VIRGINIA WATER RESOURCES RESEARCH CENTER

REPORT OF THE ACADEMIC ADVISORY COMMITTEE TO VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY: FRESHWATER NUTRIENT CRITERIA FOR RIVERS AND STREAMS

SPECIAL REPORT

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Report of the Academic Advisory Committee to the Virginia Department of Environmental Quality:

Freshwater Nutrient Criteria for Rivers and Streams

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Introduction

Nutrients (nitrogen and phosphorus), when present in surface waterbodies at elevated concentrations, often act as water pollutants. Excess nutrients cause negative effects in surface waterbodies nationwide. Recent U.S. Environmental Protection Agency (EPA) reports to the U.S. Congress have indicated 8% to 10% of assessed freshwater rivers and streams are impaired by nutrient-related causes (U.S. EPA, 1998; 2000a). Therefore, the EPA is requiring all states to develop criteria to protect waters from impairment due to nutrient enrichment. The developed nutrient criteria must incorporate either the methods described by EPA or other scientifically defensible approaches (U.S. EPA, 1998; 2000b).

Under the Clean Water Act, criteria are components of water quality standards. The U.S. Code of Federal Regulations (CFR) defines criteria as "elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use" [40 CFR 131.3(b)].

This report describes an approach for establishing nutrient criteria in Virginia's freshwater rivers and streams as recommended by the Academic Advisory Committee (AAC), an interdisciplinary team of scientists from Virginia's colleges and universities. The report addresses questions raised by personnel from the Virginia Department of Environmental Quality (DEQ) and was prepared at the request of and in consultation with DEQ staff. The report is presented as the following sections:

1. Recommended Approach: This section describes the rationale and potential structure for nutrient criteria development in Virginia. The proposed approach incorporates two major components: one to protect individual stream segments from impairment (localized component) and a second to be applied only in stream segments that contribute nutrients to nutrient-impaired downstream waters (downstream-loading component).

2. Scientific Background: This section explains how nutrients and other factors, such as light availability, hydrology, and sediments, impact the algal biomass of streams and rivers and their downstream waters (tidal rivers).

3. Localized Component: This section provides a conceptual background for the "screening value" approach that is advanced as a means for establishing localized nutrient criteria in wadeable streams.

4. Downstream-Loading Component: This section investigates issues relevant to implementation of a downstream-loading component that includes the potential to utilize the Chesapeake Bay Watershed Model.

5. Data Analysis: This section analyses nutrient data from DEQ's ambient and probabilistic-monitoring programs. These results are compared with nutrient reference values proposed by EPA and simulated nutrient concentrations from the Chesapeake Bay tributary strategies developed from the Chesapeake Bay Watershed Model.

6. Statistical Issues: This section describes the potential use of and uncertainties associated with an approach to evaluate water quality that is based on the spatial and temporal frequency of violation. This section also provides additional information on the use of the "10% rule" as a way to determine nutrient criteria exceedances.

1. Recommended Approach

Background

The approach to establishing nutrient criteria for freshwater rivers and streams is based on prior AAC recommendations regarding an overall approach to nutrient criteria development. These primary recommendations were communicated to DEQ in earlier reports (AAC, 2004; AAC, 2005) and are summarized below:

- Virginia should develop nutrient criteria to protect designated uses as required by the Clean Water Act;
- Criteria development should be based in scientific logic and confirmed with statistical interpretations of field data when possible; and
- DEQ should proceed in a manner that avoids implementation of EPA Guidance Criteria[1] as regulatory standards.

Furthermore, the committee has been consistent in recommending that DEQ pursue a strategy of criteria development that will minimize problems of implementation, which we define in this context to mean instances where numeric criteria are exceeded but designated use is not impaired, and vice versa. Problems of implementation can be expected to cause inefficient expenditure of resources by DEQ and dischargers (both point and nonpoint). In our view, it is preferable to expend the time and effort required to develop appropriate criteria – and thus to minimize the potential for implementation problems – at the beginning of the process. This approach is seen as an alternative to a less-intensive effort that leads to a higher likelihood of less-appropriate criteria and a higher incidence of implementation problems. Given the natural variation in stream characteristics across the state and the complexity of environmental processes that cause nutrient impairments, the committee recognizes that some implementation problems are likely under almost any criteria-development scenario. Therefore, we have been consistent in recommending that DEQ build into nutrient criteria implementation a systematic process for evaluation and refinement of criteria, *i.e.*, a systematic process for identifying implementation problems, and for refining the criteria in a manner that takes advantage of the institutional knowledge generated through that experience.

Recommended Approach for Rivers and Streams

The AAC recommends that DEQ establish nutrient criteria for rivers and streams by addressing independently the two goals defined by EPA guidance: localized effects and downstream effects. We suggest that DEQ proceed by developing criteria comprised of 1.) A localized component intended to protect designated uses within any stream segment that is monitored and assessed, and 2.) A downstream-loading component intended to be protective of the designated uses of receiving waterbodies[2] (Figure 1-1). The downstream-loading component

[1] "Guidance Criteria" are reference values calculated by U.S. EPA (2000c, 2000d, 2000e) as 25th percentiles of all water monitoring data available from specified sources.
[2] The term "receiving waterbody," as used in this text, refers to estuaries and impoundments that receive nutrients transported by Virginia streams and the lower segments of those stream systems.

would be applicable only in stream segments contributing to a receiving waterbody that has been designated as nutrient impaired. For such stream segments, Virginia nutrient criteria would have both localized and downstream-loading components.

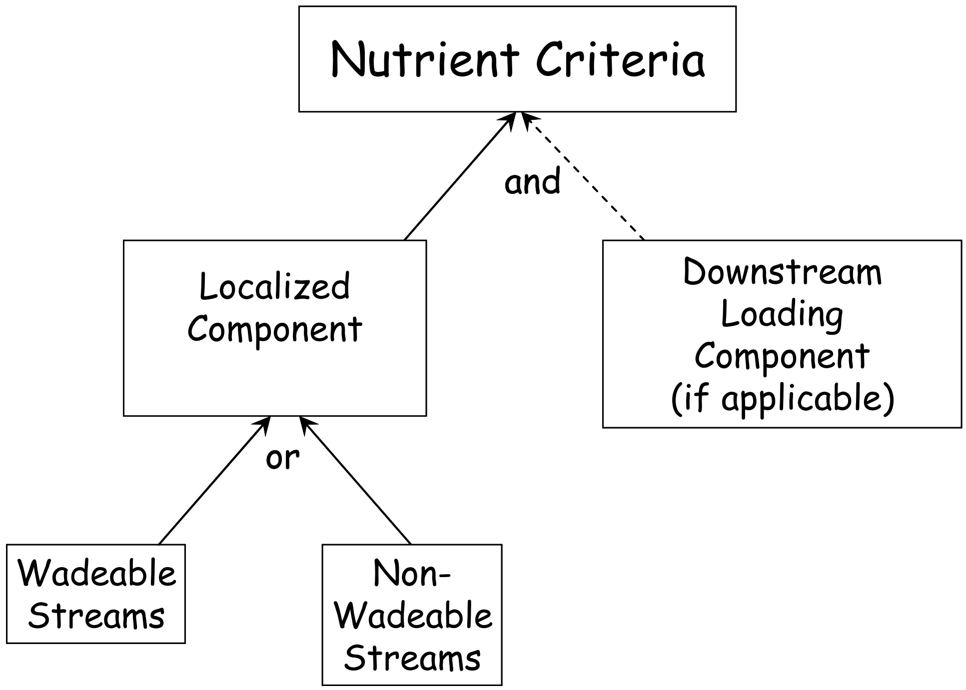

Figure 1-1. A conceptual representation of a nutrient criteria development process for a given stream segment. The localized component of nutrient criteria would be developed and applied to all stream segments. The downstream-loading component would be based on the capability of receiving waterbodies to accommodate N- and/or P- inputs and would be implemented only in stream segments that contribute to a receiving waterbody that is impaired and for which nutrient-loading limits have been defined.

Localized Component

Virginia's nutrient criteria should be protective against localized effects of nutrient overenrichment.

Wadeable Streams

Excess algal growth is the primary mechanism by which excess nutrients impair the capability of a waterbody to support aquatic life and other designated uses. As stated by EPA (2000b, p. 31): "Algae are either the direct or indirect cause of most problems related to nutrient enrichment." Scientific studies of relationships between in-stream nutrient levels and algal biomass have found that numerous factors other than nutrient levels affect algal biomass in streams (e.g., shading, substrate, stream gradient, time since last scouring event), and that such relationships can be complex.

We suggest that nutrient criteria for wadeable streams be developed with the primary goal of protecting the stream's capability to support aquatic life. If the stream is supporting aquatic life, it should also be capable of supporting noncontact recreational uses (*e.g.*, fishing). We expect that criteria which limit in-stream algal levels to protect aquatic life, if imposed in association with existing Virginia criteria for ammonia (9 VAC 25-260-155) and nitrates (9 VAC 25-260-140), would be more restrictive than necessary to protect the streams' capability to serve as water supplies and therefore, would also serve to protect that designated use.

We suggest that the localized component of nutrient criteria for wadeable streams be based on a "screening value" approach described in Section 3 of this report. More specifically, we recommend the following approach (see Figure 1-2):

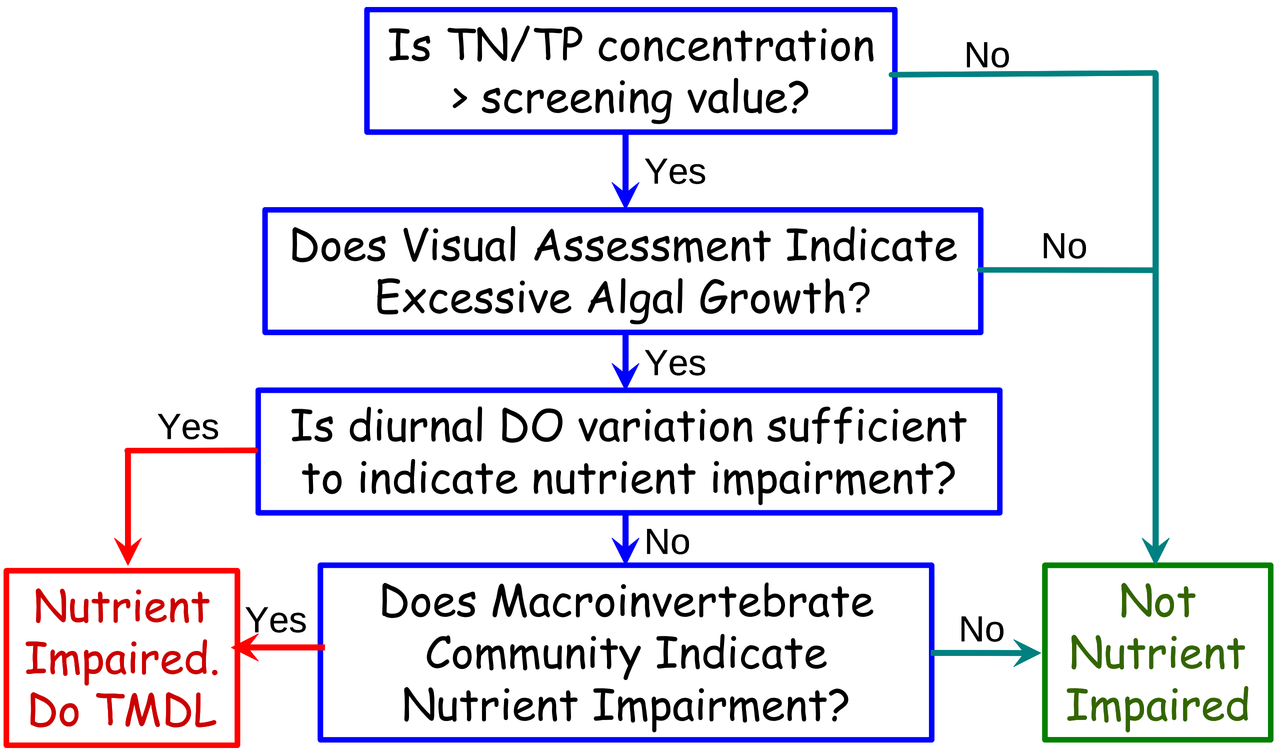

Figure 1-2. A representation of the "screening value" decision process recommended for application as localized nutrient criteria for wadeable streams.

1.) Monitor Water-Column Nutrient Concentrations (total nitrogen [TN], total phosphorus [TP]): If nutrient levels are below a predefined level known to correspond with a measurable probability of nutrient impairment ("screening value"), conclude there is no impairment. If the TN or TP concentration equals or exceed the screening value, go to step 2.

2.) Conduct Visual Assessment: The visual assessment should be conducted using a standard protocol to evaluate phytoplankton and periphyton density. The visual assessment would be applied during time periods when excessive algal growth is likely to be visible (*i.e.*, during warm-weather seasons and not immediately following potentially scouring storms). If the DEQ biologist, using best professional judgment, finds no evidence of excess algal growth, conclude that there is no nutrient impairment. If the visual assessment indicates a potential for impairment, go to step 3.

3.) Monitor Diurnal Dissolved Oxygen (DO) Levels: Monitor *in-situ* diurnal fluctuations in DO and temperature for several days. Monitoring should be conducted during a period that is favorable to algal growth (warm temperatures, sunny days, low flow). If this study indicates low DO concentrations or excessive diurnal fluctuation, consider the stream as impaired. Otherwise, go to step 4.

4.) Assess Benthic Macroinvertebrate Community: Conduct a benthic macroinvertebrate assessment to determine if the stream is supporting the aquatic life designated use. If the stream is supporting the benthic macroinvertebrate community, conclude there is no impairment. If the stream is not supporting the benthic macroinvertebrate community, perform a stressor analysis to determine if excess nutrients are the cause of impairment. If not, the stream is not impaired owing to nutrient levels. If so, the stream is considered impaired because of nutrients.

The above procedure is proposed with the intent of enhancing assessment accuracy while considering the limitations of resources available to DEQ. Although DEQ's process for assessing a stream's capability to support aquatic life is based on benthic macroinvertebrate community status, benthic macroinvertebrate sampling and analysis are resource intensive processes. Therefore, the screening approach is intended to reduce the incidence and/or frequency of benthic macroinvertebrate sampling needed for assessing compliance with localized nutrient criteria. The following provides further detail about the proposed approach.

Step 1—Monitor Water-Column Nutrient Concentrations (TN, TP): This step would be implemented using DEQ ambient monitoring data and using any other available and qualified [3] monitoring data. As a component of its FY 2007 work plan (to be conducted between July 2006 and June 2007), the AAC will evaluate ambient and probabilistic monitoring data provided by DEQ in an effort to determine in-stream nutrient levels that may serve as nutrient screening values.

Step 2—Conduct Visual Assessment: Step 2 would be conducted by DEQ biologists when water column nutrient levels equal or exceed the screening value. A protocol would be developed for conducting the visual assessment and would include elements such as estimation of the proportion of stream bottom covered by periphytic algae. The protocol would also define suitable periods for assessment, which would exclude times after major storms with potential to scour periphytic algae from the stream bed. The visual assessment protocol would be developed with the intention of limiting the potential for incorrect determinations of nonimpairment, *i.e.*, unless visual evidence allows the biologist to conclude that the stream is not impaired, Step 3 would be implemented.

Step 3—Monitor Diurnal DO Levels: Step 3 is based on current procedures used by DEQ to supplement TMDL studies in streams defined as impaired because of poor benthic macroinvertebrate community status. In these streams, a common procedure is to measure

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[3] Data that have been collected by an organization other than DEQ using procedures that allow their use in water quality assessment under DEQ's policies of acceptance of such data.

diurnal variations of water-chemistry parameters that can serve as indicators of DO depletion due to excessive algal growth. If step 2 is inconclusive, the biologist would measure and record diurnal DO and temperature (using a data-sonde) for a several-day period during a time conducive to algal growth. Based on its experience in evaluating similar data through its TMDL program, DEQ would develop a protocol for evaluating such data to determine if DO depletion is impairing the stream's ability to support aquatic life.

