Recommended Nutrient Criteria for West Virginia Lakes

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1 Executive Summary

West Virginia must establish nutrient criteria under a mandate from the United States Environmental Protection Agency (USEPA). USEPA has invited states to either accept criteria that it suggests, or to propose different standards and to provide a scientific analysis demonstrating that those standards will be protective.

The Nutrient Criteria Committee (NCC) was established as a technical working group by the West Virginia Environmental Quality Board in 2002 and was charged with recommending nutrient criteria for lakes and reservoirs and for rivers and streams. In 2005, rulemaking authority for water quality standards was transferred to the West Virginia Department of Environmental Protection (WVDEP). The authors of this document are all members of the NCC.

The NCC decided to focus first on developing nutrient criteria for lakes and reservoirs, and to focus later on rivers and streams. This document is being submitted by the West Virginia Rivers Coalition, the Cacapon Institute, the Conservation Fund's Freshwater Institute, and the Appalachian Center for the Economy and the Environment upon request to WVDEP for its consideration in proposing defensible criteria to the legislature and to USEPA.

These organizations recognize both the legal mandate for West Virginia to set criteria to protect the designated uses of lakes and reservoirs, and also the important economic, social and environmental consequences of that action. In light of our mandate, the organizations recommend that WVDEP reject the criteria proposed by USEPA as too stringent. Instead, the weight of evidence indicates that standards considerably higher than those proposed by USEPA will be adequately protective of our water bodies.

Based on analyses of West Virginia data, phosphorus criteria should be between 23 and 53 ug/L, but because of data gaps it is not possible to derive one single number in this range. The number that is ultimately chosen depends on how much risk of harm is to be tolerated. A TP criterion near the low end of the range—30 ug/L mean—should protect cold and cool water lakes from most if not all harms due to nutrients. A TP criterion at the top of the range—50 ug/L mean—may well protect warm water lakes from harm, but is unlikely to protect cool or cold water lakes. **We recommend TP criteria of 30 ug/L mean for cool water lakes and 50 ug/L mean for warm water lakes.**

Chlorophyll a criteria should also be different for cool and warm water lakes. **We recommend chlorophyll a criteria of 10 ug/L mean for cool water lakes and 25 ug/L mean for warm water lakes.**

These criteria are only sufficient if a comprehensive list of cool water lakes is included in the rule. We propose such a list in Section 7.

Expressing all nutrient criteria as means as opposed to percentiles is also crucial, as this will allow WVDEP to implement the criteria in assessment and permitting decisions.

USEPA's recommendations and those proposed in this report are shown in the following table.

Lake and reservoir criteria recommended for West Virginia

Recommended by	Designated use	TP (not to exceed)	Chlorophyll a (not to exceed)	Secchi depth (not less than)	TN (not to exceed)
USEPA	Not specified	8 µg/L	2.8 µg/L	9.4 feet	0.46 mg/L
This report	B and C, Cool water	30 µg/L	10 µg/L	None	None
This report	B and C, Warm water	50 µg/L	25 µg/L	None	None

Note: USEPA recommendations from USEPA (2000a). The USEPA recommendation for Secchi depth of 2.86 meters is converted to 9.4 feet. USEPA's chlorophyll a recommendation is rounded.

2 Introduction

USEPA now requires states to develop nutrient criteria. If no state action is taken, USEPA plans to impose ecoregion-based criteria already derived for TP, total nitrogen (TN), chlorophyll a, and Secchi depth (USEPA, 2000a). These standards for Ecoregion XI, in which West Virginia is located, are listed in Table 1.

Table 1: Lake and reservoir criteria recommended for West Virginia

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In 2002, the West Virginia Environmental Quality Board convened the NCC, a technical working group, to study the issue and to recommend criteria that would protect designated uses of West Virginia's waters. The committee consists of representatives of industry, municipalities, conservation groups, agriculture, and forestry, as well as various agencies, and has generally met monthly. In 2005, the Governor executed Senate Bill 287, which transferred the authority to set forth rules relating to water quality standards to WVDEP.

The NCC decided to focus first on developing nutrient criteria for lakes and reservoirs, and to focus later on rivers and streams. This document is being submitted by the West Virginia Rivers Coalition, the Cacapon Institute, the Conservation Fund's Freshwater Institute, and the Appalachian Center for the Economy and the Environment upon request to WVDEP for its consideration in proposing defensible criteria to the legislature and to USEPA.

These organizations recognize both the legal mandate for West Virginia to set criteria to protect the designated uses of lakes and reservoirs, and also the important economic, social and environmental consequences of that action. In light of our mandate, the organizations recommend that WVDEP reject the criteria proposed by USEPA as too stringent. Instead, the weight of evidence indicates that standards considerably higher than those proposed by USEPA will be adequately protective of our water bodies.

Based on analyses of West Virginia data, phosphorus criteria should be between 23 and 53 ug/L, but because of data gaps it is not possible to derive one single number in this range. The number that is ultimately chosen depends on how much risk of harm is to be tolerated. A TP criterion near the low end of the range—30 ug/L mean—should protect cold and cool water lakes from most if not all harms due to nutrients. A TP criterion at the top of the range—50 ug/L mean—may well protect warm water lakes from harm, but is unlikely to protect cool or cold water lakes. **We recommend TP criteria of 30 ug/L mean for cool water lakes and 50 ug/L mean for warm water lakes.**

Chlorophyll a criteria should also be different for cool and warm water lakes. **We recommend chlorophyll a criteria of 10 ug/L mean for cool water lakes and 25 ug/L mean for warm water lakes.**

These criteria are only sufficient if a comprehensive list of cool water lakes is included in the rule. We propose such a list in Section 7.

Expressing all nutrient criteria as means as opposed to percentiles is also crucial, as this will allow WVDEP to implement the criteria in assessment and permitting decisions.

The mission of the NCC is to propose nutrient standards that will protect the designated uses of West Virginia's waters, and that can be justified using scientific analyses. The standards will protect waters in three roles. First, they will be used to identify appropriate discharge limitations for National Pollutant Discharge Elimination System permits, so that no permitted discharge will cause or contribute to an impairment of a water body. Second, they will be used as assessment tools for the 303(d) and 305(b) reports. Third, for impaired waters, nutrient criteria will be used as clear objectives for total maximum daily loads designed to restore water quality and meet the designated uses.

This document reviews the risks that nutrient over-enrichment poses to West Virginia's waters and their designated uses. It then summarizes the analyses the NCC performed to determine protective nutrient levels. These analyses led to a number of numerical results. After examining the level of risk to designated uses associated with each numerical result, this report then chooses specific criteria based on a weight-of-evidence approach. Based on that careful weighing of risks and benefits of different numerical standard levels, the authors propose language for the actual criteria.

3 Guidelines adopted by the NCC

NCC adopted certain principles to guide it as it selected nutrient standards.

First, the NCC agreed that it was very important to carefully set criteria so that waters would be accurately assessed. Clearly, setting criteria too low would mean unwanted and unnecessary expense for both dischargers and agencies. Setting criteria too high would mean that West Virginia would unnecessarily suffer the consequences of increased nutrient pollution such as decreased recreational enjoyment and harm to aquatic life.

Second, NCC agreed to address lakes and reservoirs in its first efforts, and to propose standards for rivers and streams for later legislative cycles.

Finally, NCC adopted certain definitions of impairment, summarized in Table 2.

Table 2: The Nutrient Criteria Committee's definitions of use impairment

Designated use	Definition of impairment
Category B Propagation and maintenance of fish and other aquatic life	A water of the State fails to attain this use if nutrients directly or indirectly cause a shift in community integrity. A shift in community integrity is defined as increasing or decreasing the relative abundance of species or diversity of indigenous communities of fish, shellfish, other aquatic life, or wildlife - outside the normal range of variability.
Category C Water contact recreation	A water body is impaired if nutrients directly or indirectly cause nuisance algae, unacceptable water clarity, unacceptable odor, or unacceptable microbial growth.

