Collection and Evaluation of Ambient Nutrient Data for Rivers and Streams in New England

Data Synthesis Report
Final Report

A Cooperative Effort of the Following:

New England Interstate Water Pollution Control Commission

United States Environmental Protection Agency-New England

ENSR International

New England States Regional Technical Advisory Team

September 2003

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1.0 OVERVIEW OF NEW ENGLAND NUTRIENT DATABASE FOR RIVERS AND STREAMS

1.1 Purpose and Goal of Data Synthesis Report

The purpose of the Data Synthesis Report (DSR) is to summarize and document the results of ENSR's acquisition and database entry of qualified nutrient-related data. This data were collected to support and facilitate the development of regional New England nutrient criteria for rivers/streams and to provide analysis of potential approaches or classification schemes that States might consider in development of their nutrient criteria implementation plans. This document is a deliverable under Phase III, Year 2 of the "Collection and Evaluation of Ambient Nutrient Data" Project being conducted for the New England Interstate Water Pollution Control Commission ("the Commission") with funding provided by the United States Environmental Protection Agency (U.S.EPA) New England region.

This document identifies and describes data and its sources collected and evaluated for inclusion in the New England Nutrient Database for Rivers and Streams ("the Nutrient Database"). An analogous data collection and database development was conducted for lake and ponds and resulted in the New England Nutrient Database for Lakes/Ponds/Reservoirs (NEIWPCC, 2000). In the DSR, the Rivers and Streams Nutrient Database is fully described and summarized. Finally, the DSR identifies potential methods of developing draft nutrient criteria through as well as any outstanding issues that may need to be addressed further will be identified.

Specific objectives of the DSR are as follows:

- Provide sufficient regulatory background as a framework for the project objectives;
- Document and describe the sources of electronic nutrient data acquired;
- Describe the basic structure and features of the draft Database;
- Describe and summarize the contents of the draft Database with regard to amount of data, number of waterbodies, parameters of interest, ecoregional coverage, etc.;
- Refine the draft Database to identify waterbodies of interest (i.e., those for which sufficient nutrient data is available for comparison and analysis);
- Describe selection of reference, test, and impacted waterbodies;
- Provide examples of preliminary draft nutrient criteria based on suggested methods from the EPA Technical Guidance Document and other source; and
- Identify potential issues regarding development of nutrient criteria.

1.2 Relationship of Nutrient Database to Regional Nutrient Criteria Development

Development of regional waterbody-specific nutrient criteria is a national priority first identified in the *National Strategy for the Development of Regional Nutrient Criteria* (U.S. EPA, 1998). The U.S. EPA has issued Ambient Water Quality Criteria Recommendations (or "reference conditions") for nutrients for rivers and lakes in the 14 national ecoregions and States must make significant progress towards adopting nutrient criteria as water quality standards by the end of 2004. For New England, U.S. EPA has established numeric nutrient criteria recommendations for rivers in Ecoregions VII, VIII, and XIV (U.S. EPA, 2000b; 2000c; 2001). U.S. EPA has also issued waterbody-specific technical guidance, in the form of the *Nutrient Criteria Technical Guidance Manual Rivers and Streams* (U.S. EPA, 2000a.)

This project is being conducted as part of the overall U.S. EPA National Strategy, with the stated objective to investigate promising approaches to ecoregion-specific nutrient criteria and to assist the states in their development of implementation plans to adopt nutrient criteria. The major elements of this strategy are presented below, *with those elements most relevant to this project marked in italics*:

- *Use of regional and waterbody-type approach for the development of nutrient criteria;*
- Development of waterbody-type technical guidance documents (i.e., documents for streams and rivers; lakes and reservoirs; estuaries and coastal waters; and wetlands) that will serve as "user manuals" for assessing trophic state and developing region-specific nutrient criteria to control overenrichment;
- *Establishment of an U.S. EPA National Nutrient Team with Regional Nutrient Coordinators to develop regional databases and promote State and Tribal Involvement;*
- *Development by U.S. EPA of nutrient water quality criteria in the form of numerical regional target ranges, which U.S. EPA expects States and Tribes to use in implementing State management programs to reduce overenrichment in surface waters, i.e., through the development of water quality criteria, standards, NPDES permit limits, and total maximum daily loads (TMDLs); and*
- Monitoring and evaluation of the effectiveness of nutrient management programs as they are implemented.

To support this effort in New England, ENSR was contracted by the Commission to construct a regional database from existing Federal, State, academic and Tribal nutrient data. The development of the regional database for Rivers and Streams followed the following tasks:

- **Collection of Electronic Data** – recent vintage (i.e., 1990 or later) electronic databases of nutrient, trophic status response indicators, and ancillary water quality, flow, and watershed information will be obtained from Federal, State, Tribal sources, as well as other qualified sources (i.e., academic institutions, watershed groups);

- **Conduct QA/QC Reviews** – prior to inclusion into the regional database, information will be reviewed and documented with regard to accuracy, sufficiency, representativeness, and analytical quality. Data will be separated into those to be incorporated into the database and those deferred (and broadly classified as to quality) for later consideration (see Data Gap Analysis);

- **Data Distribution Report** – based on the primary data collection efforts, a Data Distribution Report (DDR) was generated (as internal document NEIWPCC and U.S. EPA) to that describes the nature and extent of the qualified waterbody nutrient data, along with summary statistics and preliminary analyses. The DDR identified potential data gaps; and

- **Data Synthesis and Final Report** – the completed regional Nutrient Database is presented with complete description of its development and a wide array of analyses and comparisons to support nutrient criteria development.

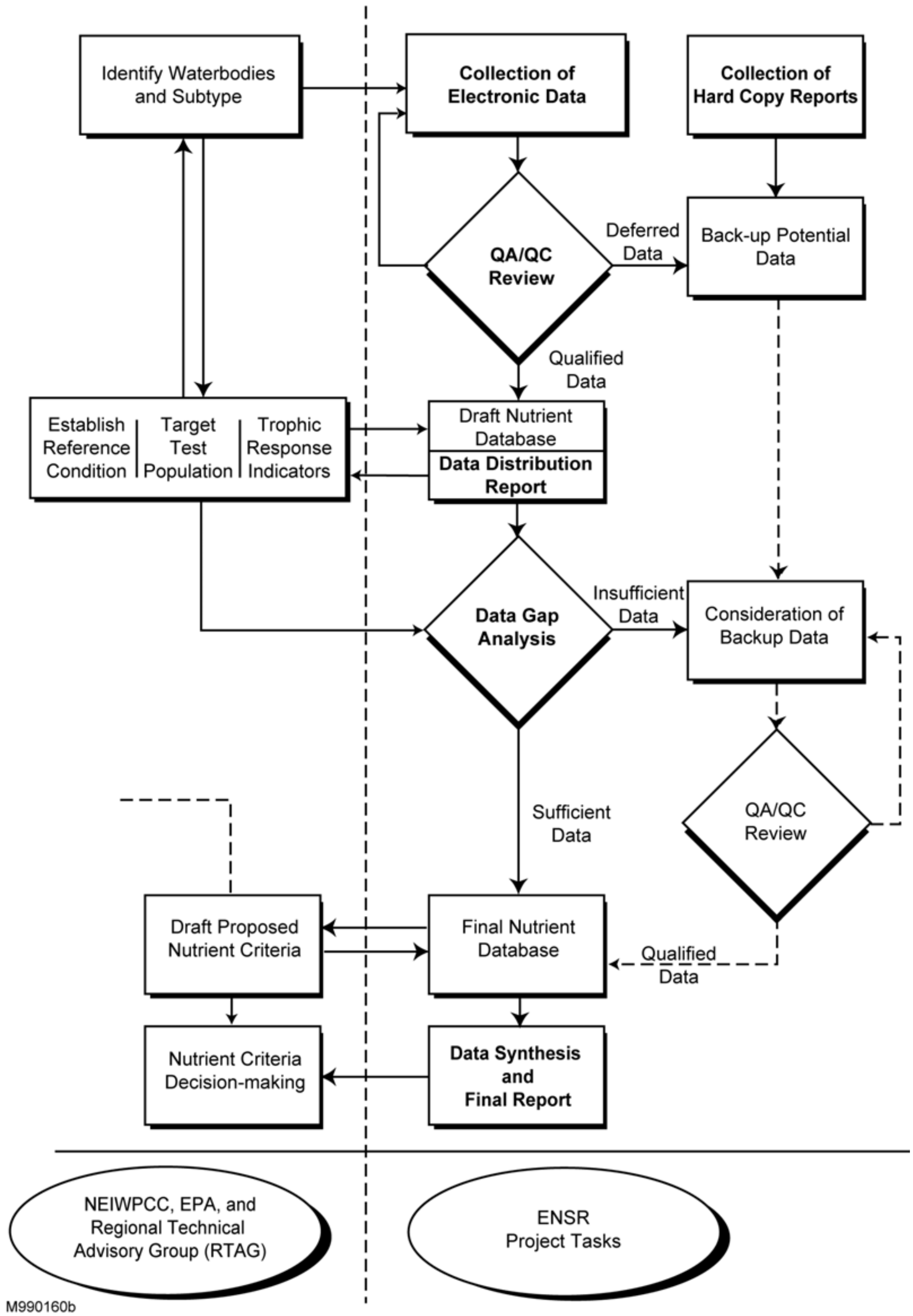
The general relationship between project tasks and the specific objectives is depicted in Figure 1-1, which provides a simplified flowchart indicating the sequence for development of the New England Nutrient Database for Rivers and Streams and its applicability to development of nutrient criteria.

The approach used for acquiring and classifying nutrient data in the database is similar to that for lakes and ponds and originally described in a Technical Memorandum (ENSR, 1999) during Phase I of this project. The Technical Memorandum was distributed and presented to the New England regional technical assistance group (RTAG), consisting of a selected number of state and federal agency contacts, U.S. EPA, and the Commission. The approach described by the Technical Memorandum was reviewed, discussed, and approved by the RTAG, U.S. EPA, and the Commission. This same approach was used in developing the R/S Nutrient Database

1.3 Organization of Report

This report is organized in the following fashion. Section 1.0 contains background material. Section 2.0 identifies the data sources for the New England Nutrient Database for Rivers and Streams. The structure and framework of the Database are described in Section 3.0, as is the quality assurance/quality control (QA/QC) aspects. Section 4.0 contains the Development Strategy used to develop and “refine” the initial database into a more focused and useable set of waterbodies and parameters and describes the data gaps analysis. Section 5.0 provides initial Summary Statistics on the waterbodies and major parameters of interest. Section 6.0 provides application of database to various potential classification and approaches for development of nutrient criteria. Section 7.0 looks at outstanding issues with the development of nutrient criteria for rivers and streams and a Summary is presented in Section 8.0.

Figure 1-1 Creation of Nutrient Database to Support Nutrient Criteria Development



2.0 SOURCES OF DATA

2.1 Data Sources

The primary goal of the project is to collect and analyze good quality data to help establish the basis and justification for regional nutrient criteria. To provide for this good quality database, nutrient data, trophic status response indicators, ancillary water quality parameters, flow, and watershed information on waterbodies in New England were acquired from a variety of qualified sources including state and Federal agencies, Tribal sources, academic institutions, watershed groups, and other sources. A list of the databases that were primary sources of data and the respective contact person are listed in Table 2-1. The data requested were for electronic databases of a fairly recent vintage (i.e., 1990 or later). A compilation of the databases used, with a brief description of the dataset, its parameters, and contact person is contained in Appendix A.

2.2 Spatial Data

The Geographical Information System (GIS) software ArcView (ESRI) was used to support some of the data mining and analysis tasks. The GIS interface was used to distinguish waterbodies from those with similar names, and to identify the correct ecoregion for each waterbody. Specific websites that were used are noted below. The spatial coverages were obtained electronically – from internet sites in most cases – and used to complete the database.

The EPA Non-Aggregated Ecoregions for United States were obtained from the EPA ftp site (ftp://cerberus.epa.orst.edu). The file covers the entire United States and shows five ecoregions within New England. Delineations of the 8-digit Hydrologic Units Codes (HUCs) were obtained from the USGS web site (www.usgs.gov). Counties and towns political boundaries were obtained from the ESRI Data CD of New England.

Additional spatial data sets were also obtained from each of the state's official GIS data web sites to help support technical analyses. These state-specific GIS sites are:

- Connecticut: http://magic.lib.uconn.edu/
- Maine: http://apollo.ogis.state.me.us/
- Massachusetts: http://www.magnet.state.ma.us/mgis/
- New Hampshire: http://nhresnet.sr.unh.edu/granit/overview.htm
- Rhode Island: http://www.edc.uri.edu/rigis/
- Vermont: http://geo-vt.uvm.edu/

Land use attributes for sampling station watersheds were derived from the USGS Spatially Referenced Regressions On Watershed Attributes (SPARROW) model (Smith et al., 1997). The SPARROW model is described on the web site (http://water.usgs.gov/nawqa/sparrow/). The specific land use categories were further combined into general land use classifications as urban, forest, agricultural, and water/wetland land uses.

2.3 Reference and Impacted Streams and Biocriteria Data

The States were submitted a list of the waterbodies listed for their state under the New England R/S Nutrient Database and requested to provide indication of reference or locations. Positive responses were received from Connecticut, New Hampshire, and Vermont in the form of either quantitative biocriteria scores or narrative text indicating whether the water quality station was fully, partially or non-supportive of aquatic life. In most case, waterbodies were identified such as reference stations or as impacted waste-receiving streams, or non-assigned waters. This information was used for the initial selection of reference locations further described in Sections 5.3 and 6.2. For determination of impacted streams, the major information source was the individual State's most current 303(d) list available at the State water quality agency website.

Table 2-1 Organizational Contacts for Water Body and Nutrient Data

Organization	Contact	Dataset Description	Example of Parameters	Years
Connecticut				
CTDEP	Michael Beauchene Mike.beauchene@po.state.ct.us	Electronic data for rivers and streams	Organic N, NH3, NO2, NO3, TKN, TP	1997-2002
Maine				
ME-DEP	Paul Mitnik Paul.Mitnik@maine.gov	River and streams data	CHL *a*, pH, SDT, TKN, NH3, TP	1980-1998
Penobscot Indian Nation	Dan Kusnierz Pinwater@mint.net	Rivers data for the Penobscot Watershed, ME	CHL *a*, SDT, Temperature, TN, TP, TSS	1994-1997
Massachusetts				
MADEP	Tom Dallaire, Russell Isaac thomas.dallaire-eqe@state.ma.us Russell.Isaac@state.ma.us	River and stream data	ALK, DO, NH3, pH, Temperature, TKN, TP	1994-1998
UMASS Acid Rain Monitoring Project	Paul Godfrey godfrey@tei.umass.edu	Data for streams located in 13 different counties in MA	ALK, NO3, pH, TP	1983-1993
New Hampshire				
MODERNIZED STORET	Deb Soule Dsoule@des.state.nh.us Gregg Comstock Gcomstock@des.state.nh.us	Data for NH rivers and streams, contributed by NHDES.	CHL *a*, DO, NH3, SDT, TKN, TP	1990-2000
Vermont				
VTDEC	Eric Smeltzer eric.smeltzer@anmail.state.vt.us Doug Burnham	River and stream data	CHL *a*, phytoplankton, SDT, TN, TP	1990-2001
Rhode Island				
RIDEM	Connie Carey ccarey@dem.state.ri.us	River and stream data	DO, pH, Temperature, TN, TP, TSS	1991-2001
URI Watershed Watch Program	Linda Green Lgreen@uri.edu	River and stream data	CHL *a*, SDT, TN, TP	1995-1998
RIUSGS		Data on 4 RI rivers	DO, NH3, pH, temperature, TP	1989-1997
National Level				
STORET	Dan Parker Parker.dan@epamail.epa.gov	Stations in CT (70), MA (48), ME (12), RI (5), VT (22)	DO, SDT, Temperature, TP, TKN	1990-1997
EMAP	Stephen Hale Hale.Stephen@epamail.epa.gov	Stations in CT (1), MA (2), NH (1)	CHL *a*, SDT, TN, TP, Turbidity	1991-1994

3.0 DATABASE DESCRIPTION

The New England Nutrient Database was assembled from the data acquired from the data sources identified in Section 2.0. A description of the structure of the Database is given in Section 3.1. The main data tables are described in Section 3.2. The Quality Assurance / Quality Control measures taken in reviewing, verifying, and accepting the data are described in Section 3.3.

3.1 Database Structure

A relational database was designed and implemented in Microsoft Access97 to accumulate and manipulate the extensive amount of available electronic data. This database was adapted from an existing one provided by national U.S. EPA headquarters. It has been revised and adapted to meet the needs of this project. A relational database is a collection of data items organized as a set of formally-described tables that are linked into a logical structure. The New England Nutrient Database includes tables and queries. Tables are collections of data on a given topic, and their content and the relationships defined among the different tables form the core of the database applications. Queries present a certain view of the data contained in tables, or may be used to update, append or edit data records.

The data were organized into four main tables each representing one level of information, as shown in Figure 3-1. These tables contain information on the waterbody, station, sample, and water quality data, respectively. The tables are linked to each other through one-to-many relationships with enforced referential integrity. Referential integrity means that records in each main (or so-called "parent") table are unique but may be associated with one or more derivative (or so-called "child") records in other tables. As such, a given waterbody may have one or more stations, each measured at one or more points in time, and each water sample may have been analyzed for one or more parameters. This staged structure ensures that each data item appears once only in the database, eliminating duplicate information and minimizing possible errors.

Within a given table, uniqueness of information is enforced through a single unique key field or unique combinations of fields. In the waterbody and station tables, a single field contains the identification of a unique record, the waterbody_ID and station_ID fields, respectively. In the case of the sample table, a unique record is one with a unique combination of Station ID, Sampling Date, Sampling Time, Sample Depth, and Sample Type. In table WQData, a unique record is one with a unique combination of Sample ID, Parameter, and Reported Value.

In addition to the four main data tables, a number of lookup tables have been developed to provide the possible range of values or categories for some of the fields. The relationships between the main data tables and lookup tables are indicated in Table 3-1.

3.2 Main Data Tables

As noted above, the data is contained in four main data tables representing different levels of information. A listing of the fields found in each of the main data tables is provided in Appendix B. This section discusses some of the implications of the logical organization of the data.

The table Waterbody contains information that is specific to a given waterbody. A waterbody is defined as a body of water with finite, well-defined extents and relatively homogeneous physical characteristics. A waterbody can be an entire river or stream, or a specified segment or reach along a given river or stream. The subdivision of rivers and streams into segments with relatively homogeneous characteristics is complicated, as depth, flow, and other physical characteristics are expected to change with the distance from the headwaters.

The tables Waterbody and Station contain information at two different levels of spatial extent. The table Waterbody contains overall characteristics of the waterbody while the table Station refers to a specific location on that waterbody. For example, a waterbody may have stations located in different ecoregions.

3.3 Quality Assurance and Quality Control Issues

An important part of the project was Quality Assurance / Quality Control ("QA/QC"). The following section addresses important QA/QC issues for the Database.

3.3.1 Data Import and Database Structure

The majority of the data were obtained electronically from qualified sources in the form of databases or spreadsheets. In most cases, the format of the data needed only to be manipulated slightly to make it compatible for importing into the Nutrients Database. As such, data entry errors were assumed to be limited to those that could have taken place in the original data source.

The database enforces referential integrity of the information. For example, records can only refer to existing "parent" records (e.g., sample at existing stations). In many cases, unique identifiers were defined that prevent the duplication of information such as lake name, station ID, etc. The referential integrity check also prevents the importation of unassociated or so-called "orphan") data (i.e., data without associated sample, station, or waterbody). The use of lookup tables to provide a limited choice of valid values for some of the fields in the main tables also ensures minimal error in the content of the database. This ensures consistency of values and codes across data sources. For example, water quality parameters are limited to values listed in the Parameters lookup table.

3.3.2 Duplication of Data Among Data Sources

Because of the large number of data sources utilized, and the realization that some waterbodies potentially had measurements reported by two or more different agencies, the water quality measurements present in the draft Database were scanned for duplicates. This verification was performed by comparing the combination of information relating to waterbody, sampling date, sample depth, parameter and value reported. In cases where more than one unique such “combination” was found for different data sources (e.g., between STORET records and a State Agency electronic file), the duplicate STORET record was flagged as non-useable, and not included in subsequent data analyses. Duplicates within a single data source were assumed to be legitimate and were identified as “DUP” in the sample type field.

3.3.3 Additional Verifications

As noted in Section 3.1, no attempt was made to verify the electronic data submitted by the agencies. However, data for selected trophic parameters within the refined Database (described in Section 4.0) were compared with a likely range of values (based on best professional judgment) to insure that the reported values were within the range of “reasonable” values. Reported values for total phosphorus (TP), total nitrogen (TN), and chlorophyll *a* (Chl *a*) were compared to the reasonable range (Table 3-2). Reported values that were outside of the range were further investigated and verified against the original source of the data. Negative and null concentrations were also searched for and investigated. When data were outside the expected range and there was some potential explanatory factor readily available (negative values, unit errors, etc), the data were removed from the database. On the other hand, some reported values were outside of the range, but there was no reason to question the accuracy of the data. In these cases, the values were retained in the Database.

Many data contributors had initially estimated latitudes and longitudes of sampling stations from USGS quadrangles or road atlases. Since the Global Positioning System (GPS) has become widely available in the interim, agencies were requested to provide updated station coordinates for stations lacking coordinates or for stations with potentially inaccurate coordinates as identified with GIS and SPARROW.

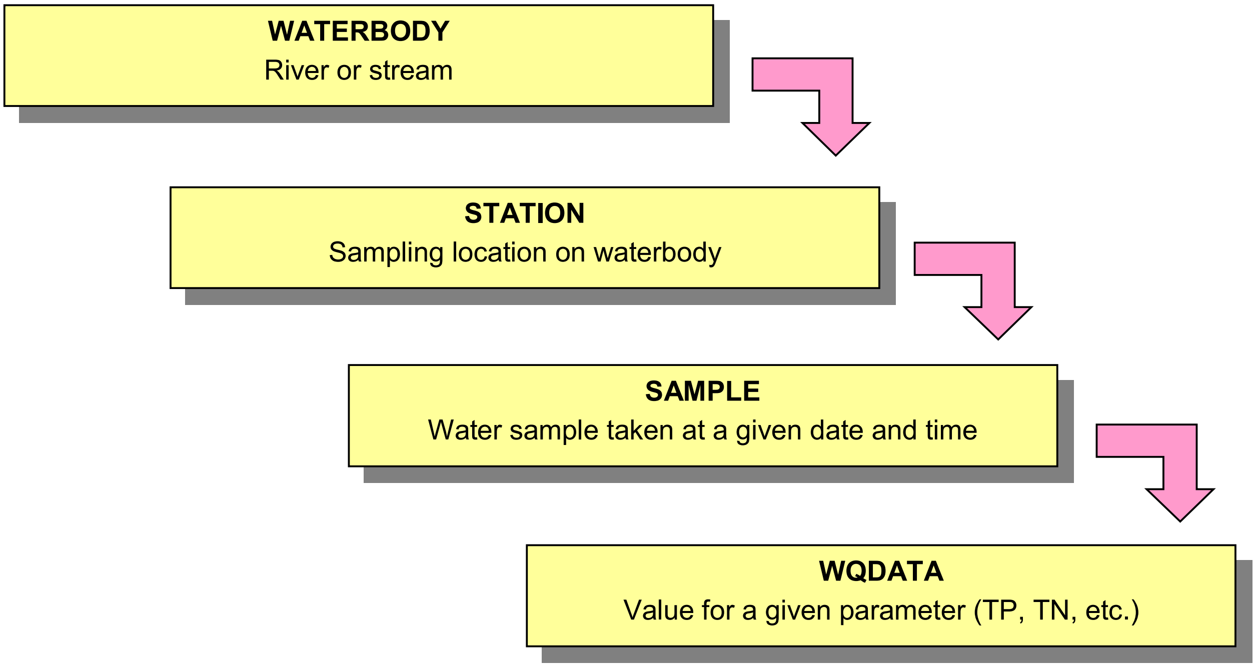
Table 3-1 Relationships Between Main Data Tables and Lookup Tables

Lookup Table	Main Table	Field	Source for Link Field
LTBL_AnalysisMethod	WQData	Analysis Method	Code for analysis method used.
LTBL_EPAEcoregion	Waterbody	EPA Ecoregion	Name of non-aggregated ecoregions for New England .
LTBL_Parameters	WQData	Parameter	Code for chemical/biological/physical parameter measured
LTBL_Qualifier	WQData	Reported_Qualifier	Remark on value reported. Unless specified, codes are same as used in STORET.
LTBL_Sample_Type	Sample	Sample Type	Type of sample collected (target, duplicate, etc.)
LTBL_Sampling_Conditions	Sample	Sampling Conditions	Conditions at time of sampling (dry, wet, unknown)
LTBL_Sampling_Method	Sample	Sampling Method	Sampling method used (grab, hose, composite, etc.)
LTBL_State	Waterbody Station	State	Two-letter postal abbreviation.
LTBL_Units	WQData	Unit of Measure	Abbreviation of measurement units
LTBL_WaterbodyType	Waterbody	Waterbody Type	Code for waterbody type (P, R, S, M, O)

Table 3-2 "Reasonable" Range of Values Expected for Trophic Parameters

Trophic Parameter	Minimum Value	Maximum Value
Chl *a* (ug/L)	0	250
TN (ug/L)	0	5,000
TP (ug/L)	0	5,000

Figure 3-1 Database Main Data Tables Structure



4.0 DEVELOPMENT OF NUTRIENT DATABASE

This section describes the initial draft Database and its contents (Section 4.1). Due to the size of the initial draft database and the inclusion of many water quality records of lesser importance to the development of regional nutrient criteria, a subsequent “refined” New England Nutrient Database for Rivers and Streams (“refined Database”) was developed. Section 4.2 describes the strategy used to develop the refined Database and Section 4.3 provides a summary of its contents. Section 4.4 discusses the sequence for processing of nutrient data for calculation of a representative value for an individual waterbody and/or ecoregion.

4.1 Initial Database Waterbody and Parameter Inventory

Historical water quality and ancillary data were collected from a multitude of sources that included federal and state agencies, volunteer groups and a Native American Nation. The data sources are previously discussed in Section 2.0. No attempt was made to filter data during the initial data collection period. Some of the features of this so-called “initial” Database are discussed below.

4.1.1 Distribution of Data Sources

The distribution of the water quality measurements by source of data is presented in Figure 4-1. The major portion of the data came from twelve sources: state and federal agencies, academic institutions, and a Native American Nation. It should be noted that the distribution shown represents all of the water quality records in the initial Database. It is quite different from the distribution in the refined Database, which consists solely of data from water quality stations where one or more of the key trophic indicators (i.e., Chl *a*, Secchi disk transparency (SDT), TN, and TP) was measured.

4.1.2 Time Period and Seasons Covered

The initial Database contains data from June 1980 to August 2002, although the vast majority of data were collected from 1990 to 2001. The temporal distribution of the data for the selected trophic parameters is presented in Figure 4-2. This graphic presents the number of records available for each year for the selected trophic parameters. As indicated on Figure 4-2, the period 1990-91 provided the largest contribution of nutrient data, but significant contributions where made to the database during all periods of interest, without one period unduly over-represented.

A further breakdown of the data by season is presented in Figures 4-3 and 4-4 for the key trophic parameters TP and TN, respectively. It can be seen that TP was typically sampled in the spring (to capture spring runoff events) and in summer, with minimum sampling in winter. For TN, the summer season predominates among data records. The seasonal distributions of data were further evaluated in the calculation of representative parameter values (see Section 4.4).

4.1.3 Water Quality Measurements

The initial Database contained over 2,150 rivers and streams and over 172,000 water quality data records. However, because of the diverse goals of the various monitoring programs that provided the information (e.g., Acid Rain Monitoring (ARM) Program), a large portion of the data reported were for parameters that are not necessarily directly related to nutrients, such as alkalinity, temperature, and pH. Whereas these parameters may be potentially useful in allowing secondary classification of the waterbodies, they do not provide information directly applicable to the trophic status of the waterbody. Conversely, some of the nutrient data were not appropriate for application to surface waterbodies (e.g., groundwater nitrate records).

Despite these limitations, the identified critical trophic parameters of interest are reasonably well represented by records within the initial Database. This includes about 11,370 TP records, 3,880 TN records, and 1,490 Chl *a* records. The least-represented trophic parameter was SDT, with fewer than 590 records; which is not surprising since this parameter is not typically measured in streams and rivers.

4.1.4 Distribution of Waterbodies

The distribution by state of the rivers and streams contained in the initial Database is presented in Table 4-1. Massachusetts data sources provided the largest fraction of the sampled waterbodies in the initial Database. However, many of these waterbodies were sampled as part of the ARM program, were typically not sampled for nutrients, and therefore had little utility for purposes of this analysis.

4.2 Development of a Refined Database

At the end of the primary data collection period, the initial Database contained a large number of waterbodies (>2,150) and water quality records (>172,000). While this amount of data is impressive, much of the data were not directly applicable to the issue of developing regional nutrient criteria; although, as noted above, some of the data may be useful for further correlation with and/or categorization of waterbodies. In addition, there were pragmatic considerations regarding the availability of ancillary information for the selected waterbodies. For example, it was necessary to identify the spatial coordinates (i.e., latitude and longitude) for each waterbody sampling station to assign watershed and ecoregional status. Therefore, it was considered prudent to first reduce the size of the database to those waterbodies and qualified data necessary for further analyses and investigations to support nutrient criteria development.

