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

Cupsuptic River

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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 be a bad thing. Too much nutrients can cause negative environmental impacts. For example, excess nutrients can cause algal blooms in lakes, impoundments, and 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 fast flowing streams and rivers. Excess nutrients can 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 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.

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 freshwater nutrient indicators 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

Determining Attainment of Water Quality Standards

The State of Maine’s Water Classification System 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.

Nutrient Indicators 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:

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

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

- 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).

The proposed decision framework does not create new criteria for phosphorus or nitrogen. It does include some new numeric guidelines to interpret attainment of designated uses and narrative criteria.

Environmental Response Limits

The proposed rule includes many environmental response indicators 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 indicators that can be used for different types of waterbodies. One or more of the indicators that are appropriate for a waterbody type should be selected and sampled. Table 3 lists the limits of the environmental response indicators for the different statutory classes. Descriptions of each environmental response indicator follow the two tables.

Table 2. Ecological response indicators for different waterbody types.
Sample one or more of the ecological response indicators shown for the waterbody type.

Waterbody Type	Ecological Response Indicators
GPA (Not Colored)	Secchi disk depth Water column chl *a* Aquatic life pH
GPA (Colored)	Secchi disk depth[1] Water column chl *a*[1] Aquatic life pH
A, B, or C (waterbodies or segments <1 m deep)	Water column chl *a* Percent algal cover Dissolved oxygen Aquatic life Diatom total phosphorus index pH Patches of bacteria and fungi
A, B, or C (waterbodies or segments ≥1 m deep)	Water column chl *a* Aquatic life Dissolved oxygen pH Patches of bacteria and fungi
Impounded Class A, B, or C waters	Secchi disk depth[1] Water column chl *a*[1] Dissolved oxygen pH Aquatic life

[1] – Secchi disk depth and water column chl *a* should be sampled together in colored GPA, impounded Class B, and impounded Class C waters.

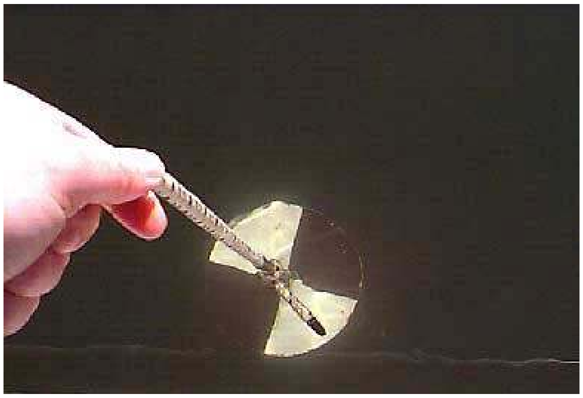
Table 3. Environmental response limits for different statutory classes.

Statutory Class	AA/A	B	C	Impounded A	Impounded B	Impounded C	GPA Not colored	GPA colored
Secchi Disk Depth (meters)^{a}	--	--	--	≥ 2.0	≥ 2.0	≥ 2.0	≥ 2.0	≥ 2.0
Water Column Chl *a* (µg/L, parts per billion)	no single value > 3.5 (5.0^{b})	no single value > 8.0	no single value > 8.0	OR spatial mean of 3.5^{c} and no single value > 5.0^{c}	AND spatial mean of 8.0^{c} and no single value >10.0^{c}	AND spatial mean of 8.0^{c} and no single value >10.0^{c}	OR no single value > 8.0^{d}	AND no single value > 8.0^{d}
Diatom Total Phosphorus Index^{a}	≤ 20.0	≤ 32.0	≤ 37.0	--	--	--	--	--
Percent of Substrate Covered by Algal Growth^{a}	≤ 20.0	≤ 30.0	≤ 40.0	--	--	--	--	--
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 and Department of Environmental Protection 06 096 Chapter 579						See 38 M.R.S.A. § 465-A	

a - Instantaneous reading at any time
b - Applicable to waterbodies with water velocity less than 5.0 centimeters per second
c - Chlorophyll *a* samples from impoundments are based on depth-integrated, photic-zone averages
d - GPA chlorophyll *a* samples are based on depth-integrated, epilimnetic averages

Secchi Disk Depth for Lakes and Impoundments

Figure 1: Secchi Disk



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 1). 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.

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 low. When the amounts of color or suspended sediments are high, then biologists take chlorophyll *a* measurements to confirm that the low Secchi depths are caused by algae.

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 2). Algal blooms can harm aquatic life and reduce the quality of recreation in and on the water, such as swimming and boating.

Figure 2: 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. 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

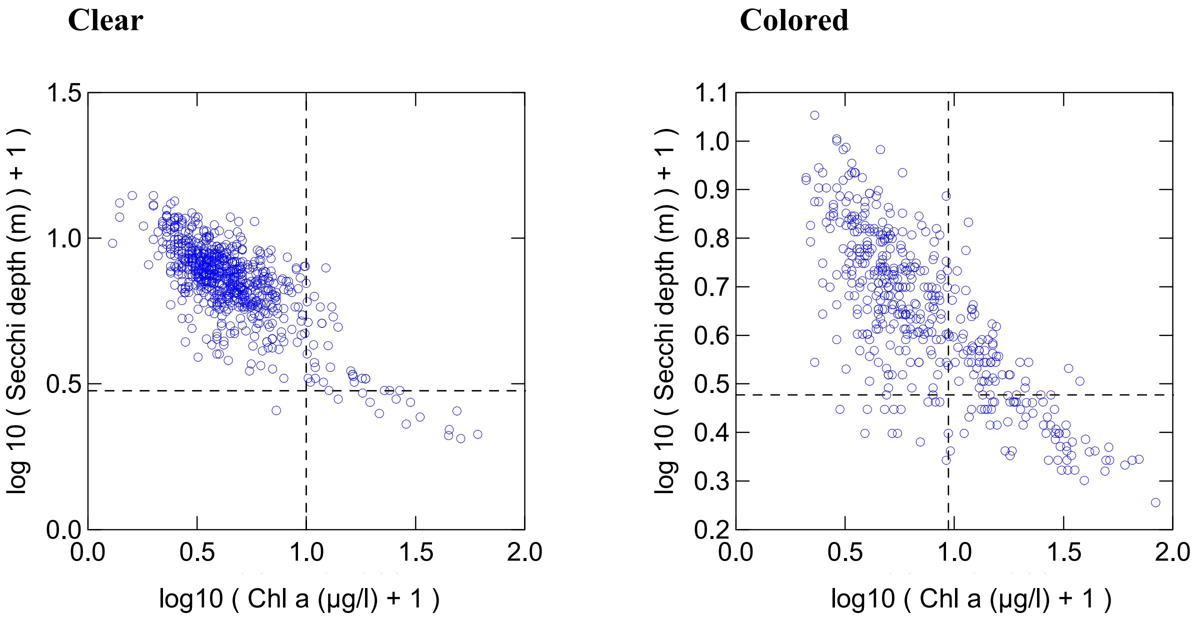
August over a span of several decades. We analyzed the data to determine if there were natural thresholds or "changepoints" in the data. The changepoint analysis uses a statistical procedure called nonparametric deviance reduction, which seeks the chl *a* concentration at which there is the greatest difference in Secchi depths (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). We estimated uncertainty about the changepoint by calculating the 95% confidence interval using 1,000 bootstrap simulations. We also used a statistical test (approximate χ^2 test) to determine if the changepoint was ecologically significant (Qian et al. 2003, Paul and McDonald 2005). We trimmed 5 outliers and 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 lower 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.

