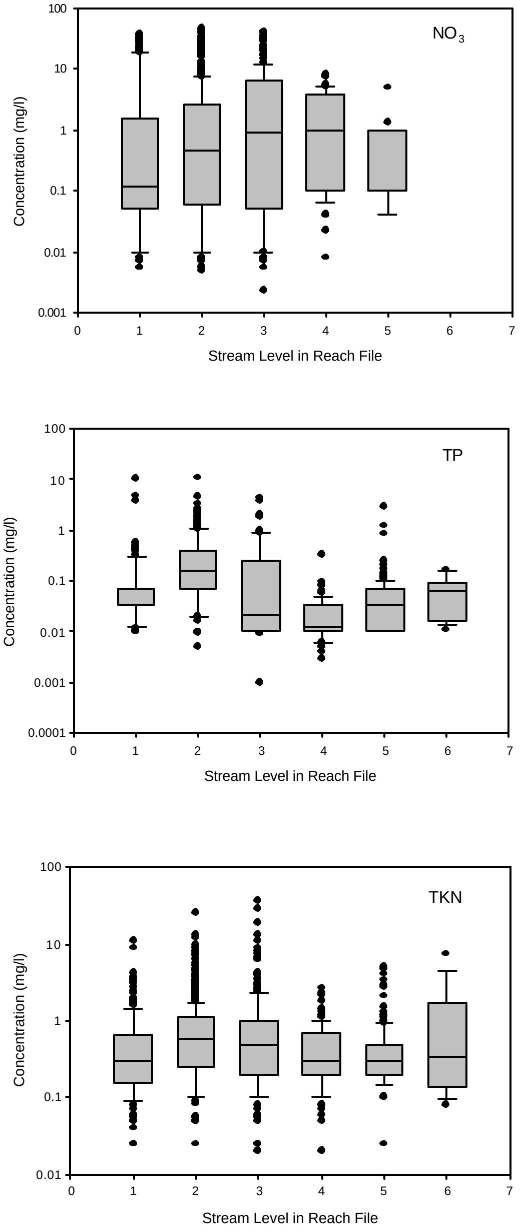
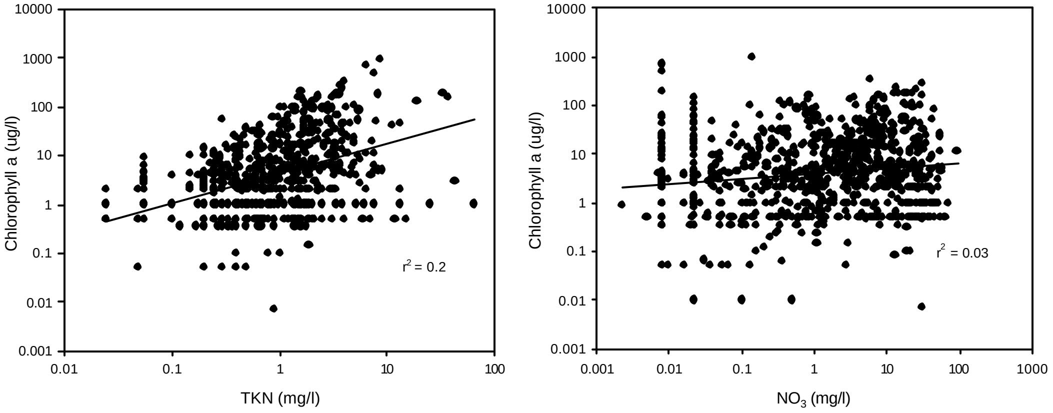


Figure 3-23. NO$_3$, TP, and TKN measurements in unimpaired streams of Ecoregion 6 related to stream level in the Reach File 1 Database.

Data for All Year



Data for May Through September

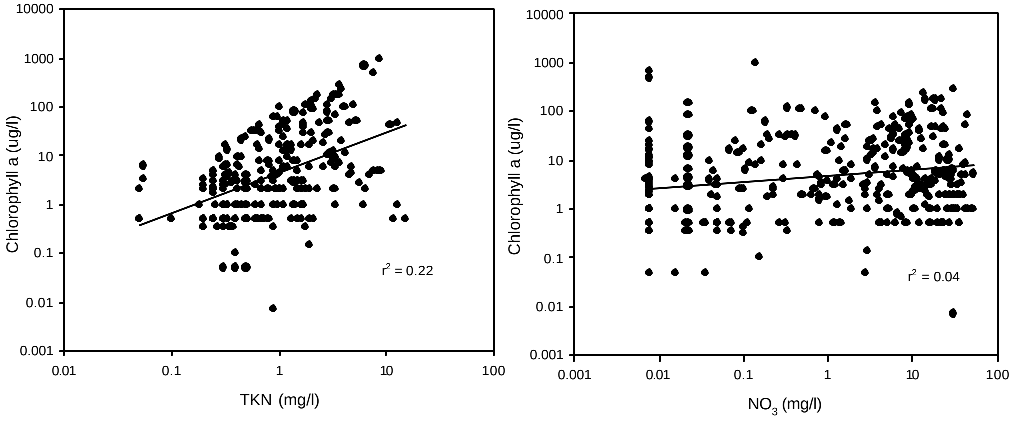
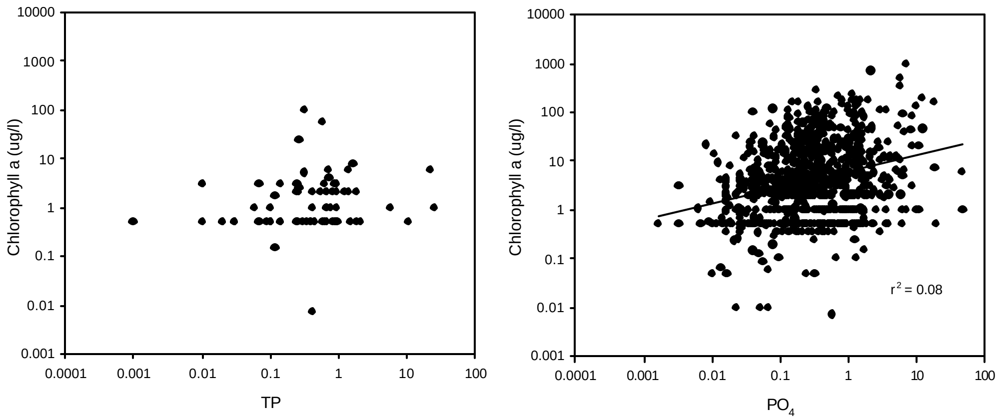


Figure 3-24. NO_3 and TKN measurements in RWQCB 3 streams related to chlorophyll a. Data are shown for (a) the whole year and (b) for May through September.

Data for All Year



Data for May Through September

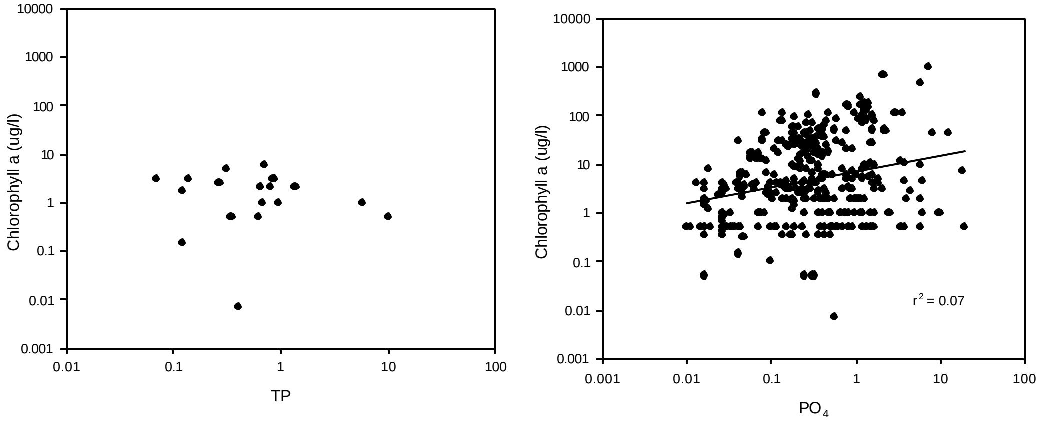


Figure 3-25. PO$_4$ and TP measurements in RWQCB 3 streams related to chlorophyll a. Data are shown for (a) the whole year and (b) for May through September.

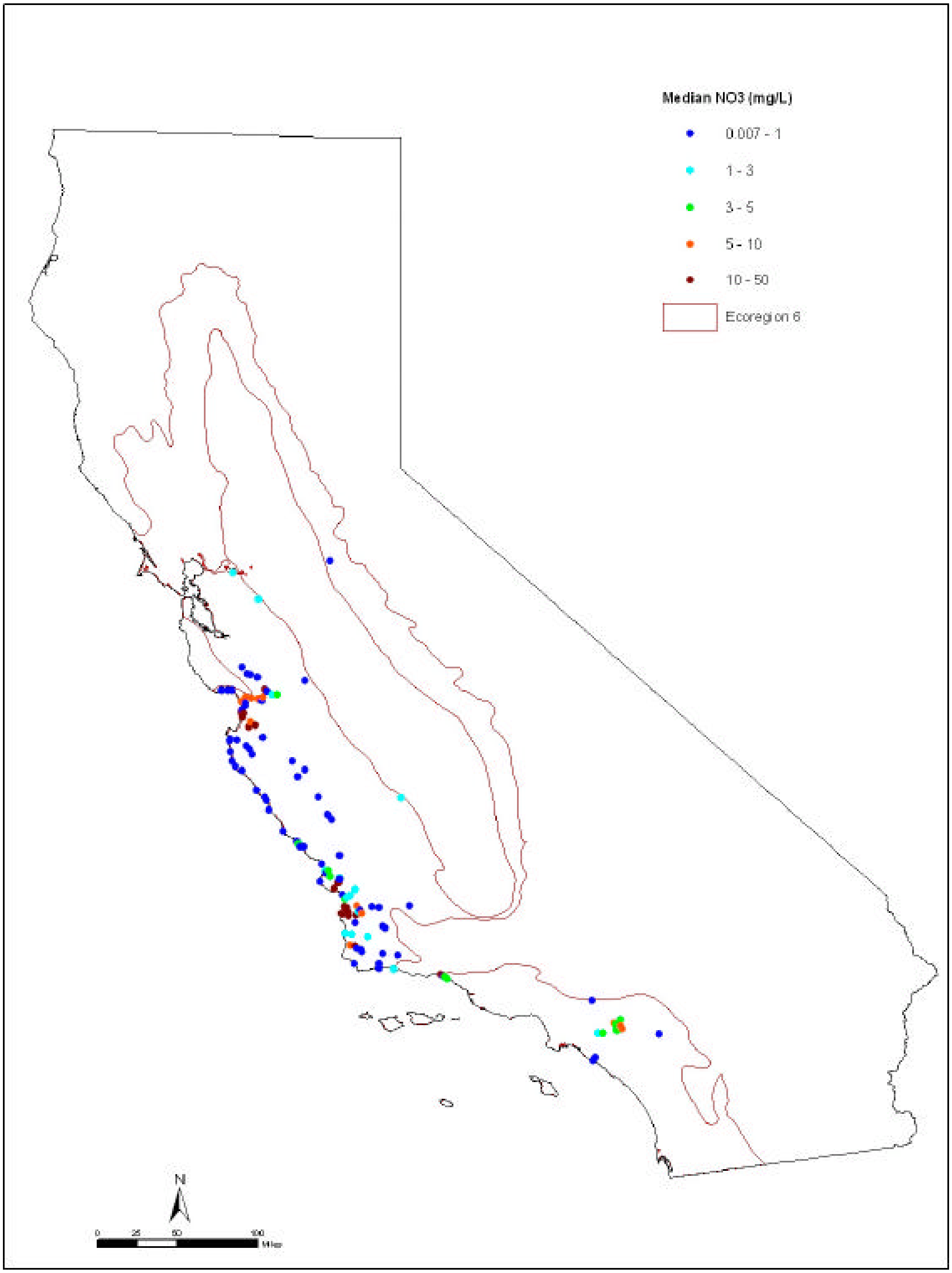


Figure 3-26. Median concentrations of NO_3 across Ecoregion 6.

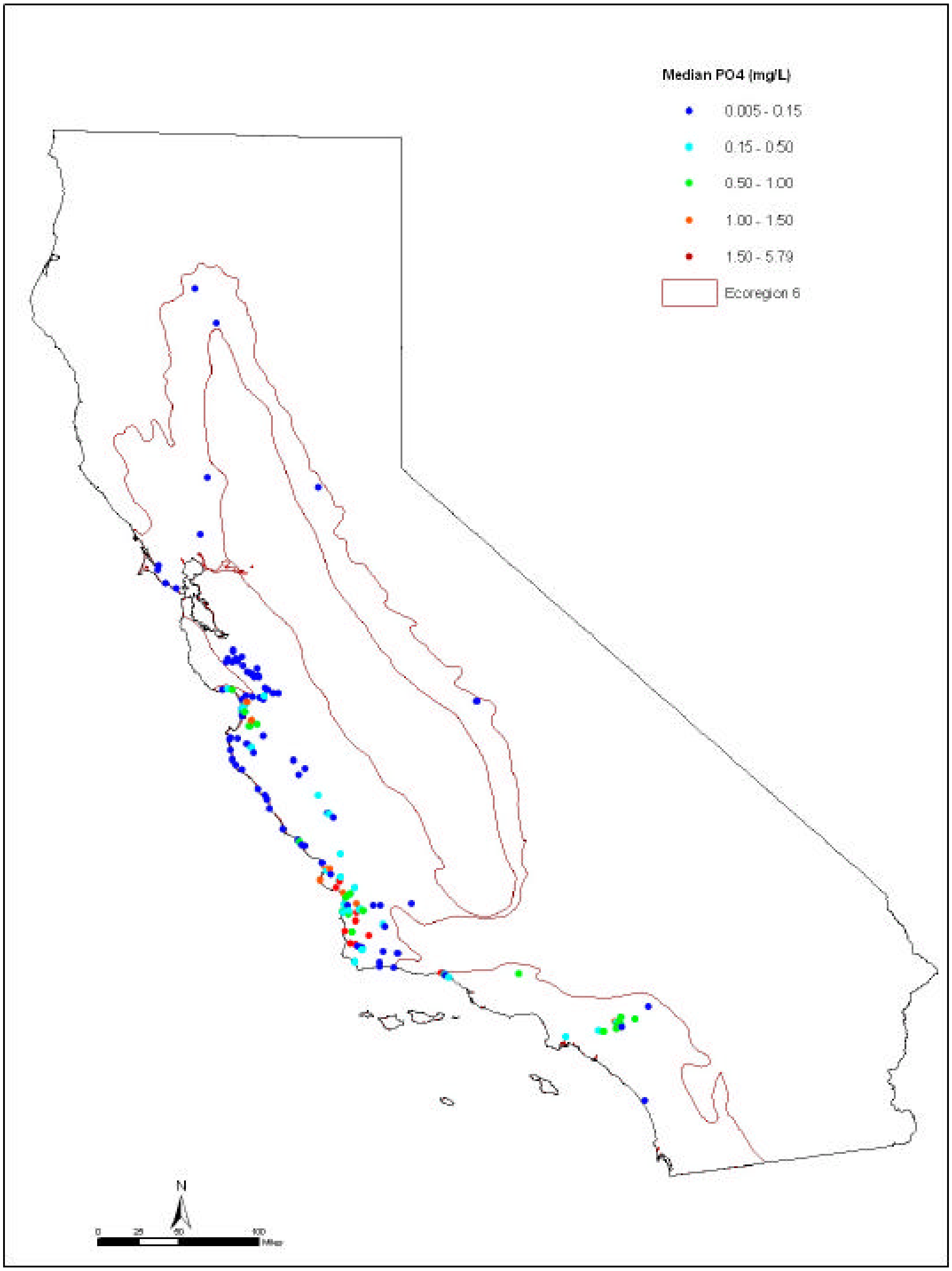


Figure 3-27. Median concentrations of PO_4 across Ecoregion 6.

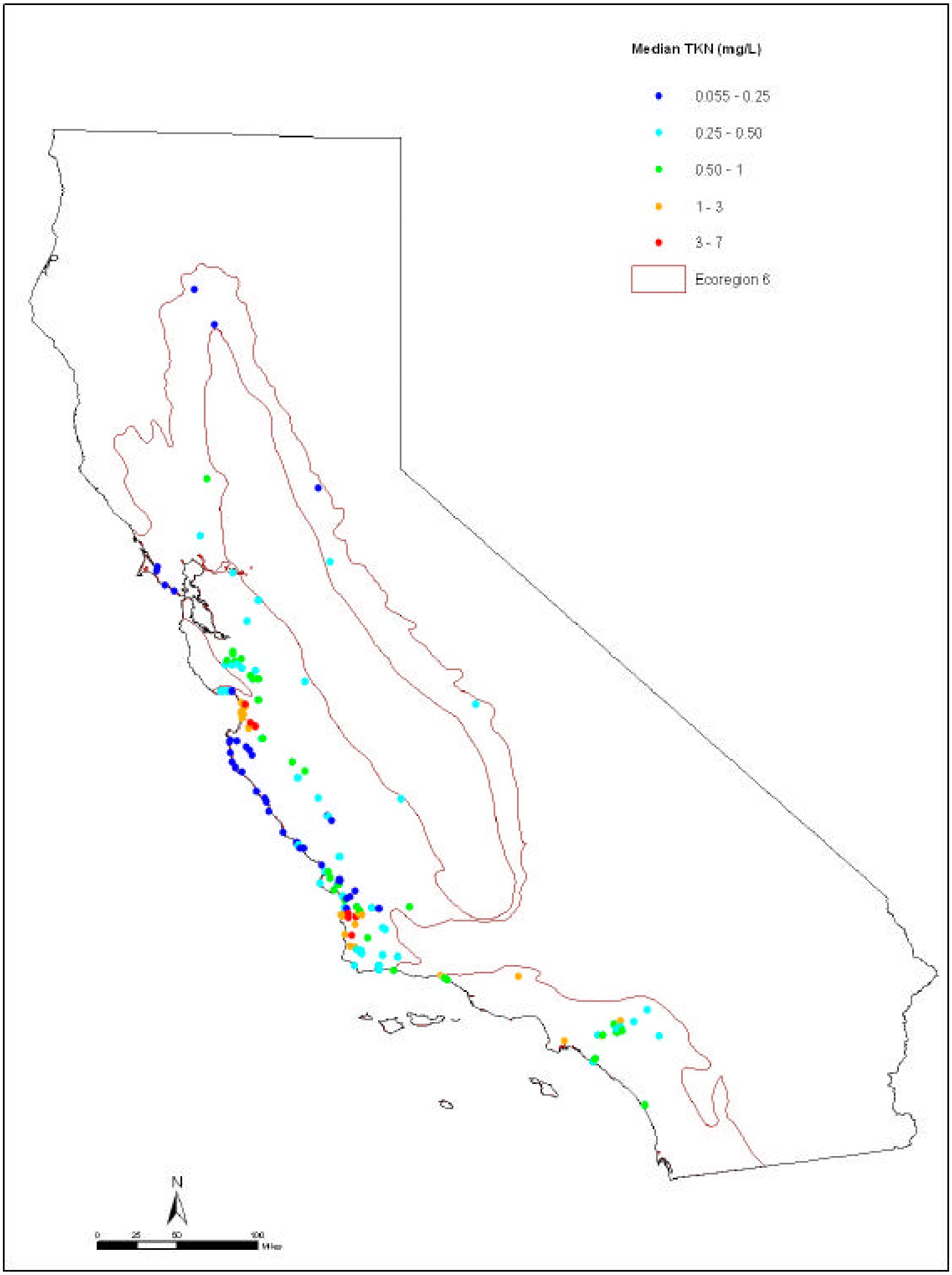


Figure 3-28. Median concentrations of TKN across Ecoregion 6.

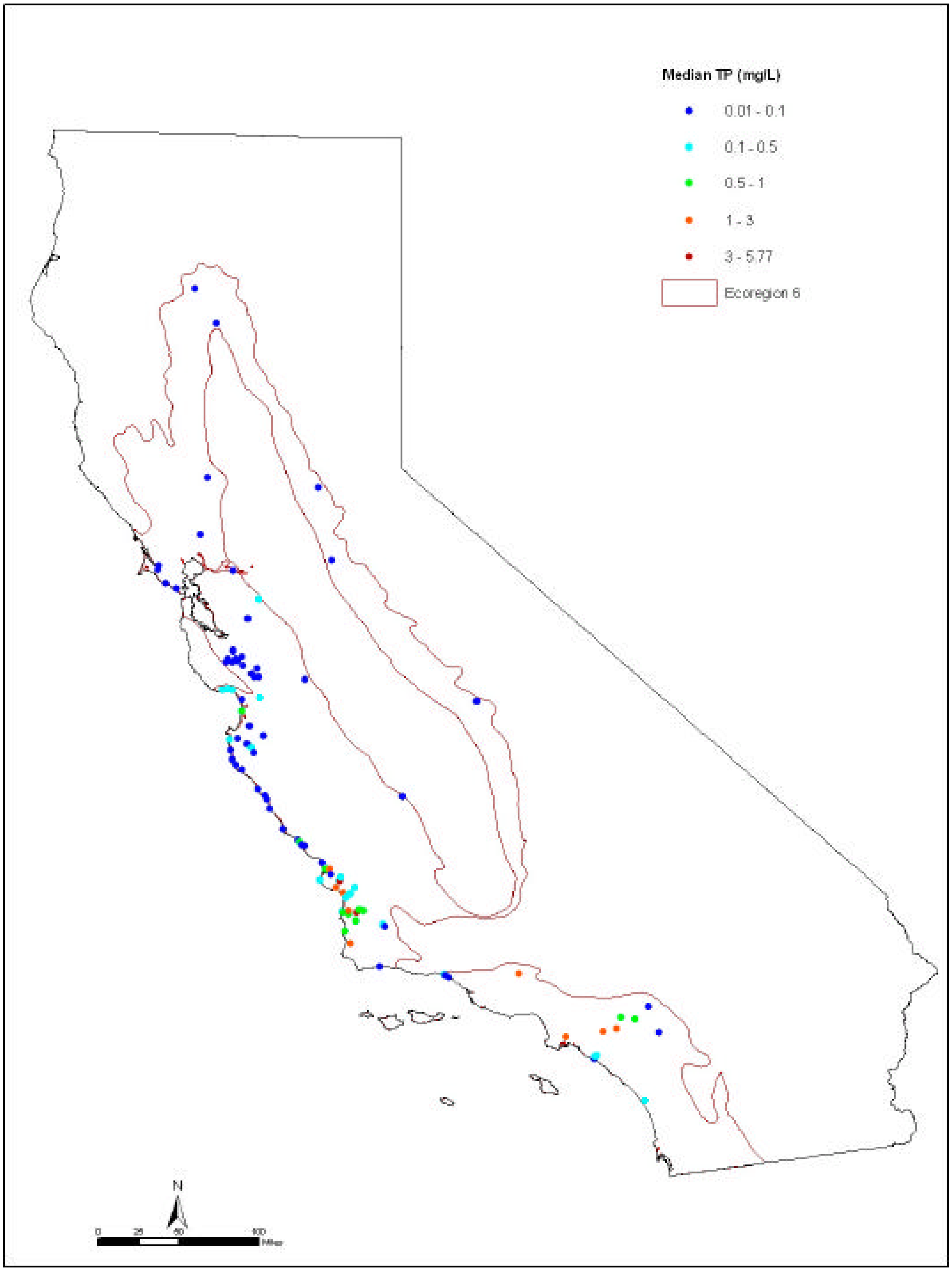


Figure 3-29. Median concentrations of TP across Ecoregion 6.

4 MODELING ANALYSIS FOR NUTRIENT CRITERIA

The nutrient criteria pilot study focuses on Ecoregion 6 (California Oak and Chaparral). The overall strategy is to develop three lines of investigation to support the development of criteria recommendations: 1) review of long-term monitoring studies; 2) empirical data analysis of existing water quality data; and 3) watershed modeling assessments of natural background loading and response. This section describes the modeling component.

Simulation models alone do not provide a firm and defensible foundation for criteria development. However, models are valid and useful tools for the nutrient criteria analysis for a number of reasons:

- Models can provide a process-based interpretation of observed data, thus helping to sort out multiple causes.
- Models provide a tool for generalizing from conditions at specific sites to conditions representative of typical conditions in a classification stratum.
- In some areas, very few “unimpacted” reference sites exist due to extensive human modification of the stream network and the addition of point and nonpoint loads.
- Many observed cases of impairment may be due to factors other than nutrients. For instance, poor biological integrity may be due to habitat alteration, while elevated periphyton concentrations in a low-order stream may be due more to removal of riparian shading than to nutrient levels. To attribute these impacts to nutrients could result in unnecessarily stringent criteria. Conversely, some lakes receive nutrient loads that would be sufficient to cause impairment due to eutrophication if it were not for the suppression of algal growth by high turbidity. Models provide a method for controlling these confounding factors.

There are two major ways in which models are employed in this study. The first is to assist in evaluation of responses to nutrient concentrations and loads; the second is to assist in estimating reference or unimpacted conditions (Table 4-1). These two uses have somewhat different requirements. The “Response” component is focused on the waterbody of interest and is essentially a translator from nutrient concentrations (or loads) to effects. The “Reference” component begins at the watershed scale – the source of nutrient loading – and evaluates the anticipated nutrient concentrations in receiving waters based on the natural land cover and other characteristics of the watershed.

Table 4-1. Generic Modeling Components

	Response	Reference
Lakes and Impoundments	Lake response model	Watershed model - > stream transport model -> lake model
Rivers and Streams	Stream response model	Watershed model -> stream transport model

Determination of a criterion should begin on the response side, e.g., by determining the concentration that is sufficient to cause a nutrient-related impairment. However, a criterion must also take into account the reference side, as a criterion should not be set at a value less than is predicted for unimpacted natural conditions, regardless of whether this is estimated to cause an undesirable response.

The general conceptual relationships among potential modeling components for nutrient criteria development are summarized in Figure 4-1. Initial drafts of the lake response, stream transport, and watershed loading model components have been completed within this phase of the project. A stream response model that can address eutrophication and other nutrient responses within flowing streams, has not yet been developed.

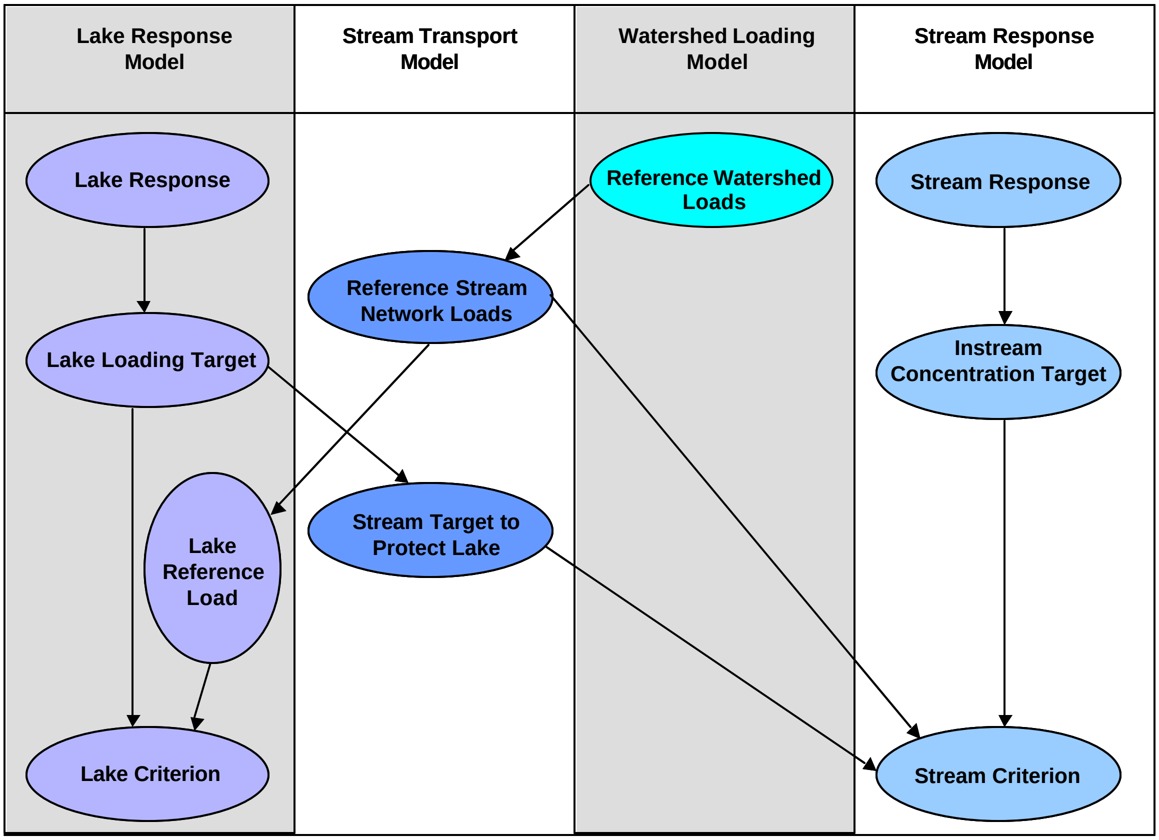


Figure 4-1: Conceptual Inter-relationships of Modeling Tasks for Nutrient Criteria Development

4.1 MODELING APPROACH

Determining nutrient criteria requires information on both watershed loads and waterbody responses. Criteria should not be less than background; neither should they be set at levels lower than associated with a risk of degradation. In many cases, target nutrient levels may be "inherited" from downstream waterbodies that may be more stringent than the concentration target needed to prevent impairment within the stream itself. A set of linked loading, transport, and response models was used to translate the potentially more stringent receiving water standards to upstream watershed export. These models may also be applied in the downstream direction to estimate loads and concentrations associated with natural land uses.

On both the response and the reference model sides of the evaluation, what is most needed for nutrient criteria development is a set of relatively simple (yet reliable) tools that can be used to evaluate general conditions and responses in a given classification stratum, rather than a highly complex model of a specific system. Tetra Tech developed a system combining the BATHTUB, SPARROW, and SWAT models to provide one line of evidence to estimate reference or unimpacted conditions within EPA Ecoregion 6. Each model requires a number of inputs defining the physical and chemical processes represented. To the extent possible, each model was tailored to simulate the conditions seen in the

California Oak and Chaparral ecosystem. Response models are needed to estimate loading targets consistent with protection of beneficial uses from excessive algal growth for lakes and reservoirs. The BATHTUB model (Walker, 1987) provides a useful tool for estimating lake response to nutrients. The model simulates phosphorus, nitrogen, phytoplankton chlorophyll *a*, Secchi depth, and hypolimnetic oxygen consumption. Algal response in flowing streams is a more difficult problem for modeling and has not been addressed in this phase of the project.

A combination of the USGS Spatially Referenced Regressions On Watershed Attributes (SPARROW) model (Smith et al., 1997) and the USDA Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1990) were used to predict the watershed loading and stream transport used to generate the inputs to the response models. SWAT is a long-term, continuous time watershed model that simulates watershed nutrient export based on weather, soil, topography, and vegetation data. Significant losses of nutrients can occur during instream transport due to plant uptake, loss to sedimentation, or, in the case of nitrogen, volatilization. SPARROW provides a simple empirical approach to estimation of transport losses for application to multiple sites within an ecoregion.

The results of the modeling analysis are an estimate of watershed loading rates and instream nutrient concentrations that reflect natural conditions which is predicted to meet instream and receiving water designated uses and is consistent with ecoregional characteristics. The estimates provide a baseline from which to evaluate conditions where designated uses should be fully realized and allow decision-makers to discriminate water quality impacts that are due to nutrient over-enrichment.

4.2 SWAT WATERSHED MODEL DEVELOPMENT

SWAT is used in this project to estimate nutrient load generation from native land cover on the local watershed scale. SWAT is a long-term, continuous watershed simulation model. This model simulates land cover impacts with weather, soil, topography, and vegetation data. SWAT is based directly on the Simulator for Water Resources in Rural Basins (SWRRB, Williams et al., 1985; Arnold et al., 1990) with features from several other ARS models. The SWAT simulation and output is organized by Hydrologic Response Units (HRUs), which are areas with unique land cover and soil properties.

Within SWAT, runoff is simulated separately for each HRU and then routed to calculate total runoff. The model considers moisture and energy inputs, including daily precipitation, maximum and minimum air temperatures, solar radiation, wind speed, and relative humidity. SWAT simulates a complete set of hydrologic processes including canopy storage and evapotranspiration. It uses the Modified Universal Soil Loss Equation (MUSLE) to model erosion and sediment yield with runoff. MUSLE variables include above-ground biomass, residue on the soil surface, and the minimum C factor for each species. For sediment deposition and degradation, SWAT defines the maximum sediment transportation from a reach segment as a function of peak channel velocity. SWAT simulates the nitrogen and phosphorus cycles, including plant uptake of nutrients and the mineralization of organic nutrients in plant residue. SWAT employs a detailed simulation of plant growth and the effects of plant cover on nutrient balances, making it an ideal tool for evaluating unimpacted nutrient balances. The model differentiates between annual and perennial species as well as woody and non-woody species. Nutrient routing for the system was simulated using the SPARROW model.

4.2.1 Initial Selection and Delineation of Watersheds

Although the pilot analysis focuses on a single ecoregion, there is considerable variability in conditions within the ecoregion due to differences in soils, slopes, and precipitation regimes. Thus, subsampling is needed to represent the range of conditions in the ecoregion. Fifty random points were generated within the Ecoregion 6 polygon. The goal was to select 5 to 10 points in relatively undisturbed areas that vary by geography, topography, and rainfall. Nine points were selected, and 100,000-acre buffers were created around these points. Within the buffer boundaries, each watershed was delineated using CALWATER 2.2 watersheds as masks. For each watershed delineation, one to two CALWATER 2.2 watersheds were used as masks so that the total area of the mask was within 10,000 to 40,000 acres. Figure 4-2 shows the locations of the nine reference watersheds.[1]

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[1] [1] CALWATER 2.2 contains a set of detailed watersheds delineated by the California Department of Forestry and Fire Protection 1999. NRCS 14-digit hydrologic units are not yet available for California. CALWATER 2.2 watersheds between 10,000 and 40,000 acres are similar to the size of 14-digit hydrologic units (NRCS, 2003).

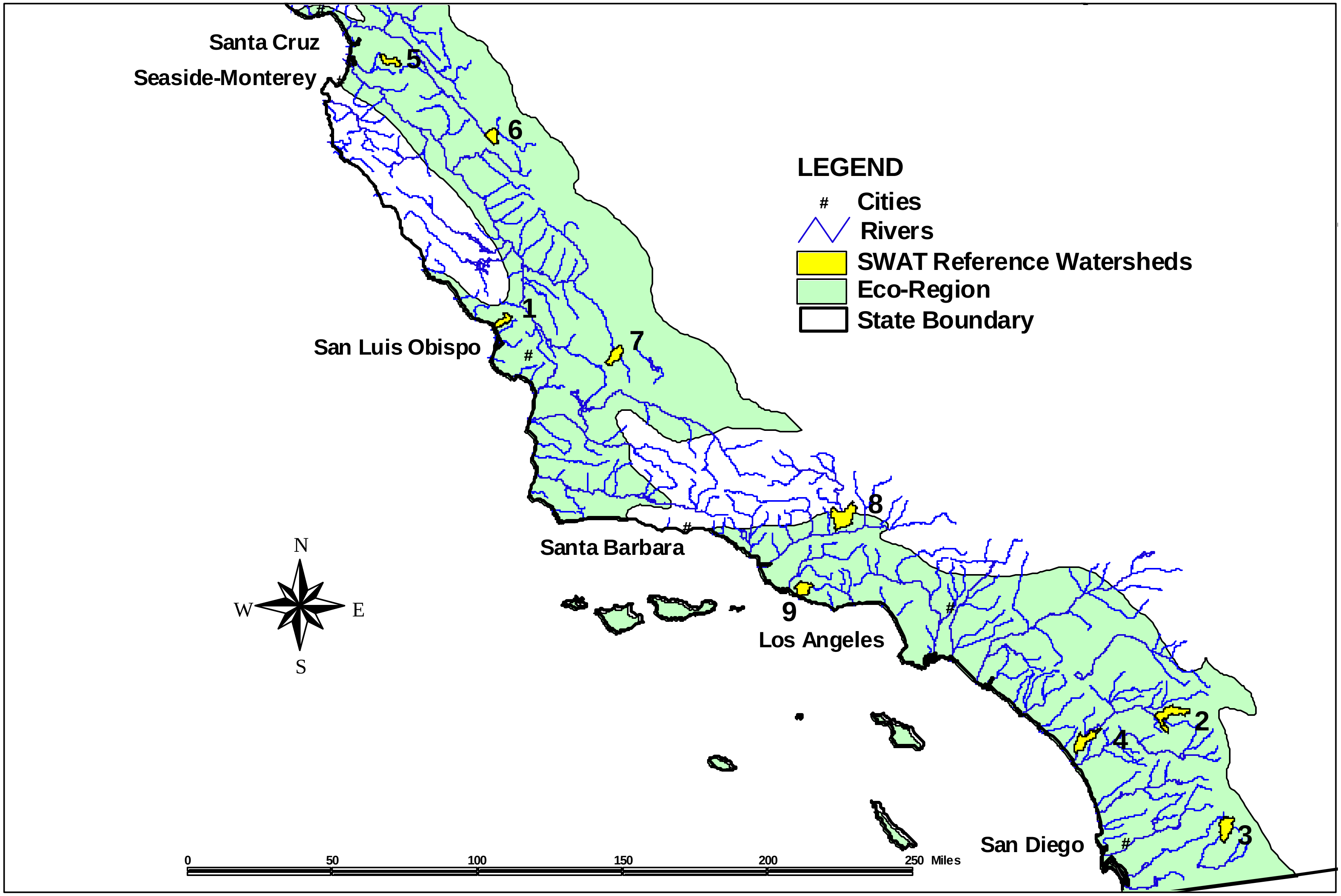


Figure 4-2: Locations of SWAT Reference Watersheds

4.2.2 Sources of Input Data

Soils Data

The SWAT application uses STATSGO soils data, which is a broad inventory of soils and nonsoil areas developed by the National Cooperative Soil Survey and distributed by the Natural Resources Conservation Service of the U.S. Department of Agriculture. This dataset was available for the SWAT model as part of the BASINS 3.0 modeling system. The primary soil parameters obtained directly or derived from the STATSGO database used by the SWAT model are presented in Table 4-2.

Table 4-2: STATSGO Soil Parameters Utilized by the SWAT Model

Variable	Description
HYDGRP	Hydrologic group
SOL_ZMX	Maximum rooting depth
SOL_BD	Bulk density
SOL_AWC	Available water capacity
SOL_K	Hydraulic conductivity
SOL_CBN	Organic carbon content
CLAY	Percent clay
SILT	Percent silt
SAND	Percent sand
ROCK	Percent rock
USLE_K	Soil erodibility

Digital Elevation Data

Nine 7.5 minute, 30 meter DEM grids that cover EPA Ecoregion 6 were downloaded from the USGS National Elevation Dataset website (http://seamless.usgs.gov/). These grids were published in 1999 and downloaded June 2003. Of these grids, five DEM grids were used to delineate the reference watersheds and analyze slopes.

