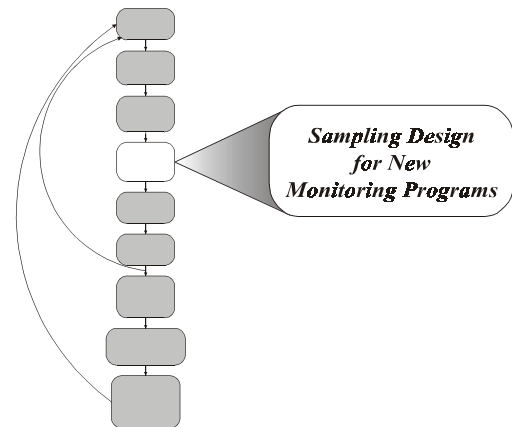


Chapter 4.

Sampling Design for New Monitoring Programs



4.1 INTRODUCTION

The purpose of this chapter is to provide technical guidance on designing effective sampling programs for reconnaissance. Appropriate data describing stream nutrient and algal conditions are lacking in many places. Where available data are not sufficient to derive criteria, it will be necessary to collect new data through existing or new monitoring programs. New monitoring programs should be designed to assess nutrient and algal conditions with statistical rigor while maximizing available management resources.

Nutrient monitoring programs are used to better define nutrient and algal relationships within stream systems. At the broadest level, monitoring data should detect:

1. Seasonal patterns in nutrient levels and their relationship to algal biomass levels;
2. The assimilation capacity of the system for nutrients: i.e., how much nutrient loading can be assimilated without causing unacceptable changes in water quality or the algal community (biomass and composition);
3. Whether nutrient concentrations are increasing, decreasing, or staying the same over time.

This Chapter provides discussion on issues to consider with regard to monitoring nutrients and their effects in stream systems. The various forms of nutrients to consider for sampling are discussed in Chapter 3. Field sampling and laboratory methods for nutrient assessment are described in Appendix B.

Monitoring programs are often poorly and inconsistently funded or are improperly designed and carried out, making it difficult to collect a sufficient number of samples over time and space to identify changes in water quality or estimate average conditions with statistical rigor. This Chapter provides a procedural approach for assessing water quality condition and identifying impairment by nutrients and algae in stream reaches. The approaches described below present sampling designs that allow one to obtain a significant amount of information with relatively minimal effort. Probabilistic and stratified random

sampling begin with large-scale random monitoring designs that are reduced as nutrient and algal conditions are characterized. The tiered approach to monitoring begins with coarse screening and proceeds to more detailed monitoring protocols as impaired and high-risk systems are identified and targeted for further investigation.

Water quality variables other than the primary variables discussed in Chapter 3, e.g., DO, pH, TSS, etc., should be critically selected in a monitoring design to obtain the most cost-effective information required to assess river system nutrient and algal conditions. Sampling should be designed to answer questions such as: how, when, where and at what levels do nutrient concentration and algal biomass contribute to unacceptable water quality conditions (e.g., offensive odors, aesthetic impairment, degraded habitat for aquatic life, diurnal decreases in DO and pH increases)? These questions are interrelated, and a well-designed program that monitors the primary variables (TN, TP, chl *a*, turbidity) with other water quality variables can contribute to answering them.

4.2 SAMPLING PROTOCOL

CONSIDERATIONS FOR SAMPLING DESIGN

Developing nutrient criteria and monitoring the success of nutrient management programs involve important considerations for sampling design. Initially, the relationships between critical response variables and nutrient concentrations need to be established. Next, reference reaches should be sampled and assessed for specific classes of streams. **Nutrient concentrations and algal biomass levels in reference reaches should define the ecological state that could be attained if impaired reaches were restored.** In some streams and rivers, nutrient levels may be naturally high if bedrock, soils, or wetlands are nutrient-rich sources in the region. However, human actions can exacerbate nutrient enrichment regardless of the natural nutrient condition.

Reach/stream selection for establishing causal relationships between nutrients and algal biomass is based on the need to sample a relatively large number of streams with nutrient concentrations distributed along the entire nutrient gradient for each class of streams in a specific regional setting. Cause-response relationships can also be identified using large sample sizes and streams with low as well as medium and high nutrient concentrations. All ranges of responses should be observed along the gradient from reference condition to high levels of human disturbance. Therefore, streams should be selected based on land-use in the region so that watersheds range from minimally impaired with expected low nutrient runoff to high levels of development (e.g., agriculture, forestry, or urban) with expected high runoff.