Step 4—Assess Benthic Macroinvertebrate Community: If a nutrient screening value is exceeded (Step 1) and potential impairment from excessive algal growth is evident (Step 2), but DO is not sufficiently depleted to cause impairment (Step 3), benthic macroinvertebrate community data should be assessed. If biomonitoring has not previously been conducted at the site, DEQ would conduct a benthic macroinvertebrate assessment using those procedures routinely used in its biological monitoring program. If the benthic macroinvertebrate community shows impairment, a stressor analysis would be performed to determine whether nutrients or some other pollutant or condition is the most probable cause of the impairment.

Even if Step 3 does not indicate DO depletion, there is still a good reason for conducting the assessment in Step 4. Because the benthic macroinvertebrate community integrates stressor effects over extended time periods, their assessment may reveal a chronic long-term source of stress, even if it is absent on the sampling dates. It is also possible that conditions leading to excessive algal growth observed in Step 2 may not be present during the chosen time period for diurnal DO measurements, but the benthic community may still exhibit impairment. Excessive algal production may also affect the benthic macroinvertebrate community in a manner other than via DO depletion (e.g., by stimulating an excessive population of algal grazing organisms), that might be detected by the benthic macroinvertebrate assessment.

It should be noted that the screening process, as a general procedure, identifies impaired waters, but may not conclusively identify the impairment cause. It is possible for waterbodies with nutrient concentrations that exceed the screening value (Step 1) and that lack excessive algae or extreme diurnal DO variations (Steps 2 and 3) be defined as impaired because they support poor macroinvertebrate communities (Step 4); such systems may be impaired by factors other than nutrients. Should DEQ choose to implement the proposed approach, we suggest that the process for defining the causes for impairments be implemented with this consideration.

Non-Wadeable Streams

Non-wadeable streams differ from wadeable streams in several key features, mainly high depth and flow volumes. In wadeable streams, periphyton are the dominant primary producers, whereas in non-wadeable streams, phytoplankton are the dominant primary producers. In wadeable streams, benthic macroinvertebrates are commonly utilized for bioassessment, but benthic macroinvertebrates are not commonly utilized for bioassessment in non-wadeable streams.

We do not have a well-formulated recommendation on how to proceed in non-wadeable streams at this time. During the next year, we will further discuss with DEQ potential approaches to defining of localized criteria for non-wadeable streams. For this discussion to proceed, it will be necessary to decide how wadeable and non-wadeable streams will be discriminated in nutrient criteria implementation: by regulation (*i.e.*, via listing of those stream segments that are considered as "non-wadeable" in regulatory documents), on an ad-hoc basis by sampling personnel (*i.e*., if the sampling personnel determine that a stream segment cannot be sampled for benthic macroinvertebrates, it is defined as "non-wadeable"), or by some other method.

Downstream-Loading Component

The downstream-loading component of nutrient criteria would be expressed as nutrient concentrations – probably as total N (TN) and total P (TP). This component would need to be consistent with applicable TMDLs and tributary strategies in the Chesapeake Bay watershed, with nutrient criteria for downstream waterbodies in neighboring states receiving Virginia's water, and with the localized component of the nutrient criteria. The downstream-loading component may vary across the state. Primary determinants would be the nutrient sensitivity of the receiving waterbodies and degraded aquatic life caused by nutrients originating from upstream areas. Should no N- and/or P-loading and/or concentration limits be in place or anticipated for the downstream segments of a given waterbody, no downstream-loading component would be defined for that drainage. The downstream-loading component of nutrient criteria would be applicable only in stream systems where a receiving waterbody is impaired by nutrients transported by the stream system from upstream areas.

We suggest that development of downstream-loading criteria be approached individually for the state's major drainages.

Approximately 56% of the state's area drains into the Chesapeake Bay (Figure 1-3, Table 1-1). Nutrient loading goals have been established for the Bay through a long and resource-intensive process and with involvement by Bay watershed states and federal agencies. The Tributary Strategies (Commonwealth of Virginia, 2005), an outcome of this process, would be a logical basis for establishing downstream-loading criteria for rivers and streams in the Bay watershed. Section 4 of this report addresses application of the downstream-loading concept to the Chesapeake Bay watershed.

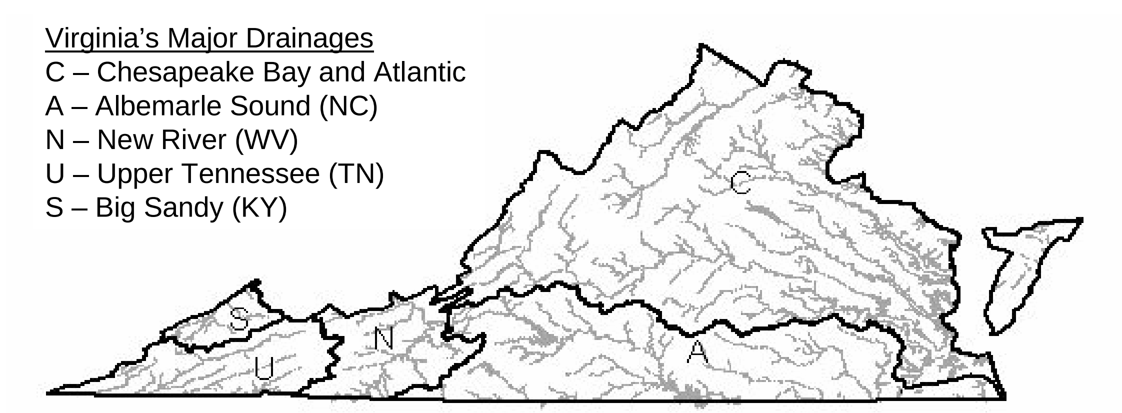


Figure 1-3. Virginia's major drainages

Table 1-1. Virginia's major drainages and approximate areas.

Major Drainage / DEQ Basin		- - - Area - - - Sq Miles	% of Total
Chesapeake and Atlantic		22,918	56%
1	Potomac and Shenandoah Rivers	5,747	
2	James River	10,206	
3	Rappahannock River	2,715	
7	Small Coastal Basins and Chesapeake Bay	1,588	
8	York River	2,662	
Albemarle / Pamlico		10,443	26%
4	Roanoke River	6,382	
5	Chowan and Dismal Swamp River	4,061	
6A	Big Sandy	990	2%
6B&C	Upper Tennessee	3,150	8%
9	New River	3,070	8%
	Total	40,571	

Approximately 20% of the state's area drains into North Carolina's Albemarle Sound. North Carolina has classified Albemarle Sound as a nutrient-sensitive waterbody, with current criteria for the Sound expressed as chlorophyll *a*. To our knowledge, nutrient loading limits for Albemarle Sound comparable to those established for the Chesapeake Bay have not been developed as yet. Nutrient loading limits for Albemarle Sound would be a logical basis for defining the downstream-loading component of nutrient criteria for the Roanoke and Chowan basins, should such limits be developed. Furthermore, should lower segments of these drainages located within Virginia be impaired by nutrients originating upstream, nutrient loading limits of these lower segments might also be a cause for development of a downstream-loading component of nutrient criteria.

Another basin of concern is the Clinch-Powell, a portion of the upper Tennessee River Basin. A study by Chaplin *et al.* (2000) ranked all U.S. areas for biodiversity using a procedure that considered both rarity of individual species and species richness. The study found a southern Appalachian area in the Upper Tennessee Basin to be among the top 5 biodiversity resources in the U.S. In that basin, the highest density of rare and at-risk aquatic species occurs in the Clinch and Powell rivers near the Virginia-Tennessee border. These systems contain at least 20 federally threatened or endangered species. The Endangered Species Act requires that federal actions "not jeopardize the continued existence" of federally listed species. We suggest that DEQ initiate a formal process to determine whether or not nutrient loadings are acting as a stressor on these systems at present, and/or the likelihood that these systems would be imperiled by increased nutrient loadings. A decision by DEQ on whether and/or how to establish nutrient loading limits in the Clinch-Powell basin should consider the outcome of such a process.

Other drainages in the state include small streams that drain from the Delmarva Peninsula into the Atlantic, the New River and associated drainages that drain into West Virginia, and the

Big Sandy basin areas that drain into Kentucky. We do not have specific recommendations on how to proceed in these basins, other than to suggest that they be approached individually.

Antidegradation Policy

We expect that the above concepts would be applied to defining criteria for most of the state's waters. However, among the state's resources are exceptional waters that serve as unique resources, including those defined in 9 VAC 25-260-30 that describes the state's antidegradation policy. Nutrient criteria should be implemented in a manner that allows a higher level of protection to be applied to unique and exceptional waters, such as those that harbor rare species and/or support unique recreational activities that are known to be nutrient sensitive.

Phased Approach

We recognize that the above suggestions and recommendations, when taken as a whole, could be interpreted as presenting a major challenge to DEQ staff due to resource demands, including demands on staff time. In light of the resource limitations, we recommend that DEQ pursue a phased approach to carrying out these recommendations and work with EPA to implement this approach. A phased approach, for example, could be initiated by conducting activities to develop the localized component of nutrient criteria for wadeable streams throughout the state and the downstream-loading component for waterbodies where nutrient loading limits are already in place. Then the localized component of nutrient criteria for non-wadeable streams could be developed. Such an approach would stretch activities out over a longer time period, reducing immediate demands on DEQ staff and resources while allowing more thorough efforts to be applied at each stage.

2. Scientific Background

Prepared by P. Bukaveckas

AAC Task: Address strengths, weaknesses and practical limitations of adopting nutrient criteria for flowing waters based on (a) protection of in-stream/river living resources (mitigation of proximal effects), or (b) protection of living resources in downstream receiving waters (inclusive of impoundments, estuaries and lower reaches of tributary networks).

Background

An understanding of the causal factors regulating algal production in streams and rivers is central to the development of impairment criteria for these systems. An approach that considers longitudinal gradients in hydrology and geomorphology along a stream-river continuum provides a template for predicting the effects of nutrient enrichment on algal production (Figures 2-1 and 2-2). In the following section, we adopt a longitudinal-template approach to analyze the sensitivity of stream and river environments (inclusive of tidal freshwater habitats) to nutrient enrichment based on the underlying mechanisms regulating algal production.

Streams

Algal biomass in streams is principally constrained by light limitation due to shading by the riparian canopy. For survey data, algal biomass is expected to be poorly correlated with stream nutrient concentrations because light limitation is the principal determinant of production. Stream responses to nutrient enrichment will depend upon the co-occurrence of canopy-disturbance effects. Where riparian habitats have been altered (*e.g.*, urban and agricultural streams), high light conditions favor increases in algal production and may facilitate secondary limitation by nutrients. The interaction (non-additive) effect will occur where nutrient enrichment is accompanied by riparian disturbance and allows for localized impairments to be detected from elevated algal biomass. These two factors, however, may also act independently giving rise to elevated nutrient concentrations that are not accompanied by increases in algal biomass (*e.g.*, nutrient enrichment without canopy loss) or, increases in algal biomass that are not associated with elevated nutrient concentrations (canopy loss without nutrient enrichment).

Rivers (non-tidal)

The transition from stream (wadeable) to riverine (non-wadeable) conditions is accompanied by a shift from predominantly benthic (periphyton) to predominantly suspended (phytoplankton) forms of algal production. Phytoplankton production in rivers is determined by light dosages experienced by cells traveling down river. The light-dosage concept integrates the combined effects of water transparency, depth of the water column, and transit time (within a specified reach) on the net balance between photosynthesis and respiration. In rivers, algal biomass is often poorly correlated with nutrient concentrations because of constraints imposed by low light availability and short transit time. Nutrient enrichment is unlikely to result in increases in algal biomass unless accompanied by water regulation effects that favor a shift from light- to nutrient-limited conditions. Water storage effects result in greater light dosages and favor secondary limitation by nutrients. Algal-based metrics may be used to detect localized impairment where the nutrient-enrichment effect and the water-regulation effect co-occur. In these cases, site-specific monitoring in proximity to regulation structures may be useful for detecting localized effects and establishing N-, P-, and/or algal-based criteria. These criteria, however, would not be useful for detecting impairment in adjacent river segments if hydrologic-optical conditions in these segments favor light limitation. In these segments, elevated nutrient concentrations may not result in increased algal biomass (*e.g.*, nutrient enrichment without water regulation) or, increases in algal biomass may not by associated with elevated nutrient concentrations (water regulation without nutrient enrichment).

Rivers (tidal)

The transition from fluvial to tidal conditions is marked by an increase in transit time due to bi-directional water movement in tidal rivers. The additive effects of longer transit time coupled with increases in water transparency and decreases in the average (cross-sectional) depth of tidal rivers lead to a marked increase in light dosages and a corresponding peak in algal biomass. The lessening of constraints imposed by hydrologic and optical conditions results in nutrient-limited conditions in tidal rivers, which are hypothesized to exhibit greater sensitivity to nutrient enrichment relative to streams and non-tidal rivers. Anthropogenic nutrient inputs amplify these effects, giving rise to positive associations between nutrient levels and algal biomass. This correlation could be used to define impairment criteria based on either nutrient concentrations or algal abundance because tidal rivers are minimally impacted by factors that confound nutrient-algal interactions in streams and non-tidal rivers (riparian loss, impoundment effects).

Recommendations

It will be problematic to establish N- and/or P-based criteria for the protection of designated uses (inclusive of living resources) in streams and non-tidal rivers given the poor correspondence between nutrient concentrations and algal biomass. Many sites that exhibit chronic nutrient enrichment would not be considered nutrient-impaired based on algal metrics because the autotrophic potential is constrained by other factors (predominantly, light limitation). For sites that exceed N- and/or P-based threshold criteria, implementing nutrient mitigation would not be expected to yield localized effects on algal biomass but would serve to protect downstream, nutrient-sensitive resources (tidal freshwater rivers and estuaries). Alternatively, algal-based metrics could be used in conjunction with N- and/or P-based criteria to identify impaired streams and non-tidal rivers. It should be recognized that this approach will target sites where sensitivity to nutrient enrichment has arisen because of riparian disturbance or river impoundment. Nutrient mitigation at sites identified by this approach would be expected to yield localized improvements arising from reductions in algal production. This approach would also serve to protect downstream (nutrient-sensitive) resources but only for the subset of sites where nutrient enrichment has resulted in elevated algal biomass. If these cases represent a minority of the instances where nutrient enrichment has occurred, the downstream benefits would be minimal.

Tidal rivers may offer the best opportunity for developing N- and/or P-based criteria given the hypothesized nutrient sensitivity of these systems. Development of criteria for tidal rivers should follow defensible targets for algal biomass based on end points that are linked to designated uses (*i.e.*, mitigation of toxic algal blooms, promotion of balanced communities that support higher trophic levels, mitigation of hypoxic conditions in adjacent estuarine environments). DEQ has already made substantial strides in this regard through justification of proposed chlorophyll *a* criteria for the James River.

Once targets are established for algal biomass, modeling approaches could then be used to link algal abundance to nutrient availability. Through this process, concentrations could be defined that would protect tidal rivers from adverse effects associated with excessive algal production. Existing models (*e.g.*, VIMS HEM3-D) could be used for an exploratory analysis of simulated reductions in nutrient inputs on algal production. The benefit of using a modeling approach is that other factors influencing algal production in these systems (*e.g.*, geomorphometry, temperature, sediment loads, and tidal exchange) can be explicitly incorporated in the analyses. Determination of the nutrient ranges corresponding to chlorophyll *a* targets in tidal rivers could allow for the establishment of nutrient concentrations in contributing streams and non-tidal portions of these rivers. The rationale would be to establish nutrient limits in upstream waters that would protect designated uses in the most sensitive (tidal freshwater) segments of the river network.

