Description of Nutrient Criteria for Fresh Surface Waters (Chapter 583)

Cupsuptic River

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1 - Introduction

Nutrients are essential to all plant and animal life, however too much nutrient inputs can have a negative impact on water quality. Whereas compounds such as mercury or dioxin are directly toxic to plant and animal life, nutrients such as phosphorus and nitrogen are required by plants and animals for growth through production of proteins and other essential organic compounds. Plants and animals can not survive without them. People commonly add fertilizers containing phosphorus and nitrogen to gardens to increase plant growth. In a similar way, increasing the amount of phosphorus in a stream or lake can increase the growth of plants and algae. More plants and algae may usually mean more food for some animals that eat plants and algae. Also, it may mean more food for the fish and other predators that eat the plant and algae grazers.

Some nutrients in a lake, stream, or river can be a good thing, however too much nutrients can cause negative environmental impacts. For example, excess nutrients can cause algal blooms in lakes, impoundments, streams, and rivers. Algal blooms, in turn, can cause large swings in the supply of oxygen available to fish and many other aquatic organisms. These large swings in oxygen supply can be accompanied by large swings in how acidic the water is. In addition, algal blooms can cause fish kills by removing oxygen from the water, thereby suffocating the fish. Severe algal blooms dominated by cyanobacteria (blue-green algae) sometimes produce toxic chemicals called cyanotoxins that damage livers and nervous systems of many animals, including people.

Too much nutrients can also damage streams and rivers and promote extensive mats of algae. Similar to lakes, the algae can cause problems with the supply of oxygen and with how acidic the water is. Thick mats of algae can also smother the stream bottom and reduce habitat quality for macroinvertebrates, which are animals without backbones that can be seen without magnification. Many species of macroinvertebrates, such as mayflies, stoneflies, and caddisflies that are favorite prey of trout, need the spaces between and under rocks. Extensive algal mats can smother the stream bottom, fill the spaces, and destroy their habitat. Algae mats can also have a negative impact reproduction of some fish species.

1.1 - Existing Phosphorus Standards

Maine already has phosphorus standards designed to limit phosphorus runoff from new development. The standards were established because state law requires that all lakes shall have "stable or decreasing trophic state" and that no change in land use in a watershed of a lake may result in water quality impairment or increase of trophic state of the lake (Title 38, Article 4-A, § 465-A.1). These two provisions are addressed in part by the Maine Department of Environmental Protection (DEP) under the Chapter 500 Stormwater Management Rules and by many local ordinances, both of which require certain new developments to incorporate stormwater phosphorus mitigation measures based on lake specific watershed phosphorus budgets and other provisions in Volume II of the Maine Stormwater Best Practices Manual - Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development (MDEP 2008). The guidance also defines the acceptable increase in phosphorus concentration for different types of lakes (Table 1). The proposed nutrient criteria will be in addition to and will not change these existing standards.

Table 1. Acceptable increase in lake phosphorus concentrations (ppb).

Water Quality Category	Public Water Supplies & Coldwater Fisheries	All Other Lakes
Outstanding *Exceptional clarity; very low phosphorus and chlorophyll concentrations; low risk of internal recycling from sediments*	0.5	1.0
Good *Average to better than average clarity, phosphorus, and chlorophyll; low risk of recycling from bottom sediments*	1.0	1.5
Sensitive *Average clarity, phosphorus, and chlorophyll; high potential for phosphorus recycling from bottom sediments*	0.75	1.0
Poor (restorable) *Poor clarity; high phosphorus, and chlorophyll concentrations; supports blue green algal blooms; good prospects for restoration*	(0.2 – 0.5)	(0.2 – 0.5)
Poor (natural) *Poor clarity; high phosphorus, and chlorophyll concentrations; supports blue green algal blooms; poor prospects for restoration because lake is naturally very productive*	2.0	2.0

1.2 - Maine's Water Quality Standards

The State of Maine's Water Classification System (38 M.S.R.A. §§ 464 – 470(H)) defines water quality standards for each class. Water quality standards include designated uses and criteria. Designated uses are the ecological goals and types of activities that are desired of each class, such as supporting healthy communities of aquatic life, fishing, swimming, boating, supplying drinking water, and generating electricity from hydroelectric plants. The criteria are the measuring sticks for determining if the goals are being attained.

The Water Classification System describes several classes of fresh surface waters. Class GPA applies to lakes and ponds. There are four classes for other fresh surface waters, such as streams, rivers, and wetlands. Class AA is the most protective and Class AA waters must be "as naturally occurs". Class A waters also must be "as naturally occurs" but more permitted activities are allowed, such as dams and limited effluent discharges. More permitted activities are allowed in Class B waters, but no detrimental changes to communities of fish, macroinvertebrates, and other aquatic life are allowed. Class C waters allow the most permitted activities, but Class C waters must still support all fish indigenous to the receiving waters and maintain the structure and function of aquatic life communities.

Most criteria are in place to maintain healthy communities of aquatic life. For example, there are criteria to maintain sufficient oxygen levels in the water so fish and other aquatic life do not suffocate. Other criteria define how much bacteria are allowed, how acidic the water can get, how green lakes can get from algal blooms, and the composition of biological communities. Some criteria are narrative and consist of written statements, such as “the habitat should be characterized as free flowing and natural.” Other criteria are numeric and define specific numbers or concentrations, such as “the dissolved oxygen content shall not be less than 7 parts per million or 75% of saturation.” Some designated uses, such as physical habitat, only have narrative statements. Some designated uses, such as bacteria, only have numeric criteria. A few designated uses, such as the support of aquatic life, have both narrative and numeric criteria. DEP staff must use best professional judgment using sound data and ecological theory to interpret narrative criteria and determine when a waterbody no longer supports a designated or existing use. For a numeric criterion, DEP staff must determine if the sampling result is greater than or less than the specified amount by the criterion. For example, the dissolved oxygen concentration in a Class B waterbody must be at least 7 parts per million. If the average concentration from a Class B waterbody was only 4 parts per million, then the waterbody would be impaired.

2 - Methods for analyzing data

2.1 - Units of measure

Water quality data are expressed in units of milligrams per liter (mg/L) or micrograms per liter (µg/L, ug/L in some graphs). A milligram (mg) is 1/1,000th of a gram and microgram (µg/) is 1/1,000,000th of a gram. Fortunately, a milliliter (mL, 1/1000th of a liter) weighs 1 mg and 1 L weighs 1,000 g. Therefore, 1 mg/L is equivalent to 1 part per million (ppm) and 1 µg/L is equivalent to 1 part per billion (ppb).

Biologists use a variety of terms to describe community of organisms. Richness is simply the number of different kinds and relative richness is the number of kinds divided by the total number of kinds in a sample. Algae are typically identified to the species level so richness counts are the number of different species. Macroinvertebrate counts are aggregated to the genus level (Davies and Tsomides 2002), so richness counts are the number of different genera. A stream algal community having 25 species has a richness of 25. If the same algal community had 10 species of pollution sensitive species, then the relative richness of sensitive algal species would equal 0.40 (10/25=0.40). Relative abundance is the abundance divided by the total abundance of all organisms in a sample. If a macroinvertebrate sample has 30 mayflies out of 100 individuals, then the relative abundance of mayflies equals 0.30 (30/100=0.30).

2.2 - Percentiles

Percentiles are statistical measurements that help describe the distribution of a data set. Percentiles define a value at which a certain percent of data points are less than or equal to the value. If the 50th percentile of a set of 100 total phosphorus (TP) samples is 30 ppb, then that means that 50 of the 100 samples (i.e., 50% of samples) have values less than or equal to 30 ppb. Similarly, a 75th percentile of 40 ppb means that 75 of the 100 samples (i.e., 75% of samples) have values less than or equal to 40 ppb.

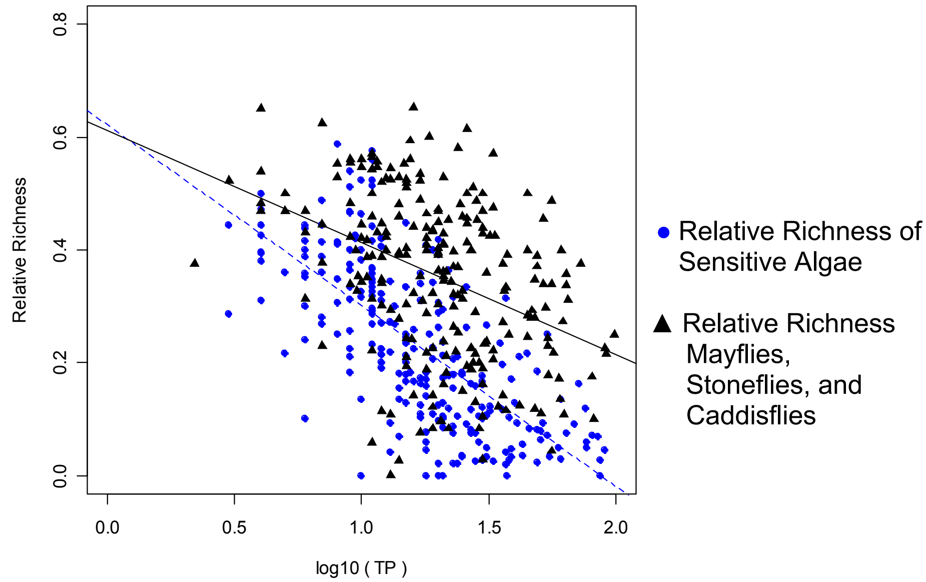
We used two percentile thresholds when examining TP and environmental response variables. We used the 90th percentile for data collected from minimally disturbed reference sites, which were rivers and streams that 1) did not have dams, 2) did not have point source discharges, and 3) had 95% or more of upstream watershed land use consisting of forest or wetlands. USEPA recommends using the 75th percentile of reference sites to establish reference conditions (USEPA 2000, Rohm et al. 2002). We chose the 90th percentile to set the limits for Class AA and A because it was unacceptable to automatically have one quarter of reference sites over the limit. In addition, Montana Department of Environmental Quality found that the threshold where they observed impacts to designated uses was at the 86th percentile of reference sites (Suplee et al. 2007).

We used a value between the 75th and 90th percentiles as the threshold for river and stream data related to the protection of aquatic life. Maine DEP uses aquatic macroinvertebrates as the primary measure of the aquatic life designated use; however the designated use extends to all aquatic life. We know from experience that there are other aquatic organisms that are more intolerant of nutrient enrichment. For example, the relative richness of mayflies, stoneflies, and caddisflies (MSC_RR) decreases with increasing TP. A linear regression (n=232) of $\log_{10}$ transformed TP and MSC_RR found a slope of -0.206, constant of 0.623, and r^2 of 0.193 (Figure 1). In contrast, a linear regression (n=244) of $\log_{10}$ transformed TP and the relative richness of algae that are sensitive to pollution (SEN_RR) found a slope of -0.320, a constant of 0.621, and an r^2 of 0.485 (Figure 1). The slope of -0.320 for SEN_RR is less than the slope of -0.206 for MSC_RR, which means that the sensitive algae decline at a greater rate than the mayflies, stoneflies, and caddisflies. Therefore, a percentile between the 75th and 90th were selected on a case by case basis for data sets representing the protection of aquatic life.

Box 1: What is $\log_{10}$?
Log_{10} is a type of data transformation that is commonly used to adjust data for statistical analysis. It adjusts a value to its corresponding value on the logarithmic base 10 scale. Some examples are shown below.

Value	Log_{10} Value
1	0
5	0.7
10	1
50	1.7
100	2
500	2.7
1000	3

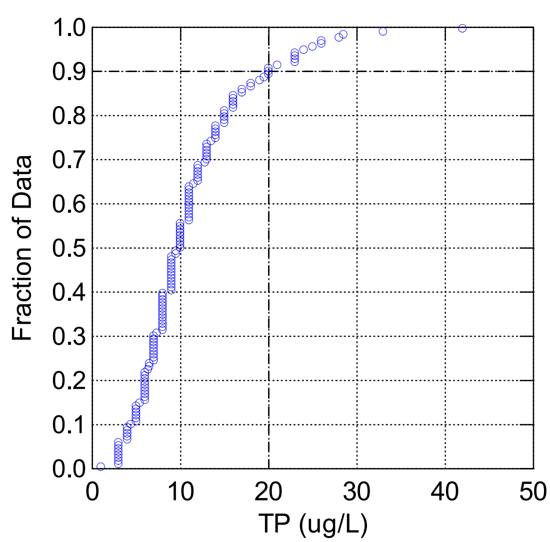
Figure 1. Relationships between TP and both relative richness of mayflies, stoneflies, and caddisflies and relative richness of sensitive algae.



2.3 - Quantile plots

Quantile plots are graphs that display percentiles (Figure 2). The X-axis has TP concentrations and the Y-axis has the percentiles expressed as proportions. A proportion of 0.75 is the same as the 75th percentile. Figure 2 shows that the 90th percentile of TP concentrations collected from reference streams and rivers is 20 µg/L or ppb. The 50th percentile is approximately 10 µg/L. In other words, half of the data points are less than or equal to 10 µg/L.

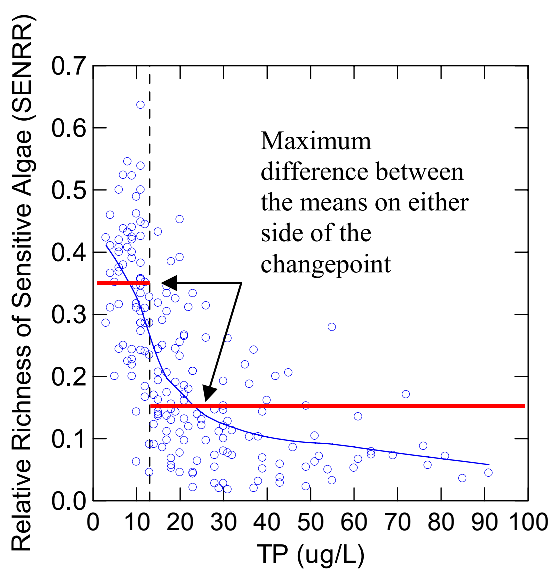
Figure 2. Cumulative distribution function of TP data collected from reference streams and rivers.



2.4 - Changepoint analysis

Changepoint analysis uses a statistical procedure called nonparametric deviance reduction, which seeks the value for one variable at which there is the greatest difference in a second variable (Qian et al. 2003, Qian et al. 2004). This method was used by Wisconsin to identify nutrient thresholds (Wang et al. 2007) and was one of the methods recommended by U.S. EPA (Paul and McDonald 2005). Changepoint analysis sequentially 1) selects a TP concentration, 2) splits the data into one group of samples with values less than the TP concentration and another group of samples with values greater than the TP concentration, 3) calculates means of the second variable for both groups of data, and 4) calculates the difference in the two means. The changepoint analysis repeats this process for all TP concentrations. The changepoint is the TP concentration with the greatest difference in the means of the second variable (Figure 3). We estimated uncertainty about the changepoint by calculating the 95% confidence interval using a resampling technique (bootstrap permutations). We also determined if changepoints were ecologically significant by 1) using knowledge of relationships between variables and 2) using a statistical test (approximate χ^2 test) (Qian et al. 2003, Paul and McDonald 2005).

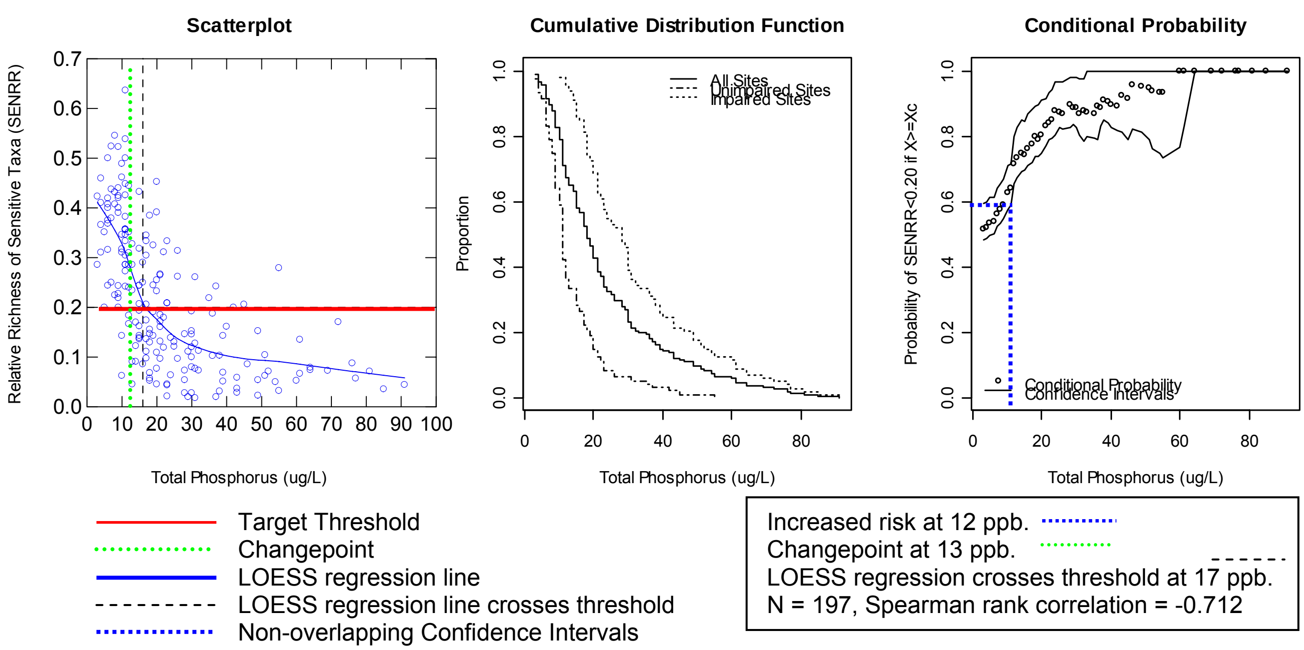
Figure 3. Example of changepoint analysis showing maximum difference between the means of relative richness of sensitive algae on either side of the TP changepoint (13 ug/L).