Meteorological Data

The SWAT model is designed to use either observed timeseries or statistically generated meteorological inputs to simulate weather patterns. For the purpose of the ecoregion nutrient loading estimation, statistically generated weather data is used to drive the SWAT model. SWAT's weather generators were created from historical data at long-term meteorological stations. Stations used for the simulation are summarized in Table 4-3.

Within mountainous areas, meteorology can change rapidly with elevation. Lapse rates are used to correct precipitation and temperature based on elevation differences between the weather station and watershed (Table 4-4).

Table 4-3: Meteorological Station Association

Watershed	Meteorological Station
1	PASO ROBLES AP
2	EL CAPITAN DAM
3	EL CAPITAN DAM
4	TUSTIN IRVINE RANCH
5	SALINAS 3E
6	PRIEST VALLEY
7	PASO ROBLES AP
8	FAIRMONT
9	LOS ANGELES WB AP

Table 4-4: SWAT Meteorological Parameters

Variable	Description	Value
ELEVB	Elevation at center of elevation bands [m]	Equal to mean elevation
PLAPS	Precipitation lapse rate [mm/km]	+1.06
TLAPS	Temperature lapse rate [^{o}C/km]	-6.0

Land Cover/ Plant Growth Data

SWAT simulates the removal of water and nutrients from the root zone, transpiration, and biomass yield production based on the combination of soils and the biophysical properties of the landcover. The primary purpose of the SWAT application is to estimate nutrient loading characteristics under natural conditions of native vegetation cover in Ecoregion 6. Although it is a single ecoregion, native vegetation shows considerable variability within the ecoregion, and it is important to specify vegetation types that match the site-specific conditions. Such information is provided by the California GAP Analysis. The GAP landuse dataset developed from satellite flyover analyses in the early 1990s was used to estimate the distribution of landcover within each delineated watershed. Human influenced landuses (e.g., urban areas, agricultural land) in the watersheds were converted to undisturbed cover for simulation of unimpacted watersheds.

The National Gap Analysis Program (GAP) has developed this data to provide detailed information on the distribution of common species (USGS, 2003). The data for California provides a list of co-dominant species and habitat type for each small-scale polygon. It provides more detailed information about vegetation type compared to MRLC land cover data. About 5 to 10 polygons were found within each reference watershed.

Figure 4-3 describes the relationship between the three major GAP attributes that will define the SWAT land cover classes. The first attribute is Primary Habitat Type, a broad classification of the local vegetation; examples include annual grassland (AGS), coastal shrub (CSC), and Chamise-Redshank Chaparral (CRC). Secondly, the GAP data provides a group of three co-dominant species for each polygon (Species A through E in Figure 4- 3). Multiple co-dominant species groups may exist within each habitat type. The final attribute is major plant type (colored labels Figure 4-3). In the reference watersheds, the major plant types are herbaceous plants, chaparral shrubs, coastal scrub shrubs, hardwood trees, and conifers.

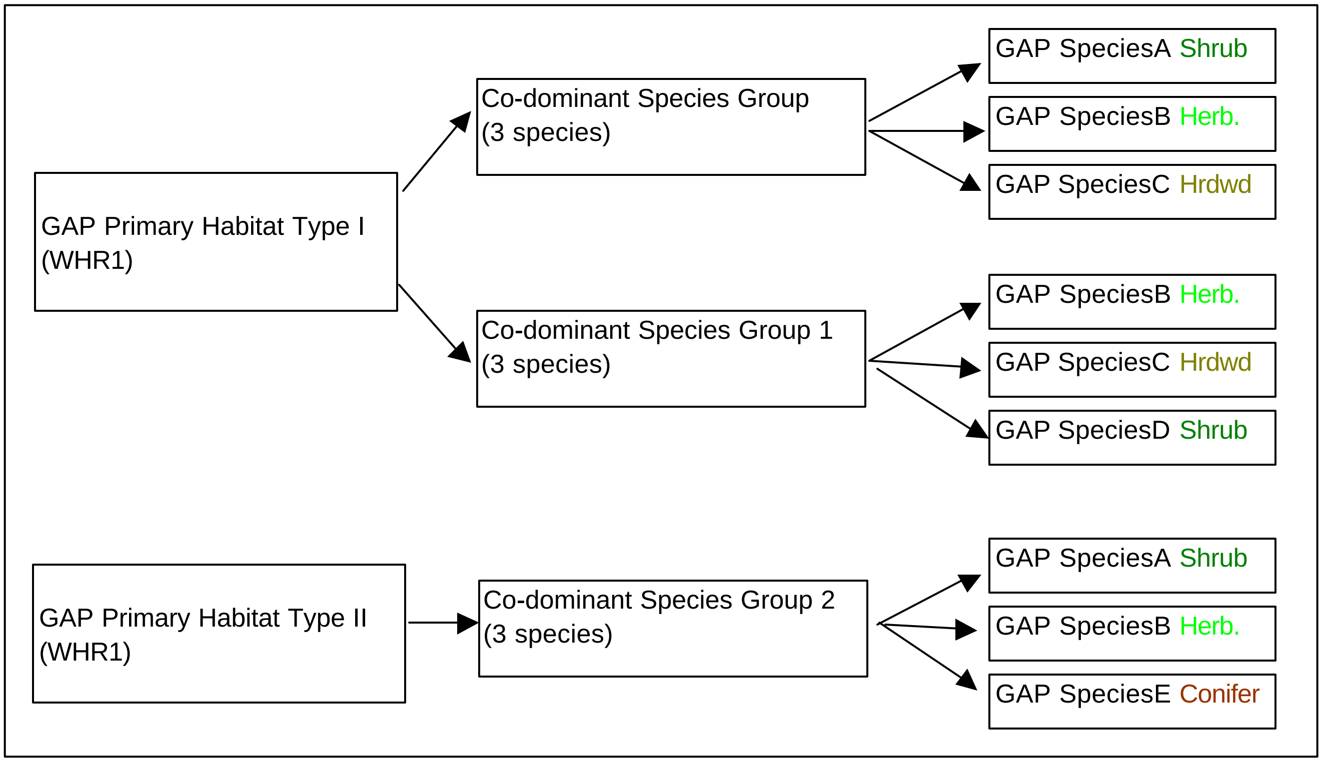
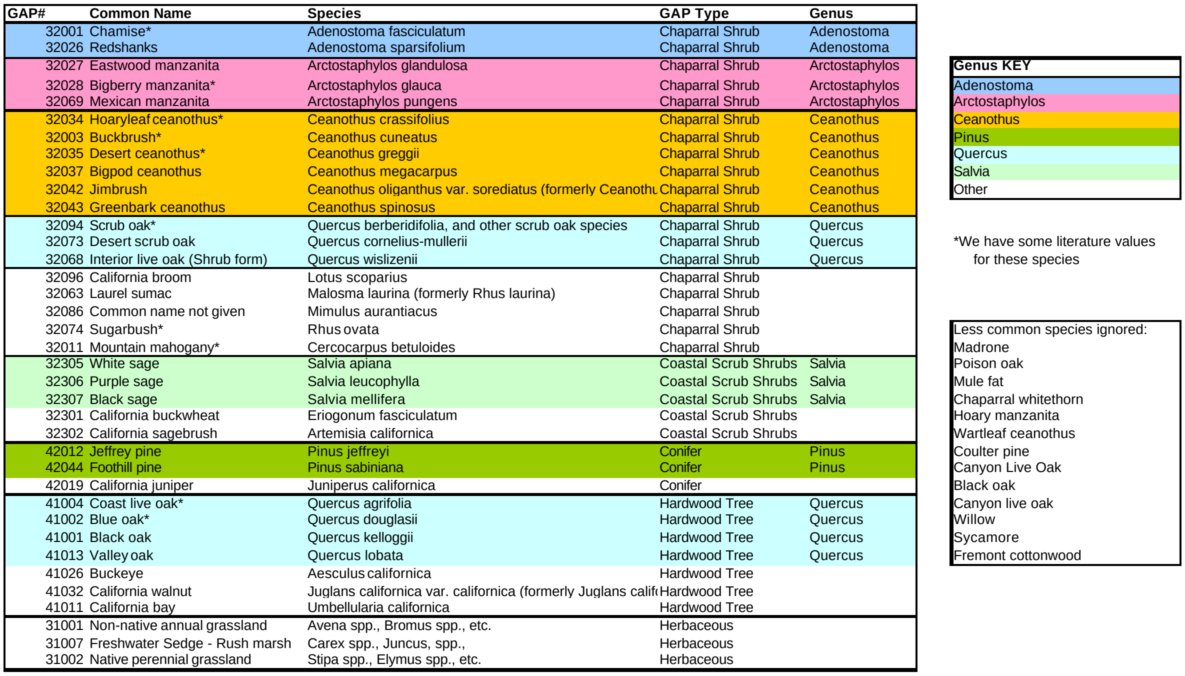


Figure 4-3: Relationship Between Major GAP Polygon Attributes

The GAP data identifies 48 co-dominant species in the reference watersheds including Adenostoma, Arctostaphylos, Ceanothus, Quercus, Salvia, and Pinus species. Table 4-5 lists the species that occur within 90 percent of the watershed areas. Species with the same genus are highlighted, and the table is sorted by GAP plant type.

Table 4-5: Species that Occur within 90% of Reference Watershed Areas



GAP#	Common Name	Species	GAP Type	Genus
32001	Chamise*	Adenostoma fasciculatum	Chaparral Shrub	Adenostoma
32026	Redshanks	Adenostoma sparsifolium	Chaparral Shrub	Adenostoma
32027	Eastwood manzanita	Arctostaphylos glandulosa	Chaparral Shrub	Arctostaphylos
32028	Bigberry manzanita*	Arctostaphylos glauca	Chaparral Shrub	Arctostaphylos
32069	Mexican manzanita	Arctostaphylos pungens	Chaparral Shrub	Arctostaphylos
32034	Hoaryleaf ceanothus*	Ceanothus crassifolius	Chaparral Shrub	Ceanothus
32003	Buckbrush*	Ceanothus cuneatus	Chaparral Shrub	Ceanothus
32035	Desert ceanothus*	Ceanothus greggii	Chaparral Shrub	Ceanothus
32037	Bigpod ceanothus	Ceanothus megacarpus	Chaparral Shrub	Ceanothus
32042	Jimbrush	Ceanothus oliganthus var. sorediatus (formerly Ceanothu	Chaparral Shrub	Ceanothus
32043	Greenbark ceanothus	Ceanothus spinosus	Chaparral Shrub	Ceanothus
32094	Scrub oak*	Quercus berberidifolia, and other scrub oak species	Chaparral Shrub	Quercus
32073	Desert scrub oak	Quercus cornelius-mullerii	Chaparral Shrub	Quercus
32068	Interior live oak (Shrub form)	Quercus wislizenii	Chaparral Shrub	Quercus
32096	California broom	Lotus scoparius	Chaparral Shrub	
32063	Laurel sumac	Malosma laurina (formerly Rhus laurina)	Chaparral Shrub	
32086	Common name not given	Mimulus aurantiacus	Chaparral Shrub	
32074	Sugarbush*	Rhus ovata	Chaparral Shrub	
32011	Mountain mahogany*	Cercocarpus betuloides	Chaparral Shrub	
32305	White sage	Salvia apiana	Coastal Scrub Shrubs	Salvia
32306	Purple sage	Salvia leucophylla	Coastal Scrub Shrubs	Salvia
32307	Black sage	Salvia mellifera	Coastal Scrub Shrubs	Salvia
32301	California buckwheat	Eriogonum fasciculatum	Coastal Scrub Shrubs	
32302	California sagebrush	Artemisia californica	Coastal Scrub Shrubs	
42012	Jeffrey pine	Pinus jeffreyi	Conifer	Pinus
42044	Foothill pine	Pinus sabiniana	Conifer	Pinus
42019	California juniper	Juniperus californica	Conifer	
41004	Coast live oak*	Quercus agrifolia	Hardwood Tree	Quercus
41002	Blue oak*	Quercus douglasii	Hardwood Tree	Quercus
41001	Black oak	Quercus kelloggii	Hardwood Tree	Quercus
41013	Valley oak	Quercus lobata	Hardwood Tree	Quercus
41026	Buckeye	Aesculus californica	Hardwood Tree	
41032	California walnut	Juglans californica var. californica (formerly Juglans calif	Hardwood Tree	
41011	California bay	Umbellularia californica	Hardwood Tree	
31001	Non-native annual grassland	Avena spp., Bromus spp., etc.	Herbaceous	
31007	Freshwater Sedge - Rush marsh	Carex spp., Juncus, spp.,	Herbaceous	
31002	Native perennial grassland	Stipa spp., Elymus spp., etc.	Herbaceous	

Genus KEY
Adenostoma
Arctostaphylos
Ceanothus
Pinus
Quercus
Salvia
Other

*We have some literature values for these species

Less common species ignored:
Madrone
Poison oak
Mule fat
Chaparral whitethorn
Hoary manzanita
Wartleaf ceanothus
Coulter pine
Canyon Live Oak
Black oak
Canyon live oak
Willow
Sycamore
Fremont cottonwood

The SWAT input parameters required to simulate the biophysical processes of each landcover are shown in Table 4-6.

Table 4-6: Input Variables for the SWAT Land Cover/ Plant Growth Database

Variable	Description
BIO_E*	Radiation use efficiency in ambient CO2 (kg/ha)/(MJ/m2)
HVSTI	Potential harvest index for the plant at maturity given ideal growing conditions
BLAI*	Potential maximum leaf area index for the plant
FRGRW1	Fraction of the growing season corresponding to the 1st point on the optimal leaf area development curve
LAIMX1	Fraction of the maximum plant leaf area index corresponding to the 1st point on the optimal leaf area development curve
FRGRW2	Fraction of the growing season corresponding to the 2nd point on the optimal leaf area development curve
LAIMX2	Fraction of the maximum plant leaf area index corresponding to the 2nd point on the optimal leaf area development curve
DLAI	Fraction of growing season at which senescence becomes the dominant growth process
CHTMX*	Plant’s potential maximum canopy height (m)
RDMX*	Maximum rooting depth for plant (mm)
T_OPT*	Optimal temperature for plant growth (?C)
T_BASE*	Minimum temperature for plant growth (?C)
CNYLD	Fraction of nitrogen in the yield
CPYLD	Fraction of phosphorus in the yield

BN1*	Normal fraction of nitrogen in the plant biomass at emergence
BN2*	Normal fraction of nitrogen in the plant biomass at 50% maturity
BN3*	Normal fraction of nitrogen in the plant biomass at maturity
BP1*	Normal fraction of phosphorus in the plant biomass at emergence
BP2*	Normal fraction of phosphorus in the plant biomass at 50% maturity
BP3*	Normal fraction of phosphorus in the plant biomass at maturity
WSYF	Harvest index for the plant in drought conditions, the minimum harvest index allowed for the plant
USLE_C	Minimum value of USLE C-factor applied to the land cover or plant
GSI	Maximum stomatal conductance in drought conditions
VPDFR	Vapor pressure deficit corresponding to the fraction maximum stomatal conductance defined by FRGMAX
FRGMAX	Fraction of maximum stomatal conductance that is achievable at a high vapor pressure deficit
WAVP	Rate of decline in radiation-use efficiency per unit increase in vapor pressure deficit (kg/ha)/(MJ/m2)
CO2HI	Elevated CO2 atmospheric concentration (ppmv)
BIOEHI	Radiation use efficiency at elevated CO2 atmospheric concentration value for CO2HI (kg/ha)/(MJ/m2)
RSDCO_PL	Plant residue decomposition coefficient

* The literature search focused on these variables.

To simulate the growth of Southern California vegetation, each land cover class required the input variables listed in Table 4-6. Therefore, each GAP polygon needed a unique land cover identifier associated with a series of input variables. The GAP species and plant types were aggregated into nine groups according to genus and plant type, and each genus-plant type had one set of SWAT input values. The genus-plant types were chosen so that each type included at least one species with SWAT input variables. The nine genus-plant types are the following:

1. Chaparral-Adenostoma
2. Chaparral-Arctostaphylos
3. Chaparral- Buckbrush (Ceanothus)
4. Chaparral- Hoaryleaf ceanothus
5. Chaparral- Desert ceanothus
6. Chaparral-Scrub Oak
7. Chaparral- Mountain mahogany
8. Chaparral- Sugarbush
9. Scrub-Shrub
10. Conifer
11. Hardwood-Blue Oak
12. Hardwood-Coast Live Oak
13. Herbaceous

A new attribute was created for the GAP data that identifies each co-dominant species group by its three genus-plant types. For example, one polygon was labeled “Chaparral-Adenostoma/ Herbaceous/ Chaparral-Ceanothus.” The input values were aggregated from the three genus plant types in each polygon. Depending on the input variable, the aggregation involved taking the average, minimum, or maximum within the three species groups. The aggregated values were entered into the SWAT Land Cover/ Plant Growth database, and this process created 92 new SWAT land cover classes.

The input values were acquired from the SWAT Land Cover/ Plant Growth database and from literature values obtained for individual species. SWAT provided default values for several of the variables listed in Table 6. The SWAT Land Cover/ Plant Growth database also contained input values for pine, oak, poplar, and honey mesquite trees as well as the more general deciduous, mixed, and evergreen forest classes. The GAP data defined annual grassland as including Avena and Bromus species; for this land cover, the SWAT input values for Avena sativa, Bromus inermis, and Bromus biebersteinii can be used.

The estimation of input values focused on radiation use efficiency, height, root depth, leaf area index, base and optimal growth temperatures, and nutrient biomass concentrations. A literature search was conducted for nine species (marked by asterisks in Table 4-5). Maximum heights were found for all species. Leaf area indices for most species were acquired, and several values for rooting depth and nutrient biomass concentration were found. According to the literature search and personal communication with SWAT co-developer Jim Kiniry, the literature does not provide estimates of radiation use efficiency (RUE; in biomass units) for the Southern California species. With Mr. Kiniry's advice, Tetra Tech estimated RUE by comparing leaf area indices of Southern California species with other species for which RUE values were available.

Additional HRU Inputs

Table 4-7 lists three inputs specified for water flow and erosion in the HRU input files. The average slope length specifies the length during which sheet flow is the dominant water transport. If SWAT did not calculate the slope length of a watershed, an average slope length of 50 meters was used. The soil evaporation compensation factor was set to 0.5 instead of the default 0.95. By reducing the soil evaporation factor, evaporation was simulated at greater depths in the soil profile, a condition appropriate for the arid climate of Southern California. The initial residue cover was set at 150 kg/ha to account for naturally occurring litter cover.

Table 4-7: Parameters Affecting Water Flow and Erosion

Variable	Description	Value
SLSUBBSN	Average slope length [m]	50 if not calculated by SWAT
ESCO	Soil evaporation compensation factor	0.5
RSDIN	Initial residue cover [kg/ha]	150

Ground Water Nutrient Concentrations

The concentration of nutrients in the ground water contribution to streamflow was determined from California monitoring data for minimally impacted streams (Table4-8). The streams were designated as minimally impacted with the following criteria: they 1) met their designated use, 2) had a well-developed riparian corridor with large reaches and stable channels, 3) maintained greater than 60 percent natural substrate, 4) drained largely undisturbed watersheds, and 5) had flows that were not severely depleted. The mean low flow nitrate concentration from the monitoring data was used for the nitrate concentration in groundwater (GWNO3) in SWAT. Low flow was designated as flow less than 3.14 cfs, and the mean nitrate concentration in this range was 0.03 mg N-NO_3/L. Since none of the flow data corresponded with soluble phosphate observations, the overall mean soluble phosphate of 0.01 mg P/L was used for the soluble phosphorus concentration in groundwater (GWSOLP).

Table 4-8: Summary of Monitoring Data

Parameter	No. of Stations	n	Min	Mean	Max
Nitrate (mg/L)	19	123	0.001	0.20	2.84
Nitrate (mg/L) low flow*	7	32	0.025	0.030	0.200
Dissolved P (mg/L)	1	13	0.025	0.04	0.20
Soluble PO4 (mg/L)	56	66	0.001	0.01	0.06

*Low flow was defined as between 0 and 3.14 cfs.

Management Options

SWAT allows the user to simulate one or more "management operations" throughout the growing season. For natural land covers, SWAT defaults to Option 5, entitled "Harvest and Kill," which results in stopping growth and removing non-woody biomass at the end of the growing season. This can lead to overestimation of erosion and associated soil nutrient loading, as soil residue cover is not fully replenished. Accordingly, the simulation of the end of the growing season was switched to Option 8 entitled "Kill/End of Growing Season." This option stops growth and converts all plant biomass to ground residue.

4.2.3 SWAT Watershed Simulation Results

SWAT simulations were run for 10 years, with the first year discarded to reduce model spinup effects. Results across eight of the watersheds are summarized graphically in Figure 4-4 through Figure 4-9. These results exclude simulations from watershed 9, which appear anomalously high relative to the others..

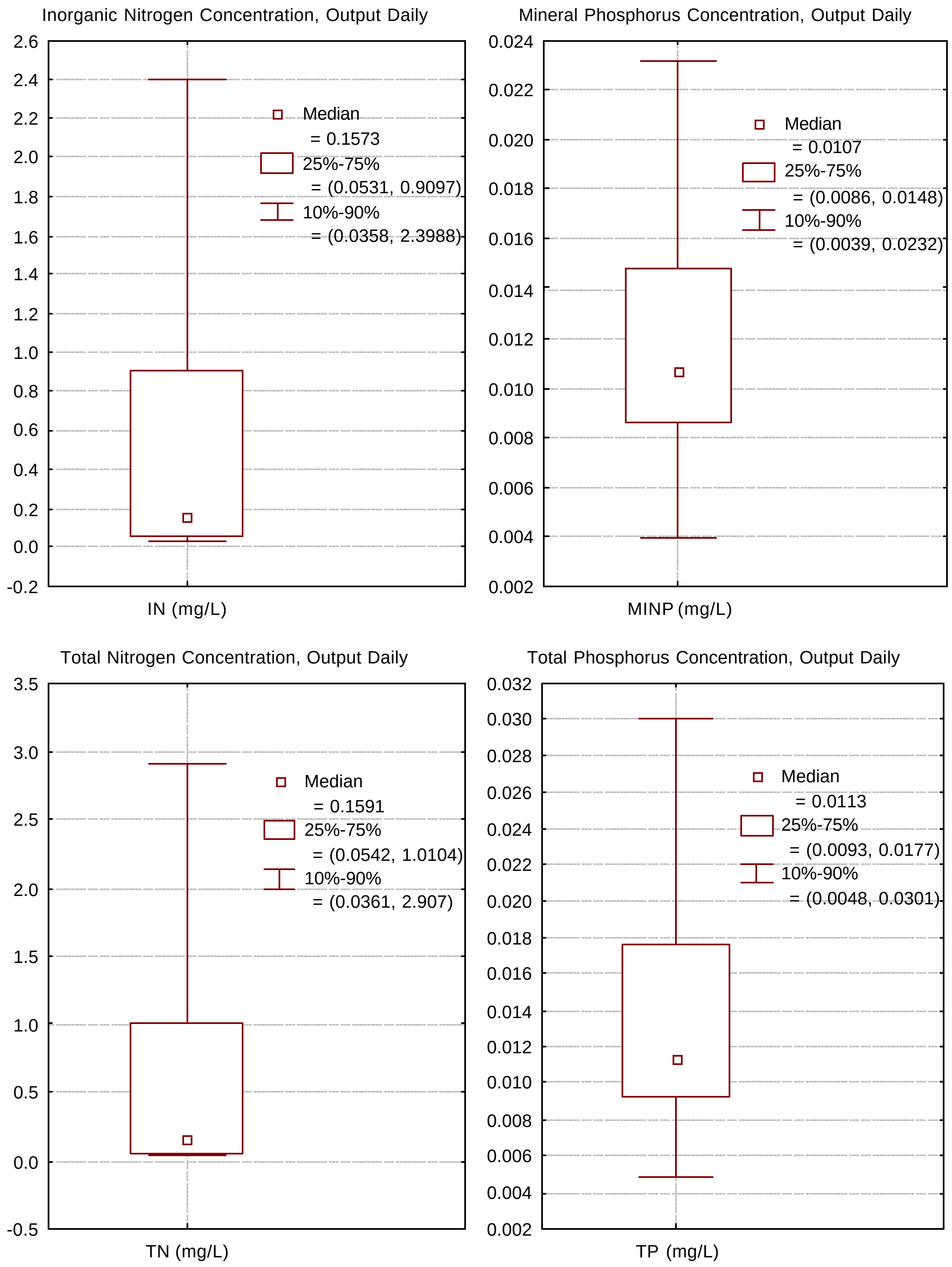


Figure 4-4: SWAT Daily Nutrient Concentrations (Years 2-10); Watershed 9 and No Flow Observations Excluded.

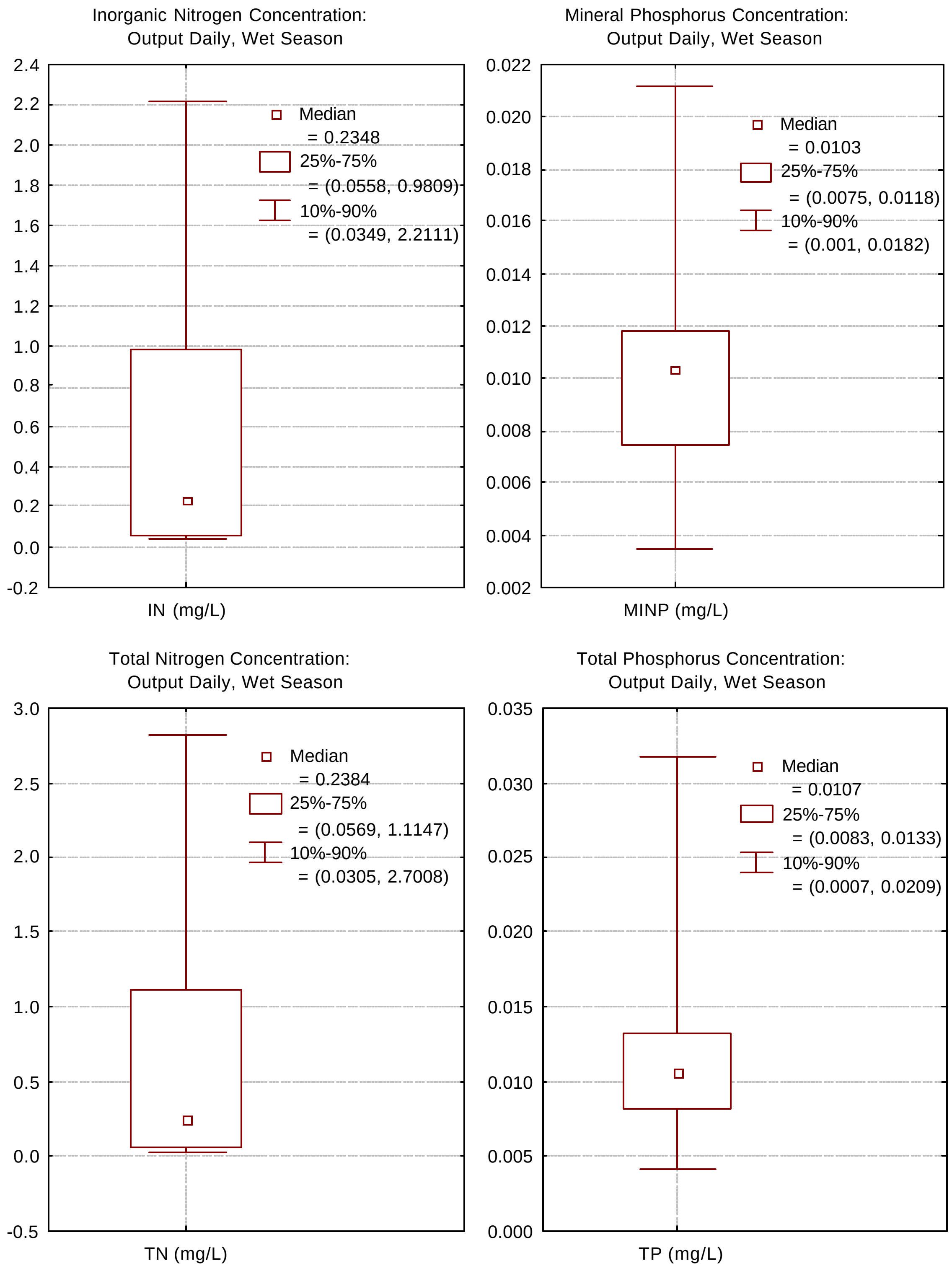


Figure 4-5: SWAT Daily Nutrient Concentrations during the Wet Season (Years 2-10, Nov. 1 through April 30); Watershed 9 and No Flow Observations Excluded.

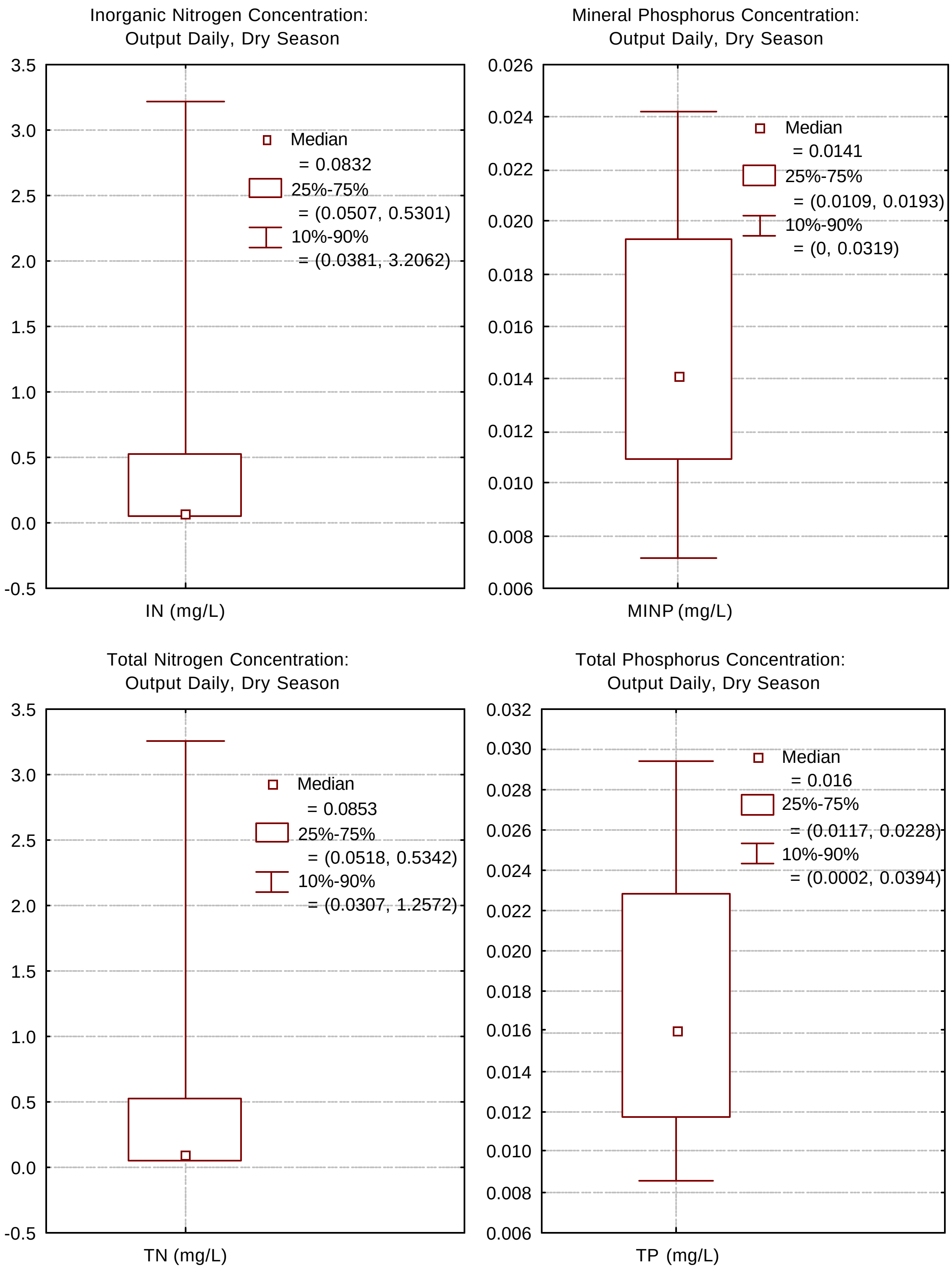


Figure 4-6: SWAT Daily Nutrient Concentrations during the Dry Season (Years 2-10, May 1 through Oct. 31); Watershed 9 and No Flow Observations Excluded.

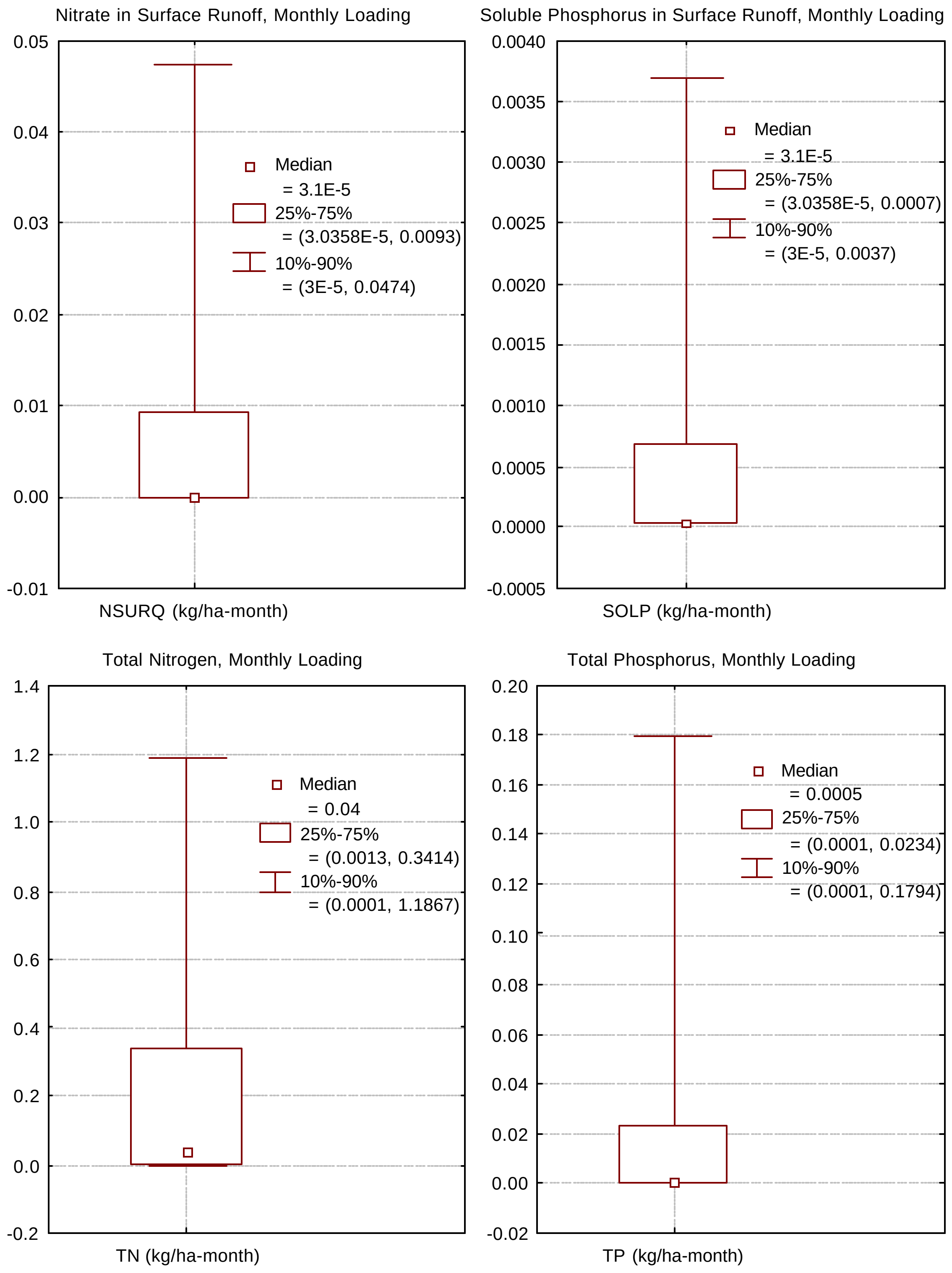


Figure 4-7: SWAT Monthly Nutrient Loading (kg/ha/mo, Years 2-10); Watershed 9 and No Flow Observations Excluded.

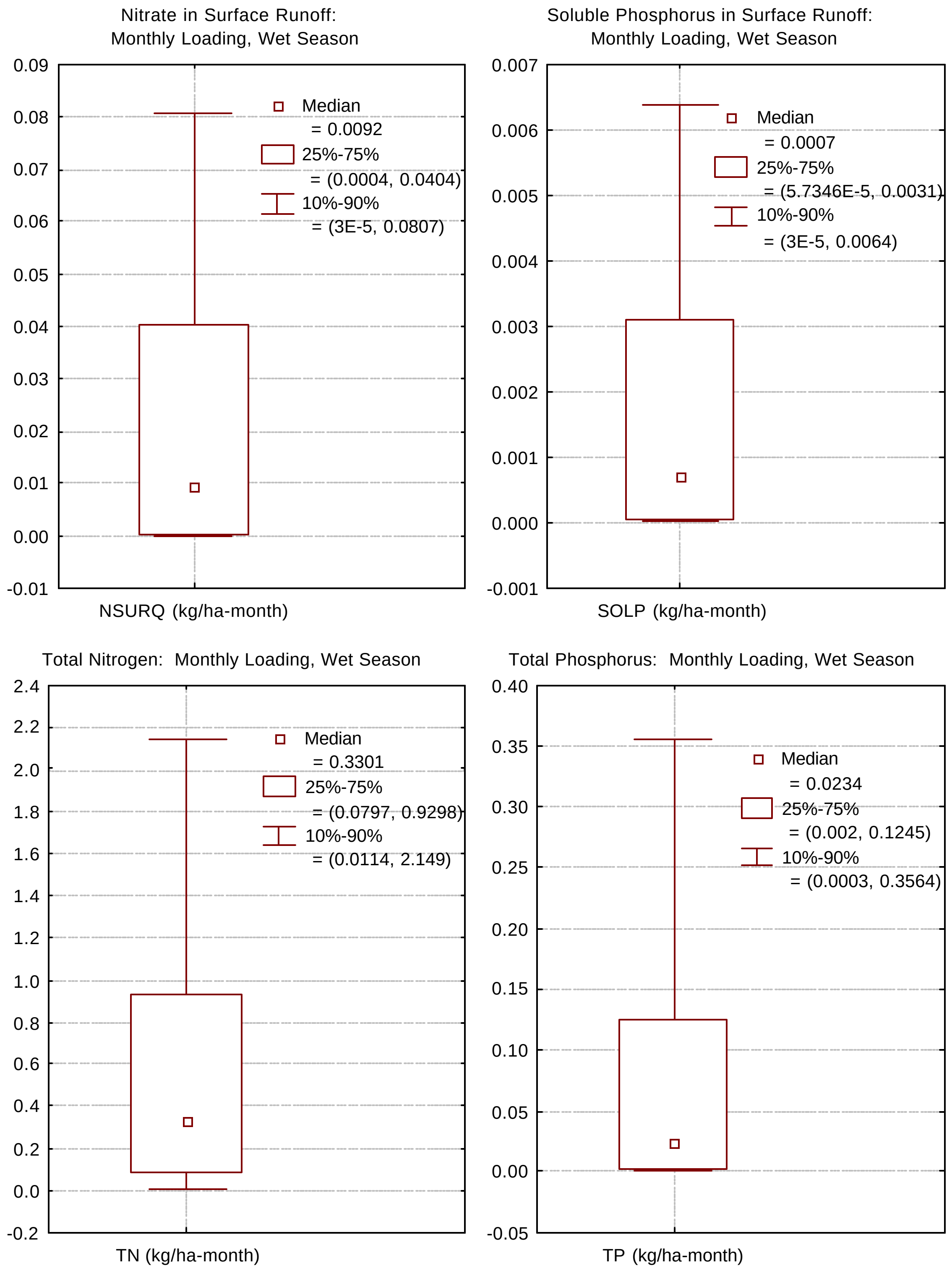


Figure 4-8: SWAT Monthly Nutrient Loading during the Wet Season (kg/ha/mo, Years 2-10, Nov. 1 through April 30); Watershed 9 and No Flow Observations Excluded.