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

Both data sets had strong inverse relationships between chl *a* and Secchi depth (Figure 3). 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 3: 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.)


Clear

Colored

Water Column Chl a for Streams, Rivers, and Impoundments

Algal blooms and low 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 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 90th percentile of the chl *a* concentrations. The 90th 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 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 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. 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.

Diatom Total Phosphorus Index for Streams and Rivers

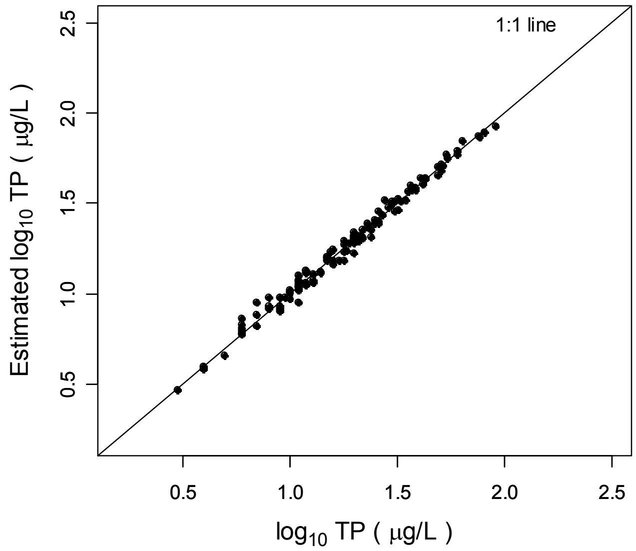
The Diatom Total Phosphorus Index (DTPI) is a tool that can be used to determine attainment of narrative aquatic life criteria (38 M.R.S.A. § 465). The DTPI is a multiple regression model that infers total phosphorus in a stream or river based on the species composition of diatoms collected from the 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 4). 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.

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 score of 1 and a 0 means absolutely no relationship. The r^2 for the DTPI was 0.90. 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. 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 4: DTPI estimates of TP concentrations.



Aquatic Life Use Attainment

This variable is an indicator of the condition of aquatic biological communities. A waterbody must attain narrative aquatic life use criteria as described in 38 M.R.S.A. §§ 465 and 465-A as well as numeric criteria in Department of Environmental Protection 06 096 Chapter 579. DEP follows standard protocols for sampling macroinvertebrates in streams and rivers (Davies and Tsomides 2002). Class A waters must support communities of aquatic life that are "as naturally occurs". Class 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 5). Streams that support Class B communities often have a little nutrient enrichment and more organisms (Figure 6). 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 7).

Figure 5: Example of a Class A macroinvertebrate sample.

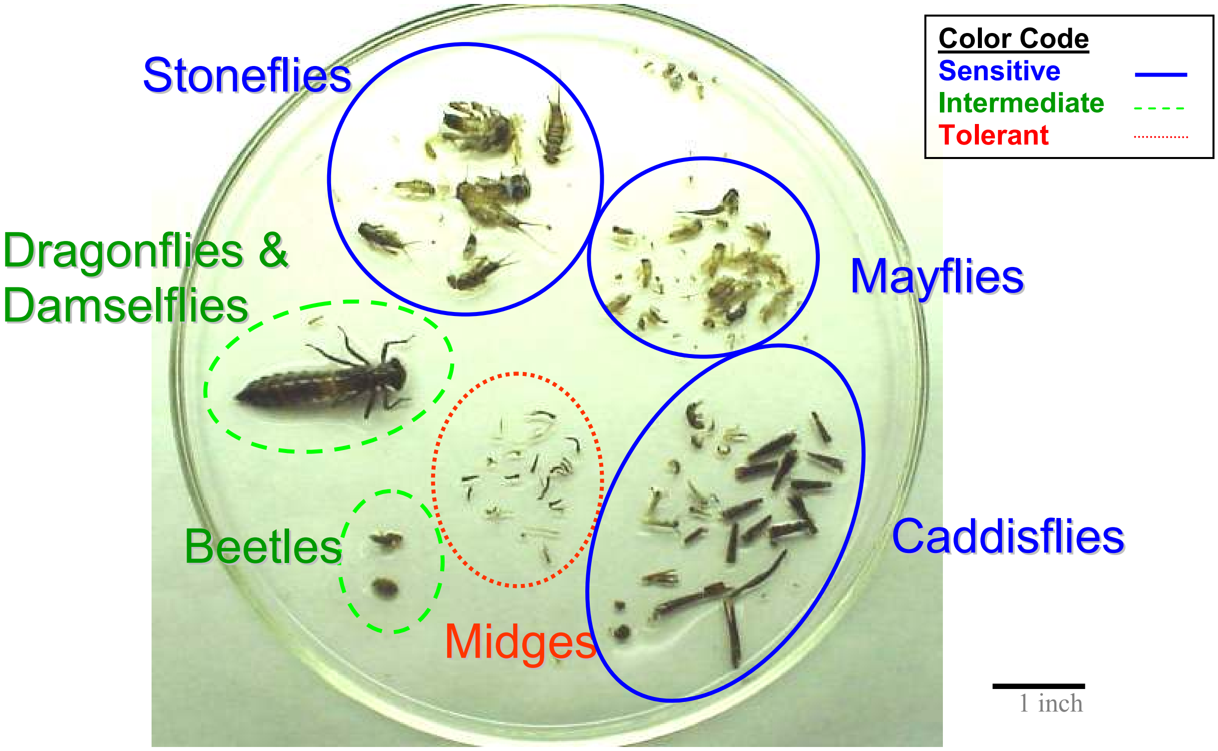


Figure 6: Example of a Class B macroinvertebrate community.