Some of the data were discarded through elimination of data with apparent transcription errors or unrealistically large concentrations (see Section 3.3). This results in an intermediate database, which was termed the “qualified” database since the data had gone through the QA/QC process. However, this database did not significantly reduce the amount of data nor did it deal with the problem of water quality stations and samples for non-trophic parameters.

Accordingly, a decision was made to produce a second, smaller and more focused database. We have used the term "refined" Database to refer to this effort since it represents a distillation of the information in the initial Database. Since the purpose of the project is to provide a database for further analyses and investigations to support regional nutrient criteria, the refined Database contains only those rivers and streams for which information is available for the relevant trophic parameters. The purpose and strategy for development of a refined Database was discussed and consensus reached with the Commission and U.S. EPA Regional Nutrient Coordinator in meetings during summer 1999. This approach was presented to the RTAG at the September 30, 1999 meeting and is consistent with the overall goals of the program. While the approach was originally designed for application to lakes and ponds, it is considered a sound and appropriate approach for rivers and streams as well.

Briefly, the strategy acknowledges that not all waterbodies were sampled for the key trophic parameters (Chl *a*, SDT, TN and TP). In fact, fewer than 2% of the waterbodies in the initial Database had information for three of these four parameters. Comparison of the number and location of these waterbodies indicated that this clearly was an insufficient number to meet the target ranges for waterbodies discussed in the Technical Memorandum (ENSR, 1999), as well as provide the ecoregional coverage desired. Therefore, the next step was to significantly relax the requirements for the representation of trophic parameters.

Based on the uneven availability of data, the decision was made to include those waterbodies that had data for Chl *a*, SDT, TN or TP (see Figure 4-5). Adoption of this strategy greatly increased the number of available waterbodies, and allowed inclusion of most of the key trophic parameter data that was in the initial Database (Table 4-2). The refined Database is composed of 569 rivers and streams. The distribution of rivers and streams across the states is shown in Table 4-3. Potential limitations to the development of the nutrient criteria from looking at this number of waterbodies will be discussed in Section 7 of this report.

The waterbodies represented by the totals in Table 4-3 were the basis of the further investigation. The spatial coordinates of each waterbody sampling station were obtained wherever possible and used to ascertain the ecoregion classification via GIS, as well as to characterize via the SPARROW model (through cooperation of the USGS) the land use attributes of sampling station watersheds (see Section 5.1). With the help of the respective state agencies, efforts were made to review and complete as much of the descriptive information as possible for these waterbodies and their sampling stations as to their physical characteristics, location coordinates, etc., in order to provide a complete basis for evaluation.

The refined Database contains water quality data from rivers and streams from all six New England states. However the largest numbers of rivers and streams are located in Connecticut (149) and New

Hampshire (182), with variable distribution among the other states, ranging from 29 in Vermont to 92 in Massachusetts.

4.3 New England Rivers and Streams Nutrient Database

The refined Database (henceforth refer to as the New England Rivers and Streams (NE R/S) Nutrient Database) represents a valuable compendium of recent water quality data from New England waterbodies, collected from a multitude of sources that includes federal and state agencies, academic institutions volunteer groups and Native American groups. The nature and characteristics of the NE R/S Nutrient Database are discussed further below.

4.3.1 Waterbodies Represented in the NE Rivers and Streams Nutrient Database

The NE R/S Nutrient Database is comprised of nutrient and ancillary water quality data from 569 New England rivers and streams. These include both relatively well-studied as well as poorly characterized waterbodies. This disparity is reflected by the variability regarding the number of water quality sampling stations on each of these waterbodies, ranging from a single station to 47 stations (Penobscot River, ME). The vast majority of streams were characterized by data from either a single (355) or two (94) water quality sampling stations. Approximately 90% of the rivers and streams (512 waterbodies) were characterized by data from 5 or fewer stations. The distribution of the number of water quality stations per waterbody is shown on Figure 4-6. Closer inspection of the database indicated that waterbodies with greater than 10 stations are generally major rivers. However the converse is not always true, since several major rivers or segments of rivers may be represented only by a few water quality stations (e.g., two sampling locations for the Connecticut River in Connecticut).

Twenty of the waterbodies in the NE R/S Nutrient Database were rivers with water quality sampling locations in more than one state. Table 4-4 provides a listing of the interstate rivers represented by two states in the NE R/S Nutrient Database. For purposes of the analyses conducted in the DSR, the segments sampled by different states are treated in the database as separate waterbodies. Similarly, waterbodies identified as “West Branch of…”; Tributary to…” etc. were considered separate waterbodies for this stage. Potential pooling of all segments of a large river system will be evaluated in Section 6.3).

4.3.2 Watershed Characteristics of Rivers and Streams of NE R/S Nutrient Database

The rivers and streams in the NE R/S Nutrient Database range in size from headwater streams (i.e., first or second-order tributaries) to major regional rivers (e.g., Merrimack River, Connecticut River). Both the absolute size and existing land use in these watersheds have an important influence on the water quality of the waterbody draining it. It was possible to quantify the watershed areas for waterbodies using the USGS SPARROW model’s estimate of watershed size associated with a point sampling location (Moore and Hayes, 2003 pers. comm.). ENSR provided the geographical coordinates of the appropriate water quality stations to USGS staffers (under the direction of Keith Robinson - whose cooperation and coordination is gratefully acknowledged). USGS, through the use of its watershed and land use layers in its SPARROW model, used these coordinates to provide ENSR with the estimated watershed size, estimated flow (based on a fixed watershed yield model), and watershed land uses (based on National Resource Inventory).

It should be noted that the watersheds provided by the SPARROW model are not precise measurements of the true watershed area (i.e., estimate of all land draining through a point on the waterbodies). Rather, the watershed estimates are based on the location of the stream reach that the water quality station fell on (e.g., a station may have fallen in the middle of a SPARROW reach). Since most SPARROW reaches are relatively small in length (e.g., on order of 0.3-0.5 miles long), the differences in the watershed SPARROW provided vs. the true watershed was considered minimal.

In the case of waterbodies with greater than one station, the water quality station furthest downstream was selected as representing the watershed (and its watershed land use). This assumption is most accurate for rivers and streams with 1 or 2 water quality sampling stations and least accurate for large rivers with multiple stations widely separated. Thus, the land use associated with the watershed of large rivers represents a cumulative influence upon the waterbody rather than a tightly coupled effect at a specific point.

Figures 4-7 and 4-8 provide comparison of the frequency distribution of watershed sizes in the initial and NE R/S Nutrient Databases, respectively. As can be seen in both figures, most watersheds are fewer than 25 square miles in size, with a progressive reduction in numbers with increasing watershed size. The shape of both figures is very similar in both initial and refined Database. This indicates that the sub-sample of waterbodies represented by the NE R/S database provides a representative spectrum of watershed size classes from within all available New England river and stream sampling locations. It should be noted that the spectrum of waterbodies for which sampling has been conducted is not a true statistically non-biased representation of all New England rivers and streams. As noted in Rohm et al. (2001), sampling stations are preferentially located on larger streams or those waterbodies where issues regarding ambient water quality or associated discharges warranted regular monitoring.

4.3.3 Frequency Distribution of Key Trophic Parameters

The range and distribution of data for the key trophic parameters in the NE R/S Nutrient Database was further investigated. Figures 4-9 to 4-11 show the frequency distribution of TP, TN, and Chl *a*, in rivers and streams of the NE R/S Nutrient Database. As these figures indicate, populations of trophic parameters are differentially distributed. For example, the data distribution for TP strongly indicates a bimodal distribution indicative of a potential underlying distinction among various classes of rivers and streams (Figure 4-9). This distribution is suggestive of two populations of waterbodies, presumably based on the presence of point-source wastewater loadings. This same pattern is not seen in the nitrogen and chlorophyll distribution, which are more log-normally distributed (Figures 4-10 and 4-11).

The identification of streams and rivers receiving wastewater or otherwise impacted is discussed further in Section 6.2.1).

4.4 Sequence for Nutrient Data Processing

The NE R/S Nutrient Database contains a large amount of information that has to be extracted, sorted and analyzed to answer the very specific questions for the development of nutrient criteria. One of the critical decisions in application of the database to nutrient criteria development is to determine how trophic parameter data will be "averaged" to produce a representative value from the dataset of an individual waterbodies, regardless of the number of samples obtained from that waterbody. There are several ways to produce such a representative value, with potential advantages and drawbacks to each of these methods.

U.S. EPA has provided the following protocol for statistical summarization of water quality parameters in the Ambient Water Quality Criteria Recommendation documents (U.S EPA, 2000b; 2000c; 2001). The data are sorted by season, with the seasonal indices adjusted by aggregate ecoregion. New England contains rivers and streams in Level III Aggregate Ecoregions VII, VIII, and XIV and these have slightly different seasonal indices. Therefore, the following definitions of seasonal indices were used for the Data Synthesis Report:

- Spring – months of March to May;
- Summer – months of June to August;
- Fall – months of September to November; and
- Winter – month of December to February.

To provide a single representative parameter value for a waterbody, U.S. EPA developed a median value for all parameters within a waterbody for each of the four seasons over the period of record (U.S. EPA, 2001). This method is used to prevent over-representation of an individual waterbody with a large amount of data vs. those with fewer data. The 25th percentile for "all seasons" is calculated by taking the median of the four seasonal 25th percentiles (this can be done with 3 seasons, if only those are available). This process is graphically displayed in Figure 4-12.

For calculation of the individual representative values for New England rivers and streams, ENSR followed the U.S. EPA protocol using the step-wise data transformation procedure outlined below.

1. All measurements for a water quality parameter made during a seasonal index period (e.g., September to November) for a waterbody are combined and the median value calculated. This produces a stream- and season-specific value;

2. All stream- and season-specific values for a water quality parameter for a particular ecoregion are pooled, the various statistical indices calculated (e.g. the 25th percentile). This produces an ecoregion- and season-specific value; and

3. The four ecoregion- and season-specific values are pooled (e.g., the four seasonal 25th percentiles from an ecoregion) and the median value taken. This produces an ecoregion and "all seasons" value.

This protocol was used to produce the statistical values described in the following chapters. This allowed direct comparison with ecoregion–specific values listed in the EPA nutrient criteria recommendation documents (U.S. EPA, 2000b; 2000c; 2001).

Table 4-1 Number of New England Rivers and Streams in Initial Database by State

State	Rivers and Streams
Connecticut	153
Massachusetts	1,613
Maine	46
New Hampshire	218
Rhode Island	91
Vermont	41
New England Total	**2,162**

Table 4-2 Distribution of Data in the Initial Database and Refined Database by State and Source

State	Data Source	Min. Sample Date	Max. Sample Date	Number of Data Points in Initial Database	Percent	Number of Data Points in Refined Database	Percent
CT	CTDEP, 2002	23-Apr-97	26-Aug-02	6,520	3.8%	1,101	6.3%
CT	EMAP	15-Aug-94	15-Aug-94	13	0.0%	4	0.0%
CT	STORET	08-Jan-90	21-Mar-97	12,520	7.3%	2,801	16.1%
MA	EMAP	19-Jul-91	28-Jul-93	25	0.0%	8	0.0%
MA	MA-ARM	20-Mar-83	25-Jul-93	58,999	34.3%	0	0.0%
MA	MA-DEP	15-Jun-94	22-Apr-98	10,342	6.0%	671	3.9%
MA	STORET	08-Jan-90	25-Mar-97	1,655	1.0%	386	2.2%
ME	ME-DEP Bouchard	17-Jun-80	17-Oct-98	445	0.3%	59	0.3%
ME	ME-DEP Mitnik	02-Aug-89	21-Aug-98	5,408	3.1%	919	5.3%
ME	Penobscot Indian Nation	21-Jul-94	17-Sep-97	1,383	0.8%	546	3.1%
ME	STORET	24-Jan-90	28-Aug-96	1,097	0.6%	235	1.4%
NH	EMAP	21-Jul-91	21-Jul-91	11	0.0%	0	0.0%
NH	MODERNIZED STORET, 12/2002	28-May-90	07-Dec-00	50,656	29.4%	3,629	20.9%
NY	VT-DEC Nutrients DB	14-Mar-90	10-Nov-97	5,141	3.0%	0	0.0%
NY	VTDEC, 2002	22-Oct-96	29-Aug-01	37	0.0%	0	0.0%
RI	RI-DEM	12-Mar-91	16-Sep-97	1,762	1.0%	129	0.7%
RI	RI-USGS	03-Oct-89	07-Nov-97	760	0.4%	54	0.3%
RI	RIDEM, 2002	14-Apr-98	25-Apr-01	1,556	0.9%	447	2.6%
RI	STORET	16-Jan-90	27-Mar-97	2,359	1.4%	556	3.2%
RI	URIWW	15-Apr-95	10-Dec-98	2,961	1.7%	2,961	17.1%
VT	STORET	18-Jan-90	12-Sep-95	585	0.3%	263	1.5%
VT	VT-DEC Nutrients DB	14-Mar-90	10-Nov-97	7,756	4.5%	2,492	14.4%
VT	VTDEC, 2002	24-Jul-95	02-Jul-01	101	0.1%	90	0.5%
			Totals:	**172,092**		**17,351**	

Table 4-3 Number of New England Rivers and Streams in Refined Database by State

State	Rivers and Streams
Connecticut	149
Massachusetts	92
Maine	36
New Hampshire	182
Rhode Island	86
Vermont	29
New England Total	**569**

Table 4-4 List of Interstate Rivers in Refined Database

Interstate Rivers	States
ANDROSCOGGIN RIVER	ME, NH
BLACKSTONE RIVER	MA, RI
COCHECO RIVER	ME, NH
CONNECTICUT RIVER	CT, NH
FALLS RIVER	CT, RI
FRENCH RIVER	CT, MA
GREEN RIVER	CT, RI
HOUSATONIC RIVER	CT, MA
KONKAPOT RIVER	CT, MA
MERRIMACK RIVER	MA, NH
MILLERS RIVER	MA, NH
MOOSUP RIVER	CT, RI
NASHUA RIVER	MA, NH
PAWCATUCK RIVER	CT, RI
QUINEBAUG RIVER	CT, MA
SACO RIVER	ME, NH
SALMON FALLS RIVER	ME, NH
SHUNOCK RIVER	CT, RI
TEN MILE RIVER	MA,RI
WOOD RIVER	CT, RI

Figure 4-1 Distribution of Water quality Data in the Initial NE R/S Database by Source of Data

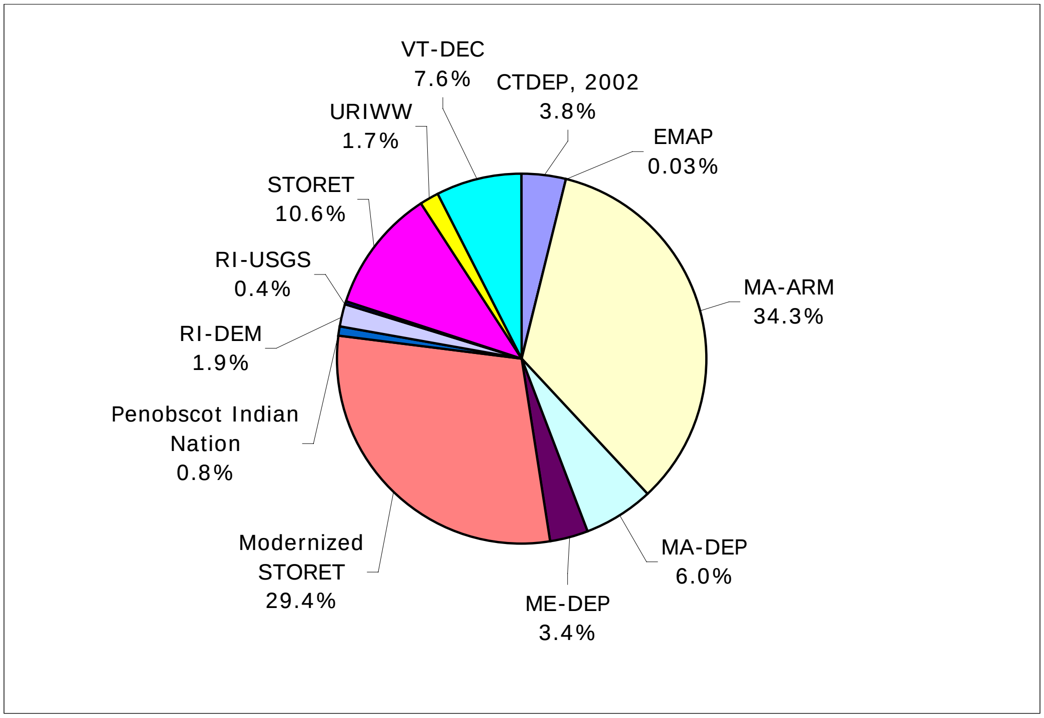
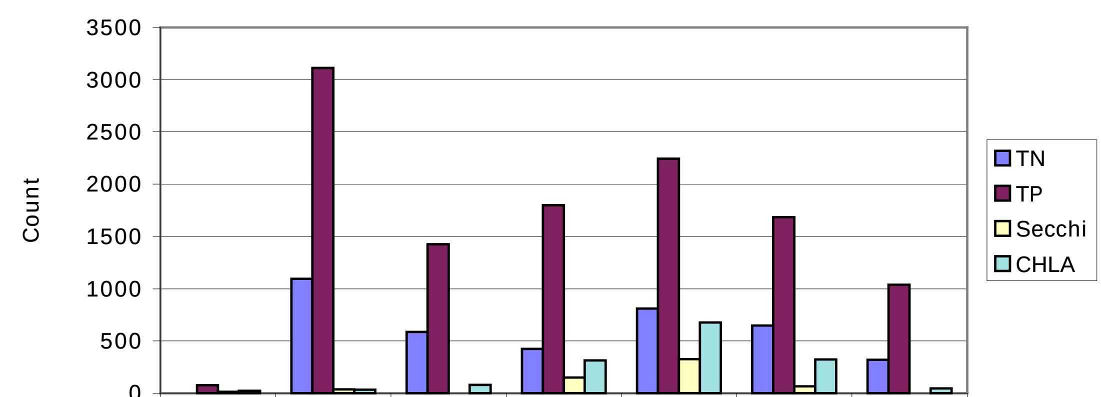


Figure 4-2 Distribution of Records in the Qualified Database by Year for Selected Parameters



	Prior to 1990	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	>2000
TN	0	1096	587	425	810	647	319
TP	76	3112	1427	1800	2244	1684	1037
Secchi	13	36	1	151	325	66	0
CHLA	23	33	79	315	676	322	45

Year

Figure 4-3 Seasonal Distribution of Total Phosphorus Records in the NE R/S Nutrient Database

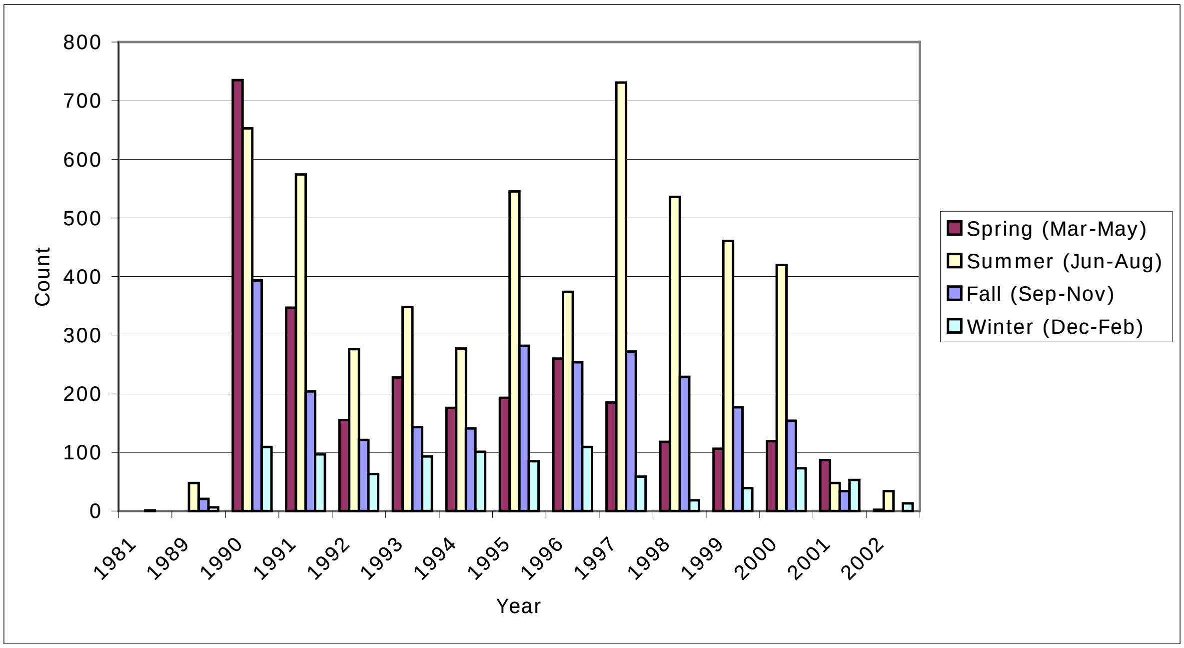


Figure 4-4 Seasonal Distribution of Total Nitrogen Records in the NE R/S Nutrient Database

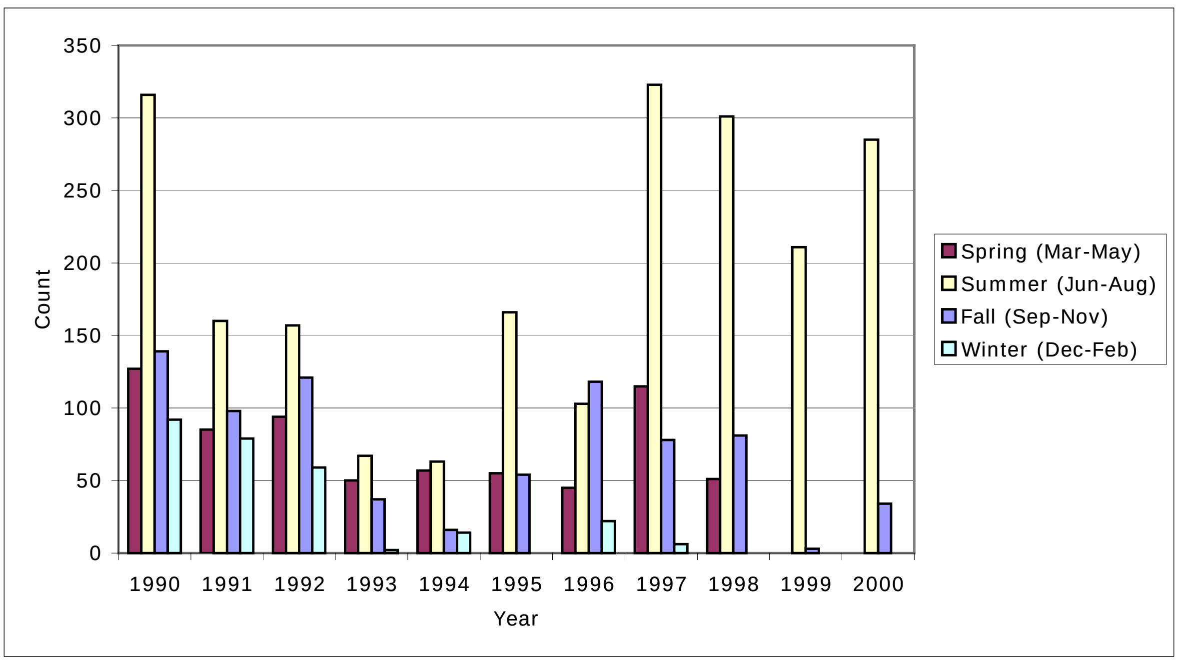


Figure 4-5 Flow Chart of Water Quality Sampling Location Selection for NE R/S Nutrient NE Nutrient Database

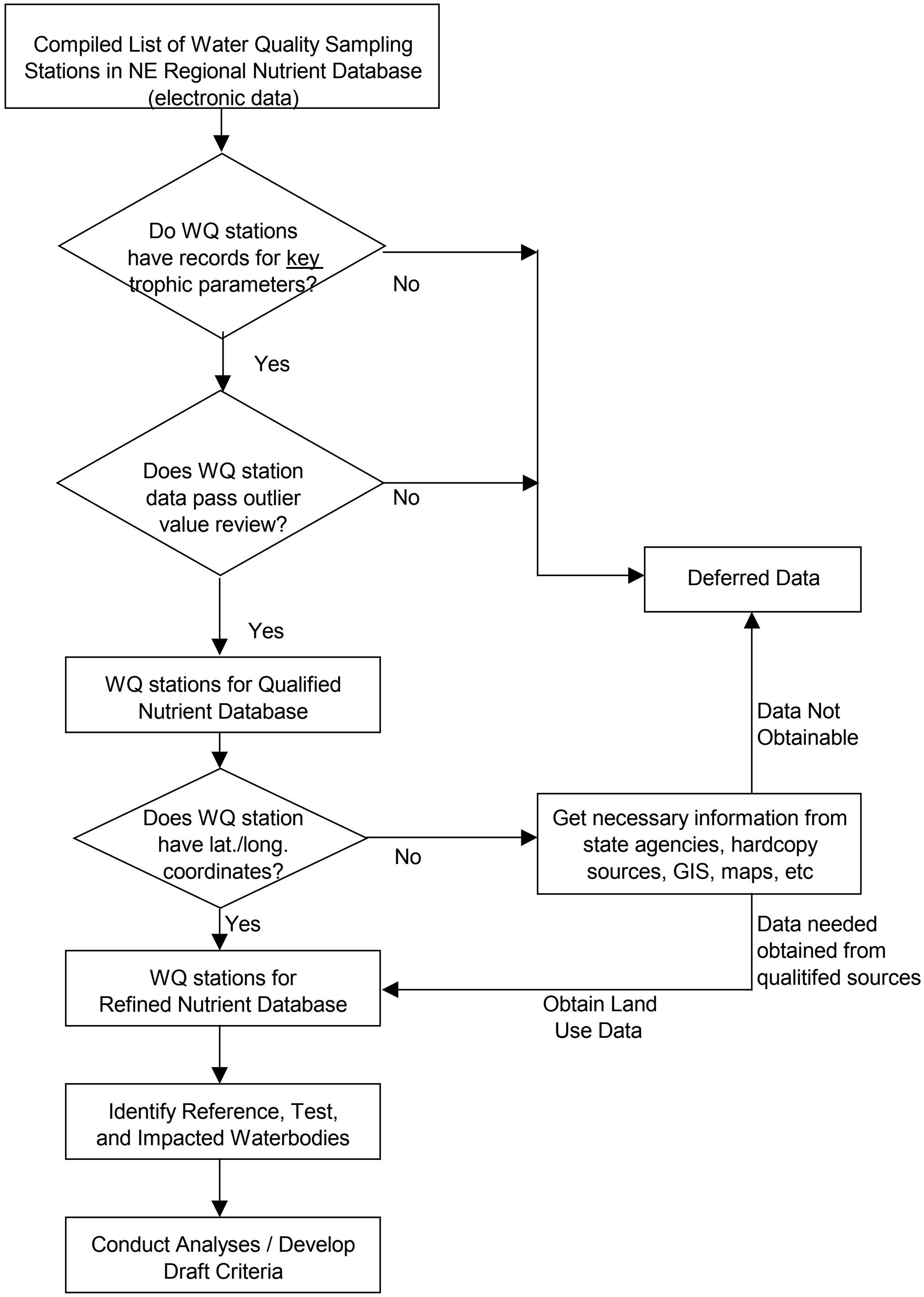


Figure 4-6 Number of Water Quality Stations per Waterbody in NE R/S Nutrient Database

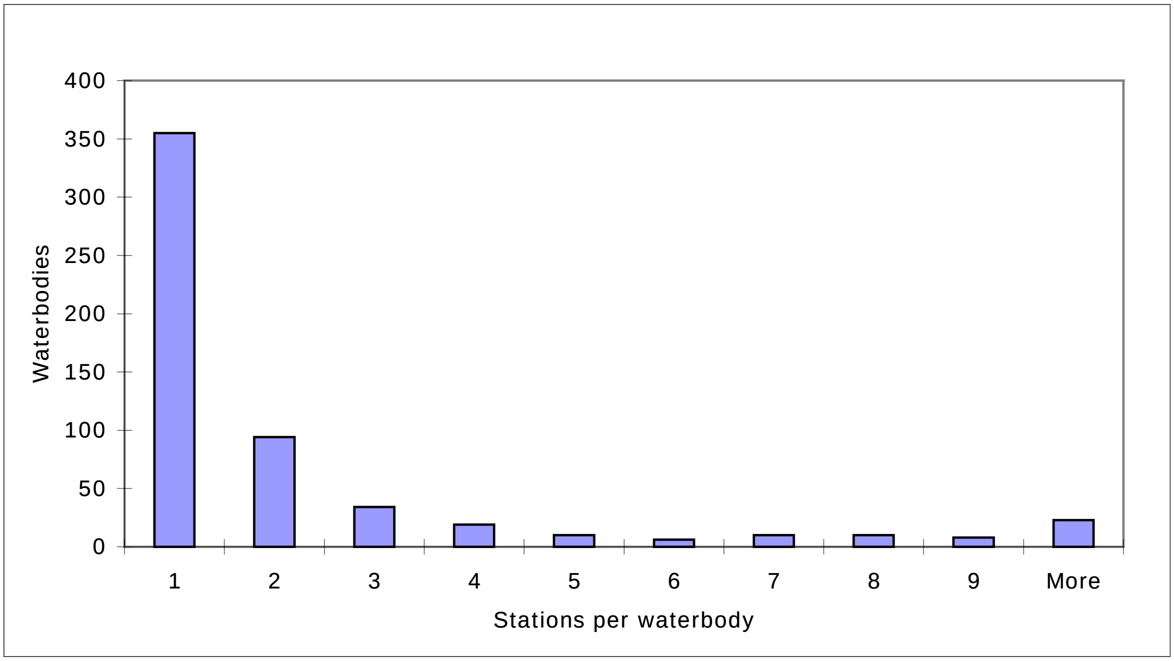


Figure 4-7 Frequency Distribution of the Average Watershed Size for All Stations in Initial Data