Although this approach places a disproportionate emphasis on tidal rivers in designating whole-watershed criteria, it has several practical advantages. First, nutrients and algae in tidal rivers are well characterized (*e.g.*, monthly monitoring of 12 stations in the James River), allowing for an accurate depiction of their relationship and increasing the likelihood of detecting positive responses to nutrient mitigation. By comparison, streams and the non-tidal portions of rivers are infrequently sampled (particularly for algal metrics), and this represents a substantive obstacle to both the development of criteria and the detection of impairment in these systems. Second, tidal rivers are often a focal point for commercial and recreational activities. The goods and services they provide, coupled with their sensitivity to nutrient enrichment, make them a principal focus of stakeholder concerns. Third, the basins of tidal rivers comprise much of the land area in the Commonwealth of Virginia, and therefore, a tidal river-based approach to criteria development would be broadly applicable.

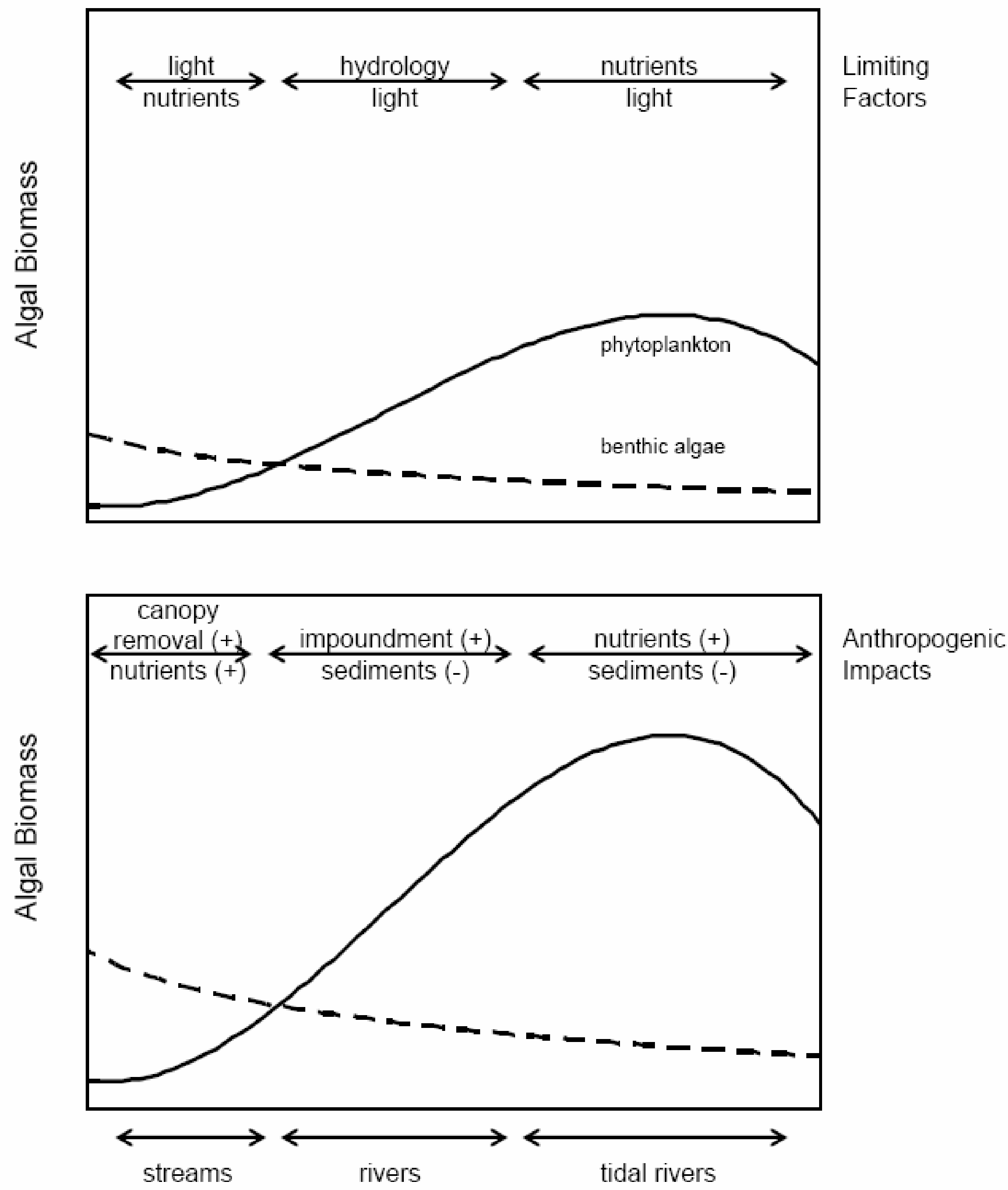


Figure 2-1. Mechanisms regulating algal production in river networks (upper panel) and hypothesized effects of anthropogenic influences (lower panel) on longitudinal variation in suspended and benthic algal biomass.

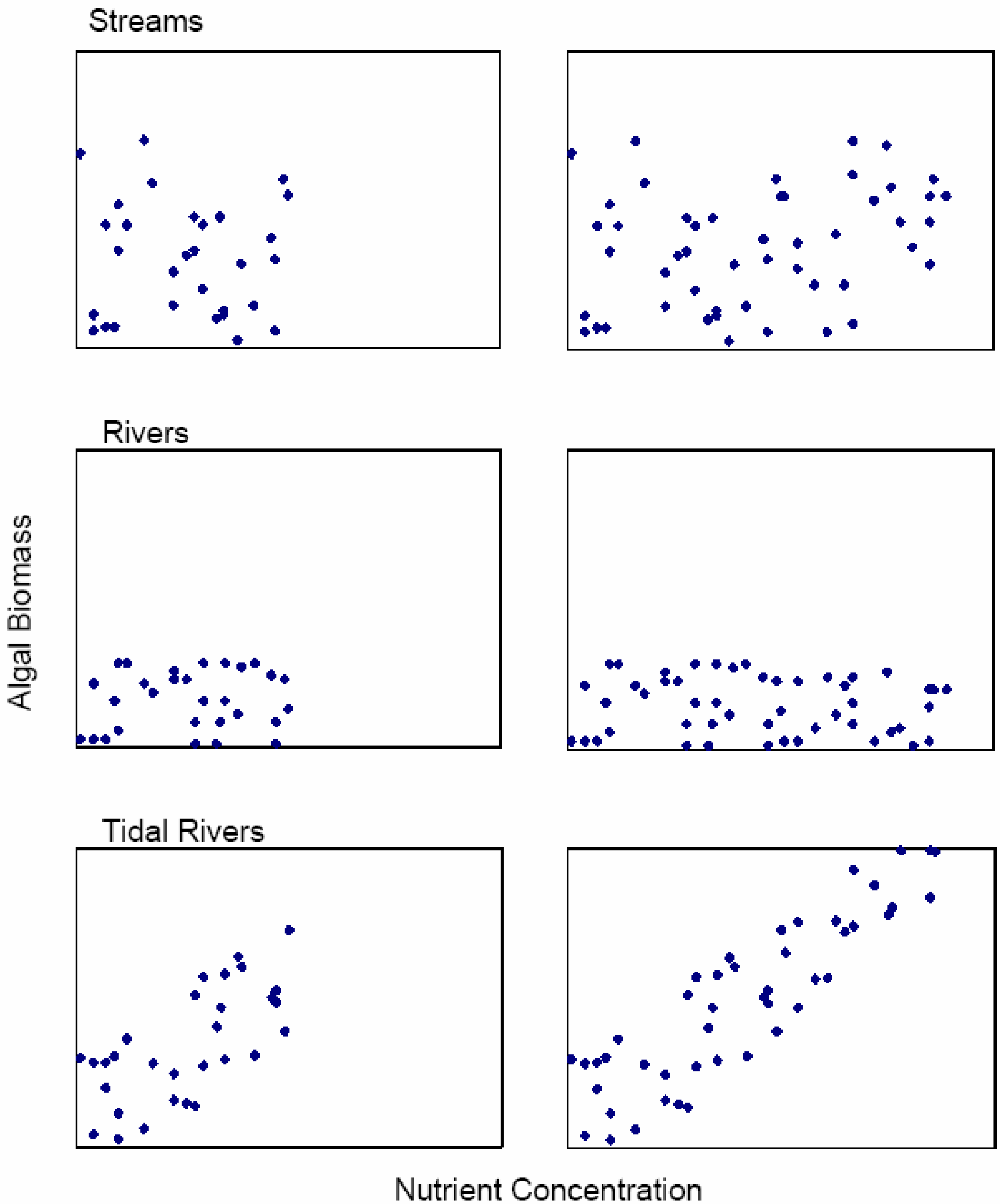


Figure 2-2. Hypothesized relationships between algal biomass and nutrient concentrations in streams, rivers and tidal-rivers (left panels) and their response to nutrient enrichment (right panels).

3. Localized Component

Prepared by L. Shabman and K. Stephenson

AAC Task: Develop and describe a practical and flexible framework for potential application in implementing statewide nutrient criteria. The framework would include minimum nutrient criteria thresholds for broad uses (*e.g.*, aquatic life, swimming, fishing, water supply) and a process for responding to threshold exceedances that includes an evaluation of whether alternative, more site specific criteria would be more appropriate for the waterbody in question than the broad-use criteria.

The AAC has consistently recommended that nutrient criteria be developed to identify whether the designated uses of a waterbody are being achieved. The identification of a single numeric nutrient criterion for all locations and waterbody situations is difficult, in part, because of the limited data available, the time and resources needed for intensive monitoring, and the significant costs of making an incorrect classification. In response to these challenges, the conceptual description and rationale for the AAC screening values recommendation is described.

Screening Approach

The approach recommended for determining nutrient impairment could be described as a "screening approach" (see Figure 3-1). During the first step of the screening process, an initial water quality screening parameter(s) is identified. The screen would be a relatively easily monitored and/or widely sampled water quality parameter for which there is an extensive database. Although the selected water quality parameter may be readily available, the selected screening value is not a direct or highly certain measure of whether the designated use is or is not being achieved (if the monitoring parameters were clearly linked to the designated use, there would be no need for the screening approach). For example, the AAC recommends total phosphorus and total nitrogen concentration as screening parameters. Elevated TP and TN levels would be generally associated with nutrient impaired streams, but not all streams with elevated nutrient levels will result in impairments of aquatic life, recreation, or some other designated use. The numeric value of the screening parameter, as well as the statistical interpretation of the monitoring data, should be specified to assure that nutrient impaired streams will not be incorrectly identified as unimpaired. When supported by available data, numeric screening values should also be differentiated by ecoregion because variation in physical and biological processes may produce different nutrient load-aquatic function relationships across ecoregions.

The initial screening is intended to classify stream segments that *might* be impaired. By making use of readily available data, the screening approach makes it possible for a broad and extensive assessment of state waterbodies. If a stream reach passes the screening test, the stream is not impaired by nutrients (see Figure 3-1).

If the screening value is exceeded, the waterbody is slated for more intensive monitoring that is focused on a criterion of closer proxy for the designated use. The additional monitoring would be required in order to determine whether designated uses are or are not being achieved in stream segments with elevated nutrient levels. The more intensive monitoring process would impose additional agency costs but would be necessary to avoid the possibility of listing a waterbody as impaired when in fact all designated uses are being achieved. In addition if the water is impaired, the more intensive monitoring will provide a firm foundation for the ensuing TMDL development process. The additional monitoring costs are likely to be small relative to the costs incurred under the TMDL program.

The needed monitoring data to assess if the designated use is being met may not exist or may be insufficient (ex., lack of biological monitoring data). Therefore, the amount and type of monitoring necessary to make a determination of listing should also be specified. The protocol might include identification of conditions or guidelines on the type and number of samples as well as temporal and spatial guidance for sampling.

Once monitoring data sufficient for the assessment are collected and analyzed, the determination of whether or not the stream reach is achieving its designated uses is made. Such a determination would include articulation of the statistical decision rules for listing a stream reach as impaired.

It should be noted that the screening process, as a general procedure, identifies impaired waters but may not conclusively identify the impairment cause. DEQ should recognize that, if a waterbody has elevated nutrients and fails to support designated use, the cause of impairment may be factors other than nutrients. If DEQ has compelling evidence that a factor other than nutrients is the cause of impairment, DEQ should list the waters as impaired by that cause.

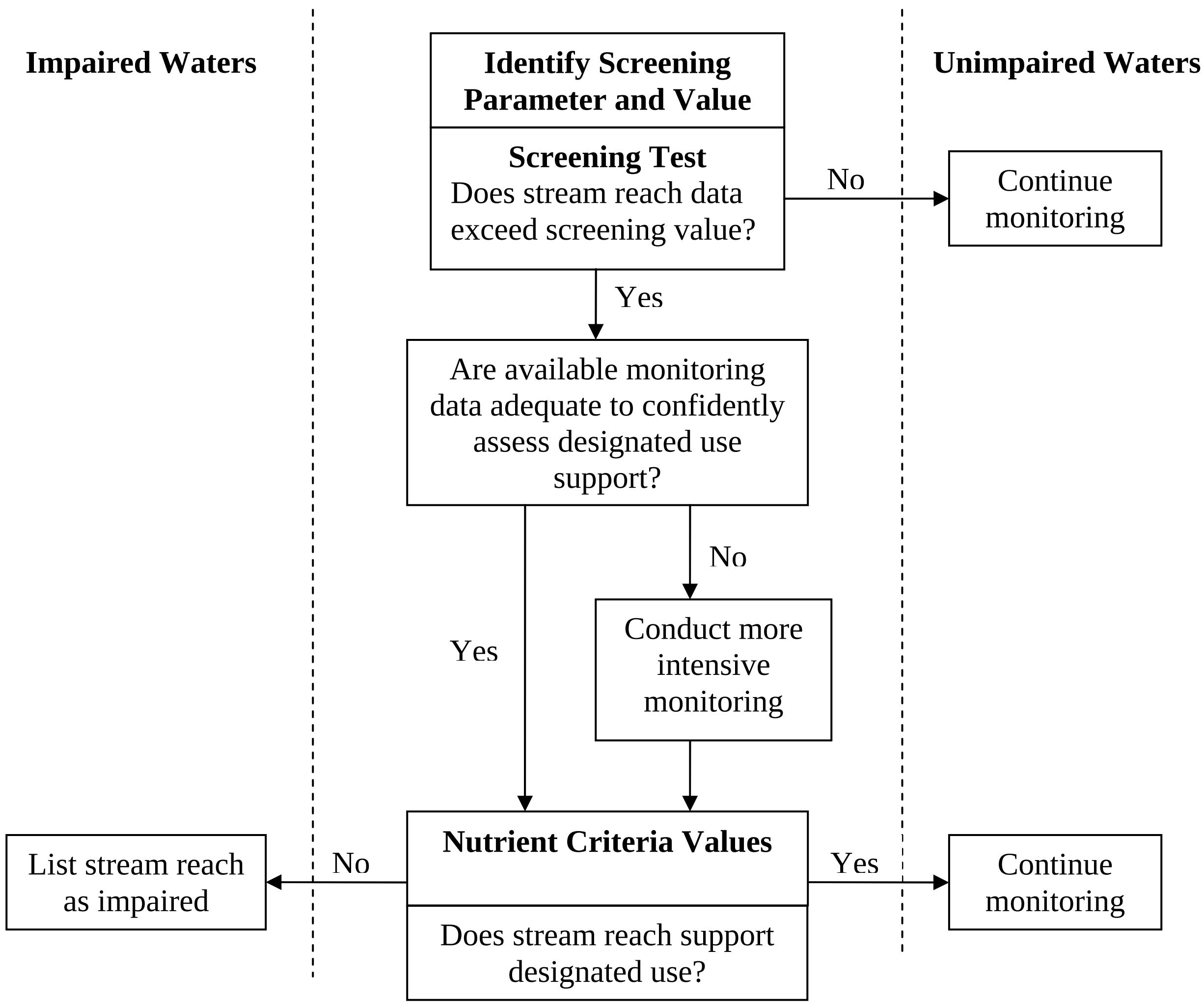


Figure 3-1. Nutrient Criteria Screening Approach

4. Downstream-Loading Component

Prepared by G. Yagow

AAC Task: Investigate the feasibility of using the Chesapeake Bay Watershed Model output to establish freshwater nutrient criteria for flowing waters that address downstream-loading effects.