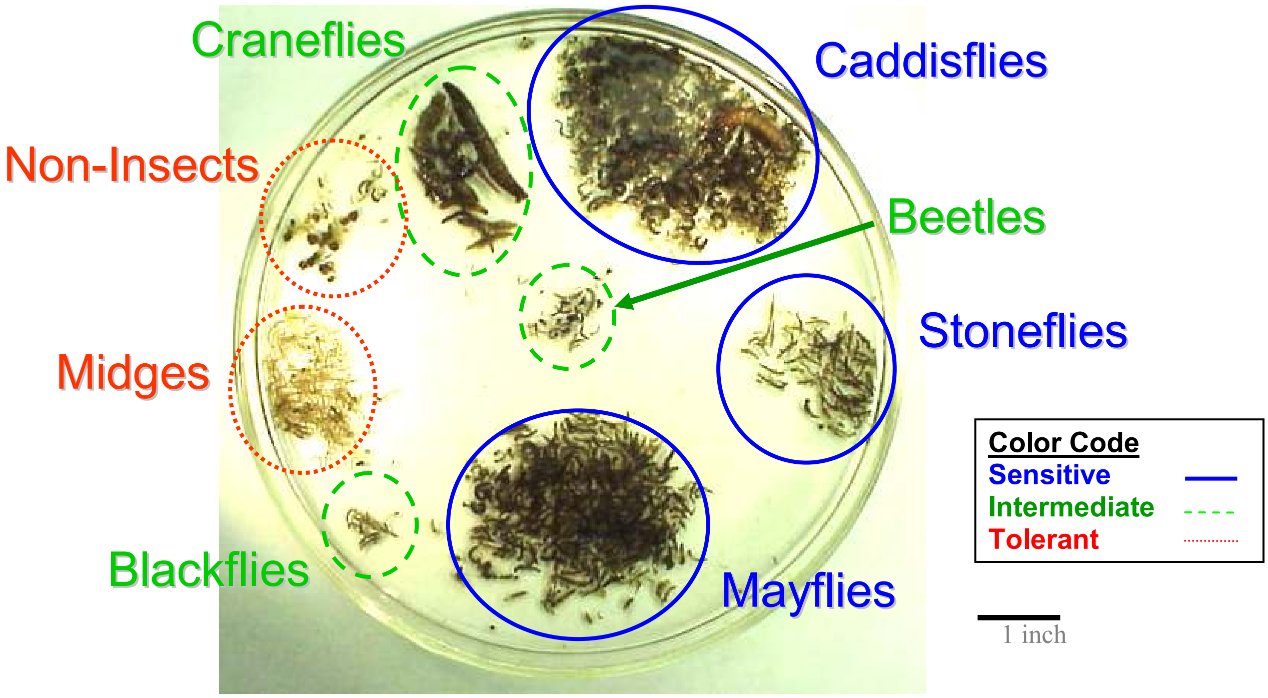
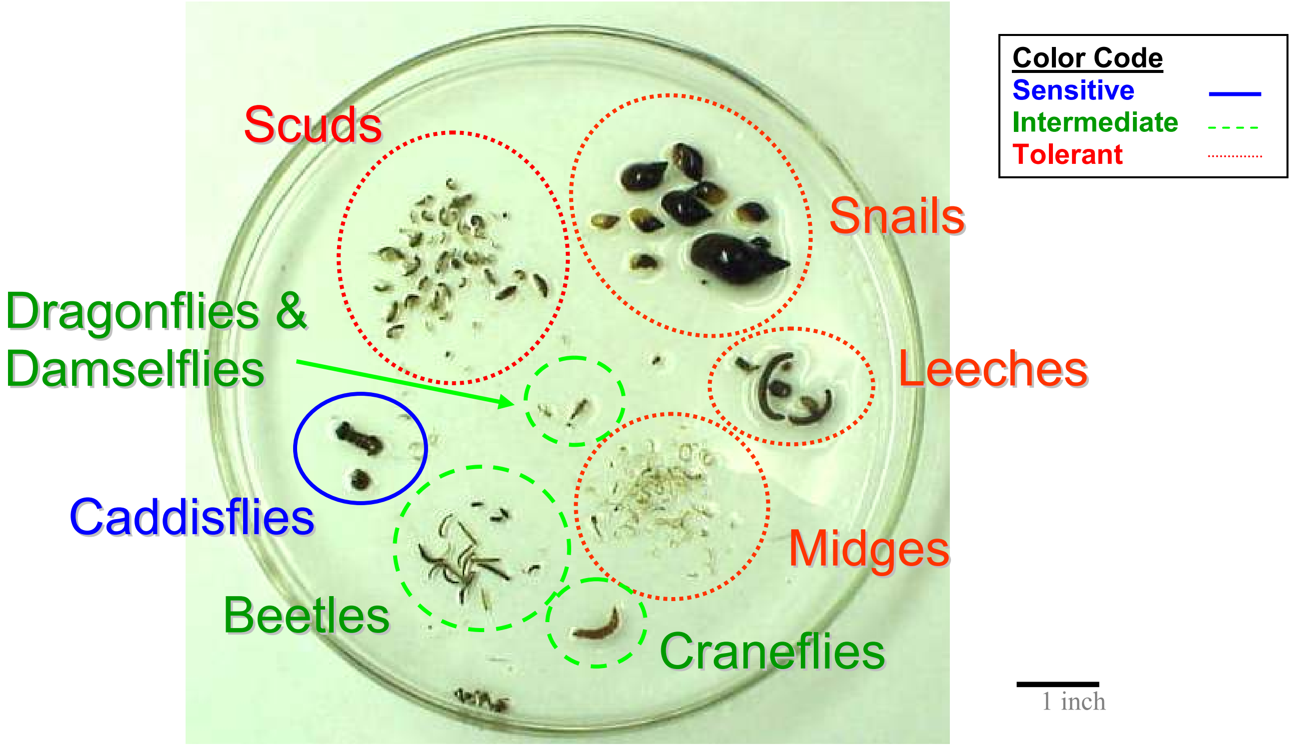


Figure 7: Example of a non-attainment stream that does not meet Class C.