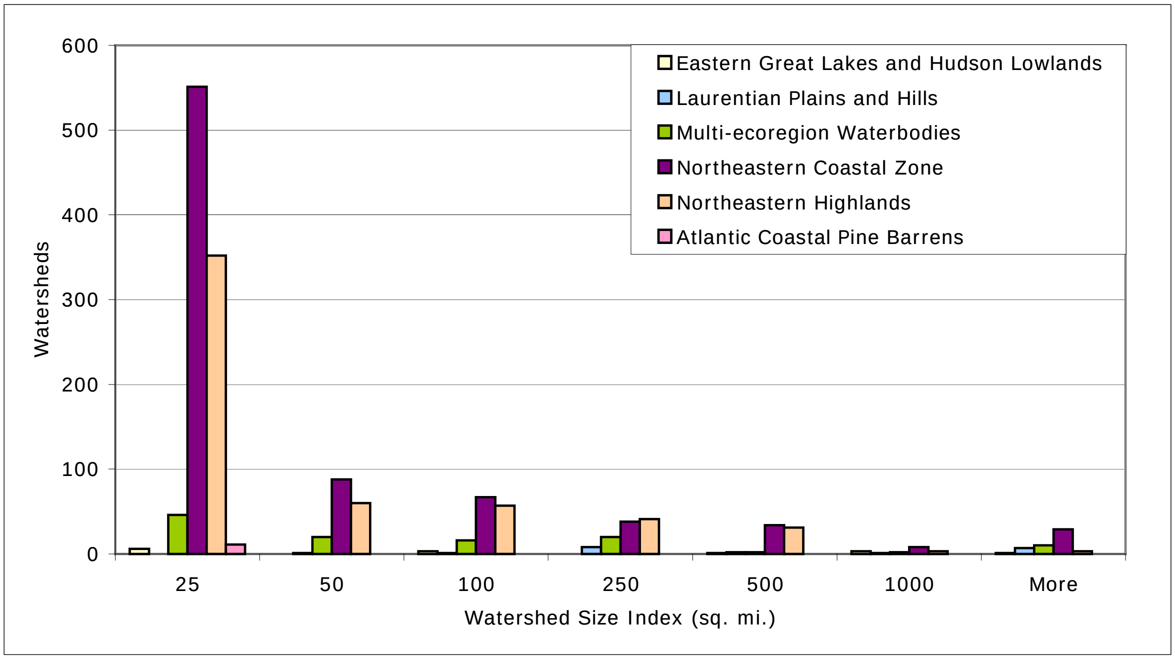


Figure 4-8 Frequency Distribution of the Average Watershed Size for NE R/S Nutrient Database

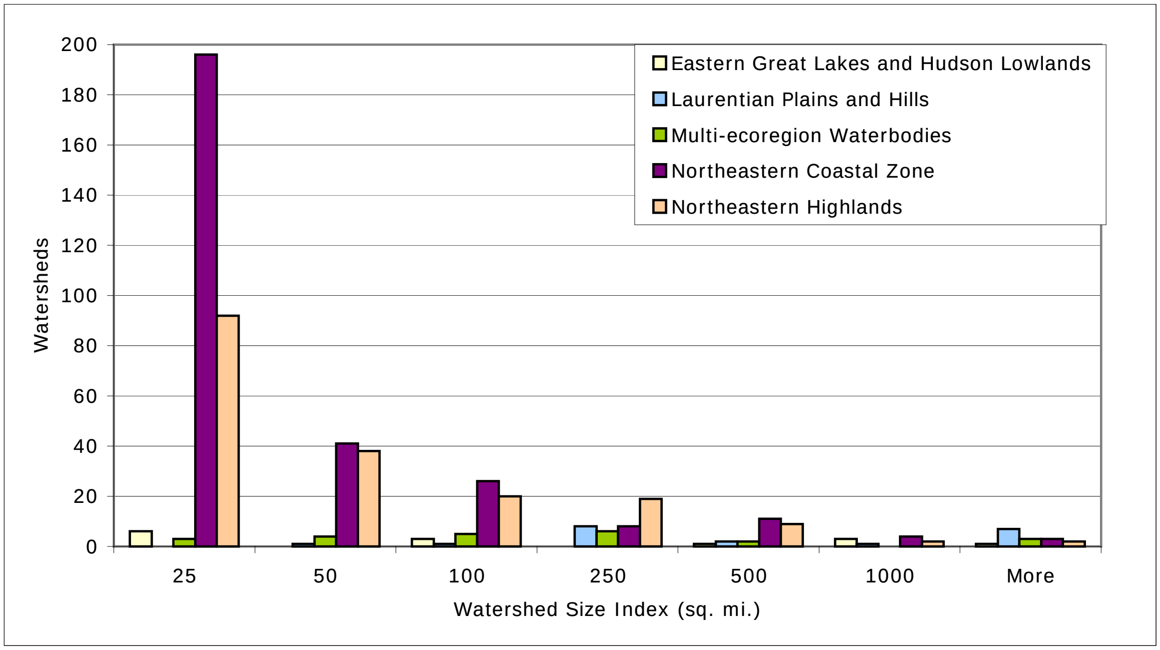


Figure 4-9 Frequency Distribution of Total Phosphorus Measurements in NE R/S Nutrient Database

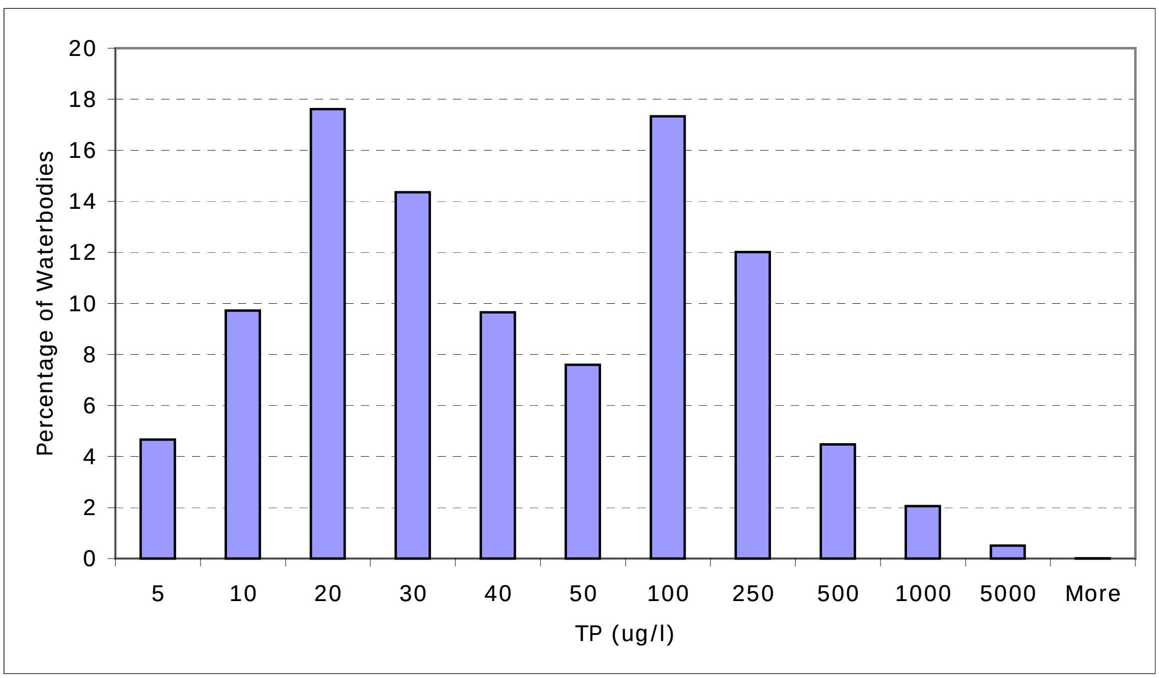


Figure 4-10 Frequency Distribution of Total Nitrogen Measurements in NE R/S Nutrient Database

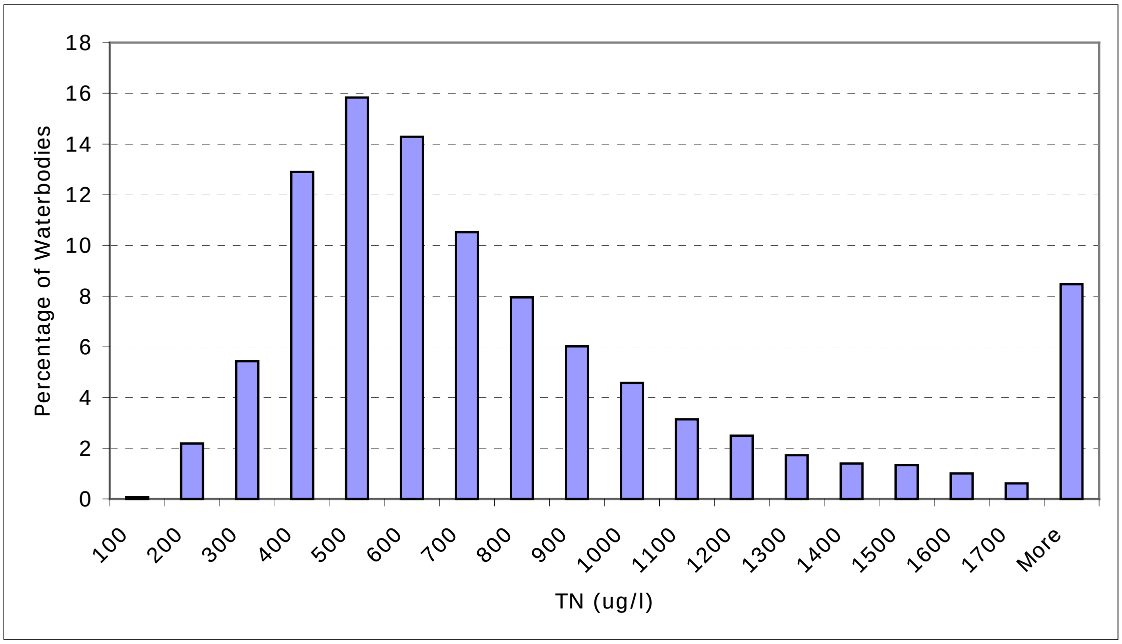


Figure 4-11 Frequency Distribution of Chlorophyll *a* Measurements in Rivers and Streams in NE R/S Nutrient Database

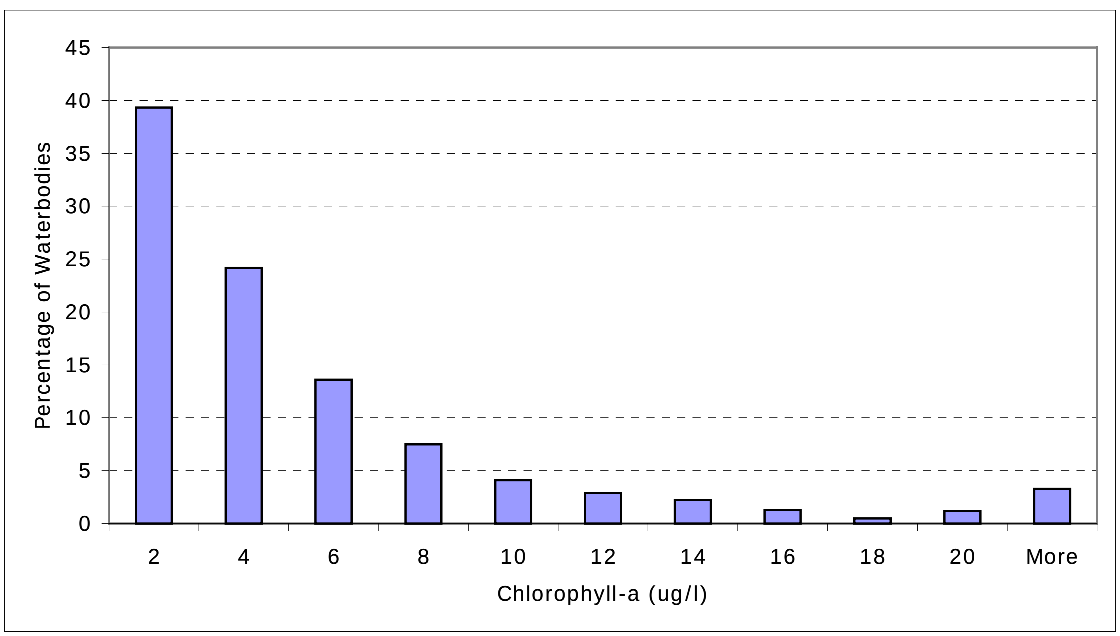
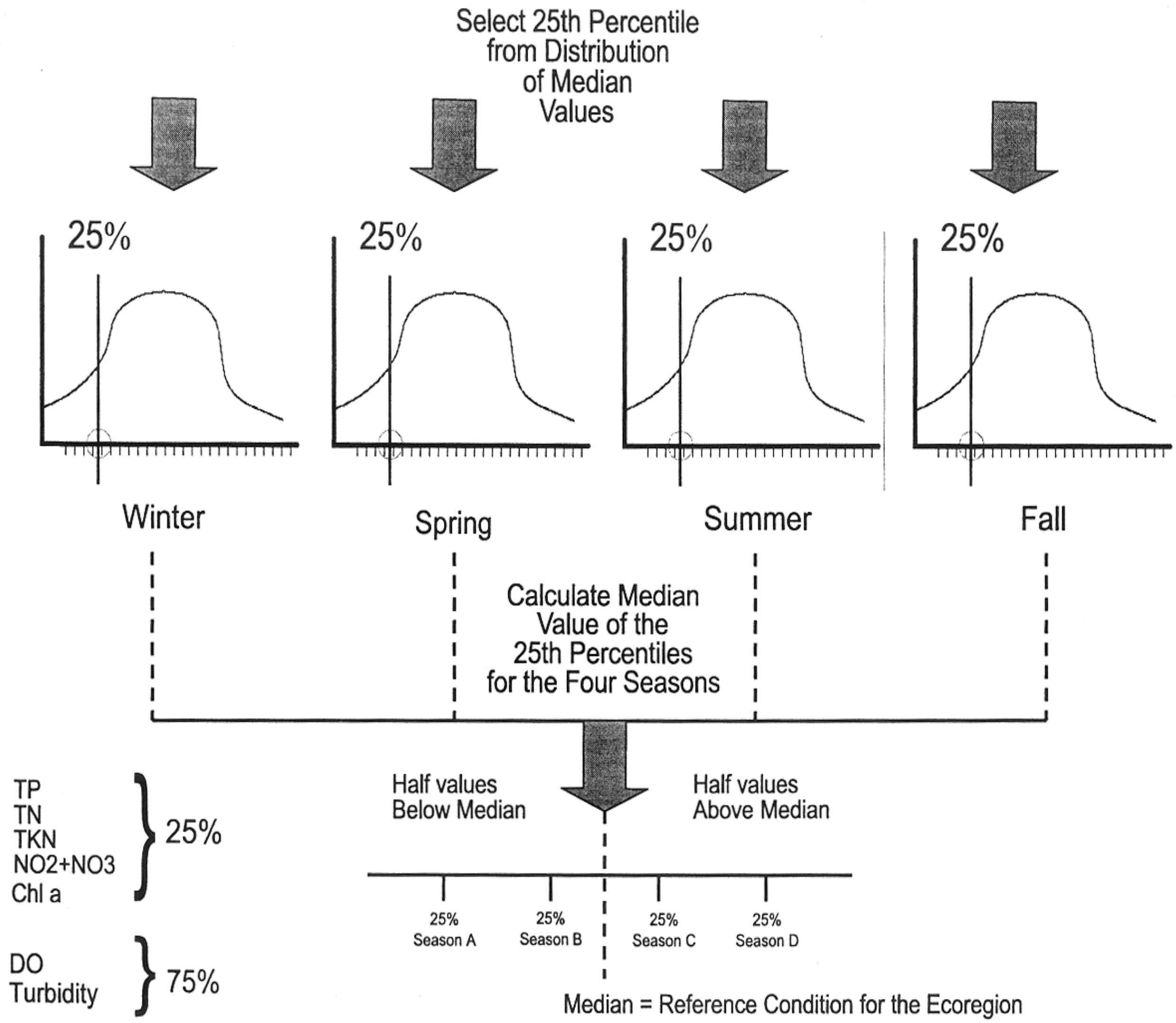


Figure 4-12 Schematic of Protocol Used for Calculation of "Four Seasons" Stream Median Value for Waterbody/Ecoregion



5.0 SUMMARY STATISTICS OF NEW ENGLAND R/S NUTRIENT DATABASE

The New England R/S Nutrient Database was used to look at the trophic parameters at a finer scale with particular attention to the four New England ecoregions (EGLHL, LPH, NEH, NCZ). Section 5.1 discusses the New England ecoregions of interest and their associated land use. Section 5.2 characterizes rivers and streams in the R/S Database. Section 5.3 examines the distribution of waterbodies and identifies potential data gaps. Section 5.4 discusses selection of reference and impacted water quality stations.

5.1 New England Ecoregions of Interest

An important facet of the development of regional nutrient criteria is the concept of ecoregion-specific criteria. Ecoregions are generally defined as relatively homogeneous areas with respect to geomorphology, climate, ecological systems and the interrelationships among organisms and their environment (Omernik, 1987; 1995). They can be defined on a range of scales from national to very regional subdivisions.

Several potential ecoregion classification levels or schemes were identified in the course of the work. These included classification Level III Aggregated and Non-Aggregated Nutrient Ecoregions proposed by Omernik, 2000), state-specific ecoregions (e.g., MA, ME), and other proposed classifications (e.g., USDA Forest Service, U.S. EPA Region I). Following review and discussion, the U.S. EPA Level III ecoregions were selected as the basis for the analysis since these were the lowest spatial level chosen for development of ambient water quality criteria recommendations (U.S. EPA, 2000b; 2000c; 2001). The U.S. EPA Level III Nutrient Ecoregions separate New England into the five distinct regions shown in Figure 5-1. These regions are the:

- Atlantic Coastal Pine Barrens (ACPB) (U.S. EPA Level III ecoregion 84);
- Eastern Great Lakes and Hudson Lowlands (EGLHL) (a small portion of the around Lake Champlain, Vermont) (U.S. EPA Level III ecoregion 83);
- Laurentian Plains and Hills (LPH) (U.S. EPA Level III ecoregion 82);
- Northeastern Coastal Zone (NECZ) (U.S. EPA Level III ecoregion 59); and
- Northeastern Highlands (NEH) (U.S. EPA Level III ecoregion 58),

The ecoregions were used to evaluate the number of applicable waterbodies in the NE R/S Nutrient database versus the target range of waterbodies identified in the Technical Memorandum (ENSR, 1999). For ecoregion determinations, the point location of the water quality sampling station was used rather than a determination of which ecoregion the majority of the watershed fell in. Due to the very limited spatial coverage of the ACPB ecoregion relative to other New England ecoregions and the general lack of nutrient data (particularly total phosphorus), the river and streams in this ecoregion were deferred from further analysis in the NE R/S Nutrient Database. The remaining four ecoregions had sufficient waterbodies and nutrient data to warrant their inclusion in further analyses (see Section 5.4).

The four Level III ecoregions selected for further analysis have differing climates, land uses, and population densities. As a rough characterization of these difference, land uses in watersheds selected for inclusion in the New England R/S Nutrient databases were pooled and an ecoregional profile provided using land use classifications provided by USGS's SPARROW model. For simplicity of comparison, several land use categories were combined into the following general land use categories:

- Agricultural (cultivated, orchard)
- Forested (deciduous, evergreen, mixed)
- Urban (urban, suburban, barren and recreational grass (park))
- Water and wetlands (water, wetland)

The relative percentages of the area coverage of land use categories for each ecoregion are illustrated in Figure 5-2. As we can see, the LPH and NEH ecoregions are very similar in terms of the overall land use, particularly in the amount of urban land use and forested portions of the watershed. The NECZ is characterized by a higher percentage of urban land use (about 9%), while the EGLHL ecoregion differs from its other ecoregions by the higher proportion of agricultural areas (20%), particularly in the Lake Champlain watershed. These contrasts in land use suggest potential differences in water quality may be expected.

5.2 Water Quality Characteristics of Rivers and Streams of NE R/S Nutrient Database

The water quality data of the waterbodies contained in the R/S Nutrient Database were characterized. The results of this analysis are given in Table 5-1, which provides an overview of the characteristics and ranges of key trophic parameters in New England rivers and streams before data transformation (i.e., not subject to EPA's data transformation protocol - see Section 4.4). Values in Table 5-1 are presented for the four ecoregions as well as a composite "New England" value and indicate the amount of data available for each region and parameter. Comparison among ecoregions indicate large differences in mean concentration of TP (EGLHL – 97 ug/L; LPH – 29 ug/L; NECZ – 110 ug/L; NEH – 38 ug/L), and TN (EGLHL – 695 ug/L; LPH – 431 ug/L; NECZ – 1,107 ug/L; NEH – 570 ug/L). Differences in Chl *a* values were much less pronounced (EGLHL – 4.4 ug/L; LPH – 3.4 ug/L; NECZ – 22.8 ug/L; NEH – 2.8 ug/L).

However, it should be noted that the values in Table 5-1 are based on the pooled data for all the water quality stations in an ecoregion. This data is therefore biased by values from the larger rivers (which typically have WWTP discharges) that are more regularly monitored and which, subsequently, are represented by a large number of samples. To provide a more representative value for an ecoregion, the data were transformed using the EPA-recommended protocol (see Figure 4-12) to provide for seasonal-specific and "all seasons" values for each water quality location. Table 5-2 shows the various season-specific values for 25th percentile and a four season value that can be used for a representative annual value. The values for the 25th, 50th, and 75th percentiles are shown in Table 5-2 that provides ecoregion-specific values for each season and all seasons. The range of values in Table 5-2 indicates how the season affects the range or availability (e.g., lack of Chl *a* or SDT values in winter). For some ecoregions, the seasons do not seem to significantly affect the parameters (e.g., TP in NECZ or NEH), while others are highly variable (e.g, TP for EGLHL or LPH). It is likely that some of this variability is due to the fewer water quality stations among ecoregions.

The distribution of the four season medians for TP, TN, and Chl *a* for individual rivers and streams sorted by the various ecoregions are displayed in Figures 5-3 through 5-5, respectively. In Figure 5-3, the EGLHL and NECZ ecoregions exhibit a higher TP concentration than do the LPH and NEH, which are very similar in both the peak and shapes of their distribution curves. The distributions for TN (Figure 5-4) also indicate low values for the LPH and NEH with higher concentrations in the EGLHL and particularly for the NECZ, which has many high TN concentrations. The Chl *a* distribution (Figure 5-5) shows a high chlorophyll distribution for the NECZ, with the other ecoregions somewhat clumped together.

To more clearly illustrate the distribution of TP and TN among the ecoregions, the statistical parameters are graphically shown in so-called "box and whiskers" plots in Figures 5-6 and 5-7. This shows that while there is great overlap in the range of individual values the individual ecoregions show significant differences. The basis for these differences was explored further in Section 6.0.

5.3 Data Gaps

The overall objective of the Nutrient Data Project is to provide a sufficient database to support ecoregional nutrient criteria development in New England. A data gaps analysis was conducted to identify potential data gaps with regard to numbers and spatial distribution of the waterbodies in the NE R/S Nutrient Database. However, it should be recalled that the NE R/S Nutrient Database is not intended to be a comprehensive compilation of waterbodies in New England but, rather, a collection of data that provide good representation of the expected range of trophic state indicators for similar waterbodies in an ecoregion. The following sections describe this process.

5.3.1 Establishment of Target Ranges for Waterbodies

A strategy for identifying the target number of waterbodies was originally developed as part of the Technical Memorandum (ENSR, 1999). Based on estimated numbers of waterbodies in New England (Peterson et al. 1998), a set of target goals were established to get a reasonable sub-sample of the population. For lakes, this reasonable sub-sample of this estimated test population was based on the EMAP estimates. However, the number of rivers and streams in New England and the number of potential sample reaches was not estimated by EMAP. In lieu of any confirmatory data, ENSR proposed an arbitrary target goal of 100 reaches, with a range of 50-150, and 10% reference waterbodies (ENSR, 1999). As the availability of nutrient data for rivers and streams was found to be significantly fewer than for lakes and ponds, it became clear that the lower end of the range (50 rivers) was a more realistic goal.

5.3.2 Comparison of Waterbodies in NE R/S Nutrient Database with Targets

The first step in the comparison of waterbodies in the NE R/S Nutrient Database with targets was to establish the number of rivers and streams found within the relevant ecoregions. The coordinates of the water quality sampling locations were obtained from the database or through follow-up and confirmation with state contacts. Each water quality sampling station was then assigned to the U.S. EPA ecoregion corresponding to its coordinates.

Figure 5-8 shows the distribution of the river and stream sampling locations by ecoregion from the NE R/S Nutrient Database assembled from available electronic data files. As can be noted on that figure, two ecoregions are very well represented, specifically the NECZ and NEH ecoregions. There were fewer than optimal representations of rivers and streams located in the LPH or EGLHL. As noted earlier, no measurements of TP or TN data were reported in rivers and streams for the ACPB ecoregion and this ecoregion was deferred from further discussion. The number of rivers and streams located in each of the four New England ecoregions of interest is given in Table 5-4.

The number of river and streams in the NCZ and NEH ecoregions exceeded the minimum target number of 50 waterbodies established in ENSR's proposed strategy (ENSR, 1999) while those for EGLHL and LPH did not meet these goals. Reference waterbodies were identified by two of the states (CT, VT), based on biocriteria (see Section 2.3). Only the NECZ met the criteria for reference streams. Given the more remote spatial locations of some stations shown on Figure 5-8, it was assumed that reference or non-impacted waters are represented within the NE R/S Nutrient Database. Determination of reference waterbodies/stations will be further analyzed in Section 6.2. For the EGLHL, the amount of waterbodies is non-optimal, but appears to be an adequate spatial representation since this is the smallest of the New England ecoregions considered for the Data Synthesis Report. The fewer than optimal number in the LPH appears to be due to the reliance of data from only a few larger rivers in the ecoregion, which may be consistent with the patterns of population distribution and/or regulatory concern. The smaller tributaries and headwater streams in the LPH are perhaps underrepresented due to the fact that they are not currently impacted by discharges or watershed non-point sources, and monitoring is not required.

Figures 5-9 though Figure 5-14 indicates the wide disparity in the distribution of water quality sampling for nutrients in rivers and streams among the New England States. Examination of the distributions of water quality sampling station in the various states indicate that streams and rivers in Connecticut (Figure 5-9) and New Hampshire (Figure 5-12) are well sampled with good spatial coverage. In Massachusetts (Figure 5-11) and Rhode Island (Figure 5-13), there is a moderate density of stations with diverse locations. For Maine (Figure 5-10) and Vermont (Figure 5-14), there are fewer stations and they are distributed very non-uniformly. For example, most of the Vermont water quality sampling stations are located in the Lake Champlain Valley in EGLHL ecoregion with very sparse coverage in the NEH ecoregion. Similarly, water quality stations in Maine are preferentially located in the LPH and some in NECZ.

Table 5-1 Statistical Indicators of Trophic Parameters in the R/S Nutrient Database (Raw Data)

Ecoregion	Parameter	Unit	Min	Max	Avg	Count
Eastern Great Lakes and Hudson Lowlands	CHLA	ug/l	0.1	76	4.4	164
	TN	ug/l	220	3240	695	520
	TP	ug/l	7.0	2470	97	1,898
Laurentian Plains and Hills	CHLA	ug/l	0.5	14	3.4	211
	SECCHI	m	1.2	5.2	2.9	120
	TN	ug/l	185	880	431	37
	TP	ug/l	5.0	390	29	288
Northeastern Coastal Zone	CHLA	ug/l	2.8	174	23	92
	SECCHI	m	0.9	3.0	1.5	17
	TN	ug/l	100	6,680	1,107	1,625
	TP	ug/l	0.0	3,900	110	5,712
Northeastern Highlands	CHLA	ug/l	1.3	5.3	2.8	18
	SECCHI	m	0.5	3.0	1.5	20
	TN	ug/l	95	3,390	570	783
	TP	ug/l	1.0	1,400	38	2,108
Composite New England	CHLA	ug/l	0.1	174	7.4	485
	SECCHI	m	0.5	5.2	2.6	157
	TN	ug/l	95	6,680	885	2,965
	TP	ug/l	0	3,900	90	10,006

Table 5-2 Seasonal Patterns of Trophic Parameter Concentrations in the R/S Nutrient Database

Ecoregion	Parameter	Spring	Summer	Fall	Winter	Median of Four Seasonal 25th Percentiles
Eastern Great Lakes and Hudson Lowlands	CHLA	2.1	2.7	1.5	NA	1.6
	TN	558	405	526	744	470
	TP	53	29	34	84	31
Laurentian Plains and Hills	CHLA	NA	1.6	3.3	NA	1.7
	SECCHI	NA	2.2	NA	NA	2.5
	TN	310	340	375	295	330
	TP	5.0	13	28	30	14
Northeastern Coastal Zone	CHLA	NA	6.4	NA	NA	4.9
	SECCHI	1.1	1.0	NA	NA	1.1
	TN	538	520	533	544	560
	TP	17	20	18	20	20
Northeastern Highlands	CHLA	NA	1.3	2.1	NA	2.2
	SECCHI	0.9	1.3	NA	NA	1.2
	TN	373	348	244	181	360
	TP	10	9.0	10	10	10
Composite New England	CHLA	2.1	1.7	1.5	NA	1.9
	SECCHI	1.2	1.2	NA	NA	2.0
	TN	454	380	500	506	460
	TP	15	13	15	20	20
NA - No data available.						