Assessing watershed characteristics through aerial photography and the use of geographical information systems (GIS) linked to natural resource and land-use databases, can aid in identifying reference and impaired streams. Some examples of watershed characteristics which can be evaluated using GIS and aerial photography include land-use, land-cover (including riparian vegetation), soils, bedrock, hydrography, infrastructure (e.g., roads, public sewerage systems, private septic systems), and climate. Watersheds with little or no development that receive minimal anthropogenic inputs could potentially contain streams that would serve as reference sites (see section below). Watersheds with a high percentage of their area occupied by nutrient-rich soils, heavily fertilized agricultural land, and extensive unsewered development in coarse soils are likely to contain streams receiving high nutrient loads that could potentially be considered 'at risk' for developing nutrient and algal problems. The USDA

agricultural census provides information on agricultural land use (crops, livestock, irrigation, chemicals used) at the national, state, and county levels. Data are available on their website at: <http://www.nass.usda.gov/census/>.

Once the watershed level has been considered, a more stream-specific investigation can be initiated to better evaluate nutrient and algal conditions. Rivers and streams need adequate light and nutrients to develop and maintain high levels of algal biomass. In addition, attached algae (periphyton) require coarse substrata (cobbles, boulders) and a flow regime that provides sufficient periods between scouring floods (at least one month) to accumulate high levels of biomass. The condition of the riparian zone needs to be considered. Riparian buffer zones may mediate the effects of nonpoint sources of nutrients and turbidity and, depending on the slope of the system, may reduce the velocity of overland runoff to a stream. Riparian wetlands may serve as both sources and sinks for nutrients varying with wetland type, seasonal flows, and degree of disturbance. The presence or absence of streamside trees can affect light limitation in a stream. Light is unlikely to limit algal growth where streamside trees have been removed or the stream is wide, shallow and clear enough to permit sufficient light to reach much of the bottom. Shaded streams may have high nutrient concentrations with no correlative response in algal growth, though the nutrient load may stimulate algal growth further downstream. The relative risk to develop nutrient and algal problems could be assessed by noting how many of the above factors that permit higher algal levels and/or nutrient concentrations are common to a stream or reach.

WHERE TO SAMPLE

Nutrient inputs can occur at a myriad of points along a river system resulting in highly variable concentrations of nutrients throughout the system. System variability and multiple nutrient input points require numerous sampling sites for assessing the nutrient condition of a river system. Monitoring stations for nutrients in streams and rivers should be located upstream and downstream from major sources of nutrients or diluting waters (e.g., discharges, development, tributaries, areas of major groundwater inputs) to quantify sources and loads.

WHEN TO SAMPLE

Nutrient and algal problems are frequently seasonal in streams and rivers, so sampling periods can be targeted to the seasonal periods associated with nuisance problems. Nonpoint sources may cause increased nutrient concentrations and turbidity or nuisance algal blooms following periods of high runoff during spring and fall, while point sources of nutrient pollutants may cause low-flow plankton blooms and/or increased nutrient concentrations in pools of streams and in rivers during summer. In most state monitoring programs, sampling is only conducted once during the season when greatest impacts are expected. If only a one-time sampling is possible, then sampling between two to four (2-4) weeks after a storm or high flow event has disturbed algal assemblages (Stevenson and Bahls 1999) is recommended. Two to four weeks will allow sufficient time for algal biomass recovery in streams where algal biomass predominantly consists of diatoms or micro-algae. Alternatively, sampling should be conducted during the growing season at the mean time after flooding for the system of interest. In streams where macroalgae or macrophytes comprise the dominate photosynthetic biomass, recovery of photosynthetic biomass may take one or more growing seasons following a major high-flow event. However, if a high-flow event does not move anchoring substrata, the flow event will only have a nominal effect on photosynthetic biomass. High flow events late in the growing season when algal and macrophyte filaments and fronds

are more prone to slough, may cause a reduction in the photosynthetic biomass. A one-time sampling approach may be adequate for indicators of nutrient status, designated use, and biotic integrity. However, criteria and biological or ecological indicator development (see Assessing Algal Biomass below) may require more frequent sampling to observe nutrient conditions that relate to peak algal biomass (Biggs 1996; Stevenson 1996; Stevenson 1997b).