4 Scientific background

Nutrients may impair the designated uses of surface waters in a number of ways, and standards would ideally be developed with each mechanism in mind. Some harms occur with higher or lower levels of nutrients. The lake criteria that are ultimately chosen must address all of the harms enumerated in this section..

4.1 Hypoxia due to eutrophication

A large number of possible impairment scenarios are based on the consumption of oxygen in the hypolimnia of lakes. Biomass, mostly algal, sinks to the bottom of lakes and fuels the oxygen consumption. Anoxia in the hypolimnion can contribute to hypoxia in the epilimnion, as described below. Preventing additions of nutrients—especially P—to lakes will prevent hypoxia from anthropogenic sources. The current dissolved oxygen (DO) standard for West Virginia lakes other than trout waters is 5 mg/L; this value must be protected at all times in lakes, even after lake layers mix in the fall.

The NCC shared a number of observations concerning the effort to prevent hypoxia by enforcing TP standards:

- A TP standard that is based on a DO standard is useful for preventing conditions that may lead to violations of the DO standard.
- DO levels in the epilimnia of lakes are related to those in the hypolimnia. Diffusion to the hypolimnion is a constant oxygen sink for the epilimnion. Furthermore, mixing between epilimnion and hypolimnion may cause regions of a lake or entire lakes to violate the 5 mg/L DO standard.
- DO levels are highest during the day when photosynthetic organisms, especially algae, are active. DO levels are lowest just before dawn, when respiration of the entire community, including the algae, has depleted some of oxygen added to the lake during the previous day. Standards protecting DO must take into account that the pre-dawn period is critical. Data obtained by the NCC documented diel fluctuations exceeding 3 mg/L.
- An average TP concentration is a reasonable way to characterize the status of lakes. While the median value is less influenced by episodic extremely high concentrations, the high inputs that those high numbers represent will have an important effect on the nutrient balance of the lake.
- DO values respond to many factors, including average temperatures and retention time. An adequate TP standard will protect lakes not only in average years but also in unusually hot years with unusually low flows.
- Some fish species require colder water to survive year-round. Hypolimnia in certain lakes may provide sufficient volumes of cold water for these fish, but only if they maintain adequate DO concentrations. Cold and cool water lakes therefore likely require more stringent nutrient criteria, unless the criteria are so protective that they protect all lakes.

4.2 Degradation of, and shifts in, fish communities

Nutrient harms include direct physiological effects of nutrient chemicals, effects mediated by algae, and direct chemical effects. Table 3 lists harms in these categories, and relates them to designated use categories. An additional category of downstream effects is added for the protection of uses in waters to which West Virginia's waters flow.

Table 3: Relationship between nutrient harms and designated use categories

		Designated use				
Category	**Concern**	**A**	**B**	**C**	**D**	**E**
Downstream uses	Meeting criteria set by other states, tribes and intergovernmental bodies	X	X	X	X	X
Direct physiological	Nitrite toxicity (methaemoglobinemia, possibly fish and amphibian effects)	X	?			
	Cancers (non-Hodgkin's lymphoma, stomach)	X				
	Decreases in fish egg survival		X			
	Effects on amphibians		X			
Algal mediated	Growth of filamentous green algae	X	X	X	X	X
	Chemicals excreted by algae (toxins, taste and odor chemicals, trihalomethanes)	X	X	?	X	
	Decreases in dissolved oxygen	X	X	X	X	
	Increases in pH		X			
	Changes in the plant community		X			
	Structure-mediated and trophic-web mediated changes to biological communities, including fish communities		X	X		
	Release of toxic chemicals from anoxic sediments	X	X	X	X	
Direct chemical	Corrosion to pipes	X				X

Note: Designated uses are as follows: A = Water Supply, Public; B = Propagation and maintenance of fish and other aquatic life; C = Water contact recreation; D = Agriculture and wildlife uses; E = Water supply industrial, water transport, cooling and power. An "X" signifies that the concern will affect the designated use. A "?" signifies that the concern may affect the designated use.

One of the most important harms listed in Table 3 is structure-mediated changes to fish community. At low nutrient levels, fish communities support salmonids, such as trout. At low to moderate nutrient levels, fish in the perch family, such as walleye or yellow perch, generally replace the salmonids as top predators. At yet higher nutrient concentrations, bass, which were present at lower concentrations, replace the perch as the top predators. In the most eutrophic lakes, "rough fish" (e.g., carp, bullhead catfish) predominate.

According to the NCC's definition of impairment shown above in Table 2, the NCC has agreed that fish communities are vitally important. The most cherished use of many of West Virginia's lakes is fishing. It is imperative to protect excellent fishing in as many lakes as possible. The NCC did not choose to protect natural fish communities in lakes because, for the most part, the lakes themselves are man-made and the fish communities are often manipulated to encourage fishing. Their fish communities therefore cannot be held to pre-settlement standards. But the approach ultimately recommended in this report—relating TP to DO—is designed specifically to ensure that nutrients do not cause drops in DO below what is necessary to prevent shifts in fish communities. The authors also recognize that the higher trophic levels in an ecosystem, such as fish in lakes, are good indicators of the health of the entire ecosystem.

4.3 Damage to recreation

Many studies have documented repeatable patterns in the preferences of swimmers, boaters and others for lakes with low levels of algal biomass. These preferences can be measured by comparing users' reactions to the lake to actual measurements of TP, chlorophyll-a, or Secchi depth taken at the same time (Smeltzer and Heiskary, 1990; Heiskary, 1989). User surveys are scientifically defensible and, in fact, are the only possibly way to truly measure people's preferences related to nutrient criteria.

5 Review of analyses

5.1 Lake residence time

Because many reservoirs in West Virginia have short residence times and may behave more like rivers, the NCC considered classifying some reservoirs as rivers based on residence time. Thresholds of 14 days or other similar time periods have been discussed in several articles and reports (Dickman, 1969; Dillon, 1975; Williams et al., 1977; Jones and Lee, 1982; Pridmore and McBride, 1984; Walker, 1987; Heiskary and Walker, 1995; PDEP, 2003). A 14-day threshold is recommended for use in the new lake nutrient criteria.

5.2 Total phosphorus

The authors of this report recommend adopting a TP criterion that will ensure that DO is sufficient in the epilimnion. To identify TP levels at which the risk of epilimnetic hypoxia during warm, dry summers is acceptable, NCC committee members performed the following analyses.

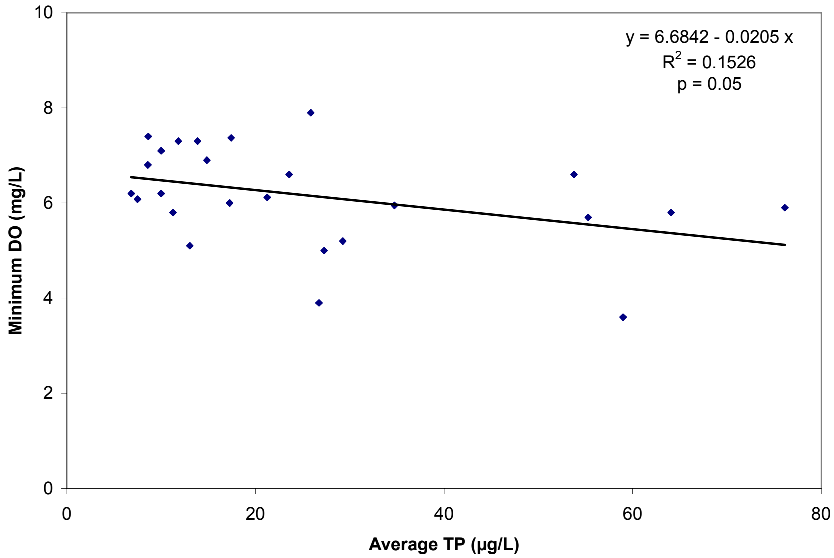
5.2.1 Comparison of TP and epilimnetic DO values: West Virginia lakes

Linear regression was used to compare the average of all TP values in a lake with the minimum DO value measured in that lake. While the average TP reflects the general condition and characteristics of the lake, the minimum DO reflects that lake's response to those climatic conditions most likely to deplete oxygen from the entire lake, so that even the epilimnion is hypoxic.