Table 5-3 Four-Season Medians Based on 25th, 50th and 75th Percentile Values for Waterbodies in the R/S Nutrient Database

Ecoregion	Parameter	Unit	25th Percentile	50th Percentile	75th Percentile
Eastern Great Lakes and Hudson Lowlands	CHLA	ug/l	1.6	2.8	450
	TN	ug/l	470	589	780
	TP	ug/l	31	55	120
Laurentian Plains and Hills	CHLA	ug/l	1.7	2.6	4.1
	SECCHI	m	2.5	2.9	3.3
	TN	ug/l	330	325	500
	TP	ug/l	14	23	40
Northeastern Coastal Zone	CHLA	ug/l	4.9	7.8	28
	SECCHI	m	1.1	1.2	1.8
	TN	ug/l	560	702	1,210
	TP	ug/l	20	29	100
Northeastern Highlands	CHLA	ug/l	2.2	1.7	3.1
	SECCHI	m	1.2	1.2	1.8
	TN	ug/l	360	479	680
	TP	ug/l	10	16	40
Composite New England	CHLA	ug/l	1.9	2.8	5.6
	SECCHI	m	2.0	1.4	3.1
	TN	ug/l	460	636	970
	TP	ug/l	20	27	88

Table 5-4 Comparison of New England NE R/S Nutrient Database Rivers and Streams with Targets

Ecoregion	Target R/S	Database R/S	Target Ref R/S	Database Ref R/S
Eastern Great Lakes and Hudson Lowlands	50	14	5	1
Laurentian Plains and Hills	50	21	5	NA
North Eastern Highland	50	316	5	2
North Eastern Coastal Zone	50	206	5	5
New England Total	**200**	**557***	**20**	**8**
*slightly lower total from Table 4-3 reflect some stations which could not be located due to lack of coordinates				

Figure 5-1 New England Level III Ecoregions

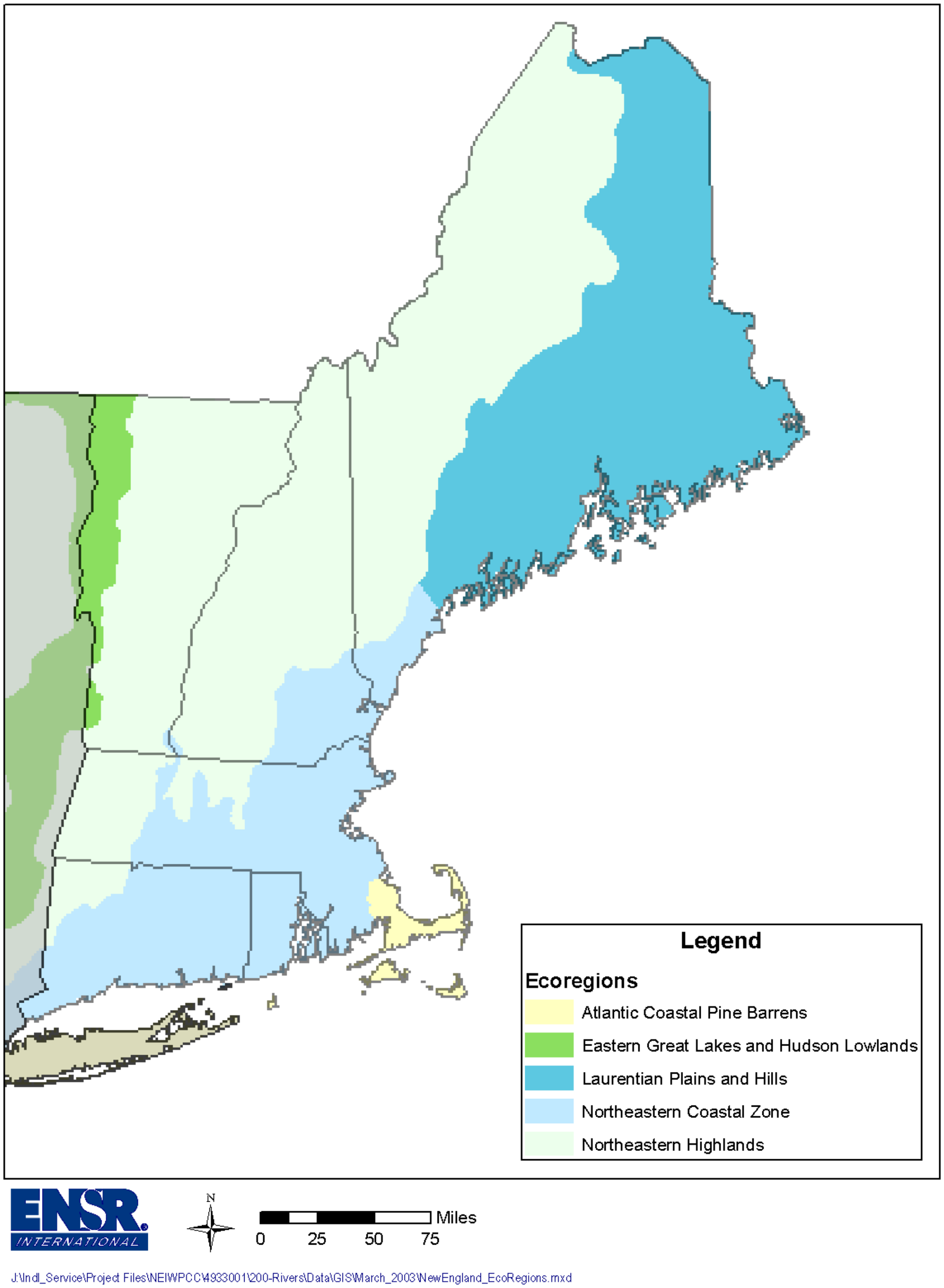


Figure 5-2 Land Use Distribution in New England Ecoregions

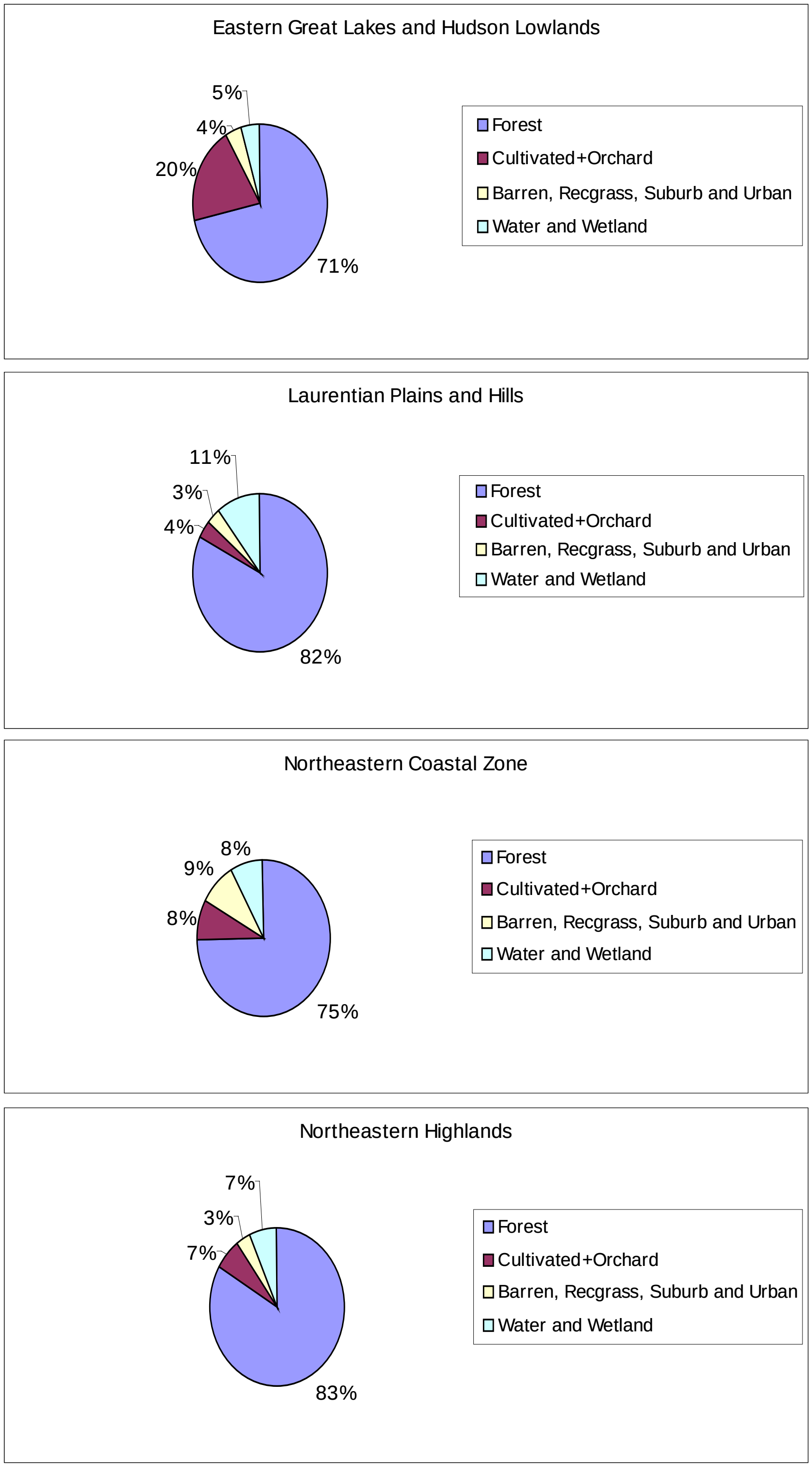


Figure 5-3 Distribution of Four Season Medians for Total Phosphorus Sorted by Ecoregion

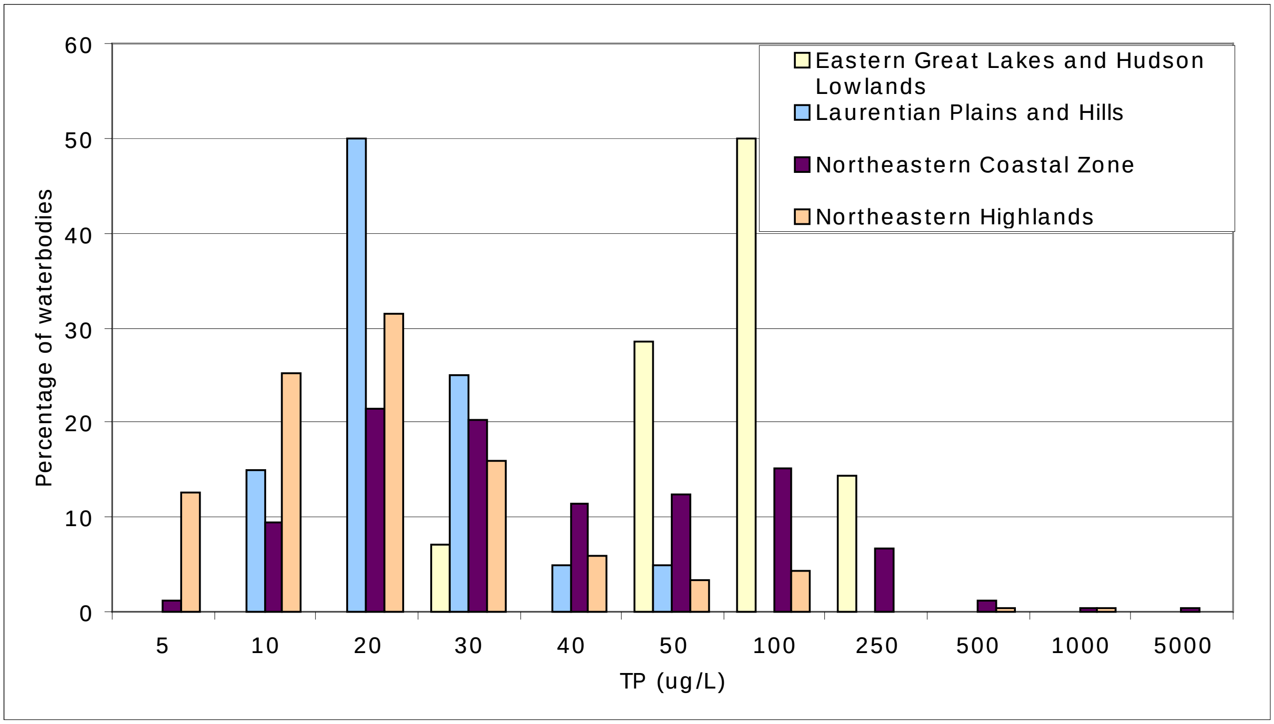


Figure 5-4 Distribution of Four Season Medians for Total Nitrogen Sorted by Ecoregion

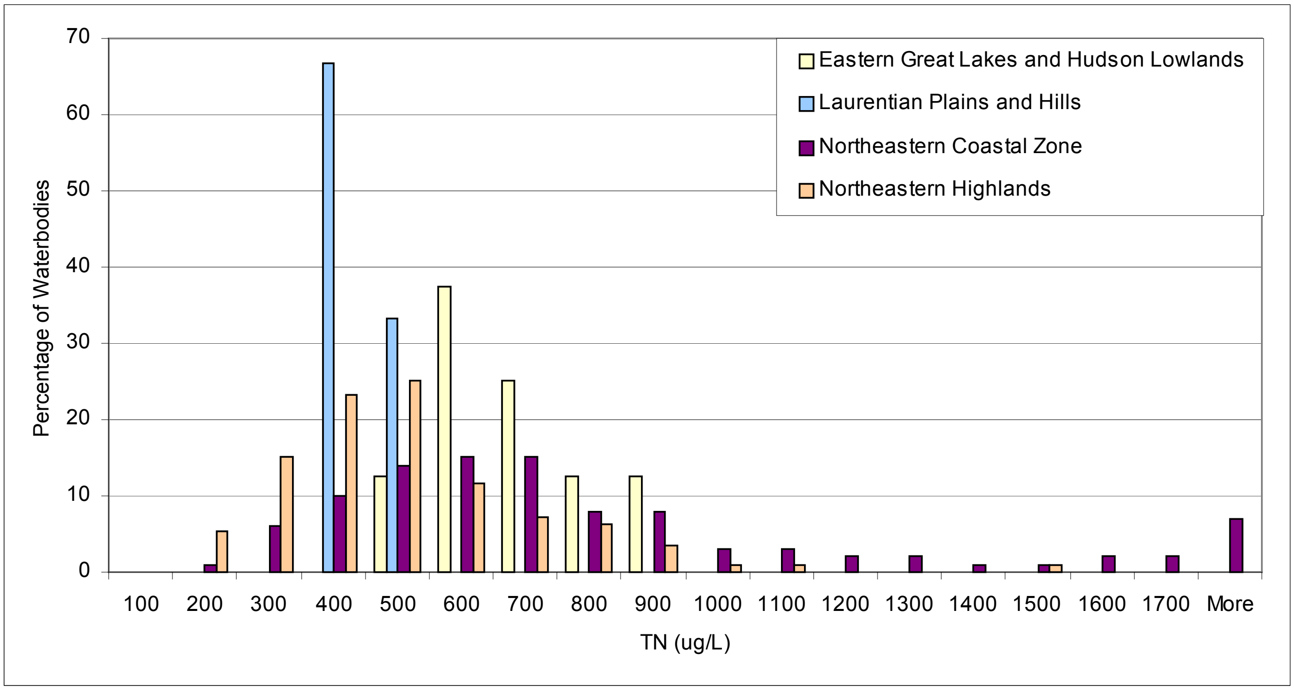


Figure 5-5 Distribution of Four Season Medians for Chlorophyll *a* Sorted by Ecoregion

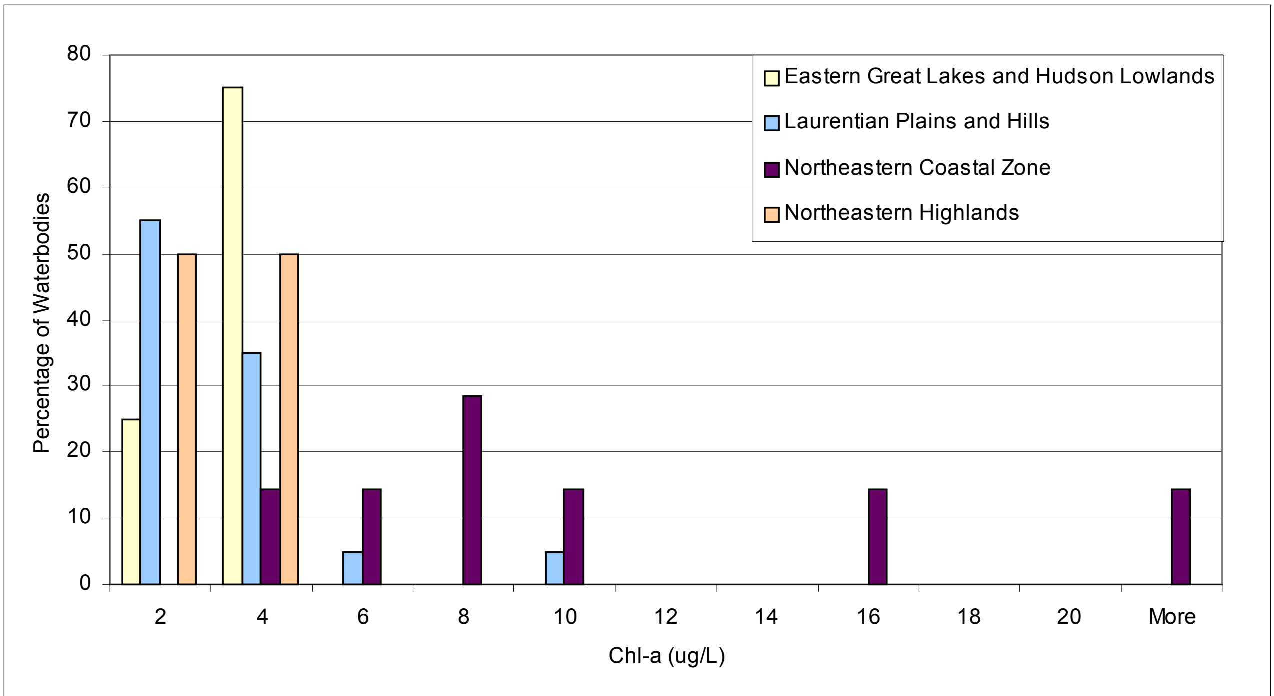


Figure 5-6 Statistical Distributions of Total Phosphorus Medians Among New England Ecoregion

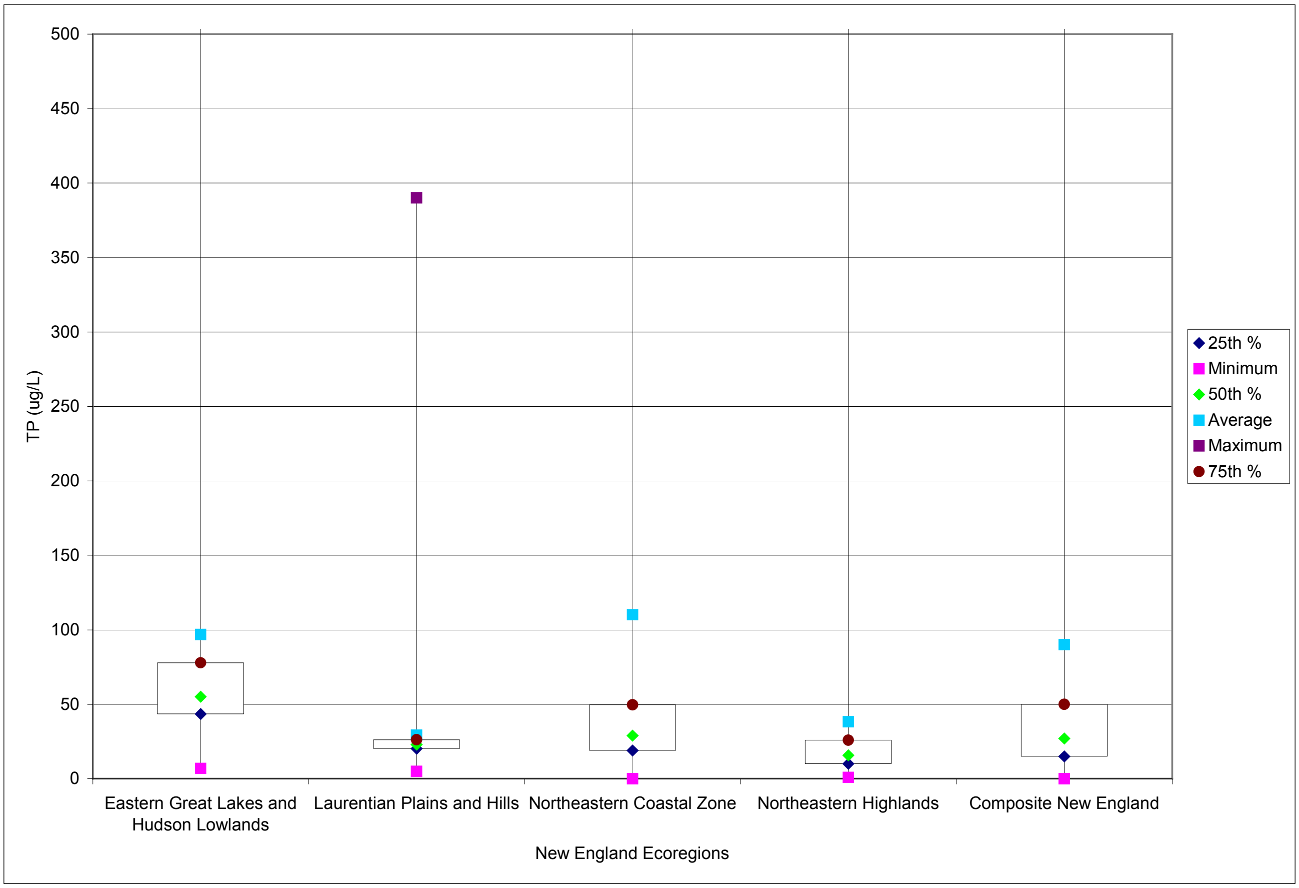


Figure 5-7 Statistical Distributions of Total Nitrogen Medians Among New England Ecoregions