2.5 - Conditional Probability Analysis

Conditional probability analysis is used to estimate the risk of exceeding or going below an ecological threshold at increasing concentrations of TP (Paul and McDonald 2005). Conditional probability sequentially 1) selects a TP concentration, 2) creates a subset of data with TP concentrations greater than the selected concentration, 3) determines the portion of the samples that exceed (or are below) a threshold of a second environmental variable. Ecological thresholds may be based on established criteria, such as the dissolved oxygen criteria for Class B is 7 mg/L. Other ecological thresholds may be based on expectations from minimally disturbed reference sites. Conditional probability repeats this process for every TP concentration in the data set and estimates uncertainty in the risk estimates with a resampling technique (bootstrap permutations). Changepoint analysis is often performed with conditional probability analysis to provide supporting information (Paul and McDonald 2005). Conditional probability analysis produces 1) a scatterplot of TP and the second variable (left graph in Figure 4), 2) a cumulative distribution function (middle graph in Figure 4), and 3) the conditional probabilities with confidence intervals (right graph in Figure 4). We supplemented scatterplots with locally weighted regression (LOWESS) lines that represent general trends in the paired data. The cumulative distribution functions are similar to the quantile plots in Section 2.2, but display the proportion of samples greater than a given TP concentration instead of the proportion of samples less than a given TP concentration . The circles in the conditional probability plots (right graph in Figure 4) show the risk of exceeding (or being below) the threshold value in the second variable at each TP concentration. The lines above and below the circles represent the confidence intervals around the risk estimates. The confidence intervals often get larger with greater TP concentrations because there are few samples with high TP concentrations.

Figure 4. Example of conditional probability plots based on the relationship between TP and relative richness of sensitive algal taxa.



There are several approaches of setting criteria using conditional probability analysis. One approach is to find the TP concentration at which the conditional probability reaches a predetermined level of risk. The non-overlapping confidence interval approach finds the TP concentration at which the lower confidence interval exceeds the initial value of the upper confidence interval. The dashed blue lines in the conditional probability plot of Figure 4, for example, show that the lower confidence interval exceeds the initial value of the upper confidence interval at 12 ppb TP.

3 - Nutrient Criteria and Decision Framework

DEP proposes to use a decision framework to first determine if there is impairment of a use and then determine if phosphorus or another nutrient caused or contributed to the impairment. The decision framework includes a number of designated uses because nutrients can damage fresh waters in different ways and this rule applies to all classes of freshwater and many different kinds of waterbodies. The decision framework includes the following existing numeric criteria:

1. pH, which measures acidity (38 M.R.S.A. Section 464.4.A.5),
2. dissolved oxygen concentrations and saturation (38 M.R.S.A. Section 465), and
3. aquatic life (Department of Environmental Protection 06 096 Chapter 579).

The decision framework also relies on the following existing uses and narrative criteria:

- recreation in and on the water (38 M.R.S.A. Sections 465 and 465-A),
- aquatic life (Sections 465 and 465-A),
- trophic state (38 M.R.S.A. Sections 465-A), and
- habitat (38 M.R.S.A. Section 465).

3.1 - Environmental Response Limits

The proposed rule includes many environmental response criteria because the rule covers a variety of waterbody types, such as lakes, impoundments, small rocky streams, slow streams, and large rivers. In addition, nutrient enrichment can harm aquatic resources in many ways. Table 2 lists the environmental response criteria and limits for different statutory classes. The Department samples and evaluates one or more of the most appropriate environmental responses from Table 2 depending on the type of surface water being sampled. The environmental response criteria are described below.

Table 2. Environmental response criteria for different statutory classes.

Statutory Class	AA/A	B	C	Impounded A	Impounded B	Impounded C	GPA Not colored	GPA colored
Secchi Disk Depth (meters)[a, b]	≥ 2.0	≥ 2.0	≥ 2.0	≥ 2.0	≥ 2.0	≥ 2.0	≥ 2.0	≥ 2.0 AND
Water Column Chl *a* (µg/L, parts per billion)	≤ 3.5[a] (≤ 5.0[a,c])	≤ 8.0[a]	≤ 8.0[a]	≤ 5.0[a,d]	spatial mean ≤ 8.0[d] and no value > 10.0[d]	spatial mean ≤ 8.0[d] and no value > 10.0[d]	≤ 8.0[a,e]	≤ 8.0[a,e]
Percent of Substrate Covered by Algal Growth[a]	≤ 20.0	≤ 25.0	≤ 35.0	--	--	--	--	--
Patches of Bacteria and Fungi[a]	None observed	None observed	None observed	None observed	None observed	None observed	--	--
Dissolved Oxygen (mg/L, parts per million)[a]	See 38 M.R.S.A. § 465						--	--
pH[a]	6.0 – 8.5							
Aquatic Life[a]	See 38 M.R.S.A. § 465 or Department of Environmental Protection 06 096 Chapter 579						See 38 M.R.S.A. § 465-A	

a - Can be based on single sample following standard protocols and quality control.

b - This variable is attained if the Secchi disk depth is 1) greater than or equal to 2.0 meters for waterbodies greater than or equal to 2.0 meters deep or 2) equal to the depth of the waterbody for waterbodies less than 2.0 meters deep. If the water is colored or turbid because of non-algal particles, Secchi disk depth shall be accompanied by chlorophyll *a* samples to confirm nonattainment condition.

c - Applicable to Class A and AA waters with water velocity less than 5.0 centimeters per second.

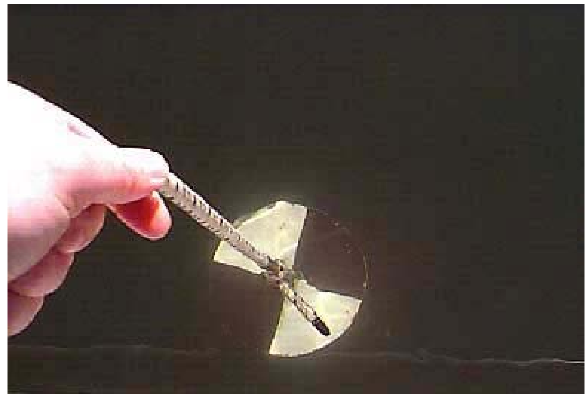
d - Chlorophyll *a* samples from impoundments are collected using depth-integrated, photic-zone cores or depth-integrated, epilimnetic cores.

e - GPA chlorophyll *a* samples are collected using depth-integrated, epilimnetic cores.

3.1.1 - Secchi Disk Depth

For decades, DEP has used average Secchi disk depth readings less than 2 meters as the primary indicator of algal blooms in lakes (Class GPA). The Secchi depths are related to the existing trophic state criteria (38 M.R.S.A. § 465-A). A Secchi disk is a disk with a black and white pattern that is attached to a rope and lowered into the water to the point where it can not be seen any more (Figure 5). DEP uses a standard operating procedure for making this measurement (Potvin and Bacon 2003b). Many lakes in Maine have Secchi depths of 4 meters or more. Some lakes with algal blooms have Secchi depths less than 2 meters. The greener the water, the lower the Secchi depth.

Figure 5. Secchi Disk



Other factors besides algae can limit water clarity and reduce Secchi depths. Some waterbodies are tea colored because of water soaking through leaves on land around the waterbodies, just like water moving through a tea bag. The darker the color, the less one can see through the water. In addition, some waterbodies are cloudy because of the amount of silt and clay floating in the water. The more suspended sediment, the less one can see through the water. The Secchi depth is reliable by itself when the amounts of color and suspended sediments are small. When the amounts of color or suspended sediments are high, then biologists take chlorophyll *a* measurements to confirm that the small Secchi depths are caused by algae.

3.1.2 - Water Column Chlorophyll a for Lakes (Class GPA)

Chlorophyll *a* (chl *a*) is the primary pigment inside the cells of plants and algae that allows them to harvest energy from sunlight to build sugars in the process of photosynthesis. Biologists measure the concentration of chl *a* to measure how much algae is in the water and how green the water appears. Large amounts of planktonic (floating) algae make the water appear green and reduce clarity (Figure 6). Algal blooms can harm aquatic life and reduce the quality of recreation in and on the water, such as swimming and boating.

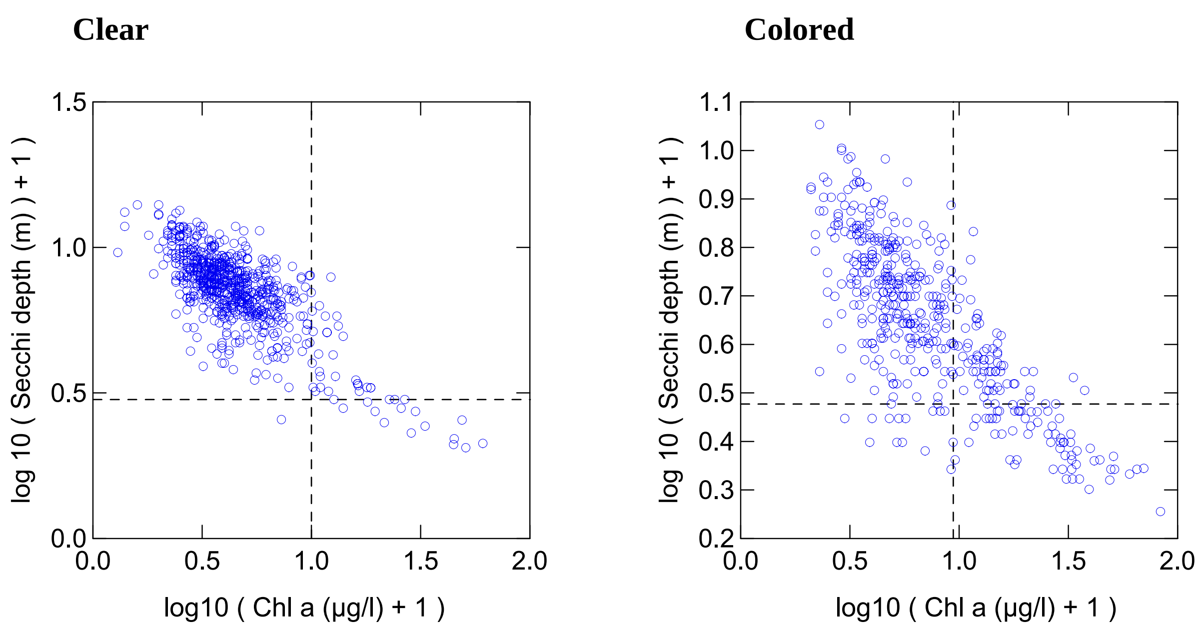
Figure 6. Green water caused by an algal bloom

Chl *a* is measured in concentrations of micrograms per liter (µg/L), which are equivalent to parts per billion (ppb). For decades, DEP staff have used 8 µg/L or higher to define an algal bloom. This is also an international threshold for eutrophic conditions (OECD 1982). DEP biologists typically take an epilimnetic core samples and use standard operating procedures (Bacon 2003, Potvin and Bacon 2003a).

We double checked to see if this cutoff was appropriate by looking at the relationship between paired chl *a* and Secchi depth measurements from 1,151 samples collected during August over a span of several decades. We analyzed the data to determine if there were natural thresholds or "changepoints" in the data. We trimmed 5 outliers with high chl *a* concentrations but unusually high transparency because of blooms of colonial algae such as *Gloeotrichia*. We transformed both chl *a* and Secchi depth by adding one and then calculating the $\log_{10}$ value (Box 1). We split the data into two groups based the amount of color because it can decrease Secchi depths and confound the relationship between chl *a* and Secchi depths. The "colored" group consisted of 399 samples with natural color ≥ 25 standard platinum units (SPU) and the "clear" group consisted of 752 samples with natural color < 25 SPU. We also calculated the Spearman rank correlation between chl *a* and Secchi depth for both groups.

Both data sets had strong inverse relationships between chl *a* and Secchi depth (Figure 7). A correlation measures the strength of a relationship with values between 1 (a perfect, positive relationship) and -1 (a perfect inverse relationship). A value of 0 indicates no relationship. The correlation for the colored and clear groups were -0.74 and -0.65 respectively ($p<0.001$). The colored group had a changepoint of 8.4 µg/L with a 95% confidence interval between 7.4 and 11.7. The clear group had a changepoint of 9.0 µg/L with a 95% confidence interval between 4.2 and 12.6. The changepoints for both groups were shown to be ecologically significant based on the approximate χ^2 tests ($p<0.001$). Both changepoints are close to the 8 µg/L threshold that DEP has used for decades to define algal blooms. We saw no need change the long-standing threshold based on these results.

Figure 7. Relationship between chl *a* and Secchi depth in clear and colored lake samples (Vertical lines represent transformed changepoints. Horizontal lines are the 2 m Secchi.)



3.1.3 - Water Column Chl *a* for Streams, Rivers, and Impoundments

Algal blooms and poor water clarity in streams, rivers, and impoundments harm recreational opportunities, such as fishing, swimming, and boating. Algal blooms can also harm aquatic life and alter their habitat. DEP biologists use chl *a* measurements in streams, rivers, and impoundments as one tool to interpret attainment of the following narrative criteria: recreation in and on the water (38 M.R.S.A. §§ 465 and 465-A), aquatic life (§§ 465 and 465-A), and habitat (38 M.R.S.A. § 465). DEP follows standard protocols for sampling chl *a* samples (Potvin and Bacon 2003a, Danielson 2006).

Class AA and A waters are supposed to be "as naturally occurs". We compiled chl *a* data from 115 sample events from streams that were used as controls in water quality studies or had mostly forested (>95%) watersheds and took the 90^{th} percentile of the chl *a* concentrations. The 90^{th} percentile is the concentration at which 90% of the samples have concentrations less than or equal to it. In this case, 90% of the samples had chl *a* concentrations less than 3.5 µg/L, so we set the limit for most Class AA and A waters at that level. We noticed that some of the samples with the highest chl *a* concentrations were sluggish, low gradient streams with low water velocity. These streams naturally can have higher chl *a* concentrations because of their low flow. All of the 115 sample events were less than or equal to 5.0 µg/L. Therefore, we will give staff the discretion of using 5.0 µg/L as the limit for low gradient Class AA and A streams and rivers with water velocity less than 5 centimeters per second.

The limits for Class B, Class C, and all impoundments were set at 8.0 µg/L to be consistent with the way we define algal blooms in lakes. In addition, 8.0 µg/L was defined as the threshold of eutrophic conditions in rivers and streams (Van Nieuwenhuyse and Jones 1996). A water sample of 8.0 µg/L chl *a* will look the same if it is collected from a lake or a flowing water, except for atypical lakes dominated by colonial bluegreen algae such as *Gloeotrichia*. There are some subtle differences about sampling, however. For impoundments, DEP assumes that an impoundment is not as well mixed as a lake because of its linear flow. Therefore, DEP measures chl *a* in multiple locations starting at the dam and moving upstream. The average chl *a* concentration in an impoundment should not exceed 8.0 µg/L and no single measurement should exceed 10.0 µg/L.

3.1.4 - Aquatic Life Use Attainment

This variable is an indicator of the condition of aquatic biological communities. A waterbody must attain appropriate narrative aquatic life use criteria as described in 38 M.R.S.A. §§ 465 and 465-A as well as numeric criteria in *Classification Attainment Evaluation Using Biological Criteria for Rivers and Streams,* 06-096 CMR 579 (Effective May 27, 2003). DEP follows standard protocols for sampling macroinvertebrates in streams and rivers (Davies and Tsomides 2002). Class AA and A waters must support communities of aquatic life that are "as naturally occurs". Class AA and A waters typically have many different kinds of macroinvertebrates and are dominated by taxa that are sensitive to pollution and require cold, clean water, such as mayflies, stoneflies, and caddisflies (Figure 8). Streams that support Class B communities often have a little nutrient enrichment and more organisms (Figure 9). Class B waters may have reduced abundance of some of the most sensitive species, but their communities still have many mayflies, stoneflies, caddisflies, and other sensitive taxa. Waters that support Class C communities often have only a few different kinds of mayflies and stoneflies. The overall abundance can vary from low to very high depending on the type of stressor causing the impact. The community, however, still retains structure and function as well as some sensitive taxa. In contrast, non-attainment waterbodies have most if not all of the sensitive taxa and is dominated by tolerant taxa (Figure 10).

Figure 8. Example of a Class A macroinvertebrate sample.

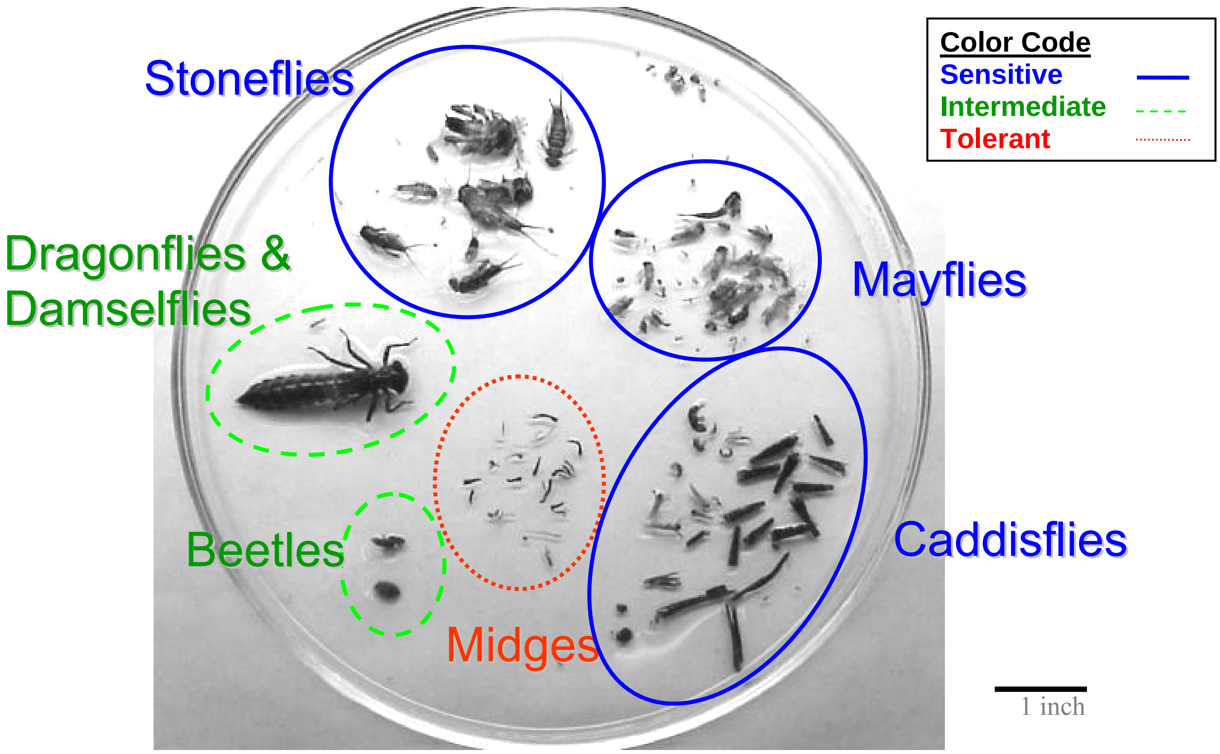


Figure 9. Example of a Class B macroinvertebrate community.