The objective of the analysis was to identify average TP concentrations at which there was a substantial risk of DO dropping below 6 mg/L during the daytime, when the measurements supporting the analysis were made. This 1 mg/L margin of safety provides some protection against the decreases in DO that are expected at night, when photosynthetic organisms are not adding oxygen to the water column. Measurements of Charles Fork and Elk Fork Lakes by WVDEP indicated daily DO fluctuations averaging 1.3 and 1.0 mg/L, respectively. Although DO fluctuations at times exceeded 3 mg/L, the average value of 1 mg/L was selected as the margin of safety.

The results of the regression are shown in Figure 1. The relationship is significant, and predicts minimum epilimnetic DO values of less than 6 mg/L for lakes with average TP greater than 33 µg/L. This relationship implies that lakes with TP levels as high as 33 µg/L are not likely to experience hypoxia in the epilimnion, even in hot summers with little rainfall.

Figure 1: Relationship between average TP and minimum DO concentrations in West Virginia lakes



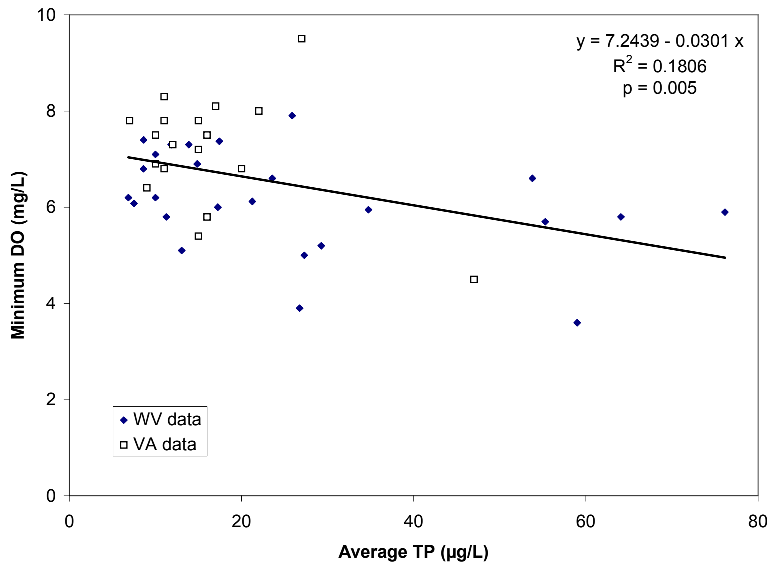
Source: West Virginia lake data combined from three sources: WVDEP's Clean Lakes Program, United States Army Corps of Engineers, and NCC summer 2004 monitoring program. Lakes with summer residence times < 14 days are excluded. Lakes with 2 or fewer data points are also excluded.

5.2.2 Comparison of TP and epilimnetic DO values: Virginia and West Virginia lakes

The analysis that was performed for West Virginia lakes was repeated after adding Virginia lakes in Ecoregion XI to the data set.[1] The additional data increased the R^2 value of the regression and decreased the p value, suggesting that additional data makes the relationship both more predictive and more highly significant. In this case, lakes with TP less than or equal to 41 µg/L were unlikely to have DO levels less than 6 mg/L. The regression is presented in Figure 2. This relationship implies that lakes with TP levels as high as 41 µg/L are not likely to experience hypoxia in the epilimnion, even in hot summers with little rainfall. However, the lakes from the Virginia data set generally had lower TP levels than did those from the West Virginia dataset. The expanded data set may be no more precise in determining the relationship in the higher TP ranges.

[1] All of West Virginia and part of Virginia are located in Ecoregion XI, as defined by USEPA (2000).

Figure 2: Relationship between average TP and minimum DO concentrations in Ecoregion XI lakes in Virginia and West Virginia



Source: West Virginia lake data combined from three sources: WVDEP's Clean Lakes Program, United States Army Corps of Engineers, and NCC summer 2004 monitoring program. Virginia data from Academic Advisory Committee. Lakes with summer residence times < 14 days are excluded. Lakes with 2 or fewer data points are also excluded.

5.2.3 User survey to evaluate suitability for recreation

User surveys were necessary to determine what levels of nutrients and nutrient-related parameters protect the water contact recreation use. During the lake and reservoir monitoring program in summer 2004, user surveys were conducted on the same days that water monitoring data were collected. Survey results and monitoring data were analyzed to determine what levels of TP correspond to user perceptions that the lake water is not suitable for recreation.

The key question in the user survey asked users how suitable the lake water is for recreation and enjoyment today. After about the first month of monitoring, this question was expanded to ask about four separate types of recreation: fishing, swimming, boating, and enjoying the lake from the shore. Users were asked to provide a ranking of one—meaning as nice as can be—to five—meaning very poor.

Before analyzing the user surveys, responses with questionable explanations were removed. Rules used to exclude or include responses are shown in Table 4.

Table 4: Rules used to exclude and include responses to user surveys

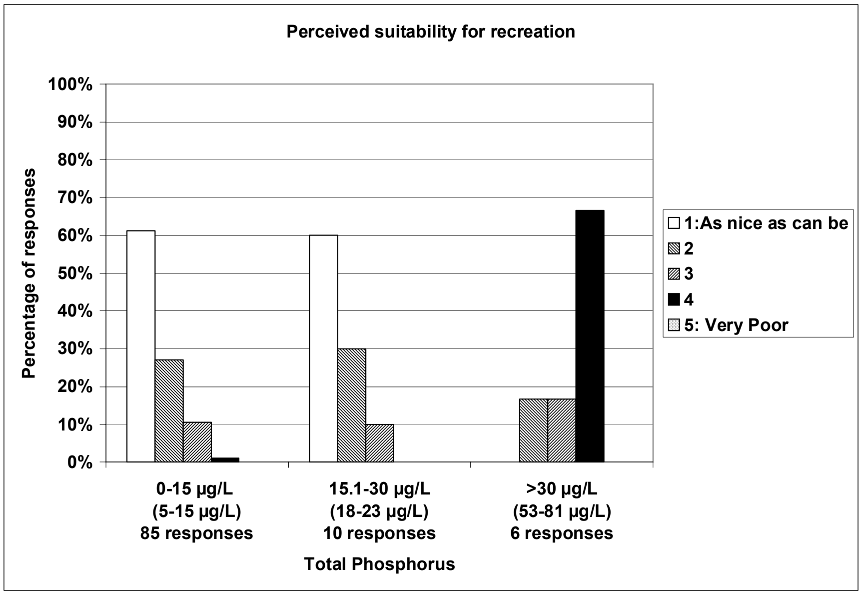
Keep responses if explanations…	Remove responses if explanations…
are blank	relate to on-shore facilities (e.g., boat landing)
relate to whether or not water is clean	relate to whether or not fish were caught, what kind of fish are present, or whether the fish are hungry
relate to water clarity or color	relate to water temperature
relate to water vegetation	relate to an aspect of the weather that is specified but unrelated to rain (e.g., cold)
relate to rain	relate to lake ameneties (e.g., sand on beach or layout of lake)
relate to an unspecified aspect of the weather	
relate to debris, trash, sticks, or leaves	
fit one or more of the categories in this column, even if one or more explanations fit into the second column	

Lakes were divided into three categories based on surface TP levels measured the same day that user surveys were collected: 0-15, 15.1-30, and >30 µg/L. The distribution of responses in each of the clusters is presented in Figure 3. When surface TP levels are low (below 15 µg/L), users report that the lake water is generally nice for recreation. More than 60% of respondents give the lake water a ranking of 1 or 2 when TP is below 15 µg/L. When TP levels are in the middle cluster—between 15.1 and 30 µg/L—Figure 3 shows that users consider the lakes similarly suitable for recreation.