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 (§§ 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.

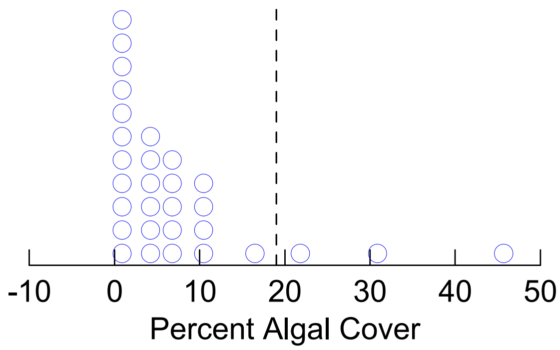
Figure 8: Viewing bucket for estimating percent algal cover

DEP has a standard protocol for estimating percent algal cover using a viewing bucket survey (Danielson 2006). DEP uses a method slightly modified from the U.S. EPA Rapid Bioassessment Protocols (Stevenson and Bahls 1999). 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 8). At a sample location, we typically established two or 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 9). 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 9: Using viewing bucket.

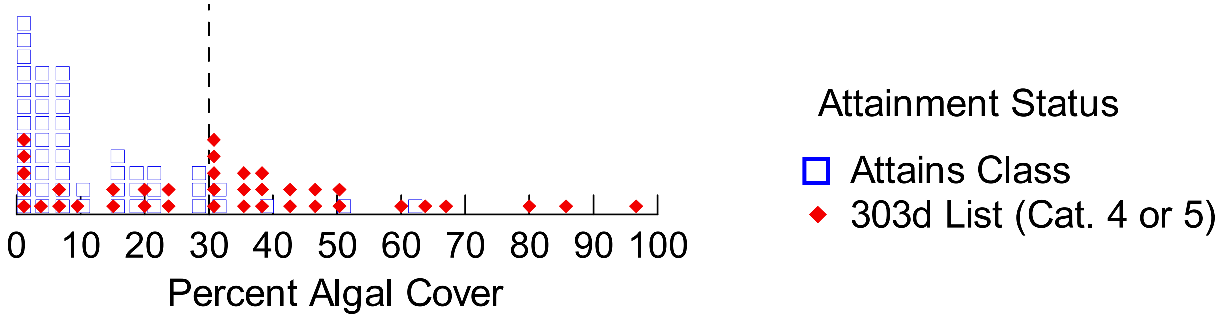
The limit for Class A streams and rivers was established by examining the percent algal cover from a set of 30 reference streams from across the state. The following criteria were used in selecting reference sites: (1) 95% of land area within the watershed was forest or wetland, (2) no major dams, and (3) no major discharges of effluent. The 90th percentile of the reference streams was 19% algal cover (Figure 10). We decided to set the limit for Class A streams and rivers at 20% algal cover. This is close to the guidelines to protect fisheries in British Columbia, Canada (Nordin 1985).

Figure 10: Distribution of percent algal cover from reference sites.



We set the Class B limit by examining the relationship between percent algal cover and the attainment of Class B water quality standards. We assembled data from 91 locations on Class B streams. Some of the sites are listed on the 303d list for water quality impairments (Figure 11, red diamonds). Other sites are from streams without identified water quality impairments (Figure 11, blue squares). The 90th percentile of the 50 streams that attain Class B (blue squares) was 30% algal cover. Most samples with percent algal cover greater than 30% were identified as having water quality impairments. Therefore, we set the Class B limit for percent algal cover at 30%.

Figure 11: Distribution of percent algal cover in samples from streams and rivers with the water quality goal of Class B.



We did not have enough data from streams that attain Class C biological criteria to set a percent algal cover limit. Therefore, we did a literature search. New Zealand has done the most research on this topic. Their streams are similar to Maine streams in many ways and many support trout fisheries. In a survey of 400 streams, Biggs and Price (1987) observed that filamentous algae are very conspicuous when they cover more than 40% of the stream bottom. New Zealand set a limit of 40% cover to prevent nuisance algal growths and protect aquatic life and recreational opportunities (Zurr 1992). The U.S. Environmental Protection Agency (USEPA) proposed a limit of 40% algal cover to protect recreation and aquatic life (USEPA 2000). Similar or more stringent limits have been proposed by a variety of other researchers and agencies using comparable measurements of benthic chl *a* (Horner et al. 1983, Welch et al. 1988, Welch et al. 1989, Dodds et al. 1997, Dodds et al. 1998, Tetra Tech 2006). We decided to set the Class C limit of percent algal cover at 40% to protect recreational uses.

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 organic material, such as sewage, compost, and 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 12 illustrates the shift in biological communities below an untreated discharge of organic pollution. Please note that most licensed discharges in Maine <u>do</u> <u>not</u> 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 13 and 14 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 13) 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 14) had lower diversity and was dominated pollution tolerant species.

Figure 12: 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)