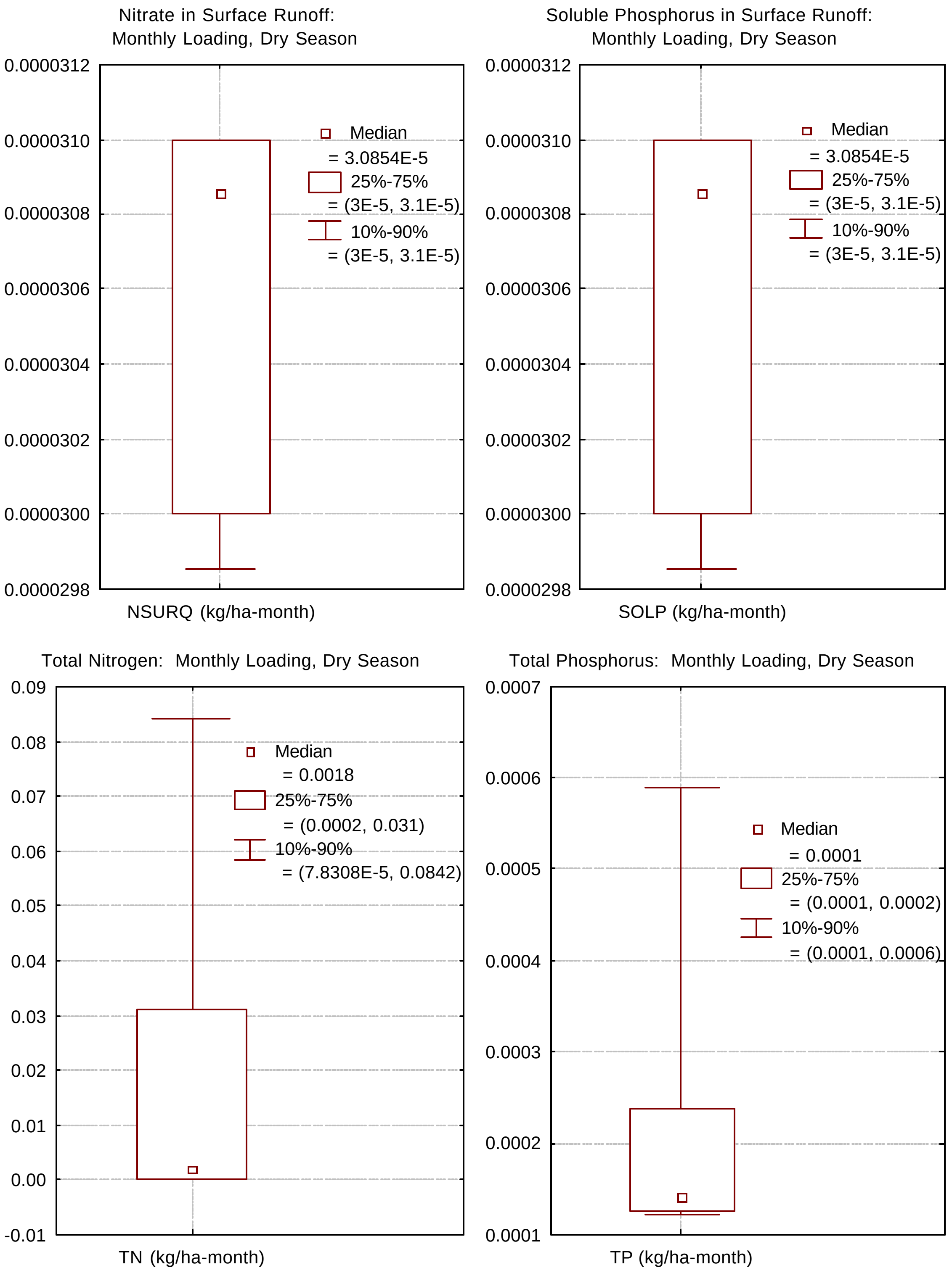


Figure 4-9: SWAT Monthly Nutrient Loading during the Dry Season (kg/ha/mo, Years 2-10, May 1 through Oct. 31); Watershed 9 and No Flow Observations Excluded.

SWAT simulated notable variation in sediment and nutrient loading for the nine reference watersheds. Table 4-9 and Table 4-10 present detailed statistics for SWAT output of sediment, nitrogen, and phosphorus loading and concentrations. Results for watershed 9 appear anomalously high and are omitted from the overall averages.

Concentration results in the box plots are time-weighted averages of surface and subsurface runoff for days with non-negligible predicted flow. These results can be expected to differ from the ambient concentrations found in streams, which represent a mixture of successive runoff events. Further, because much of the loading occurs during brief washoff events, the time-weighted averages are much lower than flow-weighted averages (load divided by flow). For instance, the time-weighted mean runoff concentration for total nitrogen (excluding watershed 9) is 0.16 mg/L and the time-weighted median is 1.22mg/L, but the flow-weighted mean concentration is 3.9 mg/L. For phosphorus, the time-weighted mean and median are 11 and 6 µg/L respectively, while the flow-weighted mean is 550 µg/L. Actual average concentrations in flowing streams are likely to fall between the medianan and mean values due to retention and mixing of loads from a variety of events.

Medianan and mean time-weighted concentration values estimated by SWAT generally bracket the draft nutrient criteria recommended in U.S. EPA (2000) for sub-ecoregion 6. That document cites the 25th percentile concentration for total nitrogen in streams as 0.52 mg/L and the 25th percentile concentration for total phosphorus as 30 µg/L. Smith et al. (2003) used the full SPARROW model to produce estimates of medianan and upper quartile concentrations in reference streams for Nutrient Ecoregion 3 (Xeric West, which includes sub-ecoregion 6) of 0.08 and 0.11 mg/L for total nitrogen, which is much lower than the value in U.S. EPA (2000), but similar to the SWAT mean results presented here. Smith et al. (2003) estimated the reference stream medianan and upper quartile concentrations for total phosphorus at about 22 and 30 µg/L, consistent with U.S. EPA (2000). These values are both above the 75th percentile of the time-weighted concentrations obtained from SWAT, but less than the mean concentration. Phosphorus shows a larger percent difference between medianan and mean concentrations in the SWAT output because phosphorus is more particle-reactive than nitrogen and groundwater flux is not a significant part of the the total load. Observed data from minimally impacted streams shows a similar skew, with the mean much greater than the medianan concentration.

The distribution of loads is even more highly skewed than concentrations, with the bulk of delivered loads occurring in a few high-runoff/high erosion events. For instance, the medianan monthly total nitrogen load is only 0.04 kg/ha/mo (0.48 kg/ha/yr); however, average annual load is 6.87 kg/ha/yr. Similarly, for phosphorus the average annual load of 0.96 kg/ha/yr is much greater than the sum of the medianan monthly loads (0.006 kg/ha/yr).

This phenomenon is shown in Figure 4-10, which displays the monthly series of phosphorus loads predicted for watershed 1. The total loading is dominated by a few months with high erosion rates, during which large amounts of organic and sediment-sorbed phosphorus are washed off. In addition, only a small sample of watersheds have been run, and these are not necessarily representative of the ecoregion as a whole. As a result, total estimated nutrient yield rates appear high relative to the literature, including the results of Smith et al. (2003). This is a source of considerable uncertainty in the current analysis, with the uncertainty present in both observations and the model. Monitoring data are typically sparse for high flow events. Further, much of the nutrient mass moved during these events may be transported in bed load or within relatively large organic detritus, both of which are not represented in standard water quality monitoring. As a result, interpretation of flow and concentration monitoring data may significantly underestimate actual load in “flashy” semi-arid stream systems. The SWAT results, on the other hand, are highly sensitive to the specification of parameters that control erosion simulation, including the residue balance on the soil surface. Analysis of additional watersheds would help to determine if the test watersheds are representative of SWAT output for the ecoregion in general; however, only additional study of local loading rates and the development of calibrated simulation models would fully resolve these issues.

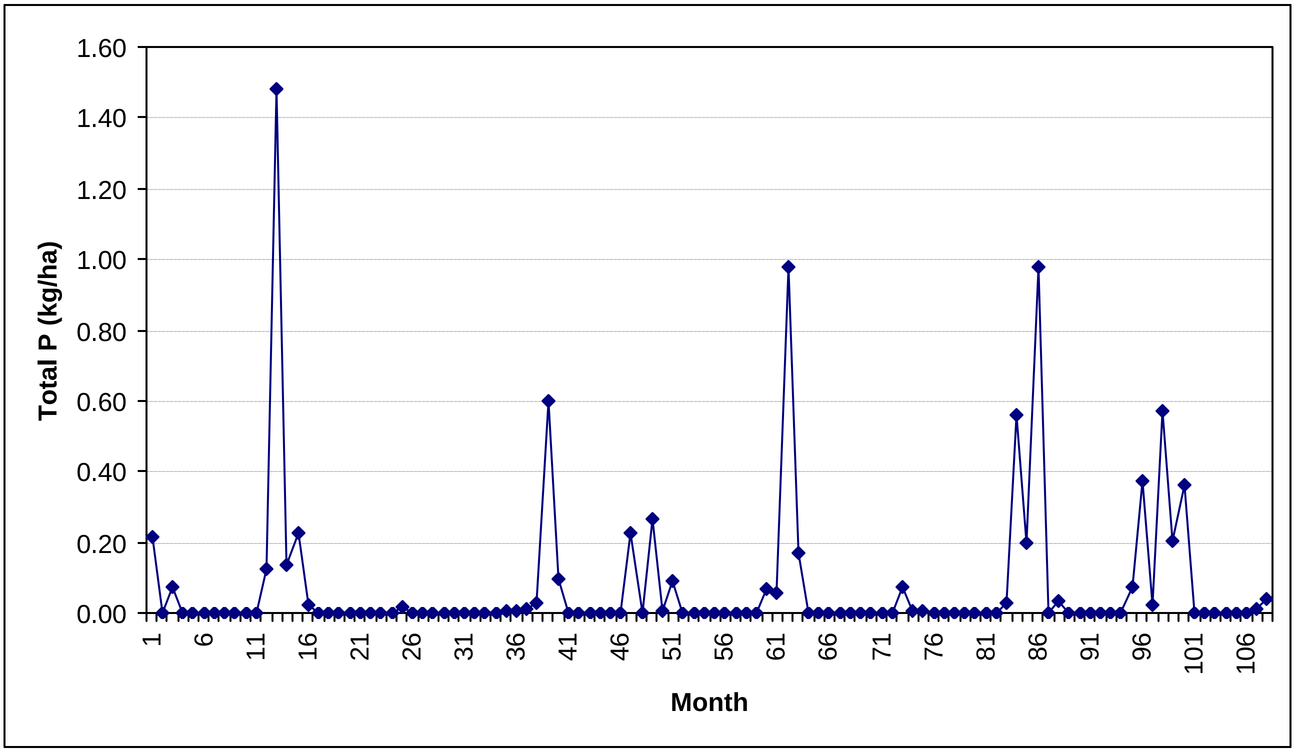


Figure 4-10: Simulated Monthly Total Phosphorus Loading, Watershed 1

Table 4-9: Sediment and Nutrient Annual Loading Statistics for 10-Year SWAT Run

Watershed # Dominant Cover		Sediment Yield (tons/ha)	Organic Nitrogen (kg/ha)	Organic Phosphorus (kg/ha)	Total Nitrogen (kg/ha)	Total Phosphorus (kg/ha)
1 Grassland	Min	0.10	0.18	0.02	0.21	0.03
	Medianan	3.07	4.05	0.51	4.55	0.82
	Average	3.32	4.43	0.55	4.98	0.87
	StDev	2.43	3.04	0.38	3.16	0.61
	Max	6.67	9.99	1.24	10.61	1.87
2 Chaparral	Min	0.47	0.40	0.05	2.55	0.13
	Medianan	2.21	1.27	0.16	3.63	0.35
	Average	2.05	1.18	0.15	4.25	0.31
	StDev	1.13	0.61	0.08	2.33	0.14
	Max	3.46	2.09	0.26	10.39	0.52
3 Chaparral	Min	0.09	0.26	0.03	1.23	0.08
	Medianan	0.38	1.21	0.15	2.40	0.22
	Average	0.63	1.69	0.21	3.32	0.31
	StDev	0.78	1.51	0.19	2.56	0.23
	Max	2.72	5.27	0.65	9.77	0.83
4 Chaparral Scrub-shrub Grassland	Min	0.05	0.03	0.00	1.34	0.01
	Medianan	0.32	0.17	0.02	2.04	0.05
	Average	0.47	0.26	0.03	2.28	0.08
	StDev	0.39	0.22	0.03	0.81	0.06
	Max	1.23	0.62	0.07	3.65	0.17
5 Hardwood Grassland	Min	0.72	0.42	0.05	0.90	0.11
	Medianan	3.90	2.03	0.25	3.42	0.42
	Average	5.91	4.77	0.58	6.22	0.83
	StDev	7.30	7.14	0.87	7.10	1.14
	Max	25.22	23.98	2.92	24.82	3.87

Watershed # Dominant Cover		Sediment Yield (tons/ha)	Organic Nitrogen (kg/ha)	Organic Phosphorus (kg/ha)	Total Nitrogen (kg/ha)	Total Phosphorus (kg/ha)
6 **Mixed**	Min	14.99	2.23	0.28	3.11	0.50
	Medianan	27.29	6.05	0.75	7.12	1.20
	Average	41.94	10.04	1.24	11.65	1.86
	StDev	28.60	12.30	1.50	13.02	2.12
	Max	91.48	43.86	5.37	47.24	7.69
7 **Hardwood** **Grassland**	Min	4.77	1.32	0.16	3.10	0.30
	Medianan	27.23	5.18	0.63	7.97	1.23
	Average	27.00	7.06	0.86	10.86	1.52
	StDev	12.32	5.01	0.61	8.58	0.88
	Max	44.80	18.23	2.23	32.66	3.38
8 **Chaparral** **Scrub-shrub** **Grassland**	Min	2.96	0.78	0.10	1.30	0.17
	Medianan	30.61	8.35	1.05	10.20	1.73
	Average	32.80	9.41	1.19	11.42	1.93
	StDev	27.85	7.77	0.99	8.75	1.55
	Max	96.54	22.19	2.86	24.29	4.46
9 **Scrub-shrub** **Grassland**	Min	34.83	11.75	1.43	12.20	1.80
	Medianan	86.21	32.15	3.92	32.77	4.95
	Average	121.40	31.47	3.84	32.16	4.80
	StDev	106.85	13.30	1.63	13.53	1.99
	Max	372.90	51.44	6.30	53.06	7.61
All Excluding #9	Min	0.05	0.03	0.00	0.21	0.01
	Medianan	3.49	3.04	0.38	4.09	0.62
	Mean	14.27	4.86	0.60	6.87	0.96
	St. Dev.	15.03	6.12	0.75	7.01	1.09
	Max	96.54	43.86	5.37	47.24	7.69

Table 4-10: Sediment and Nutrient Concentration Statistics from Daily, 9-Year SWAT Run (first year omitted)

Watershed # Dominant Cover		Organic N (mg/L)	NO3 (mg/L)	NH3 (mg/L)	NO2 (mg/L)	Inorganic N (mg/L)	Total N (mg/L)	Organic P (mg/L)	Mineral P (mg/L)	Total P (mg/L)
1 Grassland	Min	<0.001	<0.001	0.001	<0.001	0.007	0.039	<0.001	<0.001	0.002
	25%	<0.001	0.046	0.005	<0.001	0.074	0.078	0.001	0.009	0.010
	Medianan	0.001	0.322	0.016	<0.001	0.416	0.473	0.002	0.014	0.016
	Mean	1.275	1.013	0.215	<0.001	1.228	2.503	0.197	0.095	0.292
	St. Dev.	4.033	1.814	0.666	<0.001	1.926	5.021	0.614	0.281	0.892
	75%	0.010	1.195	0.037	<0.001	1.607	2.546	0.005	0.021	0.026
	Max	41.600	18.700	8.020	<0.001	18.779	49.910	6.210	3.310	9.520
2 Chaparral	Min	<0.001	0.030	<0.001	<0.001	0.031	0.031	<0.001	<0.001	<0.001
	25%	<0.001	0.034	0.001	<0.001	0.050	0.051	<0.001	0.009	0.009
	Medianan	<0.001	0.119	0.003	<0.001	0.133	0.135	<0.001	0.011	0.011
	Mean	0.026	0.934	0.016	<0.001	0.950	0.976	0.006	0.013	0.019
	St. Dev.	0.163	3.121	0.031	<0.001	3.123	3.129	0.031	0.015	0.044
	75%	0.001	0.727	0.017	<0.001	0.751	0.772	0.002	0.014	0.016
	Max	3.510	47.800	0.510	0.004	47.820	47.822	0.644	0.271	0.915
3 Chaparral	Min	<0.001	0.030	<0.001	<0.001	0.031	0.031	<0.001	<0.001	0.001
	25%	<0.001	0.084	0.001	<0.001	0.090	0.091	<0.001	0.009	0.009
	Medianan	<0.001	0.228	0.002	<0.001	0.235	0.236	<0.001	0.010	0.011
	Mean	0.037	0.920	0.013	<0.001	0.933	0.970	0.007	0.013	0.020
	St. Dev.	0.252	2.330	0.038	<0.001	2.334	2.347	0.035	0.014	0.047
	75%	0.002	0.654	0.013	<0.001	0.685	0.771	0.003	0.014	0.017
	Max	6.680	25.000	0.882	<0.001	25.030	25.034	0.904	0.290	1.194
4 Chaparral Scrub-shrub Grassland	Min	<0.001	0.063	<0.001	<0.001	0.067	0.068	<0.001	<0.001	<0.001
	25%	<0.001	0.144	0.005	<0.001	0.156	0.156	0.001	0.007	0.009
	Medianan	0.001	0.838	0.010	<0.001	0.863	0.865	0.001	0.012	0.013
	Mean	0.025	1.710	0.021	<0.001	1.732	1.757	0.007	0.014	0.020
	St. Dev.	0.160	2.546	0.031	0.001	2.547	2.563	0.032	0.018	0.050
	75%	0.002	2.340	0.033	<0.001	2.375	2.400	0.004	0.017	0.021
	Max	3.370	24.200	0.619	0.009	24.201	24.202	0.690	0.393	1.083
5 Hardwood Grassland	Min	<0.001	0.030	<0.001	<0.001	0.031	0.031	<0.001	<0.001	0.001
	25%	<0.001	0.034	0.001	<0.001	0.049	0.050	<0.001	0.007	0.008
	Medianan	<0.001	0.129	0.004	<0.001	0.136	0.137	0.001	0.010	0.011
	Mean	0.267	0.655	0.049	<0.001	0.704	0.971	0.042	0.025	0.067

Watershed # Dominant Cover		Organic N (mg/L)	NO3 (mg/L)	NH3 (mg/L)	NO2 (mg/L)	Inorganic N (mg/L)	Total N (mg/L)	Organic P (mg/L)	Mineral P (mg/L)	Total P (mg/L)
	St. Dev.	2.650	1.487	0.406	<0.001	1.550	3.424	0.372	0.135	0.507
	75%	0.001	0.731	0.014	<0.001	0.765	0.787	0.002	0.013	0.016
	Max	65.300	21.600	10.100	<0.001	21.631	76.131	8.930	3.220	12.150
6 Mixed	Min	<0.001	0.030	<0.001	<0.001	0.030	0.031	<0.001	0.001	0.001
	25%	<0.001	0.032	0.001	<0.001	0.038	0.038	<0.001	0.009	0.010
	Medianan	<0.001	0.052	0.001	<0.001	0.061	0.062	<0.001	0.011	0.011
	Mean	0.282	0.409	0.046	<0.001	0.455	0.737	0.045	0.028	0.073
	St. Dev.	1.372	0.847	0.197	<0.001	0.880	1.824	0.211	0.080	0.291
	75%	0.001	0.384	0.009	<0.001	0.468	0.495	0.002	0.014	0.016
	Max	30.200	9.870	4.170	<0.001	9.877	35.790	4.600	1.700	6.300
7 Hardwood Grassland	Min	<0.001	0.032	<0.001	<0.001	0.032	0.032	<0.001	<0.001	<0.001
	25%	<0.001	0.037	0.001	<0.001	0.039	0.039	<0.001	0.009	0.010
	Medianan	0.001	0.051	0.001	<0.001	0.061	0.063	0.001	0.011	0.012
	Mean	0.168	1.367	0.028	<0.001	1.395	1.563	0.031	0.024	0.055
	St. Dev.	1.050	6.267	0.156	<0.001	6.267	6.374	0.183	0.078	0.260
	75%	0.002	0.959	0.006	<0.001	1.050	1.140	0.003	0.015	0.017
	Max	19.300	131.000	3.020	<0.001	131.003	131.004	3.050	1.290	4.340
8 Chaparral Scrub-shrub Grassland	Min	<0.001	0.030	<0.001	<0.001	0.031	0.032	<0.001	<0.001	<0.001
	25%	<0.001	0.033	0.003	<0.001	0.048	0.049	<0.001	0.009	0.010
	Medianan	0.001	0.090	0.006	<0.001	0.117	0.119	0.001	0.011	0.012
	Mean	0.233	1.185	0.054	<0.001	1.239	1.472	0.040	0.030	0.070
	St. Dev.	1.514	4.444	0.269	0.001	4.452	4.781	0.249	0.121	0.369
	75%	0.001	0.945	0.020	<0.001	1.094	1.155	0.002	0.015	0.018
	Max	28.100	86.900	5.660	0.013	86.923	86.924	4.510	2.500	7.010
9 Scrub-shrub Grassland	Min	<0.001	<0.001	<0.001	<0.001	0.009	0.031	<0.001	<0.001	0.001
	25%	<0.001	0.034	0.001	<0.001	0.044	0.044	<0.001	0.010	0.010
	Medianan	<0.001	0.054	0.003	<0.001	0.069	0.071	0.001	0.011	0.011
	Mean	1.432	0.381	0.276	<0.001	0.657	2.090	0.183	0.089	0.272
	St. Dev.	9.807	0.918	1.842	<0.001	2.070	11.688	1.240	0.522	1.760
	75%	0.002	0.236	0.014	<0.001	0.254	0.261	0.002	0.015	0.018
	Max	22<0.001	8.020	40.500	<0.001	41.127	261.127	27.900	11.500	39.400

Watershed # Dominant Cover		Organic N (mg/L)	NO3 (mg/L)	NH3 (mg/L)	NO2 (mg/L)	Inorganic N (mg/L)	Total N (mg/L)	Organic P (mg/L)	Mineral P (mg/L)	Total P (mg/L)
All excluding #9	Min	<0.001	<0.001	<0.001	<0.001	0.007	0.031	<0.001	<0.001	<0.001
	25%	<0.001	0.038	0.001	<0.001	0.053	0.054	<0.001	0.009	0.009
	Mediananan	<0.001	0.149	0.004	<0.001	0.157	0.159	0.001	0.011	0.011
	Mean	0.214	0.967	0.043	<0.001	1.010	1.224	0.035	0.025	0.060
	St. Dev.	1.643	3.255	0.262	0.001	3.266	3.770	0.248	0.105	0.352
	75%	0.002	0.813	0.016	<0.001	0.909	1.010	0.003	0.015	0.018
	Max	65.300	131.000	10.100	0.013	131.003	131.004	8.930	3.310	12.150

4.2.4 Variability among Watersheds

Variation in slope, soil type, and vegetation influenced the simulated sediment and organic nutrient loading. Watersheds that had the steepest average slope (39 and 37 percent for watersheds 8 and 9 respectively) also produced the highest sediment and organic nutrient loading. For HRUs with identical land cover, one soil type resulted in higher sediment loading compared to other soil types. Vegetation was not as influential as slope and soil type, but HRUs dominated by grassland species did produce higher sediment and organic nutrient loads than HRUs with other cover.

To further investigate the variability among the watersheds, the SWAT sediment, organic nitrogen, organic phosphorus, nitrate, and soluble phosphorus loading predictions were investigated in a stepwisde regression versus average elevation, precipitation, k-factor, latitude, and slope. As shown in Table 4-11, the USLE soil erodibility K-factor and latitude were not selected as promising explanatory variables, and average elevation and average slope were the only significant explanatory variables selected in the regression ($p<0.05$). According to the selected model, a watershed that is 10 percent steeper than a similar watershed is likely to produce 6.6 kg/ha more organic nitrogen and 0.8 kg/ha more organic phosphorus than its counterpart. The model also suggests that with every 100 meter increase in elevation, nitrate in surface runoff is likely to increase by 0.02 kg/ha, and soluble phosphorus is likely to increase by about 0.0015 kg/ha. These variables explained about 60 percent of the variability in predicted organic and inorganic nutrient loading among the watersheds.

Table 4-11: Forward, Step-wise Regression of Monthly SWAT Loading on Stratification Parameters

Explanatory Variable	Sediment Yield (R^2=0.29)	Organic Nitrogen (R^2=0.58)	Organic Phosphorus (R^2=0.59)	Nitrate in Surface Runoff (R^2=0.60)	Soluble Phosphorus (R^2=0.67)
Elevation	NS[1]	NS	NS	1.961E-04*	1.467E-05*
Precipitation	NS	-0.049	-0.006	NS	NS
USLE K-Factor	NS	NS	NS	NS	NS
Latitude	NS	NS	NS	NS	NS
Slope	2.576	0.661*	0.081*	NS	NS

Notes: NS not selected for regression model; Variables were selected if $p<0.15$.
* Variable significant at the 0.05 probability level.

Watershed 9 produced unusually high sediment and organic nutrient loading compared to the other watersheds. This watershed would be expected to have high sediment and organic nutrient loading because of its steep slopes and high percentage of grassland cover compared to more woody, protective land cover. Watershed 8 shares similar features with watershed 9, but did not produce the same degree of high loading. In Table 4-12, a comparison of HRUs with the same land cover and different soil types revealed that the soil association Lodo is producing the extremely high loading. This soil association has a K-factor of 0.32 and a rock fragment percentage of 5.71. Although more erodible soils can be found among the nine watersheds, the combination of steep slopes and erodible soil is the likely cause of the high loading output. SWAT may not be accurately reflecting the spatial overlay of steep slopes and erosive soil, potentially leading to unrealistic erosion estimates for watershed 9. Therefore, Watershed 9 was excluded from the overall watershed statistics and SPARROW modeling.

Table 4-12: Comparison between Soil Associations by Land Cover type for Watershed 9: Organic Nitrogen, Average Monthly Loading (kg/ha-month)

Land Cover	Hambright	Lodo
Chaparral	0.15	1.09
Chaparral and Scrub-Shrub	0.28	1.56
Chaparral and Grassland	0.52	2.05
Grassland	2.36	3.45
Scrub-Shrub and Grassland	2.50	3.48
Scrub-Shrub and Grassland	2.56	3.47

4.3 TRANSPORT MODELING

The SWAT application provides an estimate of nutrient concentrations and loads at the scale of local, low-order wastersheds. These concentrations can be expected to generally decline as flow accumulates to higher-order streams. This occurs due to a variety of trapping and removal processes during transport. As pollutant mass is removed, the exerted concentration of upstream watersheds declines, and the concentration at a downstream point represents a mixture of full-strength contributions from local watersheds and reduced concentrations from upstream watersheds. If all sub-watersheds generated the same pollutant concentration and flow response, concentration would necessarily decline with movement downstream.

4.3.1 Transport Representation

The processes that result in trapping of nutrients during transport are varied. Among them are uptake by rooted plants, sequestration in the sediment, export to the flood plain during high flow events, loss to ground water, and, for nitrogen, conversion to gaseous forms and volatilization to the atmosphere. Simulation models handle these processes explicitly or implicitly at varying levels of accuracy.

SWAT provides routines (based on QUAL2E kinetics) that describe transport through streams and cover some of the potential trapping processes. These routines, in our experience, do not provide very reliable results without site-specific calibration, and are thus of limited use for generic analysis. An alternative is to take an empirical approach. For this we utilize the stream transport component of the USGS SPARROW model (Smith et al., 1997). SPARROW refers to spatially referenced regressions of contaminant transport on watershed attributes, and was developed based on nationwide USGS NASQAN monitoring of 414 stations. The model empirically estimates the origin and fate of contaminants in streams, and quantifies uncertainties in these estimates based on model coefficient error and unexplained variability in the observed data.

The SPARROW tool actually contains two portions, one to generate upland loads and one to account for mass transport through stream reaches. Our approach is to use SWAT to generate the upland loads, and then apply the portion of SPARROW that estimates instream transport losses.

In SPARROW, nutrient mass reduction during transport is calculated using first order decay equations that are a function of time-of-travel:

$$C_t = C_o \cdot e^{-d\,t}$$

where:

C_o = pollutant mass present at the upstream end of a reach

C_t = pollutant mass present at the downstream end of a reach following travel time *t*

δ = decay or removal rate (1/day)

t = time of travel (days)

4.3.2 SPARROW Transport Model Setup

The key parameters for SPARROW transport are the decay coefficient or rate of loss (δ, day^{-1}) and time of travel.

Decay coefficients are based on the national SPARROW model. The values initially developed and reported in Smith et al. (1997) have subsequently been updated and reported in Smith et al., (2003). These values are summarized in Table 4-13. It should be noted that these national values are not specifically calibrated to Ecoregion 6, and could well be biased relative to typical geochemical processes for this ecoregion. However, they should be sufficient to provide a relative representation of net transport processes.

Table 4-13: SPARROW Decay Coefficients (from Smith et al., 2003)

Mean Flow Regime	Total Nitrogen	Total Phosphorus
< 1000 cfs (<28.3 m^3/s)	0.455	0.258
1000 – 10000 cfs (28.3 – 283 m^3/s)	0.118	0.096
10000 – 30,000 cfs (283 - 850 m^3/s)	0.051	0
> 30,000 cfs (> 850 m^3/s)	0.005	0

The SWAT model provides nutrient load/concentration estimates at the sub-watershed scale. SPARROW transport is applied above this scale – that is, to flow leaving the pour point of each sub-watershed. For this calculation,time of travel is based on path length and mean flow velocity within the major stream network. Both estimates are assembled from data included in EPA's Reach File 1 (RF1; U.S. EPA 1996). Accuracy of these data is often low, but, again, the information is sufficient to produce relative estimates.

4.3.3 Application to Reference Watersheds

Each reference watershed is embedded in a network of watersheds that together form a complete stream system. Pollutant load generation characteristics are likely to vary across the network of watersheds, but SWAT is only applied to the reference watershed itself. To develop a relative analysis of the patterns that evolve for loads and concentrations at higher stream orders, it is assumed that each of the sub-watersheds in the network generates nutrient loads and flows at the same unit areal rate as the reference watershed. Thus, the analysis examines changes downstream only as a function of transport characteristics, with other factors held constant. While this does not yield a direct prediction of downstream concentration in a specific watershed, it does explore the evolution of concentrations caused by network configuration.

Example analyses were developed for six of the reference watersheds. For each of these watersheds, the complete surrounding watershed network was delineated, forming a total of six to seventeen subwatersheds. Sub-watershed connectivity, travel paths, and mean stream velocities were extracted from the RF1. The assumptions of constant average load and flow generation were then applied to each sub-watershed in the network, with reductions in transport calculated using the SPARROW approach.

Two of the reference watersheds are located in the same overall stream network (the Santa Magarita River) as shown in Figure 4-11. Reference watershed 2 is located in the Temecula Creek drainage, which joins the Santa Margarita River at the outlet of subwatershed SM5, while reference watershed 4 is located farther west, overlaying SM2 and SM2a. Both SWAT model results and RF1 stream velocities differed by a factor of two between the two reference watersheds. The portion of the Santa Margarita River upstream of the confluence with Temecula Creek was assumed to have loading rates and runoff more like reference watershed 2 based on a visual inspection and similar RF1 stream velocities. Reference watershed 2 loading rates and runoff were therefore used for subwatersheds SM1 through SM4 only. Note Group #4 results include the incoming load from Group #2.

Results for the six groups are shown in Figure 4-12 through Figure 4-17. As stated above, these results do not give actual concentrations and loads at the mouth of each watershed, but rather show relative reduction patterns. The amount of nitrogen delivered to the mouth of the network ranges from a low of 22 percent (watershed 8) to a high of 79 percent (watershed 3), while the amount of phosphorus delivered to the mouth ranges from 39 percent to 87 percent. Flow-weighted concentrations decline by the same fraction relative to the average headwater concentration.

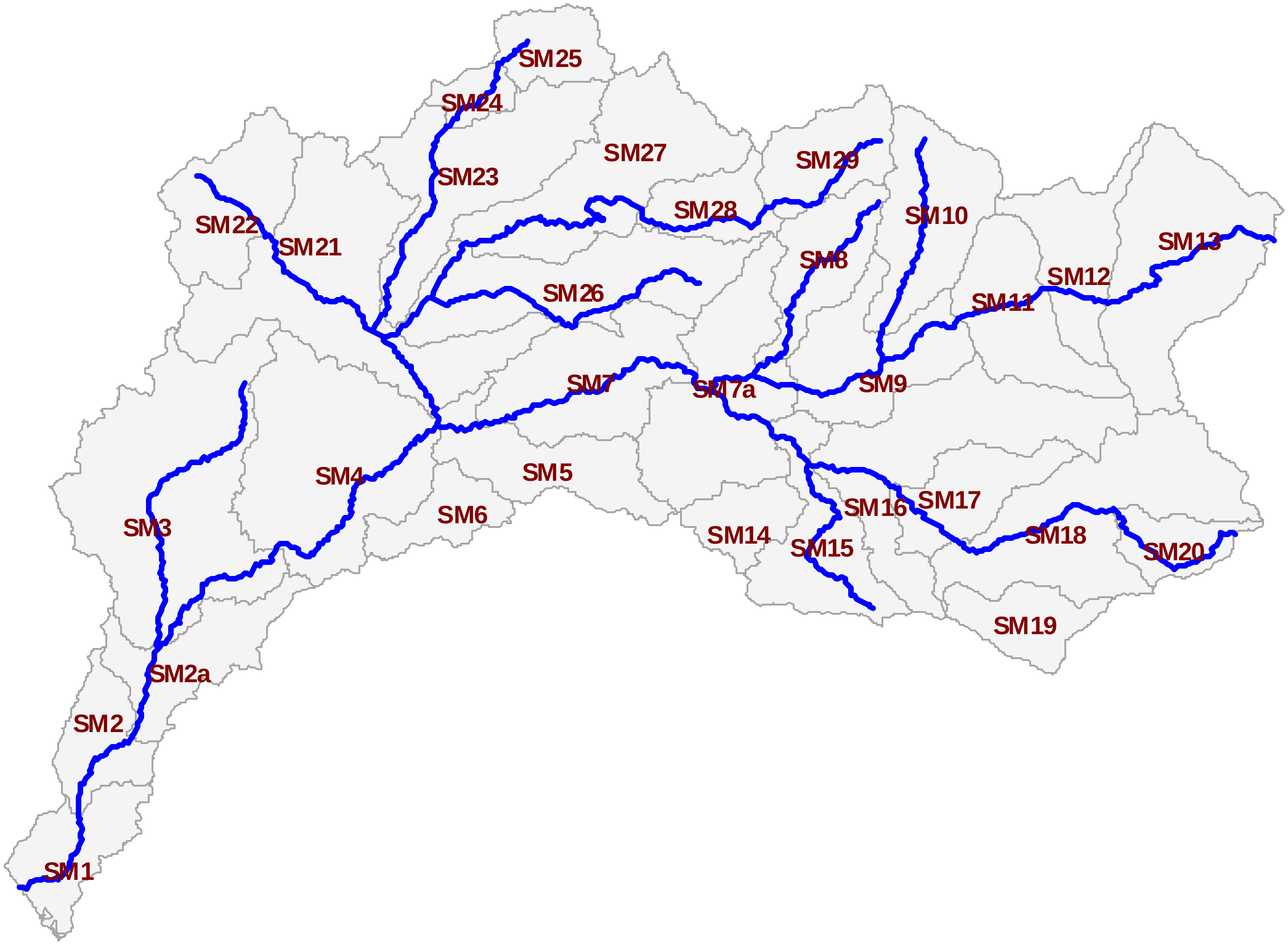
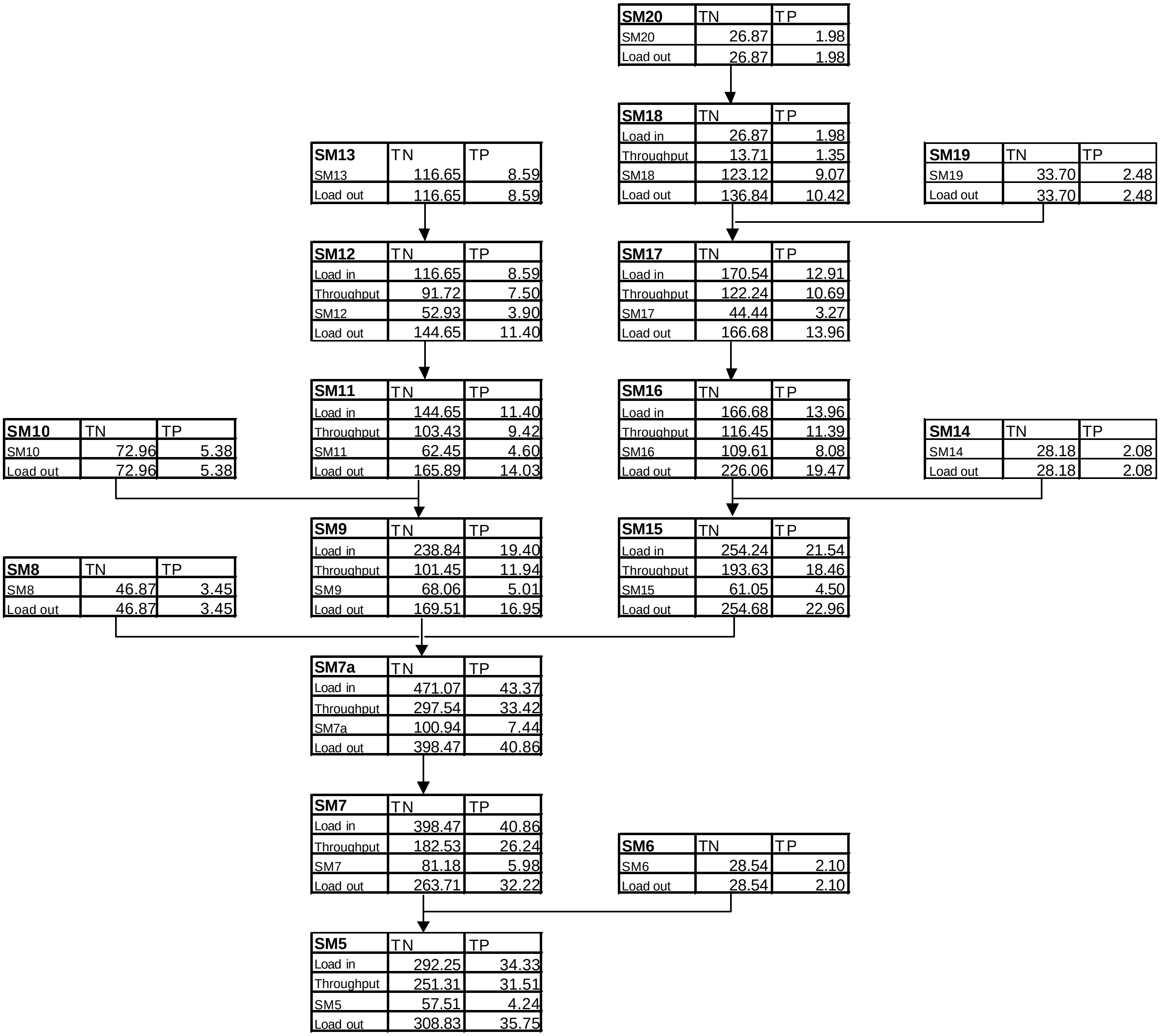