The expected distaste for more eutrophic lakes was not detected near the 8 µg/L level proposed as the standard by the USEPA. Rather, distastes was only detected as TP levels rose above 30 µg/L. Above this level, a threshold seems to have been crossed between lakes that users consider nice for recreation and those that users consider poor. When TP levels are above 30 µg/L, almost 70% of users give the lake water a ranking of 4.

There is a large gap between the highest TP value in the middle cluster (23 µg/L) and the lowest TP value in the highest cluster (53 µg/L). It is impossible to say exactly how high TP can rise before the lakes elicit negative responses by users. Nevertheless, with the information available through this user survey, the EPA standard of 8 µg/L would be overprotective, and a criterion as high as 23 µg/L would be adequately protective. A criterion at 53 ug/L would clearly not be protective.

Figure 3: TP user survey analysis



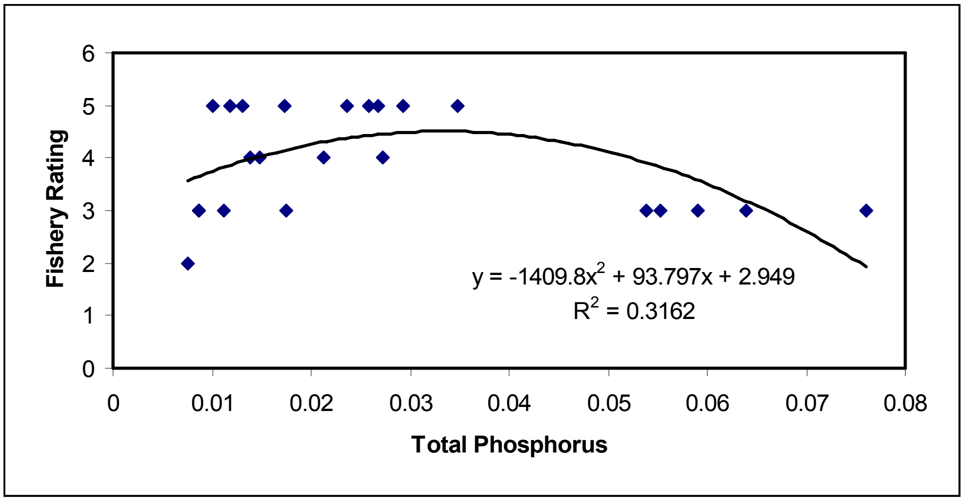
Note: Actual values shown in parentheses.

5.2.4 Fish communities

The NCC agreed that nutrient enrichment should not decrease the attractiveness of lakes for anglers. Dr. Todd Petty of West Virginia University compared average TP concentrations and an evaluation of fishing quality in lakes for which both kinds of data were available (Figure 4).[2] The comparison does not show a decline in fishing quality as TP values exceed USEPA's proposed 8 µg/L standard. Rather, it indicates that average fishery ratings increase as TP in lakes increases from below 10 µg/L (0.010 mg/L in Figure 4) to as high as 35 µg/L (0.035 mg/L). This is to be expected, as higher nutrient levels lead to increased fish stocks, up to a level. At some point between 35 and 53 µg/L, however, average fishery ratings decline: No ratings are above 3.

[2] Fishing quality ratings were provided by West Virginia Division of Natural Resources biologists.

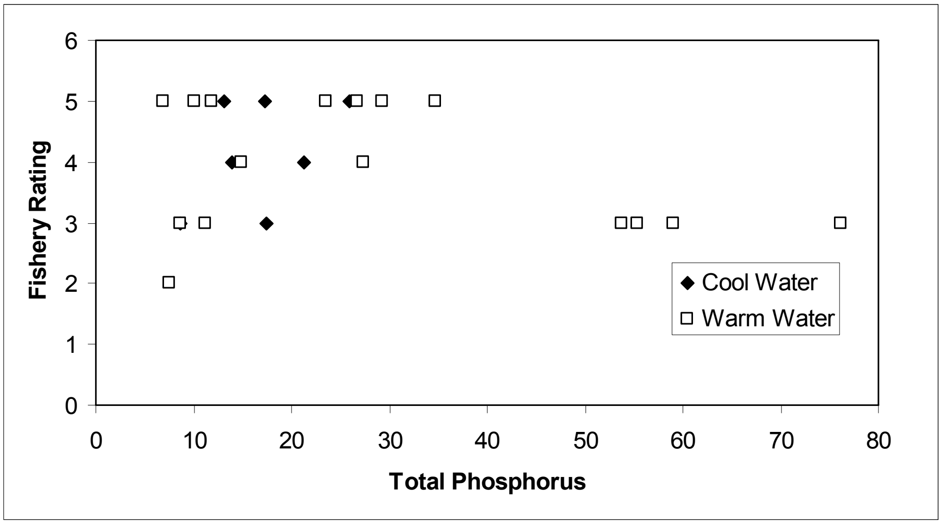
Figure 4: Comparison of TP with fishery ratings



Note: Total phosphorus is shown in mg/L. Fishery ratings are between 1 and 5, as follows: 1 = poor: biologists recommend anglers avoid. 2 = fair: biologists recommend anglers not expect fishing success. 3 = average: lake supports adequate fishery. 4 = good: biologists recommend for fishing. 5 = excellent: biologists highly recommend for fishing. Chart provided by Todd Petty to NCC March 31, 2006.

DNR biologists also classified each lake as warm or cool water fisheries. This distinction is important because cool water fisheries will be harmed if the cool bottom water in the hypolimnion becomes anoxic due to high nutrient levels. There are no cool water fisheries with TP levels greater than 35 µg/L (Figure 5); however, these ranking suggest that a criterion of 30 µg/L would be protective of cool water lakes.

Figure 5: Comparison of TP with fishery ratings, presented to distinguish warm and cool water fisheries



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5.2.5 Use of the TSI continuum

A large body of limnological research has identified repeatable patterns in the characteristics of lakes along a gradient from low nutrient to high nutrient. Equations relate three lake characteristics—TP, chlorophyll a, and Secchi depth—to a continuum of change corresponding to eutrophication. A trophic state index (TSI) can be calculated from any one of these variables, and the results should be close, regardless of which variable was used. The behavior of oxygen in these lakes follows relatively predictable patterns. Table 5 is a reproduction of a summary of this body of knowledge from USEPA guidance on setting lake nutrient standards.

Table 5: Changes in temperate lake attributes according to trophic state

TSI value	Secchi depth (m)	TP (µg/L)	Attributes	Water supply	Recreation	Fisheries
<30	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion			Salmonid fisheries dominate
30-40	4-8	6-12	Hypolimnia of shallower lakes may become anoxic			Salmonid fisheries in deep lakes
40-50	2-4	12-24	Mesotrophy: Water moderately clear but increasing probability of hypolimnetic anoxia during summer	Iron and manganese evident during the summer. THM precursors exceed 0.1 mg/L and turbidity >1 NTU		Hypolimnetic anoxia results in loss of salmonids. Walleye may predominate
50-60	1-2	24-48	Eutrophy: Anoxic hypolimnia, macrophyte problems possible	Iron, manganese, taste, and odor problems worsen		Warm-water fisheries only. Bass may be dominant
60-70	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems		Weeds, algal scums, and low transparency discourage swimming and boating	
70-80	0.25-0.5	96-192	Hypereutrophy (light limited). Dense algae and macrophytes			
>80	<0.25	192-384	Algal scums, few macrophytes			Rough fish dominate, summer fish kills possible

Source: USEPA (2000b) p. 7-9, as adapted from Carlson and Simpson (1996).

The TSI continuum suggests that for those lakes that are not designated as trout waters, TP levels could rise as high as 24 µg/L and still support the other diverse fisheries that West Virginians enjoy.

The NCC has been hesitant to apply this continuum because West Virginia reservoirs may differ from the population of lakes that have generally been studied. In particular, West Virginia reservoirs generally have shorter residence times and may carry loads of sediment that compromise the relationships between TP or chlorophyll-a and turbidity or Secchi depth.