Nutrient concentrations vary with climate-driven changes in flow. Algal blooms, both benthic and planktonic, can develop rapidly and then may dissipate as nutrient supplies are depleted or flow increases. Thus sampling through the season of potential blooms may be necessary to observe peak algal biomass and to characterize the nutrient conditions that caused the bloom. Sampling through the season of potential problems is important for developing cause-response relationships (with which biological and ecological indicators can be developed) and for characterizing reference conditions. Keep in mind that there is a time-lag between nutrient enrichment and algal response. Therefore to characterize algal response to a specific enrichment event, nutrient sampling should be conducted prior to algal sampling. Samples for nutrients should also be collected during the season of lowest algal levels (at least 3 samplings spread over the period) to determine current background levels of algal biomass; avoid the problem of algal uptake attenuating nutrient concentrations, and help provide an estimate of maximum nutrient concentration. Many nutrient monitoring programs are based on quarterly sampling. However, quarterly samples are usually inadequate to detect long-term trends due to year-to-year variation in the window of high flows, the period of high nutrient uptake and algal growth, and the period of algal sloughing at the end of the growing season.

If few nutrient and algal data exist, then multi-year surveys on a twice monthly or monthly basis may be necessary to determine if nuisance algal problems occur. Frequent sampling is necessary because algal blooms may develop and dissipate rapidly with residual adverse effects, such as fish kills and impaired aquatic habitat. Multi-year sampling is necessary because unusually large annual variability can occur annually in the intensity of nutrient/algal problems, due to timing of weather (primarily scouring storm events or persistent low flow events with long residence time) and seasonality of algal blooms.

Ideally, water quality monitoring programs produce long-term datasets compiled over multiple years, to capture the natural, seasonal and year-to-year variations in waterbody constituent concentrations (e.g., Dodds et al. 1997; Tate 1990). Multiple-year datasets can be analyzed with statistical rigor to identify the effects of seasonality and unusual flow years (Miltner and Rankin 1998). Once the pattern of natural variation has been described, the data can be analyzed to determine the water quality conditions that degrade the ecological state of the waterbody or effect downstream receiving waters. Long-term data sets have also been extremely important in determining the cost-effectiveness of management techniques for lakes and reservoirs (Cooke et al. 1993). The same should be true for streams and rivers, if not more so (due to greater constituent variability), although management of nutrients to improve quality in streams and rivers has not been as well documented.

In spite of the documented value of long-term data sets, there is a tendency even in lake/reservoir management to intensively study a waterbody for one year before and one year after treatment. A more cost-effective approach would be to measure only the most essential indices, but to double or triple the monitoring period. Two or more years of data are needed to identify the effects of years with extreme climatic or flow conditions. Low periphyton biomass has often been observed during high-flow summers as well as the reverse, i.e., high biomass-low flow. The cause for that is not entirely clear; high flows

may reduce biomass through scouring and/or dilute inputs of ground water nutrients. Whatever the cause, the effect will be “averaged out” enough to discern the overall effect of treatment (e.g., nutrient reduction or diversion) if several years of data are available to minimize the effect of the unusual flow year(s). At the very minimum, two years of data before and two after implementing nutrient management, but preferably three or more each, are recommended to evaluate treatment cost-effectiveness with some degree of certainty. If funds are limited, restricting sampling frequency and/or numbers of constituents analyzed should be considered to preserve a longer-term data set. This will allow for effectiveness of management approaches to be assessed against the high annual variability that is common in most streams. High hydrological variation in a stream from year to year, requires more years of sampling before and after mitigation procedures.

Characterizing Precision of Estimates

Estimates of dose-response relationships, nutrient and biological conditions in reference reaches, and stream conditions of a region are based on sampling. Therefore, precision and accuracy must be assessed. Determining precision of measurements for one-time assessments from single samples in a reach is often necessary. The variation associated with one-time assessments from single samples in a reach can often be determined by re-sampling a specific number of reaches during the survey. Measurement variation among replicate samples can then be used to establish the expected variation for one-time assessment of single samples. Re-sampling does not establish the precision of the assessment process, but rather identifies the precision of an individual measurement. Re-sampling frequency is often conducted for one stream reach in every block of ten reaches. However, investigators should adhere to the objectives of re-sampling (often considered an essential element of QA/QC) to establish an assessment of the variation in a one-time/sample assessment. The larger the sample size the better (smaller) will be the estimate of that variation. Often, more than one in ten samples need to be replicated in monitoring programs to provide a reliable estimate of measurement precision.

APPROACHES TO SAMPLING DESIGN

The following sections discuss two different approaches to sampling design, probabilistic and goal-oriented. Both approaches have advantages and disadvantages that under different circumstances warrant the choice of one approach over the other (Table 3). The decision as to the best approach for sample design in a new monitoring program must be made by the water quality resource manager or management team after carefully considering different approaches.