The Chesapeake Bay Watershed Model (CBWM) was developed to represent loading of sediment and nutrients from the land surface by various land uses and pollutant sources in the Bay watershed. In previous versions of the model, Virginia was represented as 36 spatial modeling segments that only covered the Bay drainage portion of the state. In the current version of the model (Phase 5.0), the entire state of Virginia is included and is represented with an increased number of spatial sub-divisions. The previous 36 model segments in the Bay drainage area of Virginia have been subdivided into 263 model segments, and a total of 393 segments in the Phase 5.0 model comprise the whole of Virginia. In addition, the Phase 5.0 segmentation includes complete watersheds from neighboring states that drain into Virginia. Gary Shenk with EPA's Chesapeake Bay Program reports that the hydrology calibration for Phase 5.0 of the CBWM is complete. Furthermore, automatic calibration procedures are being developed for sediment and nutrients to calibrate the land and river segments simultaneously. Output from Phase 4.3 of the model was used as the basis for developing the Chesapeake Bay tributary strategy load allocations, which comprise the "downstream loads" or "cap loads" of concern in this analysis. Phase 5.0 model outputs of potential use for developing nutrient criteria include the time-series of flow and nutrients at the outlet of each model segment or aggregation of model segments that comprise a watershed.

In order to evaluate the "feasibility" portion of this task, several questions are addressed. Part of this analysis looks at the availability of data, both in terms of setting criteria and in terms of assessing compliance with those criteria. The availability of data at the desired spatial and temporal aggregation units should be considered when determining the needed flow and nutrient data for criteria development.

- How could receiving waters' nutrient loading limits be transformed to concentrations for use as criteria?

Nutrient loads are a function of flow and the nutrient concentration. Downstream nutrient targets, as represented in the Chesapeake Bay tributary strategies, are fixed annual loads. Because these loads will be delivered by variable amounts of annual flow, there will be a corresponding variable range of concentrations that will be supportive of these nutrient targets (fixed loads divided by variable flow produces variable concentrations).

In order to illustrate such a range of nutrient concentrations, the following example was constructed. This example is at the basin level and uses annual average historic flows and annual nutrient load allocations based on the Chesapeake Bay Program's "2010 Cap Load Allocations w/o Clear Skies" scenario. This analysis is based on data from six U.S. Geological Survey (USGS) stations, at or above the fall line (AFL), that roughly correspond with the outlets of Bay model segments, as shown in Figure 4-1. Because flow varies from year to year and will affect the concentrations needed to achieve the target loads, annual flow rates were obtained for each of these stations for the period 1985-2003. From these data, the minimum, average, and maximum annual flow rates were identified or calculated (Table 4-1).

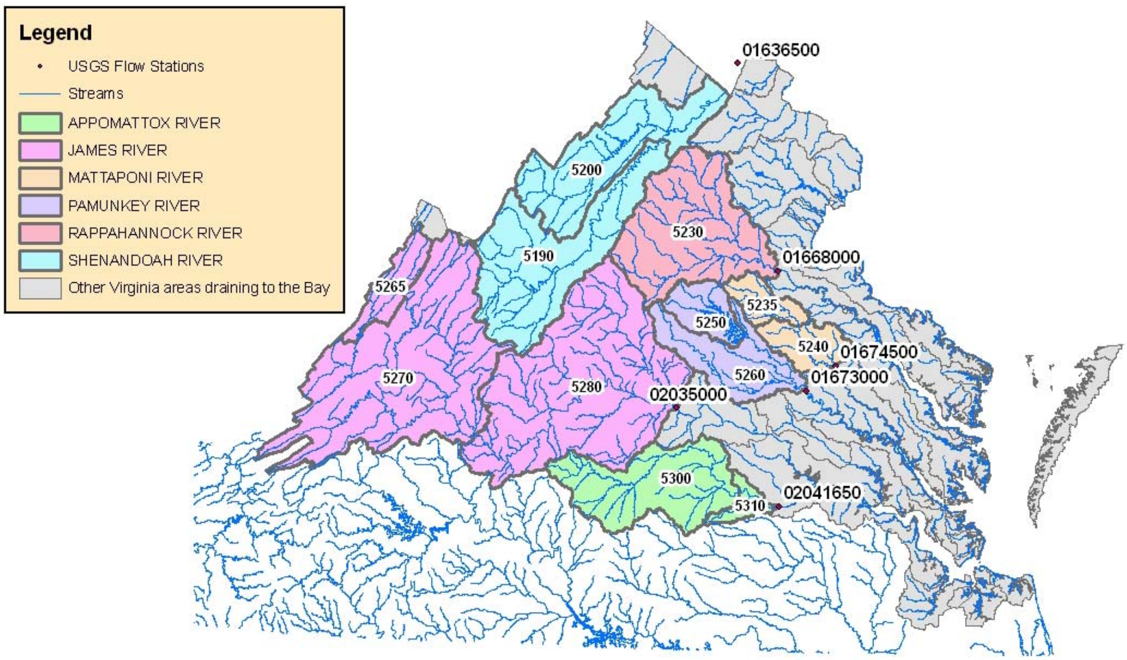


Figure 4-1. Bay Model Segments and Corresponding USGS Flow Stations

Table 4-1. Annual Range of Flows from Selected USGS Stations that Measure Flow from Above the Fall Line (AFL)

AFL Stream	Fall Line USGS Stations	Drainage Area (sq.mi.)	Virginia Bay Model Segments	Annual Flow: 1985-2003~ (cfs)		
				Min	Average	Max
Shenandoah	01636500	3,040	190,200	1,540	2,903	6,247
Rappahannock	01668000	1,596	230	787	1,739	3,873
Pamunkey	01673000	1,081	250,260	291	1,016	2,027
Mattaponi	01674500	601	235,240	155	512	995
James	02035000	6,257	265,270,280	3,436	7,260	13,669
Appomattox	02041650	1,344	300,310	577	1,227	2,974

~ Shenandoah station was missing years 2002-2003, Mattaponi station was missing years 1987-1989.

The tributary strategy 2010 cap loads were obtained from a spreadsheet named "VA_Nutrient_Allocations(calculations)_091003.xls" courtesy of the Virginia Department of Conservation and Recreation (Bill Keeling). This spreadsheet was used rather than sources available on the web from the Virginia Secretary of Natural Resources or the Chesapeake Bay Program because the allocations were broken out at the model segment level, which was essential for matching loads and flows from the same areas. The 2010 cap loads were aggregated from all sub-areas of the six fall line stations. These aggregated cap loads were then divided by the range of flows from the USGS stations in Table 4-1 to calculate the range of average annual nitrogen and phosphorus concentrations needed to meet the 2010 cap load allocations (Tables 4-2 and 4-3). The minimum concentrations result from dividing the cap loads by the maximum flows, and the maximum concentrations result from dividing the cap loads by the minimum flows. The values in Tables 4-2 and 4-3 represent annual average concentrations. The expected ranges of monthly and/or daily averages would be wider than the ranges of the annual average concentrations.

Table 4-2. Annual nitrogen concentration ranges that meet 2010 Cap Load Allocations

AFL Stream	Fall Line USGS Stations	2010 TN Cap Load* (lbs/yr)	**Nitrogen Concentration**		
			Min	Mean	Max
			(mg/L)		
Shenandoah	01636500	3,293,100	**0.27**	0.58	1.09
Rappahannock	01668000	2,427,850	**0.32**	0.71	1.57
Pamunkey	01673000	1,103,401	**0.28**	0.55	1.93
Mattaponi	01674500	525,193	**0.27**	0.52	1.72
James	02035000	6,921,385	**0.26**	0.48	1.02
Appomattox	02041650	1,220,309	**0.21**	0.51	1.07

* Calculated from 2010 Cap Loads w/o Clear Skies

Table 4-3. Annual phosphorus concentration ranges that meet 2010 Cap Load Allocations

AFL Stream	Fall Line USGS Stations	2010 TP Cap Load* (lbs/yr)	**Phosphorus Concentration**		
			Min	Mean	Max
			(mg/L)		
Shenandoah	01636500	664,071	**0.054**	0.116	0.219
Rappahannock	01668000	418,017	**0.055**	0.122	0.270
Pamunkey	01673000	157,509	**0.039**	0.079	0.275
Mattaponi	01674500	50,139	**0.026**	0.050	0.164
James	02035000	1,752,356	**0.065**	0.123	0.259
Appomattox	02041650	132,906	**0.023**	0.055	0.117

* Calculated from 2010 Cap Loads w/o Clear Skies

Because nutrient load can not be measured directly, nutrient criteria will most likely be based on concentrations. Two different approaches to setting concentration-based nutrient criteria would be to use either fixed criteria or variable criteria. Although fixed criteria may be easier to deal with administratively, criteria based on a minimum concentration from Tables 4-2 or 4-3 would be excessively restrictive under most conditions. Furthermore, use of a mean concentration would allow some violations of the criteria. Because this example produces a range of concentrations that would protect the annual load limits depending on the amount of precipitation in any given year, it would seem reasonable to explore options for developing some type of variable criteria. Variable criteria would provide more flexibility in assessing compliance with the cap loads although it would require additional work to define the criteria. The ammonia standard has set a precedence for using variable criteria in Virginia water quality standards, as the concentration criteria in this standard is a function of both pH and temperature.

One approach for establishing variable nutrient criteria could be based on load-duration, which essentially is a nutrient concentration criteria indexed to daily flow. This approach calculates the statistical probability distribution of daily flows from the historical record at a given station (flow-duration curve) as in Figure 4-2. The application of a concentration to the flow, transforms the distribution into a load-duration curve. For assessment, each nutrient sample would need to be associated with a monitored or simulated daily flow on the day of sampling. The concentration could then be plotted on the flow-duration curve to see if individual samples complied with or exceeded the statistical average load for that flow. Figure 4-3 provides an example of a load-duration curve to assess compliance of the fecal coliform criterion.

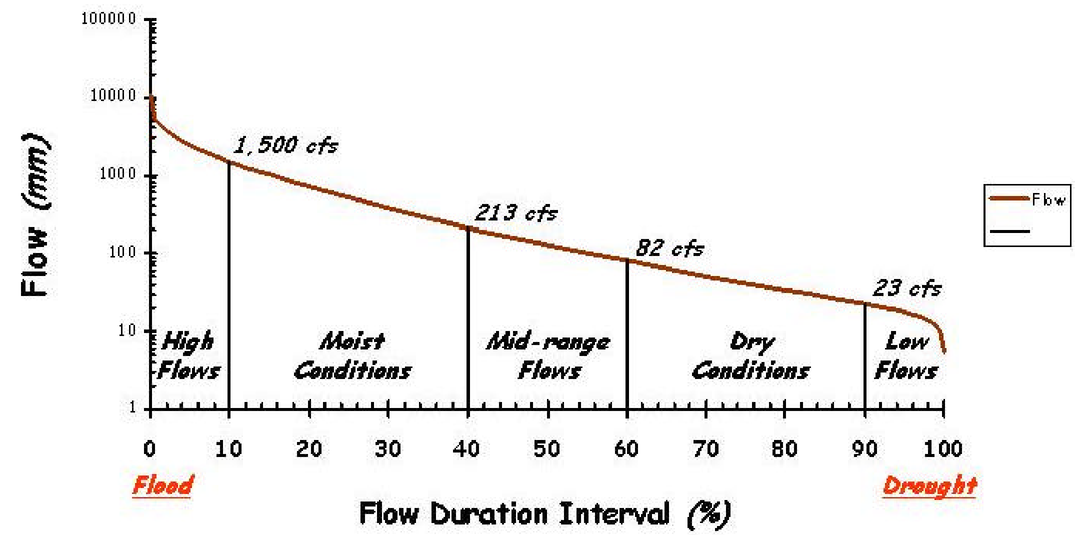


Figure 4-2. Flow-duration curve

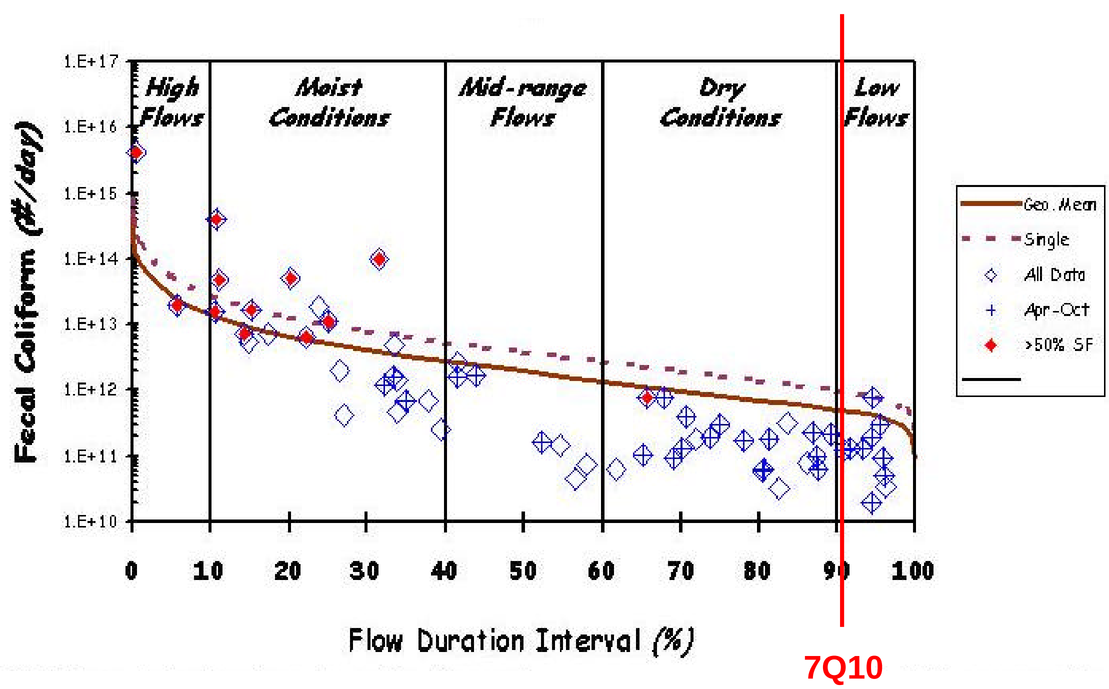


Figure 4-3. Assessing compliance of monitored data with a load-duration curve.

The load-duration approach would require development of a flow-duration curve at each DEQ monitoring site, or at the outlet of each aggregated watershed that would serve as the basis for assessing compliance. A variable concentration curve would be created for each assessment point based on the upstream drainage area's unique combination of point source (PS) and nonpoint source (NPS) cap load allocations (PS loads are not flow dependent and tend to dominate during low flows, whereas NPS loads increase with flow and usually dominate during high flows).

- How could loading limits and/or concentration-based criteria be "backed-upstream" through the drainage?

Because the addition of new monitoring sites is probably not feasible with current budget constraints (and even if the addition of new monitoring sites were economically feasible, access to the sites might not be), a procedure is needed to align monitoring and modeling sites. The primary consideration, therefore, is how to extrapolate, interpolate, or otherwise assign existing monitored or simulated flow and nutrient data to the outlets of the watershed segments of interest. An illustration of some of the alignment possibilities are shown in Figure 4-4.