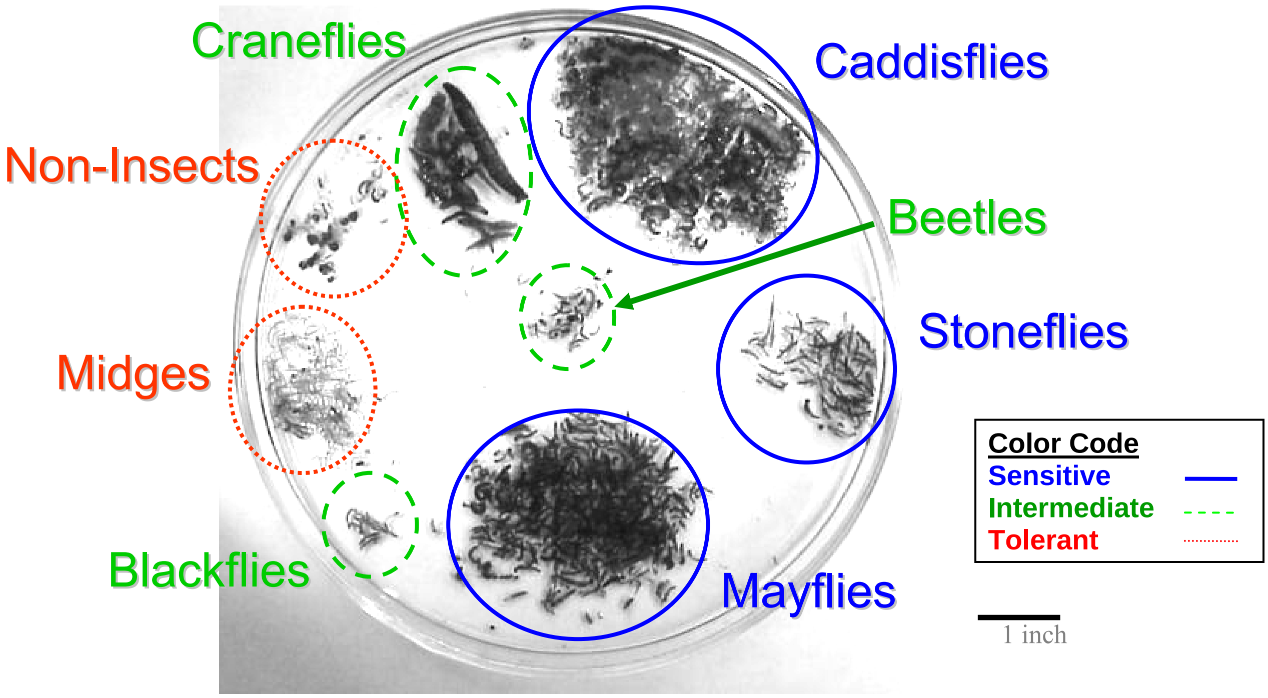
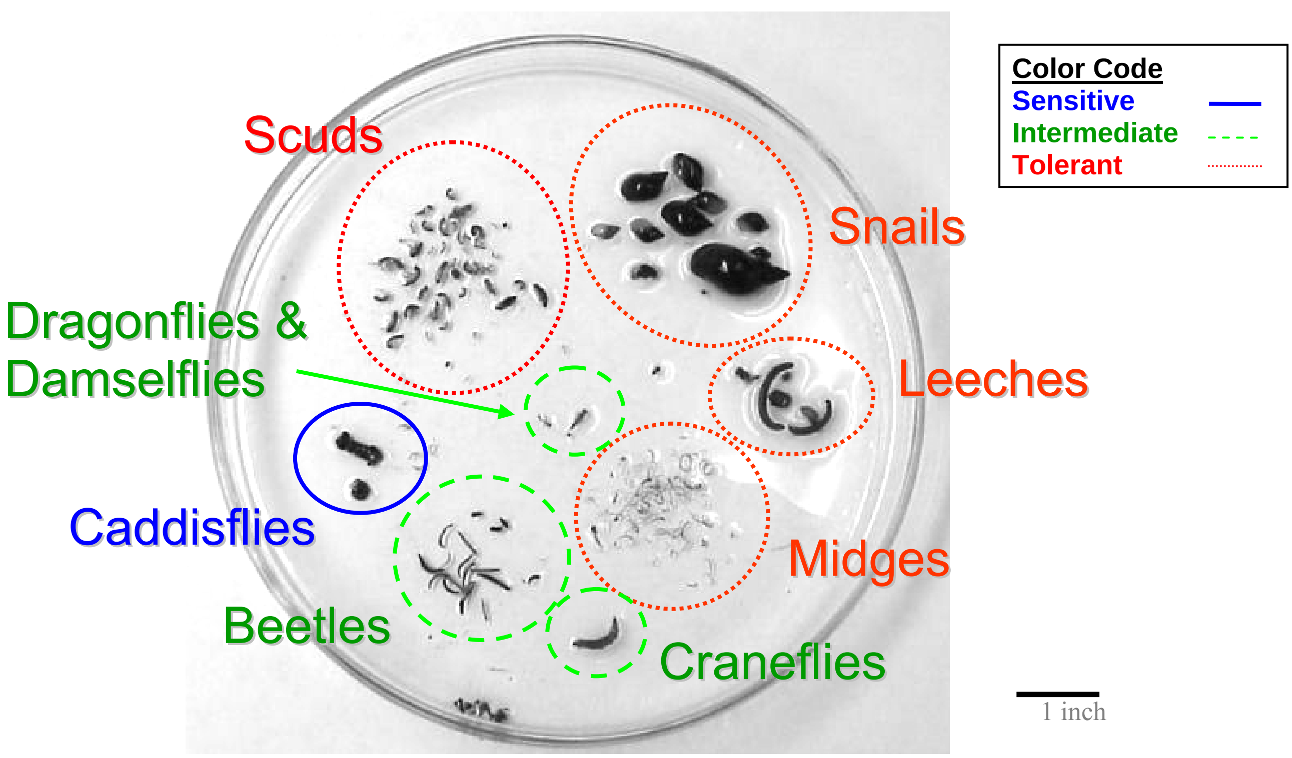


Figure 10. Example of a non-attainment stream that does not meet Class C.



3.1.5 - Percent Cover of Algae in Streams and Rivers

Nutrient enrichment can contribute to increased growth and accumulation of filamentous algae or thick mats of algae in streams and rivers. Nutrients are not the only factors influencing the growth of algae attached to the bottom of streams and rivers, but they are important ones. Other factors, such as the availability of sunlight, water temperature, water velocity, and grazing also determine how much algae grow and accumulate. Too much algae attached to the bottom of a stream or river can harm aquatic life by causing problems with dissolved oxygen concentrations. Also, too much algae can smother the stream bottom and fill spaces under and around rocks where many macroinvertebrates live. It also reduces the quality of recreation activities, such as fishing and wading. DEP uses the percent of stream bottom covered by algae (percent algal cover) as one tool to interpret attainment of the following narrative criteria: recreation in and on the water (38 M.R.S.A. §§ 465 and 465-A), aquatic life (38 M.R.S.A. §§ 465 and 465-A), and habitat (38 M.R.S.A. § 465).

Viewing bucket surveys provide a semi-quantitative estimate of algal cover on the stream bottom. The method is less subjective than visual estimates and DEP can train staff to use the same protocol. Viewing bucket surveys complement species composition data by estimating the amount and types of algae (*e.g.*, filamentous algae or thick mats) growing in a stream reach. Species composition data may show signals of nutrient enrichment as some species are replaced by other species that prefer higher nutrient concentrations. In contrast, the viewing bucket surveys may show signals of nutrient enrichment as more filamentous algae or thick mats of algae accumulate in nutrient enriched streams. Most minimally disturbed streams in Maine have little algal growth. Rocks in these streams lack thick mats of algae and extensive growths of filamentous algae. Rocks are typically clean, but may have a slippery transparent or semi-opaque layer of algae. Opaque layers of algae thicker than 1 mm are not common. Minimally disturbed streams often have some aquatic moss or plants in them.

DEP has a standard protocol for estimating percent algal cover using a viewing bucket survey (Danielson 2006), which was slightly modified from the U.S. EPA Rapid Bioassessment Protocols (Stevenson and Bahls 1999). The current method is restricted to shallow streams and river segments (<1.25 meters deep). The viewing bucket is a five-gallon storage container with a Plexiglas bottom. The Plexiglas has a grid of 35 dots that are spaced 4 cm apart (Figure 11). At a sample location, we typically established three transects across the stream reach and used the viewing bucket at three locations along each transect. At each location, one person looked through the viewing bucket and called out the amount and type of algal growth under each of the 35 dots using a qualitative scale (Figure 12). Another person tallied the results on the field sheet. We could not use this method when the water was too deep or too colored to clearly see the substrate. The data were entered into the database and the percent cover of filamentous algae or algal mats thicker than 1 mm was calculated for each sample location.

Figure 11. Viewing bucket for estimating percent algal cover

Figure 12. Using viewing bucket.

Class AA and A

The limit for Class AA and A streams and rivers was established by examining the percent algal cover from:

- A set of 30 streams and rivers with >95% of land area within upstream watersheds consisting of forest or wetland, with no dams, and no large discharges of effluent. The 90th percentile of the reference streams was **19%** algal cover (Figure 13).
- A set of 60 paired percent algal cover samples and macroinvertebrate samples that attain Class A aquatic life criteria. Class AA and A share the same aquatic life criteria. The 75th percentile was **11%** algal cover (Figure 14).
- A set of 110 samples collected from streams and rivers that 1) have the goal of Class A or AA, 2) do not have known impairment of aquatic life based on macroinvertebrates, and 3) are not listed as impaired for another designated use. The 75th – 90th percentiles ranged from **11-20 %** algal cover (Figure 15).
- A set of 155 samples from streams and rivers with macroinvertebrate community samples. Conditional probability analysis showed that there was an increased risk of not attaining Class A aquatic life criteria at **18%** algal growth (Figure 16).

Based on the weight of evidence, we decided to set the limit for Class AA and A streams and rivers at **20%** algal cover.

Figure 13. Dot density plot and quantile plot of 30 samples from streams and rivers with >95% of upstream watershed land use consisting of forest or wetland.

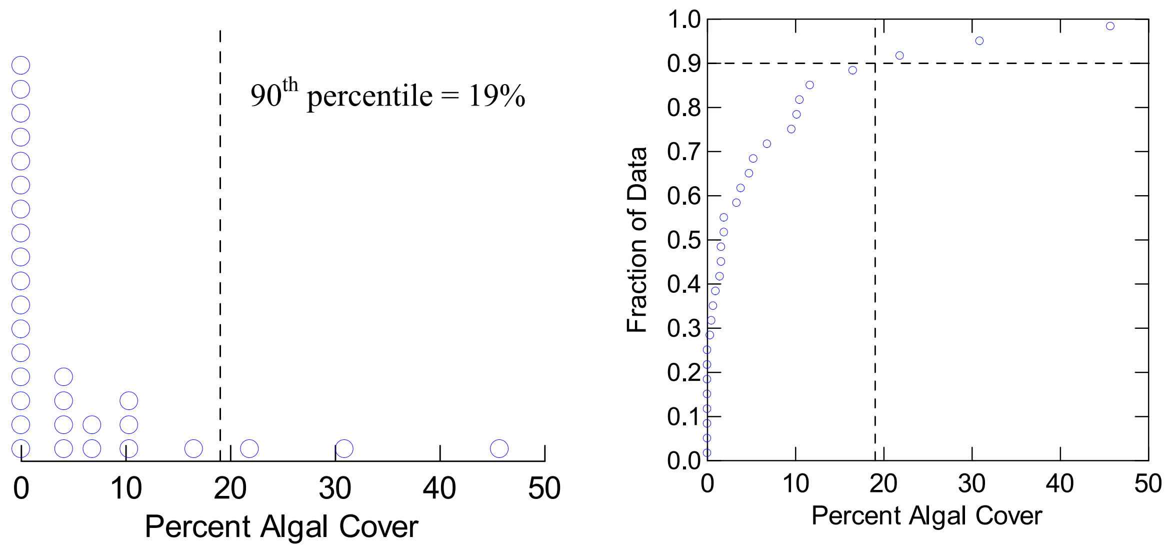


Figure 14. Dot density plot and quantile plot of percent algal cover from 60 streams and rivers that attain Class A aquatic life criteria.

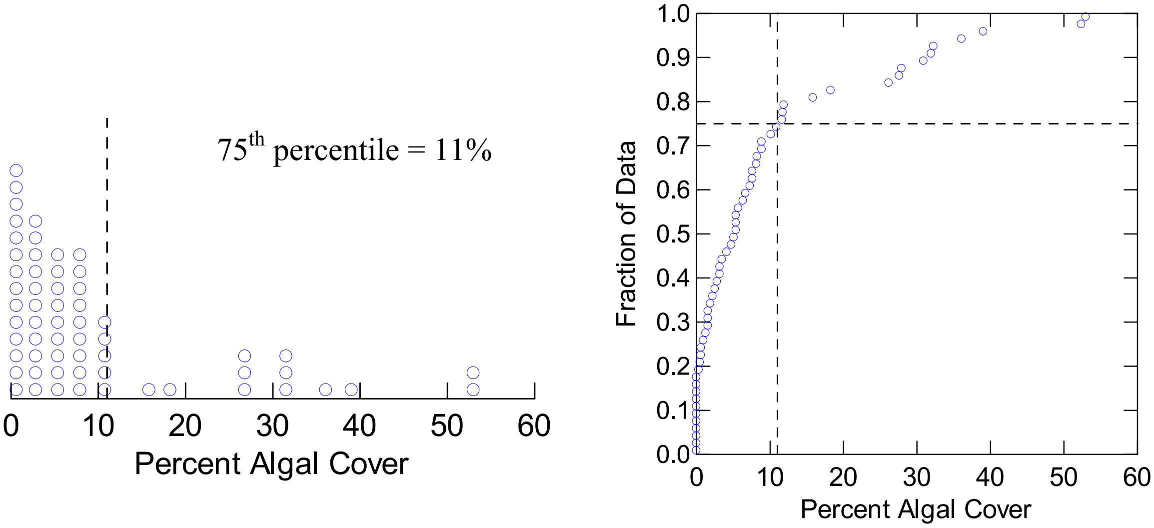


Figure 15. Dot density plot and quantile plot of 110 samples collected from streams and rivers with the goal of Class AA or A that do not have documented impairment of aquatic life based on macroinvertebrates and are not listed as impaired on the 303d list for another reason.

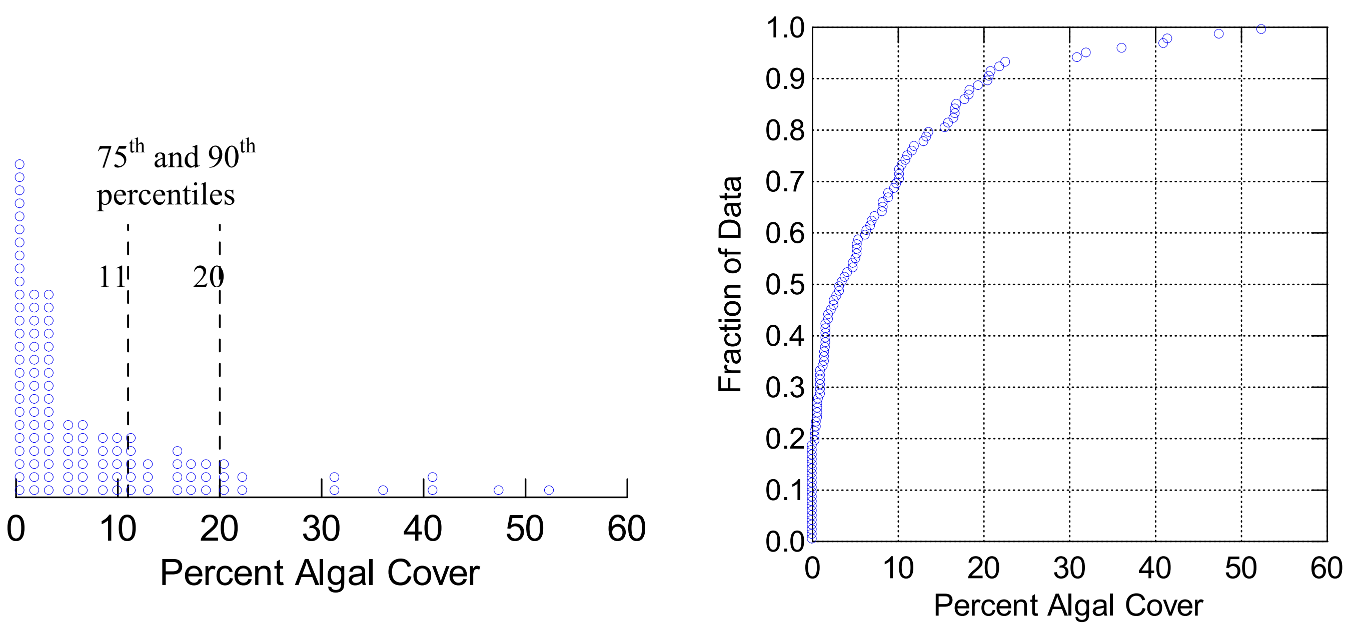
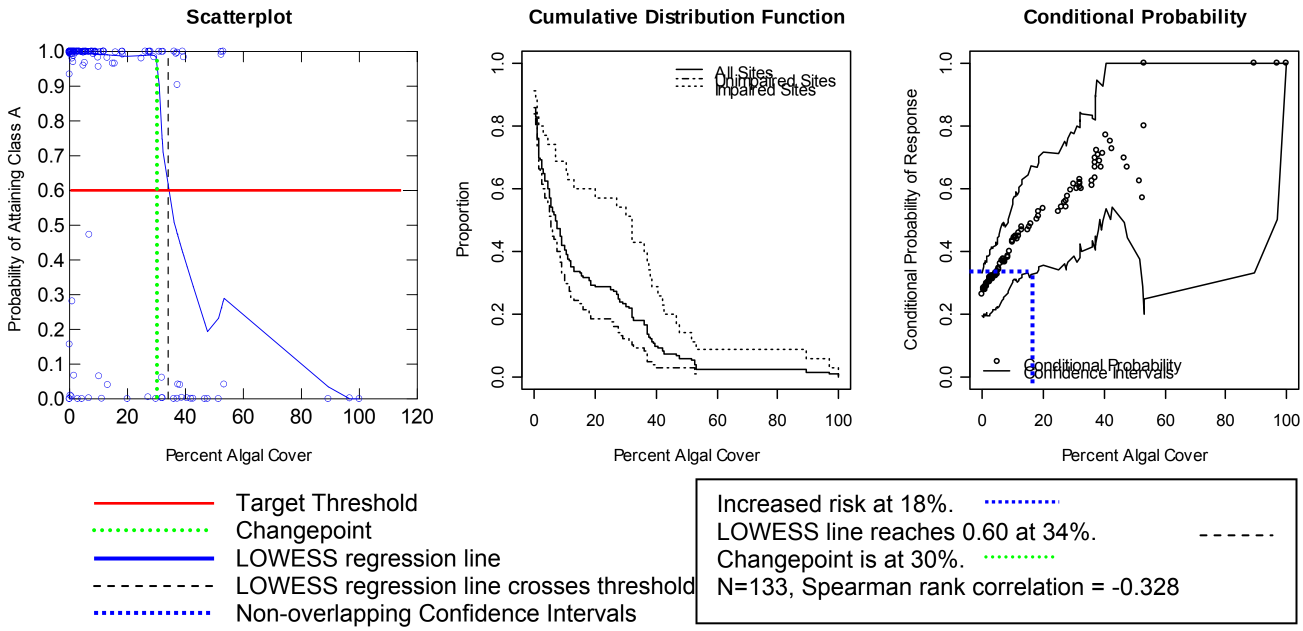


Figure 16. Scatterplot, cumulative distribution function, and conditional probability of percent algal cover and probability of attaining Class A aquatic life criteria (macroinvertebrates) for 155 streams and rivers.