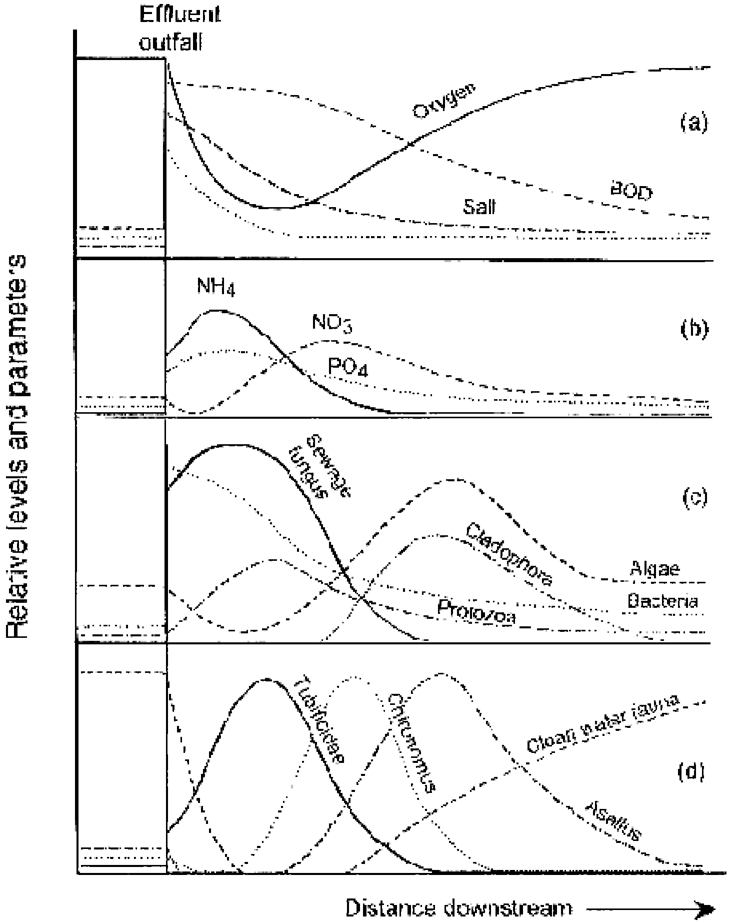


Figure 13. Macroinvertebrate community from the control stream.

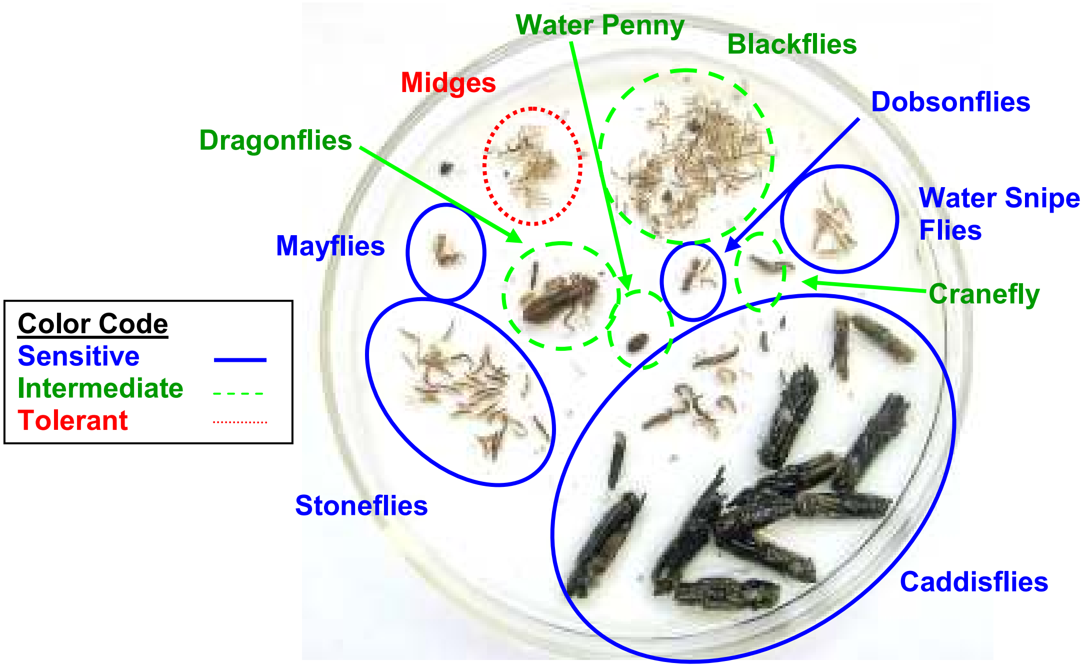
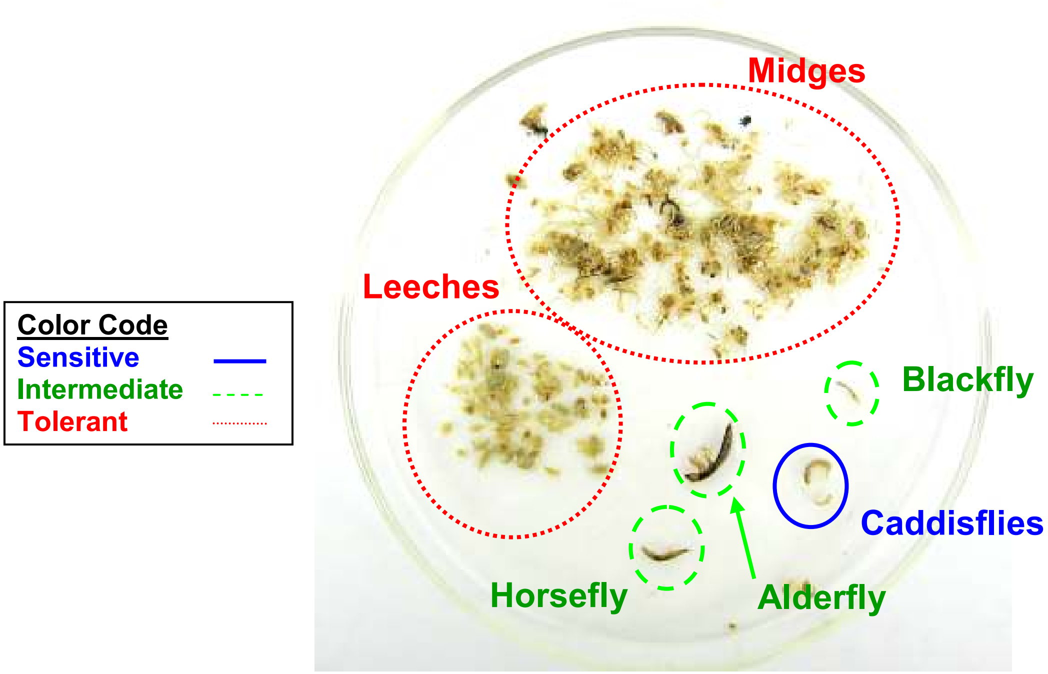


Figure 14. Macroinvertebrate community of the stream impacted by untreated, organic waste.



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.

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.

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.