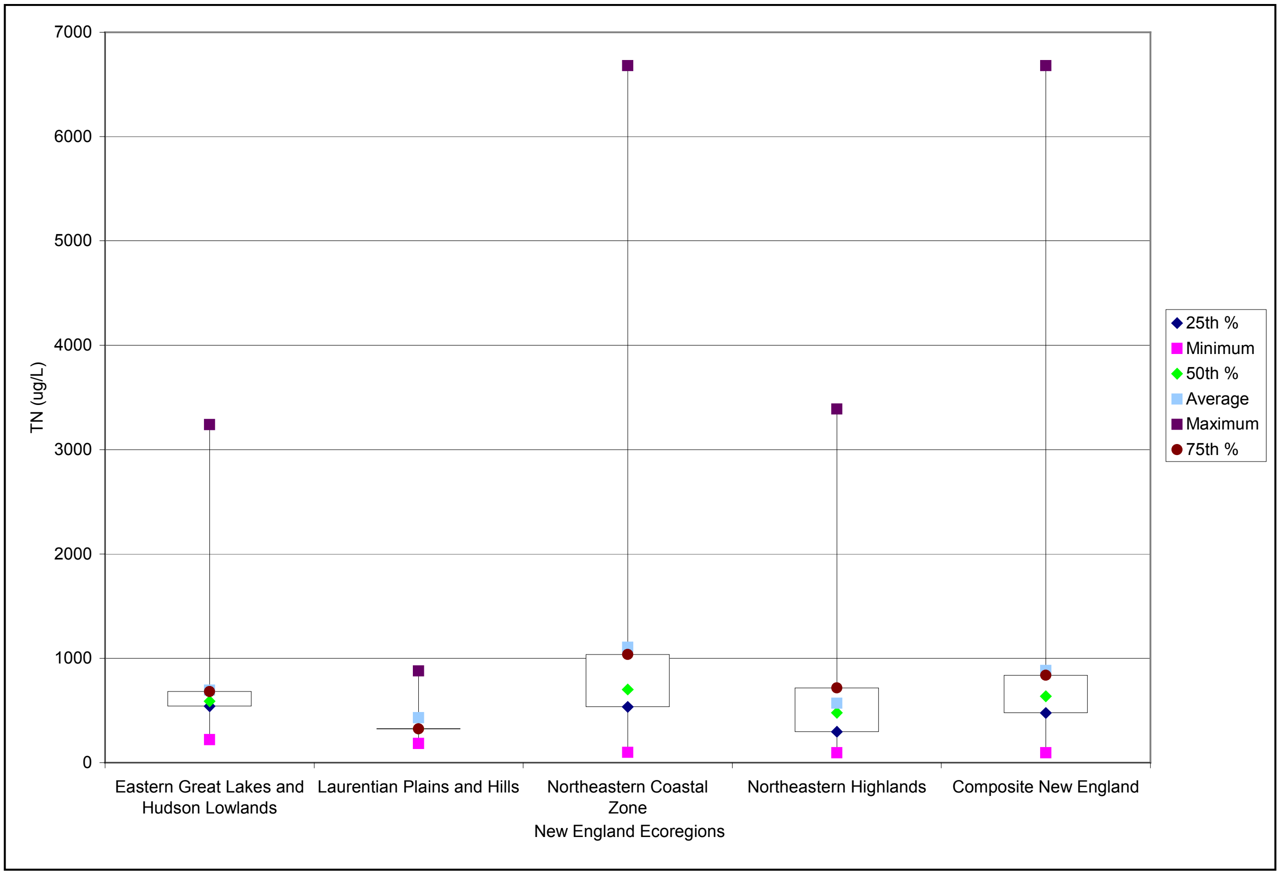


Figure 5-8 New England Water Quality Sampling Stations in R/S Nutrient Database

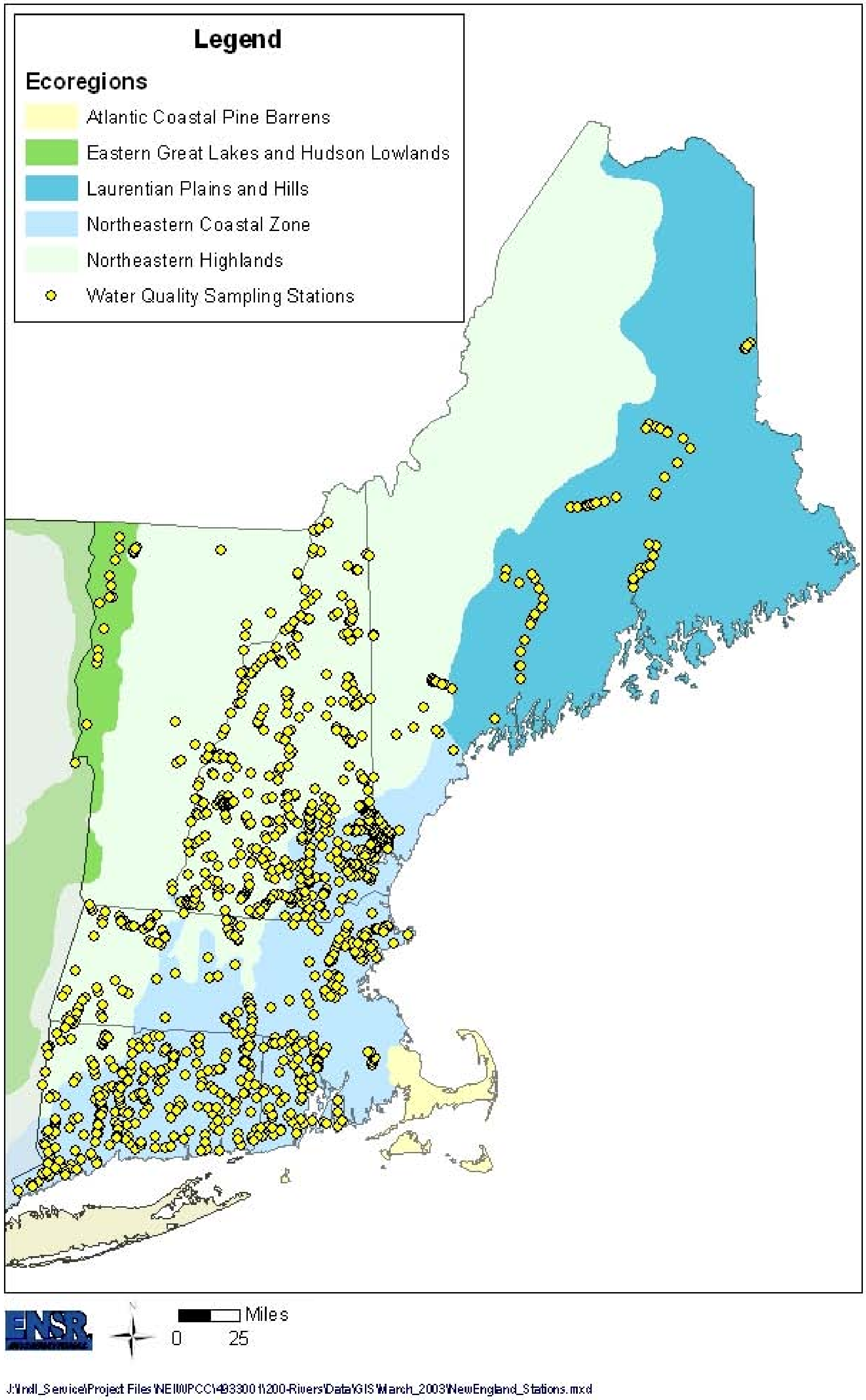


Figure 5-9 Connecticut Water Quality Sampling Stations

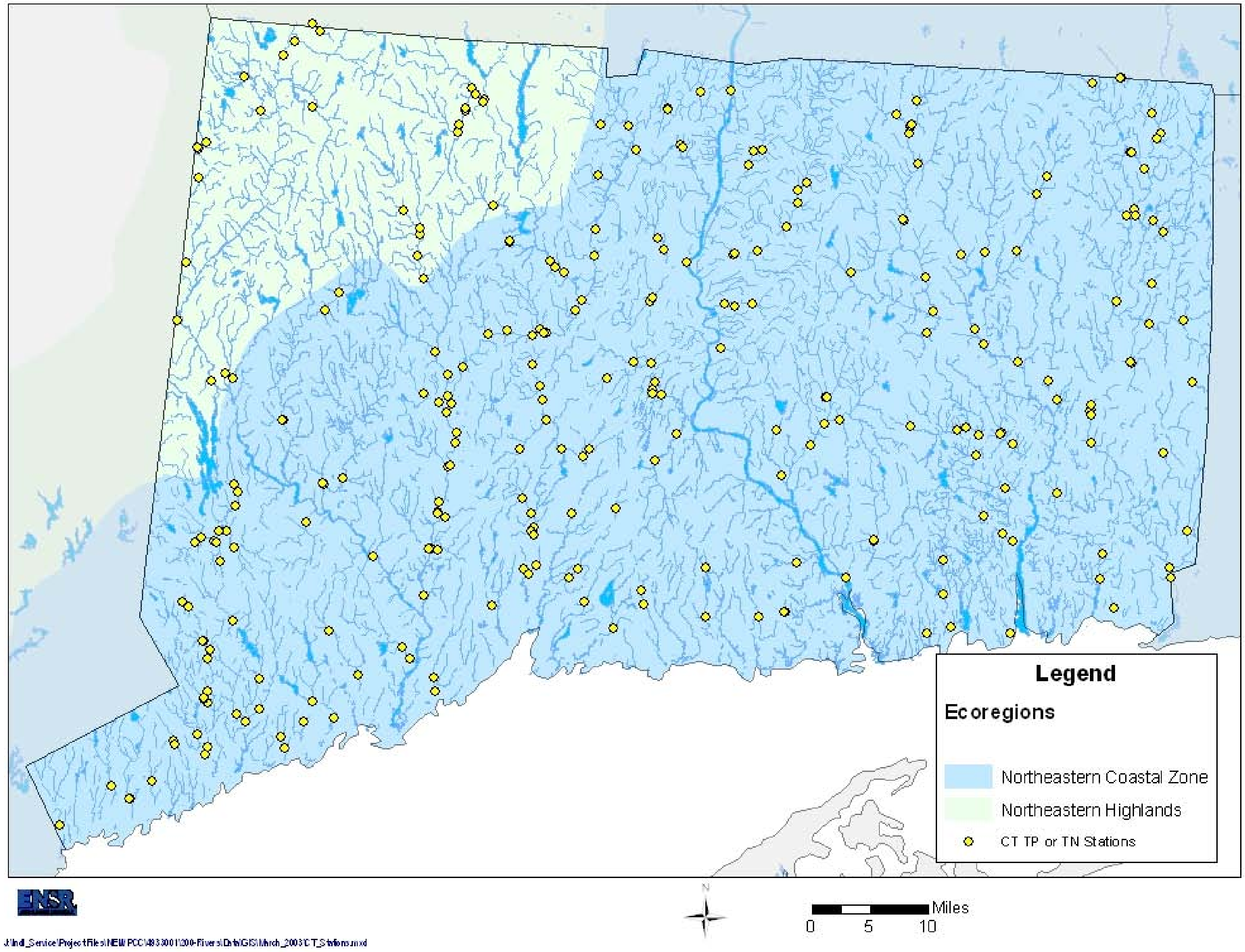


Figure 5-10 Maine Water Quality Sampling Stations

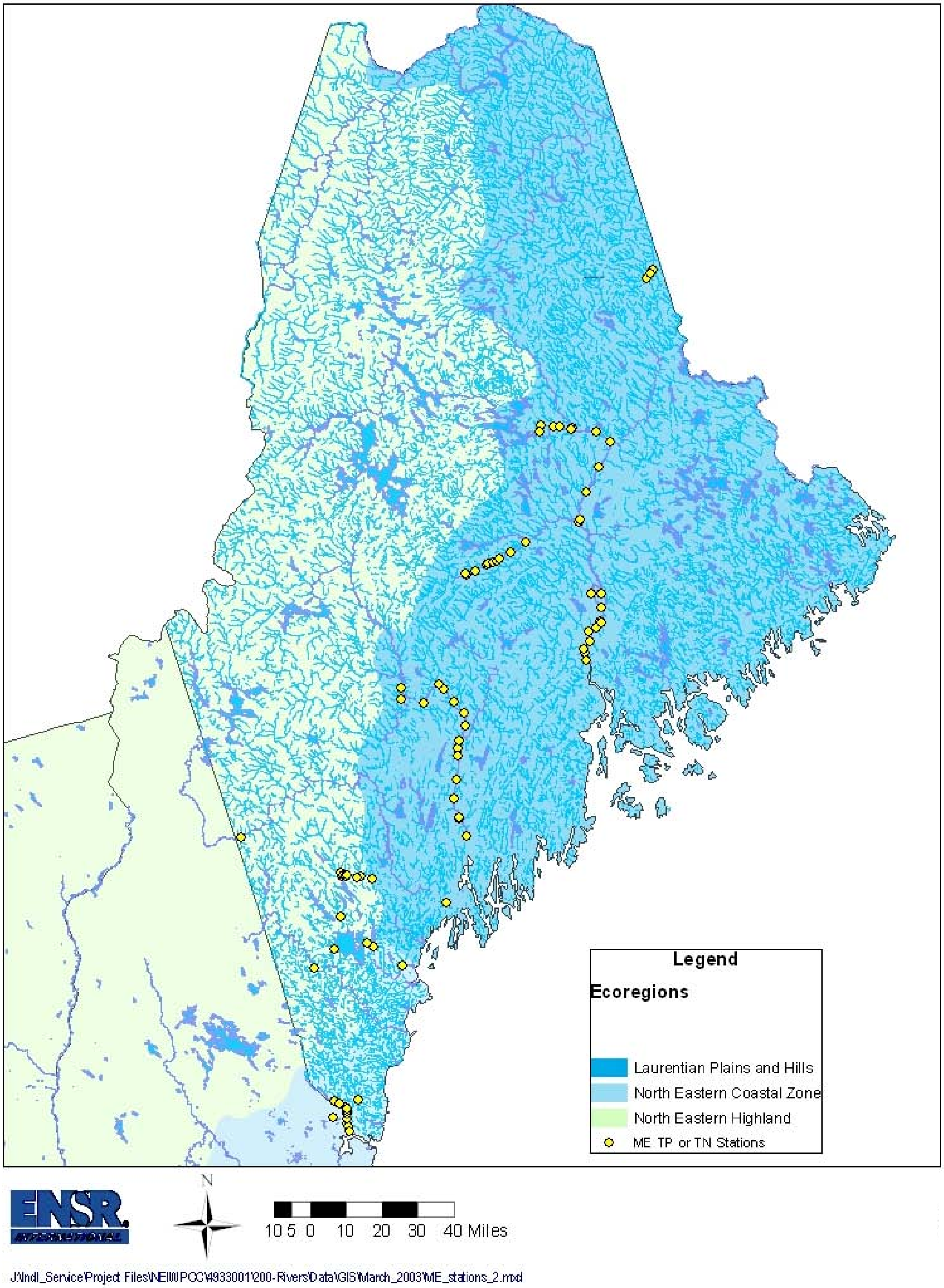


Figure 5-11 Massachusetts Water Quality Sampling Stations

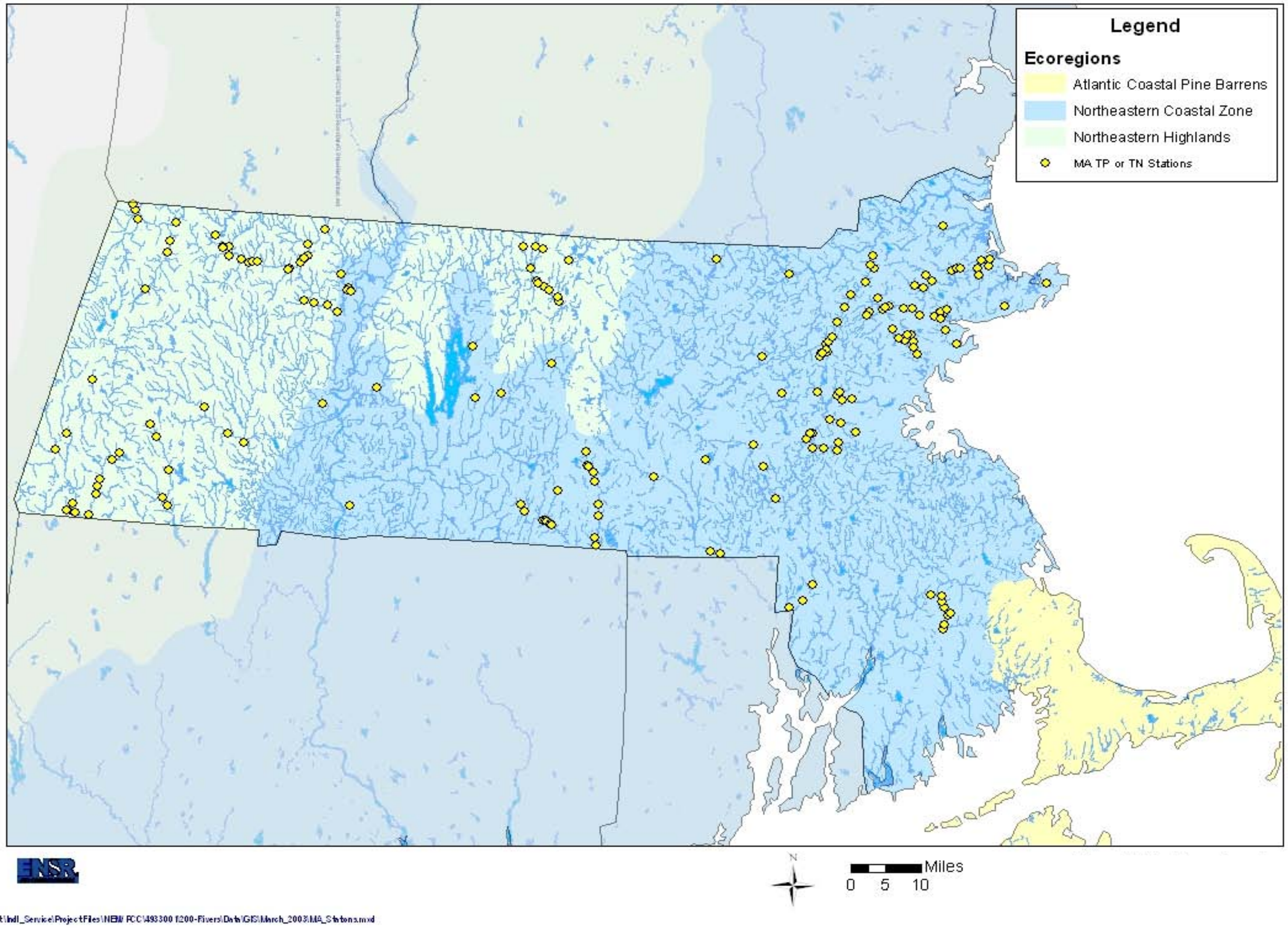


Figure 5-12 New Hampshire Water Quality Sampling Stations

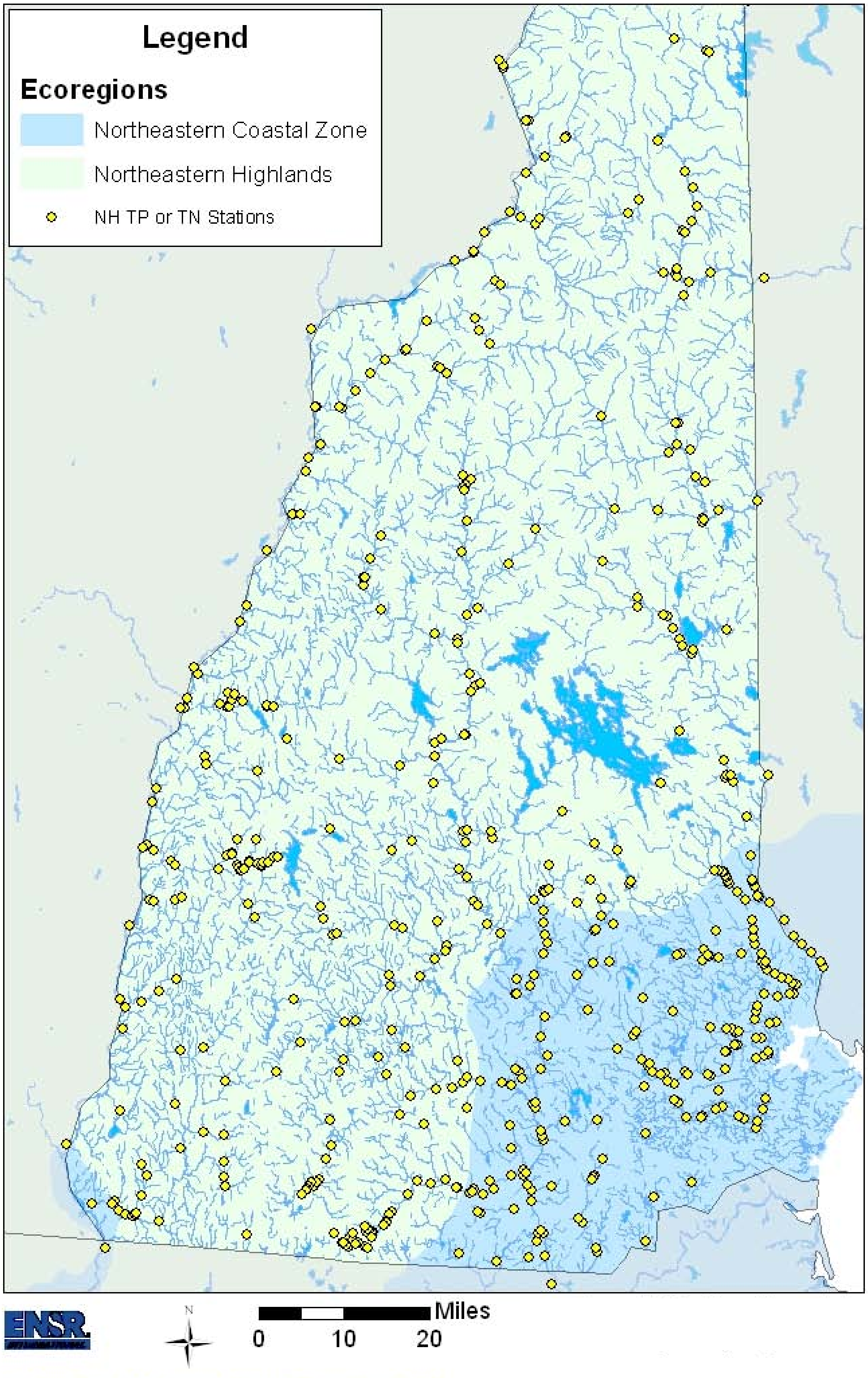


Figure 5-13 Rhode Island Water Quality Sampling Stations

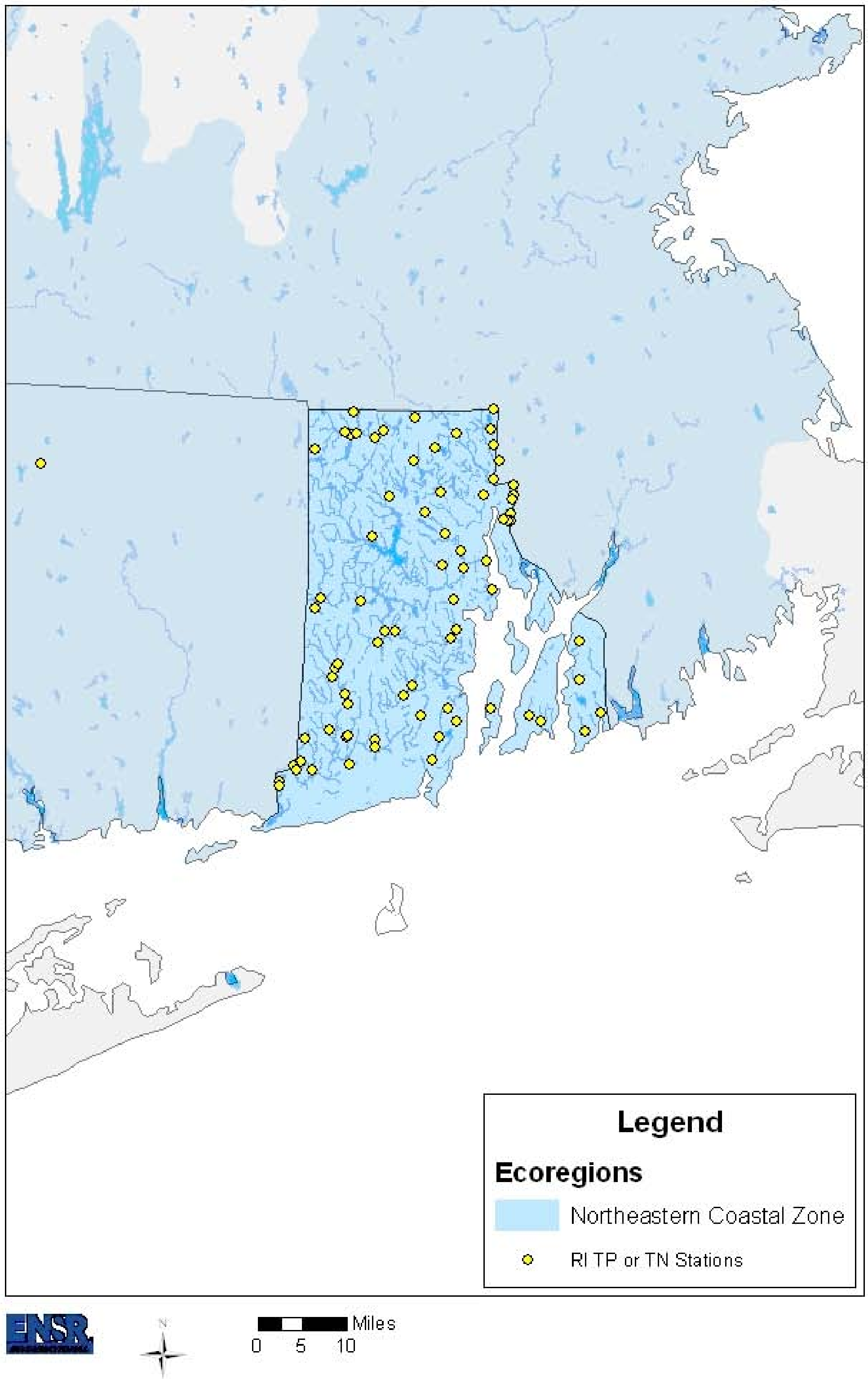
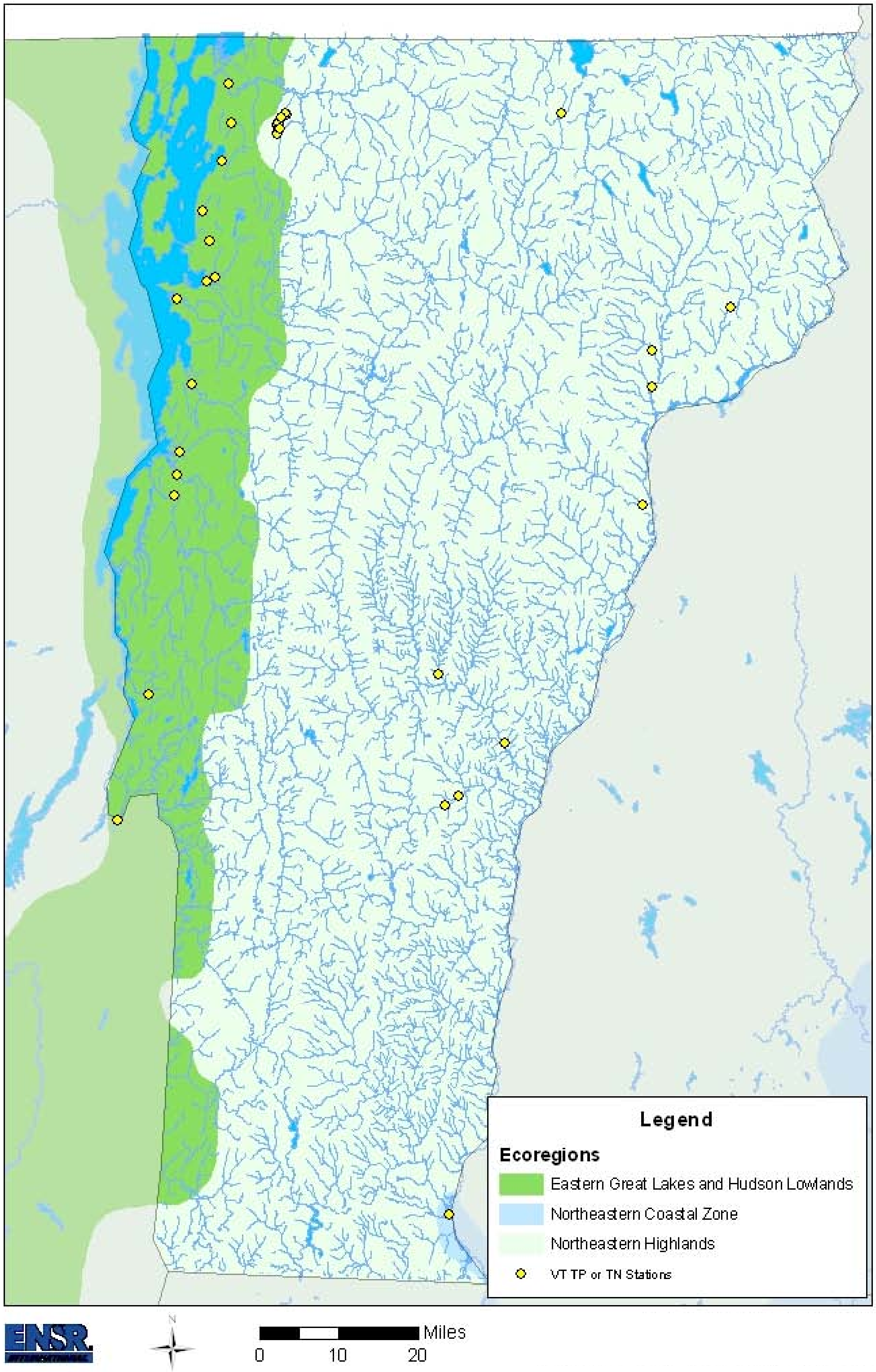


Figure 5-14 Vermont Water Quality Sampling Stations



6.0 APPLICATION TO NUTRIENT CRITERIA DEVELOPMENT

This section pertains to the derivation of preliminary draft nutrient criteria for New England rivers and streams. Section 6.1 introduces the major approaches used to investigate nutrient criteria development for rivers and streams. Section 6.2 compares the median and critical percentile values (e.g, 25th) in the NE R/S Nutrient Database vs. the U.S. EPA Ambient Water Quality Criteria (AWQC) Recommendations for the various ecoregions of interest. Section 6.2 also considers the use of populations of reference and impacted waterbodies to support criteria development. Section 6.3 discusses the influence of watershed size on nutrient parameters, with a more detailed look at differences between so-called "wadeable" streams and larger waterbodies. Section 6.4 considers the influence of watershed land use on nutrient levels, particularly urban and agricultural land uses. Section 6.5 looks at nutrient levels associated with potential impairment of in-stream designated uses, particularly benthic invertebrates and periphyton.

6.1 Approaches Used to Evaluate Nutrient Criteria Development Strategies

One of the challenges which face State agencies developing nutrient criteria is to develop a common criterion for many different types of streams and rivers in diverse geographical and watershed land use settings or to find a defensible means to adjust the criterion in accordance with river or watershed characteristics. As a starting point, ENSR explored observable ecoregional differences in lotic nutrient levels through comparison of the ecoregion-specific median and 25th percentile values generated from the NE database to the U.S. EPA AWQC Recommendations (U.S. EPA, 2000b; 2000c; 2001). As an extension of the "Statistical Method" suggested in *the Rivers and Streams Technical Guidance Manual* (U.S. EPA, 2000a), the generation of a 75th percentile for "reference" streams was considered as were other available values (Rohm et al., 2002). These results are reported in Section 6.2.

Another potential way of differentiating waterbodies is based on the their size, whereby "small" rivers may be categorized differently from "large" rivers in terms of nutrient relationships. One underlying theoretical basis for this differentiation is related to the nature of the waterbody and its relationship to its riparian zone as a source of energy. The River Continuum theory hypothesizes that as streams increase in channel width and depth, the relative importance of riparian vegetation as a carbon source decreases while that of in-stream growth of periphyton and aquatic macrophytes increase. Going further downstream, the substrate-based periphyton and macrophytes are supplanted in importance by water column phytoplankton (Vannote et al., 1980). In addition, the potential for anthropogenic influences to influence lotic waterbodies generally increases as watershed size and associated watershed population increase. Based on the availability of watershed size estimates from USGS, watershed area was used as a surrogate for other related parameters such as stream order or streamflow in interpreting patterns of nutrients. These results are reported in Section 6.3.

Watershed land use is also assumed to be a strong determinant of water quality in a stream or river. Many water quality models use nutrient export coefficients to estimate the amount of nutrients entering a waterbody. The potential relationship between nutrients and watershed land use was explored using the percentage of urban and agricultural land use. These results are reported in Section 6.4.

In addition to the investigation of factors that could be used to categorize waterbodies into more effective units for nutrient criteria development, a more direct look at the influence of nutrients on the impairment of designated uses was sought. Ultimately, nutrient criteria have to be linked to the assurance that they support all designated uses for a waterbody. For rivers and streams, the support of aquatic life is generally the most sensitive designated use. Biocriteria provides a means to assess the ability of the stream or river to support aquatic life. The relationship between nutrient levels and benthic macroinvertebrates and periphyton was examined in Section 6.5.

6.2 Statistical Method

The *Nutrient Criteria Technical Guidance Manual: River and Streams* (EPA, 2000a) suggests several approaches to derivation of nutrient criteria and contains a useful compendium of case studies. One of the suggested methods investigated is the use of target percentile (i.e., “Statistical Method”).

The Statistical Method uses two approaches for determining candidate reference condition values for TP, TN, Chl *a* and SDT, and relates these reference conditions to desired nutrient ranges. In both cases, the goal is to select the threshold value from available data for a given category of R/S waterbodies. The EPA defines a reference condition as that representative of the least impacted conditions or what is considered to be the most attainable conditions for lakes within a state, or ecoregion. Figure 6-1 graphically summarizes the two approaches of the Statistical Method.

The first approach of the Statistical Method consists of selecting a percentile from the distribution of measured variables (in this case representative values of trophic parameters of interest) from known reference R/S, (i.e., the highest quality or least impacted rivers or streams). The River and Stream *Technical Guidance Manual* suggests the 75th percentile, although this is an arbitrary value and could be replaced with higher or lower percentiles, as considered appropriate.

The second approach suggested by the Statistical Method consists in selecting a percentile from the distribution of measured variables for a general population that includes all rivers and streams within a region. In this case, the percentile level chosen should be higher since the population contains a mix of degraded (impacted) and cleaner (reference) river and streams. The River and Stream *Technical Guidance Manual* recommends the use of from the 5th to the 25th percentile depending on the relative proportion of reference waterbodies. For purposes of this calculation, the 25th percentile was used.

6.2.1 Identification of Reference, Impacted, and Test Waterbodies

The initial step in the Statistical Method is the establishment of reference waterbodies in order to establish the “reference” population used for the first approach. A related step is the identification of impacted waterbodies. Although not suggested by the Rivers and Stream *Technical Guidance Manual*, identification of impacted waterbodies was devised as a way of checking the relative level of nutrient enrichment in the general rivers/streams population.

To establish reference waterbodies, individual States were approached to provide reference stations/waterbodies among the list of water quality stations retained in the final Nutrient Database. They were asked to identify the reference rivers or streams as those most likely to represent the most desirable conditions for a representative class of waterbodies, based on their state-specific methods and/or best professional judgment. This query met with limited response from the States, as only CT and VT provided direct information on reference waterbodies, with both states using biocriteria (particularly benthic insects). Since this provided < 10 waterbodies for the dataset (see Section 5.4), an alternative means of identifying "surrogate" reference stations was established.