<u>Class B</u>

The limit for Class B streams and rivers was established by examining the percent algal cover from:

- A set of 35 samples from streams and rivers known to attain Class B aquatic life criteria based on macroinvertebrates. The 75th percentile was **19%** algal cover (Figure 17).
- A set of 96 samples from streams and rivers with the goal of Class B that do not have documented impairment of aquatic life based on macroinvertebrates and are not listed as impaired for another reason. The 75th – 90th percentiles ranged from **14-29%** algal cover (Figure 18).
- A set of 155 samples from streams and rivers with macroinvertebrate samples. Conditional probability analysis showed that there was an increased risk of not attaining Class B aquatic life criteria at **21%** algal growth (Figure 19).

Based on the weight of evidence, we decided to set the limit for Class B streams and rivers at **25%** algal cover.

Figure 17. Dot density plot and quantile plot of 35 samples from streams and rivers that attain Class B aquatic life criteria based on macroinvertebrates.

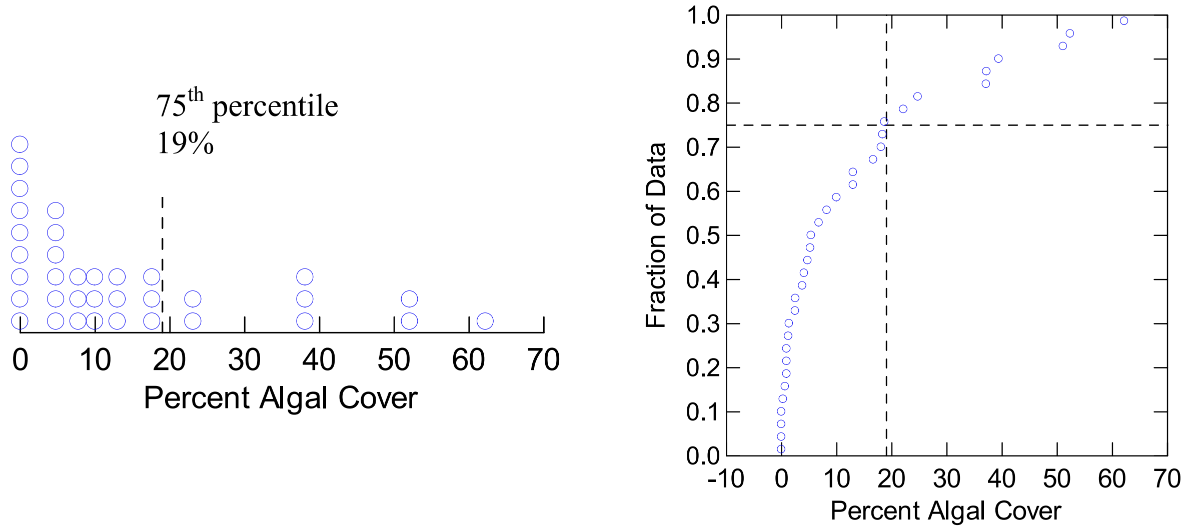


Figure 18. Dot density display and cumulative distribution function of 96 samples from streams and rivers with the goal of Class B that do not have documented impairment of aquatic life and are not listed as impaired for another designated use.

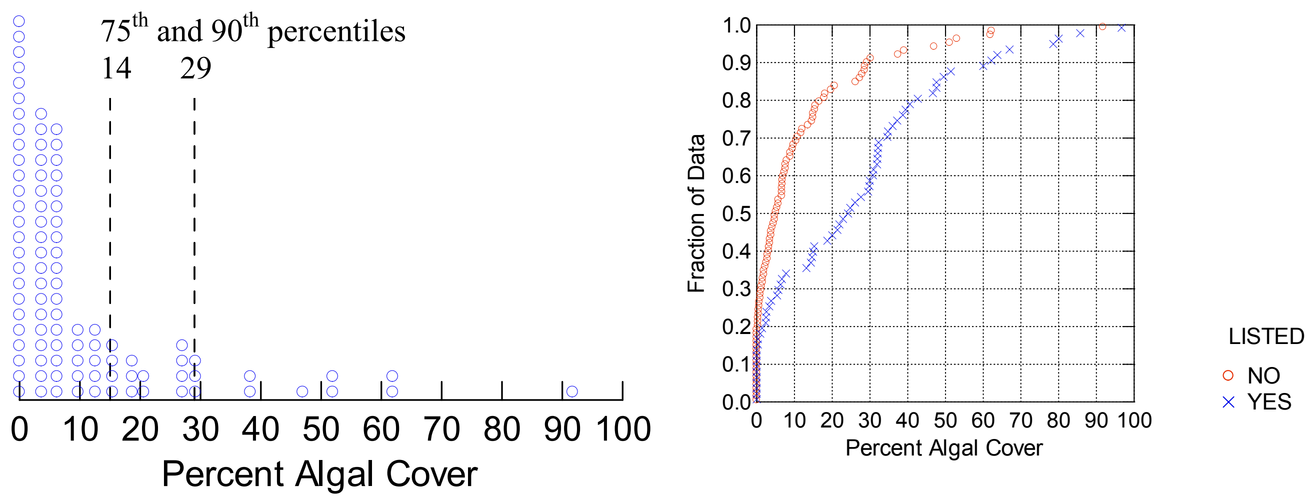
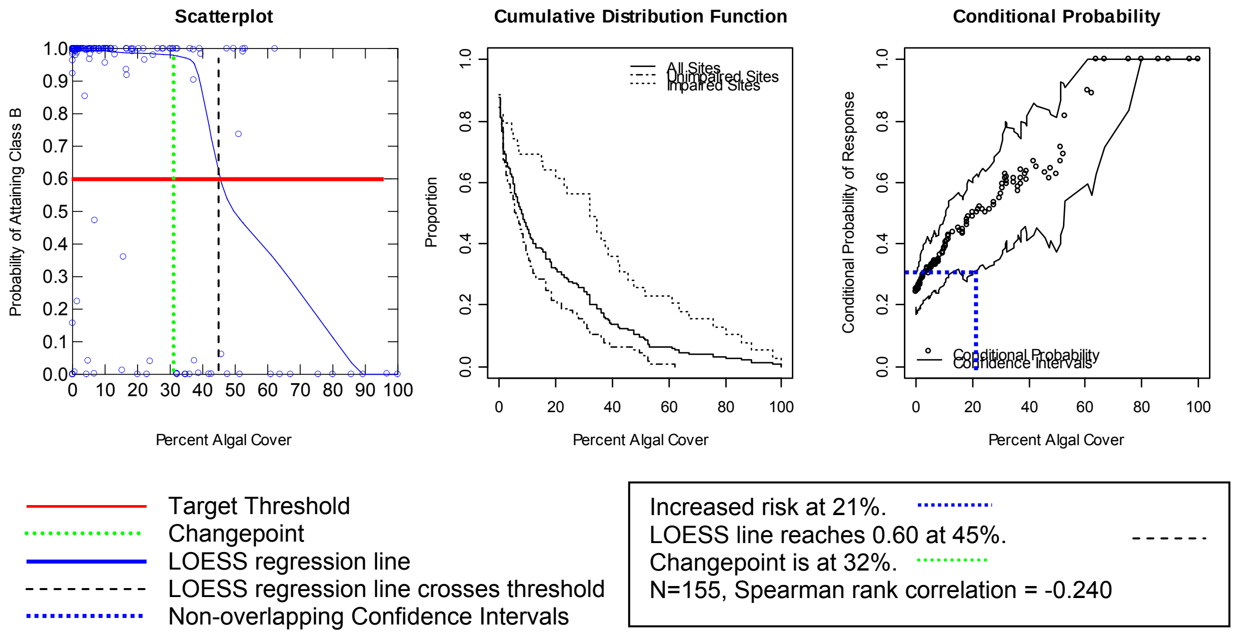


Figure 19. Scatterplot, cumulative distribution function, and conditional probability of percent algal cover and probability of attaining Class B aquatic life criteria (macroinvertebrates) for 133 streams and rivers.



<u>Class C</u>

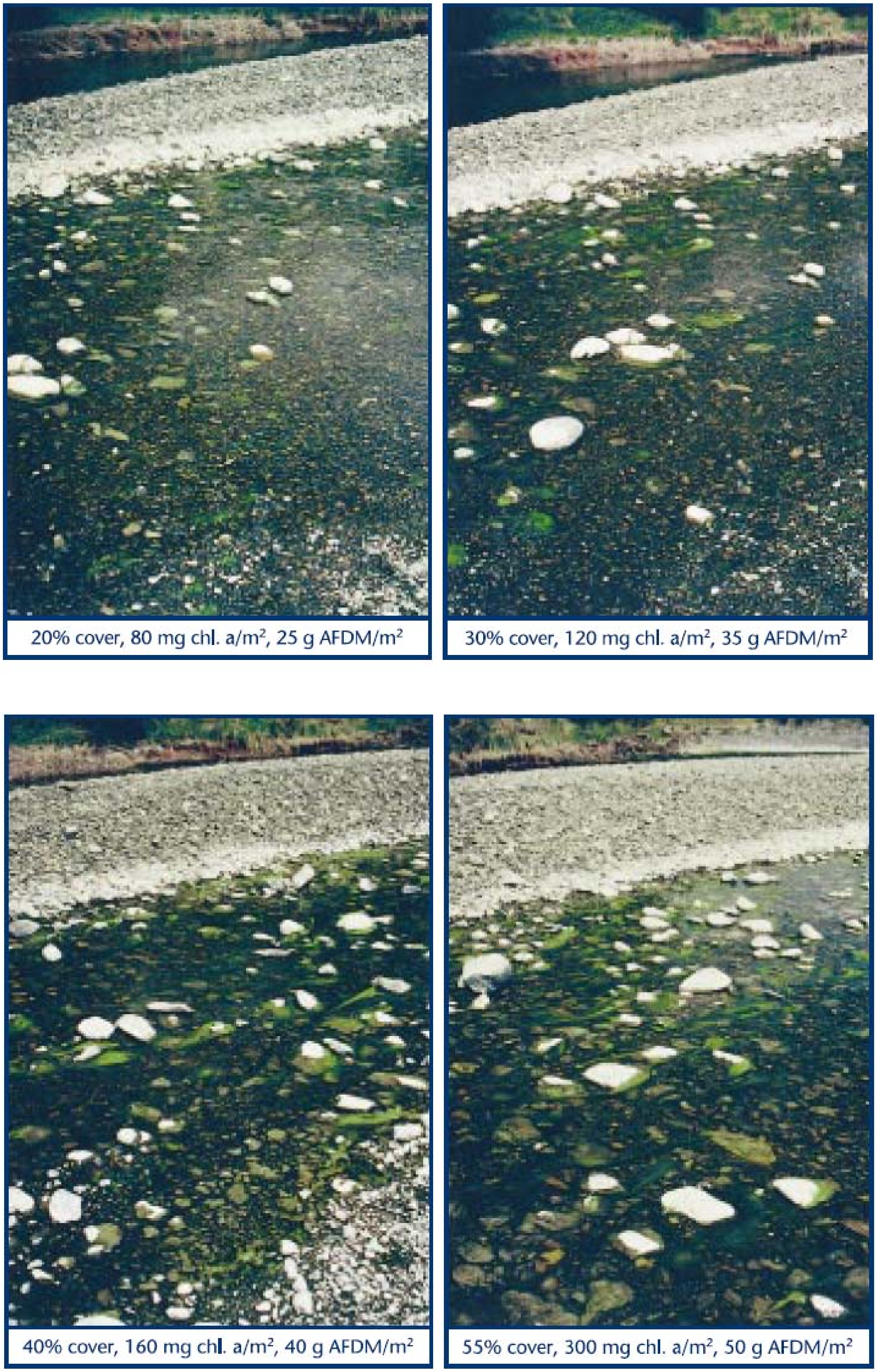
We did not have enough data to develop a criterion for Class C. Therefore, we did a literature search to identify percent algal cover thresholds used to protect aquatic life and recreation (Table 3). Some papers reported thresholds for the amount of chl *a* collected by scraping rocks in streams and rivers, and these were also listed in Table 4. New Zealand has done the most research on percent algal cover. New Zealand initially set a 40% threshold to protect recreation and aquatic life (Biggs and Price 1987, Quinn 1991, Zuur 1992) and later revised the threshold to 30% filamentous algal cover to protect aquatic life (Biggs 2000). We also wanted to protect recreational uses. New Zealand produced a series of images of the same stream reach with different amounts of percent algal cover (Figure 20). Montana recently completed a user perception survey and set a threshold for chl *a* collected from algae growing on rocks (Figure 21) (Suplee et al. 2009). Montana's threshold for chl *a* is greater than the corresponding threshold in New Zealand, suggesting that if Montana had a threshold for percent algal cover it would be somewhat greater than 30%. We set the Class C criterion at 35% to protect both aquatic life and recreation. A value somewhat greater than that used by New Zealand is acceptable because our sampling technique includes thicker periphyton mats in the calculation of percent algal cover.

Table 3. Chlorophyll *a* and percent algal cover criteria found in the scientific literature (table format adapted from Suplee *et al*., 2009).

Maximum Chlorophyll *a* (mg chl / m²)		Percent Algal Cover		Use	Source
Diatom	Filamentous	Diatoms	Filamentous		
			40%	40% cover is conspicuous from streambank	Biggs and Price, 1987 (New Zealand)
100-150			20%	Based upon 19 enrichment cases and surveys	Welch et al., 1988 Horner et al., 1983
150-200				Based on perceived impairment	Welch et al., 1989
100			40%	Recreation and aesthetics	Quinn, 1991 Zuur, 1992 (New Zealand)
150					Watson and Gestring, 1996
100-200				Nuisance	Dodds et al., 1997
200				Eutrophy	Dodds et al., 1998
n/a	120	60% (>0.3 cm thick)	30% (>2 cm long)	Contact recreation & aesthetics	Biggs, 2000 (New Zealand)
200	120	n/a	30% (>2 cm long)	Protection of trout habitat	
50	50	n/a	n/a	Protection of benthic biodiversity	
50				Recreation and aesthetics	Nordin, 2001 (British Columbia)
100				Aquatic life	
150					USEPA, 2000
100-150				Coldwater fish and recreation	TetraTech, 2006
150-200				Warmwater fish and recreation	
150			20-60%* (>3cm long)	User perception survey, protection of recreation	Suplee et al., 2009 (Montana)

* Montana did not set percent algal cover criteria, but the first stream to be found unacceptable to the public had patchy growths of filamentous algae with percent cover ranging from 20-60% (Image E in Figure 21).

Figure 20. Percent algal cover photos from New Zealand (Biggs, 2000) (http://www.mfe.govt.nz/publications/water/nz-periphyton-guide-jun00.pdf)



20% cover, 80 mg chl. a/m², 25 g AFDM/m²

30% cover, 120 mg chl. a/m², 35 g AFDM/m²

40% cover, 160 mg chl. a/m², 40 g AFDM/m²

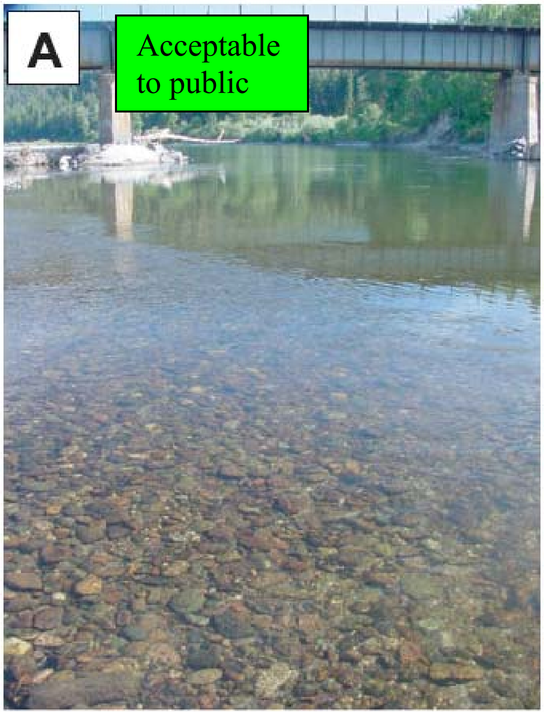
55% cover, 300 mg chl. a/m², 50 g AFDM/m²

Figure 20. Percent algal cover photos from New Zealand (Biggs, 2000) - Continued

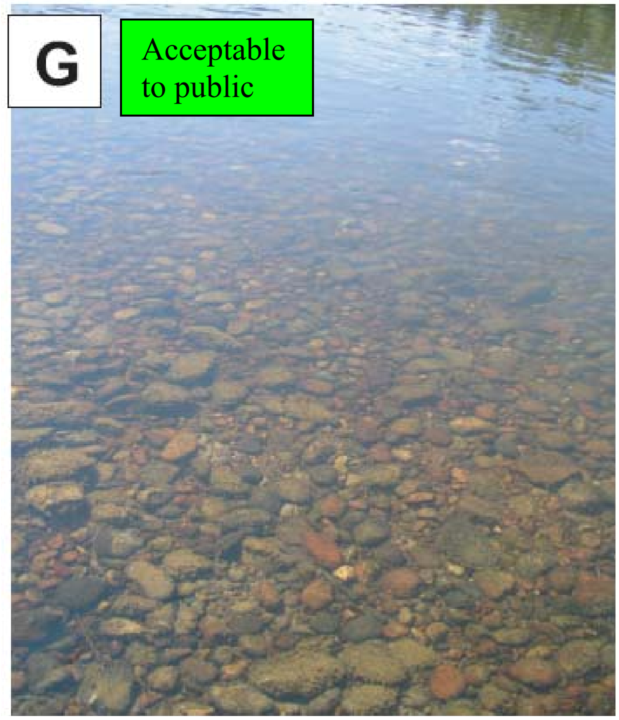
70% cover, 900 mg chl. a/m², 200 g AFDM/m²