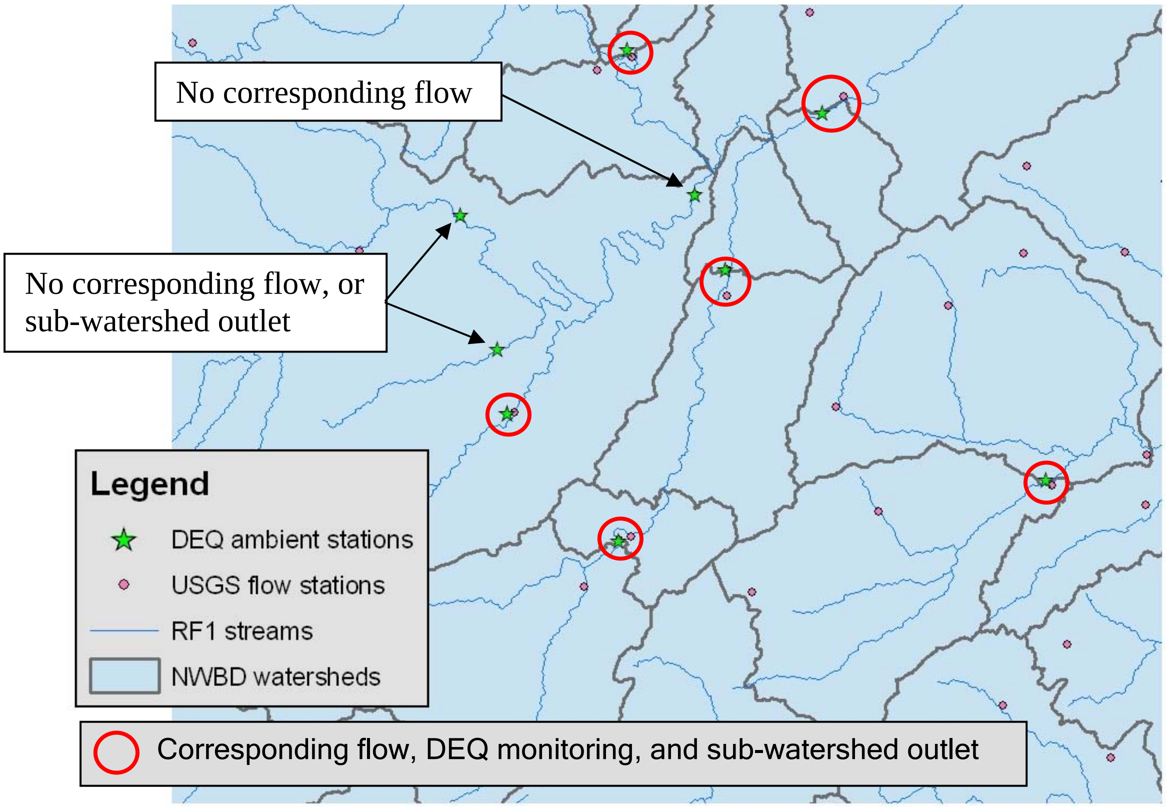


Figure 4-4. Alignment Issues between DEQ, USGS, and modeling segment outlets for Reach File Version 1.0 (RF1) streams, which are representations of streams at a scale of approximately 1:500,000, within watersheds based on the National Watershed Boundary Dataset (NWBD).

The first consideration for “backing upstream” is the availability of appropriate nutrient data. In the tributary strategy load allocations, Virginia has allocated cap loads (in essence “backed them upstream”) at the “coseg” level, which are units of county segments or county portions within sub-watersheds. Cosegs can currently only be aggregated up to the Phase 4.3 watersheds in Virginia. Therefore, nutrient data are only available at the basin level as a basis for setting nutrient criteria. It is unknown at this time whether or not the cap loads will be re-allocated to county segments within the smaller watersheds developed from the National Watershed Boundary Dataset (NWBD).

Several options are available for evaluating daily flows at the chosen watersheds. These flows can be based either on observed daily flows from existing USGS gaging stations or on simulated daily flows from Phase 5.0 of the CBWM. USGS daily flow could be assigned to a co-located or nearby station, interpolated between upstream and downstream stations, or used to estimate unit area flow (cfs/mi^2) and applied to the drainage area associated with the outlet. Ratios of simulated model flow to observed USGS flow could also be used to translate flow frequency curves developed at USGS stations to nongaged watershed outlets.

The applicable cap loads for each watershed can be calculated as area-weighted portions from tributary strategy coseg allocations by both point source (PS) loads and nonpoint source (NPS) loads, although these allocations will be much refined if the coseg load allocations are re-apportioned based on the 263 NWBD model segments rather than on the 36 Phase 4.3 model segments comprising the Chesapeake Bay drainage in Virginia. Load-duration curves could then be created at all DEQ monitoring points that correspond with watershed outlets.

As part of the work plan for 2007, it is recommended that the AAC develop a pilot application of the load-duration approach at 4 or 5 locations within a smaller basin, possibly the Rappahannock. This pilot project would help to identify more specifically the issues that might be involved with creating load-duration curves, estimating flow at nongaged DEQ sites, and translating 2010 cap load allocations into indexed concentration criteria. An additional procedure would also be needed to assess samples from DEQ monitoring points that are not encompassed in the above scheme.

- What factors should be considered in trying to use tributary strategy loads as a basis for nutrient criteria?

Nutrient loads are a function of flow and nutrient concentrations. In-stream nutrient concentrations are differentially influenced by base flow and storm flow; the nutrient sources in the watershed (PS and NPS); and the in-stream processes that impact the nutrient delivery factors. Therefore, the following factors should be considered in conjunction with nutrient criteria development:

- Annual variability of flow
- Differential trends in N and P concentrations with flow
- Seasonal variability of nutrient concentrations
- The mixture of NPS and PS loads in the upstream watershed
- Differential delivery factors for N and P

Annual variability of flow

As mentioned previously, annual flow is highly variable. This high variability is the reason why the load-duration approach was recommended as a statistical means of indexing flow and nutrient loads. The example shown in Figure 4-5 is from the USGS fall-line monitoring station on the Rappahannock (USGS Station 01668000), where annual average daily flow varies by a factor of approximately 8.5, from 452 to 3,873 cfs.

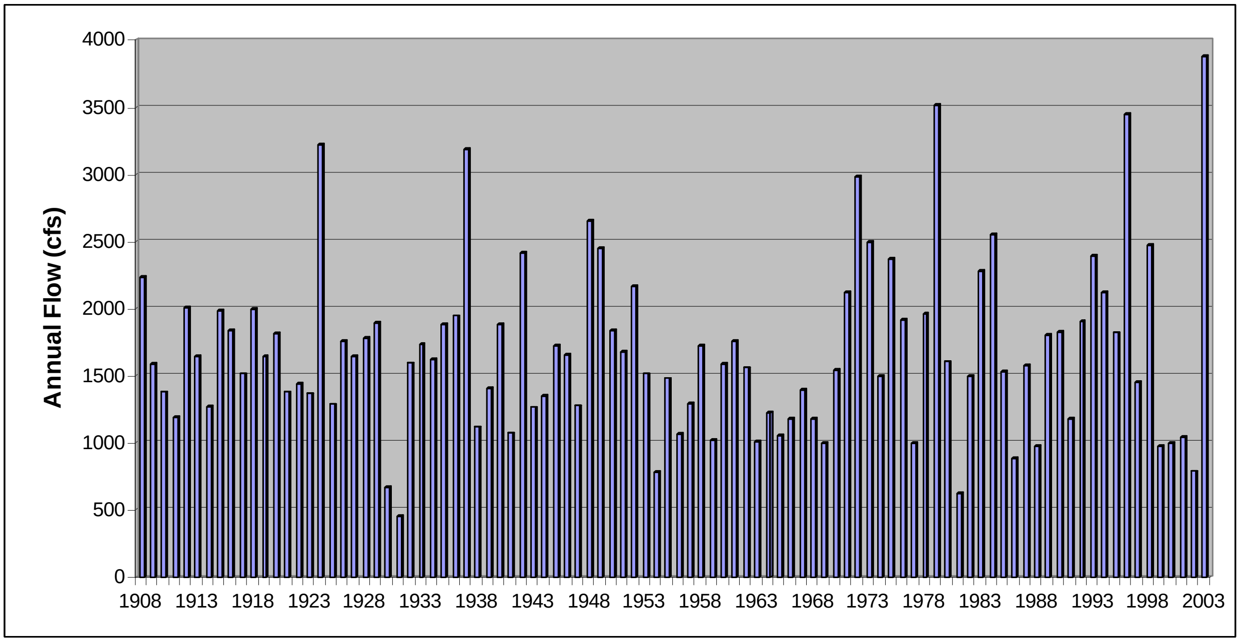
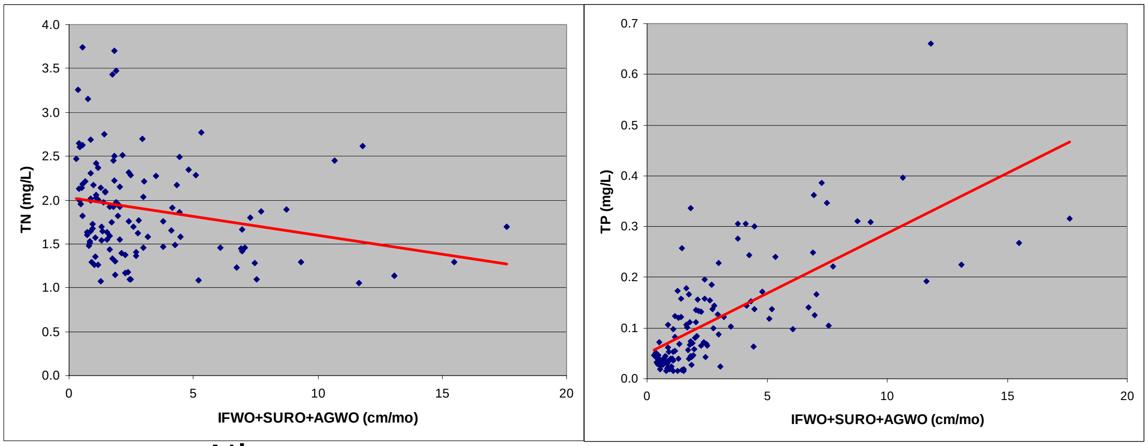


Figure 4-5. Annual average daily flow, Rappahannock River, USGS Station 01668000

Differential trends in N and P concentrations with flow

In-stream N and P concentrations are expected to vary with flow. Figure 4-6 shows the plots of simulated monthly average N and P concentrations at approximately the same location as the USGS 01668000 flow station. The two nutrients show different trends. Nitrogen concentrations decrease with increasing flow, whereas phosphorus concentrations increase with increasing flow. These trends might be related to the specific mixture of point sources and non-point sources in this watershed. Because nitrogen concentrations tend to decrease with increasing flow in this watershed, the nitrogen loads appear to be dominated by relatively constant point source or groundwater inputs, which are then diluted with increasing flow. In contrast, the increasing phosphorus concentrations in this watershed are associated with increasing flow, which is typical of nonpoint source runoff. Trend lines should be generated for other flow stations with observed N and P data to see if similar patterns or relationships with the nutrient source mixtures hold true.

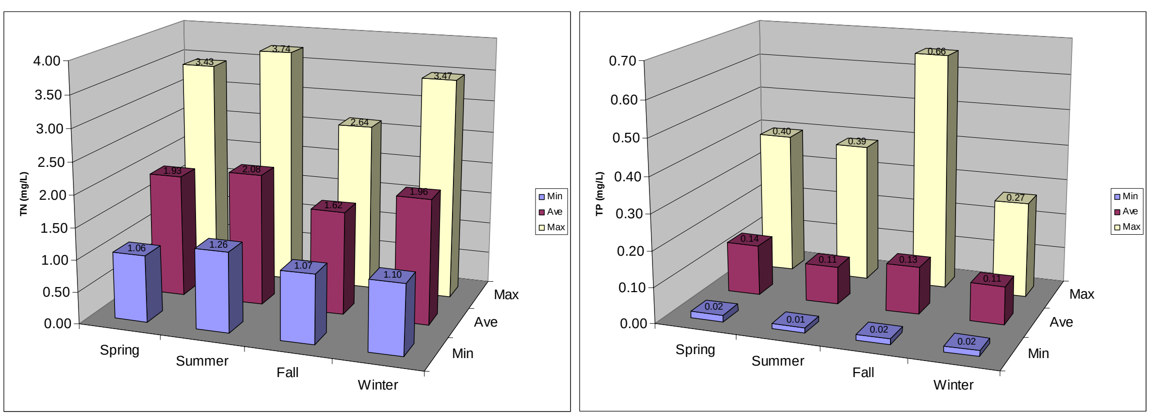


a.Nitrogen b.Phosphorus

Figure 4-6. Upper Rappahannock River, Bay model segment 230, Progress 2000 Run

Seasonal variability of nutrient concentrations

Seasonal changes in nutrient input are expected to differ for different monitoring stations. For example, stations strongly influenced by surface runoff (NPS) are expected to show more seasonal variability in nutrient concentrations. This seasonal variation depends on the seasonal differences in the amount of precipitation and land use (e.g., spring planting, timing of fertilizer application, etc.). For the Upper Rappahannock River watershed in this example, no significant seasonal variability was observed in N and P concentrations (Figure 4-7). This observation may be a result of this watershed's particular mix of upstream NPS and PS loads.



a.Nitrogen b.Phosphorus

Figure 4-7. Upper Rappahannock River, Bay model segment 230, Progress 2000 Run

The mixture of NPS and PS loads in the upstream watershed

While nonpoint source loads are relatively uniform across the state, point source loads tend to be concentrated near the downstream portions of most basins. When moving downstream, therefore, the proportions of PS to NPS loads will generally increase. Nutrient loads from PS also tend to be fairly constant regardless of flow, whereas NPS loads are generally minimal during baseflow and increase with increasing flow, as illustrated in Figure 4-8.

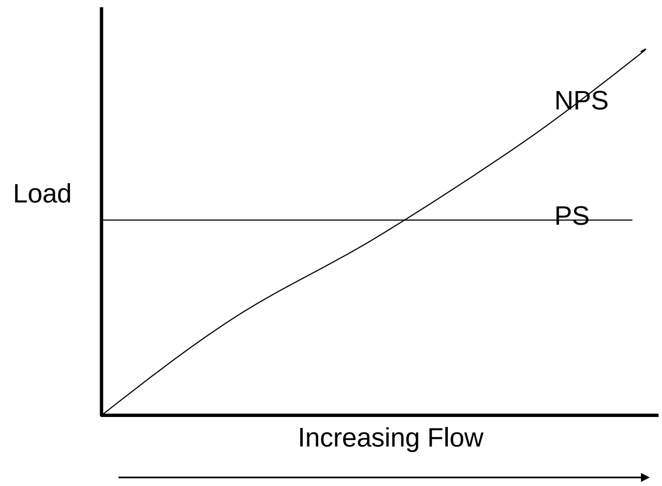


Figure 4-8. Expected Nutrient Loading Trends

<u>*Differential delivery factors for N and P*</u>

The Chesapeake Bay Watershed Model incorporates delivery factors to account for in-stream processes that may affect the relative contributions from watersheds near the Bay versus those from further upstream. Whereas transformations of P are relatively minimal because the majority of P is attached to sediment, the nitrification process works to decrease concentrations of dissolved N the longer it is in transit. This aspect was not investigated during this analysis but needs to be considered in order to maintain consistency between simulated and monitored nutrient concentrations.

- Is there a need to develop localized criteria in the Bay watershed?

If downstream criteria are more restrictive than localized criteria, then localized criteria may be superfluous and thus not needed. Localized nutrient criteria are needed if and when downstream-load targets are being met but upstream localized water quality impacts, such as algal blooms and associated low dissolved oxygen levels, are evident. One problem in determining if there is a need to develop localized criteria is that total load is what is important to downstream waters while concentrations govern localized impacts.

