Great Swamp Water Quality Monitoring Program

Aquatic Ecology and Nutrient Enrichment

Prepared for:
The Great Swamp Stream Team
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Prepared by:

F. X. Browne, Inc.

Nutrient Enrichment

According to the Environmental Protection Agency, "nutrient enrichment frequently ranks as one of the top causes of water resource impairment" (2000b). Nutrients are essential for plant growth, but overenrichment can lead to the excess growth of algae and aquatic plants, can alter the composition and species diversity of the aquatic community, and can even lead to human health problems.

There are three primary nutrients that are essential to plant growth: phosphorus, nitrogen, and potassium. Quite a few trace amounts of other elements are also necessary; however, they are not generally found to be in short enough supply to limit growth in a natural stream (Hynes 1970). Likewise, there is sufficient potassium present in all but the most mineral-poor waters, and it is generally not considered to be a limiting nutrient in aquatic systems. Therefore, nitrogen and phosphorus are the two nutrients of greatest concern in freshwaters.

One of these two nutrients usually serves as the limiting factor in algal and plant growth. Phosphorus is often found to be the limiting nutrient in lakes, but nitrogen may a greater role as a limiting nutrient in streams than in lakes (EPA 2000b). There are some indications that nitrogen is also usually the limiting nutrient in swamps, however it is likely that the limiting nutrient varies and that nitrogen and phosphorus play different roles during different seasons (Horne and Goldman 1994). Due to the importance of both nutrients, the Great Swamp Water Quality Monitoring Program has included analysis of both nitrogen and phosphorus.

Nitrogen

Nitrogen can exist in organic and inorganic, particulate and soluble forms. Generally, the soluble, inorganic forms are the most available for plant growth. Soluble, inorganic nitrogen can exist as ammonium, nitrite, or nitrate. Although ammonium can be an important source of nitrogen for bacteria, algae, and larger plants, nitrate is the fully oxidized form of nitrogen and is usually the form of inorganic nitrogen that occurs in lakes and streams (Hynes 1970; Horne and Goldman 1994; Schwoerbel 1987).

Particulate and dissolved organic fractions of nitrogen are generally not immediately available for plant growth. However, they can be converted to ammonium by bacteria and fungi and oxidized to form nitrites then nitrates. Biologic availability of organic nitrogen can range widely depending on the complexity of the structure. Urea and proteins are readily available, whereas complex humic acids are essentially biologically inert and become a nitrogen sink when deposited (Horne and Goldman 1994). In lakes and reservoirs, and potentially in slower moving streams, much of the particulate nitrogen present is live algal biomass. In fast-flowing systems, much of the algal growth is in the benthic region, and is probably not included in a water column sample. In these systems, the particulate component includes more detritus and less live biomass.

Sources of Nitrogen

Nitrogen can enter an aquatic system in a variety of ways and from a variety of sources.

- Rainfall—Precipitation contributes some nitrates to aquatic systems. Acid rain contains nitric acid. Levels of nitric acid in precipitation tend to be higher when there are more automobiles present locally.
- Overland runoff—Surface runoff can contain nitrogen in various forms including inorganic nitrogen from fertilizers and organic nitrogen from animal waste.
- Groundwater—Nitrate does not adsorb to soil particles as easily as phosphates or ammonium ions. Nitrate ions move easily through the soil to the groundwater, become inaccessible and unavailable for uptake by terrestrial plants, and can result in high groundwater concentrations of nitrates.
- Nitrogen fixation—Some types of plants can convert gaseous nitrogen into a usable form for plant growth. Blue-green algae are capable of nitrogen fixation in aquatic systems as are some wetlands plants, including alder and *Ceanothus* (e.g. New Jersey Tea).
- Point sources—Wastewater treatment facilities can be sources of nitrates. Generally, effluent undergoes aeration to convert ammonia to nitrogen, however many treatment facilities lack denitrification and export nitrogen as nitrates.