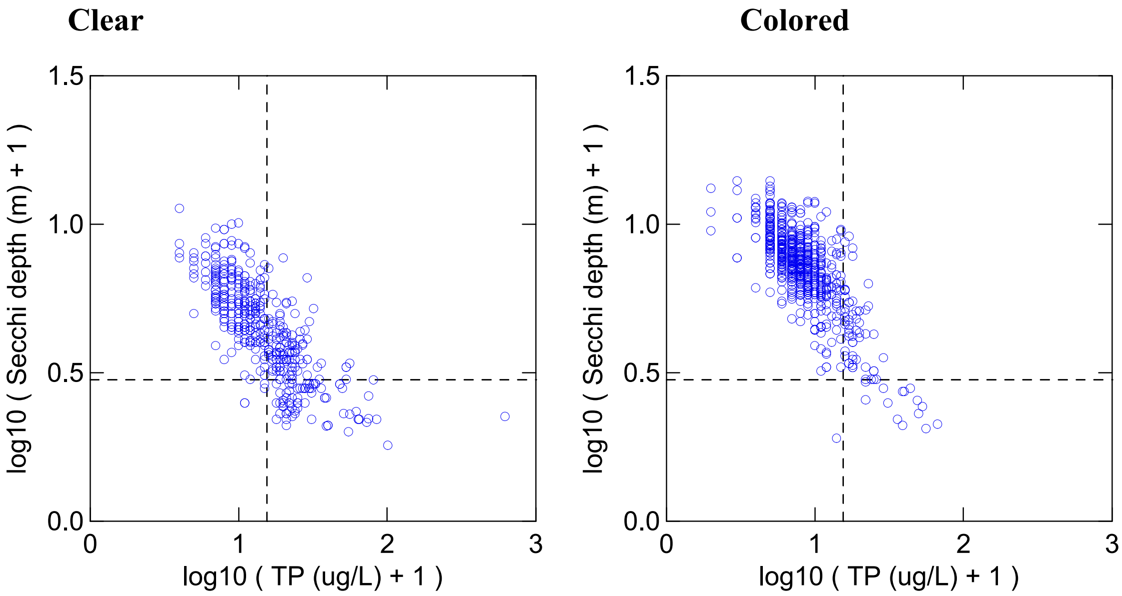
DEP staff, however, decided to use total phosphorus (TP) as the primary indicator of nutrient enrichment. There are several reasons for choosing TP. First, DEP has a long history of using TP as an indicator of the trophic state of lakes and is familiar with its effects on water quality. We have more 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 screening tool and use nitrogen and other nutrients as secondary screening tools on a case by case basis.

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 ≥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. 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.

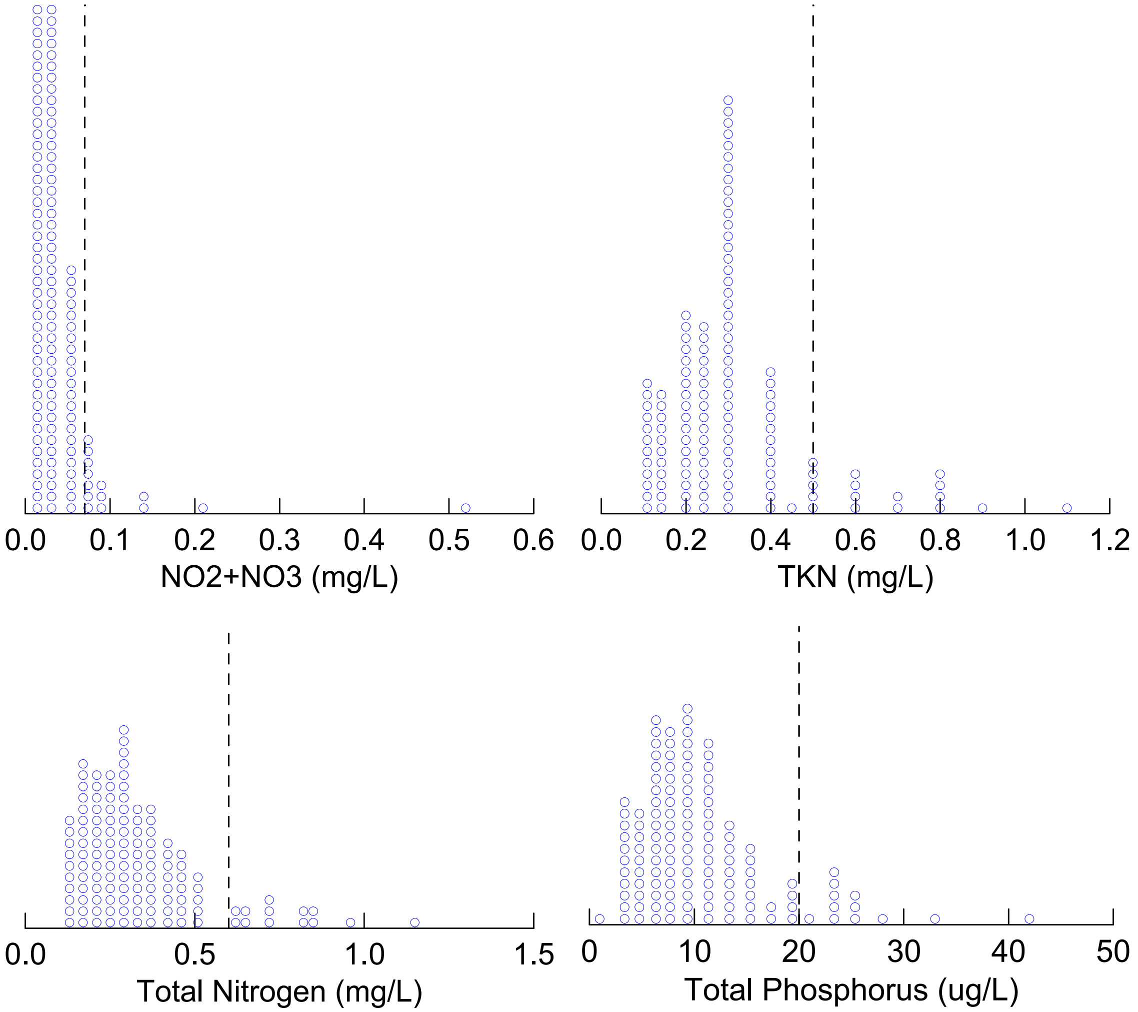
Figure 15: Relationship between TP and Secchi depth in clear and colored lake samples (Vertical lines represent transformed changepoints. Horizontal lines are the 2 m Secchi.)