95% cover, 640 mg chl. a/m², 90 g AFDM/m²

Figure 21. Results of Montana's user perception survey (Suplee et al. 2009) (http://www3.interscience.wiley.com/journal/121496183/abstract?CRETRY=1&SRETRY=0)



44 mg chl a/m^2, 0% filamentous algal cover

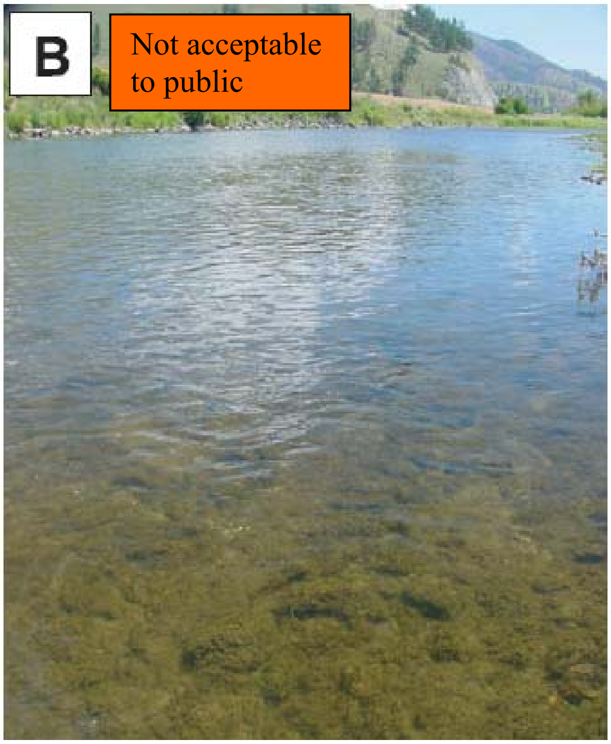


112 mg chl a/m^2, 5-10% filamentous algal cover

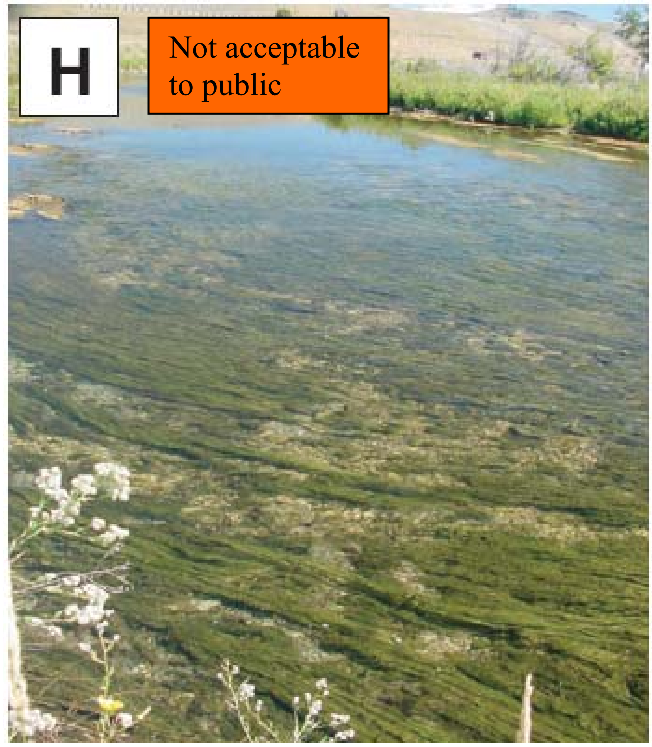
152 mg chl a/m^2, 0% filamentous algae (>2 cm) cover but 80% cover by filaments <1 cm

202 mg chl a/m^2, 20-60% filamentous algal cover

Figure 21. Results of Montana's user perception survey (Suplee et al. 2009) - Continued



235 mg chl a/m^2, 50% filamentous algal cover



299 mg chl a/m^2, 30-100% filamentous algal cover

404 mg chl a/m^2, 70% filamentous algal cover

1,276 mg chl a/m^2, 90% filamentous algal cover

3.1.6 - Patches of Bacteria and Fungi in Streams and Rivers

This variable indicates major shifts in trophic state and relates to the designated uses and narrative criteria associated with habitat, recreation, and aquatic life in 38 M.R.S.A. §§ 464.4 and 465. Fungi and filamentous bacteria are present in every waterbody in the state. Observable patches of fungi and filamentous bacteria, however, are rare and typically occur in waters receiving large inputs of carbon in the form of sewage, compost, or propylene glycol. Waterbodies with patches of fungi and bacteria typically smell very bad because of the decomposing organic matter. This variable excludes iron and manganese bacteria because they primarily gain energy by converting reduced forms of iron and manganese into oxidized forms instead of decomposing organic matter.

Figure 22 illustrates the shift in biological communities below an untreated discharge of organic pollution. Please note that most licensed discharges in Maine do not cause similar impacts because of the implementation of treatment technology. Panel *a* shows that organic waste increases the biological oxygen demand (BOD) of microorganisms that decompose the waste. The microorganisms use up oxygen and lower the concentration of dissolved oxygen in the water. Panel *b* shows the increase in nutrients, such as nitrate (NO_3^-), ammonia (NH_4^+), and phosphate (PO_4^{3-}). Panel *c* shows the dominance of sewage fungus, which is a type of filamentous bacteria, along with other bacteria and protozoa in the area of greatest pollution. Panel *d* shows the dominance of pollution tolerant organisms in the area of greatest pollution. Figures 23 and 24 show the macroinvertebrate communities of a pair of streams less than a mile apart in southern Maine. The only major difference between the two streams was that one was heavily impacted by untreated, organic waste. The control stream (Figure 23) had a high diversity of macroinvertebrates and is dominated by species that are sensitive to pollution and require cold, clean water to survive. In comparison, the impacted stream was receiving a lot of untreated, organic waste and had substantial growths of filamentous bacteria. The impacted stream (Figure 24) had lower diversity and was dominated pollution tolerant species.

Figure 22. A diagrammatic representation of the longitudinal zonation established downstream of the outfall of a continuous organic effluent discharge.
(a) and (b) are physical and chemical changes; (c) changes in microorganisms and plants; (d) changes in larger organisms (Hynes 1960, Giller and Malmqvist 1998)

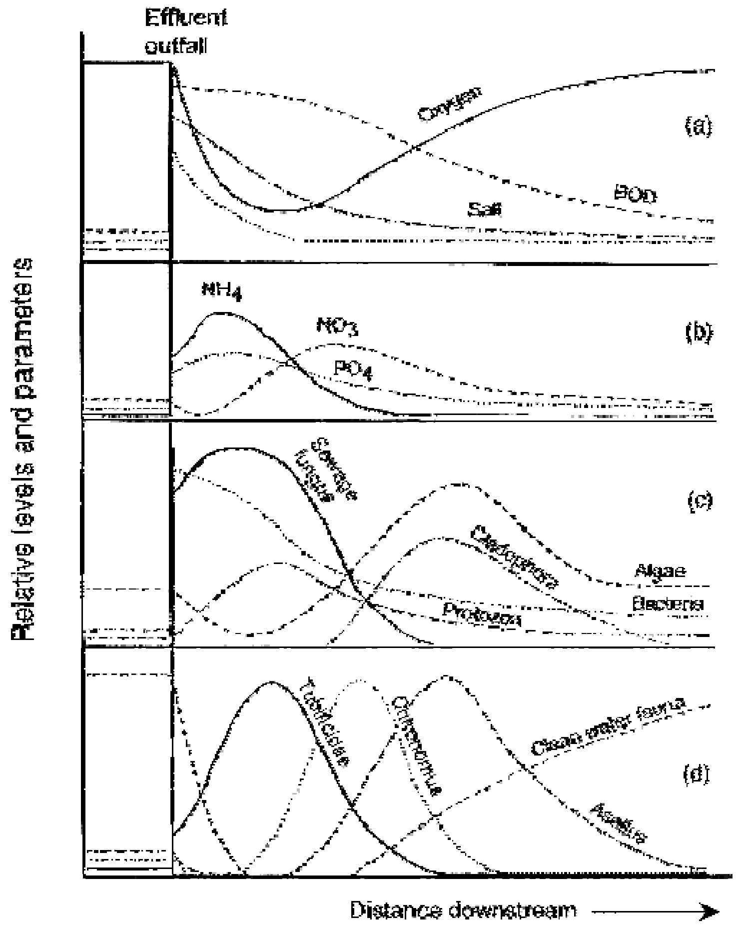


Figure 23. Macroinvertebrate community from the control stream.

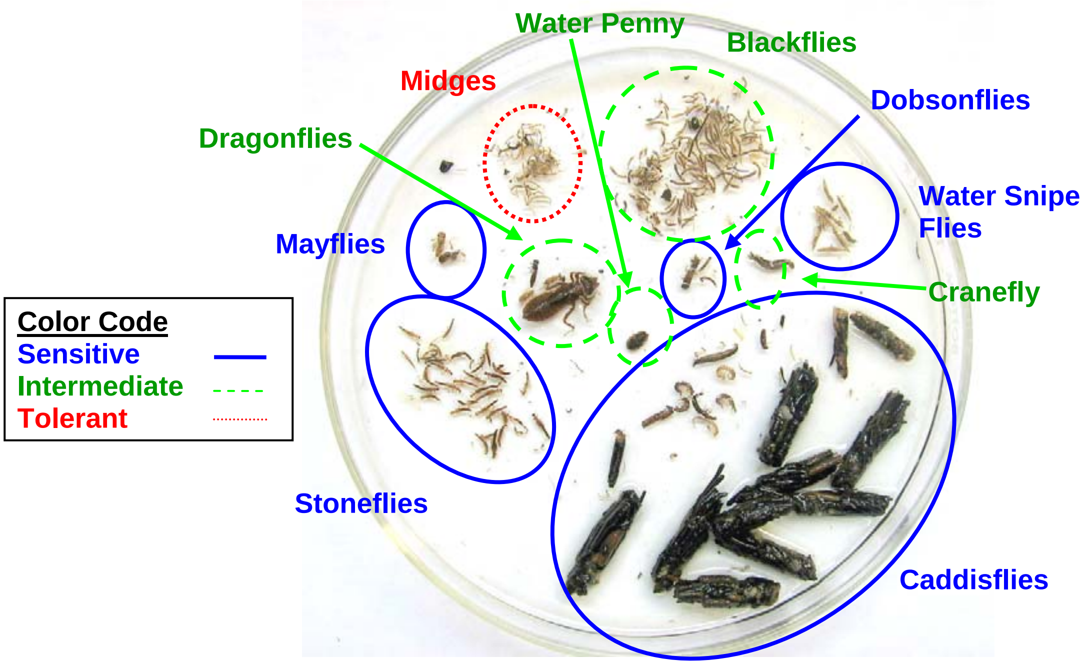
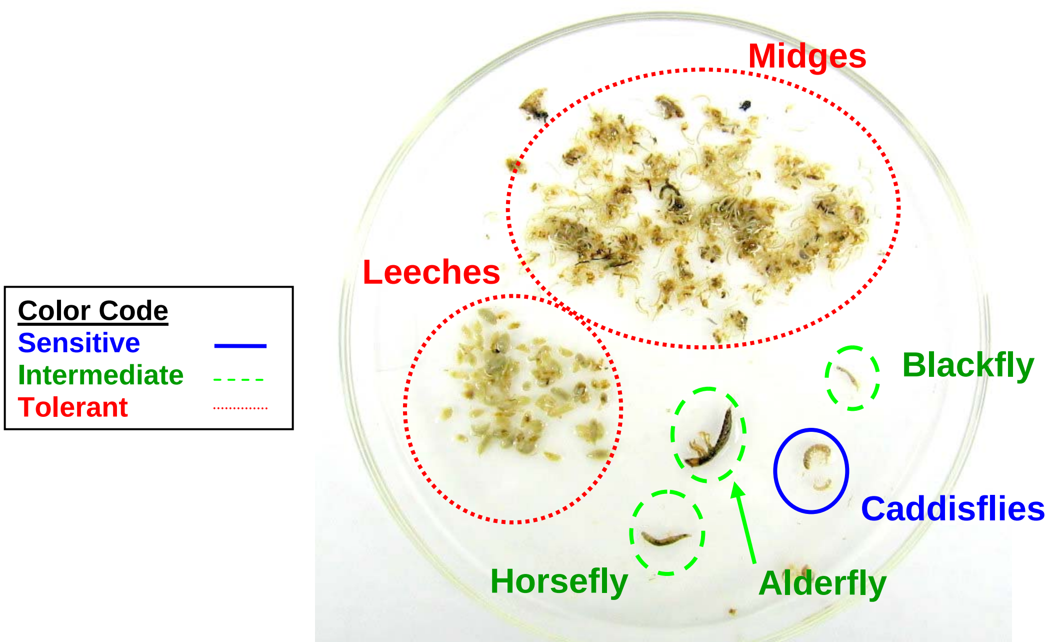


Figure 24. Macroinvertebrate community of the stream impacted by untreated, organic waste.



3.1.7 - Dissolved Oxygen Concentrations

This variable protects fish and other aquatic life from suffocation. Waterbodies must attain dissolved oxygen criteria as described in 38 M.R.S.A. §§ 465 and 465-A. Excessive algal growth can alter natural fluctuations in dissolved oxygen. Dissolved oxygen concentrations typically fluctuate because of photosynthesis and respiration. Photosynthesis is a process within the cells of algae and plants that converts energy from sunlight into sugars. Photosynthesis uses up carbon dioxide and water and creates sugars and oxygen. Respiration is the process of converting sugars into the energy to support cellular activities. Respiration uses up sugars and oxygen and creates carbon dioxide and water. Almost all aquatic organisms respire both day and night. During the day, however, there is typically more oxygen created by photosynthesis than is used up by respiration. As a result, dissolved oxygen concentrations typically go up during the day and go down at night when photosynthesis stops. Healthy streams have small daily changes or flux of dissolved oxygen. Healthy streams also have sufficient oxygen, typically more than 7 mg/L, at night to prevent stressful conditions for aquatic organisms. Nutrient enriched streams with excess algal growth can have substantial amounts of photosynthesis during the day and dissolved oxygen levels can get very high. Nutrient enriched streams also have a great amount of respiration at night from all of the organisms and decaying organic matter. Dissolved oxygen levels can plummet at night and cause stress and suffocation of fish and other aquatic life.

Some studies have found that large, daily swings in dissolved oxygen can harm aquatic life. Minnesota found a significant relationship between DO flux and number of different kinds of mayflies, stoneflies, and caddisflies in a study of large rivers (Heiskary and Markus 2003). As DO flux increased from 4 mg/L to around 7 mg/L, the number of different types of mayflies, stoneflies, and caddisflies decreased from 20 to 10. In a follow up study of large rivers, Minnesota found very strong inverse relationships between DO flux and the number of different kinds of fish and macroinvertebrates that are sensitive to pollution (Heiskary 2008). In addition, Minnesota found strong positive relationships between DO flux and the number of different kinds of pollution tolerant macroinvertebrates. High DO flux tended to occur with high water temperature, high nutrient concentrations, low dissolved oxygen concentrations, and high chl *a* concentrations (Heiskary and Markus 2003, Heiskary 2008), all of which are detrimental to water quality. DEP will consider adding DO flux to the nutrient indicator rule in the future if more information becomes available.

3.1.8 - pH

The pH of fresh waters must be within the range described in 38 M.R.S.A. § 464.4.A.5. pH is a measure of acidity and specifically measures the amount of hydrogen ions in the water. Neutral or "pH balanced" water has a pH of 7.0. Bogs and other acidic waterbodies in Maine sometimes reach pH values of 4.0 or less. Most streams and rivers in Maine have summer pH values between 6.0 and 7.5. Spring or fall pH values can be much lower in streams associated with large wetlands. Waterbodies with a lot of calcium or other minerals have higher pH values. Some streams and rivers in Aroostook County have summer pH values around 8.0.

Nutrients can cause pH values to reach high or low levels that are stressful to aquatic life. In the process of photosynthesis, algae and plants remove carbon dioxide in the water and convert it to sugars. Removing carbon dioxide increases pH and makes the water less acidic (Wetzel 2001). At night, the algae and plants stop photosynthesizing and carbon dioxide levels increase again as bacteria, algae, plants, and other aquatic organisms respire. Even healthy waterbodies see daily changes in pH. In nutrient enriched waters, however, large swings in dissolved oxygen are often accompanied by large swings of pH. The existing pH criteria are in place to protect aquatic life from harmful changes in acidity.

3.2 - Nutrient Indicators

The general rule of thumb is that phosphorus is the primary nutrient that limits the growth of algae and plants in Maine lakes, streams, and rivers (Wetzel 2001). It is well documented, however, that nitrogen can also limit the growth of algae and plants in other parts of the country (Francouer 2001). Nitrogen may in fact limit algal and plant growth by itself or in combination with phosphorus in some Maine lakes, streams, or rivers. In particular, nitrogen may be a limiting nutrient in waters with very low levels of all nutrients or in waters that have already received excessive phosphorus loading.

DEP staff, however, decided to use total phosphorus (TP) as the primary indicator of nutrient enrichment. There are several reasons for choosing TP. First, DEP has a long history of using TP as an indicator of the trophic state of lakes and is familiar with its effects on water quality. We have more phosphorus data than nitrogen data, especially for lakes. Second, concentrations of nitrogen and phosphorus are highly correlated. When one is high, the other is usually high. Finally, it is easier to manage phosphorus inputs into waterbodies than it is to manage nitrogen inputs. Therefore, we decided to use TP as the primary nutrient criterion and use nitrogen and other nutrients on a case by case basis.