Figure 4-11: Stream network for Subbasin Group #4 (Santa Margarita River) and Group #2 (Temecula Creek Arm)

Subbasin Group #2 - Santa Margarita River (Temecula Creek Arm)

(loads in kg/day)



SM20	TN	TP
SM20	26.87	1.98
Load out	26.87	1.98

SM18	TN	TP
Load in	26.87	1.98
Throughput	13.71	1.35
SM18	123.12	9.07
Load out	136.84	10.42

SM19	TN	TP
SM19	33.70	2.48
Load out	33.70	2.48

SM13	TN	TP
SM13	116.65	8.59
Load out	116.65	8.59

SM12	TN	TP
Load in	116.65	8.59
Throughput	91.72	7.50
SM12	52.93	3.90
Load out	144.65	11.40

SM17	TN	TP
Load in	170.54	12.91
Throughput	122.24	10.69
SM17	44.44	3.27
Load out	166.68	13.96

SM10	TN	TP
SM10	72.96	5.38
Load out	72.96	5.38

SM11	TN	TP
Load in	144.65	11.40
Throughput	103.43	9.42
SM11	62.45	4.60
Load out	165.89	14.03

SM16	TN	TP
Load in	166.68	13.96
Throughput	116.45	11.39
SM16	109.61	8.08
Load out	226.06	19.47

SM14	TN	TP
SM14	28.18	2.08
Load out	28.18	2.08

SM8	TN	TP
SM8	46.87	3.45
Load out	46.87	3.45

SM9	TN	TP
Load in	238.84	19.40
Throughput	101.45	11.94
SM9	68.06	5.01
Load out	169.51	16.95

SM15	TN	TP
Load in	254.24	21.54
Throughput	193.63	18.46
SM15	61.05	4.50
Load out	254.68	22.96

SM7a	TN	TP
Load in	471.07	43.37
Throughput	297.54	33.42
SM7a	100.94	7.44
Load out	398.47	40.86

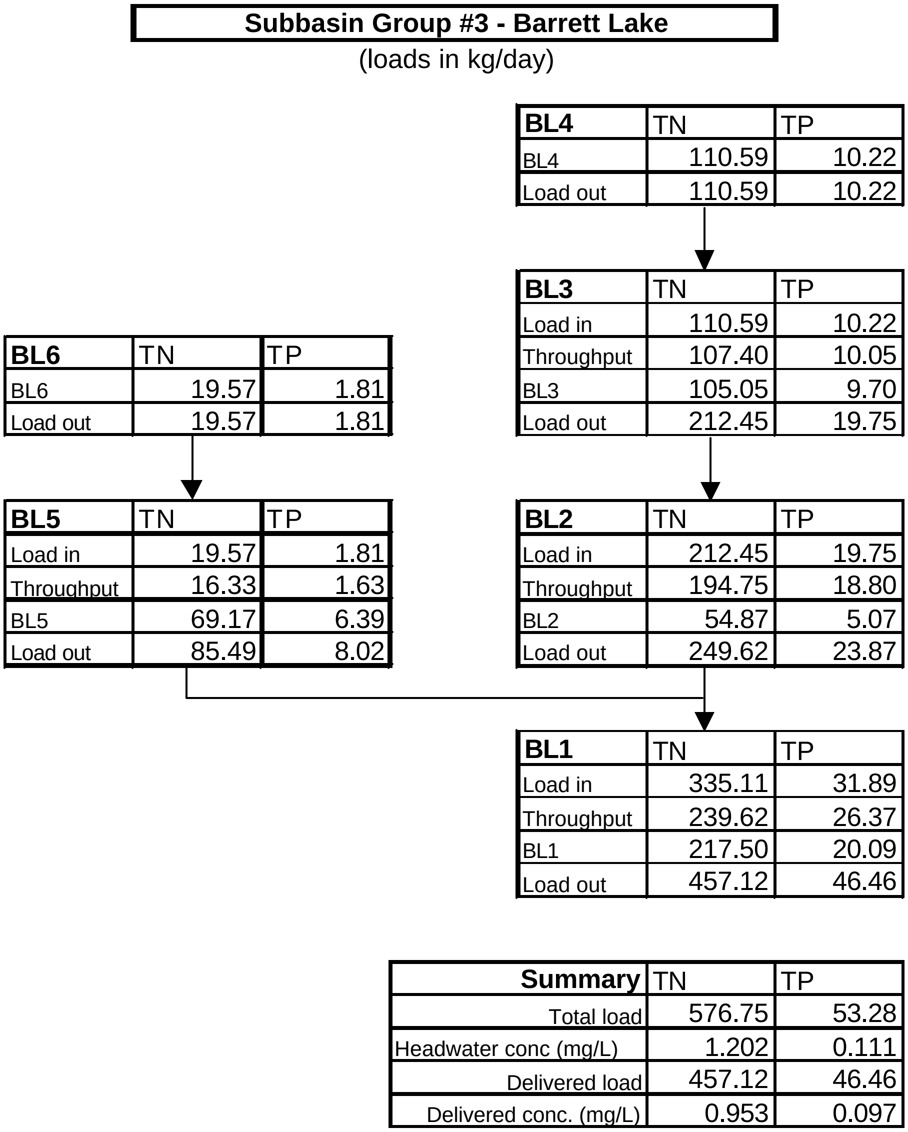
SM7	TN	TP
Load in	398.47	40.86
Throughput	182.53	26.24
SM7	81.18	5.98
Load out	263.71	32.22

SM6	TN	TP
SM6	28.54	2.10
Load out	28.54	2.10

SM5	TN	TP
Load in	292.25	34.33
Throughput	251.31	31.51
SM5	57.51	4.24
Load out	308.83	35.75

Summary	TN	TP
Total load	1115.05	82.16
Headwater conc (mg/L)	1.467	0.108
Delivered load	308.83	35.75
Delivered conc. (mg/L)	0.406	0.047

Figure 4-12: Transport Model Analysis for Reference Watershed 2



Subbasin Group #3 - Barrett Lake

(loads in kg/day)

BL4	TN	TP
BL4	110.59	10.22
Load out	110.59	10.22

BL3	TN	TP
Load in	110.59	10.22
Throughput	107.40	10.05
BL3	105.05	9.70
Load out	212.45	19.75

BL6	TN	TP
BL6	19.57	1.81
Load out	19.57	1.81

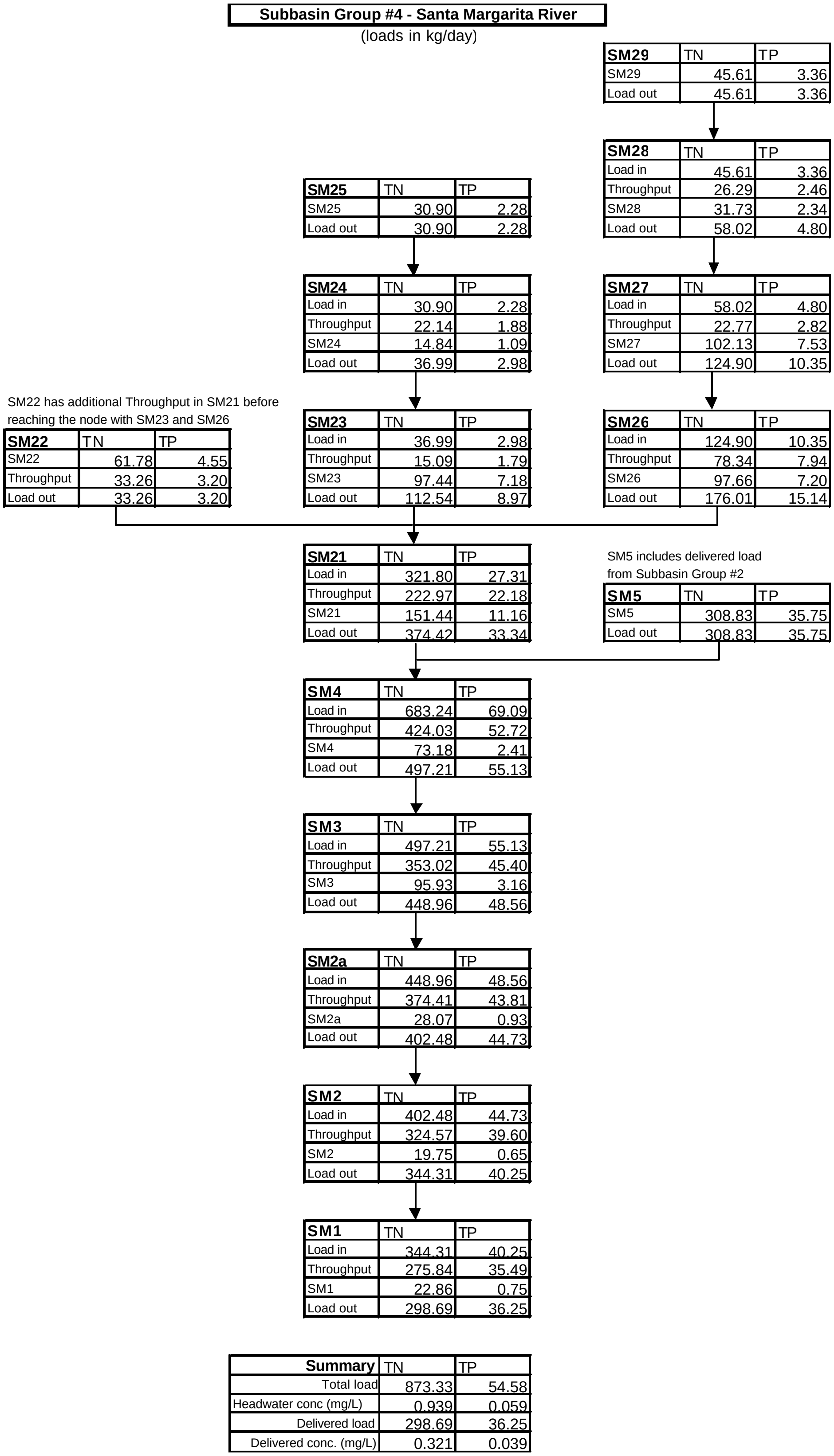
BL5	TN	TP
Load in	19.57	1.81
Throughput	16.33	1.63
BL5	69.17	6.39
Load out	85.49	8.02

BL2	TN	TP
Load in	212.45	19.75
Throughput	194.75	18.80
BL2	54.87	5.07
Load out	249.62	23.87

BL1	TN	TP
Load in	335.11	31.89
Throughput	239.62	26.37
BL1	217.50	20.09
Load out	457.12	46.46

Summary	TN	TP
Total load	576.75	53.28
Headwater conc (mg/L)	1.202	0.111
Delivered load	457.12	46.46
Delivered conc. (mg/L)	0.953	0.097

Figure 4-13: Transport Model Analysis for Reference Watershed 3



Subbasin Group #4 - Santa Margarita River

(loads in kg/day)

SM29	TN	TP
SM29	45.61	3.36
Load out	45.61	3.36

SM28	TN	TP
Load in	45.61	3.36
Throughput	26.29	2.46
SM28	31.73	2.34
Load out	58.02	4.80

SM25	TN	TP
SM25	30.90	2.28
Load out	30.90	2.28

SM24	TN	TP
Load in	30.90	2.28
Throughput	22.14	1.88
SM24	14.84	1.09
Load out	36.99	2.98

SM27	TN	TP
Load in	58.02	4.80
Throughput	22.77	2.82
SM27	102.13	7.53
Load out	124.90	10.35

SM22 has additional Throughput in SM21 before reaching the node with SM23 and SM26

SM22	TN	TP
SM22	61.78	4.55
Throughput	33.26	3.20
Load out	33.26	3.20

SM23	TN	TP
Load in	36.99	2.98
Throughput	15.09	1.79
SM23	97.44	7.18
Load out	112.54	8.97

SM26	TN	TP
Load in	124.90	10.35
Throughput	78.34	7.94
SM26	97.66	7.20
Load out	176.01	15.14

SM21	TN	TP
Load in	321.80	27.31
Throughput	222.97	22.18
SM21	151.44	11.16
Load out	374.42	33.34

SM5 includes delivered load from Subbasin Group #2

SM5	TN	TP
SM5	308.83	35.75
Load out	308.83	35.75

SM4	TN	TP
Load in	683.24	69.09
Throughput	424.03	52.72
SM4	73.18	2.41
Load out	497.21	55.13

SM3	TN	TP
Load in	497.21	55.13
Throughput	353.02	45.40
SM3	95.93	3.16
Load out	448.96	48.56

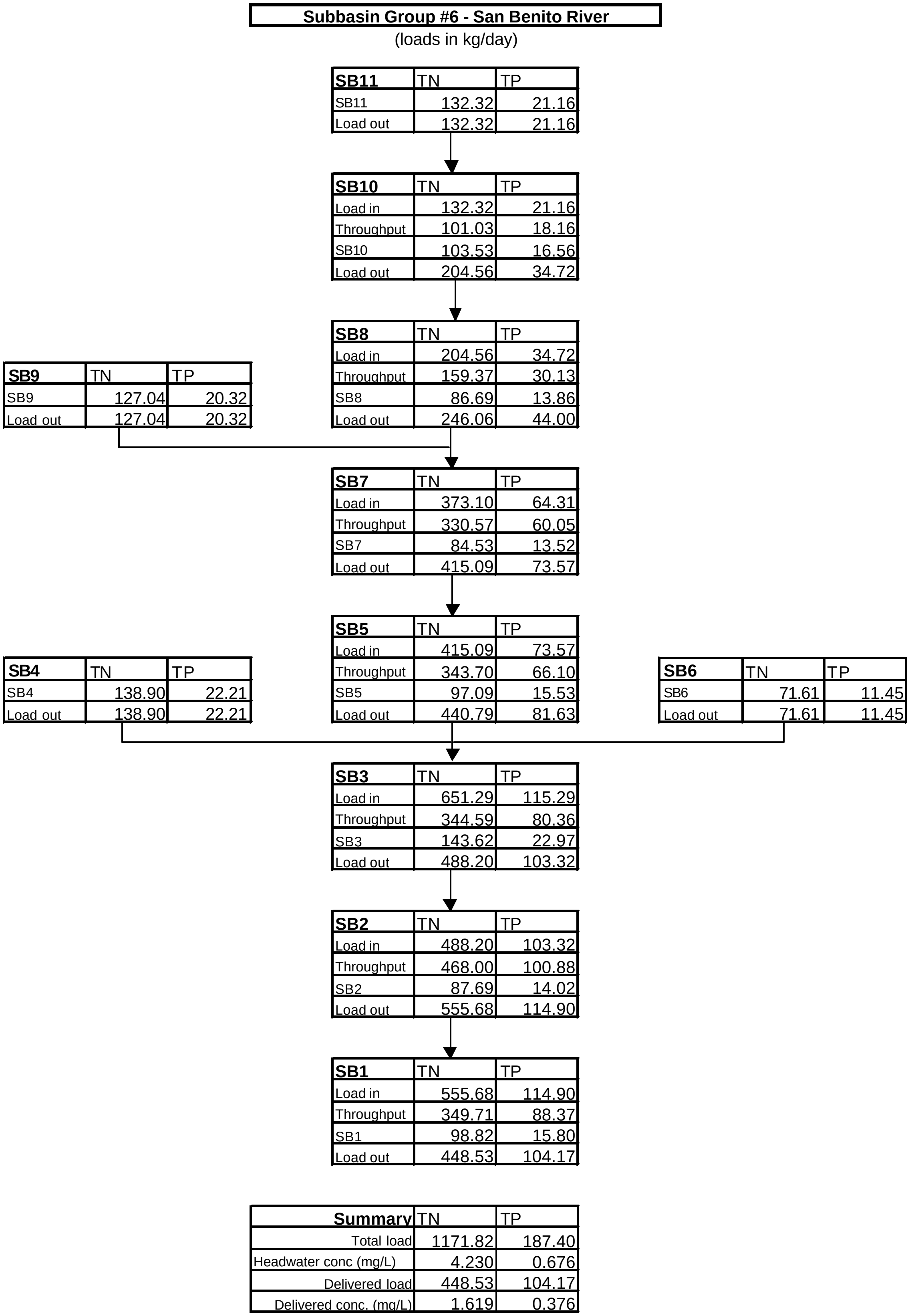
SM2a	TN	TP
Load in	448.96	48.56
Throughput	374.41	43.81
SM2a	28.07	0.93
Load out	402.48	44.73

SM2	TN	TP
Load in	402.48	44.73
Throughput	324.57	39.60
SM2	19.75	0.65
Load out	344.31	40.25

SM1	TN	TP
Load in	344.31	40.25
Throughput	275.84	35.49
SM1	22.86	0.75
Load out	298.69	36.25

Summary	TN	TP
Total load	873.33	54.58
Headwater conc (mg/L)	0.939	0.059
Delivered load	298.69	36.25
Delivered conc. (mg/L)	0.321	0.039

Figure 4-14: Transport Model Analysis for Reference Watershed 4



Subbasin Group #6 - San Benito River

(loads in kg/day)

SB11	TN	TP
SB11	132.32	21.16
Load out	132.32	21.16

SB10	TN	TP
Load in	132.32	21.16
Throughput	101.03	18.16
SB10	103.53	16.56
Load out	204.56	34.72

SB9	TN	TP
SB9	127.04	20.32
Load out	127.04	20.32

SB8	TN	TP
Load in	204.56	34.72
Throughput	159.37	30.13
SB8	86.69	13.86
Load out	246.06	44.00

SB7	TN	TP
Load in	373.10	64.31
Throughput	330.57	60.05
SB7	84.53	13.52
Load out	415.09	73.57

SB4	TN	TP
SB4	138.90	22.21
Load out	138.90	22.21

SB5	TN	TP
Load in	415.09	73.57
Throughput	343.70	66.10
SB5	97.09	15.53
Load out	440.79	81.63

SB6	TN	TP
SB6	71.61	11.45
Load out	71.61	11.45

SB3	TN	TP
Load in	651.29	115.29
Throughput	344.59	80.36
SB3	143.62	22.97
Load out	488.20	103.32

SB2	TN	TP
Load in	488.20	103.32
Throughput	468.00	100.88
SB2	87.69	14.02
Load out	555.68	114.90

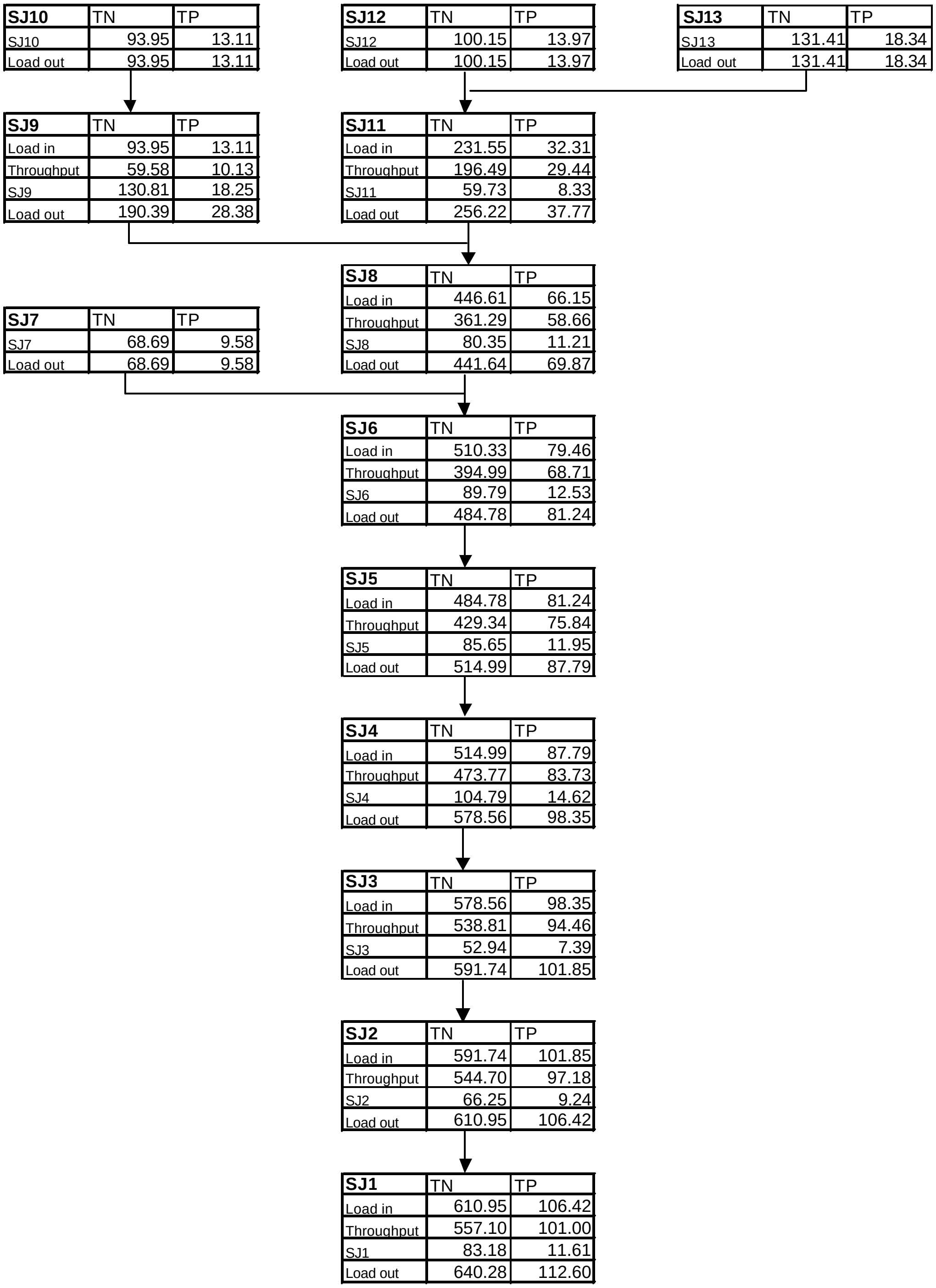
SB1	TN	TP
Load in	555.68	114.90
Throughput	349.71	88.37
SB1	98.82	15.80
Load out	448.53	104.17

Summary	TN	TP
Total load	1171.82	187.40
Headwater conc (mg/L)	4.230	0.676
Delivered load	448.53	104.17
Delivered conc. (mg/L)	1.619	0.376

Figure 4-15: Transport Model Analysis for Reference Watershed 6

Subbasin Group #7 - San Juan Creek

(loads in kg/day)



SJ10	TN	TP
SJ10	93.95	13.11
Load out	93.95	13.11

SJ12	TN	TP
SJ12	100.15	13.97
Load out	100.15	13.97

SJ13	TN	TP
SJ13	131.41	18.34
Load out	131.41	18.34

SJ9	TN	TP
Load in	93.95	13.11
Throughput	59.58	10.13
SJ9	130.81	18.25
Load out	190.39	28.38

SJ11	TN	TP
Load in	231.55	32.31
Throughput	196.49	29.44
SJ11	59.73	8.33
Load out	256.22	37.77

SJ8	TN	TP
Load in	446.61	66.15
Throughput	361.29	58.66
SJ8	80.35	11.21
Load out	441.64	69.87

SJ7	TN	TP
SJ7	68.69	9.58
Load out	68.69	9.58

SJ6	TN	TP
Load in	510.33	79.46
Throughput	394.99	68.71
SJ6	89.79	12.53
Load out	484.78	81.24

SJ5	TN	TP
Load in	484.78	81.24
Throughput	429.34	75.84
SJ5	85.65	11.95
Load out	514.99	87.79

SJ4	TN	TP
Load in	514.99	87.79
Throughput	473.77	83.73
SJ4	104.79	14.62
Load out	578.56	98.35

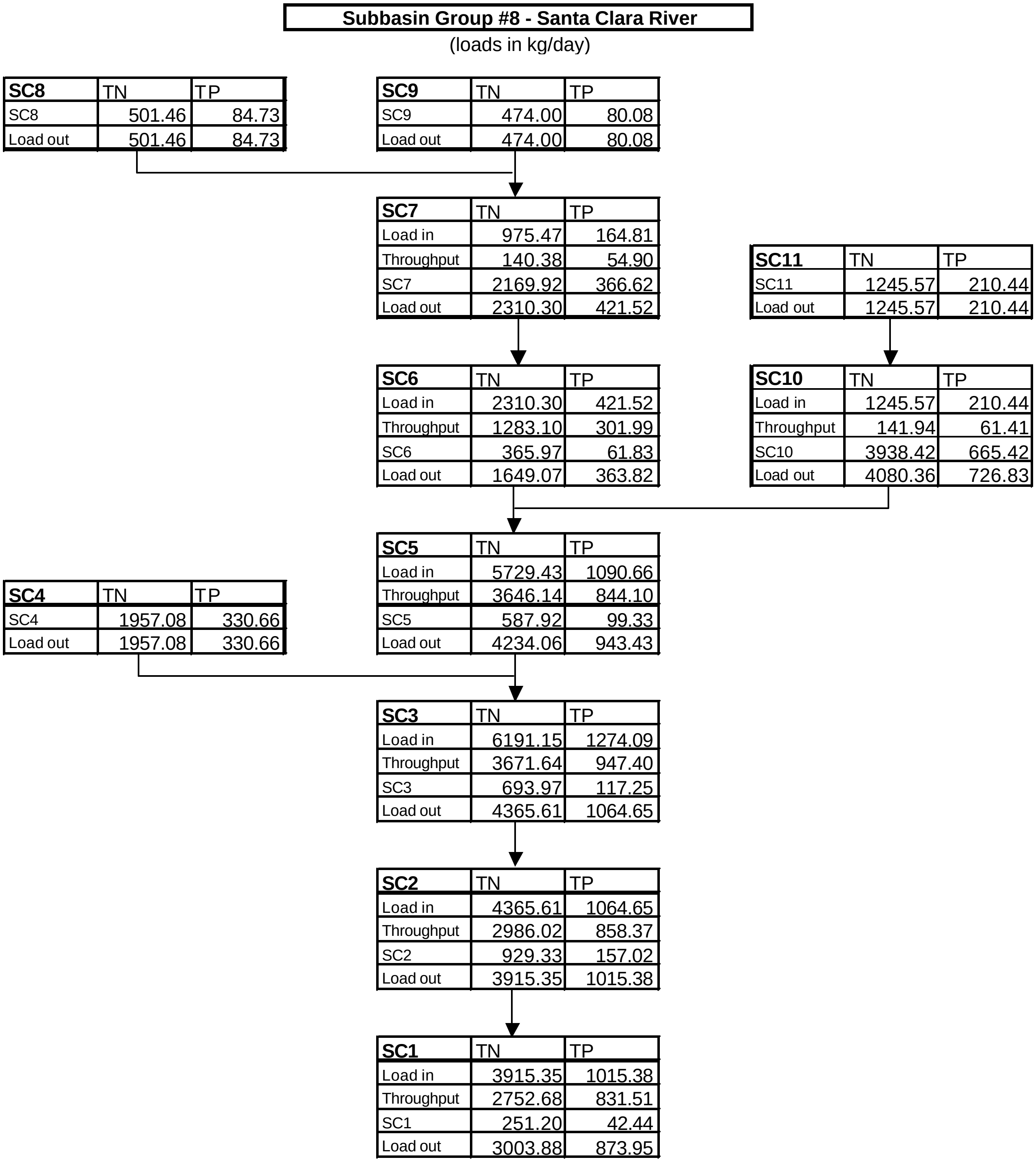
SJ3	TN	TP
Load in	578.56	98.35
Throughput	538.81	94.46
SJ3	52.94	7.39
Load out	591.74	101.85

SJ2	TN	TP
Load in	591.74	101.85
Throughput	544.70	97.18
SJ2	66.25	9.24
Load out	610.95	106.42

SJ1	TN	TP
Load in	610.95	106.42
Throughput	557.10	101.00
SJ1	83.18	11.61
Load out	640.28	112.60

Summary	TN	TP
Total load	1147.67	160.15
Headwater conc (mg/L)	5.482	0.765
Delivered load	640.28	112.60
Delivered conc. (mg/L)	3.059	0.538

Figure 4-16: Transport Model Analysis for Reference Watershed 7



Subbasin Group #8 - Santa Clara River

(loads in kg/day)

SC8	TN	TP
SC8	501.46	84.73
Load out	501.46	84.73

SC9	TN	TP
SC9	474.00	80.08
Load out	474.00	80.08

SC7	TN	TP
Load in	975.47	164.81
Throughput	140.38	54.90
SC7	2169.92	366.62
Load out	2310.30	421.52

SC11	TN	TP
SC11	1245.57	210.44
Load out	1245.57	210.44

SC6	TN	TP
Load in	2310.30	421.52
Throughput	1283.10	301.99
SC6	365.97	61.83
Load out	1649.07	363.82

SC10	TN	TP
Load in	1245.57	210.44
Throughput	141.94	61.41
SC10	3938.42	665.42
Load out	4080.36	726.83

SC5	TN	TP
Load in	5729.43	1090.66
Throughput	3646.14	844.10
SC5	587.92	99.33
Load out	4234.06	943.43

SC4	TN	TP
SC4	1957.08	330.66
Load out	1957.08	330.66

SC3	TN	TP
Load in	6191.15	1274.09
Throughput	3671.64	947.40
SC3	693.97	117.25
Load out	4365.61	1064.65

SC2	TN	TP
Load in	4365.61	1064.65
Throughput	2986.02	858.37
SC2	929.33	157.02
Load out	3915.35	1015.38

SC1	TN	TP
Load in	3915.35	1015.38
Throughput	2752.68	831.51
SC1	251.20	42.44
Load out	3003.88	873.95

Summary	TN	TP
Total load	13114.85	2215.82
Headwater conc (mg/L)	7.222	1.220
Delivered load	3003.88	873.95
Delivered conc. (mg/L)	1.654	0.481

Figure 4-17: Transport Model Analysis for Reference Watershed 8

4.3.4 Generalized Transport Analysis

The results for example stream systems depend on the spatial arrangement of contributing watersheds, along with travel path length and flow velocity. The change in load with stream order is thus a function of watershed shape, or the rate at which a stream gains contributing area relative to path lengths. For narrow, elongated watersheds, the rate of increase in path length is high relative to the accumulation of contributing area. This type of watershed should show a faster decline in nutrient concentration with increasing stream order than broader networks, given equivalent flow velocities.

These issues can be addressed in a more generalized context by consideration of some of the general features of catchment topology, as summarized in Eagleson (1970). First, it is well known that catchments tend to increase in length relative to area as total area increases – where catchment length is defined as the length of the mainstem from its outlet to its (projected) intersection with the upstream catchment boundary. Surveying data from throughout the world, Grey (1961) found that the correlation between catchment area and catchment length was well-described by the relationship

$$L = 1.40\ A^{0.568}$$

with a 25 percent standard error of estimation, where L is catchment length in miles and A is catchment area in square miles. This relationship can be used to estimate the typical change in length with increase in watershed area.

Another important topological concept is the bifurcation ratio, R_b, which describes the increase in number of stream segments with increasing catchment order. This is defined as

$$R_b = {}^{I_u}\!\big/_{I_{u+1}}$$

where I_u is the total number of stream segments of order u. Strahler (1952) found that R_b was uncorrelated with relief, had a range from 3 to 5 in natural catchments, and was remarkably stable about an average value of 4.

If a catchment is assumed to be composed of a set of individual sub-catchment blocks in which the area of first order watersheds is a constant, A_0, then the total area present at catchment order O will be given by

$$A_\Omega = \sum_{i=1}^{\Omega} A_0 \cdot R_b{}^{i-1}$$

This equation may be combined with Grey's (1961) relationship for catchment length to determine the increase in length in going from order O-1 to order O.

The generic analysis first assumes that flow is accumulated at a constant depth from all contributing areas in the watershed; thus, catchment area may be converted to an average flow, Q. Analysis of loss during transport requires travel time, which depends on both path length and velocity. Velocity in open channels is in turn a function of the square root of channel slope times hydraulic radius (the Chezy formula). In general, channel slope declines with catchment order, with the ratio of slopes at catchment order O to slope at order O-1 in the range of 0.55 to 0.57 (Eagleson, 1970). However, this is counteracted by increasing hydraulic radius. The work of Leopold and Maddock (1953) shows that velocity changes as a power function of discharge, with an exponent for river systems in semi-arid regions of about 0.1. This relationship may then be used to examine the change in velocity as a function of catchment area.

The generic analysis next assumes that nutrient load is generated in the local watersheds at some spatially constant areal loading rate. This rate is set at the average annual obtained from the SWAT model output for the reference watersheds (excluding watershed 9) – and thus includes the loading impacts of infrequent, high load events. This approach is appropriate for evaluating long-term loading impacts in a terminal reservoir or estuary that has a sufficiently long residence time that summer growing season conditions reflect loading over the preceding wet season. The exerted load downstream is, however, subject to exponential decay based on travel time, using the SPARROW relationships.

Combining these assumptions, graphical relationships can be developed between catchment area and flow, delivered load, and concentration of nutrients. This is done using average rates developed for the watersheds described in Section 4.3.3.

First-order watershed size, A_0 (mi^2)	4
Water yield (mm/yr)	176.39
Total nitrogen yield (kg/ha/yr)	6.87
Total phosphorus yield (kg/ha/yr)	0.964
Low-order stream velocity (m/s)	0.3
Decay rates (day^{-1})	As specified by SPARROW.

The relationship of flow to area is summarized in Figure 4-18 This relationship is, by assumption, linear, and can be described by

$$Q = 0.0145\,A$$

for flow in m^3/s and area in mi^2.

As a result of removal processes (which vary by flow regime), the load present at a given catchment area is not linear (Figure 4-19 and Figure 4-20). It is, however, nearly linear on a log-log plot. With the rates specified above, the annual loading rates for nitrogen and phosphorus can be approximated as a function of area (for natural cover within ecoregion 6) as follows:

$$Total\ Nitrogen\ (kg/yr) = 5119.2\ A^{0.6526}$$

$$Total\ Phosphorus\ (kg/yr) = 558.11\ A^{0.8247}$$

where area (A) is again expressed in square miles.

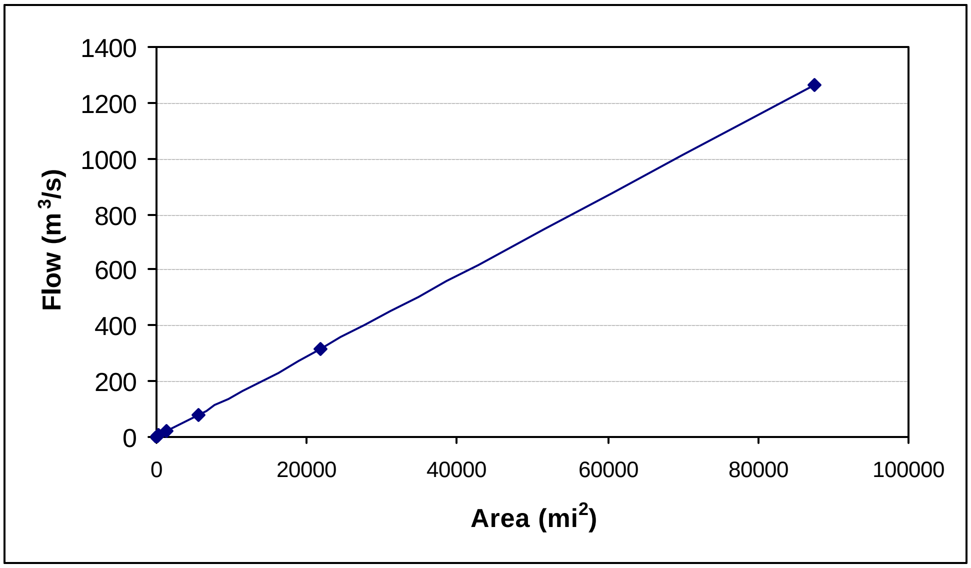


Figure 4-18: Estimated Theoretical Relationship of Average Annual Flow to Catchment Area for Ecoregion 6

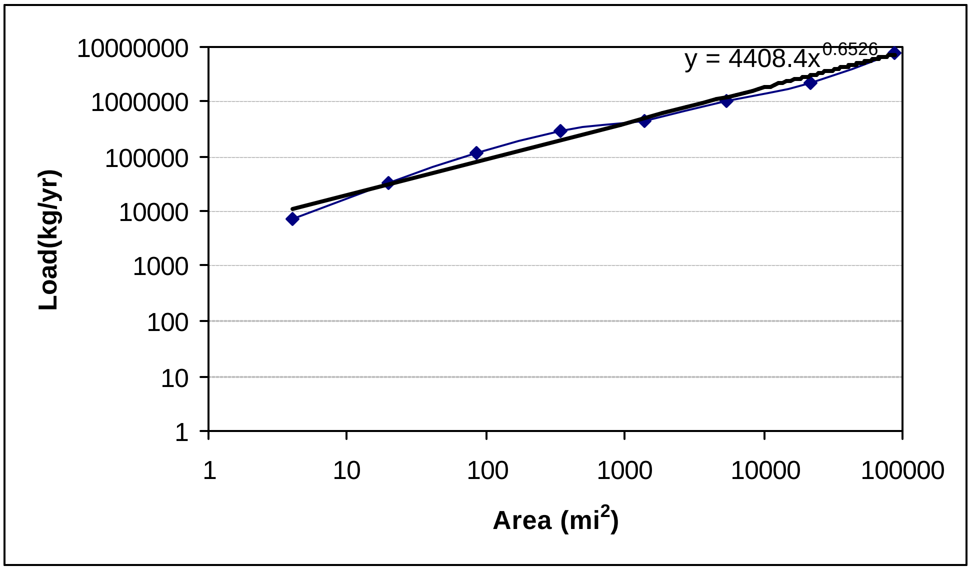


Figure 4-19: Estimated Theoretical Relationship of Annual Nitrogen Load to Catchment Area for Ecoregion 6

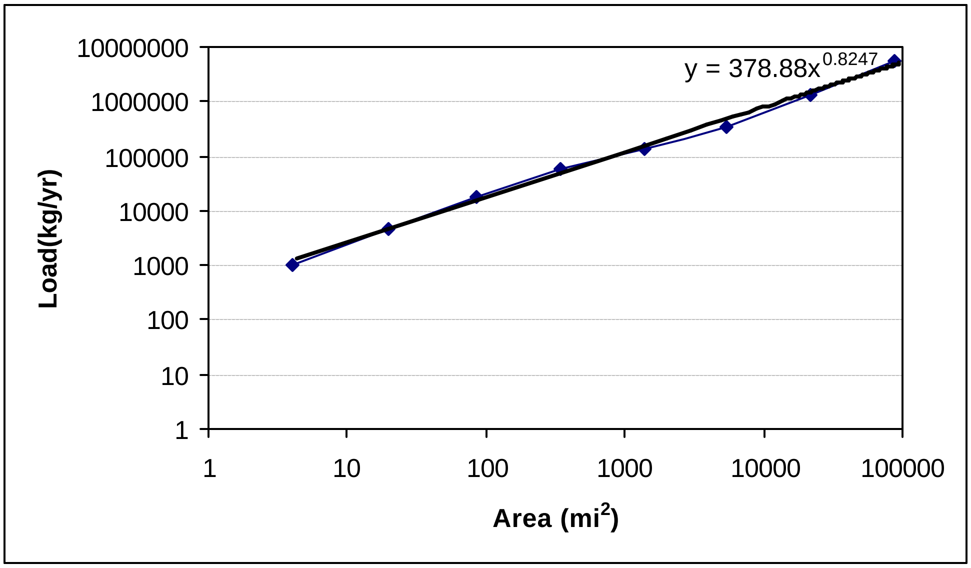


Figure 4-20: Estimated Theoretical Relationship of Annual Phosphorus Load to Catchment Area for Ecoregion 6

The average flow-weighted concentration is the load divided by the flow. Predicted concentrations as a function of area are shown in Figure 4-21 and Figure 4-22. The relationships are not linear, and exhibit kinks that are due to transitions among different SPARROW loss regimes. An approximate fit to the predicted concentration may, however, be obtained through a power function representation (shown as the magenta line on the plots):

$$Total\ Nitrogen\ (mg/L) = 9.634\ A^{-0.3474}$$

$$Total\ Phosphorus\ (mg/L) = 0.828\ A^{-0.1753}$$

Note that the phosphorus concentration converges to a constant value (about 0.13 mg/L) at large catchment size because the SPARROW loss coefficients are zero at flows greater than 283 m^3/s. Nitrogen concentrations are predicted to continue to decline with watershed area, but reach a predicted value of 0.7 mg/L (flow-weighted average concentration) at a watershed area of about 1,500 mi^2.