Sinks/Losses of Nitrogen

- Deposition—Complex humic acids containing nitrogen become biologically inert and are deposited in the benthic region.
- Denitrification—Denitrification is the bacterial reduction of nitrate to the gaseous form of nitrogen that occurs in oxygen-depleted bottom sediments. Nitrates are often lost through denitrification in wetlands.

Nitrogen Cycling

In addition to nitrogen sources and sinks, nitrogen is constantly being converted to different forms and is being recycled within the aquatic system. Urea from aquatic animal excretions is quickly broken down to ammonia. Ammonium ions are quite reactive and if they are not oxygenated, they are rapidly taken up by plants and algae. Nitrates are also taken up by plants fairly easily. Particulate organic nitrogen can exist in the water column as phytoplankton, become part of benthic algal growth and disappear from water column samples, then later appear as particulate organic nitrogen in decomposing plants.

The continuous cycling of nitrogen leads to variations in the distribution of nitrogen fractions and changes in total nitrogen concentrations depending on season, stream level, and other conditions.

Nitrogen Analysis

There is disagreement within the scientific community over whether to use total nutrient concentrations or soluble nutrient concentrations when establishing nutrient criteria in streams. Much of the total nitrogen concentration is not immediately available to plants and algae, but can be converted to usable forms. Soluble fractions are immediately available, but may be kept at low levels due to biological production (EPA, 2000b). The EPA *Ambient Water Quality Recommendations for Rivers and Streams in Nutrient Ecoregion IX* provides reference concentrations for total Kjeldahl nitrogen (TKN), which is a measure of organic nitrogen plus ammonia; nitrates plus nitrites (NO_3 + NO_2); total nitrogen (TN)–calculated, which is the sum of the total Kjeldahl nitrogen and nitrates plus nitrites fractions; and total nitrogen–reported (EPA, 2000a).

In order to quantify the soluble and total nitrogen fractions, the samples collected as part of the Great Swamp Water Quality Monitoring Program have been analyzed for two different nitrogen parameters: nitrates plus nitrites and total Kjeldahl nitrogen. Although the biologically available, soluble, inorganic component includes both nitrates and ammonia, nitrates were selected for measurement because they have been found to be the most common, biologically available form of nitrogen in stream systems. The detection limit for the nitrates plus nitrites analysis is 0.01 mg/l. Total Kjeldahl nitrogen was selected because the total Kjeldahl nitrogen fraction can be added to the nitrate concentration to yield the total nitrogen concentration in the stream. This is essential for determining the total nitrogen loading to the Great Swamp and for comparison to literature values. The detection limit for the total Kjeldahl nitrogen analysis is 0.1 mg/l. Future water quality monitoring will include analysis for ammonia nitrogen to verify the hypothesis that nitrates are the primary biologically available form of nitrogen in the Great Swamp tributaries.

Phosphorus

Phosphorus can also be found in several forms in freshwater, including soluble inorganic phosphate as orthophosphate and polyphosphates, soluble organic phosphate, and particulate organic phosphate (Schwoerbel 1987). The biologically available form of phosphorus is soluble, inorganic orthophosphate. Algae have some mechanisms for storing phosphorus and for breaking the bond between phosphates and organic material, however, for the most part, bound phosphorus is considered to be biologically unavailable. Phosphates quickly bind to soil particles and plant roots as they pass through the soil, and consequently, much of the phosphorus in aquatic systems is bound and moves as sediment particles. Some phosphorus is also found in living cells of aquatic organisms.

There is no gaseous form of phosphorus, so there is no addition or loss of phosphorus through the atmosphere. However, bound phosphorus can be released from bottom sediments under anoxic conditions and can increase the concentration of biologically available phosphates. Wetland plants can also modify the phosphorus cycle. Rooted aquatic plants take up the majority of their phosphorus from bottom sediments. Phosphorus is then released to the water when the plants die and decay.

Sources of Phosphorus

Phosphorus can enter a water body from several watershed sources.