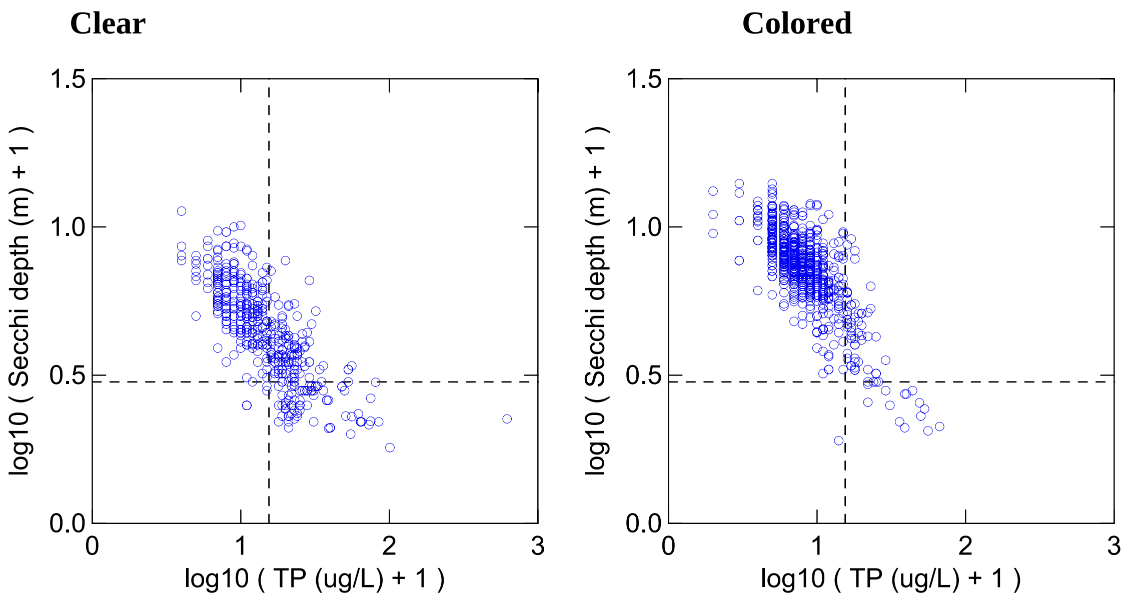
TP samples were collected during the summer (June-September) months over a period of several years. Concentrations below the detection limit were given a value one half of the detection limit. Most streams and rivers were represented by single nutrient samples. Average nutrient concentrations were used for locations with multiple samples.

3.2.1 - Lakes (Class GPA)

The TP limit for lakes (15 µg/L) was based on the prevention of nuisance algal blooms. For decades, DEP lake biologists have used Secchi disk readings less than 2 m as the primary indicator of nuisance algal blooms. The amount of natural color of lake water, however, can interfere with water clarity and Secchi depth measurements. Examination of the relationships of chl *a*, color, TP, and Secchi disk data suggests that 25 standard platinum units (SPU) natural color is a reasonable cutoff for increased interference of color with clarity.

DEP has used 15 µg/L as a TP threshold in the past. We analyzed the data in two ways to determine if this threshold was reasonable. First, we did a changepoint analysis of 1,153 paired samples of TP and Secchi depth collected in the month of August over a period of several decades (Qian et al. 2003). We $\log_{10} + 1$ transformed the data to approximate normal distributions and make the relationship more linear. We split the data into a "colored" group of 401 samples from lakes with color $\geq$25 SPU and a "clear" group of 752 samples from lakes with color <25 SPU. Both data sets showed a strong inverse relationship between TP and Secchi depth (Figure 25). The Pearson correlation for the colored group was -0.75 ($p<0.001$) and the correlation for the clear group was -0.76 ($p<0.001$). The changepoint for the colored group was 13.5 µg/L with a 95% confidence interval between 13.5 and 16.5 µg/L. The changepoint for the clear group was 14.5 µg/L with a 95% confidence interval between 9.5 and 16.5 µg/L. The 15 µg/L threshold that DEP historically used is close to the estimated changepoints are well within the 95% confidence intervals. We saw no reason to change the threshold based on these results.

Figure 25. Relationship between TP and Secchi depth in clear and colored lake samples
(Vertical lines represent transformed changepoints. Horizontal lines are the 2 m Secchi.)



3.2.2 - Class AA and A

The limit for Class AA and A streams and rivers was established by examining the following data sets:

- A set of 197 paired samples of TP and the relative richness of algae that are sensitive of watershed disturbance (SENRR) was used for conditional probability analysis (Figure 26). Most reference sites have SENRR values greater than 0.20, therefore 0.20 was used as the ecological threshold. The conditional probability estimated the probability of having a SENRR value less than 0.20 when TP concentrations are greater than or equal to a given concentration. There was an increased risk of having a SENRR value less than 0.20 at **12 ppb** TP.
- A set of 197 paired samples of TP and the relative richness of algae that are tolerant of watershed disturbance (TOLRR) was used for conditional probability analysis (Figure 27). Most reference sites have TOLRR values less than 0.185, therefore 0.185 was used as the ecological threshold. The conditional probability estimated the probability of having a TOLRR value greater than 0.185 when TP concentrations are greater than or equal to a given concentration. There was an increased risk of having a TOLRR value greater than 0.185 at **13 ppb** TP.
- A set of 210 paired samples of TP and macroinvertebrates were assembled for conditional probability analysis (Figure 28). DEP's statistical model used to predict attainment of aquatic life classes (i.e., AA/A, B, C) produced the probability of attaining Class A as one output. DEP used the probability of 0.60 as the threshold for determining if a macroinvertebrate community attains Class A aquatic life criteria. The conditional probability estimated the probability of not attaining Class A aquatic life criteria when TP concentrations were greater than or equal to a given

concentration. There was an increased risk of not attaining Class A aquatic life criteria at **20 ppb** TP.

- A set of TP samples from 126 reference streams and rivers was assembled (Figure 29). The 90th percentile of TP was **20 ppb**.
- A set of TP samples from 334 streams and rivers that had the goal of Class AA or A, did not have documented impairment of aquatic life, and were not listed as impaired for another cause was analyzed using percentiles (Figure 30). The 75th – 90th percentiles ranged from **16-22 ppb**.

Based on the weight of evidence, we set the TP criterion for Classes AA and A at **18 ppb**.

Figure 26. Scatterplot, cumulative distribution function, and conditional probability of TP and the relative richness of sensitive algae.

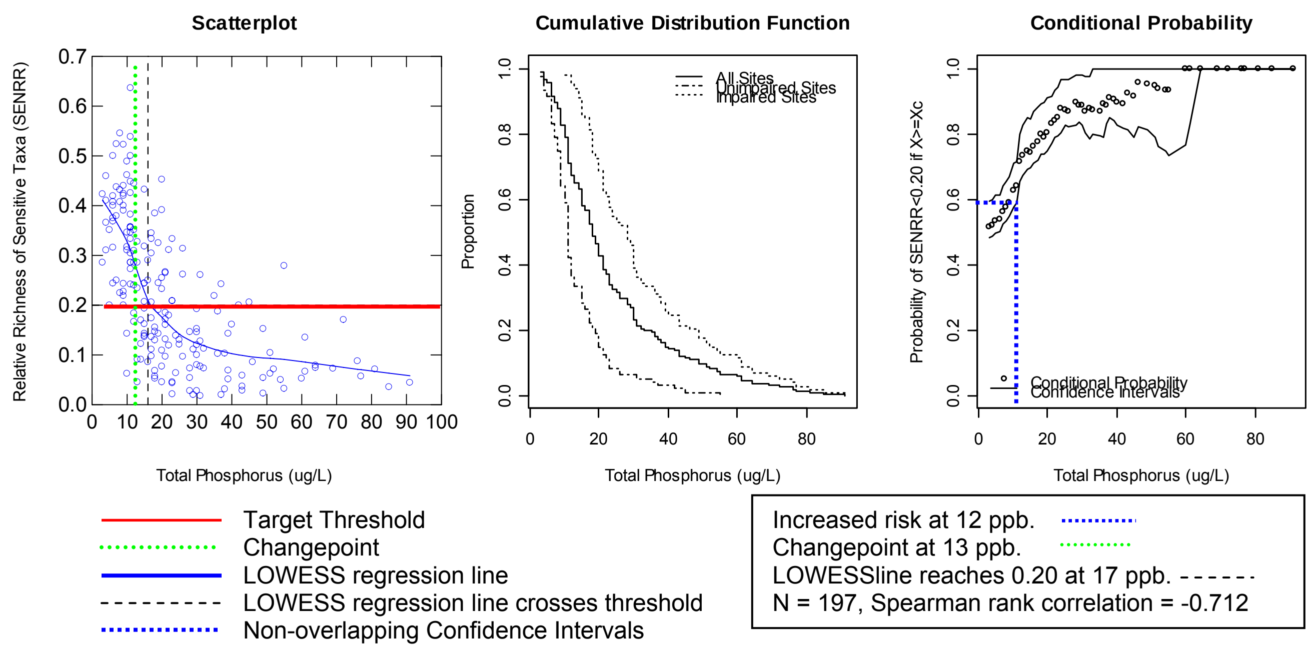


Figure 27. Scatterplot, cumulative distribution function, and conditional probability of TP the relative richness of tolerant algae.

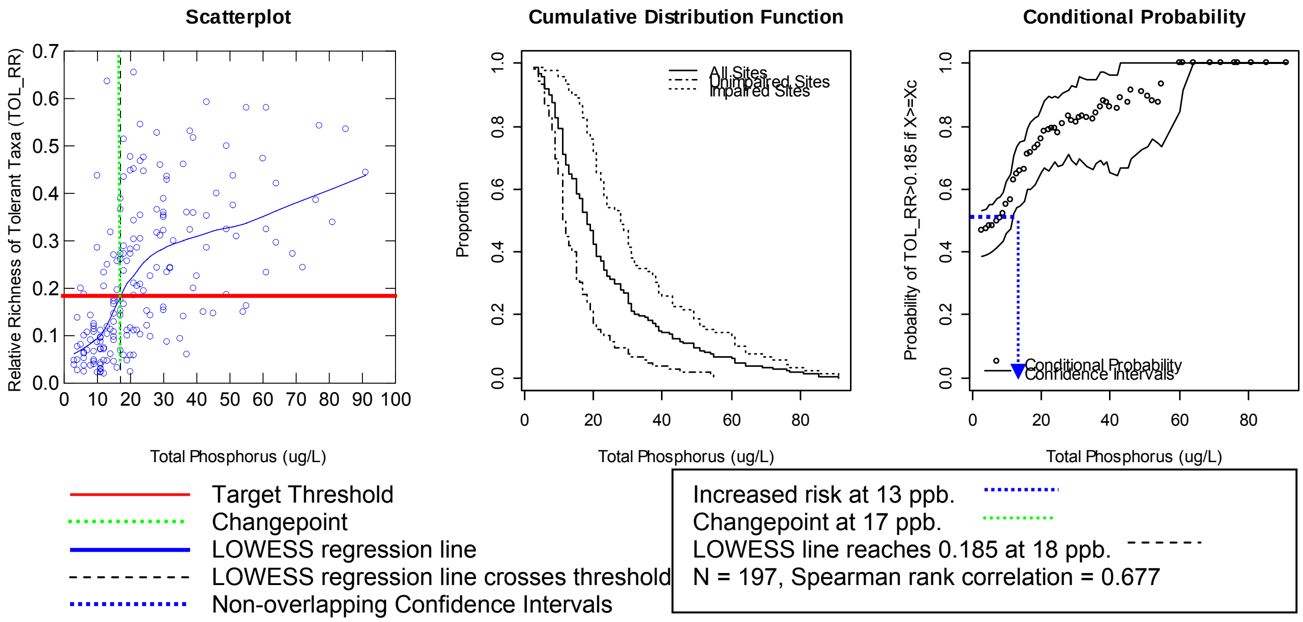


Figure 28. Scatterplot, cumulative distribution function, and conditional probability of $\log_{10}$TP and the probability of attaining Class A aquatic life criteria (macroinvertebrates).

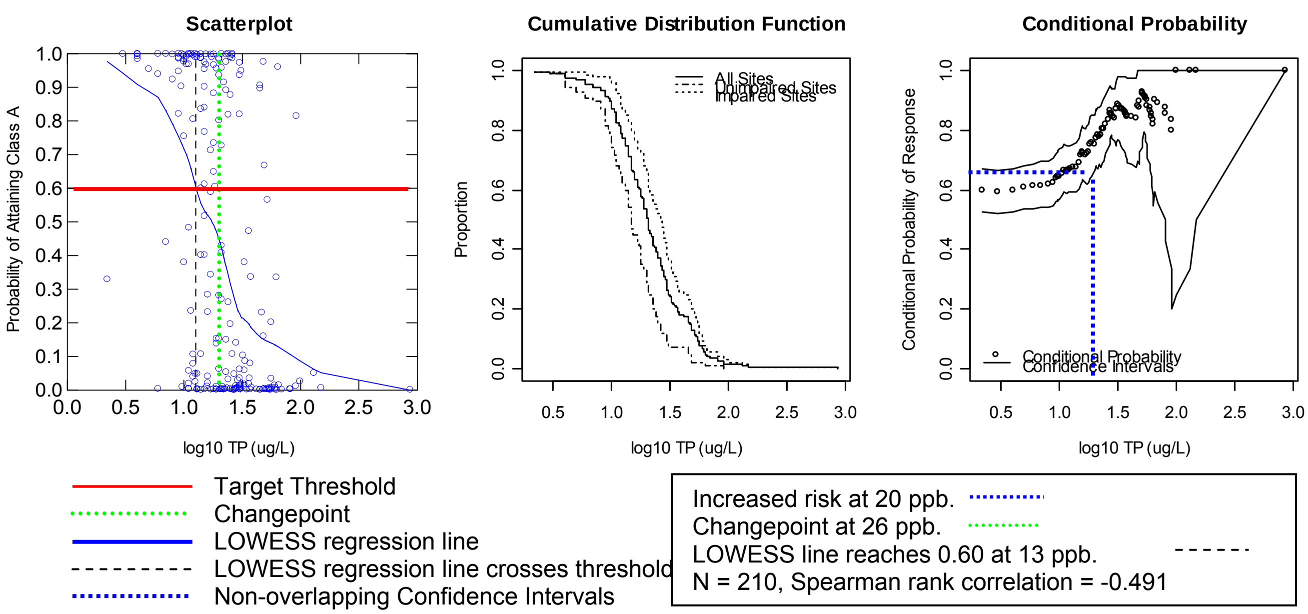


Figure 29. Dot density plot and quantile plot of TP from 126 reference streams.

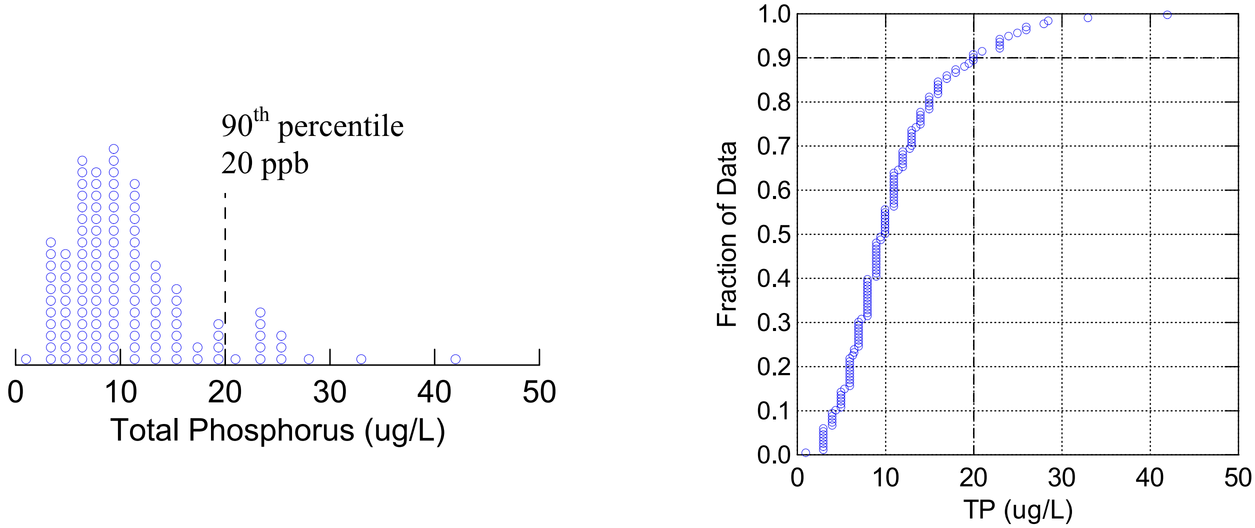
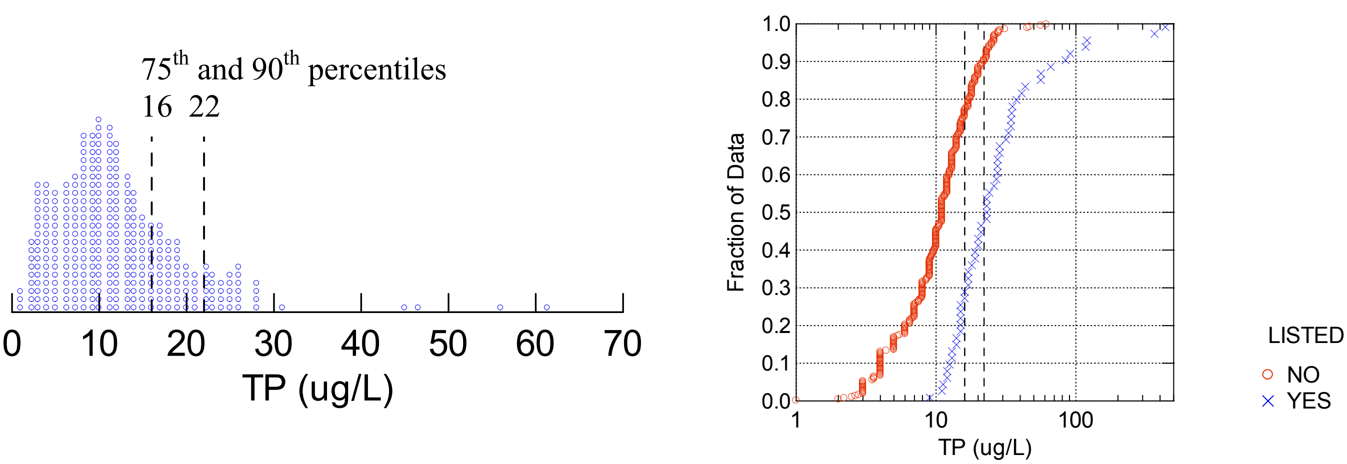


Figure 30. Dot density plot and quantile plot of 334 average TP samples collected from streams and rivers with the goal of Class AA or A, that do not have documented impairment of aquatic life, and are not listed as impaired for another reason.



3.2.3 - Class B

The limit for Class B streams and rivers was established by examining the following data sets:

- A set of 210 paired samples of TP and macroinvertebrates were assembled for conditional probability analysis (Figure 31). DEP's statistical model used to predict attainment of aquatic life classes (i.e., AA/A, B, C) produced the probability of attaining Class B as one output. DEP used the probability of 0.60 as the threshold for determining if a macroinvertebrate community attains Class B aquatic life criteria. The conditional probability estimated the probability of not attaining Class B aquatic life criteria when TP concentrations were greater than or equal to a given concentration. There was an increased risk of not attaining Class B aquatic life criteria at **21 ppb** TP.
- A set of 375 paired samples of TP and average minimum DO were assembled for conditional probability analysis (Figure 32). The DO threshold of 7 mg/L was used because it is an established criterion in Maine's water quality standards. The conditional probability estimated the probability of DO <7 mg/L when TP concentrations were greater than or equal to a given concentration. There was an increased risk of DO <7 mg/L at **27 ppb** TP.
- A set of TP samples from 59 sites known to attain Class B aquatic life criteria based on macroinvertebrates (Figure 33). The 75^{th} percentile of TP was **33 ppb**.
- A set of TP samples from 191 streams and rivers that had the goal of Class B, did not have documented impairment of aquatic life, and were not listed as impaired for another cause was analyzed using percentiles (Figure 34). The 75^{th} – 90^{th} percentiles ranged from **25-33 ppb**.