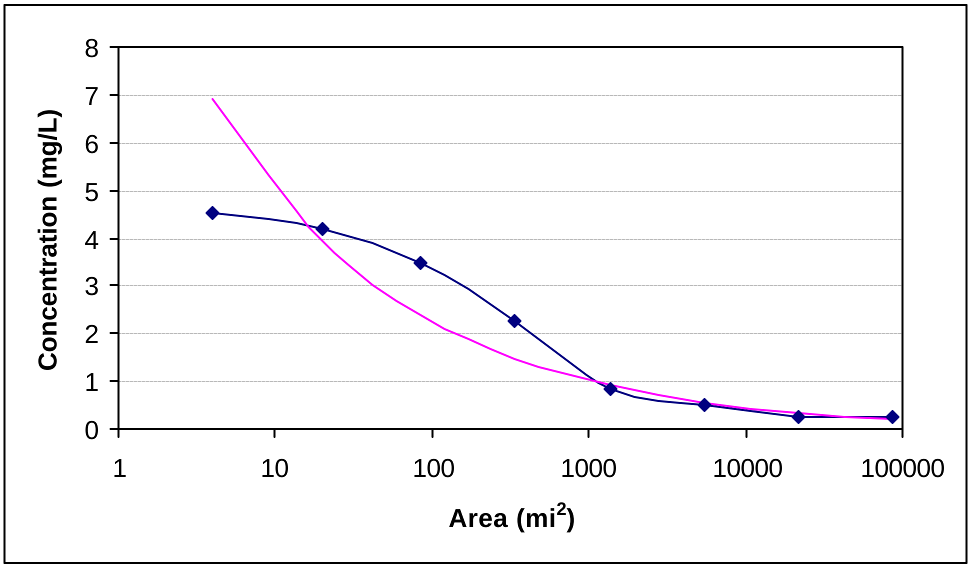


Figure 4-21: Estimated Theoretical Relationship of Flow-Weighted Average Annual Total Nitrogen Concentration to Catchment Area for Ecoregion 6

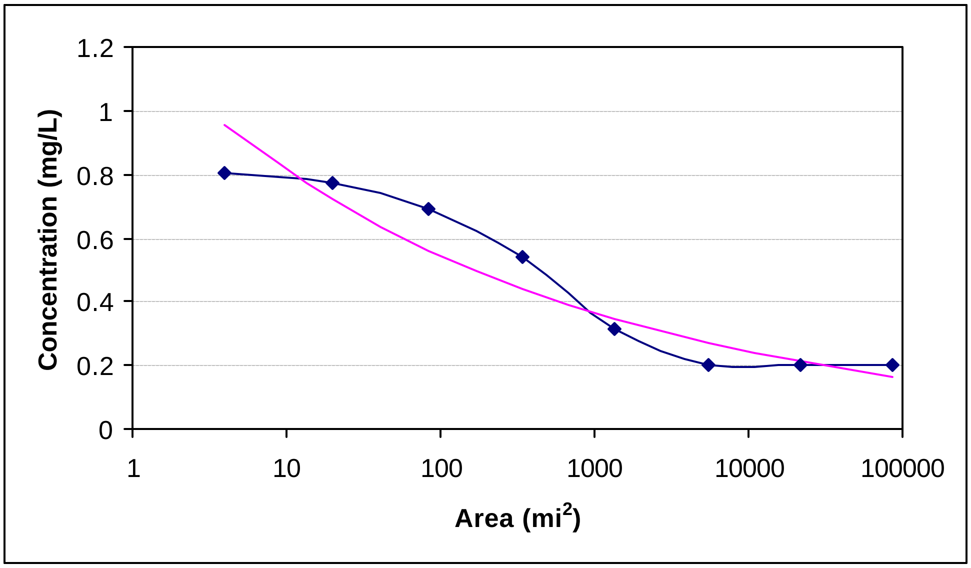


Figure 4-22: Estimated Theoretical Relationship of Flow-Weighted Average Annual Total Phosphorus Concentration to Catchment Area for Ecoregion 6

4.4 BATHTUB MODEL-RECEIVING WATER ENDPOINT ANALYSIS

The objectives of the BATHTUB Model application is to establish allowable nutrient loading into receiving waters as a function of hydraulic residence time and other key variables. Variations in other secondary parameters can then be analyzed as a secondary variable in a sensitivity analysis. The first objective is to establish a three-dimensional allowable loading response surface in which the boundary of predicted acceptable and unacceptable conditions is plotted as a function of residence time, nitrogen load, and phosphorus load. Acceptable and unacceptable conditions will be defined based upon whether the receiving waters exceed certain threshold criteria for chlorophyll-a defined as a function of the end use designation for the receiving water body.

4.4.1 Model Description

The Army Corps of Engineers' BATHTUB model (Walker, 1996) was used to analyze the water quality response in a typical Ecroregion 6 watershed lake to different nutrient loading scenarios. BATHTUB is a steady-state model that calculates nutrient concentrations, chlorophyll-a concentrations (or algal densities), turbidity, and hypolimnetic oxygen depletion based on nutrient loadings, hydrology, lake morphometry, and internal nutrient cycling processes. BATHTUB uses a typical mass balance or nutrient loading model approach that tracks the fate of external and internal nutrient loads between the water column, outflows, and sediments. External loads can be specified from various sources including stream inflows, nonpoint source runoff, atmospheric deposition, groundwater inflows, and point sources. Internal nutrient loads from cycling processes may include sediment release and macrophyte decomposition. Since BATHTUB is a steady-state model, it focuses on long-term average conditions rather than day-to-day or seasonal variations in water quality. Algal concentrations are predicted for the summer growing season when water quality problems are most severe. Annual differences in water quality, or differences resulting from different loading or hydrologic conditions (e.g., wet vs. dry years), can be evaluated by running the model separately for each scenario.

BATHTUB first calculates steady-state phosphorus and nitrogen balances based on nutrient loads, nutrient sedimentation, and transport processes (lake flushing, transport between segments). Several options are provided to allow first-order, second-order, and other loss rate formulations for nutrient sedimentation that have been proposed from various nutrient loading models in the literature. The resulting nutrient levels are then used in a series of empirical relationships to calculate chlorophyll-a, oxygen depletion, and turbidity. Phytoplankton concentrations are estimated from mechanistically based steady-state relationships that include processes such as photosynthesis, settling, respiration, grazing mortality, and flushing. Both nitrogen and phosphorus can be considered as limiting nutrients, at the option of the user. Several options are also provided to account for variations in nutrient availability for phytoplankton growth based on the nutrient speciation in the inflows. The empirical relationships used in BATHTUB were derived from field data from many different lakes, including those in EPA's National Eutrophication Survey and lakes operated by the Army Corps of Engineers. Default values are provided for most of the model parameters based on extensive statistical analyses of these data.

Spatial variability in water quality can be simulated with BATHTUB by dividing the lake horizontally into segments, and calculating transport processes such as advection and dispersion between the segments. This is appropriate for large lakes, particularly lakes with multiple sidearms and tributary inflows, that have substantially different water quality in different portions of the lake. However, this was not necessary for the Ecoregion 6 lakes due to their generally small to moderate sizes, and the lack of detailed data demonstrating significant spatial variations in Ecoregion 6 lake characteristics and water quality. Therefore, BATHTUB was applied as a whole lake model to these lakes.

4.4.2 Prior Ecoregion 6 BATHTUB Model Applications

Four urban lakes (Lindero, Westlake, Sherwood, and Malibou) within the Malibu watershed in Ecoregion 6 were simulated using the BATHTUB model as part of a TMDL investigation for Malibu Creek (Tetra Tech, 2002). The TMDL investigation identified the amounts of nitrogen and phosphorus that can be discharged to the water bodies in the Malibu Creek watershed without causing violations of applicable water quality standards, and allocated allowable nutrient loads among different discharges.

The BATHTUB model was used to develop the linkage between loadings to the four Malibu Creek lakes, and resulting lake nutrient concentrations and lake algal biomass. The Malibu Lake Models were calibrated using BATHTUB default parameters and site specific flow estimates, with total load estimates and tributary inflow concentrations determined during calibration. External loads and tributary concentrations were adjusted until the predicted nutrient concentrations in the lakes matched the observed data. The model predictions represent average algal concentrations during the growing season based on the observed nutrient levels, flushing rates, and lake geometry, as estimated from default parameters derived from many other lakes during the development of BATHTUB.

The BATHTUB model was successfully calibrated to these four Malibu Creek Watershed Lakes using the second order available phosphorus model (Phosphorus model 1) for phosphorus, the second order available nitrogen model (Nitrogen model 1) for nitrogen, and the phosphorus, nitrogen, light, and flushing model (mean chlorophyll-a model 1) for chlorophyll-a. These BATHTUB Model applications used a vertical (Z) mixing layer of 2 to 2.3 meters and had average lake depths in the range of 2 to 4.9 meters. Residence times for these lakes ranged from 0.015 to 0.34 years. The non-algal turbidity parameter in the four lakes varied from 0.6 to 2.1 m-^{1}.

A comparison of the BATHTUB model results with observed data for these four Malibu Creek Watershed Lakes is given for Lake Total Phosphorus, Total Nitrogen, and chlorophyll-a concentrations in Figures 23, 24, and 25, respectively. The predicted algae concentrations are within the same general range as the measured concentrations in all four lakes (about 20-45 ug/l chlorophyll-*a*), while the predicted nutrient concentrations are very close to measured values. Comparison of the lake monitoring data and model results with the available stream monitoring data at various locations in the watershed demonstrates that these lakes behave as nutrient sinks under current loading conditions. Nitrate and phosphate concentrations in the lakes and in the stream reaches immedianately downstream of the lakes are typically lower than in the upstream tributaries feeding the lakes. Algal growth in the lakes removes nutrients from the water and deposits them in the sediments as the algae settle. Organic sediment decomposition releases some of the nutrients back to the water, and could become a significant source if existing loads from the watershed are greatly reduced in the future. Nutrient removal in the lake waters is generally highest during the summer growing season.

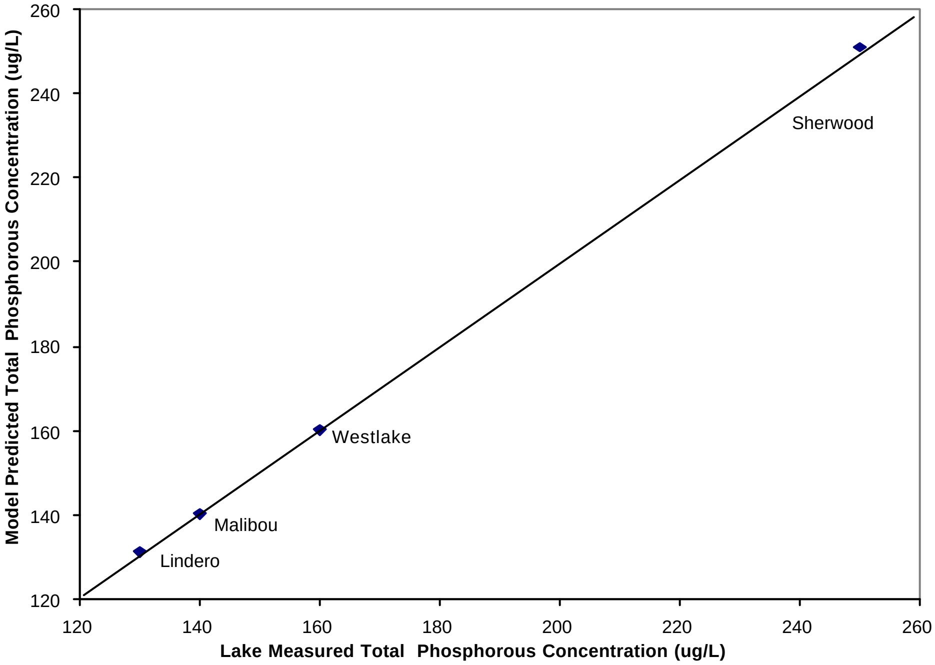


Figure 4-23. Comparison of BATHTUB Model and Measured Total Phosphorus Concentrations, Malibu Creek Lakes TMDL.

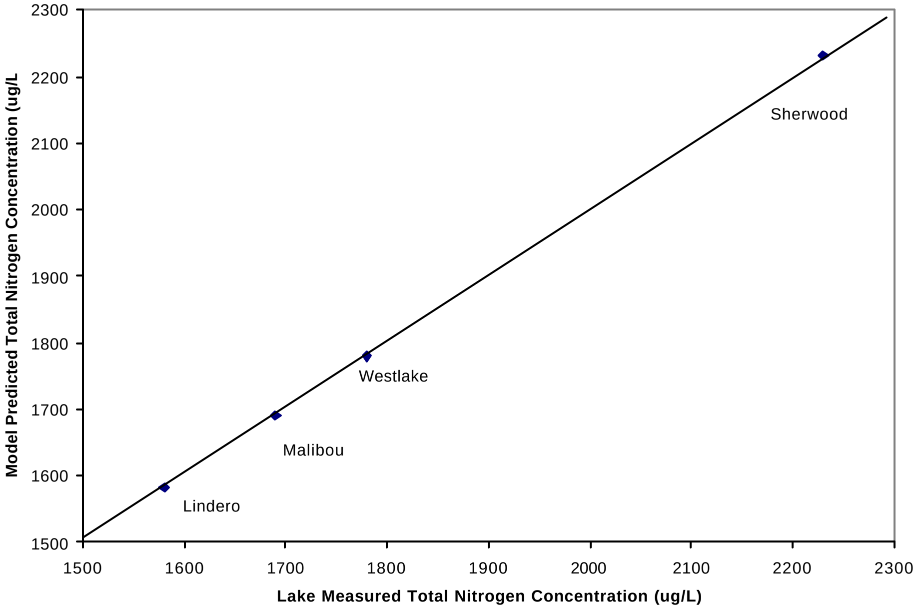


Figure 4-24. Comparison of BATHTUB Model and Measured Total Nitrogen Concentrations, Malibu Creek Lakes TMDL.

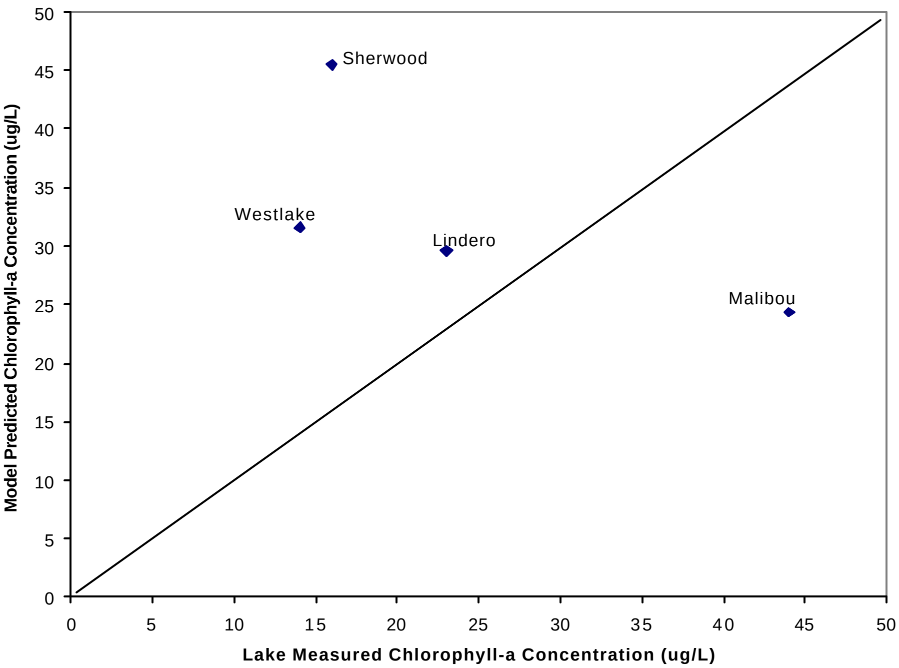


Figure 4-25. Comparison of BATHTUB Model and Measured Chlorophyll-a Concentrations, Malibu Creek Lakes TMDL.

4.4.3 Linkage with SWAT/SPARROW Model Results

In this generic application of the BATHTUB Model to a typical Ecoregion 6 lake or reservoir, it is desirable to normalize both the SWAT/SPARROW and the BATHTUB Model to the watershed area or lake size The SWAT/SPARROW Model generates output loadings in terms of nutrient mass per unit time in the inflow discharged to potential receiving water bodies such as lakes or reservoirs. In contrast, the BATHTUB Model equations use nutrient concentrations in the lake influent as input to calculate lake nutrient and algal concentrations. Thus, the SWAT/SPARROW Model output, which is in units of mass per unit time, requires some modification for use in the BATHTUB Model input, which is in units of mass per unit volume. The SWAT/SPARROW Model output and BATHTUB Model input then requires some adjustment to develop a common normalizing criteria based upon the watershed area or lake size.

Although the BATHTUB Model equations are based upon nutrient concentrations in the lake influent rather than mass flux into the lake, the BATHTUB Model lake influent nutrient concentrations can also be viewed as mass per time normalized by inflow rate since this results in final units of concentration.

Setting the following definitions:

Input loadings in BATHTUB Model (C) are mass per time normalized by inflow rate as follows:
C = Mass Inflow Rate, R (mg/year) /Water Inflow Rate, W (m^3 /year)
C = Mass (mg) /Inflow Water Volume (m^3)

Output loadings from SWAT/SPARROW (R) are mass per time based as follows:
R = Mass (mg) / Time (year)

Residence Time in lakes (T) is defined as follows:

$$T\text{ (Year)} = \text{Lake volume, } V\ (m^3) \,/\, \text{Water Inflow, } W\ (m^3/\text{year})$$

The influent concentration loadings in the BATHTUB Model can be related to SWAT SPARROW mass per time loadings using influent concentration loadings, mass flux loadings, lake volume, and lake residence times. The loadings from SWAT SPARROW (R) are normalized by the lake volume (V), resulting in mass loadings per unit lake volume per unit time (mg / m^3-year). The SWAT SPARROW normalized loadings (R/V) then correlate with the ratio of the BATHTUB Model concentration based loadings divided by the lake residence time as indicated below:

$$C / T = (R/W) / (V/W) = R/V \text{ mg/year-} m^3 \text{ lake volume}$$

Thus, lake algal concentrations are expressed as functions of the nutrient mass flux into the lake divided by the lake volume, which is identically equal to the concentration of nutrients in the lake inflow water divided by the water residence time in the lake. The model results presented in the following section are therefore developed as functions of this normalized variable.

The SWAT/SPARROW Model output for mass flux loadings (R) are given as the following functions of watershed drainage area in Section 3:

$$\text{N load (Kg/Yr)} = 4408.4\ x^{0.6526}$$

$$\text{P load (Kg/Yr)} = 378.88\ x^{0.8247}$$

where “x” refers to the watershed drainage area in square miles. A plot of lake volume versus watershed drainage area in square miles from the Ecoregion 6 database (Figure 26) illustrates that lake volume can be related to drainage area as follows:

$$\text{Lake Volume, v (Acre-feet)} = 619.43\ x^{0.6751}$$

Thus, dividing the N and P loading equations by this lake volume correlation results in the following N and P loadings normalized by lake volume:

$$\text{N/v (Kg/Acre-feet-Year)} = 7.117\ x^{-0.0225}$$
$$\text{P/v (Kg/Acre-feet-Year)} = 0.6117\ x^{0.1496}$$

Note: gm/cu meter -Year = 0.8107 Kg/Acre-feet-Year

The above relations (given in Figure 27) for N and P loadings normalized to lake volume show very little variation with watershed drainage area, which was expected based upon the normalization process. The normalized nitrogen loads range from 4.45 to 5.56 gm/cu meter-year and average 5.01 gm/cu meter-year over watershed drainage areas from 10 to 100,000 square miles. The normalized phosphorus loads range from 0.63 to 2.78 gm/cu meter-year and average 1.44 gm/cu meter-yea over watershed drainage areas from 10 to 100,000 square miles.

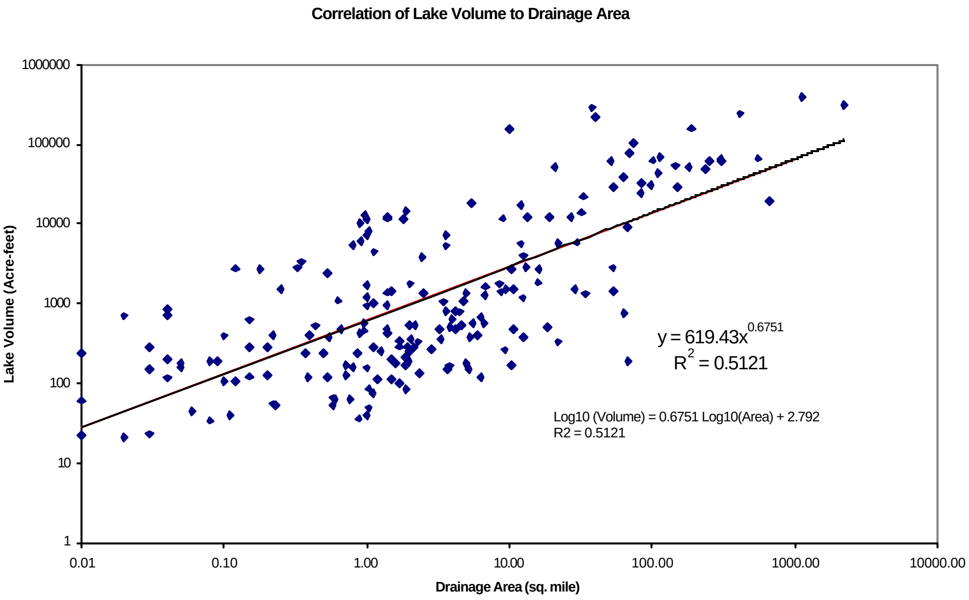


Figure 4-26. Correlation between lake or reservoir volume and watershed drainage area for Ecoregion 6.

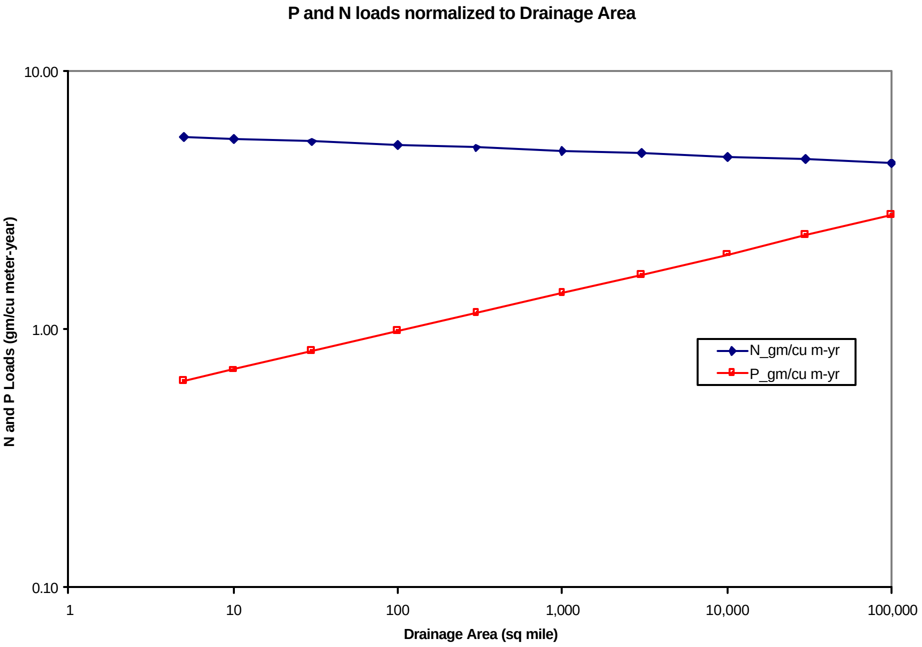


Figure 4-27. Correlation between normalized Total Nitrogen and Total Phosphorous loads and watershed drainage area for Ecoregion 6.

4.4.4 Model Parameter Selection for the Ecoregion 6 Evaluation

Chlorophyll-*a* targets for Ecoregion 6 were defined by reviewing the database for lakes in Ecoregion 6 and the results of the recent TMDL for the four lakes in the Malibu Creek Watershed. Figure 28 shows a plot of the Cumulative Distribution Frequency (CDF) for Chlorophyll-a data in Ecoregion 6. The 80th percentile of the data is approximately 10 ug/L. The Malibu Lakes TMDL set 10 ug/L as the target concentrations for the four lakes based upon a 30 percent algae cover. For this analysis, 10 ug/L, 25 ug/L, and 40 ug/L were chosen as chlorophyll-a targets, which relate to different potential designated end uses for the lake.

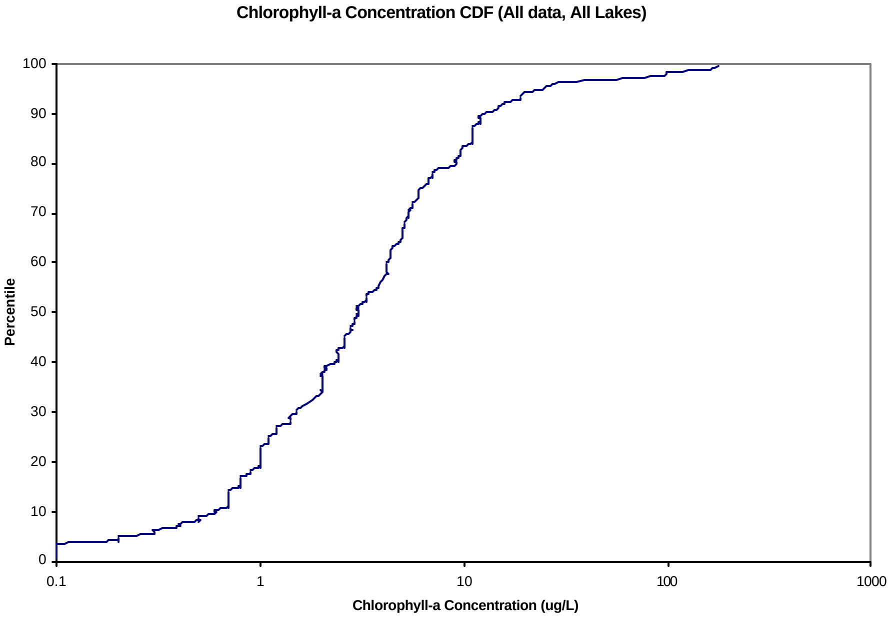


Figure 4-28. Lake Chlorophyll-a Concentration in Ecoregion 6 Lakes database.

The applications of the BATHTUB model to the four lakes in the Malibu Creek Watershed were used along with Ecoregion 6 specific data to define BATHTUB Model parameters. The Ecoregion 6 database was used to create a database of the lakes in the target area Ecoregion 6 with information on residence time, phosphorus concentration, nitrogen concentration, chlorophyll-*a* concentration, and Secchi depth as given in Figures 29 through 34. Summary data is given in Table 1.1.4-1. Hydraulic data were only available for lakes with a dam. Residence times for these reservoirs were defined using the reservoir storage capacity divided by the catchment flowrate (Figure 35), where the catchment flowrate (Q, m^3/s) is estimated based upon the drainage area (A, square miles) using the relation given in SWAT SPARROW analyses (Q=0.0145A). The medianan residence time was 0.51 years. The mean reservoir depth was defined by the average reservoir storage divided by the surface area (Figure 36). The medianan depth of all reservoirs was 5.7 meters.

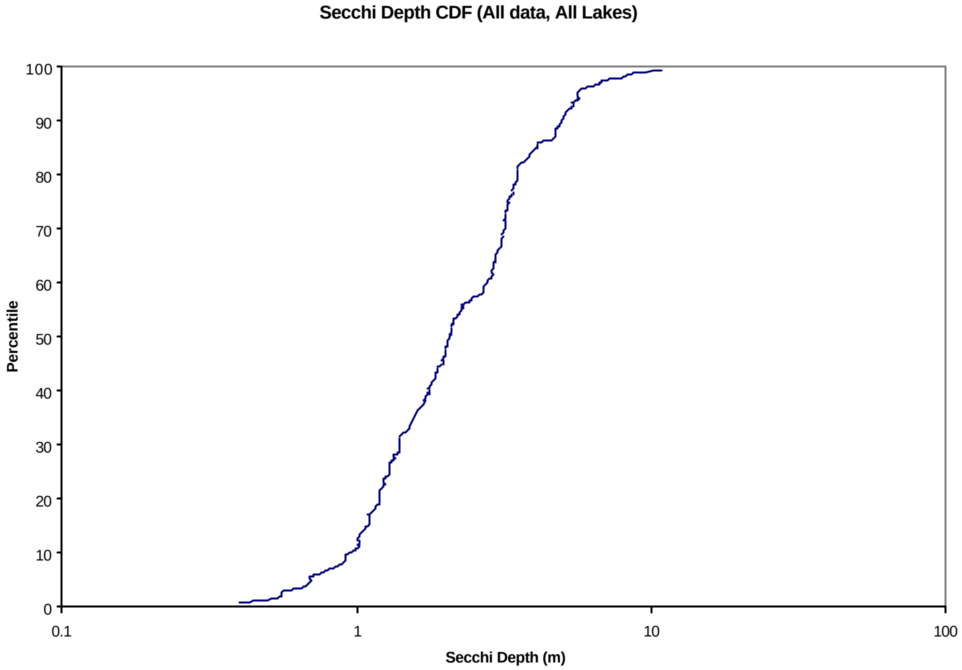


Figure 4-29. Secchi Depth measurements for lakes in Ecoregion 6.

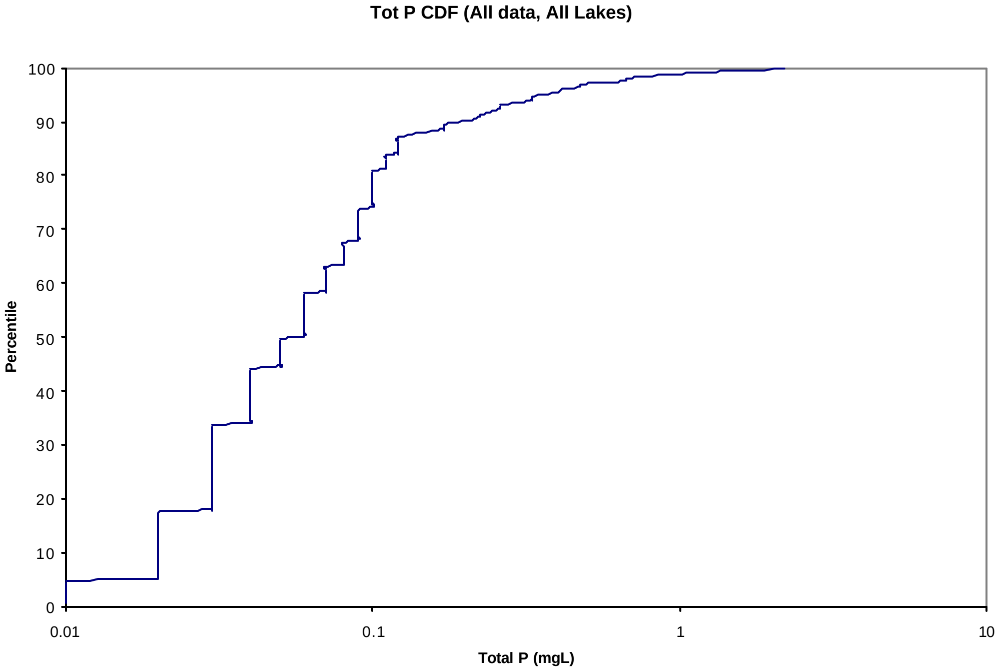


Figure 4-30. Total Phosphorus concentration measurements for lakes in Ecoregion 6.

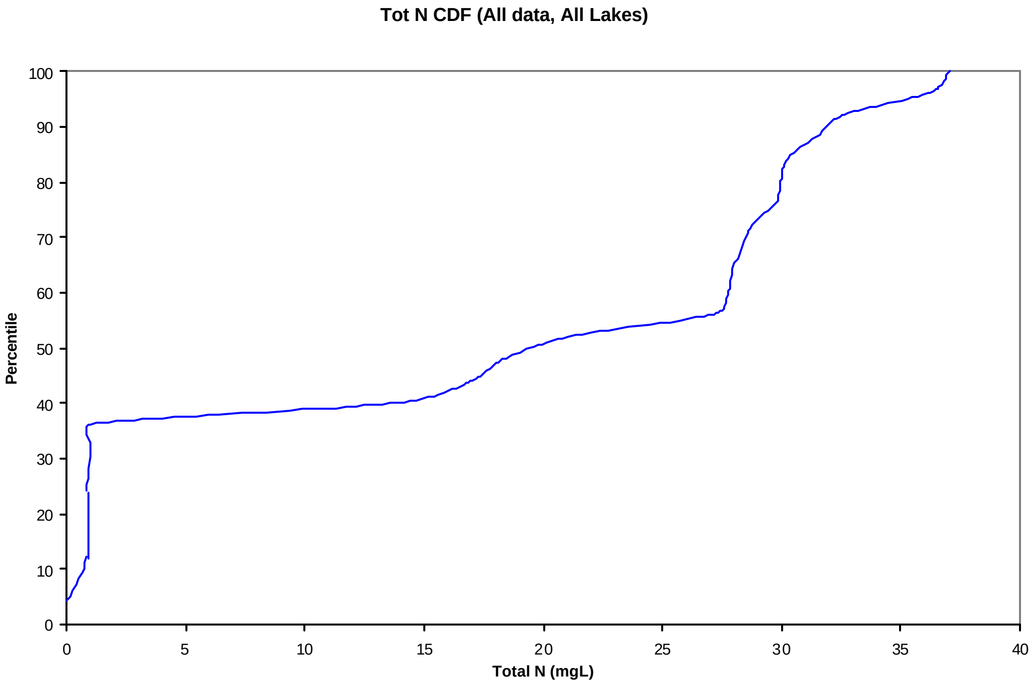


Figure 4-31. Total Nitrogen concentration measurements for lakes in Ecoregion 6.

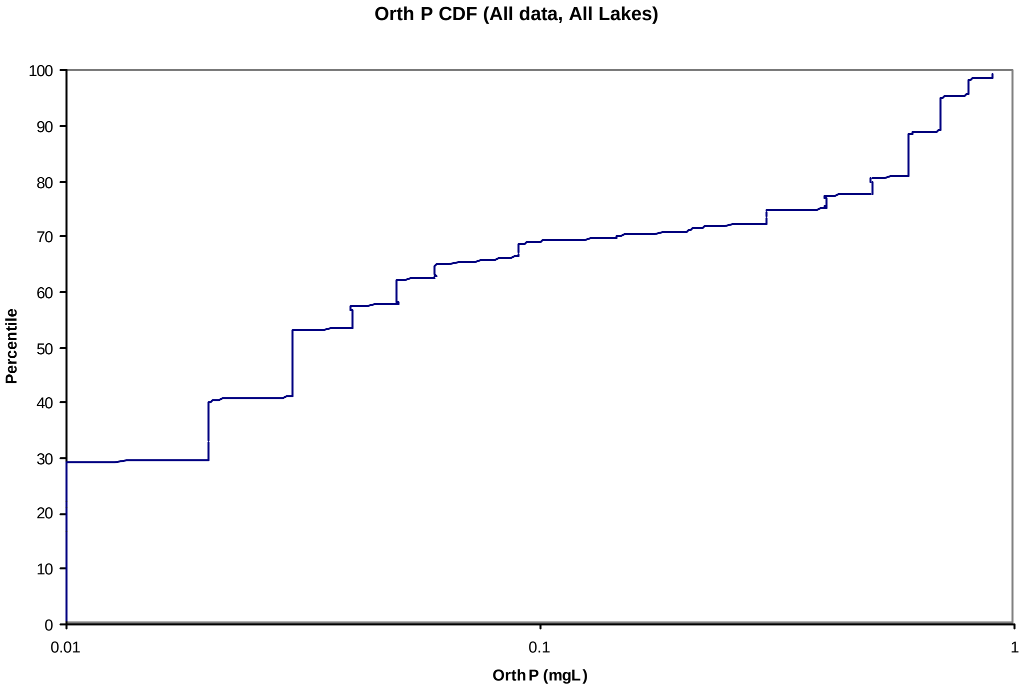


Figure 4-32. Orthophosphate (P) concentration measurements for lakes in Ecoregion 6.