Probabilistic Sampling

Probability sampling, where randomness is required, can be used to determine the variability of nutrient and algae levels in streams and rivers across a state or a region. Random sampling is a generic type of probability sampling where randomness can enter at any stage of the sampling process. Probabilistic sampling – a sampling process wherein randomness is a requisite (Hayek 1994) – can be used to characterize the status of nutrient conditions and biotic integrity in a region’s streams and rivers. Probabilistic designs are often modified by stratification (such as classification [Chapter 2]), by deleting “redundant” reaches, or by adding important sites. Stratification or stratified random sampling is a type of probability sampling where a target population is divided into relatively homogenous groups or classes (strata) prior to sampling based on factors that influence variability in that population (Hayek 1994). Analysis of variance can be used to identify statistically different parameter means among the sampling

Table 3. Comparison of probabilistic and goal-oriented sampling designs.

Probabilistic Sampling	Goal-oriented Sampling
<ul style="list-style-type: none"> • random selection of streams from entire population within a region • requires no prior knowledge of streams within the sample population • may require more resources (time and money) to randomly sample stream classes because more streams may be sampled • nutrient condition characterization for a class of streams is more statistically robust • potentially best for regional characterization of stream classes, especially if water quality conditions are not known 	<ul style="list-style-type: none"> • targeted selection of streams based on problematic (reaches known to have nutrient/algal problems) and reference reaches • requires prior knowledge of streams within the sample population • utilizes fewer resources because only targeted streams are sampled • nutrient condition characterization for a class of streams is less statistically robust, though characterization of a targeted stream or reach may be statistically robust • potentially best for site-specific and watershed-specific criteria development when water quality conditions for the reach of interest are known • selection of sites that represent a range of nutrient conditions will facilitate establishment of nutrient-algal relationships for the systems of interest

strata or classes. The strata are then used as the analysis of variance treatments (Poole 1972). Goal-oriented sampling as described in the tiered approach in this Chapter, is not as easily analyzed by rigorous statistical analyses. Goal-oriented monitoring may be better suited to statistical analyses using basic descriptive statistics and correlational analyses.

Streams are selected for probabilistic sampling by random selection of a sample of streams from the entire population of streams within a region. Thus, all stream reaches within a region must be identified to establish the statistical population of streams; then a sample of all possible streams is selected from that population. The results of collecting and assessing water quality and biotic responses with a probabilistic sample is, presumably, an unbiased estimate of the descriptive statistics (e.g., means, variances, modes, and quartiles) of all streams in a region. Probabilistic sampling designs are commonly modified by stratifying by stream size and stream classes. Otherwise, sample statistics would be most characteristic of the numerous small streams of the dominant stream types in a region.

Many state 305b and watershed monitoring programs utilize modified probabilistic sampling designs. Stratification in many of these programs is based on identifying all stream reaches in a region (or watershed) and then selecting an "appropriate" sample of reaches from the defined population. The sample population is often modified by deleting stream reaches that are too close to other reaches to be different, thereby reducing redundant collection efforts. The selected sample of streams may also be modified by adding sites that are near known sources of impact. Estimates of ecological conditions from these kinds of modified probabilistic sampling designs can be used to characterize the nutrient status, and over time, to distinguish trends in stream nutrient condition within a region. Estimates of regional conditions are best when sites near known sources of impact are removed from the analysis and later compared to the distribution of regional nutrient conditions.

Goal-Oriented Sampling

A goal-oriented approach to sampling design may be more appropriate when resources are limited. The tiered approach described here focuses the greatest efforts on identifying and characterizing rivers and streams likely to have nutrient problems, and on relatively undisturbed streams, often called reference streams or reaches, that can serve as regional or sub-regional examples of natural biological integrity. Choosing sampling stations that best allow comparison of nutrient concentrations at reference stream or river sites of known condition can conserve financial resources. Goal-oriented sampling also includes some elements of randomness. However, the identification of systems with nutrient problems and reference conditions eliminates the need for selecting a random sample of the population for monitoring.

Goal-oriented sampling assumes some knowledge of the systems sampled. Systems with evidence of impairment are compared to reference systems that are similar in their physical structure. Sites chosen to represent a range of nutrient conditions will facilitate development of nutrient concentration-algal biomass relationships. Goal-oriented sampling requires that the reaches be characterized according to assessed nutrient and algal levels. Comparison of the monitoring data to data collected from reference stream reaches will allow characterization of the sampled streams. Reaches identified as 'at risk' should be evaluated through a sampling program to characterize the degree of impairment. An impaired reach is simply a reach of any length where nutrient concentrations exceed acceptable levels, or algae interfere with beneficial uses. Once characterized, the reaches should be placed in one of the following categories:

1. Impaired reaches – reaches in which nutrients or algal biomass levels interfere with designated uses;
2. High-risk reaches – reaches where nutrient concentrations are high but do not significantly impair designated uses. In high-risk streams impairment is prevented by one or a few factors that could be changed by human actions, though water quality characteristics (e.g., DO, turbidity) are already marginal;
3. Low-risk reaches – reaches where many factors contain nutrient concentrations and algal biomass levels are below problem levels and/or no development is contemplated that would change these conditions.
4. Reference reaches – reaches where nutrient concentrations and algal biomass levels most closely represent the pristine or minimally impaired condition.