Virginia's Academic Advisory Committee, which is providing advice on nutrient criteria to Virginia Department of Environmental Quality, cites studies quantifying how natural lakes and reservoirs respond differently to nutrients (Academic Advisory Committee, 2005). In particular, Canfield and Bachmann (1981) suggests that a TP concentration near 40 µg/L leads to eutrophic conditions in a reservoir, whereas only 30 µg/L would be required in a natural lake.

5.2.6 Using WVDEP's old method for judging nutrient impairments

Between 1989 and 1996 the state collected water quality data for 22 lakes under the Clean Lakes Program. In 1996, the last collection year for Clean Lakes Program data, 15 lakes were assessed. According to the 1998 305(b) report, the lakes were evaluated to determine water quality, use support status, and trophic condition. WVDEP used this information to determine whether or not any of these lakes were impaired threatened by impairment.

According to the 1998 305(b) report, six lakes were considered impaired by nutrients based on Clean Lakes Program data: Hurricane, Burches, Turkey Run, Ridenhour, Castleman, and Bear Lakes. As of 2006, TMDLs have been written for all of these lakes.

An additional three lakes—Tomlinson Run, Saltlick Pond #9, and Mountwood Park—were listed for siltation. Four other lakes—Summit, Spruce Knob, Boley, and Cheat Lake—were considered threatened from acid deposition or acid mine drainage but were not listed.

The 1998 305(b) report also stated that "many lakes during this assessment experienced hypolimnetic (bottom water) oxygen depletion in the summertime, with several also experiencing low hypolimnetic dissolved oxygen depletion in the spring."

WVDEP's Mike Arcuri explained to the Nutrient Criteria Committee that lakes were listed for nutrients based on TSI and best professional judgment. When WVDEP listed lakes, they worked backwards to determine impairment. First, WVDEP used best professional judgment to determine which ones were impaired, then calculated the average TSI score (average of total phosphorus, secchi, and chlorophyll-a TSI scores) for each lake. WVDEP then determined that an average TSI of 65 corresponded with observed impairments.[3]

A TSI of 65 and a corresponding TP criterion of 68 µg/L correspond to lakes in a mid-eutrophic state. As shown in Table 6, four of the five lakes with a residence time >14 days that WVDEP listed as impaired by nutrients had average TP < 68 µg/L. A TP criterion of 68 µg/L would clearly not protect West Virginia lakes.

[3] The Ridenour TMDL offers a somewhat inconsistent explanation: "West Virginia uses a trophic state index when considering lakes for listing due to nutrient impairment. Lakes with a total phosphorus or chlorophyll a trophic state index greater than or equal to 65 or with summer algal blooms or excessive vegetation were considered to be impacted by nutrients."

Table 6: Average TP for West Virginia's six lakes listed for nutrient impairment

Lake	Impairment(s)	Residence time > 14 days?	Avg. TP (µg/L)
Ridenour	N, S	Y	54
Castleman	N, S	Y	55
Bear Rocks #2	N, S, DO	Y	59
Burches	N, S	Y	64
Hurricane	N, S	N	67
-----WVDEP threshold of 68 µg/L TP (TSI 65)-----			
Turkey Run	N, S	Y	76

Source: WVDEP (1998) and Hansen et al. (2005). Note: N=nutrients, S=siltation, DO=low dissolved oxygen. NA = No data available in March 14, 2005 NCC report. Avg. TP values are from all data sources.

These data add to the weight of evidence regarding an appropriate TP criterion: Lakes with average TP at 54 µg/L or above have already been listed as impaired by WVDEP. Clearly, while the 8 µg/L standard proposed by USEPA is overprotective, a standard as high as 54 µg/L would fail to protect even West Virginia's warm water lakes, and a standard based on WVDEP's past practice—68 ug/L—is unreasonably high.

5.3 Chlorophyll a

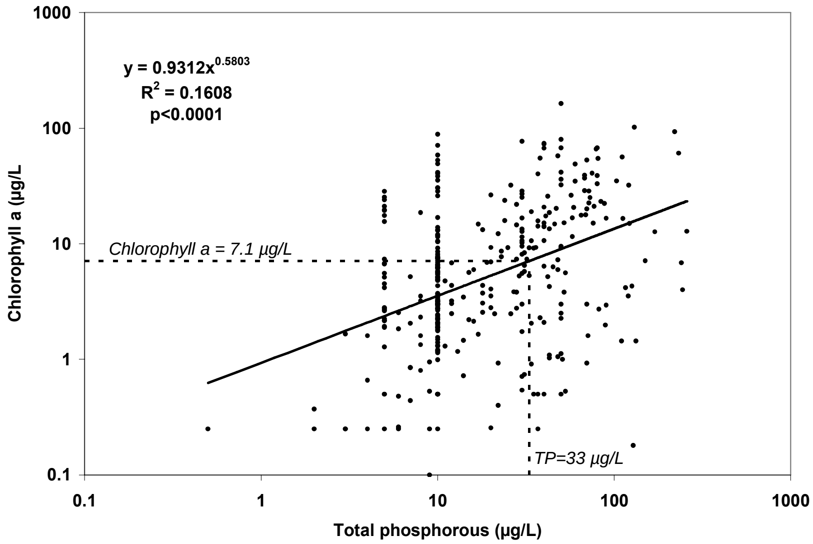
5.3.1 Comparison of TP and epilimnetic DO values versus chlorophyll *a*: West Virginia lakes

Since chlorophyll *a* levels are a response to the TP levels in a lake, a comparison of all TP measurements collected on the same day as chlorophyll *a* measurements was used to link a chlorophyll *a* standard level to a TP standard level.[4]

The regression was extremely significant, and explained approximately 16% of the variation (Figure 6). The relationship can be used with various TP levels to determine corresponding chlorophyll *a* levels. This relationship is used below to select an appropriate chlorophyll a criterion.

[4] Only data from the USACE and CLP data sets were used. NCC 04 chorophyll a data was reported as relative fluorescence, a measurement not comparable with values reported in USACE and CLP data sets.

Figure 6: Relationship between chlorophyll a and TP in the USACE and CLP datasets



5.4 Total nitrogen

West Virginia water quality rules regulate concentrations of nitrite and ammonia permissible in surface waters. These rules apply to lakes. At this time, the NCC has found no evidence that West Virginia lakes are limited by nutrients other than phosphorus.

5.5 Secchi depth

There was general consensus among NCC members not to recommend a Secchi depth criterion. In natural lakes, Secchi depth is typically the result of biological processes. All but one of West Virginia's lakes are impoundments. West Virginia impoundments receive a large influx of sediment from natural and manmade processes during high flow events. The NCC recognizes that nutrient risks may be associated with sediment influxes to lakes, but the sediment itself will make determining nutrient impairment by Secchi depth extremely difficult and unreliable.

6 Choosing nutrient criteria

6.1 Total phosphorus

The diverse analyses lead to several possible TP criteria, as summarized in Table 7. The results consistently indicate that West Virginia waters will be safe if standards are more lax than the TP level proposed by USEPA. However, they also suggest that TP levels set too high will not protect uses.

Table 7: Candidate TP criteria summarized in this document

TP concentration (µg/L)	Method
Too stringent	
8	EPA reference method
In range	
23	Category C user survey: lower bound
24	Mesotrophic/eutrophic boundary
33	Category B cause and effect analysis: avg. TP vs. min. DO (WV only)
35	Beginning of decline in fishing quality curve
41	Category B cause and effect analysis: avg. TP vs. min. DO (WV & VA)
Not protective	
53	Category C user survey: upper bound
53	End of decline in fishing quality curve
54	Lowest avg. TP value for lakes already considered impaired by WVDEP
68	TSI = 65, the threshold used by WVDEP for past decisions

The analyses that were performed and compiled were not perfect, and uncertainty remains about the exact levels that will cause impairment to the lakes. The analyses are universal in showing that a standard level as strict as 8 µg/L is unnecessary. However, in determining a final level, the risks associated with each level and the uncertainties in the analysis must be weighed. Considerations in this weighing process are compiled in Table 8.