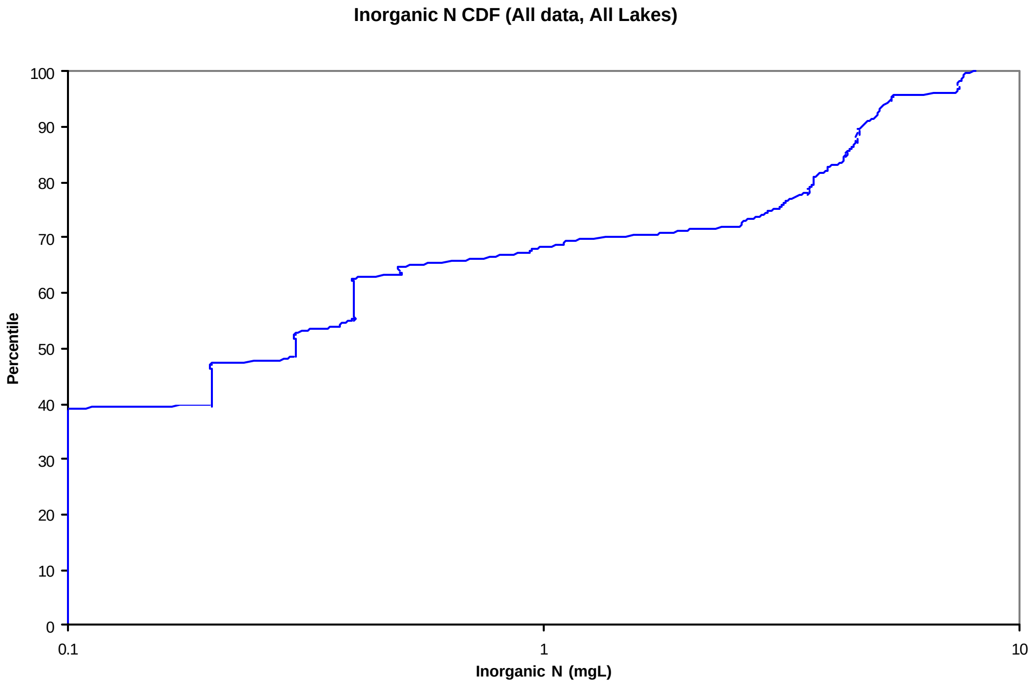


Figure 4-33. Inorganic Nitrogen concentration measurements for lakes in Ecoregion 6.

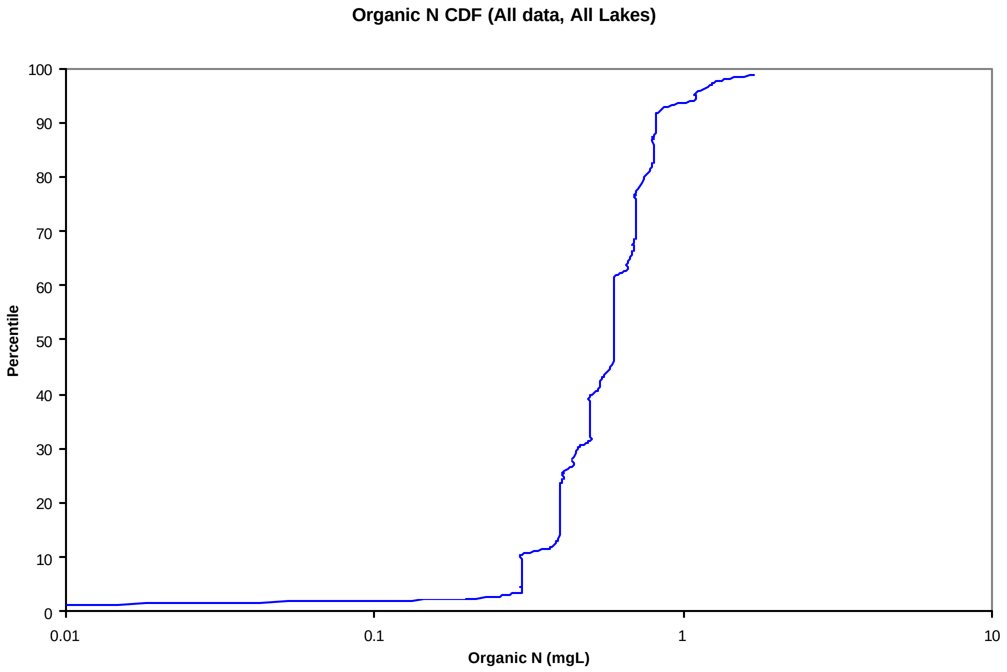


Figure 4-34. Organic Nitrogen concentration measurements for lakes in Ecoregion 6.

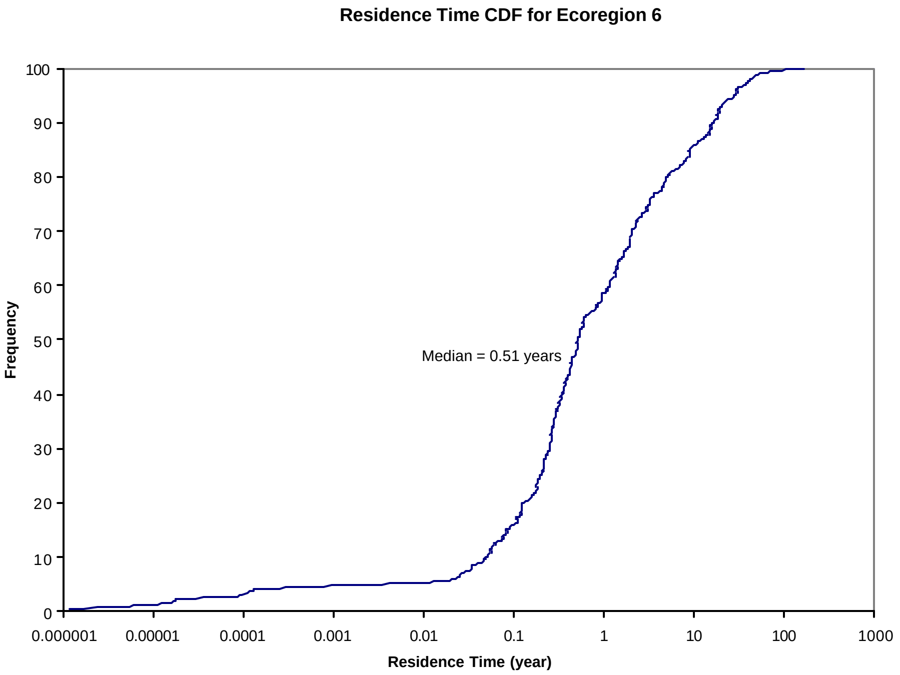


Figure 4-35. Residence time (years) for lakes (with a dam) in Ecoregion 6.

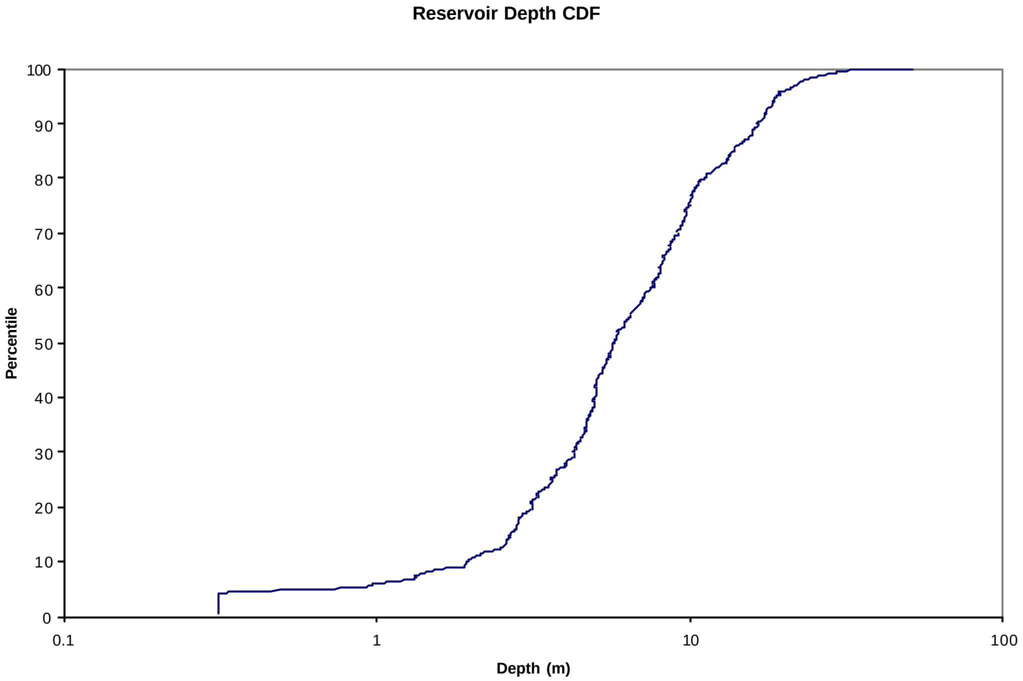


Figure 4-36. Reservoir depth (meters) for dammed lakes in Ecoregion 6.

The non-algal turbidity was calculated from Secchi depth and chlorophyll using two methods. One method was the inverse of the Secchi depth minus 2.5 percent of the chlorophyll-a concentration as given in the Bathtub Model, and the other was a more complicated relation as given in Equation 7.30 of Thomann and Mueller (1987), with the results given in Figure 37. The correlation from Thomann and Mueller was used in the model applications, which had non-algal turbidity values ranging from 0.4 to 4 1/m, with a mediannan value of 1.25 1/m. A correlation between chlorophyll-*a* and Total Phosphorus concentration is given in Figure 38.

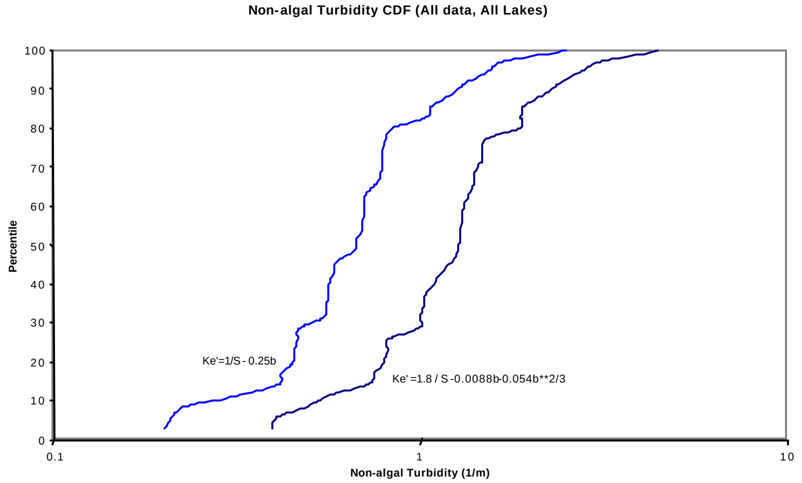


Figure 4-37. Non-algal turbidity calculated from Secchi Depth and Chlorophyll-a measurements for lakes in Ecoregion 6.

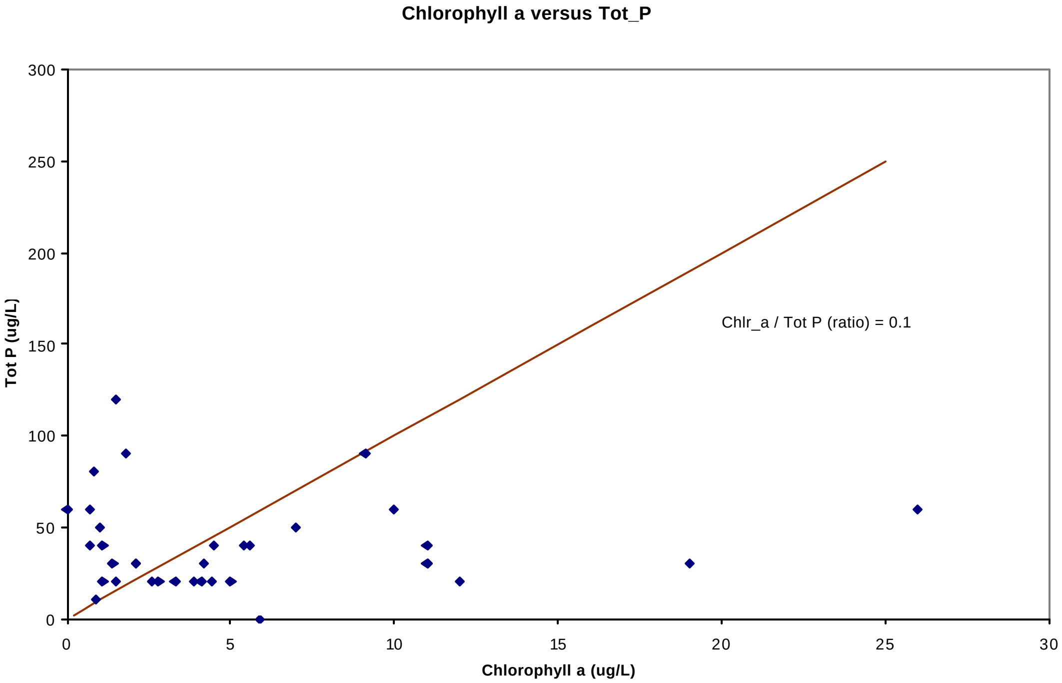


Figure 4 -38. Correlation of Chlorophyll-a with Total Phosphorus for lakes in Ecoregion 6.

The normalized P and N loads given by the SWAT SPARROW Models for Ecoregion 6 for were used to define the anticipated ranges of nitrogen and phosphorus loadings into Ecoregion 6 lakes. The normalized nitrogen loads averaged 5.01 gm/cu meter-year while the normalized phosphorus loads averaged 1.44 gm/cu meter-yea over watershed drainage areas from 10 to 100,000 square miles (Figure 27). But for the BATHTUB analysis, some estimate of the variance or variability in P and N loads is also needed. The variability about these average values was determined from the 1.4 coefficient of variation reported in the SWAT and SPARROW Model calculated P and N loads for all of Ecoregion 6. Using a 1.4 coefficient of variation results in a standard deviation for nitrogen of 7 gm/cu meter-year about a mean value of 5.01 gm/cu meter-year, and a standard deviation for phosphorus of 2 gm/cu meter-year about a mean value of 1.44 gm/cu meter-year. The upper end of the nutrient range was defined as the 95th percentile, which is roughly equal to the mean plus twice the standard deviation. For nitrogen, the 95th percentile is 19 gm/cu meter-year and for phosphorus the 95th percentile is 5.44 gm/cu meter-year. Similarly, the lower end of the range (5th percentile) is 1.3 gm/cu meter-year for nitrogen and 0.38 gm/cu meter-year for phosphorus. Based upon these results, the BATHTUB Model used nitrogen values ranging from 1 to 20 gm/cu meter-year and phosphorus values ranging from 0.1 to 5 gm/cu meter-year.

4.4.5 Model Results

Predicted Chlorophyll-A Concentrations

The BATHTUB model as developed in the Malibu Creek TMDL was applied to a generic set of lakes. The ranges of parameter values were defined from the Ecoregion 6 data in Figures 28 through 38, and the SWAT SPARROW Model results for nitrogen loading (1 to 20 gm/cu meter-year) and phosphorus loading (0.1 to 5 gm/cu meter-year). Residence times varied from 0.05 to 16.9 years, which spans from the 10th to 90th percentile of the data in Figure 35. Lake depth was held constant for this analysis at the medianan value for Ecoregion 6 (5.7 meters in Figure 36). Non-algal turbidity was varied from the 5th to 95th percentile (0.4 to 4 1/m), which spans the values defined using the Thomann and Mueller correlation in Figure 37.

Chlorophyll-a concentrations were predicted for these all these cases. The results are given in Figures 39 through 41 for residence times of 0.25 (30th percentile), 0.51(50th percentile), and 2.03 (70th percentile) years and a non-algal turbidity of 1.4 1/m. Figure 42 overlays the results for all three residence times (0.25, 0.51, and 2.03 years) on a single plot. The model results typically display phosphorus limited algal growth when nitrogen loadings exceed 5,000 ug/L-year and phosphorus loadings are less than 200 ug/L-year. Conversely, the model results display nitrogen limited algal growth when phosphorus loadings exceed 500 ug/L-year and nitrogen loadings are less than 2,000 ug/L-year. Maximum predicted chlorophyll-a concentrations are 50 to 60 ug/L at the upper end of the nutrient loadings and residence times. The minimum predicted chlorophyll-a concentrations are 2 ug/L for a residence time of 0.25 years, approximately 6 ug/L for a residence time of 0.51 years, and approximately 15 ug/L for a residence time of 2.03 years. The model predicted chlorophyll-a concentrations appear quite sensitive to residence time for the three residence time values shown, with higher concentrations at larger residence times. The model predicted chlorophyll-a concentrations are also sensitive to nutrient concentrations along the diagonal of the plots, with higher concentrations at larger nutrient concentrations. Off the diagonal, however, the model predicted chlorophyll-a concentrations are only sensitive to the limiting nutrient concentrations.

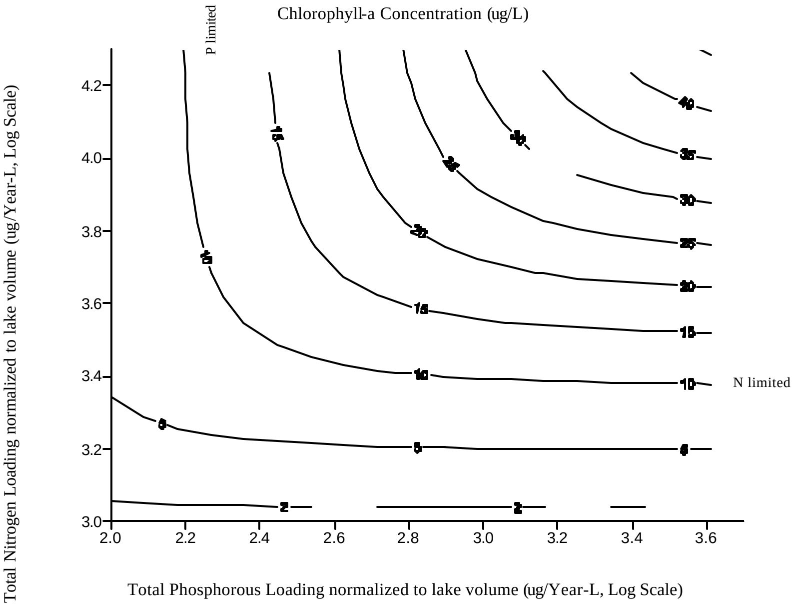


Figure 4-39. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lake volume normalized) for a Residence Time of 0.25 Years and Non-algal turbidity of 1.25 1/m.

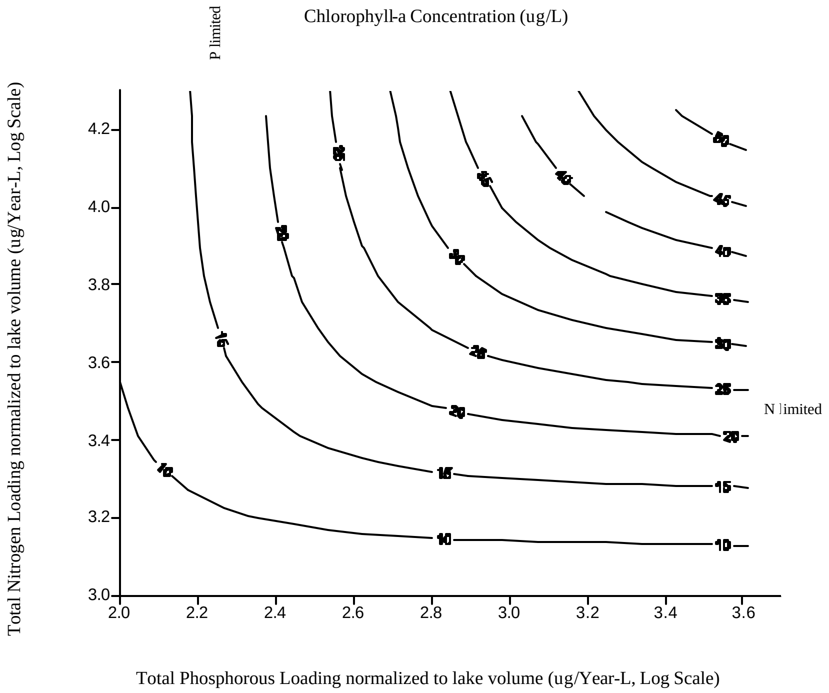


Figure 4-40. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (la normalized) for a Residence Time of 0.51 Years and Non-algal turbidity of 1.25 1/m

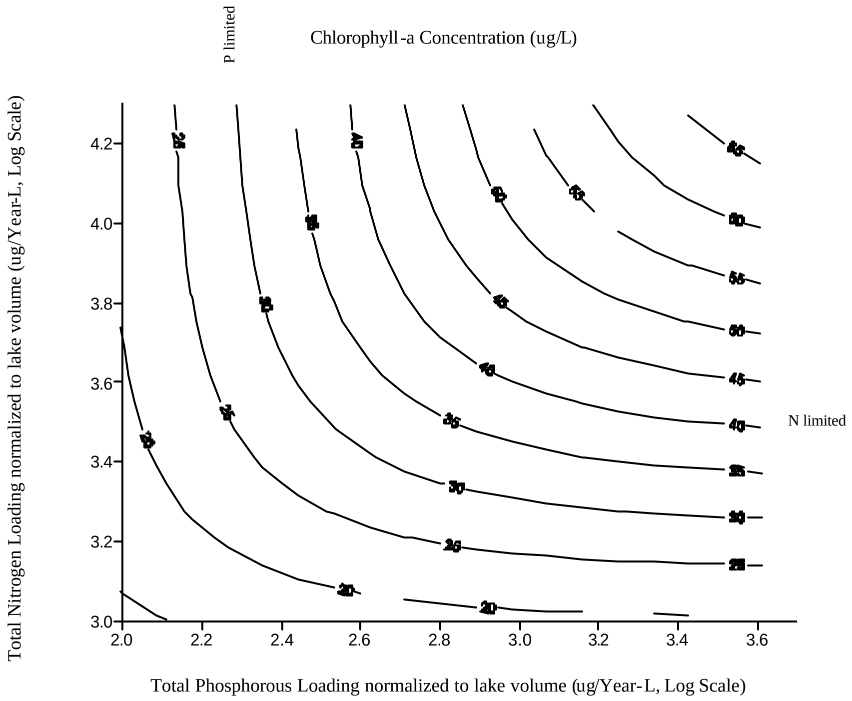


Figure 4-41. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lak normalized) for a Residence Time of 2.03 Years and Non-algal turbidity of 1.25 1/m

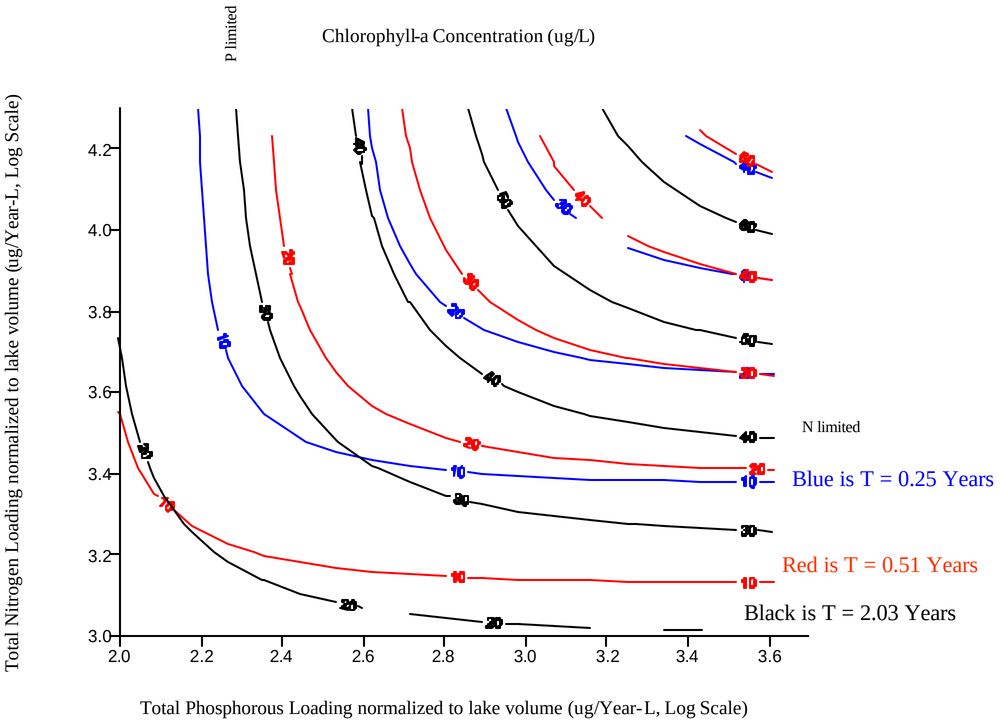


Figure 4-42. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lal normalized) for Residence Times of 0.25, 0.51, and 2.03 Years and Non-algal turbidity of 1.25 1/

Similarly, predicted chlorophyll-a concentrations are given in Figures 43 through 46 for residence times of 0.25, 0.51, and 2.03 years and a non-algal turbidity of 4.0 1/m, and in Figures 47 through 50 for residence times of 0.25, 0.51, and 2.03 years and a non-algal turbidity of 0.4 1/m Figures 46 and 50 overlays the results for all three residence times on a single plot for non-algal turbidity values of 4.0 and 0.4 1/m, respectively. The model results also display phosphorus and nitrogen limited algal growth in the lower-right and upper-left quadrants. Maximum predicted chlorophyll-a concentrations are only 35 ug/L for a non-algal turbidity value of 4.0 1/m and 70 ug/L for a non-algal turbidity value of 0.4 1/m, which contrasts with maximum predicted chlorophyll-a concentrations of 60 ug/L for a non-algal turbidity value of 1.4 1/m. The maximum predicted chlorophyll-a concentrations are sensitive to non-algal turbidity values, and appear more sensitive to highest non-algal turbidity values (the 90th percentile) than to the lowest non-algal turbidity values (the 10th percentile). The minimum predicted chlorophyll-a concentrations for a non-algal turbidity value of 4.0 1/m are less than 1 ug/L for a residence time of 0.25 years, approximately 2 ug/L for a residence time of 0.51 years, and approximately 9 ug/L for a residence time of 2.03 years. The minimum predicted chlorophyll-a concentrations for a non-algal turbidity value of 0.4 1/m are less than 2 ug/L for a residence time of 0.25 years, approximately 4 ug/L for a residence time of 0.51 years, and approximately 14 ug/L for a residence time of 2.03 years. The model predicted chlorophyll-a concentrations appear quite sensitive to residence time over the range of residence time values shown, with higher concentrations at larger residence times.

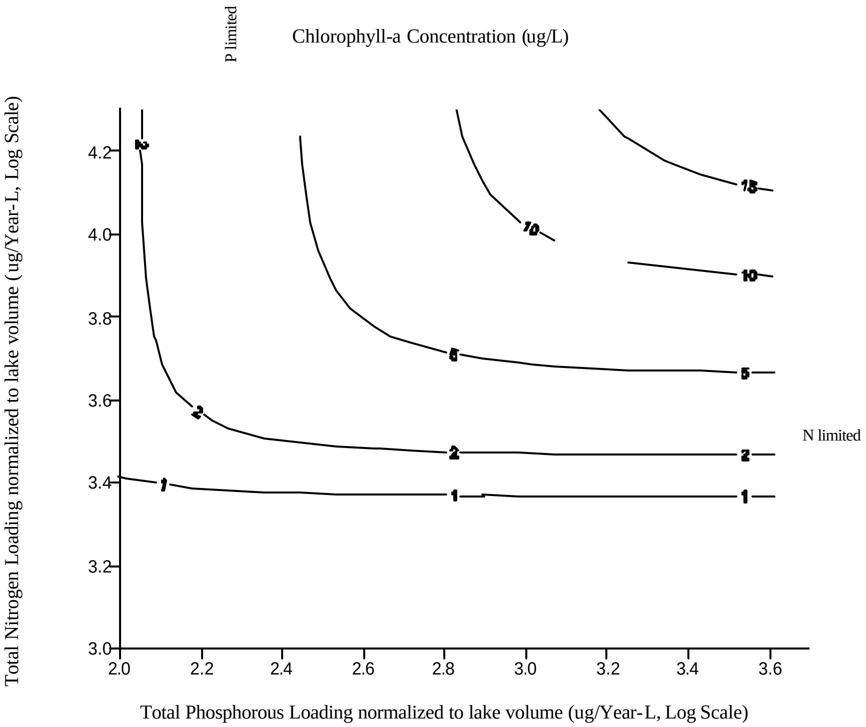


Figure 4-43. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (l volume normalized) for a Residence Time of 0.25 Years and Non-algal turbidity of 4.0 1/m

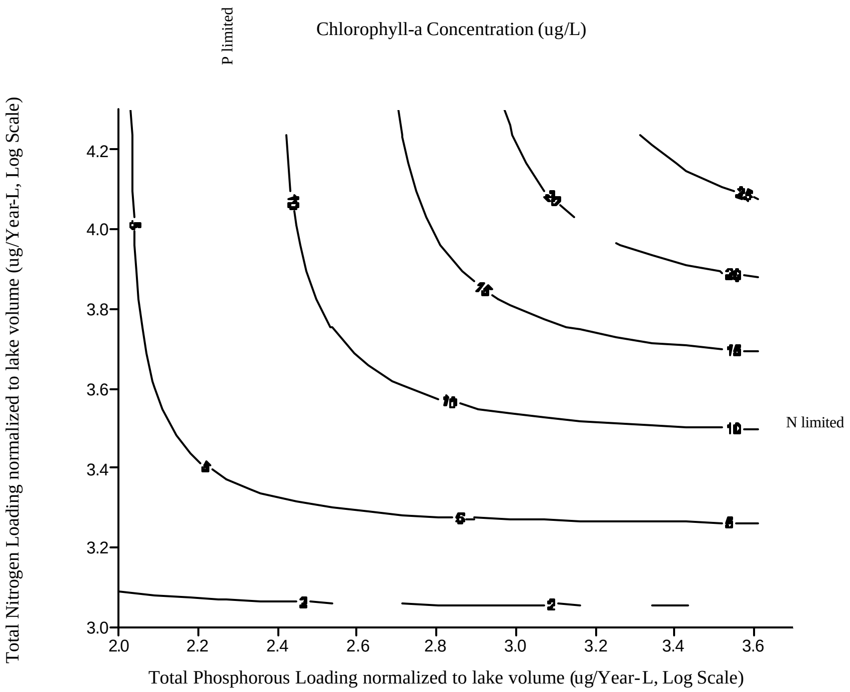


Figure 4-44. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lake volume normalized) for a Residence Time of 0.51 Years and Non-algal turbidity of 4.0 1/m

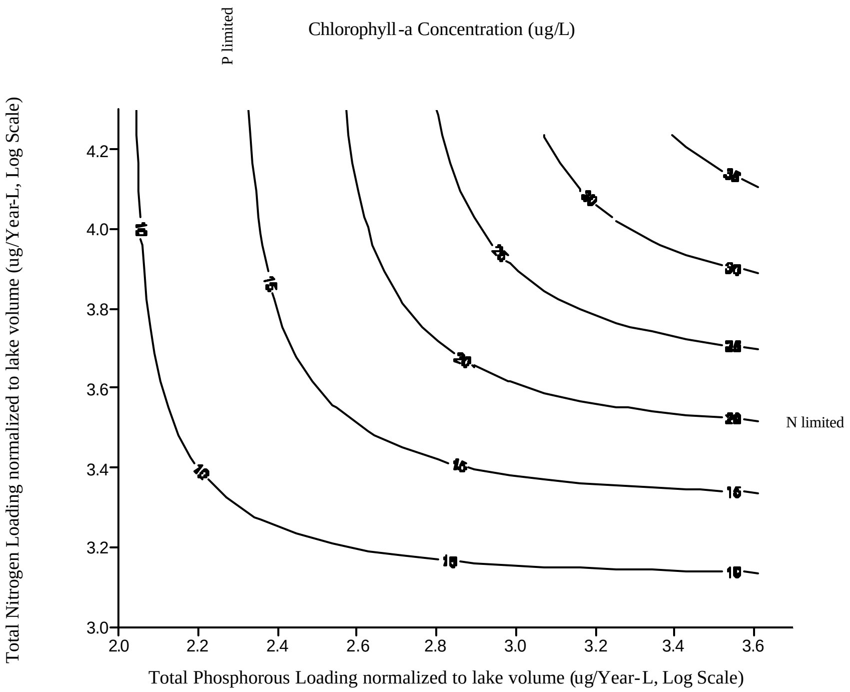


Figure 4-45. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lake volume normalized) for a Residence Time of 2.03 Years and Non-algal turbidity of 4.0 1/m

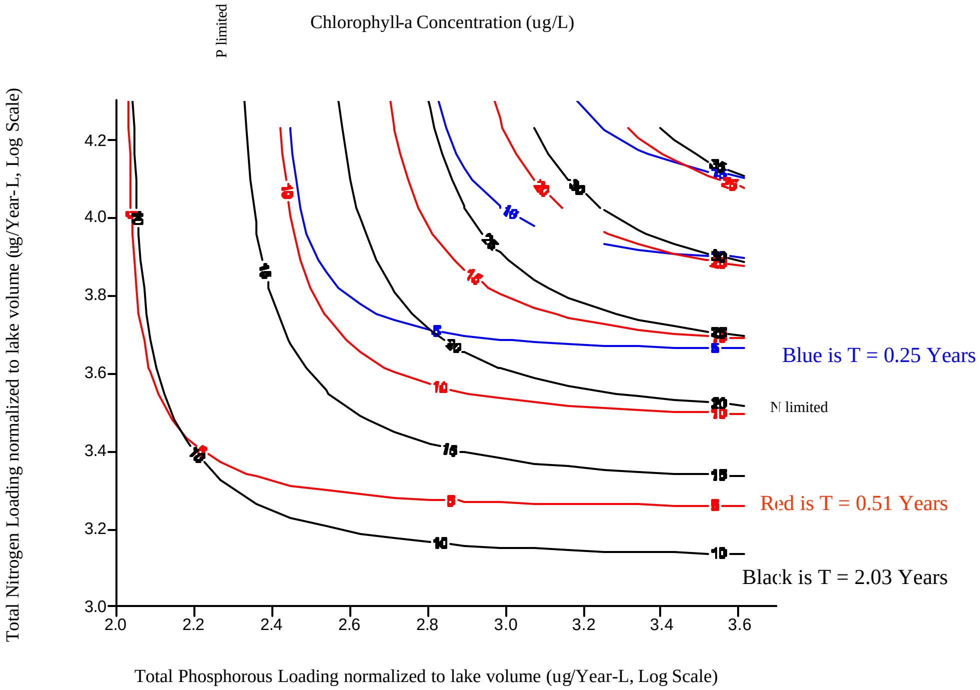


Figure 4-46. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times of 0.25, 0.51, and 2.03 Years and Non-algal turbidity of 4.0 1/m

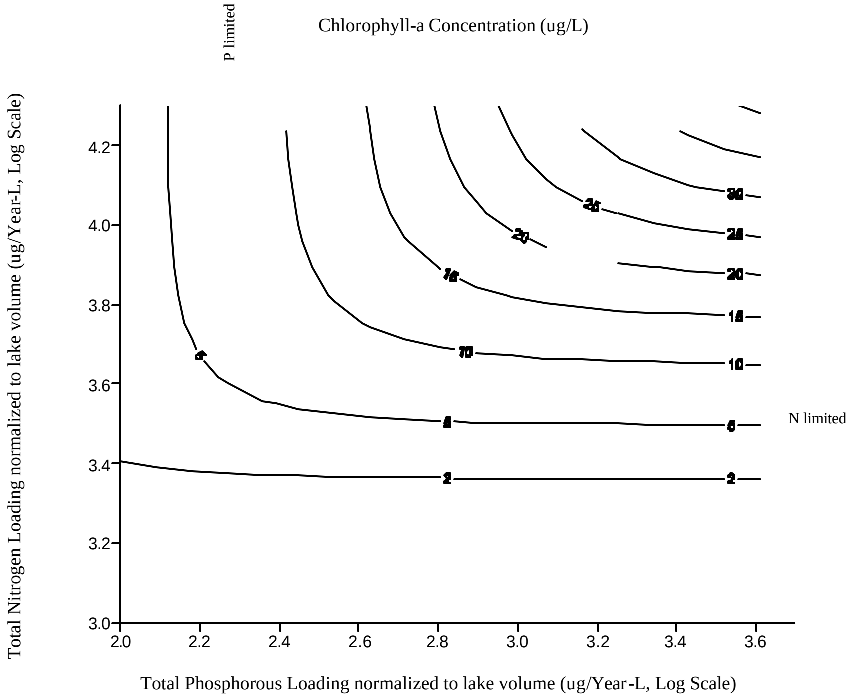


Figure 4-47. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lake volume normalized) for a Residence Time of 0.25 Years and Non-algal turbidity of 0.4 1/m

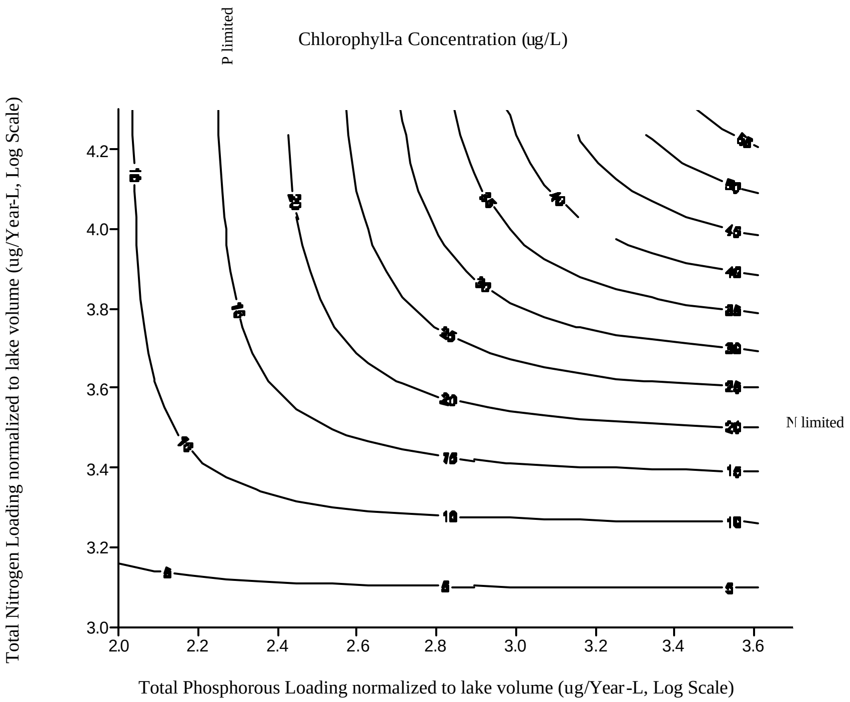


Figure 4-48. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lake volume normalized) for a Residence Time of 0.51 Years and Non-algal turbidity of 0.4 1/m

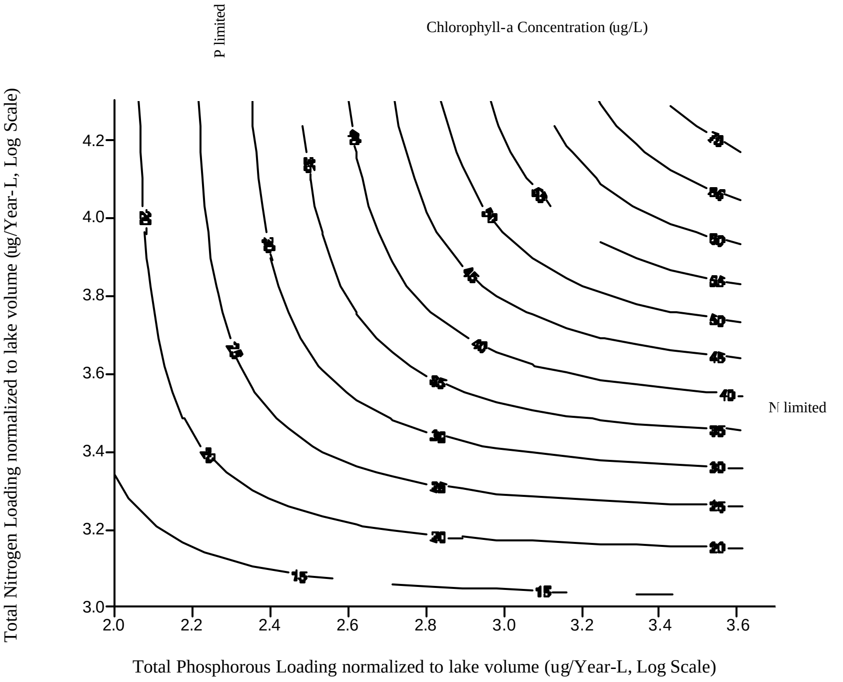


Figure 4-49. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lake volume normalized) for a Residence Time of 2.03 Years and Non-algal turbidity of 0.4 1/m

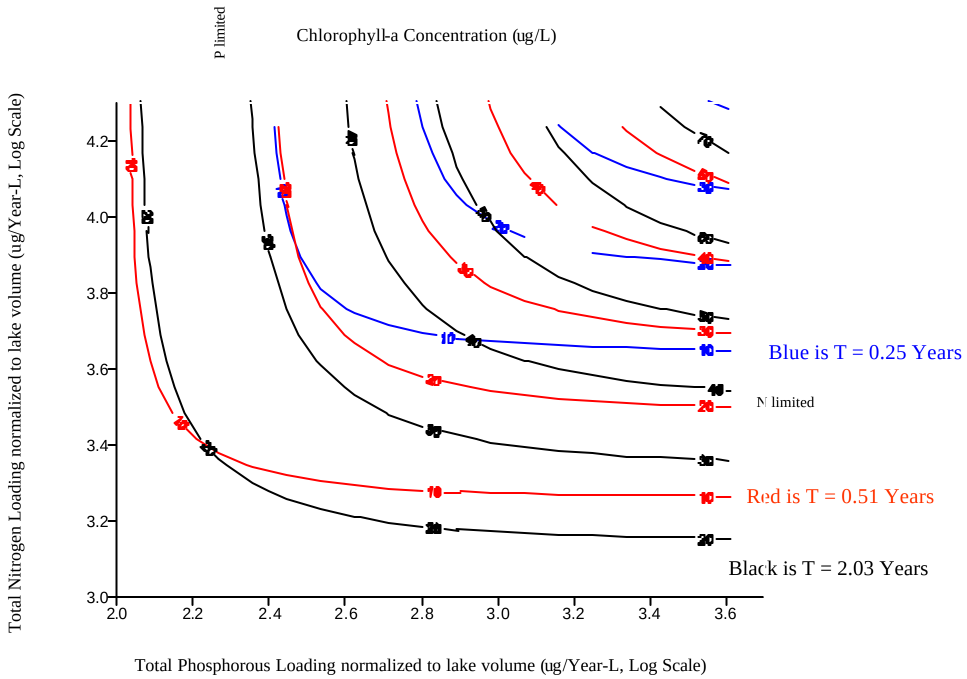


Figure 4-50. Lake Chlorophyll-a Concentration versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times of 0.25, 0.51, and 2.03 Years and Non-algal turbidity of 0.4 1/m

Chlorophyll-A Target Criteria Response Surfaces

The model results in Figures 39 through 50 were used to produce generic response surfaces for the chlorophyll-a target criteria relative to various values of non-algal turbidity. These results are given for a turbidity value of 1.4 1/m in Figures 51, 52, and 53, where chlorophyll-a targets of 10 ug/L, 25 ug/L and 40 ug/L, respectively, are plotted as a function of normalized nitrogen loading, normalized phosphorus loading, and residence time. Similarly, results are given for a turbidity value of 4.0 1/m in Figures 54, 55, and 56, and for a turbidity value of 0.4 1/m in Figures 57, 58, and 59.