- Erosion—The inflow of large amounts of total phosphorus into aquatic systems results mainly from the erosion of soil particles from steep slopes and disturbed ground (Horne and Goldman 1994). Stream channel erosion also adds sediment and consequently bound phosphorus to the water column. Changes in patterns of erosion and sedimentation transport strongly influence the overall phosphorus transport process in aquatic systems.
- Surface runoff—Orthophosphates are applied to agricultural, residential, and commercial land as fertilizers and can reach a stream via overland runoff if they do not bind to soil particles.
- Point sources—Wastewater treatment facilities are sources of soluble phosphate.

Sinks of Phosphorus

- Sediment—Although some phosphorus is released from sediment or is taken up by aquatic plants and converted to soluble phosphate, some phosphorus becomes biologically inert once it is bound to sediment.

Phosphorus Cycling

Much of the phosphorus used by algae is recycled. Decomposition releases phosphates that can then be reused by algae. Phosphorus in sediment is slow to recycle into the water column, but there is some internal loading of phosphorus from sediment. Under low oxygen conditions, sediments release phosphates to water based on a concentration gradient. These phosphates then become biologically available for algae. Wetland plants also modify the phosphorus cycle. Rooted aquatic plants take up some soluble phosphorus through their leaves, but generally obtain about 85% of their phosphorus from sediment pore water. When the plants die and decay some of this phosphorus is returned to open water as soluble inorganic phosphate (Horne and Goldman 1994).

Phosphorus Analysis

As with nitrogen, there is disagreement over whether to use total nutrient concentrations or soluble nutrient concentrations when establishing nutrient criteria in streams. The EPA *Ambient Water Quality Recommendations for Rivers and Streams in Nutrient Ecoregion IX* provides reference concentrations for total phosphorus. A critique of the USEPA *Nutrient Criteria Technical Guidance Manual* advocates that algal available phosphorus be estimated using soluble orthophosphate plus about 20% of the particulate phosphorus in agricultural and urban runoff (Jones-Lee 2002). There are other claims that the fertility of turbulent water is best measured in terms of total phosphorus, since bound phosphate is continuously released by bacterial action (Hynes 1970).

Soluble, inorganic phosphorus and total phosphorus concentrations have both been measured as part of the Great Swamp Water Quality Monitoring Program. The soluble inorganic phosphorus fraction is approximated by measuring dissolved reactive phosphorus (DRP). In this analysis, the sample is filtered to separate the dissolved component of phosphorus. The analysis of the filtered sample is largely a measure of orthophosphate, but a small fraction of any condensed phosphate that is also present in the sample is usually included in the measured concentration. The detection limit for the DRP analysis of 0.001 mg/l. Total phosphorus (TP) measures all of the organic and inorganic, particulate and dissolved phosphorus in the water column. Therefore dissolved reactive phosphorus is a fraction of the total phosphorus. The detection limit for the total phosphorus analysis is 0.002 mg/l.

Suspended Solids

Surface erosion and stream channel erosion increase sediments to surface water. Particles from the eroded sediment cause turbidity in the stream water, which can have a detrimental effect on aquatic life. Sediment can clog fish gills and impair respiration, smother spawning areas, attenuate light, and affect plant growth. Turbidity has been shown to reduce both the abundance and diversity of benthic invertebrates. This reduction has been attributed, in part, to the adverse effect on the production of periphyton, which is a food source for aquatic invertebrates. (Quinn et al, 1992). Sediment is also important because of its role in transporting phosphates and other compounds, including toxic substances.

The measurement of total suspended solids includes all particulate matter in the water, including algae, detritus, and sediment. The detection limit for the analysis of total suspended solids is 1.0 mg/l.