Once stream reaches have been classified based on their physical structure (see Chapter 2) and placed into the above categories, specific reaches need to be selected for monitoring. At this point, randomness is introduced; stream reaches should be randomly selected within each class and risk category for monitoring.

Monitoring efforts are often prioritized to best utilize limited resources. Impaired and high-risk streams should be monitored more intensively than low-risk streams. Impaired streams should be monitored to evaluate, implement, and assess management activities to reduce algal biomass and improve water quality. High-risk streams should be monitored to assure that no further degradation takes place. Low-risk streams can be monitored less frequently, but should be monitored frequently enough to identify any

increase in nutrients or algae, and/or change of water quality. Reference reaches should be monitored frequently enough to make robust comparisons with impaired and high-risk stream reaches. In addition, monitoring of changes in the watershed can help identify areas where changes are likely to result in degradation of nutrient condition. Human activities within a watershed that can increase the risk of nutrient and/or algal problems include 1) stabilization of flows (reduces scour); 2) reduction of flows (increases light, reduces dilution of nutrients); 3) removal of streamside vegetation (increases light, may decrease depth of stream; and increases the flux of nutrients from the stream hillslope due to reduced uptake from plant roots); 4) discharge of nutrient rich waste water; 5) construction of unsewered residential development (especially in thin coarse soils); 6) over fertilization of agricultural land; 7) development that increases the percent of impervious surface in the watershed; and hence nutrient runoff; and 8) discharge of toxins or release of exotic species that reduce grazer populations.

IDENTIFYING AND CHARACTERIZING REFERENCE STREAM REACHES

Potential reference streams should be characterized to allow for the identification of appropriate reference streams and reference stream reaches. Classification of streams, as discussed in Chapter 2, will allow appropriate reference reaches to be identified for specific regions and stream types. Stream classification should be supplemented with information on return frequency of flows. Reference streams or reaches may not be available for all stream classes. In this case, data from systems that are as close as possible to the assumed unimpaired state of rivers and streams in that class should be sought from States or Tribes within the same nutrient ecoregion.

The identification of reference *reaches* as opposed to reference *streams* is an important distinction (see Chapter 7, Section 7.2). Identification of impaired and reference streams would be relatively simple if an entire stream had all the same physical characteristics and risk factors. However, only one specific portion of a stream length, a *reach*, may have all the characteristics necessary to produce algal problems. It may not be possible to find an entire stream that has little or no impacts anywhere in its watershed. Therefore, stream *reaches* should be targeted, but their watersheds should also be kept in mind. The stream bed, banks, and riparian zone of a reference reach should be in a fairly natural state, and its watershed as undeveloped as possible. States/Tribes should endeavor to protect such reference reaches from future development.

Streams for reference-reach sampling should be selected based on low levels of human alteration in their watersheds and aquatic habitat. Selecting reference reaches usually involves assessment of land-use within watersheds, and visits to streams to ground-truth expected land-use and check for unsuspected impacts. Sometimes ecological impairment that was not apparent from land-use and local habitat conditions may be identified. Again, sufficient sample size is important to characterize the range of conditions that can be expected in the least impacted systems of the region (see TN case study in Appendix A).

Reference reaches should be identified for each nutrient ecoregion in the State or Tribal lands and then characterized with respect to nutrient concentrations, algal biomass levels, algal community composition and associated environmental conditions including turbidity, light, and substrata as well as factors that are affected by algae, such as DO and pH. For each ecoregion in a state, a minimum of three low impact reference systems should be identified for each stream class. Highest priority should be given to identifying reference streams for those stream types considered to be at the greatest risk from nutrients

and algae. Reference stream reaches are often less accessible than reaches adversely affected by nutrient and algal impairments. However, sampling need not be as frequent in reference reaches, except to validate models of algal response to nutrient loads for such reaches.