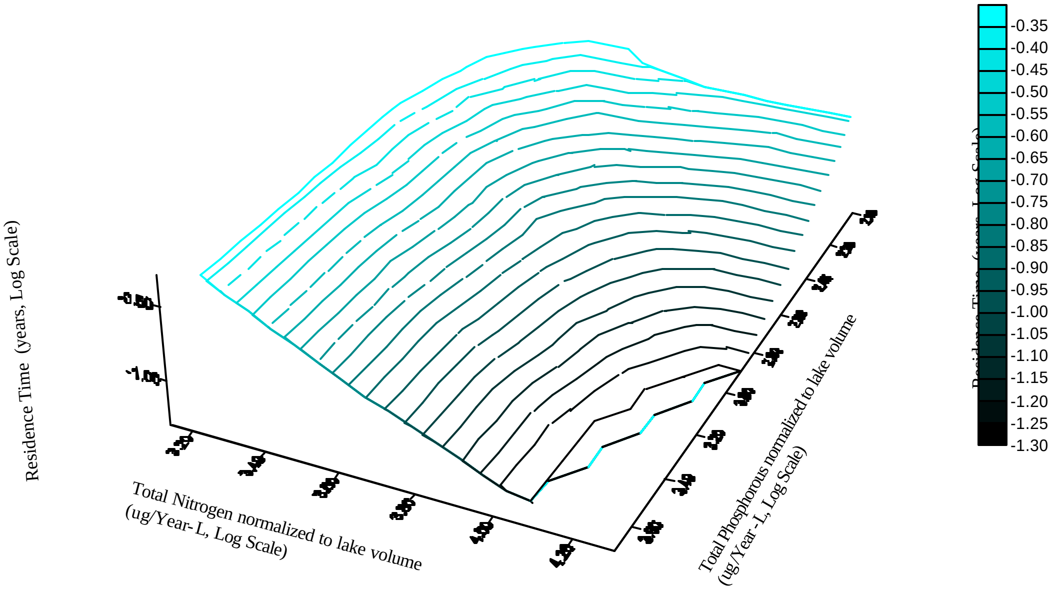


Figure 4-51. Chlorophyll-a Target Concentrations (10 ug/l) versus Phosphorous and Nitrogen Lo (lake volume normalized) for Residence Times from 0.05 to 17 Years and non-algal turbidity of 1.

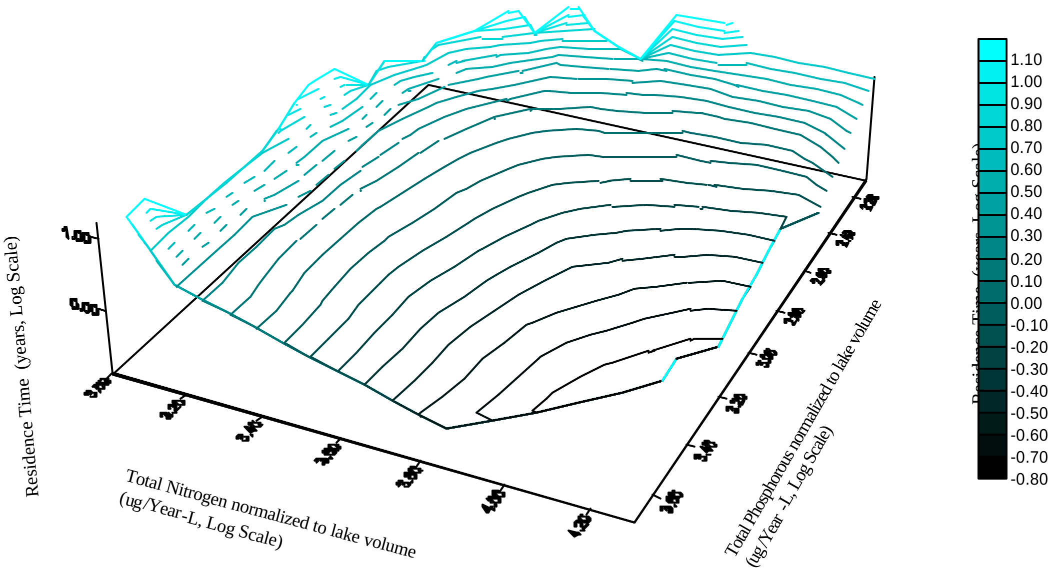


Figure 4-52. Chlorophyll-a Target Concentrations (25 ug/l) versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times from 0.05 to 17 Years and non-algal turbidity of 1.25 1/m

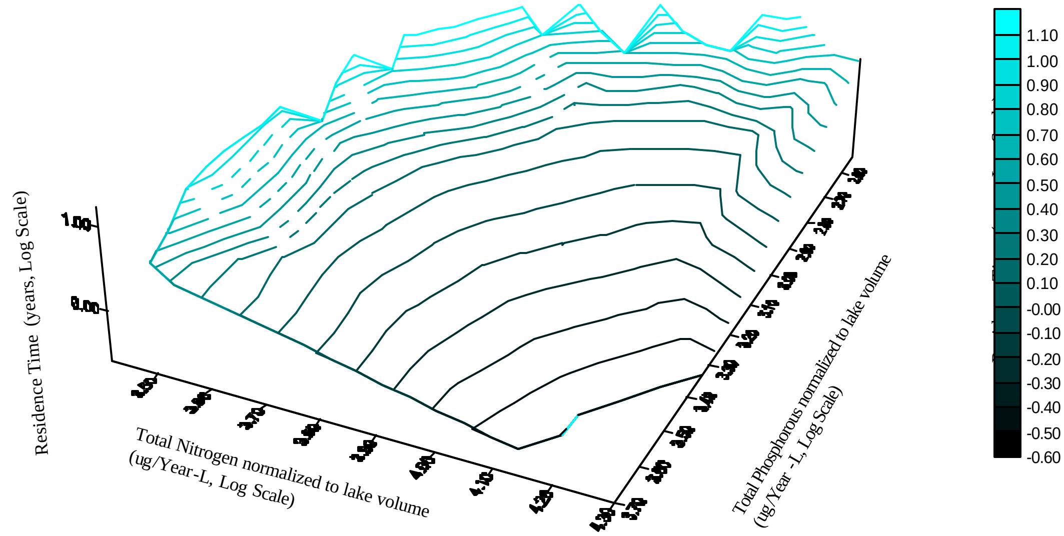


Figure 4-53. Chlorophyll-a Target Concentrations (40 ug/l) versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times from 0.05 to 17 Years and non-algal turbidity of 1.25 1/m

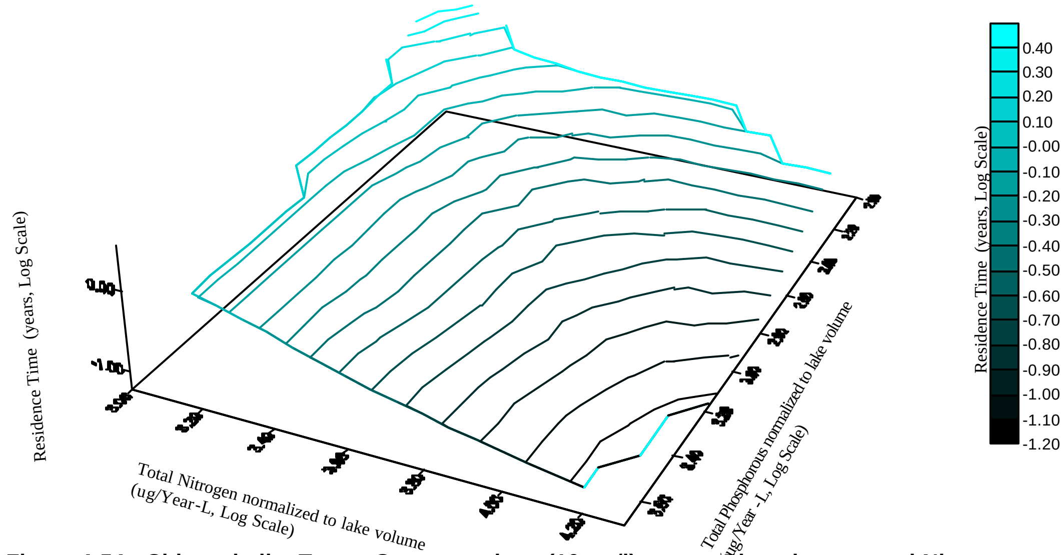


Figure 4-54. Chlorophyll-a Target Concentrations (10 ug/l) versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times from 0.05 to 17 Years and non-algal turbidity of 4.0 1/m

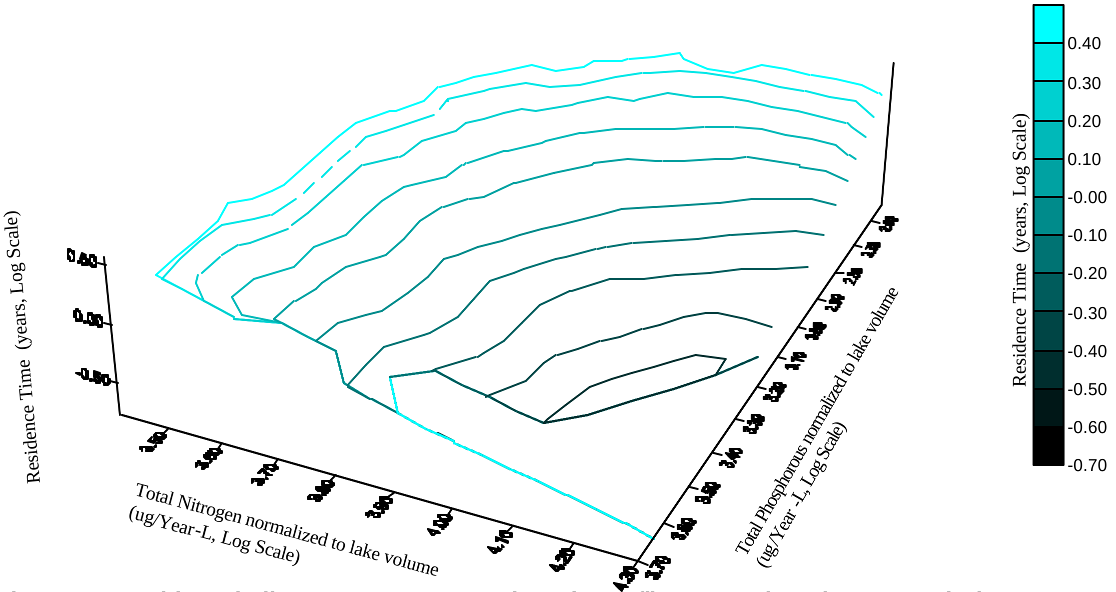


Figure 4-55. Chlorophyll-a Target Concentrations (25 ug/l) versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times from 0.05 to 17 Years and non-algal turbidity of 4.0 1/m

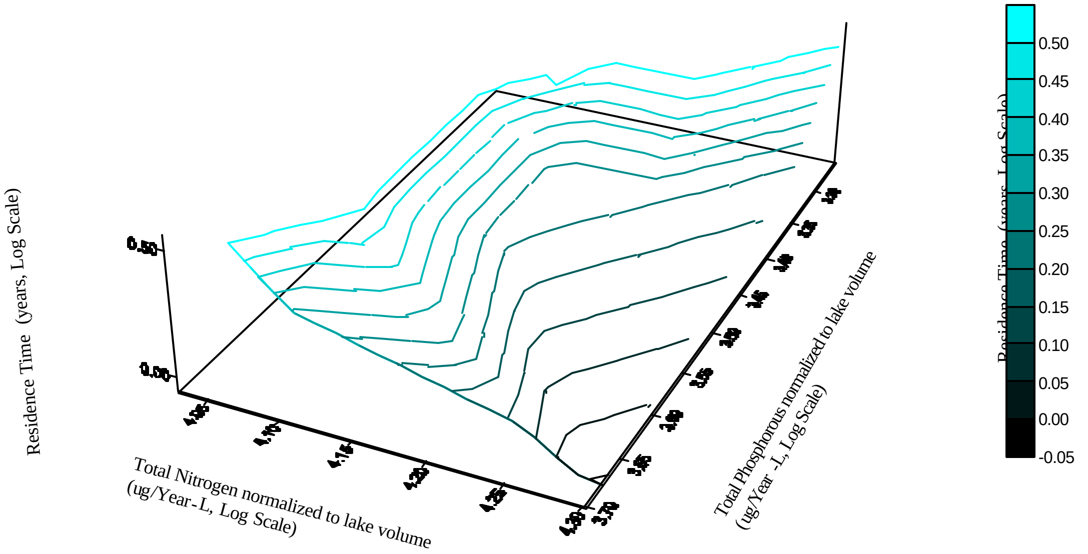


Figure 4-56. Chlorophyll-a Target Concentrations (40 ug/l) versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times from 0.05 to 17 Years and non-algal turbidity of 4.0 1/m

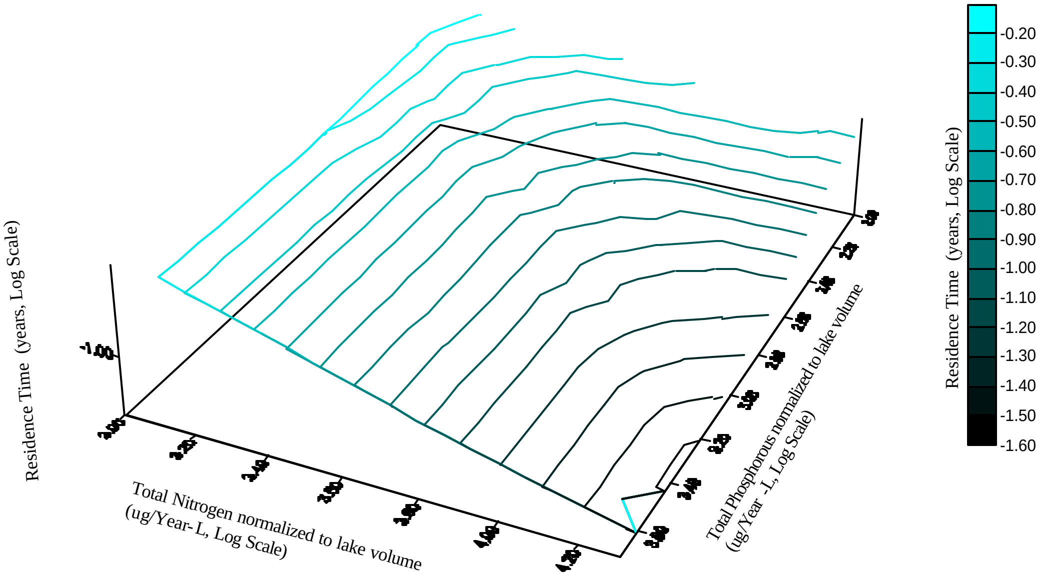


Figure 4-57. Chlorophyll-a Target Concentrations (10 ug/l) versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times from 0.05 to 17 Years and non-algal turbidity of 0.4 1/m

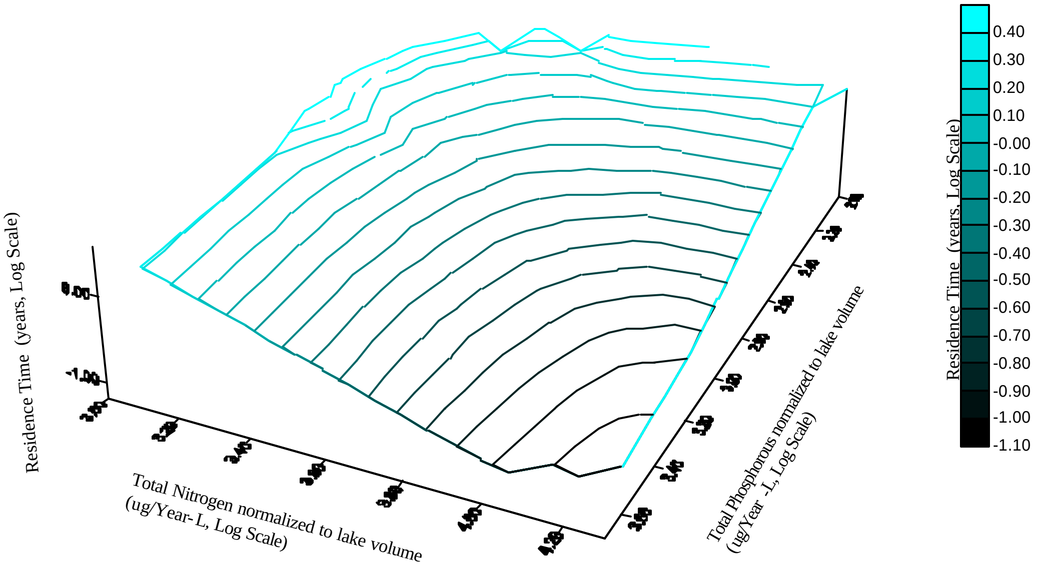


Figure 4-58. Chlorophyll-a Target Concentrations (25 ug/l) versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times from 0.05 to 17 Years and non-algal turbidity of 0.4 1/m

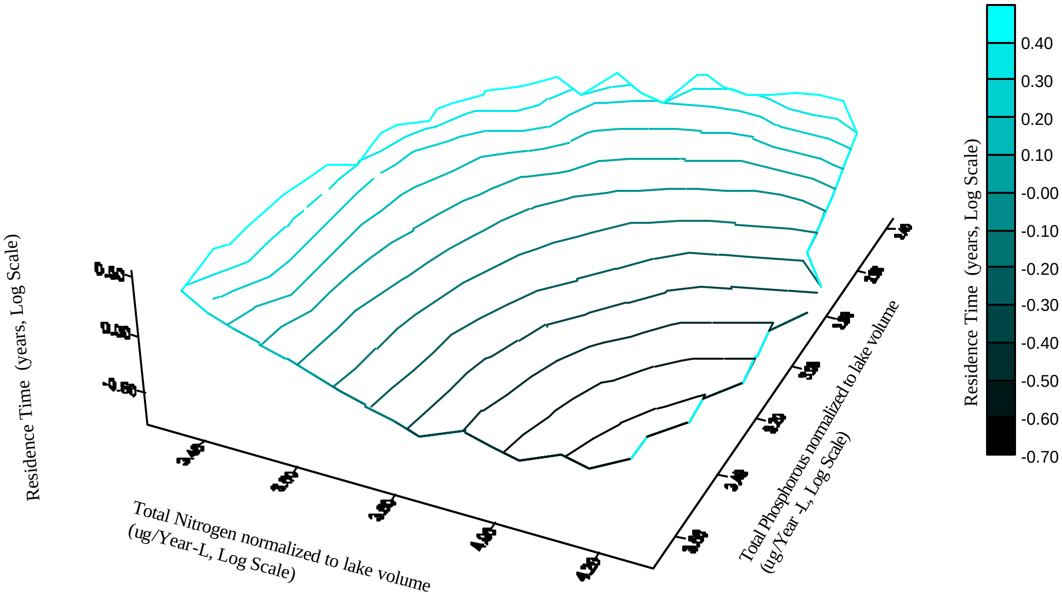


Figure 4-59. Chlorophyll-a Target Concentrations (40 ug/l) versus Phosphorous and Nitrogen Loading (lake volume normalized) for Residence Times from 0.05 to 17 Years and non-algal turbidity of 0.4 1/m

These results show that there is an approximately log-linear inverse relationship between allowable normalized nutrient concentrations and residence times, with allowable normalized nutrient concentrations increasing with decreasing residence time. Allowable normalized nutrient concentrations also increase with increasing turbidity values. A much larger range of nutrient and residence time parameter values exceeds the 10 ug/L target than the 25 or 40 ug/L target values. For example, essentially all residence times less than 0.25 years resulted in chlorophyll-a concentrations less than a 40 ug/L target, while residence times had to be less than 0.05 years to result in all chlorophyll-a concentrations less than a 10 ug/L target. All normalized nitrogen concentrations less than 3,200 ug/L resulted in chlorophyll-a concentrations less than a 40 ug/L target, while normalized nitrogen concentrations had to be less than 1,500 ug/L to result in all chlorophyll-a concentrations less than a 10 ug/L target. Similarly, all normalized phosphorus concentrations less than 400 ug/L resulted in chlorophyll-a concentrations less than a 40 ug/L target, while normalized phosphorus concentrations had to be less than 100 ug/L to result in all chlorophyll-a concentrations less than a 10 ug/L target.

Model Parameter Sensitivity Analyses

Figures 60, 61, 62, and 63 show generalized sensitivity plots for normalized total phosphorus, normalized total nitrogen, residence time, and non-algal turbidity for model results grouped into those runs exceeding 25 ug/L chlorophyll-a, and those runs with less than 25 ug/L chlorophyll-a. Residence time appears to be the most sensitive parameter (defined by the spread between the two group CDFs), and non-algal turbidity the least. Non-algal turbidity was inversely correlated with chlorophyll-a, with lower chlorophyll-a associated with higher non-algal turbidity. Normalized total phosphorus, normalized total nitrogen, and residence time are directly correlated with chlorophyll-a, with higher chlorophyll-a associated with higher normalized total phosphorus, higher normalized total nitrogen, and higher residence times.

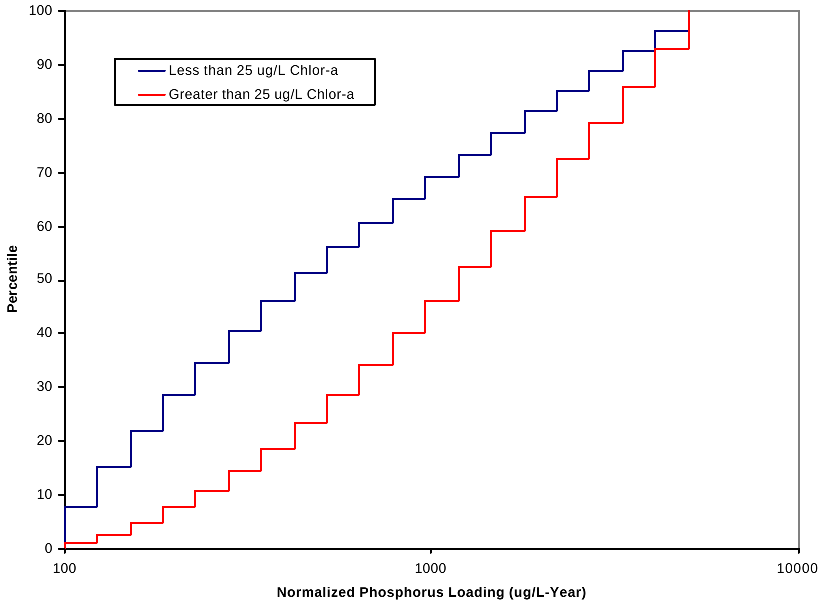


Figure 4-60. Generalized sensitivity plot for phosphorous variable, all parameters varying (P, N, Res Time, and Turbidity)

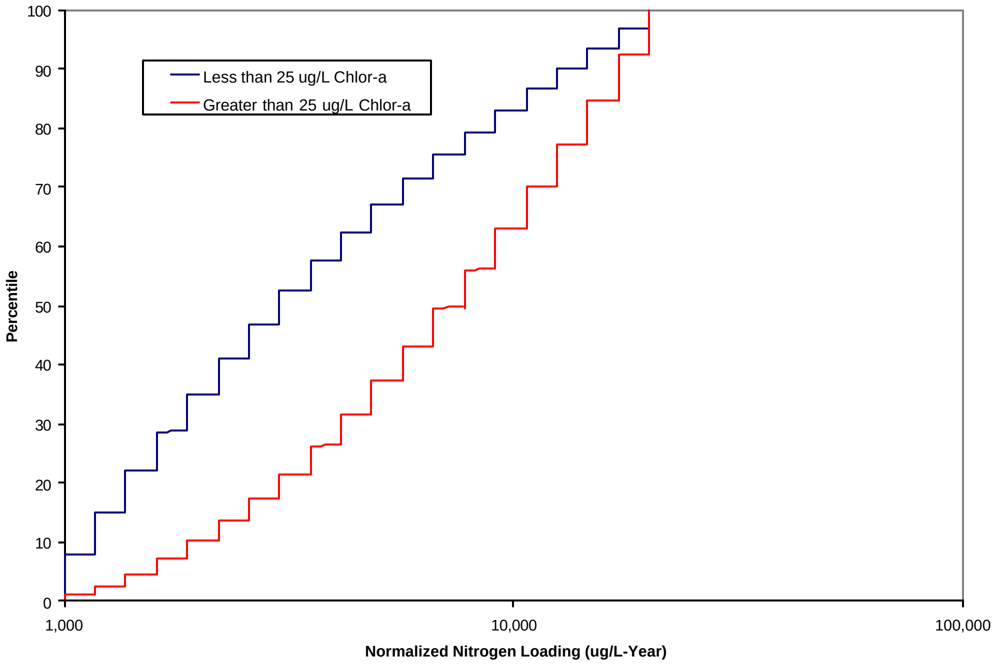


Figure 4-61. Generalized sensitivity plot for nitrogen variable, all parameters varying (P, N, Res Time, and Turbidity)

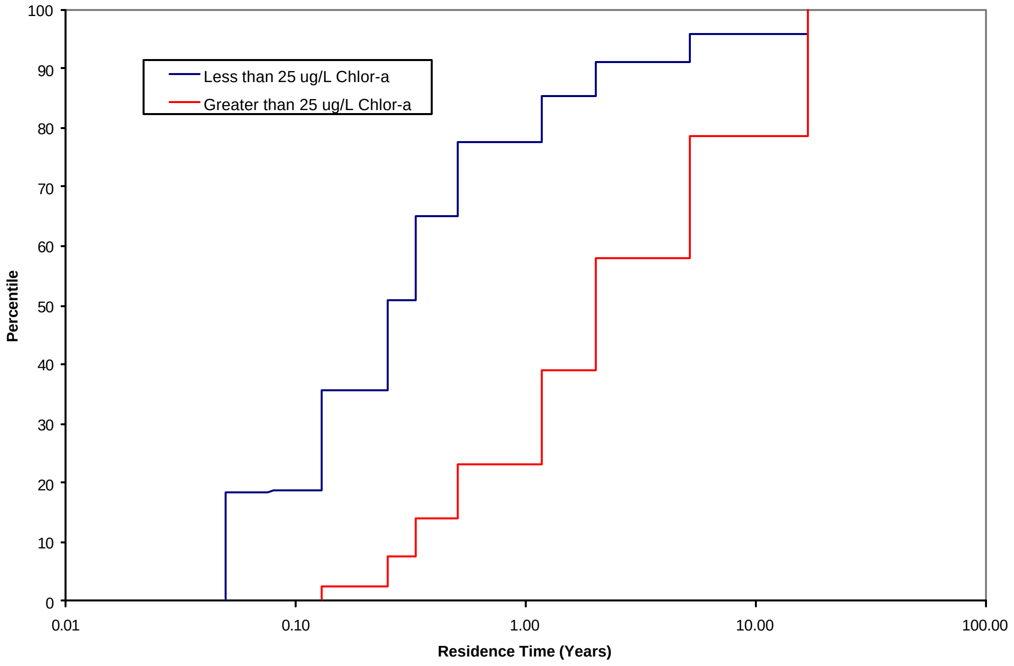


Figure 4-62. Generalized sensitivity plot for residence time variable, all parameters var (P, N, Res Time, and Turbidity)

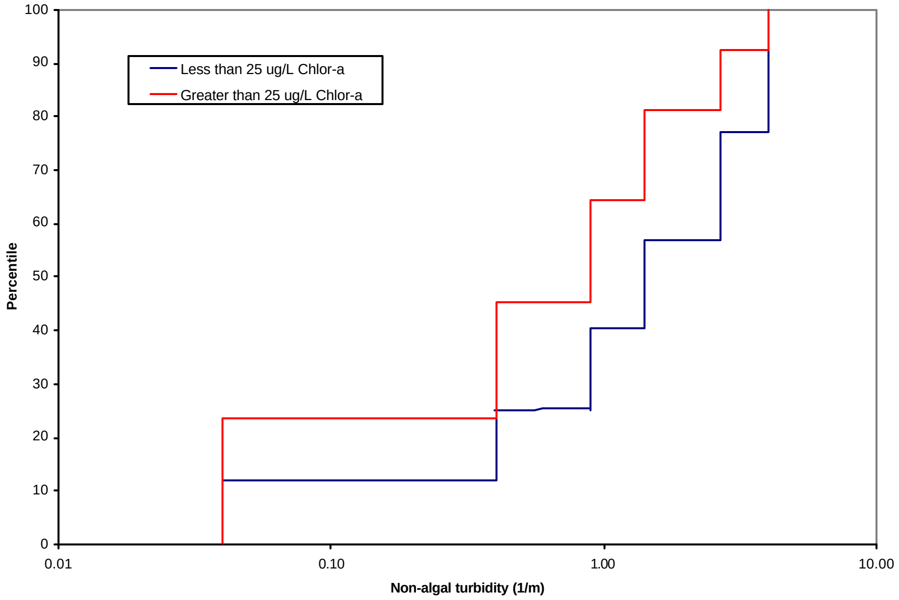


Figure 4-63. Generalized sensitivity plot for turbidity variable, all parameters varying (P, N, Res Time, and Turbidity)

4.4.5 Summary and Conclusions

The BATHTUB Model was used in this analysis for Ecoregion 6 to calculate allowable nutrient loadings as a function of lake residence time and non-algal turbidity for three target chlorophyll-a concentrations. The BATHTUB Model parameters were defined based upon prior model applications in Ecoregion 6, an Ecoregion 6 database of lake water quality and hydraulic parameters, and Ecoregion 6 nitrogen and phosphorus loadings estimated using the SWAT SPARROW model. The model results show that regardless of lake residence time or turbidity, all normalized phosphorus concentrations less than 400 ug/L resulted in chlorophyll-a concentrations less than a 40 ug/L target, while normalized phosphorus concentrations had to be less than 100 ug/L to result in all chlorophyll-a concentrations less than a 10 ug/L target. Similarly, regardless of lake residence time or turbidity, all normalized nitrogen concentrations less than 3,200 ug/L resulted in chlorophyll-a concentrations less than a 40 ug/L target, while normalized nitrogen concentrations had to be less than 1,500 ug/L to result in all chlorophyll-a concentrations less than a 10 ug/L target. The model results were very sensitive to residence time and moderately sensitive to turbidity over the range of Ecoregion 6 parameter values.

4.4.6 Recommendations

The BATHTUB Model analysis focused on a few key physical and chemical parameters to streamline this effort. Future work could investigate the variability in other parameters such as mean lake depth and the lake mixing depth that are also likely to impact the analysis.

This BATHTUB Model analysis used a uniform parameter distributions to define the ranges and frequencies of parameter variability, and assumed model parameters were not correlated. Both of these assumptions were made to expedite the completion of this effort. However, the true distributions of the parameters are most likely centered on some central tendency rather than uniformly distributed, and several of these parameters may be correlated. For example, the residence time data (Figure 35) may be log-normally distributed, and other data such as normalized nitrogen and phosphorus loadings may be normal or log-normally distributed. Parameters such as total phosphorus loading, which is typically present in insoluble forms, may also be correlated with non-algal turbidity. Future work could expand upon this sensitivity analysis by better defining the distribution of model parameters, weighting the frequency of occurrence based upon the parameter distributions, and correlating model parameters so that unrealistic outcomes (such as very high phosphorus concentrations and very low turbidity values) are avoided. This would further refine the modeling effort to better reflect Ecoregion 6 conditions.

5 TMDL EXPERIENCE IN SETTING NUTRIENT TARGETS

To date, 14 nutrient related TMDLs have been completed in California. The impairments were a combination of water quality standard exceedances and listing due to a narrative standard. The TMDLs did not directly define the targets based on biological response beyond using literature values such as EPA recommendations regarding ammonia toxicity. A summary of the TMDL endpoints for the completed nutrient related TMDLs is presented I Table 5-1.

Some variation was made from this approach in the case of the Malibu and San Diego Creek/Newport TMDLs. The Malibu Creek TMDL reviewed data from reference waters to set the stream nitrogen and phosphorus limits, although these limits are essentially the same as EPA criteria and have been questioned by Heal the Bay. The San Diego Creek TMDL used the receiving water (Newport Bay) as the controlling factor in defining the instream nutrient limits. A few of the TMDLs attempted to address the narrative criteria by using a numeric criteria for algal biomass or biomass chlorophyll a. These TMDLs did discuss the acceptable level of algal biomass that would impair aquatic life but still relied on literature values instead of site specific aquatic response.

Nutrient TMDLs were reviewed from EPA Regions 9 and 10 to determine both the values of the numeric nutrient targets and the procedures used to arrive at these numbers. Information was available for about 20 lakes and 17 streams. The key points from this review are summarized below.

Types of Targets

- Most of the numeric targets were for phosphorus and were expressed as total P. Ortho-P was used in one instance on the Willamette River. Phosphorus was usually assumed to be the limiting nutrient.
- Nitrogen targets were specified in addition to phosphorus targets in a few cases. Most of these were in streams and were defined to control algal or periphyton growth. They were usually expressed as total inorganic nitrogen. Total nitrogen was also used.
- Unnionized ammonia targets were specified in a few cases where ammonia toxicity was a problem.
- Chlorophyll-a targets were specified for a few lakes.
- Problems associated with eutrophication such as pH and DO violations were generally addressed by setting nutrient targets that would reduce algal densities, and therefore be expected to prevent the other related water quality problems.

Target Values - Lakes

- The lake nutrient targets were lower than the stream targets since lower nutrient concentrations are required to prevent eutrophication in lakes.
- The lake targets often considered the existing nutrient concentrations in the lakes and what reductions in concentrations could be accomplished.
- Most of the lakes in the Northwest had target total P values ranging from 0.012 to 0.030 mg/l.
- Lower targets were used to preserve the oligotrophic status of a few lakes. For example, the lowest target was 0.0045 mg/l TP in Lake Chelan, WA, an ultra-oligotrophic lake.
- Shallow, macrophyte-dominated, eutrophic lakes in Arizona had higher targets, on the order of 0.07 to 0.13 mg/l TP. These targets were based on what could be achieved with reasonable load reductions.

- Lake chlorophyll-a targets ranged from 5 to 10 ug/l in a few Washington lakes.
- The lake targets were generally defined as either annual averages or summer averages for a particular range of months (e.g., May to September). Longer term targets (10-year average) were used for some Idaho lakes.

Target Values – Streams

- Streams in the Northwest had target total P values ranging from 0.040 to 0.136 mg/l.
- Streams in the Southwest had higher total P targets, with values ranging from 0.070 to 0.330 mg/l.
- An ortho-P target of 0.012 mg/l was used for the Willamette River coast fork. This was the only waterbody with a target expressed as ortho-P.
- Streams in the Northwest had target total inorganic N values ranging from 0.23 to 0.30 mg/l.
- Streams in the Southwest had larger total N targets, with values ranging from 1.5 to 13 mg/l. Some of these were expressed as total inorganic nitrogen.
- Ammonia targets were specified for a few streams. The targets ranged from 0.5 to 1.0 mg/l ammonia-N. An unionized concentration of 0.020 mg/l was specified for the middle reach of the Snake River.
- The stream targets were defined using different time frames. These included annual averages, monthly averages or medians, summer averages or medians for a particular range of months (e.g., April to October), and daily maximums.