Figures 4-9 and 4-10 illustrate: 1.) The ranges of annual average concentrations of TN and TP, respectively, that satisfy downstream load targets, 2.) EPA ecoregion screening level concentrations, and 3.) the Academy of Natural Sciences (ANS) preliminary recommendations that represent potential localized nutrient criteria. The question is: Can we compare the fixed potential localized criteria with the indexed downstream concentrations and determine if the downstream criteria are more restrictive than the potential fixed localized criteria? If the potential localized criteria are all lower than the minimum downstream averages, it would be clear that localized criteria would be necessary to protect those stream segments. If all of the localized criteria were higher than the downstream averages, it might be reasonable to conclude that localized criteria would not be necessary. However, where the potential localized criteria fall between the minimum and averages or are inconsistent, it is unclear whether or not localized criteria are necessary.

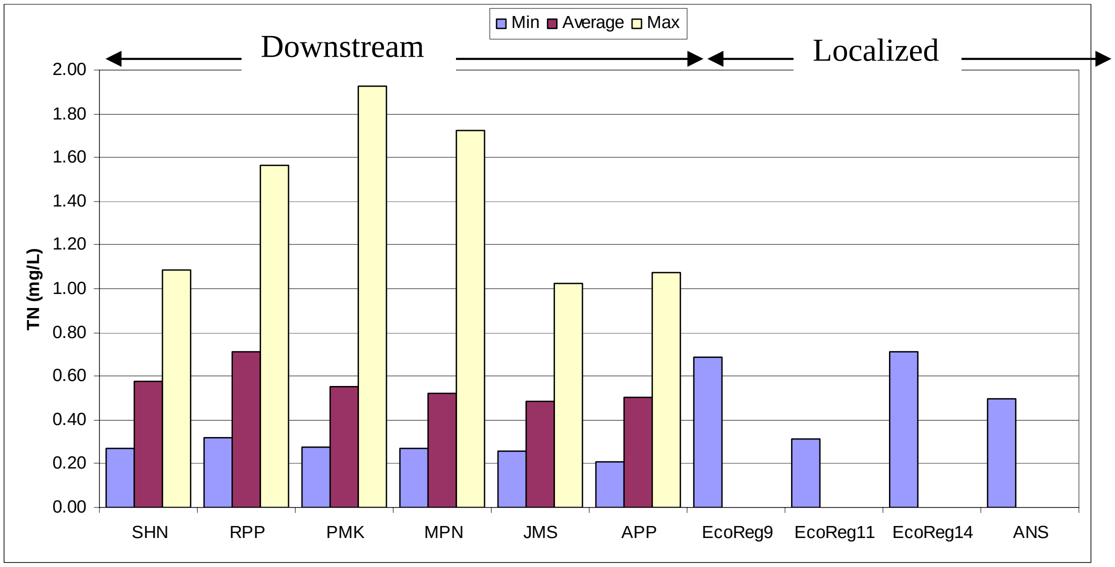


Figure 4-9. Potential Downstream and Localized TN Water Quality Criteria

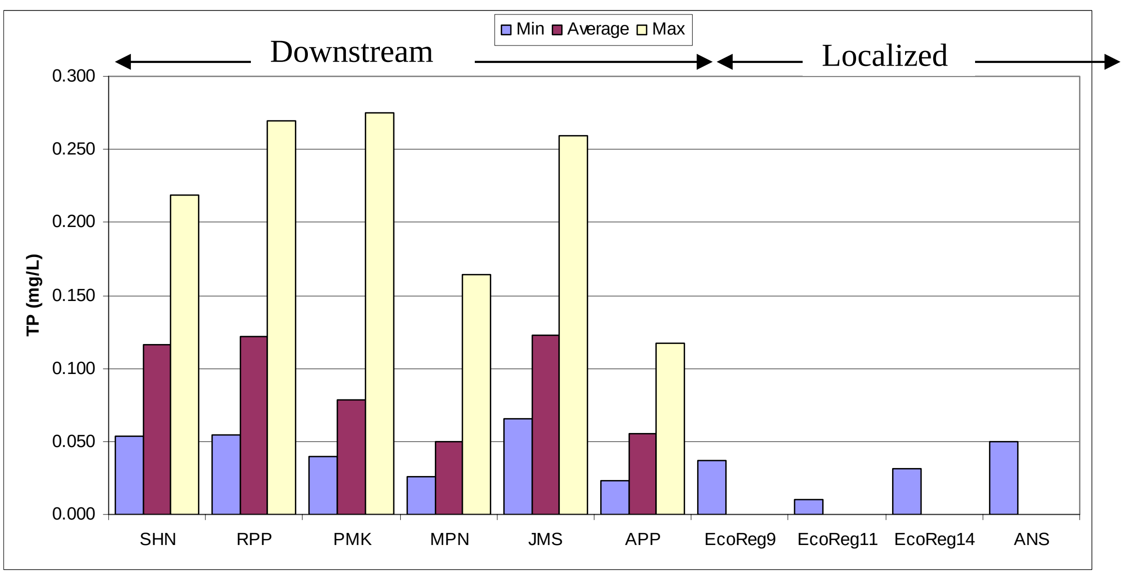


Figure 4-10. Potential Downstream and Localized TP Water Quality Criteria

For TN in Figure 4-9, all of the potential localized criteria are within the min-max ranges of the potential downstream criteria so localized impacts still might be experienced while downstream load targets are being met. For TP in Figure 4-10, some of the potential localized criteria are even lower than the min-max range of downstream target concentrations. If these localized criteria are applicable, they may indicate more of a need for localized TP criteria than for localized TN criteria.

Where localized criteria are developed, additional monitoring will be needed to assess compliance. In order to minimize the additional resources needed, a screening procedure as discussed in Section 3 of this report is needed to limit the additional monitoring to those situations where localized water quality is either not protected or indeterminate.

- What information is needed to develop downstream-loading criteria for non-Bay drainages?

Unless neighboring states have set nutrient load targets for waterbodies receiving flow from non-Bay drainages in Virginia (such as Albemarle-Pamlico Sound), downstream load targets will not be available on which to base “downstream load” limits and criteria. For streams outside the Bay drainage without a basis for load targets, downstream-loading criteria would be inappropriate. Therefore, in the non-Bay portion of the state (Southern Rivers), concentration targets would be more appropriate and could be applied to probability distributions of flows, and indexed to flow, similar to the procedure suggested for the Bay drainage area. Similarly, target concentrations could be based on the unique contributions of PS and NPS within each watershed. The spatial watershed unit should be consistent with the unit chosen for use in the Bay drainage area, either the NWBD watersheds or watersheds delineated to correspond with DEQ monitoring stations. Likewise, the same flow options could be used as in the Bay drainage – either based on interpolation/extrapolation from nearest USGS flow stations or based on simulated flows.

5. Data Analysis

Prepared by C. Zipper

AAC Task (5-1): Analyze DEQ ambient monitoring data to determine reference values (25th percentile of TN, TP, chlorophyll *a*, and turbidity) using procedures comparable to the EPA analyses applied to develop Guidance Criteria.

A complete record of ambient freshwater-streams monitoring data for the period 1995-2005 was obtained from DEQ (Roger Stewart). Although EPA recommends that a 10-year period be used to calculate reference values, we conducted our analyses over a six-year period extending from 10/1/99 – 9/30/05. This time period was used because consistent recording of TP at the 0.01 mg/L level of precision (as opposed to 0.1 mg/L) was initiated on 7/1/99. It is desirable to analyze all nutrient parameters over the same time period. Our analysis was applied to a period beginning 10/1/99 to utilize full-year periods and bring the dataset as close as possible to the present date.

All analyses were conducted over this six-year time frame using procedures outlined in EPA (2000c, d, and e). The dataset provided by DEQ was screened, and only data from monitoring locations listed as "Stream" and with latitude-longitude locations recorded in the database were utilized. Latitude-longitude coordinates were used to place each monitoring location within EPA's aggregate nutrient ecoregions (Figure 5-1). The stream ID for each monitoring location was defined using the first 5 digits of the 10-digit DEQ monitoring location code. All monitoring observations for TN, TP, chlorophyll *a*, and turbidity were grouped by stream ID and aggregate nutrient ecoregion.

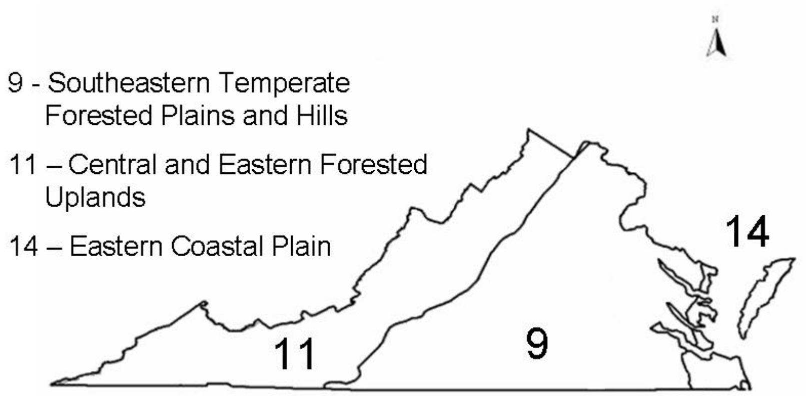


Figure 5-1. Virginia's Aggregate Nutrient Ecoregions

Each monitoring observation was characterized as occurring within the spring (Mar 21-Jun 20), summer (Jun 21-Sep 22), fall (Sep 23-Dec 21), or winter (Dec 22-Mar 20). For each parameter (TN, TP, Chl-a, and turbidity) and each season (spring, summer, fall, and winter), a median value was calculated for a given stream. Therefore, all data for a particular parameter during a particular season within a stream were reduced to one median value for that stream. This process ensured that streams with more monitoring data did not receive more representation in the database than streams with fewer data points. For each parameter, the distribution of the median values for all streams within a given ecoregion were then defined by calculating the 10th, 25th, 50th, 75th, and 90th percentiles for each season. An average of the derived median values was also calculated for each season. The ecoregion values were determined as the median of these seasonal means and percentiles. "Reference values" comparable to those calculated by EPA were defined as the 25th percentiles (Figure 5-2).

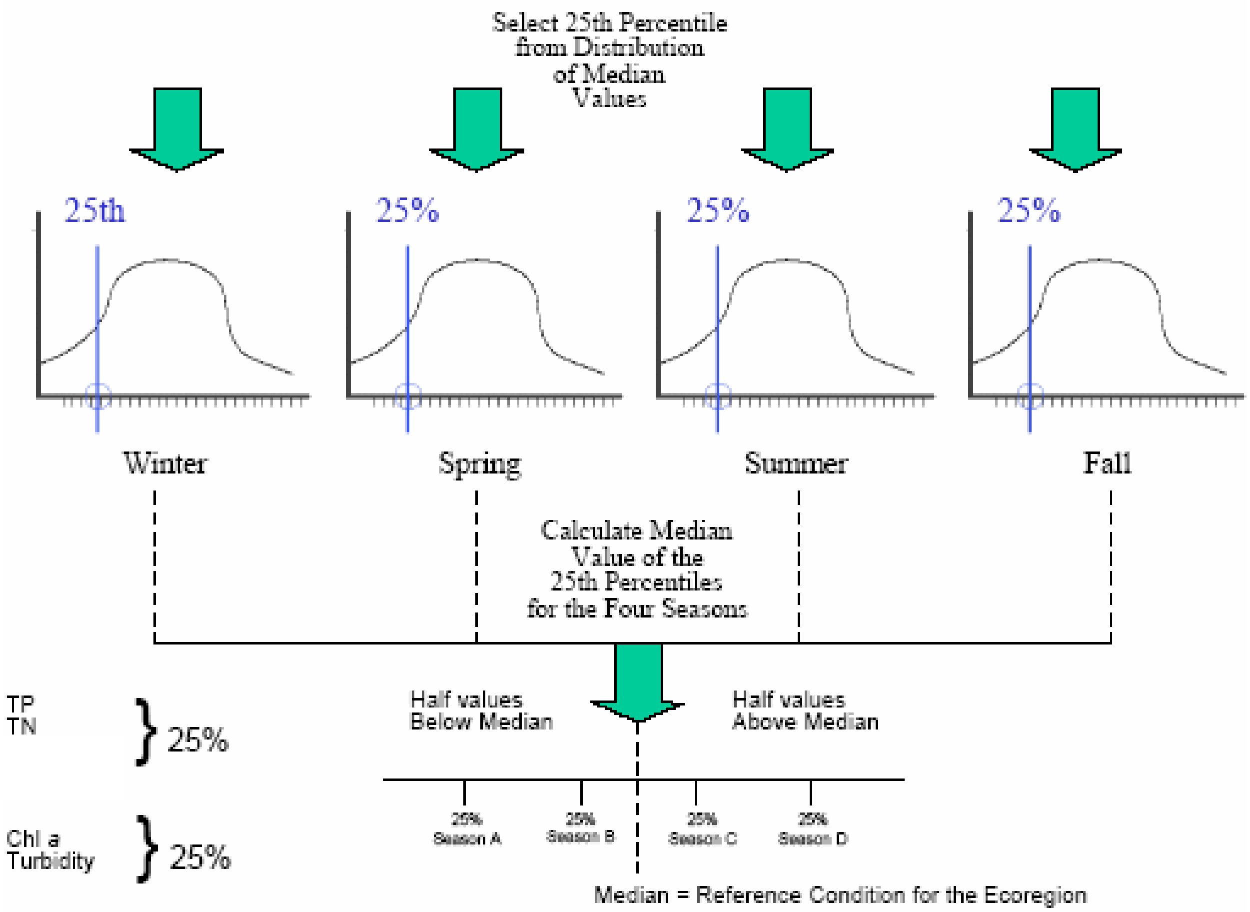


Figure 5-2. Illustration of reference condition calculation (From U.S. EPA 2000c).

Table 5-1 displays the results of the distributions of the nutrient parameters calculated from DEQ ambient monitoring data and EPA reference values for Aggregate Nutrient Ecoregions 11 (Central and Eastern Forested Uplands), 9 (Southeastern Temperate Forested Plains and Hills), and 14 (Eastern Coastal Plain). Each aggregate nutrient ecoregion within the contiguous U.S. contains several subecoregions. In Virginia, Aggregate Nutrient Ecoregions 11 and 9 contain three subecoregions, but Virginia's Aggregate Nutrient Ecoregion 14 contains only Subecoregion 63 (Mid-Atlantic Coastal Plain). Therefore, Table 5-1 includes EPA reference values (denoted as "EPA refs") for Subecoregion 63 as well as for Aggregate Nutrient Ecoregion 14.

Virginia's ambient 25th percentiles (P25s) for chlorophyll *a* are lower in all ecoregions than the corresponding EPA reference values (Table 5-1). For other parameters in Ecoregions 11 and 14 (TN, TP, and turbidity), Virginia P25s tend to be elevated relative to the corresponding EPA reference values. The TP data for Ecoregion 11 are an exception to this trend because the

P25 is equal to the analytical detection limit and to the EPA reference value. Ecoregion 14 ambient P25s for TN, TP, and turbidity are all elevated 30% or more above the corresponding Ecoregion 14 EPA reference value, but are only slightly elevated in comparison to the reference value for Subecoregion 63. In contrast, the P25s for TN, TP, and turbidity in Ecoregion 9 are all lower than the corresponding EPA reference values.

Table 5-1. Distributions of nutrient parameters calculated from DEQ ambient monitoring data, and EPA reference values.