One means of establishing "surrogate" reference stations is simply to take the waterbodies with the lowest concentrations of trophic parameters (e.g., 10th percentile of nutrient distributions). However, this simply selects the waterbodies on the basis of a statistical distribution without regard to any underlying causal factors that should result in reference conditions. This also suggests that given another year's round of sampling the "reference" stations would change based on their relative position in the statistical distribution.

ENSR preferred to consider reference conditions on the basis of their watershed characteristics. This is consistent with the approach taken by the State of Maine for lakes and with the protocol suggested by Rohm et al, (2002) for identifying reference rivers and streams. The waterbodies in the NE R/S Nutrient Database were screened for the following watershed characteristics:

- watersheds with <1% urban land use;
- watersheds with < 5% agricultural use; and
- watersheds with population densities < 20 humans / sq. mile.

The last criterion needs further explanation. It was arbitrarily based on the 10th percentile of population density for the New England watersheds evaluated. The importance of low population density in a watershed is twofold – low levels of anthropogenic non-point source inputs and a population density unlikely to require a POTW in the vicinity (more reliance on septic systems for sanitary waste disposal).

The waterbodies that met the three criterions listed above were selected as surrogate reference waterbodies and were combined with the biocriteria-based reference waterbodies for further analysis.

In addition to the selection of reference waterbodies, impacted waterbodies were also identified. The chief basis for identifying the waterbodies was inclusion on a current 303(d) list for nutrient-related factors as indicated on Table 6-1. For a waterbody where some segments were listed and others not, the length of the impacted sediment, descriptive narrative comments, and best professional judgment was used to determine if a waterbody was impacted. Due to the historical nature of the data in the NE R/S databases, waterbodies currently identified by states for de-listing from the 303(d) list were considered impacted since many of the recent or planned improvements would not be reflected in the associated water quality data in the database.

The basis for assessment of impacted conditions differed slightly from state to state. The assessment of the rivers conditions were generally based on consideration of a combination of causal factors such as the nutrients measured, impairment to benthic community, presence of POTW or CSO discharges, presence of agricultural activity, observed low DO, etc. In addition to the 303(d) list, biocriteria data from CT and VT were reviewed and R/S with severe impairment to aquatic life support (as evidenced by low biocriteria scores) were also added to the impacted category. Finally, those waterbodies which were not identified as either reference or impacted were categorized as “test” waterbodies. The distribution of reference, test, and impacted rivers and streams is presented in Table 6-2.

The distribution of nutrients in rivers and streams of these three categories are shown in Figures 6-2 and 6-3. Not unexpectedly, these figures show a clear distinction between the reference and impacted R/S categories for both TP and TN, while the test category shows a distribution in-between although not too different from the reference. This clearly indicates that selecting for a largely non-urbanized, sparsely populated watershed does indeed result in “reference” water quality conditions.

The nutrient data were processed using the EPA data transformation protocol presented in Section 4.4 for the key trophic parameters. The dataset population obtained is composed of one representative value per waterbody, expressed as the median of all measurements of season-specific values for a certain parameter (e.g., 25th percentile). The resulting 25th, 50th (median) and 75th percentiles are shown in Table 6-3. Comparison of the medians for TP indicated 43 ug/L for impacted R/S, 14 ug/L for reference R/S and 24 ug/L for test R/S. The 75th percentile values for the reference R/S was retained for use in comparison with the all NE 25th. Due to the lack of trophic data for some ecoregions some of the reference values are less likely to be representative (e.g., EGLHL).

6.2.2 Comparison with U.S. EPA Ambient Water Quality Criteria Recommendations

To provide comparability to the U.S. EPA AWQC Recommendations (U.S.EPA, 2000b; 2000c; 2001), the nutrient data were processed using the EPA data transformation protocol presented in Section 4.4. The “four seasons” 25th percentile values for all waterbodies (corresponding with “All rivers distribution” in Figure 6-1) and the 75th percentile for reference waterbodies (corresponding with “Reference rivers distribution”) were calculated. These values are displayed with the corresponding U.S. EPA ambient water quality criteria recommendations for NE ecoregions in Table 6-4.

Comparison between the NE R/S Nutrient Database 25th percentile values and the EPA criteria recommendations indicates excellent agreement between these two sets of values. This is not an unexpected result as there is considerable overlap between the two databases since both include STORET and USGS data. For example, the TN values are ranked comparably and distinguish between the more fertile EGLHL and NECZ ecoregions versus the more nutrient poor LPH and NEH ecoregions. Distributions of TP are similar although the NE R/S Nutrient database has a slightly higher value for the LPH (20.3 ug/L) than the EPA criteria recommendation (12 ug/L). Values for Chl *a* in the NE R/S Nutrient Database vary somewhat among the ecoregions (1.7 – 4.9 ug/L) but correspond to the ranges seen in the AWQC (1.6 - 3.4 ug/L). The small sample size (or mixing of different chlorophyll analytical methods) may be affecting the representativeness of the values.

The 75^{th} percentile of the reference R/S does not consistently fall above or below the values of the 25^{th} percentile of the all rivers. The composite New England shows good agreement between the two values for TP, TN, and Chl *a* (Table 6-4).

Other regional nutrient values for comparison include the medians (50% percentiles) reported by Rohm et al. (2002) for their New England EMAP R/S data. For those R/S in Level III Aggregate Ecoregion VIII, Rohm et al. reported TP and TN values of 18 ug/L and 878 ug/L, respectively; while corresponding range for LPH and NEH (Ecoregion VIII) in the R/S NE Nutrient Database were TP from 16 to 23 ug/L and TN at 325 to 479 ug/L. For Level III Aggregate Ecoregion XIV, the median TP and TN were 34 ug/L and 1256 ug/L. This compares to the NECZ TP median, which was 29 ug/L for TP and 702 ug/L for TN. Overall, the NE R/S Nutrient Database and Rohm et al. EMAP study match up well for the TP values, but the Rohm estimates of TN are roughly twice the NE database values.

6.3 Evaluation of Effect of Watershed Size on Nutrient Levels

The watershed area estimates provided by USGS were used to compare the effect of watershed size on nutrient concentrations in R/S. In this case watershed size is the surrogate parameter for other size-related factors such as stream order, water depth, or flow. The purpose of such an analysis is to determine whether, due to loading or flow characteristics, it is possible to distinguish among watersheds of a certain size, and use this distinction to adjust nutrient criteria. Another reason for separating watersheds of different size is to segregate those whose productivity may be dominated by periphyton versus those with large phytoplankton communities.

As a first analysis, the effect of watershed size was compared to waterbody median TP and TN values for the four NE ecoregions (Figures 6-4 and 6-5). In both of these figures, two patterns are evident. First, due to the large scale of potential watershed size, there is a clustering of values in the low watershed size range with great variability in nutrient levels seen in the smaller unit watersheds. Secondly, the nutrient values become somewhat uniform as watershed size increases. The very large rivers (i.e., >2,000 sq. mile watershed) do not appear to vary significantly in nutrient concentration. It is uncertain whether this decreasing variability is due to the homogenization of watershed influences, as larger rivers drain watersheds of increasing similarity in land use due to urban sprawl.

To better evaluate the small watersheds that are clustered near the origin in Figure 6-4, the same comparison was done at a smaller watershed size range (Figure 6-6). There seems to be a slight decrease in the variability of nutrients from the smallest watershed as size increases. However, the figure indicates no great pattern of nutrient increase or decrease other than a distinctive grouping of waterbodies along ecoregional lines (especially EGLHL and LPH). The basis behind these ecoregional differences are further analyzed based on the land use differences (see Section 6.4)

As another approach in evaluating the influence of watershed size on R/S nutrient levels, an arbitrary size classification was used, based on a loosely defined functional characteristic of a stream. This analysis was interested in the possible utility of a sub-classification of R/S into so-called “wadeable” streams (i.e., streams able to be forded during low flow without use of a boat) and larger waterbodies.

Wadeable streams are of particular interest because they are thought to more likely to be sensitive to nutrient enrichment due to their shallow volume and depth and their potential to support periphyton growth or aquatic macrophytes which, in excessive amounts, can lead to impairment of aquatic life support and/or aesthetics. As R/S size and depth increase, the relative sensitivity of the waterbody to nutrient enrichment is likely to decrease as light and substrate availability compete with nutrient limitation to control periphyton or macrophyte growth. As streams increase in size and channel morphometry, more biological productivity will cycle through water column phytoplankton which may present problematic blooms in downstream impoundments.

U.S. EPA has not officially defined the morphometric parameters (depth, width, etc) of a “wadeable” stream. Following discussion with the RTAG coordinator and inquiries to U.S. EPA national headquarters, an estimate of a watershed of <50 square miles was discussed. Therefore, for purposes of this analysis, a wadeable stream was defined as a waterbody with a sampling station < 50 square miles upstream watershed drainage area.

Comparison of the distribution of four season medians for TP and TN for wadeable and larger R/S are shown in Figures 6-7 and 6-8, respectively. Both figures indicate that there is very little difference in the distribution of nutrients between wadeable and larger streams. To make sure this pattern was not obscured by ecoregional influences, the same comparison was made for R/S from a single ecoregion (NECZ) in Figures 6-9 and 6-10. The within-ecoregion comparison did not further resolve nutrient distributions between wadeable and larger R/S. Thus, while differences are likely to exist in the biological response of the wadeable R/S to excessive nutrients in terms of impairment of aquatic life support (see Section 6.5), there is no clear distinction between the levels of nutrients seen in wadeable vs. larger R/S.

A further investigation was made of large multi-ecoregion rivers to see how the differences in watershed size and shift in ecoregion affected nutrient levels. The two example rivers used were the Merrimack and Connecticut Rivers. Figures 6-11 and 6-12 present TP concentrations in these two major rivers. The levels of TP increase in both waterbodies (note the discontinuity in Figure 6-11 as no

Massachusetts nutrient data were available) with distance downstream and with transition from NEH to NECZ. This is particularly true for the Merrimack River (Figure 6-12) where TP increases markedly as the river goes from the NEH to the NECZ ecoregion. Since the Merrimack Valley in the NECZ contains several large urban centers with large publicly-own treatment works (POTWs), aging stormwater infrastructures, and combined sewer overflows (CSOs) (e.g., metropolitan areas of Lowell, Lawrence), the increase in TP is likely to be associated with local land uses rather than with watershed size alone. While there are similar large urban areas and multiple POTWs along the Connecticut River, the lack of sampling stations and water quality data for this river in Southern New England, makes definitive statements about trends more uncertain. The role of watershed land use on R/S nutrient concentrations was further investigated.

6.4 Evaluation of Effect of Watershed Land Use on Nutrient Levels

The potential influence of watershed land use on the water quality of NE R/S was investigated using the land use categories provided by USGS. While increasing watershed size did not lead to a significant trend in nutrient levels, relative increases in the types of watershed land uses expected to export nutrients should be reflected in higher nutrient concentrations in receiving streams. This assumption was used in the converse during the identification of surrogate reference stations, where threshold percentages of particular land uses were used as screening criteria (Section 6.2)

The two land uses that were evaluated were urban and agricultural land use. As noted earlier, urban land use is defined as the sum of urban, suburban, recreational grassland (park) and barren (non-vegetated); while agricultural land use is the sum of cultivated and orchard land uses (Section 5.1). The overall relationships between waterbody four season median TP and TN under varying land use conditions are shown in Figures 6-13 through 6-15.

Figures 6-13 and 6-14 indicate the relationship between TP and TN and percent urban land use for New England ecoregions. Figure 6-13 indicates that TP does not show a significant trend with increasing urban land use, with variation decreasing with urban area. It is likely that the elevated TP values are due to the influence of POTWs. As in other figures, there is a cluster of values near the axes indicating watershed with low amounts of urban land. All of the waterbodies with greater than 10% urban land are in the NECZ ecoregion. In Figure 6-14, the waterbody four season median TN is related to urban land use and shows a positive correlation. A regression line has been fitted to the data for the NECZ (the most urbanized (9% of watershed area) of the ecoregions) and shows a significant correlation (R^2 = 0.227). Figure 6-15 indicates a stronger relationship between TN and agricultural land use, although there is much scatter of values near the origin. A regression line was fitted to the data for the EGLHL ecoregion (the most agricultural (20%) of the ecoregions) and shows a stronger correlation (R^2 = 0.542). This increase in TN may reflect the influence of fertilizer application and soil disturbance associated with active agricultural areas.

These figures indicate that the watershed land use is a potential determinant of water quality and nutrient levels. Since the land uses are somewhat segregated among the four ecoregions, this suggests that a portion of the observable ecoregional differences (e.g., Figures 5-6 and 5-7) are explainable on the basis of land use.

6.5 Evaluation of Effect of Nutrients on Designated Uses

Another approach for evaluation of nutrient criteria is to establish a relationship between nutrient concentrations and designated uses, the legally-protected functional capabilities that a R/S of a certain water classification is expected to provide. In the development of ecoregional nutrient criteria in New England, there has been considerable interest in establishing a more direct linkage between nutrient levels and their effects on designated uses, since this provides a perhaps more ecologically defensible means of developing quantitative nutrient criteria. For NE R/S, hypothetical designated uses range from those requiring high water quality (drinking water supply, outstanding resource waters) to moderate water quality (contact recreation, aquatic life protection) to low water quality (boating, fishing, flood control, irrigation). Most R/S in New England are Class A (all uses including drinking water) or Class B (all uses except drinking water) or their equivalent. It is not known how many of the R/S in the NE database are potential drinking water supplies. For the majority of the R/S, aquatic life support is considered to be one of the most sensitive of the designated uses to nutrient enrichment due to potential adverse impacts of eutrophication (DO fluctuations, algal biomass, etc). Two aspects of aquatic life support were investigated with regard to nutrients – benthic macroinvertebrates and periphyton.

6.5.1 Benthic Invertebrates

Benthic invertebrate data from Connecticut and Vermont were obtained from CT DEP and VT DEC as part of the identification of reference waterbodies/stretches. In each set of data, the benthic community was assessed with regard to its health and similarity to communities found in reference waterbodies or stretches. Additional narrative information provided indicated whether or not the water quality sampling station location was fully, partially, or non-supportive of aquatic life. For Connecticut data, the benthic invertebrate community was rated as a percentage of reference conditions (with 100% being equivalent to reference); while for the Vermont data, six qualitative categories were used including very poor, poor, fair, good, very good, and excellent. These qualitative categories were assigned quantitative scores using 100% for excellent, 66% for good, and 33% for poor with similar interpolation for the other categories. The biocriteria scores were compared to the median TP and TN values and are shown in Figures 6-16 and 6-17. It can be seen that TP is not strongly associated with biocriteria – wide ranges of biocriteria exist at the same phosphorus concentrations. The trend with TN is somewhat more interpretable, as impairment increases with increasing TN, especially concentrations > 1000 ug/L. These results have to be interpreted cautiously since many impacted R/S are impaired for multiple causes, including those not related to nutrient enrichment (e.g., TSS, toxics, habitat alteration), that could have a significant effect on the benthic community.

6.5.2 Periphyton Biomass

An attempt was also made to identify potentially useful relationships between periphyton biomass and nutrient levels that might be useful in developing potential nutrient criteria in rivers and streams. Before setting nutrient criteria based on such relationships, however, it is desirable to directly link periphyton biomass levels to impairment of the designated water uses. As part of this effort, ENSR identified 46 papers that investigated potential relationships between nutrient levels and algal biomass, especially periphyton (ENSR, 2001). The results from these studies were summarized and potentially useful approaches and predictive relationships identified. Some potential nutrient thresholds associated with nuisance levels of periphyton were identified from the literature (Table 6-5).

Periphyton biomass between 50 to 200 mg/m^2 Chl *a* or between 20 to 55% of sediment coverage appears to be considered at nuisance levels, with 100 mg/m^2 Chl *a* considered a median value. EPA's water quality criteria recommendations for EPA Level III ecoregions 59 and 84 for nutrients were substituted into selected regressions and the predicted periphyton levels compared with levels considered potentially harmful to designated uses. Based on those comparisons, it appeared that the predicted periphyton levels associated with the AWQC reference nutrient levels for these ecoregions do not create impairment for designated water uses (Tables 6-6 and 6-7).

Table 6-1 Nutrient Related Factors in current EPA 303(d) Listings of Impaired Waters of New England States Used to Establish Impacted Conditions

Criteria	CT	ME	MA	NH	RI	VT
Agricultural Activity	X					X
Ammonia (unionized)	X		X		X	
Algae					X	
Aquatic Life Support	X	X				X
Dissolved Oxygen (low)	X	X		X	X	X
Impaired Biologic Community /	X			X	X	
Noxious Aquatic Plants	X		X			
Nutrients	X	X	X		X	X
Organic Enrichment/ Low DO			X			X
Sediment Oxygen Demand		X				X
Phosphorus	X	X		X		
Total Suspended Solids / Turbidity		X	X		X	

Table 6-2 NE R/S Waterbodies Identified as Reference, Test, and Impacted by Ecoregion

R/S Categories	EGLHL	LPH	NEH	NECZ	Parameter Totals
Reference R/S	2 / 2 / 1	7 / 2 / 8	48 / 35 / NA	11 / 6 / NA	67 / 44 / 9
Test R/S	7 / 5 / 5	10 / 1 / 9	143 / 73 / 1	238 / 74 / 6	398 / 153 / 21
Impacted R/S	6 / 2 / 2	4 / 1 / 4	15 / 4 / 1	67 / 21 / 1	92 / 28 / 8
Ecoregion Totals	14 / 8 / 8	21 / 4 / 21	206 / 112 / 2	316 / 101/ 7	557/ 225 / 38
parameters listed in order: TP /TN /Chl *a*; NA = data not available					

Table 6-3 Four-Season Medians for Impacted, Reference and Test Rivers and Streams in the R/S Database

		Impacted			Reference and Surrogate			Test		
Ecoregion	**Parameter**	**25th %ile**	**50th %ile**	**75th %ile**	**25th %ile**	**50th %ile**	**75th %ile**	**25th %ile**	**50th %ile**	**75th %ile**
Eastern Great Lakes and Hudson Lowlands	CHLA	2.2	2.2	2.2	1.5	1.5	1.5	2.7	2.9	3.4
	TN	538	538	538	538	538	538	558	613	683
	TP	56	70	83	44	44	44	38	58	95
Laurentian Plains and Hills	CHLA	3.1	3.4	3.7	1.2	2.3	2.5	1.6	1.8	1.8
	Secchi	2.9	2.9	2.9	2.0	2.9	3.0	2.3	2.3	2.3
	TN	370	370	370	325	325	325	485	485	485
	TP	25	30	30	15	17	18	30	30	32
Northeastern Coastal Zone	CHLA	19	19	19	NA	NA	NA	6.0	7.5	9.0
	SECCHI	1.0	1.0	1.0	2.1	2.1	2.1	1.4	1.5	1.8
	TN	707	1060	1838	361	396	458	529	649	870
	TP	29	43	82	11	17	22	17	28	44
Northeastern Highlands	CHLA	2.7	2.7	2.7	NA	NA	NA	1.7	1.7	1.7
	SECCHI	2.1	2.1	2.1	1.7	1.9	2.0	1.1	1.1	1.1
	TN	571	625	696	121	121	121	338	534	712
	TP	19	30	49	8	10	12	10	16	23
Composite New England	CHLA	2.3	2.3	2.3	1.3	1.8	1.8	1.8	2.9	3.4
	SECCHI	1.0	1.4	1.8	2.0	2.2	2.7	1.3	1.3	1.6
	TN	624	856	1533	336	406	520	491	629	798
	TP	27	43	84	9	14	23	12	24	44
NA - No data available.										

Table 6-4 Comparison of All NE 25th Percentile, Reference 75th Percentile and EPA Water Quality Recommendations

Sub-Ecoregions	Parameter	NE Ecoregion Four Season 25%ile Value (ug/L)	Reference Four Season 75%ile Value (ug/L)	EPA AWQ Criteria Recommendations (ug/L)
Eastern Great Lakes/Hudson Lowlands	CHLA	1.6	1.5	1.6 (f)
(EPA sub-ecoregion 83)	TN	470	538	480
	TP	31.0	44.0	24.1
Laurentian Plains and Hills	CHLA	1.7	2.5	NR
(EPA sub-ecoregion 82)	TN	330	325	390
	TP	14.0	12.0	12.0
Northeastern Coastal Zone	CHLA	4.9	-	NR
(EPA sub-ecoregion 59)	TN	560	458	570
	TP	20.0	22.0	23.5
Northeastern Highlands	CHLA	2.2	-	3.4 (s)
(EPA sub-ecoregion 58)	TN	360	121	420
	TP	10.0	12.0	5.0
Composite New England	CHLA	1.9	1.8	
	TN	460	520	
	TP	20.0	23.0	

Notes:

Chlorophyll *a* methods: f = fluorometric, acid corrected; s = spectrophometric, acid-corrected; t = trichromatic

EPA TN criteria are reported values.

NR = not reported

Table 6-5 Periphyton Biomass Levels Associated with Potential Impairment

Reference	Criteria	Potential Impaired Water Use
Biggs 2000	> 150-200 mg/m^2 Chl *a*	Aesthetics, recreation, sports fishing
Dodds et al. 1997	> 100 mg/m^2 mean Chl *a* >150 mg/m^2 max Chl *a*	na
Nordin 1985	> 50 mg/m^2 Chl *a*	Recreational usage
Nordin 1985	> 100 mg/m^2 Chl *a*	Aquatic life
Welch et al. 1988	100-150 mg/m^2 Chl *a*	Aesthetics, oxygen content and macroinvertebrate diversity unaffected at these levels
Horner et al. 1983	> 100-150 mg/m^2 Chl *a* > 20% sediment cover	na
Zuur 1992	Seasonal max sediment cover > 40% and/or > 100 mg/m^2 Chl *a*	Recreational usage
Biggs & Price 1987	≥ 40% sediment cover	Aesthetics
Biggs & Price 1987	≥ 55% sediment cover	Extensive smothering of sediment
Wharfe et al. 1988	Cladophora and sediment cover ≥ 40% of substrate	Aesthetics, fisheries
For primary references, refer to NEIWPCC, 2001.		

Table 6-6 Estimated Periphyton Biomass at U.S.EPA Water Quality Criteria Recommendations for Nutrients for Level III Ecoregion 59

Reference	Recommended Criteria for Total Phosphorus (ug/L)	Periphyton Biomass (mg/m^2 Chl *a*)	Notes
Lohman et al. 1992	23.75	52	Mean biomass
Chetelat et al. 1999		54	
Dodds et al. 1997		23	Mean biomass, TN calculated from TP using Redfield Ratio
Dodds et al. 1997		36	Mean biomass, U.S.EPA criteria used for TN
Reference	**Recommended Criteria for TN (mg/L)**	**Periphyton Biomass**	**Notes**
Lohman et al. 1992	0.57	74	Mean biomass
Chetelat et al. 1999		60	
Dodds et al. 1997		59	Mean biomass, TP calculated with Redfield Ratio
Dodds et al. 1997		44	Mean biomass, Used U.S.EPA criteria for TP
Reference	**Recommended Criteria for NO_3+NO_2 (mg/L)**	**Mean Periphyton Biomass**	**Notes**
Biggs 2000	0.31	3	7 days between floods
		21	30 days between floods
		49	60 days between floods
For primary references, refer to NEIWPCC, 2001.			

Table 6-7 Estimated Periphyton Biomass at U.S.EPA Water Quality Criteria Recommendations for Nutrients for Level III Ecoregion 84

Reference	Recommended Criteria for Total Phosphorus (ug/L)	Periphyton Biomass (mg/m^2 Chl *a*)	Notes
Lohman et al. 1992	6.88	30	Mean biomass
Chetelat et al. 1999		18	
Dodds et al. 1997		7	Mean biomass, TN calculated from TP using Redfield Ratio
Dodds et al. 1997		17	Mean biomass, EPA criteria used for TN
Reference	**Recommended Criteria for TN (mg/L)**	**Periphyton Biomass**	**Notes**
Lohman et al. 1992	0.48	69	Mean biomass
Chetelat et al. 1999		51	
Dodds et al. 1997		52	Mean biomass, TP calculated with Redfield Ratio
Dodds et al. 1997		29	Mean biomass, Used EPA criteria for TP
Reference	**Recommended Criteria for NO_3+NO_2 (mg/L)**	**Mean Periphyton Biomass**	**Notes**
Biggs 2000	0.24	3	7 days between floods
		19	30 days between floods
		46	60 days between floods
For primary references, refer to NEIWPCC, 2001.			

Figure 6-1 Two Approaches for Finding Reference Condition Value for Total Phosphorus

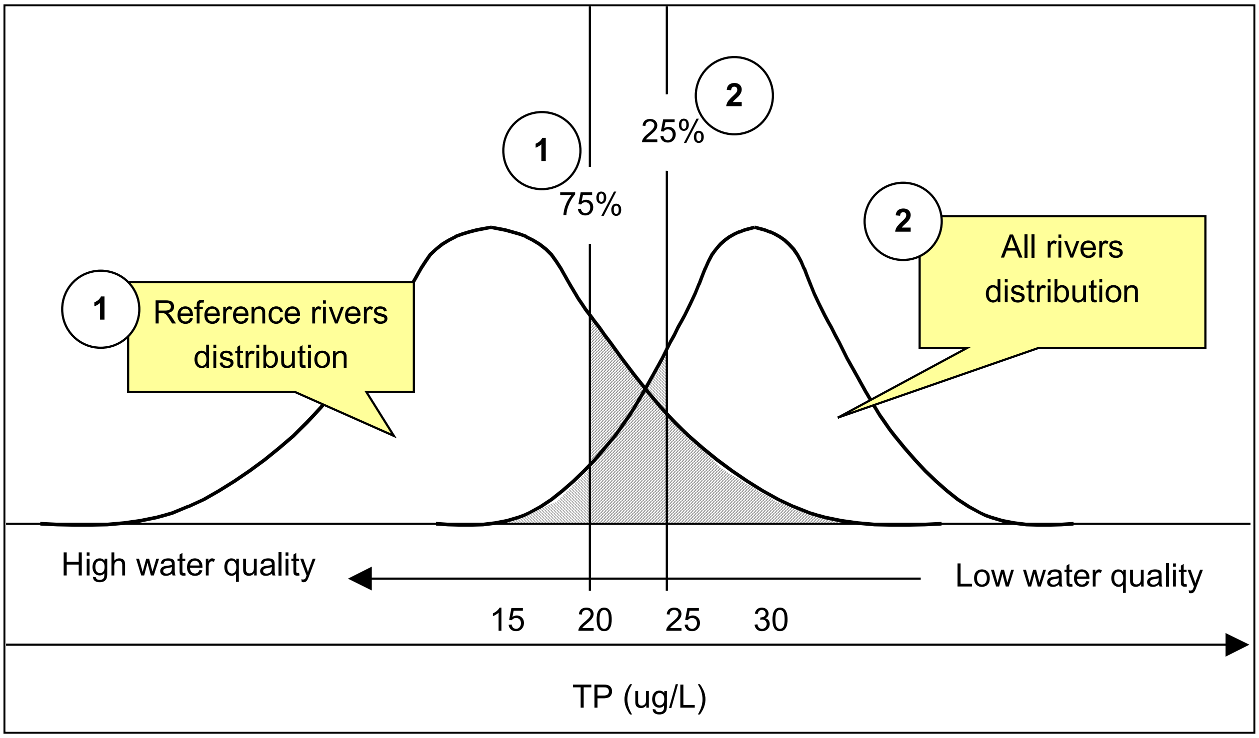


Figure 6-2 Distribution of TP in Reference, Test, and Impacted R/S in New England

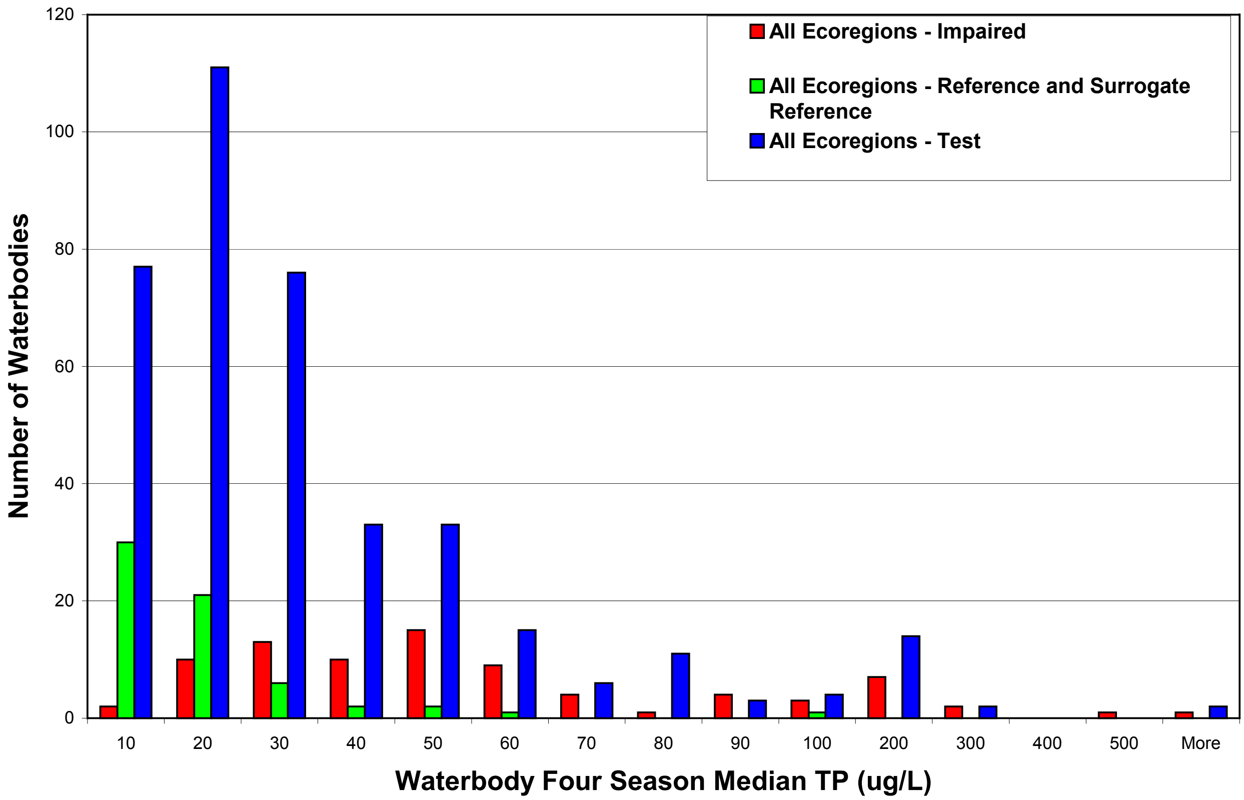


Figure 6-3 Distribution of TN in Reference, Test, and Impacted R/S in New England