Continuation of Less Intensive Monitoring of High-Risk Reaches

The continuation of monitoring of high-risk reaches should focus on factors likely to increase nutrient concentrations or limit algal growth and on any actions that might alter those factors. For example, if light is limiting, it may be most appropriate to evaluate the potential impact of the removal of streamside trees or of the manipulation of water levels which may kill streamside trees. Stabilization of flows results in the decline of flood-dependent vegetation. Increased grazing levels can reduce streamside trees degrade banks, altering the depth and width of the stream. State/Tribal water quality agencies should encourage adoption of local riparian protection plans where light is limiting to minimize nutrient-caused water quality problems.

If scouring flows limit algal accrual and significantly dilute nutrient loading, a closer evaluation of plans that could manipulate flows (by diversion, damming or altering management at existing structures) is warranted. State/Tribal water quality agencies should inform agencies that regulate water development of the potential impacts of flow manipulation.

Development plans in the watershed should be evaluated where nutrients are limiting (see Defining the Limiting Nutrient, Section 6.2). Changes in point sources can be monitored through the NPDES permit program. Changes in nonpoint sources can be evaluated through the identification and tracking of wetland loss and/or degradation, increased residential development, increased tree harvesting, and shifts to more intensive agriculture with greater fertilizer use or increases in livestock numbers. Local planning agencies should be informed of the risk of increased nutrient loading and encouraged to guide development accordingly. Nutrient levels often gradually increase due to many growing nonpoint sources. Hence, in-stream nutrient monitoring is warranted in nutrient-limited, high-risk reaches if sufficient resources remain after meeting the needs of impaired reaches. Seasonal nutrient levels should be more stable in streams with low algal biomass than in streams with high algal biomass because nutrient concentrations would not be depleted in such streams. Sampling during growing season baseflow and nongrowing season baseflow should provide a limited, yet useful, assessment of trends in nutrient levels from year-to-year.

Whenever development plans appear likely to alter factors that were limiting algae growth in a high-risk reach, instream monitoring should be initiated at a level similar to that described for impaired reaches in order to enhance the understanding of baseline conditions.

OTHER CONSIDERATIONS FOR MONITORING NUTRIENTS

Assimilative Capacity

The assimilative capacity of a stream for nutrients depends on its physical and biological nature. Assimilative capacity is the load of nutrients entering a river system at which nutrient and algal biomass levels remain low enough such that excessive diurnal fluctuations of DO concentrations and pH levels will not occur, recreation and aesthetics will not be negatively impacted, irrigation ditches will not be clogged with algae, and biotic criteria will be consistently met. Such nutrient loads are difficult to predict because nutrients are stored in many forms and released under a variety of conditions, and

because the levels of nutrients and algae causing impaired conditions may vary from system to system.

The simplest model applied has been to apply an exponential decline in instream nutrient concentrations below point sources and tributaries, with the rate of decline derived from monitored data. This approach does not quantify mechanisms (such as sedimentation, uptake, dilution by groundwater and denitrification), that can lead to nutrient losses. Such an approach was applied on the Clark Fork River (Dodds et al. 1997) to model the influence of lowered inputs from point sources on instream nutrient concentrations.

Nutrient Load Attenuation

A given nutrient load may produce a few kilometers (km) containing unacceptable algal biomass followed by a section of river containing acceptable levels because a river's load is attenuated by retention in algae and sediment. The total length of river containing unacceptable algal biomass levels may change from year-to-year due to changing nutrient loads or changes in other factors (e.g., flow, dilution) that may limit algae growth (see Section 6.2). This phenomenon was illustrated following nutrient control in the Bow River, Alberta, where TDP remained high (25 µg/L) for several km downstream from the treated wastewater source. High TDP in the portions of the stream closest to the point source release resulted in no change in algal biomass, while algae decreased farther downstream as TDP decreased (see Bow River case study, Appendix A). The length of river containing unacceptable algal biomass levels may be hypothetically estimated by the following equation described in Welch et al. (1989).

$$D_c = Q * r * (SRP_i - SRP_c) / [(P/\text{chl } a \text{ day}) * B_n * T * W * 10^3 \text{ m/km}]$$

where SRP is in µg/L (mg/m³) producing the threshold nuisance biomass (150 mg chl/m²) in the growth period (nominally ~ 1-4 mg/m³ in channel experiments [Walton et al. 1995]); Q is the daily flow in m³/day; r accounts for the recycle (~ 1.5, after Newbold et al. 1981); SRP_i is the influent concentration (ambient river and groundwater in mg/m³) to the segment; SRP_c is the critical concentration, above which nuisance algal growth occurs; P/chl *a*-day is the average uptake by periphyton with nominal value of 0.2; B_n is the nuisance threshold biomass of 150 mg chl *a*/m²; T is the factor for trophic (consumer) retention (~ 1.2 representing a 20% conversion); and W is average stream width in meters.