Based on the weight of evidence, we set the TP criterion for Class B at **30 ppb**.

Figure 31. Scatterplot, cumulative distribution function, and conditional probability of $\log_{10}$ TP and the probability of attaining Class B aquatic life criteria (macroinvertebrates).

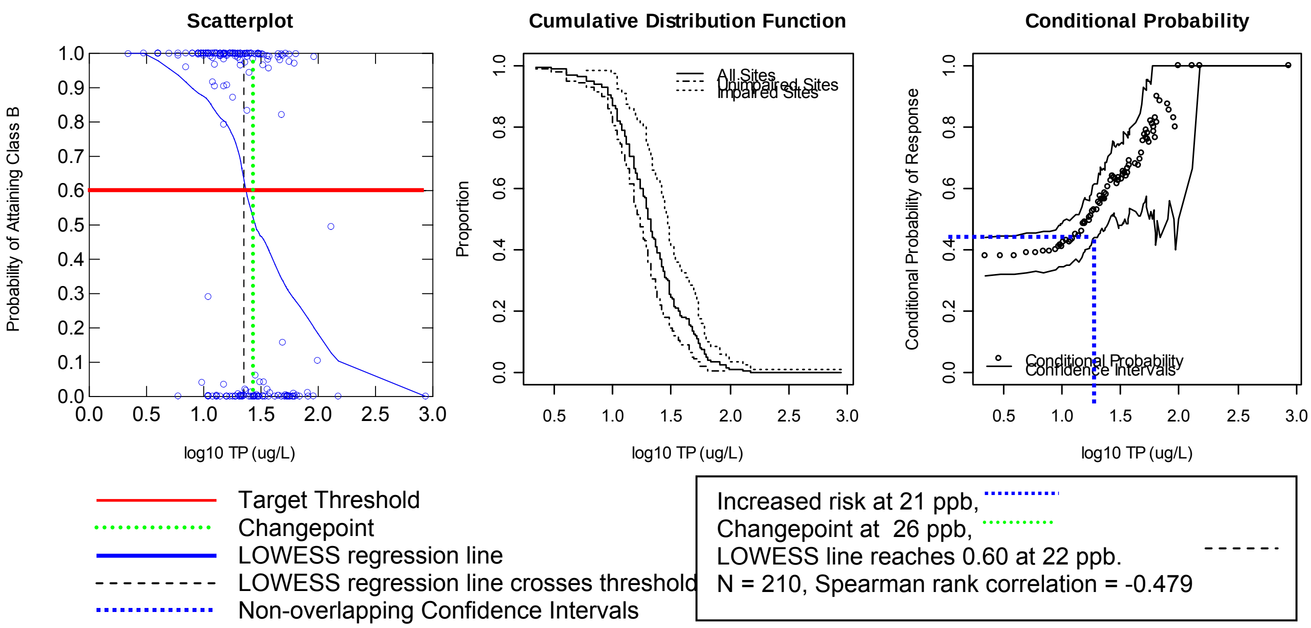


Figure 32. Scatterplot, cumulative distribution function, and conditional probability of average $\log_{10}$ TP and average minimum dissolved oxygen (DO) (ug/L).

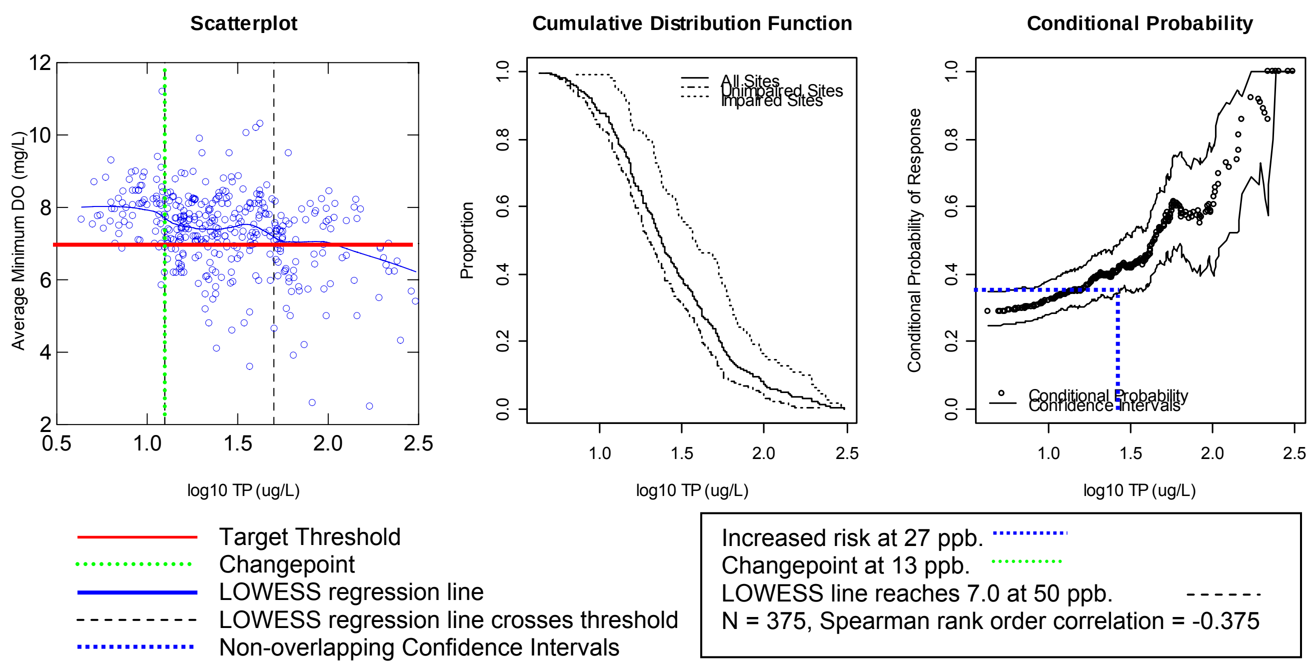
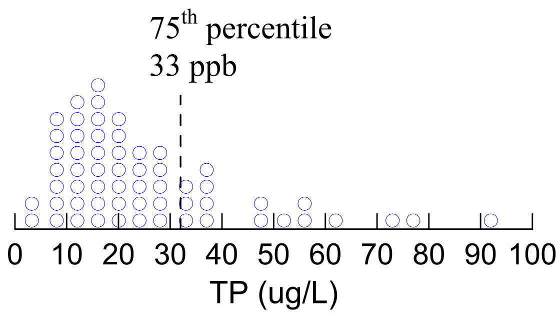


Figure 33. Dot density plot and quantile plot of TP from 59 sites known to attain Class B aquatic life criteria (macroinvertebrates).



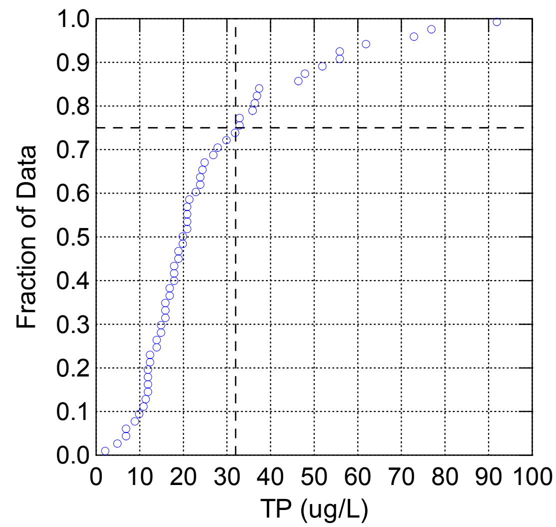
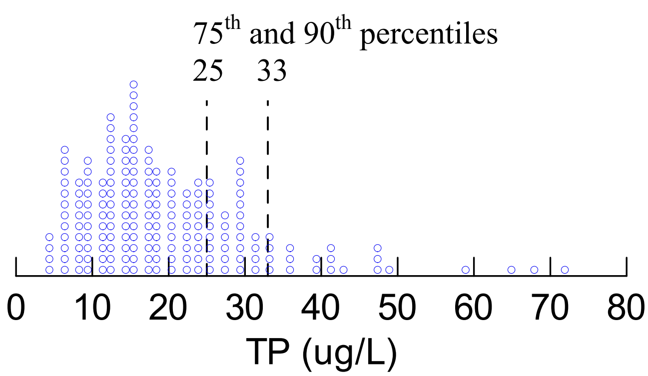
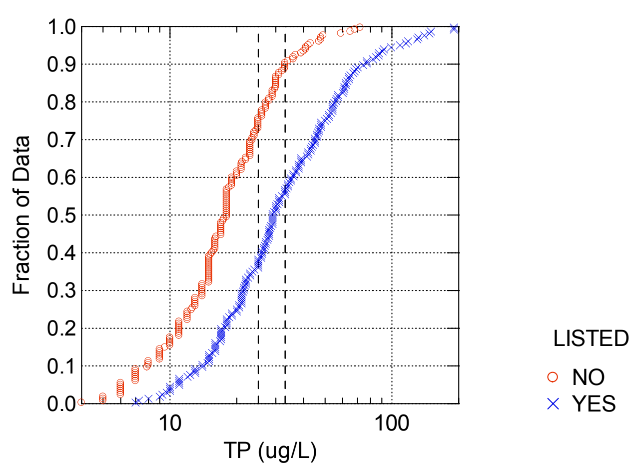


Figure 34. Dot density graph and quantile plot of 191 samples from sites with the goal of Class B that do not have documented impairments of aquatic life and are not listed as impaired for another reason.





3.2.4 - Class C

We wanted to set the Class C criterion to protect both aquatic life, recreation, and aesthetics. The following data sets were analyzed:

- A set of 135 paired samples of TP and percent algal cover were assembled for conditional probability analysis (Figure 35). The threshold of 35% algal cover was selected because that is the proposed algal cover criterion for Class C. The conditional probability estimated the probability of exceeding the 35% algal cover when TP concentrations were greater than or equal a given concentration. We decided not to accept a greater risk than 0.40 and found that the probability of exceeding 35% algal cover passed 0.40 at **33 ppb** TP.
- A set of TP samples from 43 sites known to attain Class C aquatic life criteria based on macroinvertebrates (Figure 36). The 75^{th} percentile was **52 ppb**.

In addition, we used an equation developed to describe the TP-chl *a* relationship in 292 small and large temperate streams (Van Nieuwenhuyse and Jones 1996):

- log chl a = -1.65+1.99 log TP-0.28 $(\log TP)^2$, s=0.32, r^2=0.67, n=292

When converted to regular units, the equation predicted that the chl *a* concentration reached 8.0 ppb when TP was **47 ppb** (Figure 37). The upper 65% confidence interval, used by researchers that developed the equation, reached 8.0 ppb chl *a* at **25 ppb TP**. Based on the weight of evidence, we set the TP criterion for Class C at **33 ppb** to protect both recreation and aquatic life.

Figure 35. Scatterplot, cumulative distribution function, and conditional probability of TP and percent algal cover. Threshold was set at 0.4 probability (40% risk) of a nuisance algal bloom.

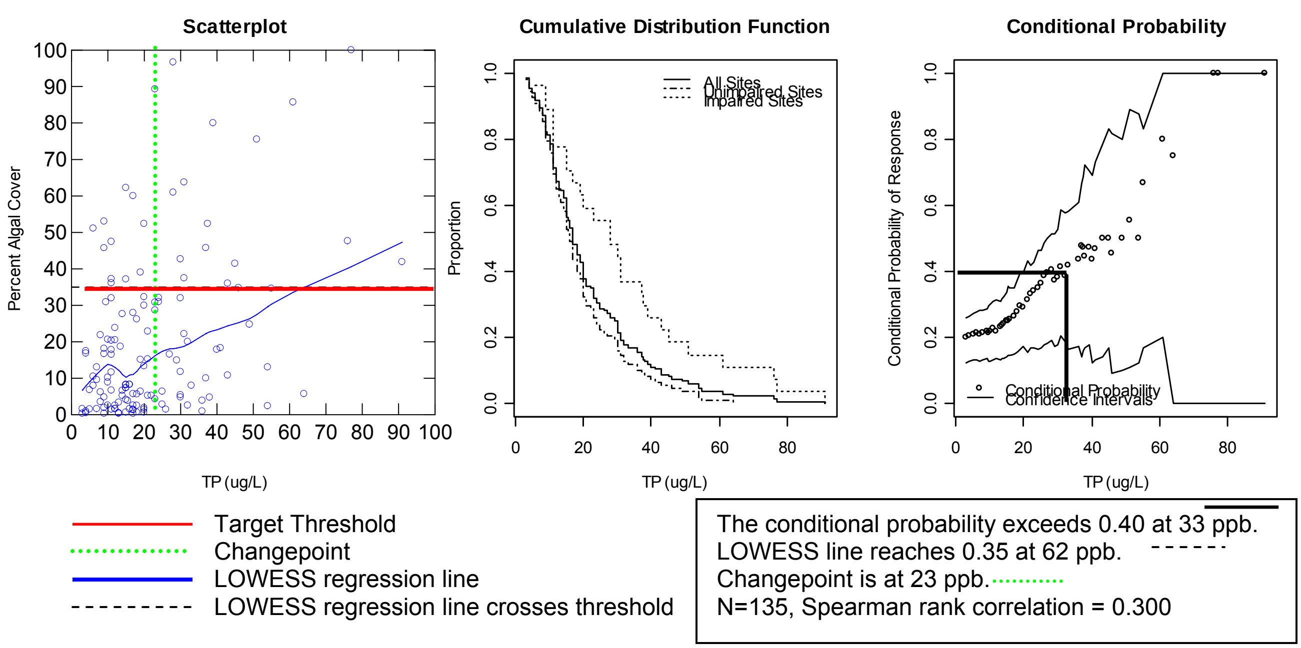


Figure 36. Dot density plot and quantile plot of 43 TP samples from sites that attain Class C aquatic life criteria (macroinvertebrates).

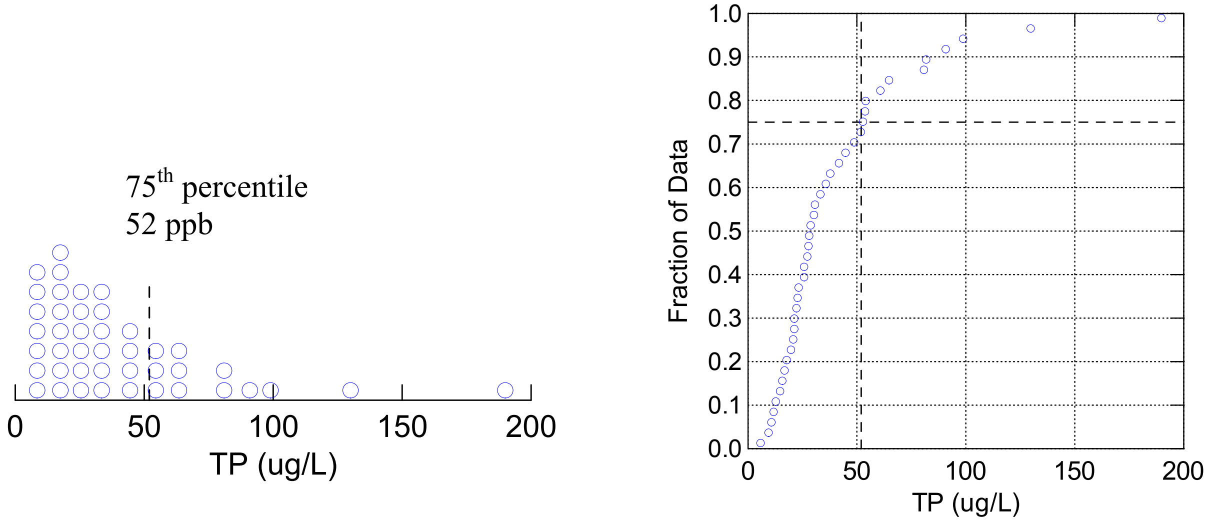
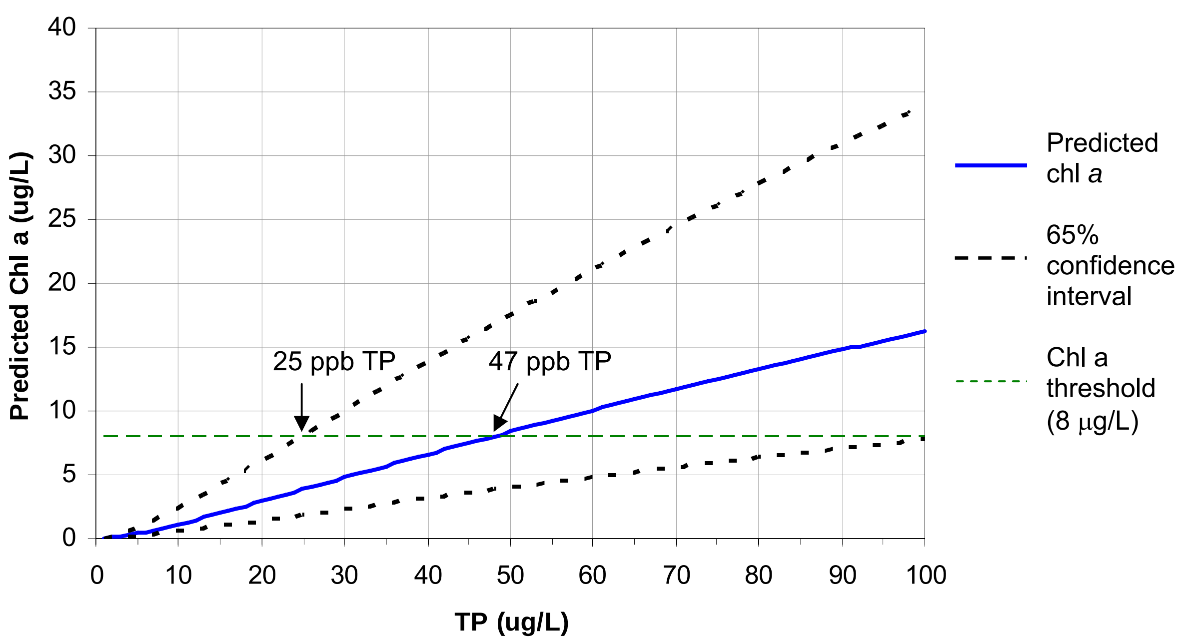


Figure 37. TP and predicted chl *a* and 65% confidence interval (Van Nieuwenhuyse and Jones 1996) with TP concentrations at which upper confidence interval and predicted chl *a* reach 8 µg/L.