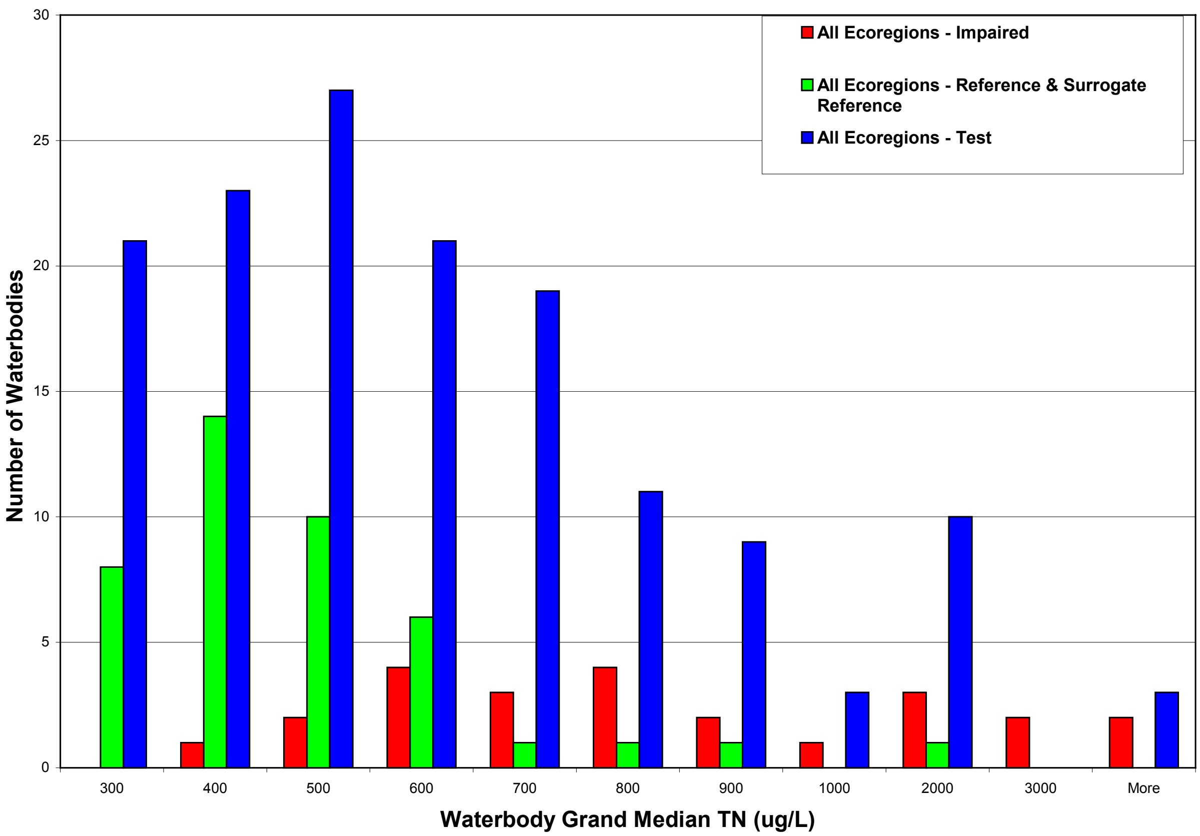


Figure 6-4 Relationship of TP and Watershed Size in New England Ecoregions

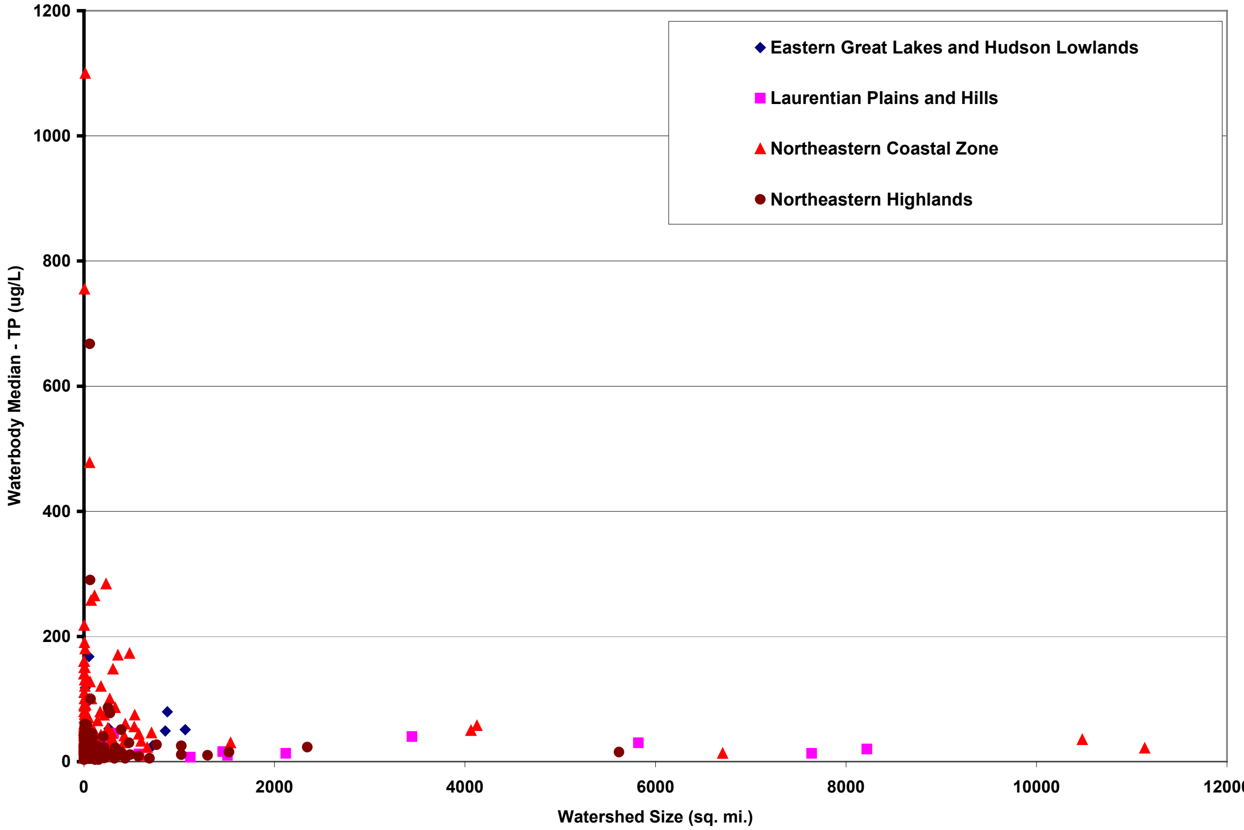


Figure 6-5 Relationship of TN and Watershed Size in New England Ecoregions

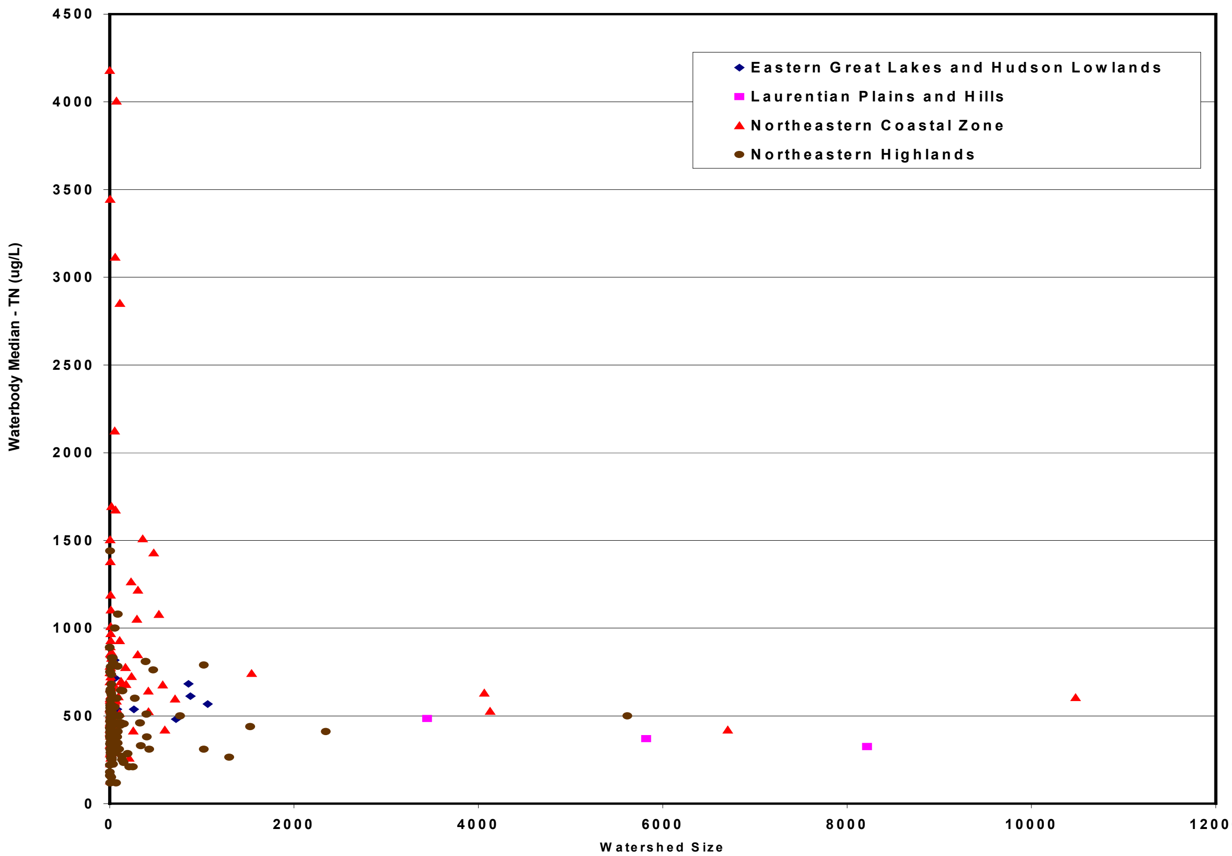


Figure 6-6 Relationship of TP and Watershed Size (Detail of Figure 6-4)