This equation is simply the ratio of SRP mass available for uptake in excess of the critical level and the expected demand for SRP by periphyton in an enriched stream reach in which the threshold nuisance biomass is attained. The basis of the formulation is that periphytic biomass will not be reduced unless SRP is less than the critical concentration (SRP_c) during low-flow, maximum growth conditions, which has been shown to be quite low in channel experiments (Walton et al. 1995). Low values for the critical P concentration were supported by the Bow River case study (see Appendix A). The length of river with unacceptable algal biomass levels increases as the criterion decreases. The important recycle rate in the equation is a nominal value taken from uptake studies in a natural stream and could be highly variable. More definite predictions of limiting nutrient content and algal biomass changes downstream from a point source requires a dynamic model for algal biomass, such as:

$$dB/dt = (u * L * B_i) - (S + G)$$

where u = nutrient uptake rate in 1/day, L = dimensionless light factor, B_i = periphyton biomass from previous time step in mg chl/m², S = sloughing loss in mg chl/m²-day and G = grazing loss in mg chl/m²-day (after Elswick 1998).

Estimating nutrient loads to a stream is at least as complex as a detailed nutrient source study for a lake and requires the tracking of nutrient sources upstream and upgradient. In some cases, loading estimates of stream and river systems may be back calculated from the loading estimate for the receiving waterbody. That is, the partition of the nutrient load to a receiving waterbody (lake or estuary) identified as belonging to a particular stream may be used as an estimate of the total load for that stream or reach. Loading is often estimated using a calibrated model that predicts nutrient loads from hydrologic inputs or other parameters if nutrient data are inadequate to calculate load.

The USGS has developed a set of spatially referenced regression models for evaluating nutrient loading in a watershed. The modeling approach is referred to as SPARROW (SPATIally Referenced Regressions On Watershed attributes), a statistical modeling approach that retains spatial referencing for illustrating predictions, and for relating upstream nutrient sources to downstream nutrient loads (Preston and Brakebill 1999) (See Appendix C). Stream-load estimates at gaged monitoring sites are generated from stream-discharge and water quality data by utilizing a log-linear regression model called ESTIMATOR. The ESTIMATOR model estimates daily concentration values based on flow, season, and temporal trend terms (Preston and Brakebill 1999) (see Appendix C).

Better Assessment Science Integrating Point and Nonpoint Sources, or BASINS, is a tool developed by EPA to facilitate water quality analysis on a watershed level for specific waterbodies or stream segments. BASINS was designed to integrate national water quality data, modeling capabilities, and (GIS) so that regional, State, local and Tribal agencies can easily address the effects of both point and nonpoint source pollution and perform sophisticated environmental assessments (<http://www.epa.gov/ost/BASINS/>).

Models should be used with caution. Models can be used incorrectly and, therefore, can be less accurate than loads calculated from data. Regardless of the method used for calculating loads, subsequent changes in the watershed may alter the relationship between hydrologic and nutrient inputs requiring loads to be re-calculated to reflect those changes.

Assessing Algal Biomass

This section focuses on assessing attached algal biomass and how to obtain a meaningful, representative algal biomass sample. Sampling strategies will vary with objectives of programs. Algal sample collection techniques for streams and laboratory methods for the analysis of chlorophyll, AFDM, and other measures of biomass are discussed in Appendix B.

If the goal of sampling is to develop a relationship between nutrients and algal problems for the rivers of a region or to assess status and trends in nutrient-related problem areas of a region (i.e. probabilistic sampling), then one representative estimate of algal assemblage characteristics is all that can be used in an analysis. In most cases, the desired estimate is a mean algal biomass measure for a reach that can be obtained with composite sampling (explained below). However, spatial extent and temporal duration of blooms or nuisance growths may also be important parameters to characterize. More than one sample (or estimate) from a site would result in pseudoreplication (Hurlburt 1984) and would be unacceptable for data analyses which require independent observations of conditions (biotic and nutrient) at each site.

Variability in attached algal biomass estimates due to spatial variability can be reduced by collecting composite samples and by sampling in targeted habitats where algal biomass is relatively uniform (e.g., riffles). Composite sampling calls for combining subsamples from many substrata into a single sample, thus incorporating spatial variability into the one sample. The targeted habitat is usually defined as the habitat in which nuisance problems are greatest, typically the riffles during higher flow seasons and pools during low-flow seasons. Variability in algal biomass assessments should decrease with increasing numbers of riffles and area of stream assessed. Therefore, composite samples should be collected over the entire study reach.