TP criteria should be between 23 and 53 ug/L, but the number that is ultimately chosen depends on how much risk of harm is to be tolerated. A TP criterion near the low end of the range—30 ug/L mean—should protect cold and cool water lakes from most if not all harms due to nutrients. A TP criterion at the top of the range—50 ug/L mean— may well protect warm water lakes from harm, but is unlikely to protect cool or cold water lakes. **We recommend TP criteria of 30 ug/L mean for cool water lakes and 50 ug/L mean for warm water lakes.**

Table 8: Comparison of strengths and weaknesses of each standard determination

TP conc. (μg/L)	Strengths	Weaknesses	Recommended treatment
8	Extremely protective	Philosophical opposition to declaring impairment without demonstrating harm	This standard level should not be used
23	Used methods based on current literature	Difficult to place correct standard level in data gap between second and third clusters	This criterion is clearly protective, but a data gap suggests that somewhat higher values may also be protective.
24	Boundary between mesotrophic and eutrophic confirmed through literature on numerous lakes	Reservoirs may behave differently than lakes	The differing responses of reservoirs and natural lakes justifies an increase in this TP value
33	Relationship is significant and matches expectation based on TSI continuum	Low R^2 value indicates relationship is not very predictive	It is difficult to assess the bias in this method. A criterion at or near this value is likely protective of cool water lakes.
35	Level is based on fishing, a highly cherished recreational use	Difficult to place correct standard level in data gap between high fishing quality and adequate fishing quality lakes.	No change in this value is justified because the decline in fishing quality past this level is clear
41	Level is based on a larger data set than the West Virginia lakes regression	Data set is weighted toward lakes with TP levels well below the crucial threshold values from 23 to 41 μg/L.	The regression using West Virginia data is preferred
53		Upper bound of data gaps in user survey and fish quality curve. Unlikely to be protective.	Not protective
54		Lakes already considered impaired by WVDEP have avg. TP at this level. Not protective of even warm water lakes.	Not protective
68		Even higher than 54, and 54 is not protective of warm water lakes	Not protective

6.2 Chlorophyll-a

A chlorophyll a standard may be chosen using the relationship between chlorophyll a and TP (Figure 6). The exponential relationship suggests that waters with a chlorophyll a value no greater than 7.1 μg/L will generally have TP concentrations no greater than 33 μg/L.

This value, however, seems unnecessarily restrictive. Instead, the authors propose adopting the chlorophyll a criteria proposed by the Virginia Academic Advisory Committee. **We recommend chlorophyll a criteria of 10 ug/L mean for cool water lakes and 25 ug/L mean for warm water lakes.**

6.3 Other considerations

<u>These criteria are only sufficient if a comprehensive list of cool water lakes is included in the rule.</u> Such a list is proposed in Section 7.

Although a minimum of four samples collected during the growing season at least 30 days apart is preferred, such a sampling regime should not be required.

7 Suggested language for nutrient criteria

The authors suggest the following language for nutrient criteria for West Virginia lakes and reservoirs:

For Categories B and C, the arithmetic mean of all samples collected over the summer growing season should not exceed 30 µg/L total phosphorus for cool water lakes or 50 µg/L total phosphorus for warm water lakes.

For Categories B and C, the arithmetic mean of all samples collected over the summer growing season should not exceed 10 µg/L chlorophyll-a for cool water lakes or 25 µg/L chlorophyll-a for warm water lakes.

Nutrient criteria are to be met by all lakes and reservoirs with summer residence times greater than fourteen days. Summer residence times are to be calculated as the average lake volume divided by the average lake outflow the summer growing season.

8 Distinguishing between cool and water warm water lakes

The authors of this report suggest more stringent nutrient criteria for cool water lakes that support—or are capable of supporting—walleye, striped bass, or yellow perch in addition to bass, sunfish and minnows. More stringent criteria may be needed because cool water fisheries will be harmed if the cool bottom water in the hypolimnion becomes anoxic due to high nutrient levels.

Our proposed list of cool water lakes is shown in Table 9 and includes lakes identified by DNR as cool water lakes, lakes listed as trout waters in 46 CSR 1 Table B2 (these lakes could be included by reference to the B2 list; the current list is shown below for convenience), very large lakes, and very deep lakes.

Table 9: Proposed cool water lakes

Lake	DNR	Trout list	Very large (> 500 ac.)	Very deep (> 30 ft. max)
Anderson				X
Beech Fork			X	
Berwind				X
Buffalo Fork	X	X		
Burnsville			X	
Charles Fork	X			X
Cheat Lake	X		X	
Conaway Run				X
Coopers Rock		X		
Dog Run		X		X
East Lynn			X	
Edwards Run and Impoundment		X		
Fort Ashby		X		X
Handley Pond	X			
Hawes Run (Brandywine)		X		
Jennings Randolph			X	
Laurel Creek Lake #1				X
Moncove	X			
Mountwood				X
New Creek Dam 14		X		X
Plum Orchard				X
RD Bailey Lake	X		X	
Rock Cliff	X	X		X
Seneca	X	X		
Silcott Fork				X
Spruce Knob	X	X		
Stephens	X	X		X
Stonecoal			X	
Stonewall Jackson			X	
Summersville Reservoir		X	X	
Summit	X	X		
Sutton Reservoir		X	X	
Teter Creek Lake		X		
Thomas Park		X		
Tracy				X
Trout Pond		X		X
Tygart Lake	X		X	
Warden Lake		X		
Watoga	X	X		
Woodrum				X

9 References

Academic Advisory Committee. 2005. January 2005 Report of the Academic Advisory Committee To Virginia Department of Environmental Quality: Freshwater Nutrient Criteria. Submitted to: Division of Water Quality Programs, Virginia Department of Environmental Quality. Prepared by: Carl E. Zipper, John J. Ney, Leonard A. Smock, Eric P. Smith, John C. Little, Paul A. Bukaveckas, Gene R. Yagow, Jane L. Walker, Tamim Younos. Submitted by: Virginia Water Resources Research Center. February 7.

Canfield, D. E. and R. W. Bachmann. 1981. Prediction of total phosphorus concentrations, chlorophyll a, and Secchi disk depths in natural and artificial lakes. *Canadian Journal of Fisheries and Aquatic Sciences.* 38:414-423.

Carlson R.E. and J. Simpson. 1996. A coordinator's guide to volunteer lake monitoring methods. North American Lake Management Society. Madison, WI.

Dickman, Mike. 1969. Some effects of lake renewal on phytoplankton productivity and species composition. *Limnology and Oceanography.* 14:660-6.

Dillon, P.J. 1975. The phosphorus budget of Cameron Lake, Ontario: The importance of flushing rate to the degree of eutrophy of lakes. *Limnology and Oceanography.* 20:28-39.

Hansen, Evan, M. Christ, and M. Pavlick. 2005. Recommended Nutrient Criteria for West Virginia Lakes and Reservoirs (Categories B and C). Draft report intended to be submitted from the NCC to the West Virginia Environmental Quality Board. March 14.

Heiskary, Steven A. 1989. Lake assessment program: A cooperative lake study program. *Lake and Reservoir Management.* 5(1):85-94.

Heiskary, Steven A. and W.W. Walker, Jr. 1995. Establishing a chlorophyll a goal for a run-of-the-river reservoir. *Lake and Reservoir Management.* 11(1):67-76.

Jones, R. Anne and G.F. Lee. 1982. Recent advances in assessing impact of phosphorus loads on eutrophication-related water quality. *Water Resources.* 16:503-515.

Pennsylvania Department of Environmental Protection (PDEP). 2003. *Total Maximum Daily Load (TMDL), Dutch Fork Lake, Washington County, Pennsylvania, State Water Plan 20E.* February 25.

Petty, J. Todd. 2006. Chart provided to NCC. March 31.

Pridmore, R.D. and G.B. McBride. 1984. Prediction of Chlorophyll a Concentrations in Impoundments of Short Hydraulic Retention Time. *Journal of Environmental Management.* 19: 343-50.