EPA Nutrient Criteria

Despite the extent of the nutrient enrichment problem across the country, most states have little more than vague language that recommends that they maintain natural nutrient levels and avoid nutrient enrichment. The EPA is advocating the development of numeric criteria to reduce ambiguity and provide distinct interpretations of acceptable and unacceptable conditions. The EPA is in the preliminary stages of developing ecoregional nutrient criteria for different types of water bodies including lakes and reservoirs, rivers and streams, and wetlands. Ecoregional recommendations have been made for the two causal variables, total phosphorus and total nitrogen. The EPA intends that the criteria be used to develop nutrient management programs for watersheds that are contributing to the water quality problems.

The EPA has divided the country into fourteen aggregate ecoregions. Each of these ecoregions has then been divided into numerous smaller level III ecoregions. The Great

Swamp Watershed is located in EPA's Aggregate Ecoregion IX - Southeastern Temperate Forested Plains and Hills and in Level III Ecoregion 64 - Northern Piedmont. The Northern Piedmont is a transitional region of low rounded hills, irregular plains, and open valleys in contrast to the low mountains to the north and west and the flat coastal plains of the ecoregion to the east.

Ambient Water Quality Recommendations for Rivers and Streams in Nutrient Ecoregion IX provides reference concentrations for total phosphorus and total nitrogen in the ecoregion. The concentrations were derived using the procedures described in EPA's *Technical Guidance Manual for Developing Nutrient Criteria for Rivers and Streams*. *Ambient Water Quality Recommendations for Rivers and Streams in Nutrient Ecoregion IX* also provides reference concentrations for Level III Ecoregion 64.

The manual describes two methods for establishing reference conditions. One method is to choose the upper 25th percentile (75th percentile) of a reference population of streams. Reference streams are those that are relatively undisturbed and are believed to represent the natural condition of the region. Use of data from reference streams is the preferred way to establish a reference condition. The 75th percentile was chosen by the EPA since it is likely associated with minimum impact conditions, will be protective of designated uses, and provides management flexibility. When reference streams are not identified, the second method is to determine the lower 25th percentile of the population of all streams within a region. The 25th percentile of the entire population was chosen by EPA to represent a surrogate for an actual reference population.

The following tables contain a summary of the reference conditions for the aggregate ecoregion and the level III ecoregion in which the Great Swamp Watershed is located. These reference conditions are based on the 25th percentile of all streams. Table 2 also includes the 75th percentile of all streams (not reference streams), which will be used for comparison to Great Swamp Watershed values.

Table 1: Aggregate Ecoregion IX Reference Conditions

Nutrient Parameters	Aggregate Nutrient Ecoregion IX Reference Conditions
Total Phosphorus (mg/l)	0.03656
Total Nitrogen (mg/l)	0.69

Table 2: Aggregate Ecoregion IX, Level III Ecoregion 64 Reference Conditions and 75th Percentile Data

Nutrient Parameters	Aggregate Nutrient Level III Ecoregion 64 Reference Conditions	Aggregate Nutrient Level III Ecoregion 64 75th percentile
Total Phosphorus (mg/l)	0.04	0.158
Total Nitrogen – calculated (mg/l)	1.295	3.6
Total Nitrogen – reported (mg/l)	2.225	5.23
Total Kjeldahl Nitrogen (mg/l)	0.3	2.8
Nitrate/Nitrite (mg/l)	0.995	2.9

References

Horne, Alexander J. and Charles R. Goldman. *Limnology Second Edition*. McGraw Hill, Inc.. New York, 1994.

Hynes, H. B. N. *The Ecology of Running Waters*. University of Toronto Press, 1970.

Schwoerbel, J. *Handbook of Limnology*. John Wiley & Sons, New York, 1987.

United States Environmental Protection Agency. *Ambient Water Quality Criteria Recommendations – Rivers and Streams in Nutrient Ecoregion IX*. USEPA, Washington, DC, 2000.

United States Environmental Protection Agency. *Nutrient Criteria Technical Guidance Manual – Rivers and Streams*. USEPA, Washington, DC, 2000.

Wetzel, Robert G. and Gene E. Likens. *Limnological Analyses, Second Edition*. Springer-Verlag, New York, 1991.