Large scale assessments are particularly important for patchy filamentous algae, which may be best assessed using rapid periphyton surveys (in-stream, visual assessments of periphyton biomass; see Stevenson and Bahls 1999). Streams and rivers shallow enough to be wadeable during the period when nuisance problems are greatest may be sampled randomly across the entire width of the stream. If variability is still too great, the focus of assessments could be reduced to an indicator zone (an area having a high potential for nuisance algal growth) with a narrow range of water velocity, depth, and substratum size. For rivers with unwadeable depths, sampling attached algae is commonly confined to the wadeable portions because deeper portions may not have enough light for dense benthic algal growth. However, SCUBA has been used to sample benthic algae in large rivers (Lowe 1974).

In streams and rivers where nuisance algal problems arise from planktonic algal blooms during low-flow conditions, sources of variability in algal biomass (and related factors like low DO) tend to be due to temporal as opposed to spatial variability. Repeated plankton sampling during the low-flow period is strongly recommended to relate nutrients to peak plankton biomass and potential problems of low DO or noxious (toxic, taste, and odor causing) algal blooms. If the goal of estimating algal biomass at a problem site is to compare estimates of biomass to a criterion, then replicate sampling of at least four samples at that site is recommended to characterize the mean and variance in observations. If the goal of sampling is to develop a relationship between nutrients and algal problems for the rivers of a region, or to assess status and trends for nutrient-related problems, then replicate sampling is not as important as accounting for temporal variability and sampling more sites.

Relating nuisance algal problems to nutrient concentrations during stream low-flow conditions can be complicated by a number of factors. Algal problems may be due to a combination of planktonic algae blooming throughout pools and benthic algae along margins of pools. Planktonic algae may settle into sediments of pools and may generate oxygen demand from those sediments. Thus, thorough sampling designs should be employed that consider both spatial and temporal variability in algal biomass and associated nutrients to ensure development of accurate and precise relationships between nuisance algal problems and nutrients.

Attached algal biomass can vary greatly in time as well as space within the same stream. Temporal variability in algal biomass can be addressed by repeated sampling during periods when high algal biomass is most likely a problem. Alternatively, algal biomass can be sampled during periods of peak biomass following flood disturbances. This period of peak biomass may endure from one week to two months, depending upon nutrient concentrations in streams and the severity of flood events. Repeated assessment of algal biomass in streams can be facilitated by using rapid periphyton surveys to reduce sampling and laboratory assay costs (see Stevenson and Bahls 1999). Even though many measurements are being made through time, only one measurement per site can be used to develop biomass-nutrient

relationships because of site-specific dependence and problems of repeated measures from the same site (Green 1979; Sokal and Rohlf 1998).

In some cases, the goal of assessment might be to estimate algal biomass at a problem site to compare estimates of biomass to a criterion. In this case, replicate sampling of at least four or many more samples at a site is recommended to characterize the mean and variance in the mean with replicate samples from a site. If the variability in algal biomass is similar to that in the Clark Fork River (see Appendix A case study), as many as 20 replicate samples may be required to detect small changes, which may be important to monitor restoration efforts.

INVOLVEMENT OF CITIZEN MONITORING PROGRAMS

Citizen input can be used to assist in identifying and prioritizing potential problem streams. For example, citizens can be asked (through the use of surveys) to identify streams in which they have observed algal biomass levels that interfere with human uses or impair aesthetic enjoyment. They can also be asked to provide their evaluation of which streams have been affected most and which uses have been impaired to the greatest degree.

While state water quality agencies will likely take the lead in monitoring impaired reaches, citizen monitors may provide much of the monitoring on high-risk reaches. If properly trained and directed, citizen volunteers can be valuable in algal and nutrient monitoring. Citizens, with training, can visually assess algal levels, collect algal samples and freeze them for analysis by an approved laboratory, and may also help in the initial characterization of streams. Citizen monitors can frequently provide more complete flow records by visiting gauges more often than state personnel. Once advised that a stream is high-risk and that the limiting factors have been identified, citizens can help monitor development plans that might affect those factors. Involvement in monitoring programs may lead citizens to effective participation in local planning.

Many excellent resources are available for training citizen monitors. EPA has a volunteer monitoring coordinator (Alice Mayo—E-mail: alice.mayo@epamail.epa.gov) and a web site that lists many resources (<http://www.epa.gov/OWOW/monitoring/volunteer/spring94/ppresf04.html>). Numerous non-governmental organizations, such as the Izaak Walton League, have developed citizen monitoring manuals. One of the best is the Streamkeeper's Guide by the Adopt-a-Stream Foundation (600-128th St. SE, Everett, WA 98208, phone 206-316-8592; web site: <http://www.streamkeeper.org/>).