Smeltzer, Eric and Steven A. Heiskary. 1990. Analysis and applications of lake user survey data. *Lake and Reservoir Management.* 109-118.

United States Environmental Protection Agency (USEPA). 2000a. Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria, Lakes and Reservoirs in Nutrient Ecoregion XI. Office of Water. EPA 822-B-00-012. December.

______________________. 2000b. Nutrient Criteria Technical Guidance Manual, Lakes and Reservoirs, First Edition. Office of Water. EPA 822-B00-001. April.

Walker, Jr., W.W. 1987. Empirical methods for predicting eutrophication in impoundments. Report 4, Phase III: Application Manual, Technical Report E-81-9. USACE WES, Vicksburg, MS.

WVDEP. 1998. West Virginia's Water Quality Assessment, 305(b) Report, 1998. Office of Water Resources.

Williams, Llewellyn R., V.W. Lambou, S.C. Hern, and R.W. Thomas. 1977. *Relationships of Productivity and Problem Conditions to Ambient Nutrients: National Eutrophication Survey Findings for 418 Eastern Lakes.* U.S. Environmental Protection Agency National Eutrophication Survey Working Paper 725. November.

10 Data tables

Table 10: Summary of TP and dissolved oxygen data from the NCC 2004 sampling program

Lake	SRT (days)	N	TP (µg/L)			DO (mg/L)		
			Avg.	Min.	Max.	Avg.	Min.	Max.
Bear Rocks #2	64	12	48	5	90	12.9	11.5	14.8
Beech Fork	81	29	31	10	134	8.6	6.2	10.7
Charles Fork	290	20	21	10	71	7.5	6.1	8.9
Cheat	21	28	10	5	43	7.7	6.4	9.3
Coopers Rock	15	12	8	5	10	8.9	6.1	9.6
Curtisville	112	16	11	10	30	8.4	5.8	10.6
Elk Fork		24	35	10	80	9.4	6.0	13.5
Moncove	222	16	14	10	66	8.5	7.6	9.5
Rock Cliff	56	12	17	10	79	8.4	7.4	9.6
Spruce Knob	230	16	13	10	42	9.0	8.0	10.1
Summit	173	16	10	10	10	9.0	8.3	9.8
Sutton	78	28	10	10	10	8.4	6.2	10.7
Tomlinson Run	11	12	37	5	157	10.2	9.5	11.4

Note: SRT = Summer Residence Time.

Table 11: Derivation of data for regression for minimum DO and average TP chart

Data source	Lake	SRT	Earlier data N	Earlier data Avg. TP	Earlier data Min. DO	NCC 2004 data N	NCC 2004 data Avg. TP	NCC 2004 data Min. DO	Data for regression Avg. TP	Data for regression Min. DO
		days		µg/L	mg/L		µg/L	mg/L	µg/L	mg/L
Residence time ≤14 days										
CLP	Edwards Run	0	2	52	8.1					
USACE	Bluestone	6	73	32	4.6				32	4.6
CLP	Hurricane WS Reservoir	7	9	67	5.5				67	5.5
CLP	Saltlick Pond 9	7	12	30	5.0				30	5.0
CLP	Tomlinson Run	11	8	45	8.3	4	37	9.5	42	8.3
Residence time >14 days										
2004	Coopers Rock	15				4	8	6.1	8	6.1
CLP	Huey	16	2[a]	37	7.8					
CLP	Turkey Run	16	13	76	5.9				76	5.9
CLP	Castleman	19	14	55	5.7				55	5.7
CLP	Cheat Lake	21	15	19	6.0	4	10	6.4	17	6.0
CLP	Burches Run	23	13	64	5.8				64	5.8
CLP	Laurel	26	13	15	6.9				15	6.9
CLP	Warden	26	2[a]	15	9.2					
USACE	RD Bailey	45	23	13	5.1				13	5.1
CLP	O'Brien	46	7	24	6.6				24	6.6
2004	Rock Cliff	56				4	17	7.37	17	7.37
CLP	Ridenour	62	14	54	6.6				54	6.6
CLP	Bear Rocks #2	64	14	62	3.6	4	48	11.5	59	3.6
USACE	Burnsville	65	11	12	7.3				12	7.3
CLP	Miletree	70	2[a]	29	8.2					
USACE	Sutton	78	9	10	7.3	4	10	6.2	10	6.2
2004	Beech Fork	81	11	25	3.9	4	31	6.2	27	3.9
USACE	East Lynn	91	84	29	5.2				29	5.2
2004	Curtisville	112				4	11	5.8	11	5.8
USACE	Summersville	166	6	10	7.1				10	7.1
CLP	Summit	173	6	8	6.8	4	10	8.3	9	6.8
CLP	Moncove	222	7	14	7.3	4	14	7.6	14	7.3
CLP	Spruce Knob	230	8	32	7.9	4	13	8.0	26	7.9
2004	Charles Fork	290				4	21	6.12	21	6.12
CLP	Boley	297	8	9	7.4				9	7.4
CLP	Mt. Storm	1017	10	7	6.2				7	6.2
Residence time unknown										
2004	Elk Fork					4	35	5.95	35	5.95
CLP	Kanawha State Forest		7	27	5.0				27	5.0
CLP	Pennsboro WS Reservoir		2[a]	25	7.0					

Note: [a]Excluded from analysis due to an insufficient number of measurements.

Table 12: Virginia and West Virginia average total phosphorus and minimum dissolved oxygen values

Lake Name	Min DO (mg/L)	Avg TP (µg/L)
West Virginia lakes		
Bear Rocks #2	3.6	59
Beech Fork	3.9	27
Boley	7.4	9
Burches Run	5.8	64
Burnsville	7.3	12
Castleman	5.7	55
Charles Fork	6.12	21
Cheat Lake	6.0	17
Coopers Rock	6.1	8
Curtisville	5.8	11
East Lynn	5.2	29
Elk Fork	5.95	35
Kanawha State Forest	5.0	27
Laurel	6.9	15
Moncove	7.3	14
Mt. Storm	6.2	7
O'Brien	6.6	24
RD Bailey	5.1	13
Ridenour	6.6	54
Rock Cliff	7.37	17
Spruce Knob	7.9	26
Summersville	7.1	10
Summit	6.8	9
Sutton	6.2	10
Turkey Run	5.9	76
Virginia lakes		
Beaverdam	5.4	15
Big Cherry	7.5	16
Carvin Cove	6.8	20
Claytor	4.5	47
Douthat	7.3	12
Elkhorn	7.5	10
Fairy Stone	8.3	11
Flannagan	6.4	9
Gatewood	6.8	11
Hungry Mother	7.8	11
Moomaw	5.8	16
North Fork Pound	6.9	10
Pedlar	7.8	15
Robertson	8.1	17
Shenandoah	9.5	27
South Holston	8.0	22
Sugar Hollow	7.2	15
Switzer	7.8	7