Methods for Selecting Targets

- Guidelines from the EPA Quality Criteria for Water (1986) were often used as the basis for setting phosphorus targets. These values were 0.025 mg/l TP for lakes, 0.100 mg/l TP for streams that do not enter lakes, and 0.050 mg/l TP for streams that enter lakes.
- A 25% safety margin was used in conjunction with the above values in some cases to produce lower targets.
- Trophic state criteria were often used to set the phosphorus targets for lakes. Depending on whether the existing lake was oligotrophic, mesotrophic, or eutrophic, a target was selected that would either improve its trophic classification, or prevent it from degrading if it was already oligotrophic. Generally, the target was selected with a margin of safety below the boundary of the next higher trophic level.
- Carlson's trophic state index was used for one lake to define the target at the boundary between eutrophic and mesotrophic conditions.
- A 25% reduction from existing average phosphorus concentrations was used to define targets in a few lakes.
- Estimated background nutrient concentrations were used to define targets for several streams. In some cases, an attempt was made to estimate natural background concentrations. For example, they were calculated from monitoring data using mass balance techniques to subtract the anthropogenic or tributary loads from each stream reach. Natural background concentrations were also estimated from monitoring data collected at upstream reaches or tributaries above load sources. In other cases, background concentrations were interpreted as existing concentrations above a major load source, such as a wastewater treatment plant discharge. When background

concentrations were used as targets, the values were often different for different reaches or tributaries of the same river.

- A total inorganic nitrogen target of 0.30 mg/l was used for a few streams based on literature suggesting that nuisance aquatic plant growth occurs above this level. An additional 25% safety factor was used to reduce the target to 0.23 mg/l in one stream.
- Algal assays were sometimes used to set nutrient targets.
- Vollenweider relationships were sometimes used to set nutrient targets.
- Model analyses were used to define nutrient targets in some cases. For example, some eutrophic systems cannot be improved to mesotrophic status because of natural loads from the watershed or internal nutrient loads from sediments or aquatic plants. In these situations, models can be used to set targets by calculating the loads from all sources, reducing the loads from all sources that can be controlled, and predicting the resulting nutrient concentrations in the receiving waters.

Table 5.1 NUTRIENT TMDL SUMMARY BY ECOREGION

WATERBODY/ TYPE	STATE	ECOREGION (LEVEL III)	Beneficial Uses[1]	Numeric Endpoint	Analytical Method	Notes
Malibu Creek	CA	6. Southern and Central CA Chaparral and Oak Woodlands	8, 9, 11, 13, 15, 16, 17, 20	Ammonia - 4-day acute toxicity standard • DO - Numeric DO standard • Nitrogen (Nitrate/Nitrite) - 1 mg/L TN, 0.1 mg/L TP • Biostimulatory Substances - Literature review to determine levels of nutrient which would promote aquatic growth to nuisance levels. > 30% algal cover in more than 10% of the samples • Floating Materials - Narrative standard – free of floating material in concentrations that cause nuisance – chose 10 ug/L chl a for lakes and 150 mg/m2 chl a for streams and lagoon	▪ Watershed modeling (SWAT) ▪ BATHTUB for lakes and reservoirs	▪ Heal the Bay report has additional monitoring for reference watersheds. Recommend 0.05 mg/L NO3 and 0.1 mg/L PO4. ▪ Biggs, B.G.F. 2000. Eutrophication of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae. J. N. American Benthol. Society ▪ Dodds, W.K. and E.G. Welsh. 2000. Establishing Nutrient Criteria in Streams. J. N. American Benthol. Society ▪ US EPA. 2000. Nutrient Criteria Technical Guidance Manual.
Calleguas Creek	CA	6. Southern and Central CA Chaparral and Oak Woodlands	*2, 3, 4, 5, 8, 9, 11, 13, 15, 16*	▪ Ammonia - EPA ammonia toxicity standard • Oxidized Nitrogen - Numeric criteria: 10 mg/l NO3- • Biostimulatory Substances - N+NO2-N, 1 mg/L NO2-N 10 mg/L NO3-N, 1 mg/L NO2-N ▪ Algae - Algal biomass < 150 mg chl a/m2. ▪ DO - Numeric DO Standard (5.0 mg/L)	Spreadsheet approach using mass balance and representation of nitrogen cycle based on differential equations estimates of nitrogen transformation	▪ Criteria are to protect MUN designated use. Assumes that these standards and the DO criteria will be sufficient to protect the recreation and aquatic life uses. ▪ Nutrient Criteria Technical Guidance
Stemple Creek	CA	6. Southern and Central CA Chaparral and Oak Woodlands	*9, 10, 13, 15, 16, 17, 20*	▪ Total and un-ionized Ammonia - EPA ammonia toxicity standard ▪ DO - Numeric DO Standard (5.0 mg/L)	Performed source analysis and identified agriculture as the only significant source of concern. Allocated 100% of reductions to agriculture.	
Indian Creek Reservoir	CA	6. Southern and Central CA Chaparral and Oak Woodlands	1, 2, 5, 6, 8, 9, 10, 13, 15	▪ Nutrients - TP of 0.02 based on lit data. Assume that algal growth and ammonia toxicity will abate as TP decreases. ▪ DO - Numeric DO Standard (7.0 mg/L) • Secchi Depth - No less than 2 feet in summer • Chlorophyll a - No greater than	Spreadsheet approach based on empirical data	▪ EPA Lake and Reservoir Restoration Guidance Manual, Protocol for Developing Nutrient TMDLs

WATERBODY / TYPE	STATE	ECOREGION (LEVEL III)	Beneficial Uses[1]	Numeric Endpoint	Analytical Method	Notes
				10 ug/L in summer • Carlson TSI - No greater than 45		
The Laguna De Santa Rosa	CA	6. Southern and Central CA Chaparral and Oak Woodlands	9, 10, 13, 14, 15, 16, 17, 20	• Total Ammonia 0.5 mg-N/L • Total Nitrogen 3.7 mg/L	For total ammonia the EPA criteria for un-ionized ammonia of 0.025 mg-N/L was used along with the un-ionized ammonia equation and pKa values derived from Emerson 1975. Where: $\text{Un-ionized Ammonia} = \frac{\text{Total Ammonia}}{1+10^{(\text{pKa}-\text{pH})}}$ *pKa was determined using the maximum temperature observed between Jan. 1990 and Jan. 1992 of 24ºC. The pH value of 8.0, corresponding to the sampling when the maximum temperature was recorded was also used. This yields the 0.5 mg-N/L value.* The total nitrogen upper limit was calculated based on the percent total ammonia in the total nitrogen observed for each significant pollutant source. The average percent ammonia in total nitrogen for all sources is 13%. This yields 0.5/0.13 or 3.7 mg/L.	Models: QUAL2E, RMA-2, and RMA-4 were used to simulate water quality conditions due to seasonal loads. Eight scenarios were used to adjust waste loads until the numeric targets were met at each of four locations in the watershed. The scenario with the best result was chosen and presented as the waste load reduction strategy.
Santa Ana River	CA	6. Southern and Central CA Chaparral and Oak Woodlands	Lower River: 1, 2, 5, 8, 9, 11, 15, 16 Upper River: 1, 2, 5, 7, 8, 9, 11, 13, 15, 16, 17	• Total Inorganic Nitrogen 10 mg/L	Taken from the basin plan. It is roughly equivalent to the 45 mg/L as NO_3 nitrate drinking water standard which protects the municipal water use (MUN).	The QUAL2E model was the primary tool used to determine the waste load allocations for meeting the numeric target.
San Diego Creek	CA	6. Southern and Central CA Chaparral and Oak Woodlands	Below Jeffrey Road: 8, 9, 11, 15 Above Jeffrey Road to Headwaters: 5, 8, 9,	• Reach 1: 13 mg/L TIN • Reach 2: 5 mg/L TIN • No numeric criteria exist for Phosphorus though narrative criteria exist for algae and DO.	Reach 1: 5 mg/L was rejected, 13 mg/L based on average of low-flow concentrations at Orange County monitoring station. Reach 2: 5 mg/L is stated in the Basin Plan.	▪ Based on water quality monitoring waste loads were set by determining what percent reduction in loads would be required to meet numeric criteria. ▪ TMDL driven by Newport Bay acceptable loadings, set at 1973 nutrient loading estimates ▪ Algal mat - Not listed for narrative standard. Stated that connection between presence of algae and beneficial use impairment had not been established.

WATERBODY / TYPE	STATE	ECOREGION (LEVEL III)	Beneficial Uses[1]	Numeric Endpoint	Analytical Method				Notes
			11, 15						
Newport Bay **This is an estuarine system*	CA	6. Southern and Central CA Chaparral and Oak Woodlands	Lower Bay: 6, 8, 9, 10, 15, 16, 17, 18, 19 Upper Bay: 8, 9, 10, 14, 15, 16, 17, 18, 19, 20	• Algal biomass density less than 1.5 kg/m^2. • DO greater than 3.0 mg/L.	Criteria were selected based on reports from Alex Horn Associates, 1998, which show relationships between algal growth density and DO depression. There is some disagreement over the relationship between these parameters (Fong, 1998).				
				•					
Luna Lake	AZ	23. Arizona and New Mexico Mountains		• PH > 6.5 and < 9.0 • DO > 7.0 mg/L or 90% saturation in upper 1 m of water depth • P < 1.0 mg/L total phosphate as P for tributaries; best professional judgment for lake • N best professional judgment Total Ammonia: • Acute exposure (<1hr) 0.35 mg/L • Chronic exposure (4 days) 0.02 mg/L • Reduce quantities of nuisance aquatic plants	Determined by AZ state water quality standards and trophic classifications: Oligotrophic Mesotrophic Eutrophic	Chl-a (µg/L) < 7 7 – 12 > 12	Total P (mg/L) < 0.010 0.010 – 0.020 >0.020	Secchi Depth (m) > 3.7 2.0 – 3.7 < 2.0	GWLF and BATHTUB models were used to determine the load allocations based on the numeric endpoints.
Rainbow Lake	AZ	23. Arizona and New Mexico Mountains		• pH > 6.5 and < 9.0 • DO > 7.0 mg/L or 90% saturation in upper 1 m of water depth • P < 1.0 mg/L total phosphate as P for tributaries; best professional judgment for lake • N best professional judgment Total Ammonia: • Acute exposure (<1hr) 0.35 mg/L • Chronic exposure (4 days) 0.02 mg/L • Reduce quantities of nuisance aquatic plants	Determined by AZ state water quality standards and trophic classifications: Oligotrophic Mesotrophic Eutrophic	Chl-a (µg/L) < 7 7 – 12 > 12	Total P (mg/L) < 0.010 0.010 – 0.020 >0.020	Secchi Depth (m) > 3.7 2.0 – 3.7 < 2.0	GWLF and BATHTUB models were used to determine the load allocations based on the numeric endpoints
Stoneman Lake	AZ	23. Arizona and New		• No numeric endpoints for N and P.	Watershed loadings are estimated using the GWLF model.				The TMDL allocations appear to increase P and N loadings from present conditions (potential error in

WATERBODY / TYPE	STATE	ECOREGION (LEVEL III)	Beneficial Uses[1]	Numeric Endpoint	Analytical Method	Notes
		Mexico Mountains		- Submerged Aquatic Vegetation (SAV) reduction of 15% - BOD reduction - Assumed pH shift to 9.1	In lake processes (N and P concentrations, phytoplankton) were simulated using BATHTUB. Submerged aquatic vegetation (SAV) was simulated using the U.S. Army COE SAV model.	document). Model results predict abundant SAV growth and hypoxia even if all anthropogenic loads are removed.
AZ Stream Segments Verde River, Oak Creek, Salt River	AZ	23. Arizona and New Mexico Mountains		*Verde River:* - 0.07 mg P/L mean annual (Federal std.) - 0.10 mg P/L mean annual (AZ std.) - 1.00 mg N/L mean annual (AZ std.) *Oak Creek:* - 0.07 mg P/L mean annual (Federal std.) - 0.10 mg P/L mean annual (AZ std.) - 1.00 mg N/L mean annual (AZ std.) *Salt River:* - 0.07 mg P/L mean annual (Federal std.) - 0.12 mg P/L mean annual (Salt River std.) - 0.10 mg P/L mean annual (White, and Black River stds.)		Using the federal and state and local standard along with the recorded flow rates from USGS gauging stations the TMDLs were calculated using a mass balance method by multiplying the standard by the flow. This was done using each set of available standards and the most conservative value was selected. For the Salt River an OECD model was also employed, but the mass balance approach described above was more conservative.
Oak Creek Basin	AZ	23. Arizona and New Mexico Mountains		- Existing AZ water quality standards for phosphorus and nitrogen.		Neither in empirical studies nor in simulated model results were the AZ water quality standards violated with statistical significance.

Waterbody/ Type	State	Ecoregion (Level III)	Beneficial Uses[1]	Numeric Endpoint	Analytical Method	Notes
US EPA Region 10						
Long Lake	WA	10. Columbia Plateau or 15. Northern Rockies		• Total P 0.025 mg/l mean June to Oct.	WA state water quality standards	Loads set to meet TP concentration with 1-in-2 year seasonal design flow
Snake River, Minidoka Dam to Milner Dam	ID	12. Snake River Basin		• Total P 0.080 mg/l mean annual Maximum TP 0.128 mg/l	Based on EPA guidance for free-flowing rivers of 0.100 mg/l TP; allowing some higher values for natural variability	
Snake River	ID	12. Snake River Basin		• Total P 0.075 mg/l mean representative for the entire mainstem	Based on EPA (1986) guidance of 0.100 mg/l TP for streams not flowing into lakes and 0.050 mg/l TP for streams entering lakes	
Middle Snake River reach	ID	12. Snake River Basin		*Tributaries:* • Total P 0.100 mg/l *Entire Waterbody:* • Unionized ammonia 0.020 mg/l	The intermediate value of 0.075 mg/l TP was selected for the mainstem since the river includes run-of-the-river impoundments. Unionized ammonia based on EPA (1972) to protect fisheries	
Billingslet Creek	ID	12. Snake River Basin		• Total P maximum of 0.100 mg/l	EPA (1986) Quality Criteria for Water	
Bruneau River	ID	12. Snake River Basin		Mainstem and Tributaries that flow into Reservoirs: • Total P monthly 0.050 mg/l mean • Total P daily 0.080 mg/l maximum Tributaries that do not flow into Reservoirs: • Total P monthly 0.100 mg/l mean • Total P daily 0.160 mg/l maximum	Based on EPA (1986) guidance of 0.050 mg/l TP for streams entering lakes and 0.100 mg/l TP for streams not flowing into lakes	

Waterbody/ Type	**State**	**Ecoregion (Level III)**	**Beneficial Uses**[1]	**Numeric Endpoint**	**Analytical Method**	**Notes**
Winchester Lake	ID	15. Northern Rockies		• Total P 0.048 mg/l mean annual • 20% margin of safety used for load analyses to give target TP of 0.037 mg/l	Carlson's trophic state index used to define the target at the boundary between eutrophic and mesotrophic	
Hayden Lake	ID	15. Northern Rockies		• Total P 0.007 mg/l mean 10-year	Goal from Hayden Lake Watershed Management Plan	
Hauser Lake	ID	15. Northern Rockies		• Total P 0.013 mg/l mean 10-year	25% reduction in existing average concentration	
Twin Lakes	ID	15. Northern Rockies		*Upper Twin Lake:* • Total P 0.022 mg/l mean 10-year *Lower Twin Lake:* • Total P 0.0115 mg/l mean 10-year	25% reduction in existing average concentration from Twin Lakes Management Plan	
Jim Ford Creek	ID	15. Northern Rockies		• *Total P 0.075 mg/l mean monthly from April to Oct.* • *Total inorganic N 0.230 mg/l mean monthly from April to Oct.*	TP based on EPA (1986) Quality Criteria for Water value of 0.100 mg/l with 25% safety margin. TIN based on Bauer and Burton (1993) recommended value for nitrate of 0.300 mg/l with 25% safety margin.	
Cascade River	ID	16. Idaho Batholith		• Total P 0.025 mg/l mean annual • Chlorophyll-a 10 ug/l mean annual	1986 EPA Quality Criteria for Water	Chapra model used to determine load reductions necessary to meet lake targets
Paradise Creek	ID	16. Idaho Batholith		• *Total P 0.136 mg/l May to Oct.*	Natural background estimated from monitoring data	
Clear Lake	OR	1. Coast Range	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	• Total P 0.0078 mg/l mean annual • Median Total P 0.009 mg/l May to Sept.	Endpoint set to maintain an oligotrophic value using a margin of safety below the mesotrophic boundary	
Collard Lake	OR	1. Coast Range	*1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15*	• Total P 0.0144 mg/l mean annual	Endpoint set to maintain a mesotrophic value using a margin of safety below the eutrophic boundary	

Waterbody/ Type	State	Ecoregion (Level III)	Beneficial Uses[1]	Numeric Endpoint	Analytical Method	Notes
Garrison Lake	OR	1. Coast Range	*1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15*	• Total P 0.025 mg/l median monthly		
Lake Fenwick	WA	2. Puget Lowlands		• Total P 0.019 mg/l mean annual •		
Lake Sawyer	WA	2. Puget Lowlands		• Total P 0.016 mg/l mean annual •		
Yamhill River	OR	3. Willamette Valley	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	• Total P 0.070 mg/l April to Oct.	Determined from algal assays, empirical analyses (Vollenweider relationship), and modeling	
Tualatin River	OR	3. Willamette Valley	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	*Mainstem Sections:* • Total P from 0.04 to 0.11 mg/l median May to Oct *Tributaries:* • Total P from 0.04 to 0.19 mg/l median May to Oct *Upper Portion:* • Ammonia-N 1.00 mg/l median monthly *Lower Portion:* • Ammonia-N 0.85 mg/l median monthly	Estimated from background concentrations for each reach or tributary; Different values for each reach; Checked that these values would meet criteria for pH, DO, and aesthetics (algae)	Mass balance approach used to estimate background TP concentrations in each reach. Mass balance based on measured flows and concentrations, subtracting anthropogenic and tributary loads.
Willamette River Coast Fork	OR	3. Willamette Valley	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	• Ortho-P 0.012 mg/l	Estimated from background concentrations above the waste treatment plant discharge	

	California
1	*Municipal and Domestic Supply*
2	Agricultural Supply
3	Industrial Service Supply
4	Industrial Process Supply
5	Groundwater Recharge
6	Navigation
7	Hydropower Generation
8	Water Contact Recreation
9	Non-contact Water Recreation
10	Commercial and Sportfishing
11	Warm Freshwater Habitat
12	Limited Warm Freshwater Habitat
13	Cold Freshwater Habitat
14	Preservation of Biological Habitats of Significance
15	Wildlife Habitat
16	Rare, Threatened, or Endangered Species
17	Spawning, Reproduction, and Development
18	Marine Habitat
19	Shellfish Harvesting
20	Estuarine Habitat

	Oregon
1	*Public Domestic Water Supply*
2	Private Domestic Water Supply
3	Industrial Water Supply
4	Irrigation
5	Livestock Watering
6	Anadromous Fish Passage
7	Salmonid Fish Rearing
8	Salmonid Fish Spawning
9	Resident Fish and Aquatic Life
10	Wildlife and Hunting
11	Fishing
12	Boating
13	Water Contact Recreation
14	Aesthetic Quality
15	Hydro Power
16	Commercial Navigation and Transportation

5.1 REVIEW OF RECENT AND ONGOING STUDIES WITHIN THE PILOT PROJECT REGION

Below are provided preliminary reviews of in-depth studies that are being conducted in Ecoregion 6. There are several studies that will need to be added. In addition, the Principal Investigators for these studies have been invited to participate in a panel at the next scheduled RTAG / STRTAG meeting to discuss the significance of their findings relative to nutrient criteria.

Malibu Creek Nutrient Study: The Southern California Coastal Research Project (SCCRP) has a contract with the SWRCB to report on the current status of water quality and periphyton abundance in the Malibu watershed. Another component of this study was to determine the factors limiting the growth of periphyton in the watershed. The study was conducted in cooperation with Scott Cooper's lab from UCSB. There have been two field seasons. In August and October of 2001 stream sampling was conducted at 12 different sites in the Malibu watershed representing different lake use practices. Rich Ambrose of UCLA was conducting a partner study in 2001 (see review below). The Ambrose study did not focus on periphyton, rather they looked at other measures of ecological health for the stream ecosystem, such as physical characteristics, biological characteristics including riparian vegetation, macro invertebrates, and fish. From the August and October 2001 sampling that UCSB conducted, SCCRP looked at water quality and abundance of periphyton at 12 different sites. The regression models results indicate that there is a strong correlation of chlorophyll a to total "P"s in the water column, and also somewhat to light availability. This was written up in an interim report, which LA Regional Board has but is not available because it was not the final report from the project. In the past year, in August 2002, UCSB conducted a nutrient limitation experiment, which placed nutrient defusing substrata out in the field at 6 different locations in the watershed to determine if nitrogen or phosphorus was more limiting to periphyton growth. The final report from the nutrient limitation experiment is about to go to the Regional Board. Overall, what they found was at some sites, nitrogen was limiting and some other sites, light is the overall limiting factor. Additional stream sampling has been completed in 2002 aqnd 2003 at many of the sites that were sampled in 2001. The report from this round of sampling is pending.

Environmental Monitoring and Bioassessment of Coastal Watersheds in Los Angeles and Ventura Counties, by Richard Ambrose, Steven Lee, and Sean Bergquist, May 2003: Ambrose et al. monitored three coastal watersheds with multiple sampling sites to represent the typical land uses found: Malibu Creek, Calleguas Creek, and Santa Clara River. The goal of the study was to find how nutrients influenced biotic indicators such as the abundance of algae and the benthic community. It was found that nutrients acted in concert with other physical and chemical variables, such as light, temperature, pH, and conductivity, to result in different algal and benthic communities. Land use associated with a sampling location was also found to influence the nutrient concentrations and the biological communities. The relationship between nutrients and biology that has been developed for this study will form an important part of the analysis for developing nutrient criteria. In particular, we can use data in this study to associate nutrients with biological changes that are determined to be unacceptable.

It is important to note that more studies need to be reviewed for this line of evidence and those included here need further analysis. However, based on this preliminary review the findings of the studies listed above are consistent with those of the 1999 Ohio EPA report, "Association Between Nutrients, Habitat, and Aquatic Biota in Ohio Rivers and Streams." These findings include that the response of the aquatic ecosystem to nutrient inputs is significantly affected by the physical habitat integrity of the system. Physical habitat and flow conditions are primary cofactors with water column nutrient concentrations in determining whether biostimulatory substances have a negative impact on aquatic life based Beneficial Uses and the development nuisance algal conditions. These findings will provide important input to the decision framework for any proposed nutrient criteria.

5.2 REVIEW OF MULTI-METRIC BIOSTIMULATORY RISK INDEX BEING DEVELOPED BY REGIONAL WATER QUALITY CONTROL BOARD 3

RWQCB 3 has developed a screening tool to estimate the potential risk of biostimulation, i.e., the potential for causing aquatic growth that negatively impact beneficial uses, across a large number of stream stations using data in six areas: nutrient chemistry, pH, chlorophyll a concentrations, dissolved oxygen, turbidity, and algal cover. The index includes variables that may be the stressor causing impairment (such as nutrient concentrations) and variables that are the result of nutrient enrichment (such as dissolved oxygen and algal cover). The data underlying this index was used in our overall analysis of Ecoregion 6 data presented in Section 3. The discussion below refers to the use of the Biostimulatory Risk Index as proposed by RWQCB 3.

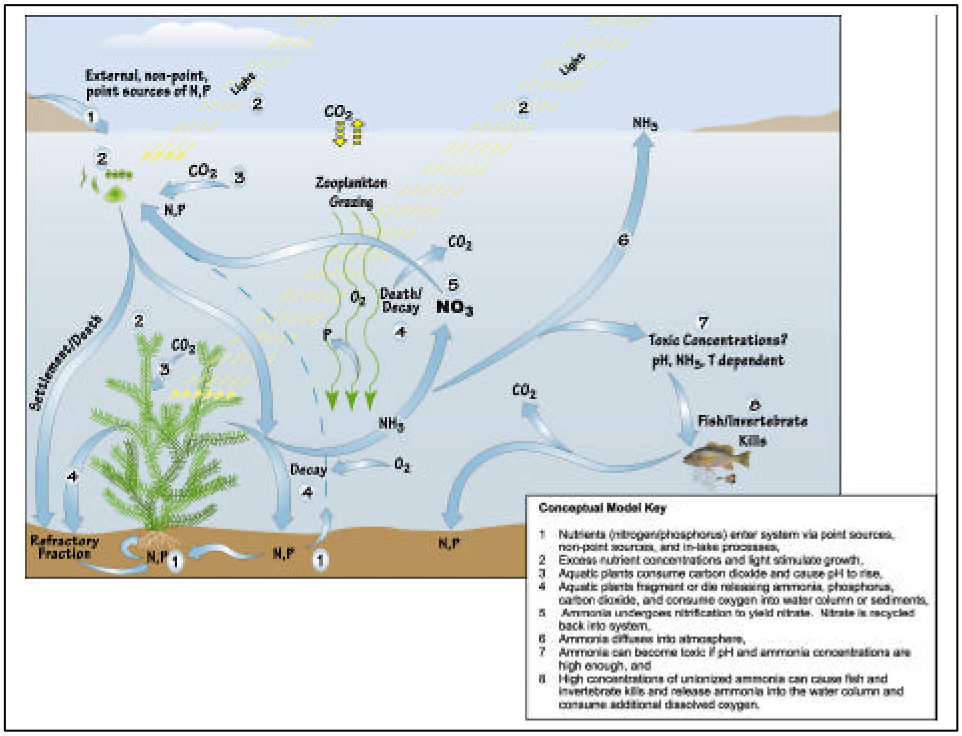
Using data from more than 150 sites, the Index ranks the observed numeric values of each of the six constituents listed above. The ranking is based on averages of the data at each site. The ranks in each of the six categories are assigned weights ranging from 1 (algal cover metrics) through 9 (chlorophyll a). By default the nutrient concentrations are assigned a weight of 6. These weights can be adjusted by the user of the tool. The weighted ranks for each of the six constituents are then combined into one category to calculate a composite ranking of the potential of adverse nutrient enrichment effects as represented by the Multi-Metric Biostimulatory Risk Index. Although not designated as such within the tool, sites with low values of the Index may be considered to be relatively unimpaired by nutrients, whereas sites with high values of the Index may be or have the potential to be impaired. An interesting feature of the Multi-Metric Biostimulatory Risk Index is the use of both the stressor and the response variables in the same Index. Thus, it may identify stations that are already impaired, as indicated by low dissolved oxygen or high chlorophyll a levels, as well as stations that have conditions likely to promote biostimulation through high levels of nutrient concentrations, possibly at downstream levels.

The Multi-Metric Biostimulatory Risk Index provides a useful template to other regions for collecting and characterizing data on nutrient chemistry and effects. Although the resulting Index cannot be used directly for developing nutrient criteria, it does provide a rapid assessment of the stations within a region that are most likely to have problems.

6 A CONCEPTUAL MODEL TO GUIDE THE DEVELOPMENT OF NUTRIENT CRITERIA IN LAKES AND STREAMS

The role of nitrogen and phosphorus in promoting primary productivity in natural waters is well understood, particularly when the nutrients are in a bioavailable form and other conditions are favorable, such as adequate light, temperature, micronutrients, and suitable habitat. Bioavailability is a function of stream flow or lake residence time conditions. Given enough time even refractory forms of nutrients can become bioavailable. Bioavailability must therefore be considered in the context of physical conditions, and not solely be based on analytical tests to measure chemical forms of nutrients. The other factors are all considered essential for algal growth, although there may be regional variations in levels.

In lakes the possible effects of nutrient loads on the lake biology are expressed in simplified form in Figure 6.1. From extensive studies of lakes, it is known that relatively small quantities of nutrients (about 0.01 mg/l of total phosphorus, and about 0.1 mg/l of total nitrogen) are sufficient to cause enough algal growth that may be considered adverse. Data collected in our study showed much higher concentrations of these constituents in minimally impacted streams and in unimpaired lakes and streams. The fact that stations in our dataset can support higher levels of nutrients without impairment of beneficial uses indicates that one or more of the limiting factors listed above are playing a role. In streams, for example, high flow rates may create conditions where the nutrients in water are not bioavailable to organisms. In such conditions,



Conceptual Model Key

1 Nutrients (nitrogen/phosphorus) enter system via point sources, non-point sources, and in-lake processes,
2 Excess nutrient concentrations and light stimulate growth,
3 Aquatic plants consume carbon dioxide and cause pH to rise,
4 Aquatic plants fragment or die releasing ammonia, phosphorus, carbon dioxide, and consume oxygen into water column or sediments,
5 Ammonia undergoes nitrification to yield nitrate. Nitrate is recycled back into system,
6 Ammonia diffuses into atmosphere,
7 Ammonia can become toxic if pH and ammonia concentrations are high enough, and
8 High concentrations of unionized ammonia can cause fish and invertebrate kills and release ammonia into the water column and consume additional dissolved oxygen.

Figure 6-1 Conceptual model of potential in lake nutrient related processes.

setting criteria at low levels, below what is seen in unimpaired water bodies of that region, may have no practical benefits. For nutrient criteria to be valid and yield a measurable change in water body conditions, they must be targeted at situations where other factors, referred to above, are not constraining the growth of algae. Thus, on a temporal basis, criteria should focus on periods when the growth of algae is greatest, and on a spatial basis, the criteria should focus on water bodies where it is known that nutrient levels are controlling algal productivity.

These findings are consistent with the proposed decision framework. The proposed decision framework is illustrated in Figure 6.2. The results of the pilot project still need to be applied to the second and third blocks of the decision framework, respectively designated use limits and environmental stratification factors. The final component of the decision framework addresses the form of the standard. The results of the pilot project suggest that the form of the standard should adopt a risk-based approach based on levels of assessment to refine and direct the regulatory response. The paragraph below describes an example of a scenario that should be considered by the RTAG / STRTAG.

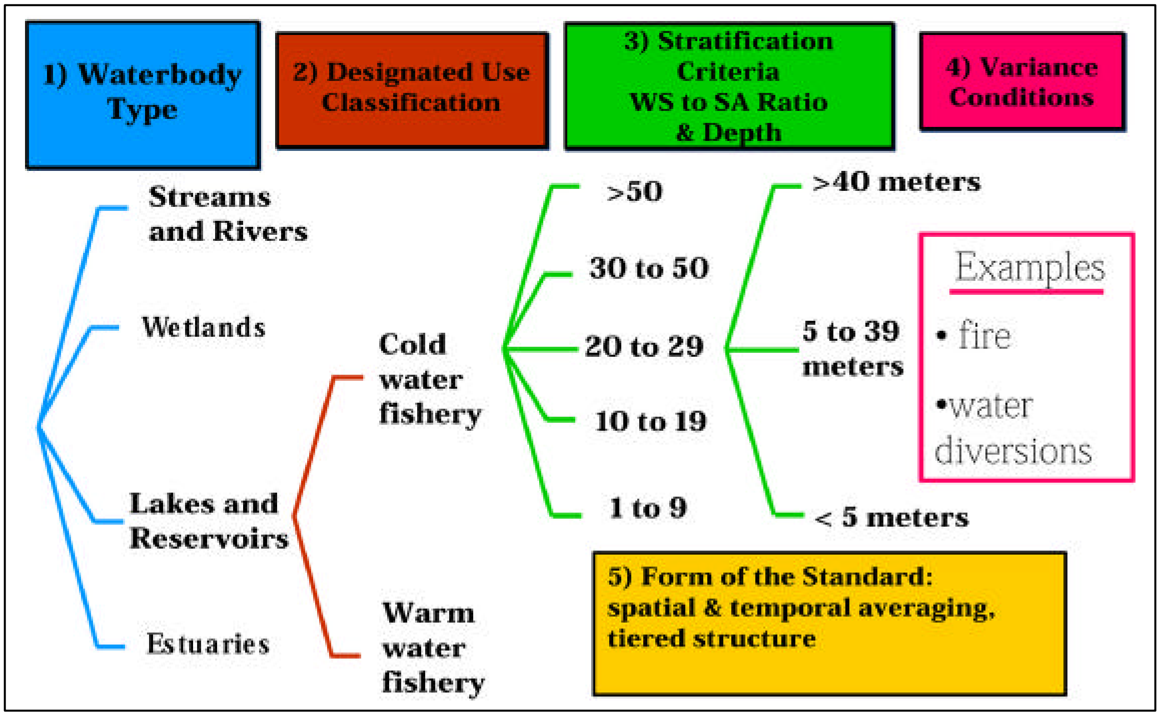


Figure 6-2. Diagram of Decision Framework

The scenario is based on the following preliminary findings of the pilot study:

1) Watershed nutrient loadings, water column nutrient concentrations, and algal densities are highly variable across streams despite their condition rating (i.e., reference).

2) Nuisance algal conditions are most likely if a combination of three factors occur: high concentrations of nutrients, persistent low flow conditions, and degraded physical habitat (both riparian and channel).

If a water body is found to have nutrient concentrations in the "risk range" then the level 1 trigger is activated to conduct an assessment. The assessment addresses something like the following questions: 1) Is the dominant / majority of nutrient loading from anthropogenic sources? 2) Does the loading occur / impact the critical growing season? 3) Have flow conditions been modified in a manner that could contribute to increase the potential for nuisance algal conditions to occur? 4) Have physical habitat conditions been degraded in a manner that would contribute to an increased potential for nuisance algal conditions?

If the answers to these questions are yes then the decision framework level-two trigger is activated to develop a nutrient management plan that includes consideration all of the risk cofactors. Examples of risk cofactors include flow and physical habitat for streams and non-algal turbidity and residence time for lakes and reservoirs. This approach would place an additional assessment burden on water quality agencies. However conducting nutrient risk assessments prior to impairment could dramatically reduce the number of water bodies on the impaired waters list. The assessments could be tied to permits (both stormwater and other point sources) with required studies prior to approval.

Further consideration is needed to refine the risk cofactors. The results of the current pilot project can be used to accomplish much of the necessary refinement. Additional data and analyses will be needed to finalize specific nutrient criteria recommendations.

6.1 FINDINGS, RECOMMENDATIONS, AND NEXT STEPS

The technical support team believes that the lines of evidence in this report support the following findings, recommendations, and next steps:

- The pilot study identified patterns in certain nutrient constituents when nutrient-impaired water bodies were compared with other water bodies. Thus, using only data at the ecoregion level, it may be possible to identify ranges of nutrient concentrations associated with unimpaired water bodies. This is an important finding because, in most instances, we find data only on nutrient concentrations, and not on biological effects.
- Based on evaluation of commonly collected data, it appears unrealistic to find characterization of biological communities (algae or benthos) on a region-wide scale except for areas that have been the focus of site-specific research studies. Information from such research studies can be useful for mechanistic understanding, although it is unclear how they may be translated to a larger scale. Of the possible biological parameters to be considered, there appears to be promising data on chlorophyll a concentrations from at least a portion of Ecoregion 6 along the Central Coast. Further data collection of this parameter is strongly recommended.
- From the individuals contacted for the data collection effort, we know that there are other data sets that could be used in our evaluation, particularly some in minimally impacted areas. The next phase of this study will work toward obtaining more of these datasets.

- High-resolution digital elevation maps can be used to calculate watersheds corresponding to each station in the database (as was done for the reference watersheds in Section 4) and put together more detailed information on watershed characteristics from large-scale GIS datasets. This information can then be used in regression and other statistical analyses to relate measured nutrient concentrations to watershed characteristics.
- Based on regional studies of small streams light availability is a key factor controlling algal density.
- To fully evaluate risk factors for streams it will be necessary to improve upon the available data for examining the relationship between flow and accrual of algae.
- Headwater stream nutrient concentrations can be higher because of loss in transit. The study results suggest that the headwater stream can be roughly double the water quality objective concentration of the receiving lake. The data analysis suggests that Ecoregion 6 headwater stream nutrient loadings and concentrations do frequently exceed the proposed EPA 304(a) criteria.
- In small streams with fast flows and an intact canopy that provides adequate shade it is unlikely that there will be any localized algal problems. The stream limit is likely to be driven by downstream receiving water body limits.
- Water quality nutrient objectives for large rivers that discharge into estuaries or lakes will be driven by conditions / limits in the estuaries or lake. Estuaries and lakes are more likely to be sensitive than the river.
- Watershed model results need to be validated against water quality data (i.e., predicted stream concentrations). This should include flux analyses estimating loads from monitoring data.
- The SPARROW coefficients, used to calculate nutrient removal in streams, were based on a national dataset. These coefficients need to be refined for California.
- The technical project team needs to continue their analysis of the Malibu datasets and interview the Principal Investigators. Other long-term or in-depth monitoring studies should be included in this effort (i.e., Santa Margarita River).
- The BATHTUB Model was used in this analysis for Ecoregion 6 to calculate allowable nutrient loadings as a function of lake residence time and non-algal turbidity for three target chlorophyll-a concentrations. Model parameters were defined based upon prior model applications in Ecoregion 6, an Ecoregion 6 database of lake water quality and hydraulic parameters, and Ecoregion 6 nitrogen and phosphorous loadings estimated using the SWAT SPARROW model. The model results show that regardless of lake residence time or turbidity, all normalized phosphorous concentrations less than 400 ug/L resulted in chlorophyll-a concentrations less than a 40 ug/L target, while normalized phosphorous concentrations had to be less than 100 ug/L to result in all chlorophyll-a concentrations less than a 10 ug/L target. Similarly, regardless of lake residence time or turbidity, all normalized nitrogen concentrations less than 3,200 ug/L resulted in chlorophyll-a concentrations less than a 40 ug/L target, while normalized nitrogen concentrations had to be less than 1,500 ug/L to result in all chlorophyll-a concentrations less than a 10 ug/L target. The model results were very sensitive to residence time and moderately sensitive to turbidity over the range of Ecoregion 6 parameter values.
- The BATHTUB Model analysis focused on a few key physical and chemical parameters to streamline this effort. Future work could investigate the variability in other parameters such as mean lake depth and the lake mixing depth that are also likely to impact the analysis.

- This BATHTUB Model analysis used uniform parameter distributions to define the ranges and frequencies of parameter variability, and assumed model parameters were not correlated. However, the true distributions of the parameters are most likely centered on some central tendency rather than uniformly distributed, and several of these parameters may be correlated. For example, the residence time data (Figure 1.4-13) may be log-normally distributed, and other data such as normalized nitrogen and phosphorous loadings may be normal or log-normally distributed. Parameters such as total phosphorous loading, which is typically present in insoluble forms, may also be correlated with non-algal turbidity. Future work could expand upon this sensitivity analysis by better defining the distribution of model parameters, weighting the frequency of occurrence based upon the parameter distributions, and correlating model parameters so that unrealistic outcomes (such as very high phosphorous concentrations and very low turbidity values) are avoided. This would further refine the modeling effort to better reflect Ecoregion 6 conditions.
- A stream response model, similar to the BATHTUB model for lakes, is needed for evaluation of processes in streams. This study considered streams to be transporters of nutrients, and biological effects within streams were not considered.
- The pilot study should be expanded to include another ecoregion even while refining the results for ecoregion 6. The Sierra Nevada Ecoregion has the advantage of research being conducted on Lake Tahoe and the Truckee River.
- EPA Region IX and the SWRCB should convene a technical meeting with key Regional Board members and regional experts from academic institutions for a meeting with the project technical team to further consider the results of the pilot project. The pilot project report should be revised and updated based on the review comments and supplemental analysis from this meeting prior to distribution of the pilot project report to the general RTAG / STRTAG. The truncated schedule did not allow for sufficient collaboration with the technical resources available to the project team through the RTAG / STRTAG or contributing academic institutions. This internal review could significantly add to the educational value of the pilot study report.

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