Class A Streams and Rivers

According to statute, Class A streams and rivers are required to be "as naturally occurs." Therefore, we based the TP limit for Class A streams and rivers on an analysis of reference streams in undeveloped watersheds. We assembled TP data from 126 reference streams located across the state. We defined reference streams as having greater than 95 percent forest, no point-source discharges, and no major dams in the upstream watershed. Nutrient samples, including TP, nitrate+nitrite (NO2+NO3), and total Kjeldahl nitrogen (TKN), were collected during the summer (June-September) months over a period of several years. Total nitrogen (TN) was estimated by adding NO2+NO3 and TKN. Concentrations below the detection limit were given a value one half of the detection limit. Most of the streams were represented by single nutrient samples. Average nutrient concentrations were used for locations with multiple samples. 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 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). The 90th percentile of TP was 20 µg/L (Figure 9). The 90th percentiles of TN, NO2+NO3, and TKN were 0.60, 0.07, and 0.50 milligrams per liter (mg/L, which are equivalent to parts per million) (Figure 9).

Figure 16: Concentrations of TP, TN, NO2+NO3, and TKN from reference streams. (Proposed limits are shown as dashed, vertical lines).



Class B and C Streams and Rivers

The draft TP limit for Classes B and C were based on the 75th percentiles of TP concentrations from streams and rivers known to attain Class B and C aquatic life criteria. We based it on the 75th percentile based on recommendations by the U.S. EPA (USEPA 2000, Rohm et al. 2002). We also chose the 75th percentile because of concerns about protecting all aquatic life. The macroinvertebrate community is used as the primary measure of attainment 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 increased nutrient concentrations and subsequent effects. 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 17). 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 17). 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, the 75th percentile was used, instead of the 90th percentile, to set the limits because there is greater uncertainty in the relationship between nutrients and protection of all aquatic life. The TP 75th percentiles of Class B and C were 32 µg/L and 52 µg/L respectively (Table 4, Figures 18 and 19). The TN 75th percentiles for B and C were 0.70 and 0.95 mg/L respectively.

Figure 17: Relationships between TP and both relative richness of mayflies, stoneflies, and caddisflies and relative richness of sensitive algae.

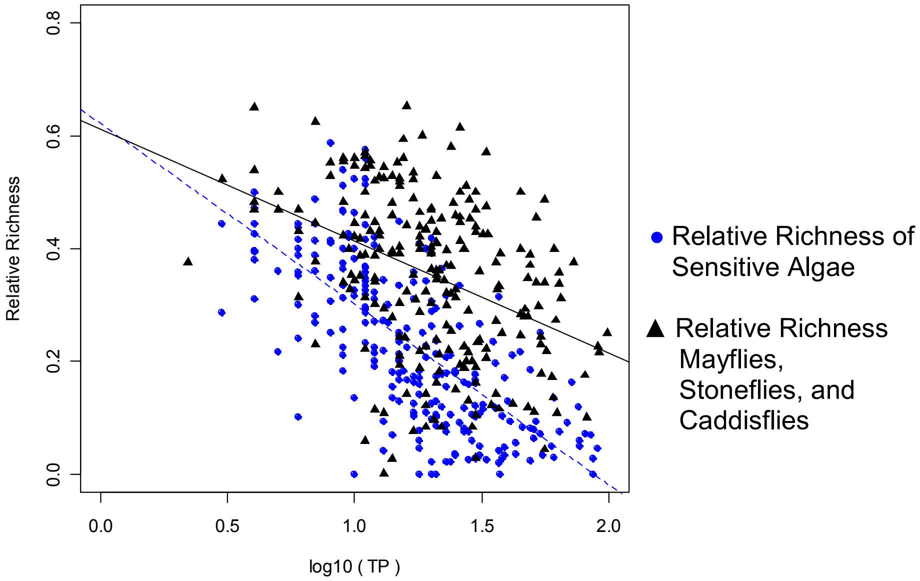


Table 4: 75th percentiles of nutrient concentrations for biomonitoring samples attaining Class B or C numeric aquatic life criteria.

The numbers of observations are enclosed in parenthesis.

	TP (µg/L)	TN (mg/L)	NO2+NO3 (mg/L)	TKN (mg/L)
Attains Class B	32 *(59)*	0.70 *(53)*	0.25 *(53)*	0.5 *(53)*
Attains Class C	52 *(43)*	0.95 *(40)*	0.39 *(40)*	0.7 *(40)*

Figure 18: Concentrations of TP, TN, NO2+NO3, and TKN from streams that attain Class B numeric aquatic life criteria.

(Proposed limits are shown as dashed, vertical lines)