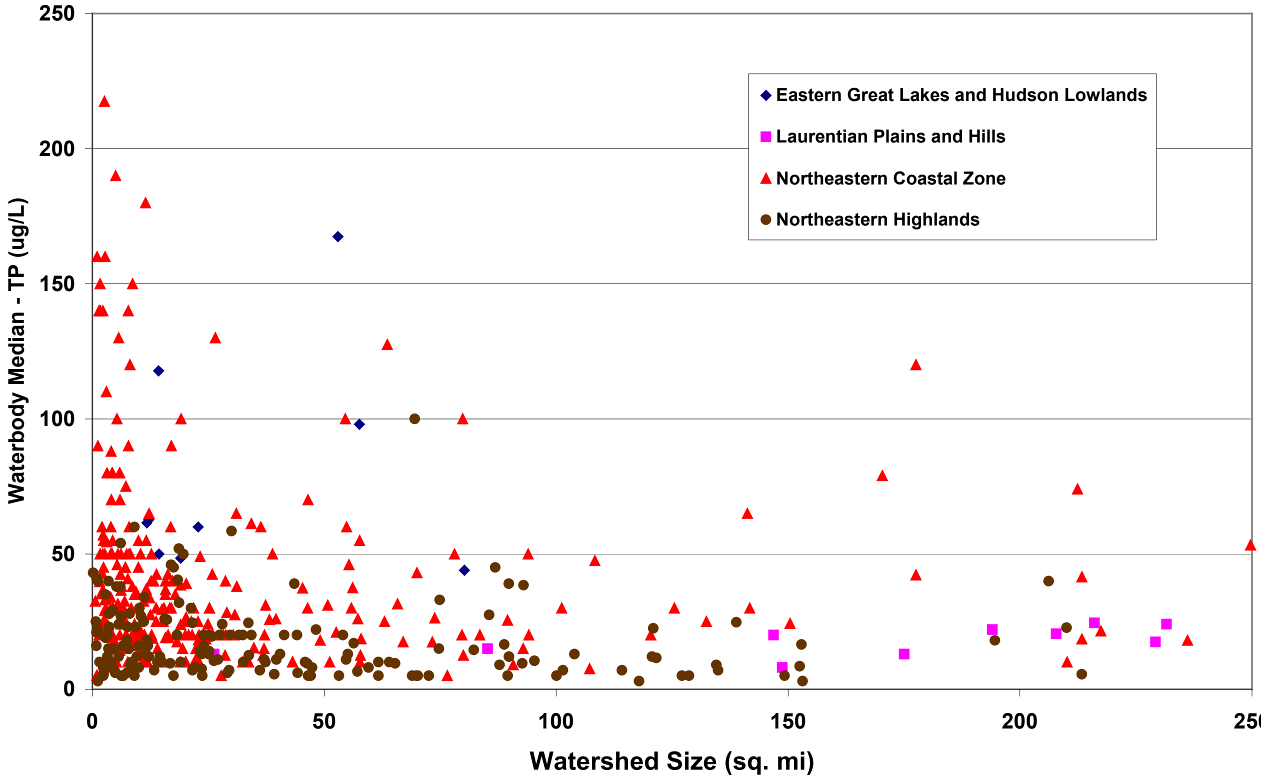


Figure 6-7 Median TP for Wadeable (Small) and Large Rivers – All NE Ecoregions

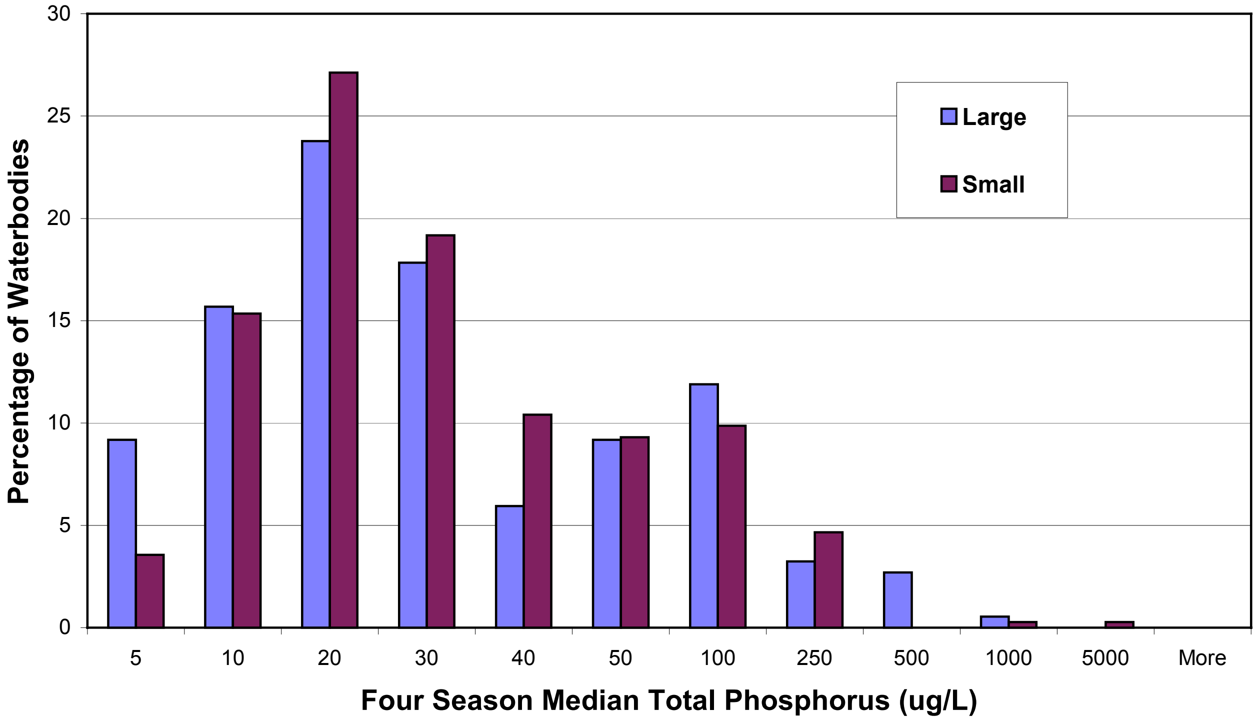


Figure 6-8 Median TN for Wadeable (Small) and Large Rivers – All NE Ecoregions

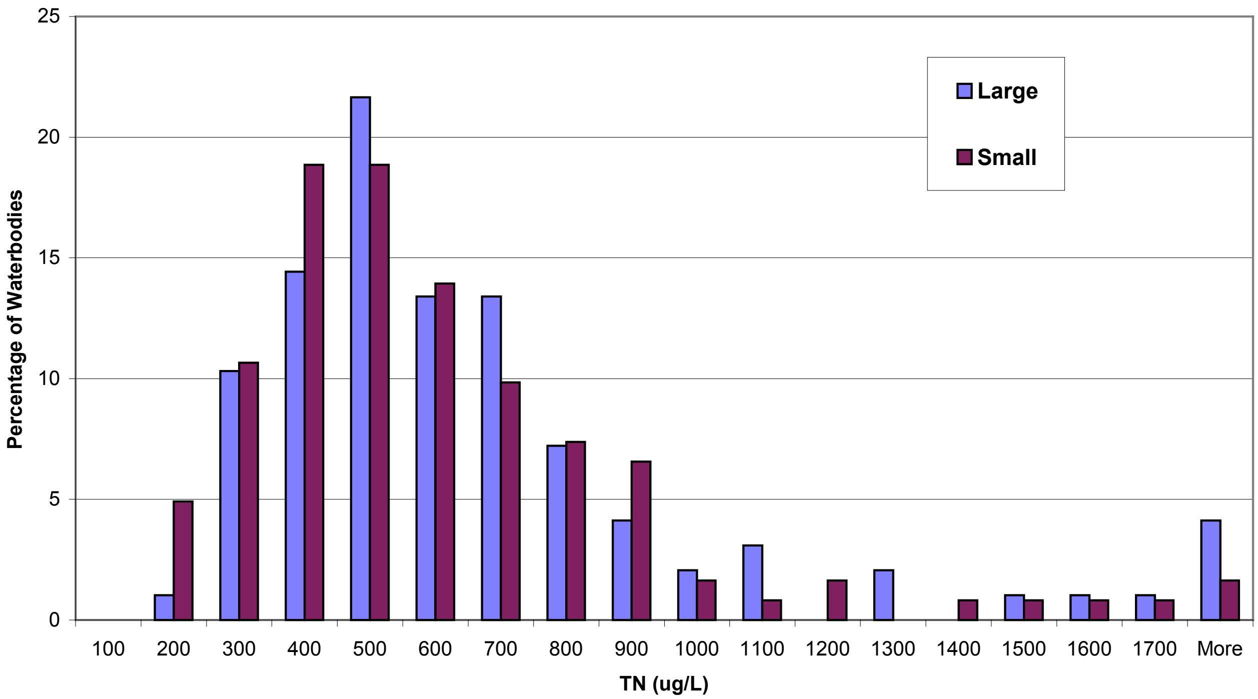


Figure 6-9 Median TP for Wadeable (Small) and Large Rivers – NECZ Ecoregion

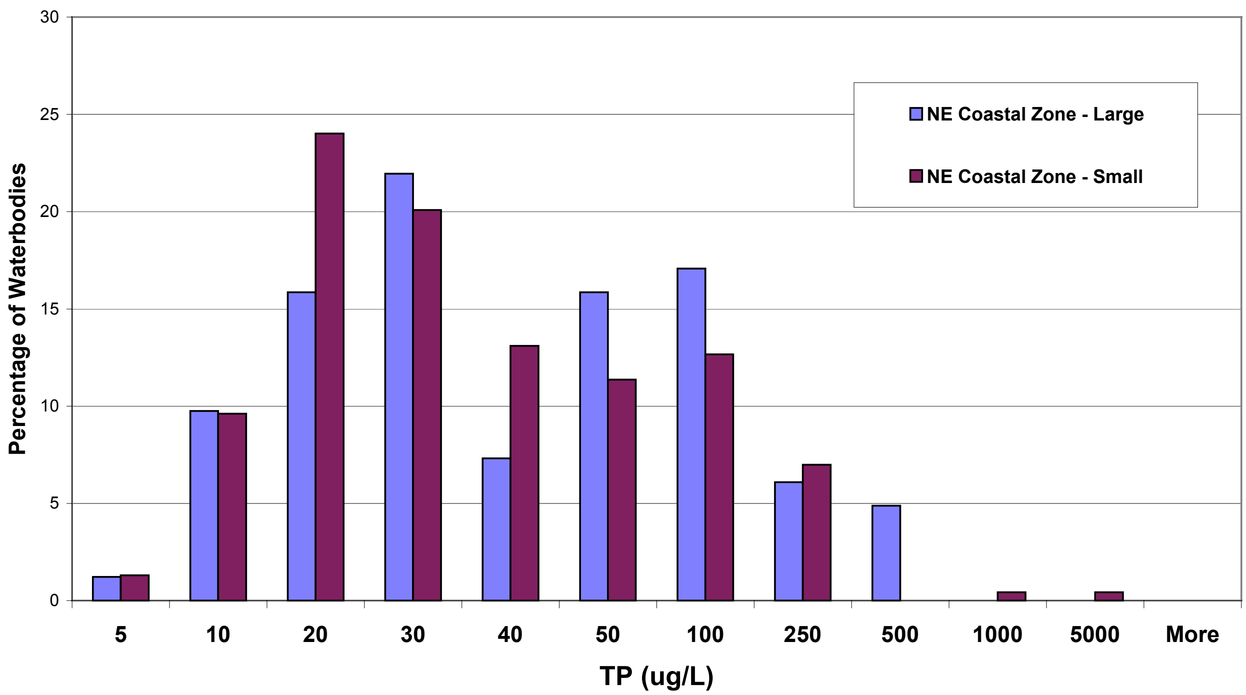


Figure 6-10 Median TN for Wadeable (Small) and Large Rivers – NECZ Ecoregion

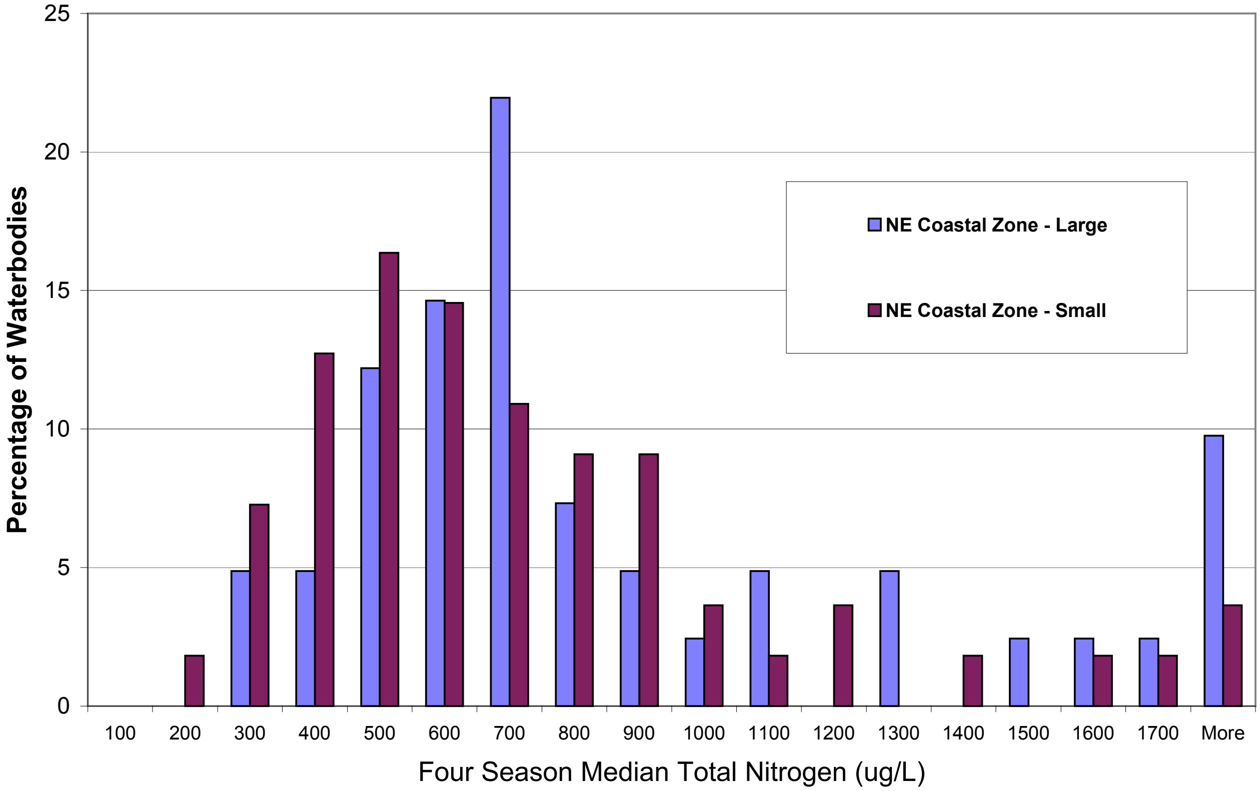


Figure 6-11 Median TP for Water Quality Stations Along the Connecticut River

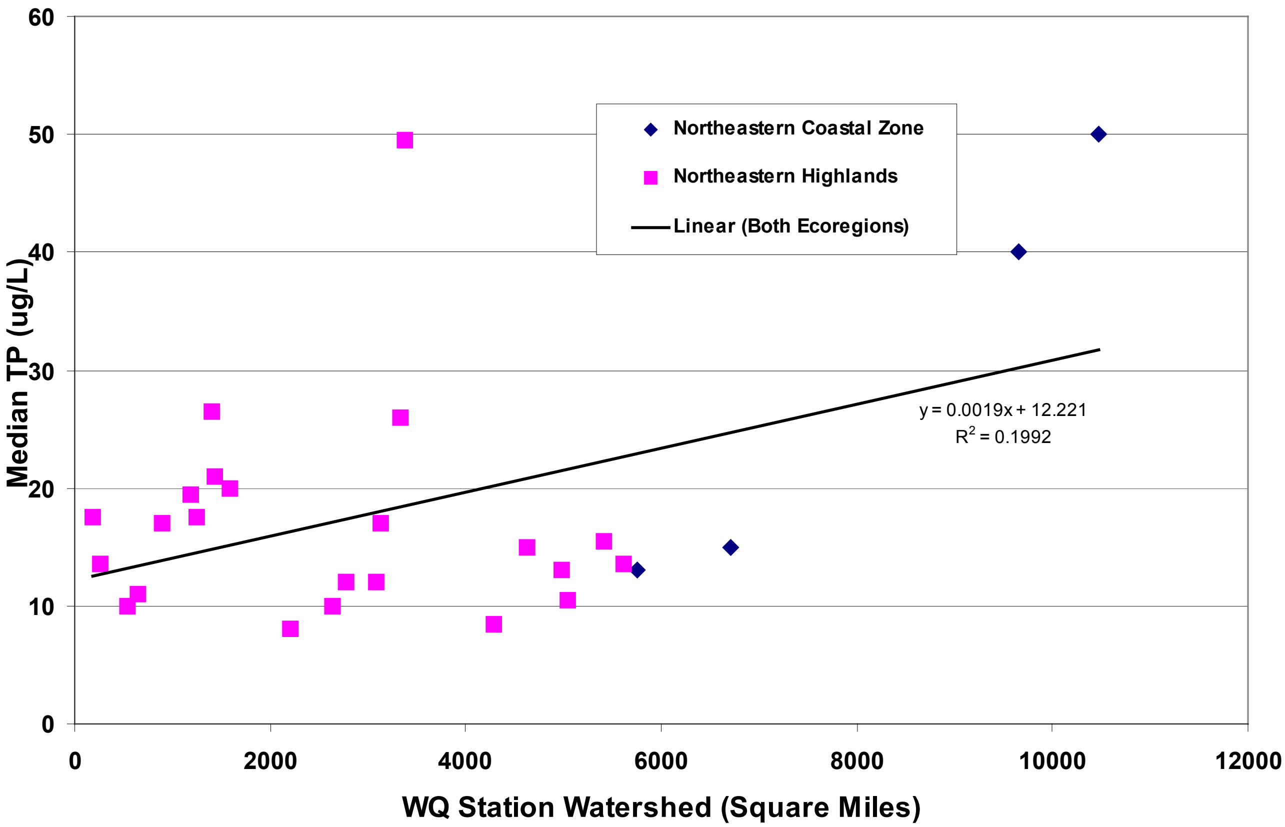


Figure 6-12 Median TP for Water Quality Stations Along the Merrimack River

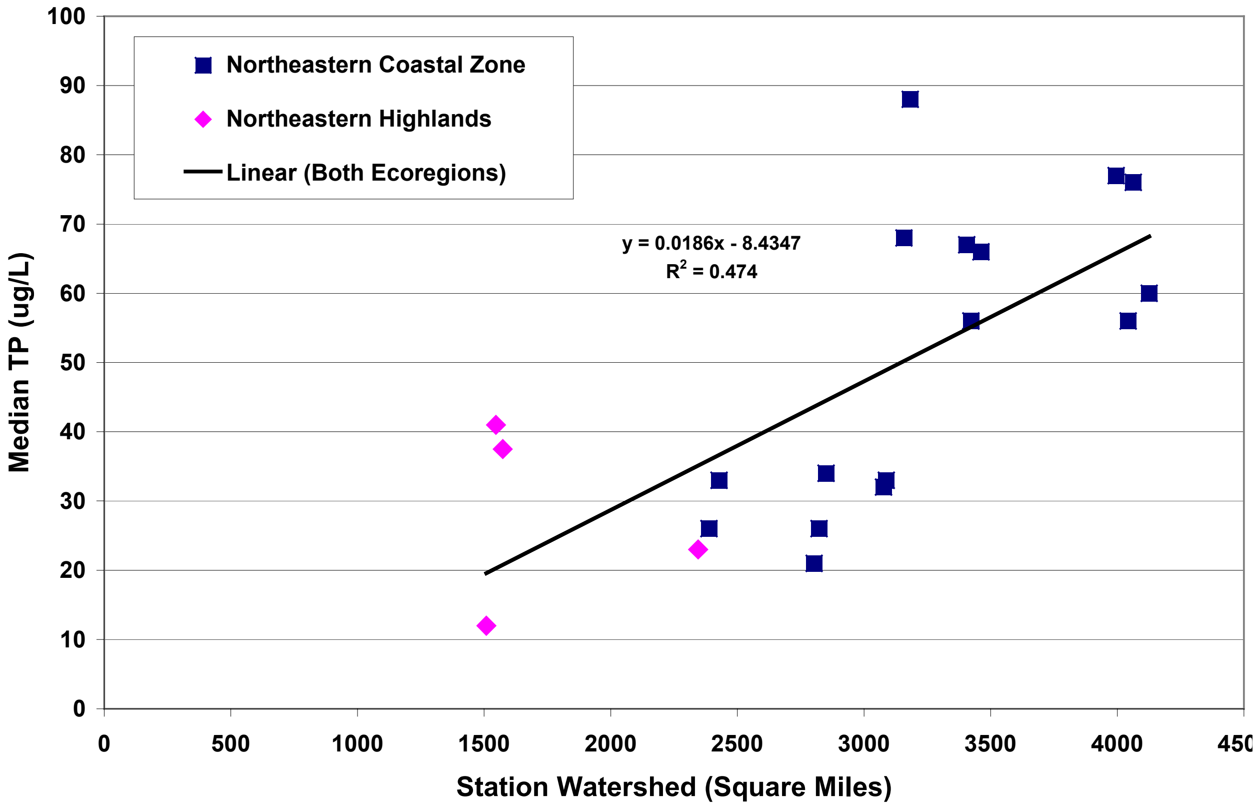


Figure 6-13 Median TP as a Function of Percent Urban Area – All NE Ecoregions

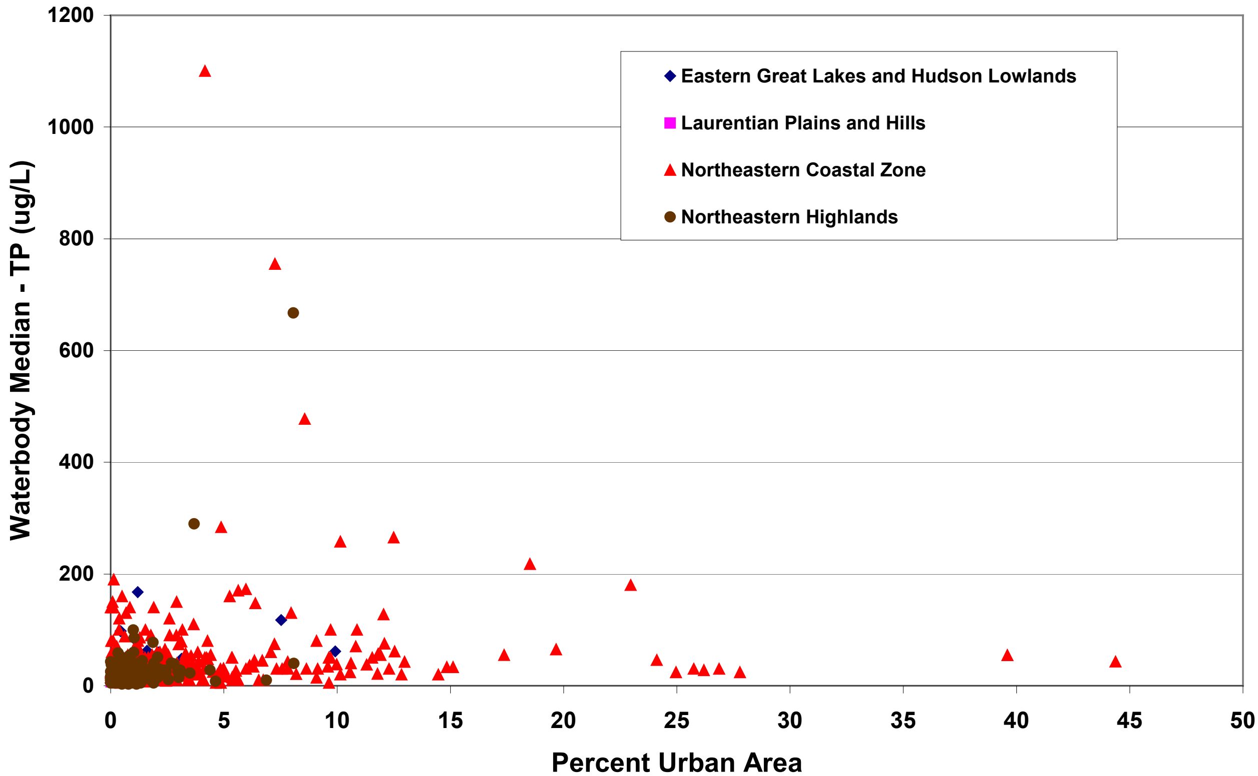


Figure 6-14 Median TN as a Function of Percent Urban Area – All NE Ecoregions

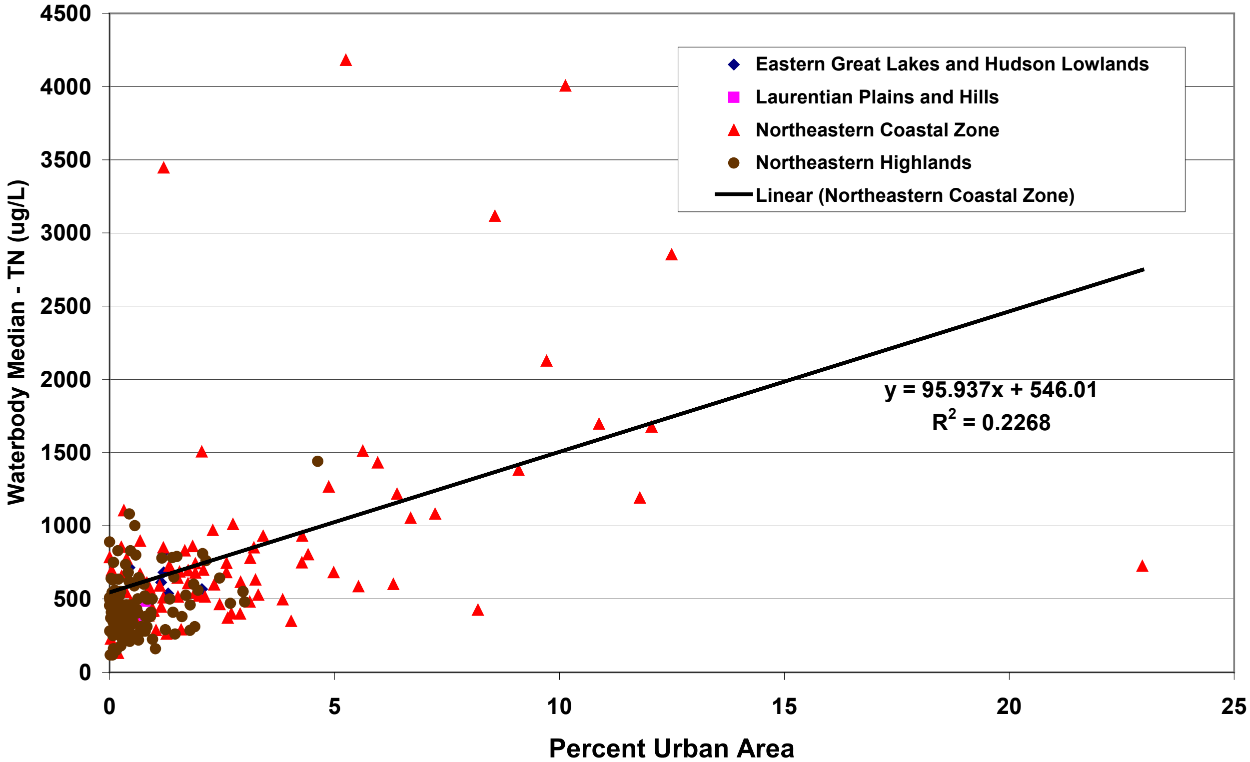


Figure 6-15 Median TN as a Function of Percent Agricultural – All NE Ecoregions

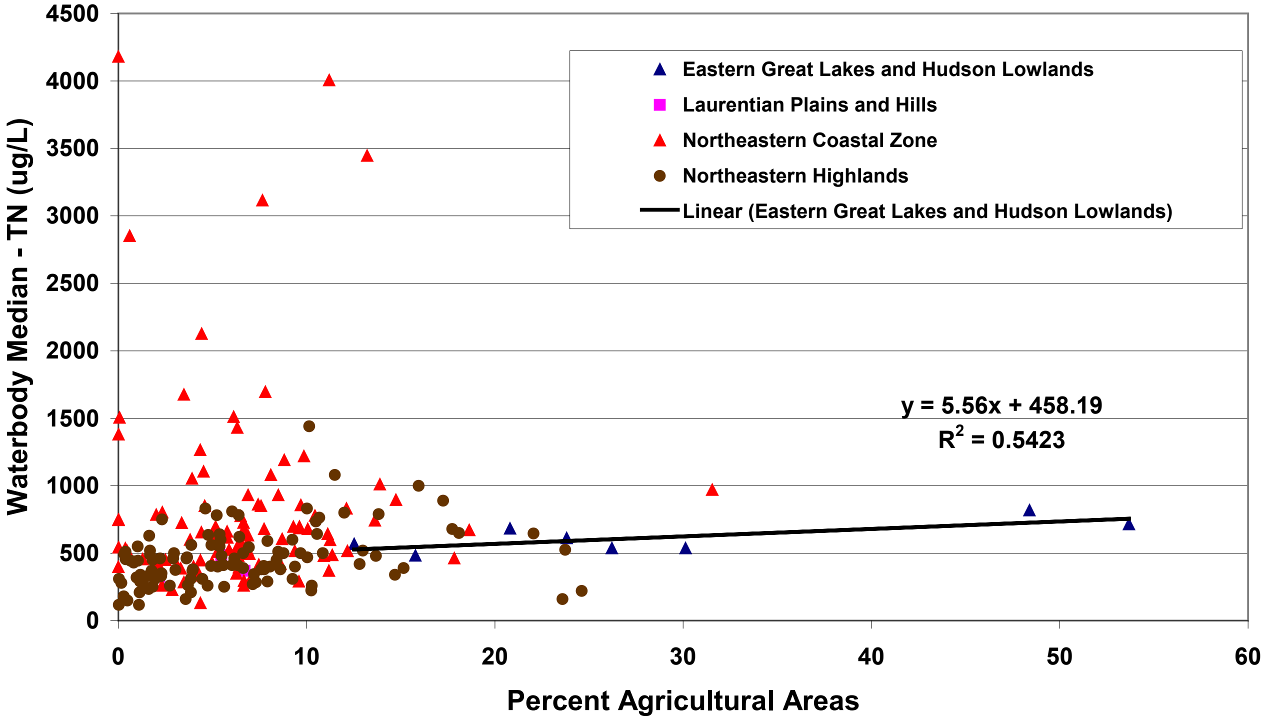


Figure 6-16 TP and Benthic Macroinvertebrate Biocriteria Scores – Connecticut and Vermont

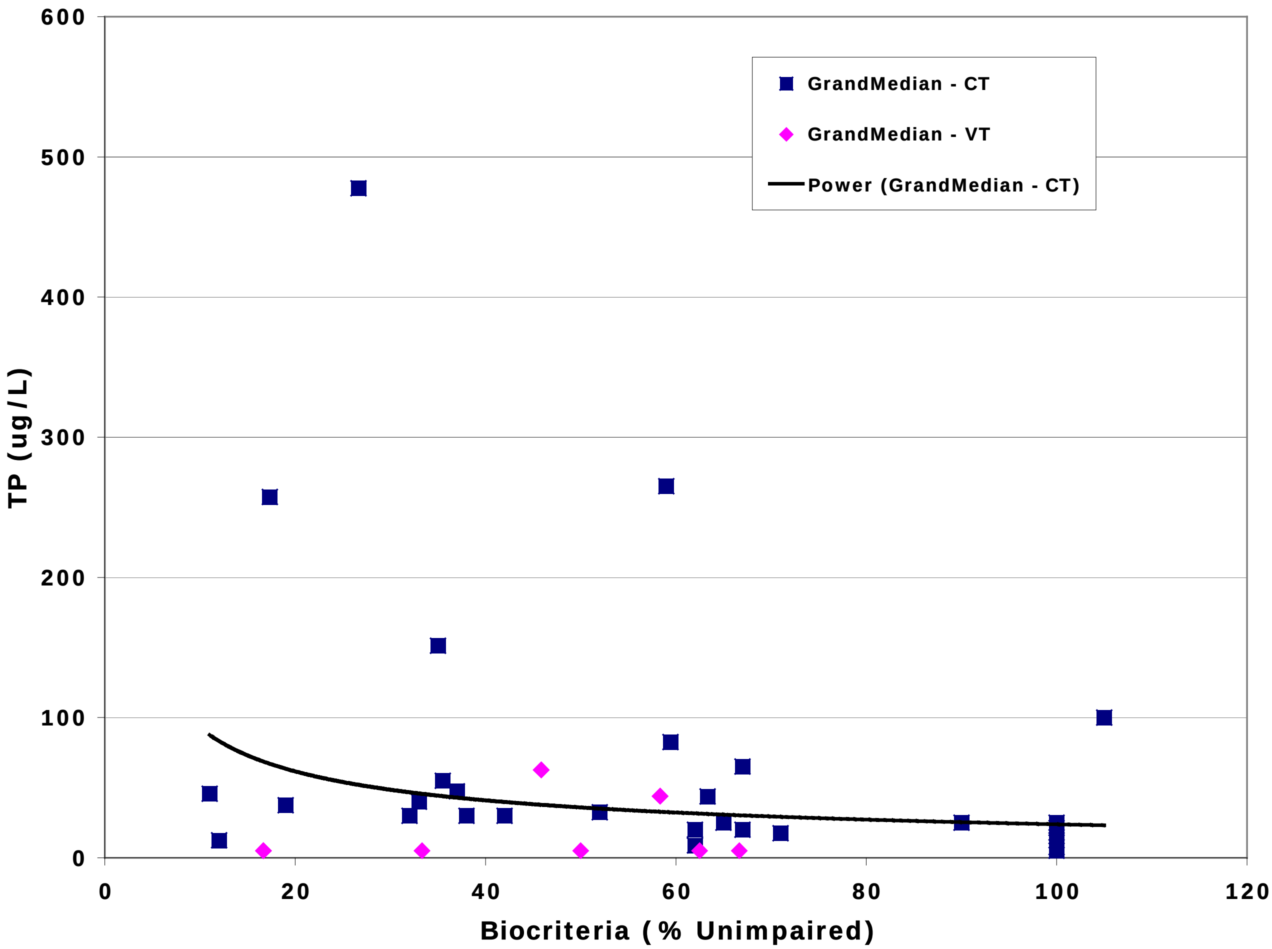
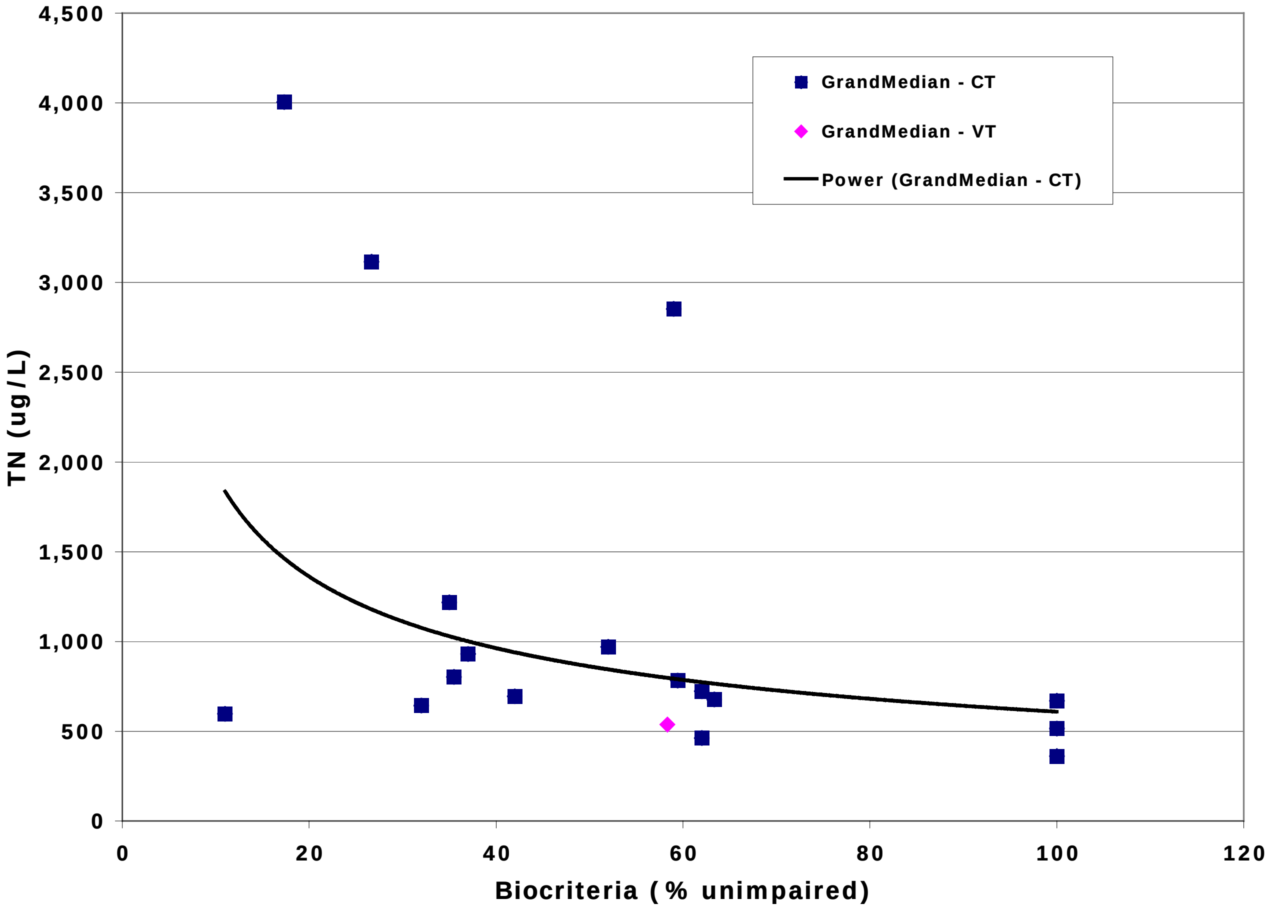


Figure 6-17 TN and Benthic Macroinvertebrate Biocriteria Scores – Connecticut and Vermont



7.0 OUTSTANDING ISSUES

During the course of the development of the NE R/S Nutrient Database and the development of preliminary draft nutrient criteria, numerous issues were identified regarding the procedures, protocols or assumptions used. Many of these issues were raised in discussion with the RTAG meetings, or through communication with individual RTAG members or state experts. In some cases, issues were identified that were not fully resolved and which may need further investigation as the regional nutrient criteria are developed. In many cases, these issues concern alternative procedures or assumptions that reflect different approaches used by New England states to collect or analyze data.

These issues may be broadly categorized into two areas of concern. The first area deals with concerns regarding the uncertainty associated with the data in the NE R/S Nutrient Database (Section 7.1) which is the basis for preliminary criteria identification. The second area of concern is the unresolved nature of addressing potential downstream impacts as part of the overall nutrient criteria application (Section 7.2).

7.1 Uncertainties Associated with Data in the NE R/S Nutrient Database

Several issues were identified with the selection of waterbodies, nutrient data, and other parameters that were incorporated into the NE R/S Nutrient Database. These issues are discussed further below.

7.1.1 Issues Associated with the Data Availability for NE Rivers and Streams

As noted earlier in the Technical Memorandum (ENSR, 1999), it was recognized at a very early stage that there were several limitations to development of the database due to:

- an uneven amount of nutrient and trophic-state related data available between the six New England States;
- the variable measured parameters in the databases provided by States, Tribes, federal agencies, and the academic community;
- the heterogeneous quality of the data, in terms of sampling effort, amount of supporting *metadata*, analytical precision, and analytical accuracy; and
- the uneven regional coverage of waterbodies, with a likely overrepresentation of rivers and streams in more densely populated areas and/or those with recognized water quality problems.

As noted in the Technical Memorandum (ENSR, 1999) and discussed in Section 5.3, the primary technical focus was the development of a nutrient database that was sufficient to support preliminary development of draft criteria. Based on comparison to *a priori* target goals for waterbodies, ENSR concluded that only the number of rivers and streams available for the NECZ and NEH ecoregions exceeded the target goals. However, it was observed that the EGLHL ecoregion was adequately populated with rivers and streams relative to its very limited spatial extent in New England, while the LPH ecoregion waterbodies were underrepresented, apparently due to a limited number of observations from sparsely-populated watersheds.

It should also be noted that there were significant differences in the availability among nutrient data parameters for the same waterbody. This was particularly true in the case of chl *a* and SDT for most ecoregions. Further, most chlorophyll values were for water column phytoplankton and not for substrate periphyton, which is more appropriate for wadeable waterbodies. This lack of periphyton data for New England has been previously identified and attempts made to rectify this deficiency (e.g., Riskin et al., 2003).

Lastly, the availability of nutrient data for all seasonal quarters was also very variable. Due to the calculation protocol of the U.S. EPA to produce the all seasons median (U.S EPA, 2001), some of this uncertainty is translated into conservative assumptions (e.g., use of a minimum value when less than optimal number of medians available). This may lead to an under-representation of the true median value in waterbodies not well characterized over all four seasons.

Accordingly, the results and conclusions based on the NE R/S data must be interpreted in light of a less than optimal database. However, follow-up discussions and inquiries with RTAG agencies did not identify other readily available nutrient databases to overcome these data gaps. It is expected that as New England States become more systematic in the sampling of nutrients in lotic systems, these data deficiencies will lessen. In should be noted that many of the U.S. EPA AWQA recommendations are based on similarly sparse data sets (U.S. EPA, 2000b; 2000c; 2001).

7.1.2 Availability of Reference Waterbodies

One of the uncertainties associated with the use of the NE R/S Nutrient Database to calculate ecoregional-specific criteria was the general lack of identified reference rivers or streams. As noted in Section 5.3, only 20 streams were identified in three states – Connecticut, New Hampshire, and Vermont – mostly on the basis of biocriteria. This is in contrast to the NE Lake/Pond/Reservoir database, when all states participated in the identification of reference lakes (NEIWPCC, 2000).

To evaluate the potential distribution of reference locations, ENSR chose to identify surrogate reference waterbodies, based on land use characteristics (Section 6.2.1). While we feel this is an appropriate method and is based on precedents in other applications (e.g., Rohm et al., 2002), it does represent another source of uncertainty, as reliance only on watershed characteristics does not take into account any localized discharges or site-specific factors that may have adversely affected the nutrient levels. However, we believe it has merit to provide a temporary means to identify non-impacted watersheds. Future riverine monitoring by the New England States, or coordination with other programs (e.g., biocriteria), may resolve this issue.

7.2 Consideration of Downstream Impacts

The need to consider the potential impact to downstream resources, in addition to protection of in-stream aquatic resources at particular site, was an area of much discussion in the RTAG meetings. This is because U.S. EPA has developed clear guidance for establishing nutrient criteria, (e.g., reference conditions), but has provided little guidance on accounting for downstream uses in the adjustment of said nutrient criteria. EPA's regulations at CFR Part 131.10(b) require that in "*designating uses of a waterbody and the appropriate criteria for those uses, the State shall take into consideration the water quality standards of downstream waters and shall ensure that its water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters*."

EPA (2000a) defines "downstream" as the distance where nitrogen and phosphorus can reasonably be treated as conservative pollutants (i.e., removal from the system does not occur). For example, criteria established for protection of tributary streams should also take into account the nutrient level necessary to protect the receiving lake. If criteria are set as reference conditions representing minimally impacted conditions, it is presumed that downstream use, no matter how far downstream, would also be protected. But site-specific effects-based criteria may protect uses in one type of water body (e.g., a wadeable stream), but not in another downstream water body type (e.g., a lake or impoundment along a river).

Discussions with states and other stakeholders have highlighted that it is difficult to account for downstream uses due to the variability in the types of streams and reservoirs and also, in determining what is considered "*immediate*". For rivers and streams, this means that criteria should be derived to be protective of designated uses in the streams, while downstream uses would be separately accounted for as load reduction targets in a total maximum daily load (TMDL) calculation. The problem with this approach is that typically nutrient enrichment is managed after a problem is manifested; this approach may not prevent impairments downstream and thus may not be protective of downstream designated uses.

This issue was not resolved in the course of the RTAG meetings, nor is it clear how States intend to accommodate this concern in their nutrient criteria implementation plans. This issue is also made more complex in the case of interstate rivers, where exceedance and potential impacts may be registered under a different set of State nutrient criteria. This may lead to the requirement of an interstate TMDL to address the root causes of the eutrophication.

The area of downstream effects is one that will likely require considerable additional dialogue and consensus among the NE states and federal agencies before resolution is approached.

8.0 SUMMARY

Water quality data, geographic characteristics, and watershed information were collected from over 2,100 rivers and streams in New England as part of the “Collection and Evaluation of Ambient Nutrient Data” Project, Phase 3 (Section 1.0). The primary source of information was from electronic data files obtained from various state and federal agencies, Tribal nations, and academic institutions (Section 2.0). A relational database was designed and implemented in Microsoft Access97® to accumulate and manipulate the extensive amount of available electronic data (Section 3.0).

Review of the initial data collection for four key trophic parameters (TP, TN, chl *a*, SDT) indicated that these were not available for a majority of the waterbodies (Section 4.0). Subsequently, the data was refined to focus on waterbodies with available trophic parameter data to produce the final New England Rivers and Streams (NE R/S) Nutrient Database. The final Nutrient Database, with 569 rivers and streams represented, was used to develop and investigate potential ecoregional nutrient criteria in four EPA Level III ecoregions (EGLHL, LPH, NECZ, NEH). The majority of these waterbodies were represented by data from one or two water quality stations; while 20 waterbodies with stations in more than one state were identified. Water quality data for the waterbodies was summarized using the U.S. EPA protocol (U.S. EPA, 2001) for calculating both seasonal and “all seasons” median values as representative statistical measures.

The NE R/S Nutrient Database was analyzed and its general characteristics described (Section 5.0). Comparison was made between the number of waterbodies and water quality data in the four ecoregions Based on the review, it appeared that additional information would be desirable for waterbodies in the EGLHL and LPH ecoregions. However, considering the small spatial coverage of the EGLHL ecoregion in New England and the potential lack of additional water quality data for rivers and streams in the sparsely populated LPH region, the available data was deemed sufficient for initial analyses. The ecoregion-specific distribution of the trophic parameters were further examined and described, indicating some underlying differences between ecoregions that likely reflect differences in typical watershed land uses.

A variety of potential approaches for developing preliminary draft regional nutrient criteria were explored (Section 6.0); including derivation of numeric criteria using the Statistical Approach with datasets from both “reference” and all waterbodies (Section 6.2); evaluating the effect of watershed size on nutrient levels (Section 6.3); evaluating the effect of watershed land use on nutrient levels (Section 6.4); and evaluating the effect of nutrients on designated uses (Section 6.5). The latter approach included consideration of nutrient impacts to benthic macroinvertebrates and periphyton biomass. New England states may wish to use some of the approaches in derivation of a numeric criteria for nutrients, particularly those based on a “weight-of-evidence” approach (Liebman, 1999).

Outstanding issues were identified that must be further discussed and consensus reached during the development of a regional approach to nutrient criteria (Section 7.0). These included the availability of nutrient data among ecoregions, parameters and seasons; the identification of reference waterbodies, and the need to consider downstream effects as part of a watershed-based nutrient criterion or TMDL approach.

9.0 REFERENCES

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