3.2.5 - Diatom Total Phosphorus Index for Streams and Rivers

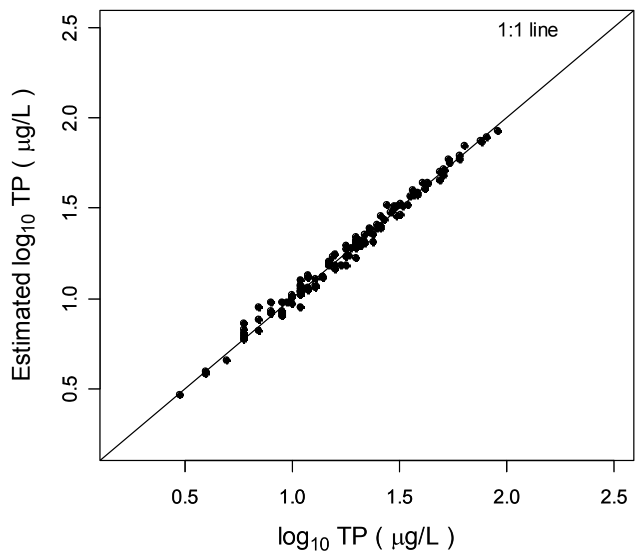
The Diatom Total Phosphorus Index (DTPI) is a tool that can be used to determine attainment of narrative aquatic life criteria (38 M.R.S.A. § 465). The DTPI is a multiple regression model that infers total phosphorus in a stream or river based on the species composition of diatoms collected from the stream bottom. An increase in the DTPI represents a change in the structure of the diatom community from a community dominated by low-nutrient species to a community dominated by high-nutrient species. Diatoms are microscopic algae that have silica shells (i.e., glass houses). There are hundreds of diatom species in Maine streams and rivers. Some are adapted to live in cold, clean water with low levels of nutrients. Others are adapted to live in nutrient enriched water and can tolerate low levels of dissolved oxygen. The community of diatoms growing in a stream is strongly influenced by the availability of nutrients. Nutrients are not the only factors shaping the diatom community, but they are important ones.

The main advantage of the DTPI is that it is a time integrator of past nutrient concentrations. The main problem with taking water samples is that total phosphorus concentrations can vary greatly in developed watersheds because of stream bank erosion and increased runoff from lawns, pavement, and farms following storms. The algal community is a better indicator of nutrient enrichment than water samples because the algae live in the stream and are exposed to the fluctuating phosphorus concentrations over a long period of time. A single diatom sample can replace 16 water samples and represent the nutrient conditions in the previous 5 weeks (Lavoie et al. 2008).

The DTPI is a linear regression using TP concentration as the response (dependent) variable and using multiple diatom species as the explanatory (independent) variables (Danielson 2009) (Figure 38). Linear regressions use a simple mathematical formula to describe a relationship between response and explanatory variable(s). Consider a simplified, hypothetical example with 3 species in a stream. A regression model can be run using TP as the response variable and relative abundances of the three species (x_1, x_2, and x_3) as the explanatory variables. The regression model will calculate a constant and a coefficient for each species (β_1, β_2, and β_3). The constant and species coefficients can then be used in the following formula to estimate TP concentrations: $TP = constant + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$. The DTPI is essentially the same, but uses more species in the calculations.

The DTPI was built with a set of 123 samples and tested with a set of 75 other samples. Statisticians use the r^2 and root mean square error (RMSE) to measure model performance. The r^2 measures the strength of a relationship with potential values between 0 and 1. A perfect relationship would have a correlation approaching 1 and a correlation approaching 0 means absolutely no relationship. The r^2 for the DTPI was 0.90 with the set of 123 and 0.50 when tested with separate set of 75 samples. The RMSE measures the error associated with a model in the original units, in this case $\log_{10}$ ppb, which is useful for comparing the performance of different models. Lower RMSE values are desirable. The DTPI had a RMSE of 0.097 and 0.225 when tested with separate set of 75 samples. The model provided good estimates and compared well to models developed in other studies of stream diatom communities (Potapova and Charles 2003, Potapova et al. 2004, Ponader et al. 2007).

Figure 38. DTPI estimates of TP concentrations.



4 - Potential for listing new impaired waters

DEP does not envision a change in how it lists Class GPA waters because Chapter 583 simply codifies current practice. Class AA, A, B, and C waterbodies that do not attain nutrient criteria because of DO, pH, or aquatic life would not be considered "new listings caused by Chapter 583" because those environmental responses are already independent criteria. The potential for "new listings caused by Chapter 583" is restricted to water column chlorophyll *a*, percent algal cover, and patches of filamentous bacteria and fungi. DEP can not predict future water quality conditions, but DEP examined historic data to estimate the number of sample events and locations that could be considered "new impairments".

4.1 - Listing methodology for the 2008 Integrated Water Quality Monitoring and Assessment Report

Determination of water quality attainment is based on a water meeting all standards and criteria established for its assigned classification (38 M.R.S.A §§ 465, 465-A, and 465-B). Waters are listed by Assessment Unit (HUC) and/or waterbody segment in one of five categories of attainment (see category descriptions below). All freshwaters in Maine in previous cycles were listed in a narrative Category 5-C "Impairment caused by atmospheric deposition of mercury" due to the Statewide fish consumption advisory due to mercury. All freshwaters are now moved to Category 4-A "Total Maximum Daily Load (TMDL) is completed", as a result of US EPA approval, on December 20, 2007, of a Regional Mercury TMDL. Other category listings are established independently from the statewide mercury advisory listing, thus all waters are listed in Category 4-A for mercury and in at least one other category.

All marine waters are listed by narrative in Category 5-D "Legacy Pollutants" as well as in one other category. Each listing provides the Assessment Unit, Waterbody Number, Name, Size, Classification, Monitored Date, and depending on assessment determination, information on impairment, notes on previous listings, or other information.

4.1.1 - Category 1: Attaining all designated uses and water quality standards, and no use is threatened.

Highest level of attainment, waters in the assessment unit attains all applicable standards. Assessment is based on combined evaluation of the following information.

1. Current data (collected within five years) indicates attainment, with no trend toward expected non-attainment within the listing period.
2. Old data (greater than five years) indicates attainment and no change in any associated conditions.
3. Water quality models predict attainment under current loading, with no projected change in loading that would predict non-attainment.
4. Qualitative data or information from professional sources indicating attainment of standards and showing no identifiable sources (e.g. detectable points of entry of either licensed or unlicensed wastes) of pollution, low impact land use (e.g. intact riparian buffers, >90% forested watershed, little impervious surface), watershed within state or federal reserve land, park, wilderness area or similar conservation protection, essentially unaltered habitat, and absence of other potential stressors.
5. Determination that the direct drainage area has a human population of <0.1 per square mile according to U.S. Census data obtained in 2000 and watershed conditions as described in item 4, above. For lakes, determinations are based on census data at the town level and consider all towns in the direct drainage of larger (referred to in previous 305(b) reports as "significant") lakes. Populations for the remaining lakes (generally less than ten acres) are determined for the town listed as the point-of-record for the water according to the Department of Inland Fisheries and Wildlife Lake Index database.

4.1.2 - Category 2: Attains some of the designated uses; no use is threatened; and insufficient data or no data and information is available to determine if the remaining uses are attained or threatened (with presumption that all uses are attained).

Assessment is based on combined evaluation of the following information.

1. Current data (collected within five years) for some standards indicating attainment, with no trend toward expected non-attainment within the listing period, or an inadequate density of data to evaluate a trend.
2. Old data (greater than five years) for some standards indicating attainment, and no change in associated conditions.
3. Water quality models that predict attainment under current loading for some standards, with no projected change in loading that would predict non-attainment.
4. (For lakes) Probabilistic-based monitoring that indicates a high expectation of use attainment for certain classes of waters based on random monitoring of that class of waters.

5. Insufficient data for some standards, but qualitative data/information from professional sources indicate a low likelihood of impairment from any potential sources (e.g. high dilution, intermittent/seasonal effects, low intensity land use).

4.1.3 - Category 3: Insufficient data and information to determine if designated uses are attained (with presumption that one or more uses may be impaired).

Assessment is based on combined evaluation of the following information. Monitoring schedules are assigned to these waters.

1. Insufficient or conflicting data that does not confirm either attainment or non-attainment of designated uses.
2. Qualitative data or information from professional sources showing the potential presence of stressors that may cause impairment of one or more uses; however, no quantitative water quality information confirms the presence of impairment-causing stressors.
3. Old data, with:
   a. low reliability, no repeat measurements (e.g. one-time synoptic data),
   b. a change of conditions without subsequent re-measurement; or
   c. no evidence of human causes or sources of pollution to account for observed water quality condition (natural conditions that do not attain water quality standards are allowed by 38 M.R.S.A. Section 464.4.C).
4. (For lakes) Current data indicates a return to (or a trend towards) attainment standards over the past few years but requires confirmation; or conversely, that trophic or dissolved oxygen profile evaluation suggests deteriorating conditions requiring further study and verification. (Since lakes respond over a longer period of time and can be highly influenced by weather attributes, it is appropriate to recommend additional monitoring before attainment is determined.)

4.1.4 - Category 4: Impaired or threatened for one or more designated uses, but does not require development of a TMDL.

A water body is listed in Category 4 when impairment is not caused by a pollutant; or, if impairment is caused by a pollutant, but where a TMDL has already been completed, or where other enforceable controls are in place. An impaired waterbody will be listed in Category 5 if both a pollutant and a non-pollutant are involved that would independently cause an impaired or threatened condition. Waters are listed in one of the following Category 4 sub-lists when:

1. Current or old data for a standard indicates either impaired use, or a trend toward expected non-attainment within the listing period, but also where enforceable management changes are expected to correct the condition,
2. Water quality models that predicted impaired use under loading for some standard, also predict attainment when required controls are in place, or,
3. Quantitative or qualitative data/information from professional sources indicates that the cause of impaired use is not from a pollutant(s) (e.g. habitat modification).

4-A: TMDL is completed. A TMDL is complete but insufficient new data exists to determine that attainment has been achieved.

Note: For the 2008 cycle the 4A category now includes all freshwaters in Maine that were listed in previous cycles in a narrative Category 5-C “Impairment caused by atmospheric deposition of mercury" due to the Statewide fish consumption advisory due to mercury. On December 20, 2007 US EPA approved a Regional Mercury TMDL for the Northeast.

4-B: Other pollution control requirements are reasonably expected to result in attainment of standards in the near future. Waterbodies where enforceable controls have a reasonable expectation of attaining standards, but where no new data are available to determine that attainment has been achieved. (Enforceable controls may include: new wastewater discharge licenses issued without preparation of a TMDL, other regulatory orders, contracts for nonpoint source implementation projects, regulatory orders or contracts for hazardous waste remediation projects).

4-C: Impairment is not caused by a pollutant. Waters impaired by habitat modification that is a result of human activity.
Note: Natural conditions that do not attain water quality standards and criteria are allowed by 38 M.R.S.A. Section 464.4.C. Waters that show impairment due to natural phenomena are listed in Categories 1 through 3.

4.1.5 - Category 5: Waters impaired or threatened for one or more designated uses by a pollutant(s) and a TMDL is required.

Waters are listed in one of the Category 5 sub-lists when:

1. Current data (collected within five years) for a standard either indicates impaired use, or a trend toward expected impairment within the listing period, and where quantitative or qualitative data/information from professional sources indicates that the cause of impaired use is from a pollutant(s),
2. Water quality models predict impaired use under current loading for a standard, and where quantitative or qualitative data/information from professional sources indicates that the cause of impaired use is from a pollutant(s), or,
3. Those waters have been previously listed on the State's 303(d) list of impaired waters, based on current or old data that indicated the involvement of a pollutant(s), and where there has been no change in management or conditions that would indicate attainment of use.

5-A: Impairment caused by pollutants (other than those listed in 5-B through 5-D). A Total Maximum Daily Load is required and will be conducted by the State of Maine. TMDL schedules are assigned based on the value of a particular water (considering size, public use, proximity to population centers, and level of public interest for water quality improvement), the nature of the impairment and the source(s) of the problem, available information to complete the TMDL, and availability of staff and contractual resources to acquire information and complete the TMDL study. Projected schedules for TMDL completion are included in Chapter 8 as well as in the Appendices.

5-B: Impairment is caused solely by bacteria contamination. A TMDL is required. Certain waters impaired only by bacteria contamination may be high priority resources, such as shellfish areas, but a low priority for TMDL development if other actions are already in progress that will correct the problem in advance of TMDL development (e.g. better compliance). Certain small streams that are impaired solely by bacteria contamination but where recreation (swimming) is impractical because of their small size are listed in 5-B. Relative to other, more ecologically detrimental causes of impairment these waters are considered a lower priority for TMDL completion. A projected schedule of TMDL completion is included where applicable. Waterbodies impaired only by Combined Sewer Overflows, where current CSO Master Plans (Long-Term Control Plan) are in place, will be monitored to demonstrate that water quality standards are attained and that provisions are in place for both funding and compliance timetables.

5-C: Impairment caused by atmospheric deposition of mercury and a regional scale TMDL is required. Due to EPA approval of a regional scale TMDL for the control of mercury all of Maine’s Category 5C waters have been administratively moved to Category 4A.
5-D: Impairment caused by a “legacy” pollutant. This sub-category includes:

1. waters impaired only by PCBs, dioxins, DDT, or other substances already banned from production or use. It includes waters impaired by contaminated sediments where there is no additional extrinsic load occurring. This is a low priority for TMDL development since there is no controllable load.
2. coastal waters that have a consumption advisory for the tomalley (hepato-pancreas organ) of lobsters due to the presence of persistent bioaccumulating toxics found in that organ. This is a low priority for TMDL development since there is no identifiable and controllable load.

4.2 - Chlorophyll a in streams rivers and impoundments

Chlorophyll *a* exceeded criteria in 23 of 288 sample events in DEP’s database. Of the 21 sample events in Box 4 of the Decision Framework, 4 were from streams and rivers without documented impairment of aquatic life and were not already listed as impaired. Of the 2 sample events in Box 3 of the Decision Framework, 1 was from a river without documented impairment of aquatic life and was not already listed as impaired. Potentially new listings of Category 3, 4, or 5 in the Integrated Water Quality Monitoring and Assessment Report include the following locations:

- Bobbin Mill Brook, Auburn (currently listed as Category 3)
- Dearborn Brook, Windsor (probably add as Category 3)
- Finn Brook, Whitefield (probably add as Category 3)
- Salmon Falls River (SF4 – tidally influenced), South Berwick
- Salmon Falls River (SF5 – tidally influenced), South Berwick

DEP also reviewed historic water quality reports that contained data not yet imported into DEP’s water quality database. The following streams and rivers had documented chlorophyll *a* concentrations greater than criteria, however most segments were already listed as impaired for other reasons:

- Androscoggin River (Gulf Island Pond in 1998, 1999, and 2000),
- Aroostook River (several locations in 2001),
- Kennebec River (Augusta and downstream in 1997 and 1998),
- Penobscot River (Dolby Pond, Rockabema Impoundment, Weldon Impoundment, and Brewer to Winterport in 2007), and
- Sabattus River (2002).

4.3 - Percent algal cover

Percent algal cover exceeded criteria in 68 of 307 sample events. Of the 41 samples ending up in Box 3 of the Decision Framework, 24 samples were from streams and rivers without documented impairment of aquatic life and were not already listed as impaired. Of the 27 samples ending up in Box 4 of the Decision Framework, 4 samples were from streams and rivers without documented impairment of aquatic life and were not already listed as impaired. Some sample events were collected from the same locations in different years. Table 4 lists potential new listings of Category 3, 4, or 5 in the Integrated Water Quality and Monitoring Report. Many of the locations probably would be listed as Category 3 because percent algal cover samples were only a little greater than criteria, locations attained criteria in other years, or other water quality samples (e.g., dissolved oxygen, aquatic life) attained class.

4.4 - Patches of bacteria and fungi

In recent years, there have been few documented observations of filamentous bacteria and fungi, such as the following locations:

- Lords Brook, Windham (runoff from composting facility),
- Martin Stream, Dixmont (runoff from cow farm),
- Kennebago River (downstream of hatchery),
- Cold Brook, Enfield (downstream of hatchery), and
- Birch Stream, Bangor (downstream of airport deicing facility).

Most sample locations also were impaired because of aquatic life, dissolved oxygen, and/or bacteria.

Table 4. Sample locations that could potentially be new additions to the Integrated Water Quality Report and listed as Category 3, 4, or 5 because they exceed percent algal cover criteria

Name	location	Town	Goal
Allagash River - Station 750	approximately 1 mile downstream of Allagash Checkpoint	Allagash	A
Bond Brook - Station 597	upstream of ball fields on Rt 11/27	Augusta	B
Bond Brook - Station 838	35 m upstream of Bond Brook Road	Augusta	B
Caribou Stream - Station 96	7m downstream of Rt. 164	Caribou	B
Chandler River - Station 503	upstream of Station Rd.	Jonesboro	A
Chase Mills Stream - Station 113	downstream of fish hatchery	East Machias	B
China Lake Outlet Stream - Station 604	downstream of Rt. 137	Winslow	B
Cobbosseecontee Stream - Station 253	downstream of Rt. 126/9	Gardiner	B
Crooked Brook - Station 510	upstream of Rt. 11/43	Corinth	B
Crooked River - Station 673	downstream of rest area on Rt. 118	Waterford	AA
Dennys River - Station 740	downstream of Rt. 86	Dennysville	AA
French Stream - Station 505	downstream of Crane Road	Exeter	B
Kenduskeag Stream - Station 563	downstream of pasture on Beans Mill Rd	Corinth	B
Kennebec River - Station 405	downstream of Abenaki powerhouse	Madison	B
Kennebec River - Station 635	upstream of treatment plant and 40m upstream of Jackson Brook	Bingham	A
Little Androscoggin River - Station 43	45 m upstream of treatment plant	Paris	C
Merritt Brook - Station 742	upstream of confluence with Aroostook River	Presque Isle	B
Mopang Stream - Station 501	downstream of Rt. 9	T30 Md Bpp	AA
Narraguagus River - Station 112	upstream of Rt. 9	Beddington	AA
Piscataquis River - Station 559	upstream of Salmon Stream outlet	Guilford	B
Sandy River - Station 617	downstream of Rt. 2/27	New Sharon	B
Schoodic Brook - Station 766	approximately 1 km upstream of North Road	Medford	A
Seboeis Stream - Station 665	upstream of Howland Road	Howland	A
Wesserunsett Stream - Station 488	downstream of Huff Road	Cornville	B
West Branch Nezinscot River - Station 664	approximately 1 km upstream of North Buckfield Road	Sumner	A
Wild River - Station 674	upstream of confluence with Little Lazy Brook	Batchelders Grant Twp	AA

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