	TN	TP	Chl-a	TURBH [b]	TURBN [c]
Ecoregion 11	(mg/L)	(mg/L)	(µg/L)	(FTU)	(NTU)
90th percentile	2.04	0.060	2.27	9.82	11.77
75th percentile	1.36	0.030	1.41	5.03	6.51
Mean	1.02	0.032	1.36	5.07	7.50
Median	0.72	0.018	0.94	3.04	3.94
25th percentile ($P25_{DEQ}$)	**0.38**	**0.010**	**0.63**	**1.85**	**2.58**
10th percentile	0.24	0.010	0.50	1.25	1.67
Count	337	339	182	246	251
EPA Ref (25th %tile)	**0.31**	**0.01**	**1.61** [a]	**1.70**	**2.30**
($P25_{DEQ}$ - EPA_{ref})/ EPA_{ref}	23%	0%	-61%	9%	12%
Ecoregion 9					
90th percentile	1.44	0.093	4.41	15.68	21.31
75th percentile	0.95	0.060	1.99	11.21	12.98
Mean	0.95	0.080	2.24	9.35	12.55
Median	0.63	0.038	1.18	7.25	8.48
25th percentile ($P25_{DEQ}$)	**0.45**	**0.025**	**0.738**	**4.90**	**5.93**
10th percentile	0.33	0.020	0.57	3.37	3.87
Count	600	605	225	396	397
EPA Ref (25th %tile)	**0.69**	**0.03656**	**0.93** [a]	**5.7**	
($P25_{DEQ}$ - EPA_{ref}) / EPA_{ref}	-34%	-32%	-21%	-14%	
Ecoregion 14					
90th percentile	4.63	0.178	16.4	18.53	19.26
75th percentile	1.93	0.105	11.7	14.87	13.90
Mean	3.59	0.169	8.6	11.31	13.26
Median	1.23	0.085	5.1	8.42	8.83
25th percentile ($P25_{DEQ}$)	**0.92**	**0.054**	**2.1**	**5.52**	**6.21**
10th percentile	0.77	0.040	1.0	4.01	4.18
Count	57	57	33	48	42
EPA Ref (Eco 14)	**0.71**	**0.031**	**3.75** [a]	**3.04**	
($P25_{DEQ}$ - EPA_{ref}) / EPA_{ref}	30%	74%	-45%	81%	
EPA Ref (Sub 63)	**0.87**	**0.0525**	**3.75** [a]	**4.50**	
($P25_{DEQ}$ - EPA_{ref}) / EPA_{ref}	6%	4%	-45%	23%	

a. Spectrophotometric
b. Hach turbidity (Storet 00076)
c. Nephelometric turbidity (Storet 82078)

AAC Task (5-2): Analyze DEQ probabilistic monitoring data to determine 25th percentile "reference values" for TN, TP, chlorophyll *a*, and turbidity.

Results of DEQ probabilistic monitoring over the period from 2001 through 2004 were obtained from DEQ (Jason Hill) and grouped by aggregate nutrient ecoregion. The distributions of TN, TP, planktonic chlorophyll *a*, and turbidity values at each location were characterized by defining the 10th, 25th, 50th, 75th, and 90th percentiles, and the mean. Distributions of the periphytic (benthic) biomass data were defined as well, however, data were only available for selected sites and monitored only in 2004.

Table 5-2 displays the results of the distributions of nutrient parameters for Virginia DEQ probabilistic monitoring sites. Because only two of the probabilistic monitoring locations were within Ecoregion 9, distributional statistics were calculated only for Ecoregions 11 and 14. In both ecoregions, the P25s of the probabilistic monitoring data compare favorably to (are lower than) the EPA references for all parameters except for TP in Ecoregion 11. For this parameter, the DEQ P25 is the analytical detection limit and tied with the EPA reference value. The EPA reference values for benthic chlorophyll *a* were calculated from limited datasets (n = 7 for Ecoregion 11, n = 6 for Ecoregion 14).

Table 5-2. Distributions of nutrient parameters by ecoregion[a] calculated from DEQ probabilistic monitoring data (2001 -2004). Benthic chlorophyll data are from 2004 only.

	TN	TP	Chl-a	Turb-H[a]	Turb-N[b]	Benthic Chl-a
Ecoregion 11	(mg/L)	(mg/L)	(µg/L)	(FTU)	(NTU)	(mg/m^2)
90th percentile	1.054	0.026	2.51	4.58	8.48	101.7
75th percentile	0.79	0.02	1.49	2.90	4.70	54.6
Average	0.592	0.017	1.11	2.53	4.47	37.3
Median	0.46	0.01*	0.61	1.54	2.60	18.9
25th percentile	**0.265**	**0.01***	**0.5***	**1.10**	**1.90**	**7.3**[a]
10th percentile	0.15	0.01*	0.5*	0.85	1.20	3.0
Count	95	95	93	25	69	16
EPA Ref (25th %tile)	**0.31**	**0.01**	**1.61**	**1.70**	**2.30**	**32.5**[c]
($P25_{DEQ}$ - EPA_{ref}) / EPA_{ref}	-15%	0%	-69%	-35%	-17%	-78%
Ecoregion 14						
90th percentile	1.34	0.10	3.72	10.30	19.00	66.4
75th percentile	0.78	0.06	2.12	7.22	12.00	49.6
Average	1.10	0.075	2.47	6.31	10.21	33.1
Median	0.545	0.03	1.16	4.34	7.60	26.7
25th percentile	**0.35**	**0.02**	**0.50**	**2.87**	**5.00**	**11.9**[b]
10th percentile	0.25	0.01*	0.5*	1.73	3.64	9.5
Count	136	136	134	31	105	16
EPA Ref (25th %tile)	**0.69**	**0.03656**	**0.93**	**5.7**		**20.35**[d]
($P25_{DEQ}$ - EPA_{ref}) / EPA_{ref}	-50%	-45%	-46%	-50%		-42%

* = analytical detection limits
a. Hach turbidity (Storet 00076) – 2001 data
b. Nephelometric turbidity (Storet 82078) – 2002-04 data
c. Calculated from small sample (n = 7 streams).
d. Calculated from small sample (n = 6 streams).

AAC Task (5-3): Analyze DEQ ambient monitoring data, and compare recent monitoring results to the above-determined values.

DEQ ambient monitoring data were analyzed as described in Task 5-1, and DEQ probabilistic monitoring data were analyzed as described in Task 5-2. Figure 5-3 displays comparisons of the distributions of DEQ ambient and probabilistic-monitoring data to EPA reference values for TN, TP, and suspended chlorophyll *a*. Ecoregion 11 ambient monitoring distributions for TN and TP represent higher nutrient levels than the probabilistic monitoring distributions. A major reason for the difference is the large number of monitoring sites in the Shenandoah watershed. Approximately 22% of the Ecoregion 11 streams represented in the ambient monitoring database are in basin 1B (Shenandoah) compared to 12% for the probabilistic monitoring. In both datasets, the Shenandoah monitoring sites exhibited higher mean nutrient levels than sites in other basins.

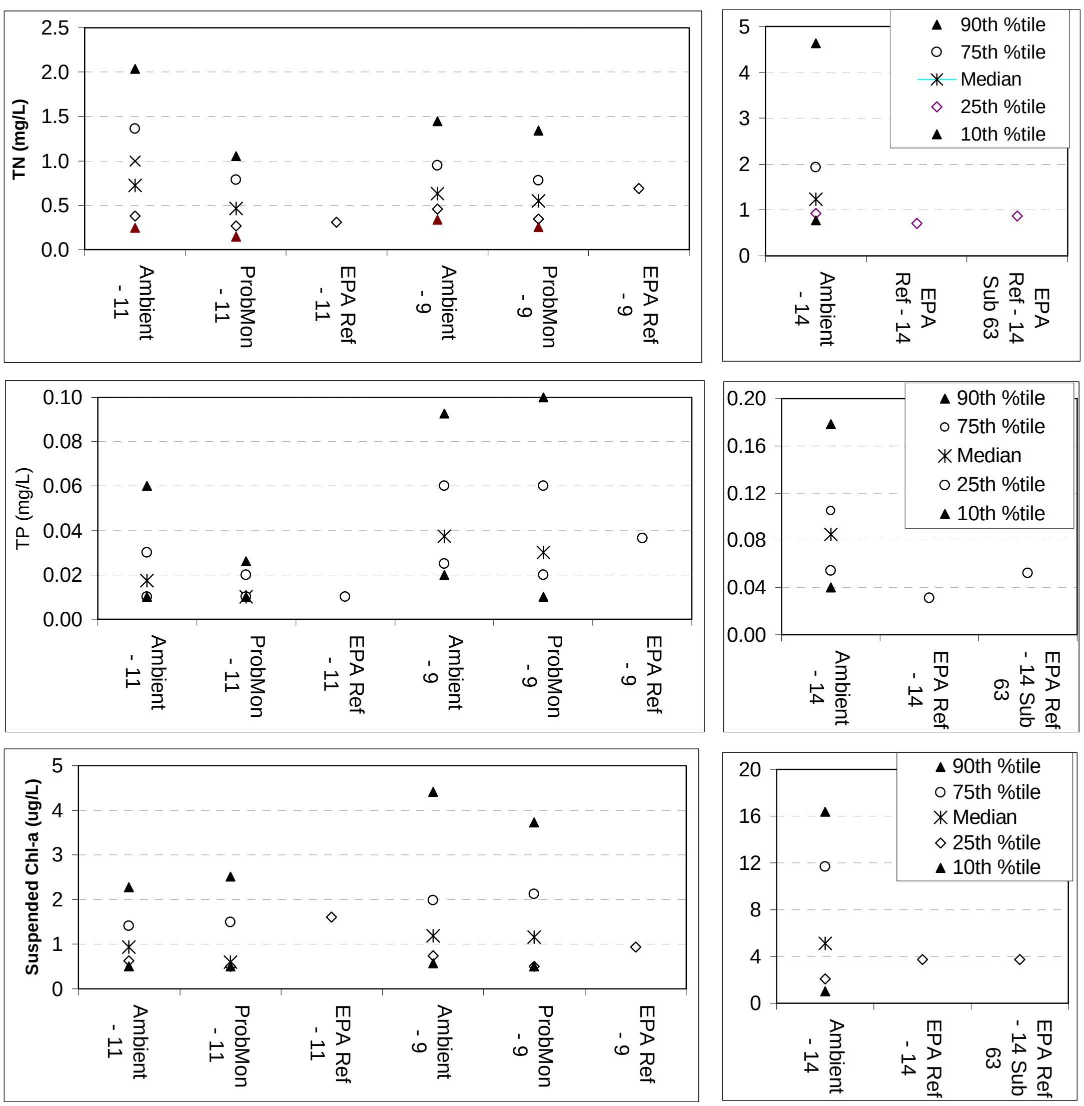


Figure 5-3. Comparison of the distributions of DEQ ambient and probabilistic-monitoring data to EPA reference values for TN, TP, and suspended chlorophyll *a*.

AAC Task (5-4): Analyze Chesapeake Bay Model 4.3 output to determine nutrient levels under the "Tributary Strategy" scenario intended to achieve Bay nutrient criteria.

Simulated TN and TP concentration values, produced as output from a Chesapeake Bay Watershed Model (CBWM) 4.3 "tributary strategy" simulation extending from 1/1/84 – 12/31/97, were obtained from the Chesapeake Bay Program (Gary Shenk) for Virginia model segments. The distribution of simulated values at each location was characterized by defining the 10th, 25th, 50th, 75th, and 90th percentile values, and the mean. Data are reported only for watershed outlet points.

Six DEQ monitoring stations coincident with or close to the CBWM 4.3 simulation points were identified, and data from these stations were analyzed. Where data were available for more than one monitoring location relatively close to a CBWM 4.3 segment outfall, the location with the most complete data record was selected for analysis. Figure 5-4 shows the Bay model segments and DEQ monitoring stations used in this report. The DEQ monitoring points are located close to the lower segment outfalls for the Mattaponi, Pamunkey, James, and Appomattox watersheds. The Rappahannock monitoring station used for analysis is located about 30 miles upstream from the CBWM segment outfall. The Shenandoah monitoring station used for analysis is close to the Virginia/West Virginia border but is somewhat upstream from the segment outfall (Figure 5-4).

For each chosen DEQ station, distributional statistics were calculated from the complete data record extending from 10/1/99 – 9/30/05. This period was selected for analysis for the reasons described under Task 5-1. The numbers of observations available from the Pamunkey and Mattaponi monitoring stations used for this analysis were small, compared to observation numbers available at the other locations.

Table 5-3 and Figure 5-5 show a comparison of CBWM 4.3 Tributary Strategy simulation output to DEQ ambient TN and TP monitoring data. For most comparisons (all but TP in the Rappahannock), DEQ ambient monitoring concentrations tend to be higher than those of the tributary strategy simulations.

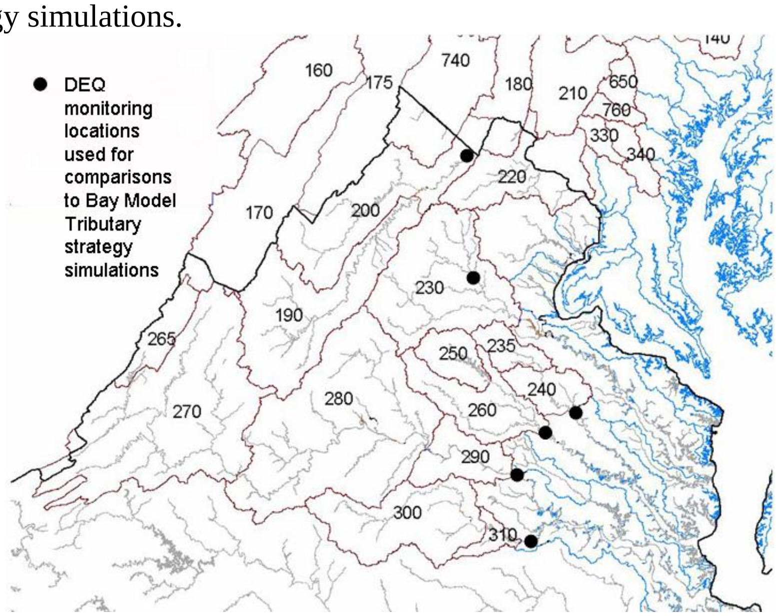
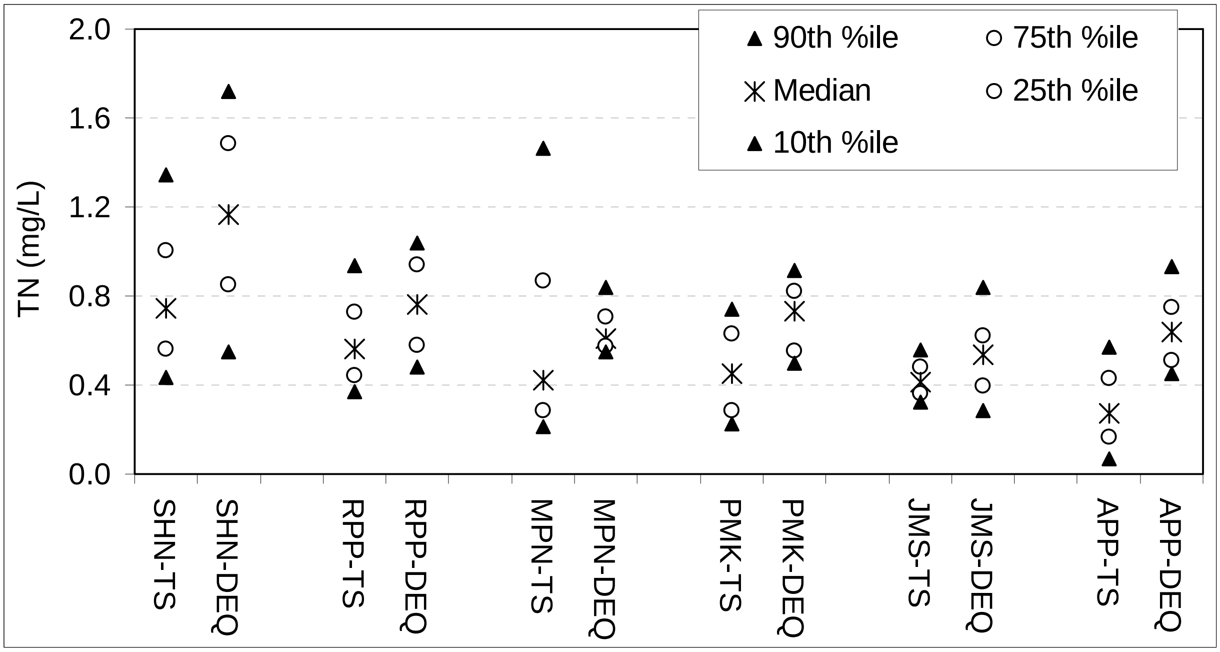


Figure 5-4. Chesapeake Bay Watershed Model 4.3 Virginia segments, and locations of DEQ monitoring stations used for comparisons to tributary strategy simulations.