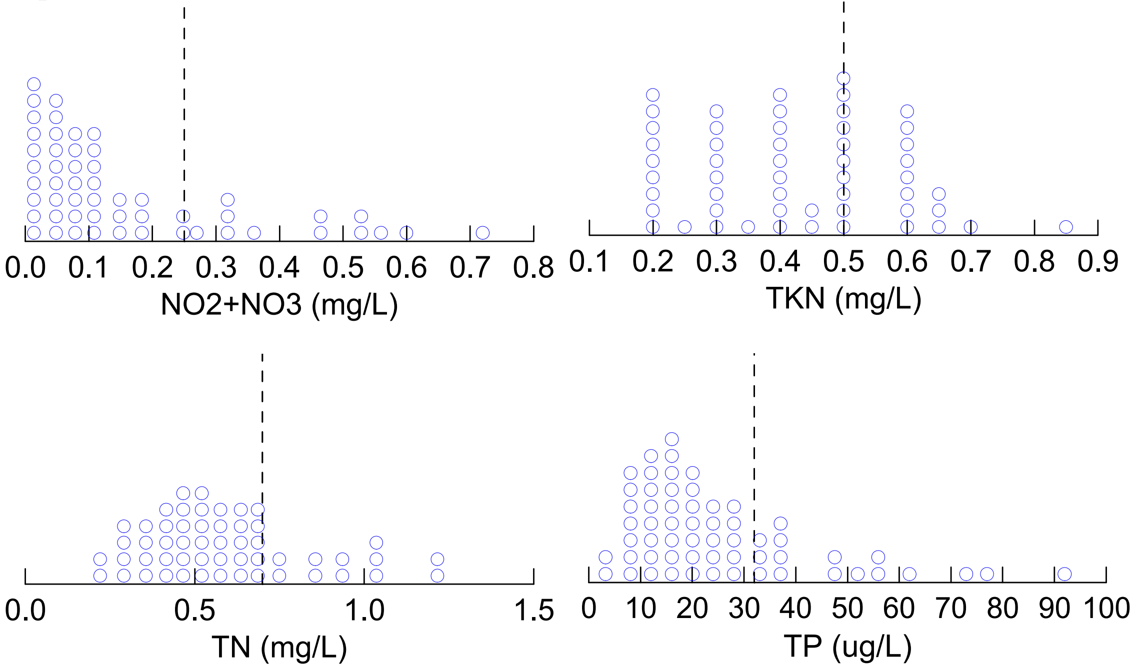
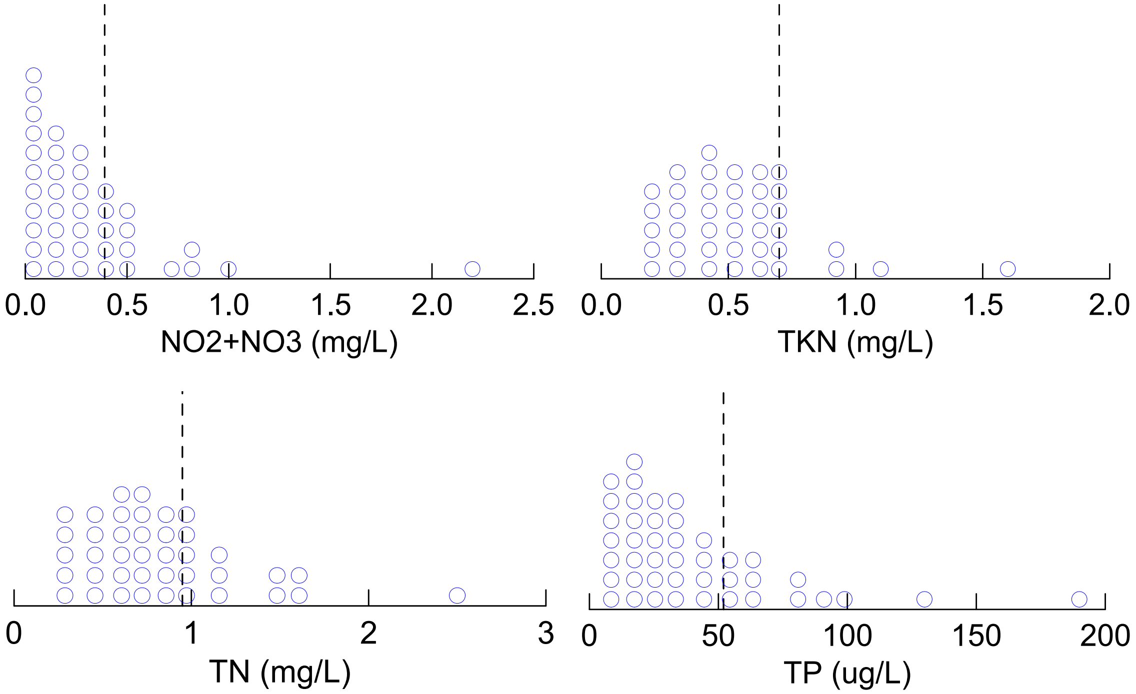


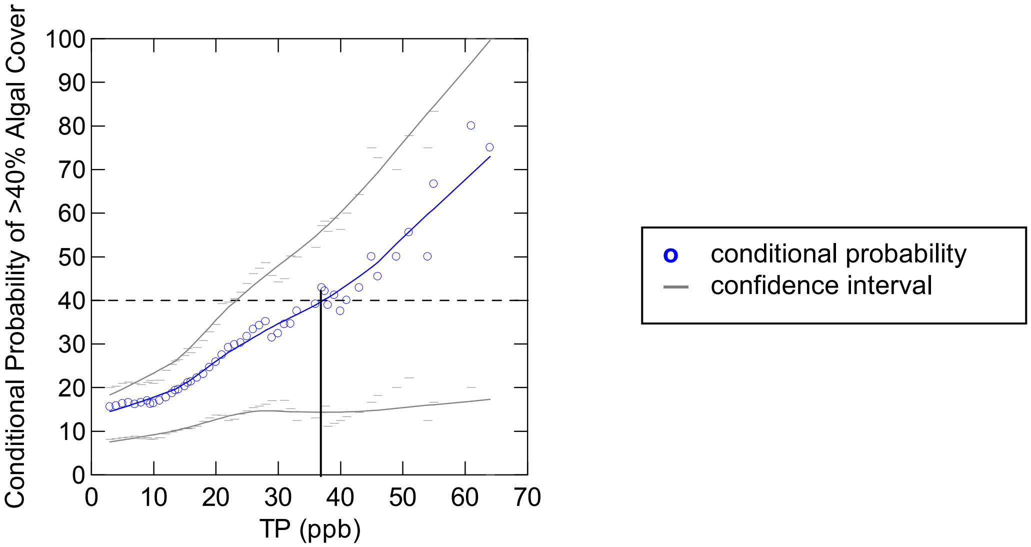
Figure 19: Concentrations of TP, TN, NO2+NO3, and TKN from streams that attain Class C numeric aquatic life criteria.

(Proposed limits are shown as dashed, vertical lines)



We also examined the relationship between TP and nuisance algal growths to ensure that the proposed TP limits also protected recreational uses. We did a conditional probability analysis to determine the probability of exceeding 40% algal cover at different TP concentrations (Paul and McDonald 2005). Conditional probability sequentially calculates the probability of exceeding 40% algal growth at increasing levels of TP. For example, the conditional probability at 10 µg/L is the probability exceeding 40% algal growth when including all samples with TP ≥ 10 µg/L. The conditional probability of 20 µg/L only includes samples with TP ≥ 20 µg/L in the calculations. The conditional probability also estimates a 95% confidence interval of the conditional probability based on bootstrap permutations. We decided that we would not accept a risk of nuisance algal growths greater than 40%. The conditional probability exceeded 40% at 37 µg/L, which is below the 52 µg/L based on the 75th percentile of streams that attain Class C macroinvertebrate communities. Therefore, we decided to set the limit for Class C at 37 µg/L.

Figure 20: Conditional probability of algal cover exceeding 40%.



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