Table 5-3. Comparison of DEQ ambient monitoring TN and TP levels (10/99 – 9/05) to Bay Model Tributary Strategy simulations (ts).

Watershed	**Shenan-doah**	**Rappa-hannock**	**Matta-poni**	**Pamun-key**	**James**	**Appo-mattox**
Bay Model Segment	200	230	240	260	290	310
DEQ Station	1BSHN 022.63	3-RPP 147.10	8-MPN 054.17	8-PMK 082.34	2-JMS 117.35	2-APP 012.79
Total N - Bay Model Trib Strategy						
90th Percentile	1.34	0.94	1.46	0.74	0.56	0.57
75th Percentile	1.01	0.73	0.87	0.63	0.48	0.43
Mean (Mean $_{ts}$)	0.83	0.61	0.65	0.47	0.43	0.30
Median	0.75	0.56	0.42	0.45	0.41	0.27
25th Percentile	0.56	0.44	0.28	0.29	0.36	0.17
10th Percentile	0.44	0.37	0.21	0.23	0.32	0.07
Total N - DEQ Monitoring						
90th Percentile	1.72	1.04	0.84	0.92	0.84	0.93
75th Percentile	1.49	0.94	0.71	0.82	0.62	0.75
Mean (Mean $_{DEQ}$)	1.16	0.79	0.72	0.71	0.55	0.68
Median	1.17	0.76	0.61	0.73	0.54	0.64
25th Percentile	0.85	0.58	0.58	0.56	0.40	0.51
10th Percentile	0.55	0.48	0.55	0.50	0.28	0.45
No. of Observations	50	40	22	15	52	45
$(Mean_{DEQ} - Mean_{ts}) / Mean_{ts}$	40%	29%	11%	50%	29%	125%
Total P - Bay Model Trib Strategy						
90th Percentile	0.07	0.10	0.07	0.06	0.12	0.07
75th Percentile	0.03	0.04	0.04	0.05	0.07	0.05
Mean (Mean $_{ts}$)	0.04	0.04	0.04	0.04	0.07	0.04
Median	0.02	0.02	0.02	0.04	0.05	0.03
25th Percentile	0.01	0.02	0.02	0.03	0.04	0.01
10th Percentile	0.01	0.02	0.02	0.03	0.03	0.01
Total P - DEQ Monitoring						
90th Percentile	0.15	0.09	0.08	0.17	0.11	0.07
75th Percentile	0.12	0.04	0.06	0.10	0.08	0.05
Mean (Mean $_{DEQ}$)	0.09	0.04	0.05	0.09	0.09	0.05
Median	0.08	0.04	0.05	0.07	0.06	0.04
25th Percentile	0.06	0.02	0.04	0.07	0.05	0.03
10th Percentile	0.03	0.02	0.03	0.05	0.04	0.02
No. of Observations	51	38	22	15	52	45
$(Mean_{DEQ} - Mean_{ts}) / Mean_{ts}$	141%	-3%	46%	107%	27%	49%
Mean Streamflow						
USGS gage	1636500	1668000	1674500	1673000	2035000	2041650
1/1/84 – 12/31/97 (ts)	3077	1818	580	1095	7646	1245
10/1/99 – 9/30/05 (DEQ)	2887	1740	483	889	6615	1298



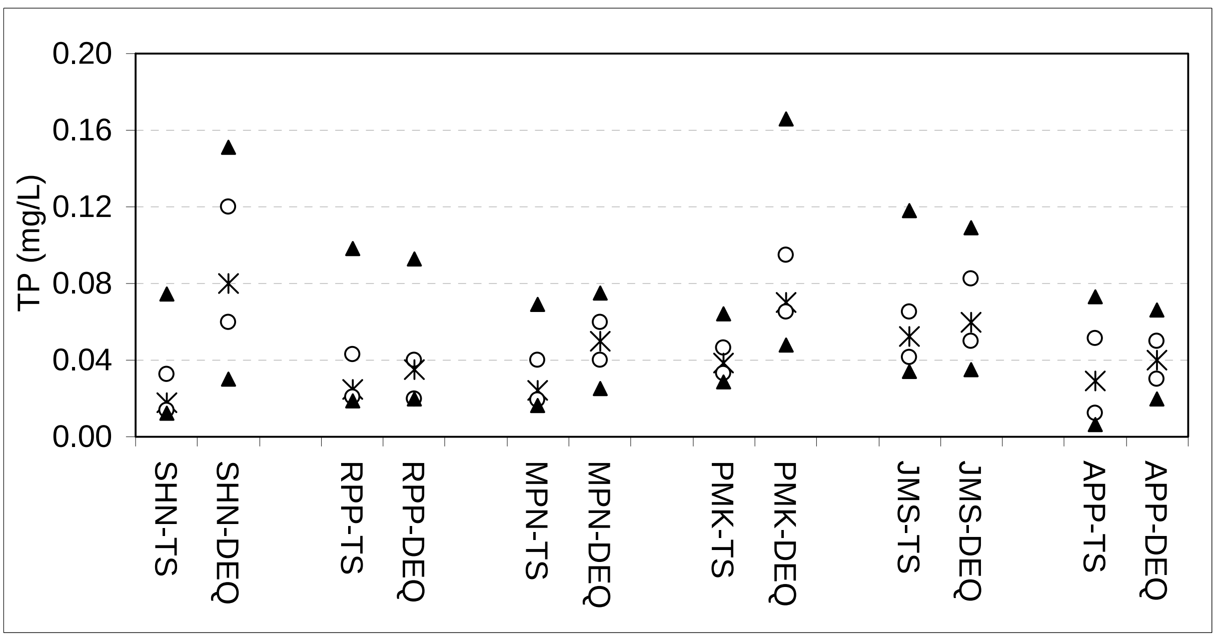


Figure 5-5. Percentile distributions of TN and TP concentrations for Chesapeake Bay Watershed Model tributary strategy simulations (TS) and DEQ ambient monitoring (10/99 – 9/05). SHN = Shenandoah; RPP = Rappahannock; MPN = Mattaponi; PMK = Pamunkey; JMS = James; APP = Appomattox

6. Statistical Issues

Prepared by Eric P. Smith

AAC Task (6-1): Evaluate of the use of cumulative frequency distributions as a means of establishing criteria for rivers and streams.

The April 2003 EPA report "Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll *a* for the Chesapeake Bay and its Tidal Tributaries" (U.S. EPA, 2003) describes an approach for evaluating these criteria based on a spatial and temporal frequency of violation (Figure 6-1). The DEQ adopted this approach for evaluating these criteria for the Chesapeake Bay and its tidal tributaries. The regulation states that in the absence of a published reference cumulative frequency distribution, the DEQ will utilize a cumulative frequency distribution that represents a 10% spatial/temporal allowable excursion frequency.

The method is innovative in the sense that violations over space and time are used to produce an estimate of the cumulative frequency of violation. By incorporating a spatial component, the method changes focus from the traditional single site approach to a regional approach. There is no reason why this approach could not be used with a probabilistic sampling program to produce regional violation curves. However, before implementing such a procedure, DEQ is advised to consider uncertainties in the methodology.

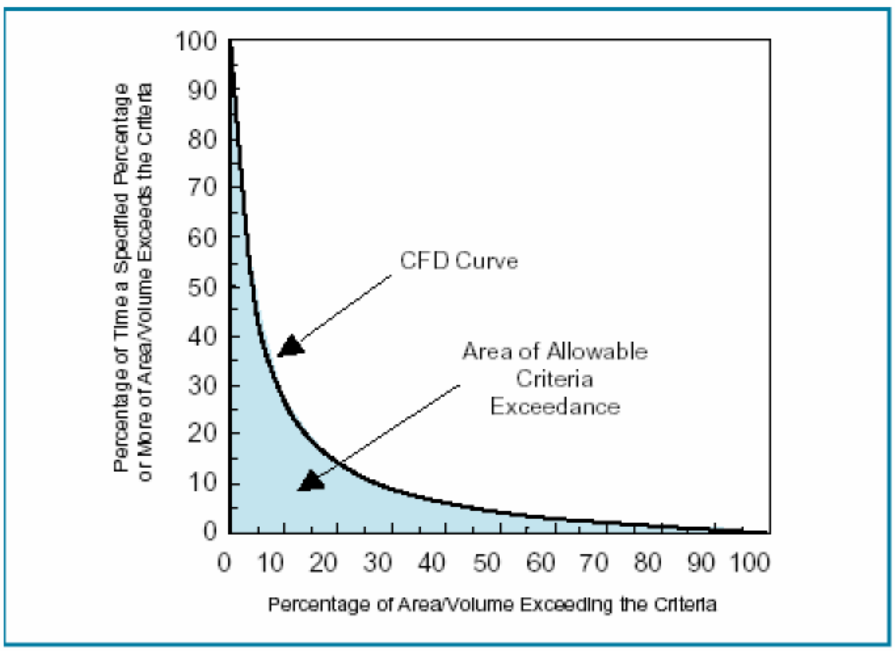


Figure 6-1. Cumulative frequency distribution (CFD) curve in the shape of a hyperbolic curve that represents approximately 10 percent allowable exceedances equally distributed between time and space (Figure VI-18 in U.S. EPA, 2003).

The method does not account for the uncertainty in monitoring. Uncertainty in monitoring includes, but is not limited to, the location and number of the sites where samples are taken as well as the number of samples collected and the dates of sample collection. The proposed method combines all the data from a region to produce a single curve that is used as either a test or reference. To be effective, there must be sufficient reference information to compute a reference curve that represents background information under a "natural" state (note that some sites may be in violation). How reference conditions are defined is clearly important. The number of reference sites is also important as it defines the uncertainty in the reference distribution. Clearly data collected during a monthly program will have more information than data collected annually. This uncertainty, however, is not part of the decision process. I view this as a major limitation. The alternative is to develop a data-free reference curve that might be based on the binomial approach. The U.S. EPA (2003) report provides two such curves in figures VI-14 (Figure 6-2 in this report) and VI-18 (Figure 6-1 in this report).

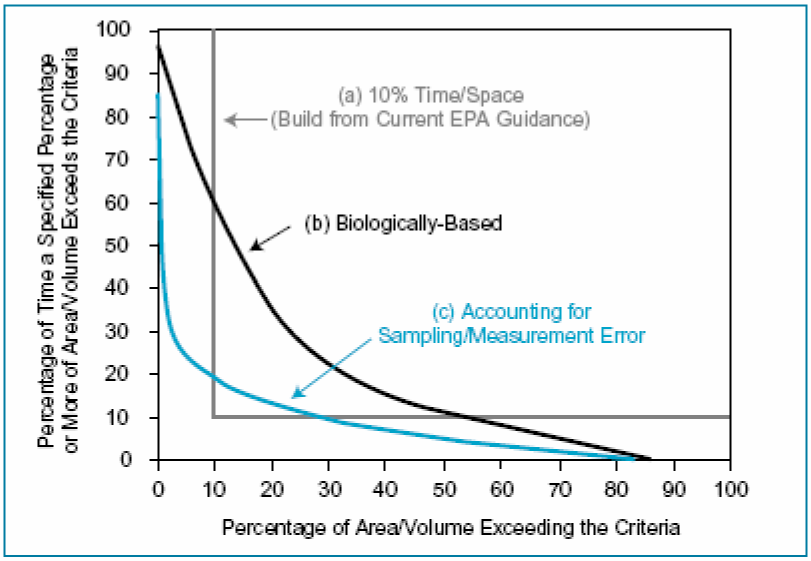


Figure 6-2. Three possible options for setting reference curves for application to the cumulative frequency distribution approach for defining criteria attainment: (a) fixed percentages based on policy decisions; (b) biological effects-based empirical field or laboratory data and; (c) observed or estimated uncertainty data (Figure VI-14 in U.S. EPA, 2003).

The EPA report alludes to a statistical test for comparing a reference distribution with a test distribution, however, the details are not provided in the report. In cases where there is not enough data to produce a reference curve, the document suggests using a curve that accounts for measurement and sampling error (Figure 6-2) or using "10% allowable exceedances equally distributed between time and space" (page 172; U.S. EPA, 2003) (Figure 6-1). Although the text refers to Figure VI-18 (Figure 6-1 in this report) as a normal distribution reference curve (page 171; U.S. EPA, 2003), it is not clear how this curve was developed or what the curve has to do with a normal distribution. My opinion, without having further information, is that the figures are somewhat similar to what I would expect for a Binomial model using a probability of violation of 0.1 with a moderate sized spatial grid (100 cells) and 12 sampling times (quarterly sampling over three years).

As indicated in the EPA report, the collection of reference data is sometimes hard to accomplish and hence deriving reference curves will be difficult. Use of biological data, where sampling may be once or twice a year, may therefore lead to the use of the non-empirical curve. Relative to a raw-score approach, which is a simple 10% rule (Figure 6-2), the sampling error approach is more likely to find a violation unless the spatial and temporal violations are around 10-30%.

As a side note, it is wrong from a statistical perspective to refer to these curves as cumulative frequency distributions (CFD) because there is no accumulation. Rather, they are reliability functions or survivor functions, as high violation rates are connected to low probability. Cumulative distribution functions have a rather strict definition in terms of accumulating probability.

In addition to the issues discussed above, an obstacle to applying this concept, which was developed for application in the Chesapeake Bay, to rivers and streams concerns differences in the physical nature of these water resources. The CFD approach addresses variability by combining its temporal and spatial/volumetric components for assessment. This method becomes necessary in a waterbody such as the Bay where the water-monitoring is essentially a three-dimensional (or four-dimensional, including time) activity. With the CFD approach, data from all four dimensions are combined to assess the Bay's impairment status. The DEQ monitoring program approaches rivers and streams differently, with the location of each monitoring point representing a single stream reach or segment. A CFD approach could be applied by changing the monitoring and assessment unit from a stream segment to a larger geographic unit such as a stream network or basin. Such a change would have the implicit effect of allowing the potential for persistent numeric-criteria exceedances in a small area, if that area was combined with "cleaner" areas for the purpose of monitoring and assessment. Whether or not such a result would be allowable under the Clean Water Act would then become a policy judgment.

AAC Task (6-2): Evaluate the "10% rule" as a means of determining nutrient criteria exceedances.

This topic has been addressed previously (Smith *et al.*, 2001). The concepts developed in that article (abstract below) could be applied to nutrients. There are also other approaches to the problem that would declare a violation based on magnitude of exceedance rather than frequency of exceedance (Smith *et al.*, 2003).

> **Abstract:** Section 303(d) of the Clean Water Act requires states to assess the condition of their waters and to implement plans to improve the quality of waters identified as impaired. U.S. Environmental Protection Agency guidelines require a stream segment to be listed as impaired when greater than 10% of the measurements of water quality conditions exceed numeric criteria. This can be termed a "raw score" assessment approach. Water quality measurements are samples taken from a population of water quality conditions. Concentrations of pollutants vary naturally, measurement errors may be made, and occasional violations of a standard may be tolerable. Therefore, it is reasonable to view the

assessment process as a statistical decision problem. Assessment of water quality conditions must be cognizant of the possibility of type I (a false declaration of standards violation) and type II (a false declaration of no violation) errors. The raw score approach is shown to have a high type I error rate. Alternatives to the raw score approach are the Binomial test and the Bayesian Binomial approach. These methods use the same information to make decisions but allow for control of the error rates. The two statistical methods differ based on consideration of prior information about violation. Falsely concluding that a water segment is impaired results in unnecessary planning and pollution control implementation costs. On the other hand, falsely concluding that a segment is not impaired may pose a risk to human health or to the services of the aquatic environment. An approach that recognizes type I and type II error in the water quality assessment process is suggested.

Acknowledgements

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