Table 13: The number of user surveys collected at each lake visit

Month	Lake	Water sampling date	No. surveys	Comments
1	Bear Rock	7/20/04	1	1 included in analysis
	Beech Fork	7/13/04	9	9 included in analysis
	Charles Fork	7/4/04	0	0 surveys collected
	Cheat	7/22/04	22	15 included in analysis
	Coopers Rock	7/19/04	2	2 included in analysis
	Curtisville	7/21/04	1	1 included in analysis
	Elk Fork	7/30/04	0	8 surveys collected 7/16/04, not included
	Moncove	7/29/04	3	2 included in analysis
	Rock Cliff	8/3/04	7	4 included in analysis
	Spruce Knob	8/2/04	7	6 included in analysis
	Summit	7/28/04	7	3 included in analysis
	Sutton	7/23/04	9	8 included in analysis
	Tomlinson	7/20/04	10	0 included because residence time < 14 days
2	Bear Rock	8/17/04	1	1 included in analysis
	Beech Fork	8/4/04	0	0 surveys collected
	Charles Fork	8/10/04	0	0 surveys collected
	Cheat	8/16-17/04	5	4 included in analysis
	Coopers Rock	8/16/04	1	1 included in analysis
	Curtisville	8/9/04	0	0 surveys collected
	Elk Fork	8/11/04	0	0 surveys collected
	Moncove	8/26/04	1	1 included in analysis
	Rock Cliff	8/31/04	0	9 surveys collected 8/25/04, not included
	Spruce Knob	8/30/04	0	3 surveys collected 8/26/04, not included
	Summit	8/24/04	0	0 surveys collected
	Sutton	8/19/04	0	0 surveys collected
	Tomlinson	8/18/04	0	0 surveys collected
3	Bear Rock	9/16/04	0	0 surveys collected
	Beech Fork	9/1/04	6	6 included in analysis
	Charles Fork	9/7/04	0	0 surveys collected
	Cheat	9/13-14/04	18	16 included in analysis
	Coopers Rock	9/13/04	4	0 included in analysis
	Curtisville	9/15/04	0	0 surveys collected
	Elk Fork	9/10/04	0	0 surveys collected
	Moncove	9/29/04	0	0 surveys collected
	Rock Cliff	9/22/04	0	0 surveys collected
	Spruce Knob	9/21/04	5	4 included in analysis
	Summit	9/22/04	0	0 surveys collected
	Sutton	9/27/04	8	2 included in analysis
	Tomlinson	9/16/04	1	1 included in analysis
4	Bear Rock	10/20/04	3	2 included in analysis
	Beech Fork	10/6/04	3	3 included in analysis
	Charles Fork	10/4/04	0	0 surveys collected
	Cheat	10/14/04	0	0 surveys collected
	Coopers Rock	10/13/04	0	0 surveys collected
	Curtisville	10/20/04	2	2 included in analysis
	Elk Fork	10/11/04	0	0 surveys collected
	Moncove	9/10/04	0	0 surveys collected
	Rock Cliff	11/4/04	0	0 surveys collected
	Spruce Knob	11/3/04	6	6 included in analysis
	Summit	10/27/04	0	0 surveys collected
	Sutton	10/12/04	3	2 included in analysis
	Tomlinson	10/21/04	2	0 included because residence time < 14 days

Table 14: User survey data for every response

Date	Lake	Perceived suitability for recreation score	Total phosphorus (µg/L)	Chlorophyll a (µg/L)	Secchi depth (feet)	Total nitrogen (mg/L)
7/20/04	Bear Rock	3	5.0	6.8	2.4	1.17
8/17/04	Bear Rock	2	53.0	8.0	3.2	0.98
10/20/04	Bear Rock	4	64.7	19.2	6.0	0.87
10/20/04	Bear Rock	4	64.7	19.2	6.0	0.87
7/13/04	Beech Fork	1	10.0	NA	NA	0.91
7/13/04	Beech Fork	1	10.0	NA	NA	0.91
7/13/04	Beech Fork	1	10.0	NA	NA	0.91
7/13/04	Beech Fork	1	10.0	NA	NA	0.91
7/13/04	Beech Fork	1	10.0	NA	NA	0.91
7/13/04	Beech Fork	1	10.0	NA	NA	0.91
7/13/04	Beech Fork	1	10.0	NA	NA	0.91
7/13/04	Beech Fork	1	10.0	NA	NA	0.91
7/13/04	Beech Fork	1	10.0	NA	NA	0.91
9/1/04	Beech Fork	2	23.4	3.3	4.2	0.41
9/1/04	Beech Fork	2	23.4	3.3	4.2	0.41
9/1/04	Beech Fork	1	23.4	3.3	4.2	0.41
9/1/04	Beech Fork	2	23.4	3.3	4.2	0.41
9/1/04	Beech Fork	1	23.4	3.3	4.2	0.41
9/1/04	Beech Fork	1	23.4	3.3	4.2	0.41
10/6/04	Beech Fork	4	80.7	5.0	1.1	0.56
10/6/04	Beech Fork	4	80.7	5.0	1.1	0.56
10/6/04	Beech Fork	3	80.7	5.0	1.1	0.56
7/22/04	Cheat Lake	1	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	1	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	1	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	1	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	1	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	1	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	1	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	2	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	2	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	1	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	2	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	1	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	1	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	2	10.0	2.9	9.2	1.66
7/22/04	Cheat Lake	3	10.0	2.9	9.2	1.66
8/17/04	Cheat Lake	3	7.1	1.5	8.1	0.43
8/17/04	Cheat Lake	1	7.1	1.5	8.1	0.43
8/17/04	Cheat Lake	3	7.1	1.5	8.1	0.43
8/17/04	Cheat Lake	4	7.1	1.5	8.1	0.43
9/13/04	Cheat Lake	2	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	2	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	2	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	2	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	1	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	1	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	1	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	1	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	2	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	2	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	2	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	1	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	1	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	2	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	1	14.7	3.1	4.5	0.65
9/13/04	Cheat Lake	2	14.7	3.1	4.5	0.65

(Continued on next page)

Table 12: User survey data for every response (continued)

Date	Lake	Perceived suitability for recreation score	Total phosphorus (µg/L)	Chlorophyll a (µg/L)	Secchi depth (feet)	Total nitrogen (mg/L)
7/19/04	Coopers Rock	1	5.0	2.8	4.3	0.17
7/19/04	Coopers Rock	1	5.0	2.8	4.3	0.17
8/16/04	Coopers Rock	2	5.0	1.4	7.2	0.15
7/21/04	Curtisville Lake	1	10.0	2.0	4.3	NA
10/20/04	Curtisville Lake	3	15.0	4.2	3.6	0.43
10/20/04	Curtisville Lake	3	15.0	4.2	3.6	0.43
7/29/04	Moncove	2	10.0	1.1	9.6	0.55
7/29/04	Moncove	1	10.0	1.1	9.6	0.55
8/26/04	Moncove	2	10.0	2.2	8.7	0.36
8/3/04	Rock Cliff	1	10.0	0.2	11.1	0.55
8/3/04	Rock Cliff	2	10.0	0.2	11.1	0.55
8/3/04	Rock Cliff	1	10.0	0.2	11.1	0.55
8/3/04	Rock Cliff	1	10.0	0.2	11.1	0.55
8/2/04	Spruce Knob	1	10.0	3.3	5.7	0.55
8/2/04	Spruce Knob	1	10.0	3.3	5.7	0.55
8/2/04	Spruce Knob	2	10.0	3.3	5.7	0.55
8/2/04	Spruce Knob	2	10.0	3.3	5.7	0.55
8/2/04	Spruce Knob	3	10.0	3.3	5.7	0.55
8/2/04	Spruce Knob	2	10.0	3.3	5.7	0.55
9/21/04	Spruce Knob	1	18.0	0.8	8.7	0.39
9/21/04	Spruce Knob	1	18.0	0.8	8.7	0.39
9/21/04	Spruce Knob	1	18.0	0.8	8.7	0.39
9/21/04	Spruce Knob	3	18.0	0.8	8.7	0.39
11/3/04	Spruce Knob	1	10.0	4.2	4.8	0.35
11/3/04	Spruce Knob	1	10.0	4.2	4.8	0.35
11/3/04	Spruce Knob	1	10.0	4.2	4.8	0.35
11/3/04	Spruce Knob	1	10.0	4.2	4.8	0.35
11/3/04	Spruce Knob	1	10.0	4.2	4.8	0.35
11/3/04	Spruce Knob	1	10.0	4.2	4.8	0.35
7/28/04	Summit	1	10.0	0.7	9.8	0.55
7/28/04	Summit	1	10.0	0.7	9.8	0.55
7/28/04	Summit	1	10.0	0.7	9.8	0.55
7/23/04	Sutton	2	10.0	1.2	11.1	0.57
7/23/04	Sutton	1	10.0	1.2	11.1	0.57
7/23/04	Sutton	3	10.0	1.2	11.1	0.57
7/23/04	Sutton	3	10.0	1.2	11.1	0.57
7/23/04	Sutton	1	10.0	1.2	11.1	0.57
7/23/04	Sutton	1	10.0	1.2	11.1	0.57
7/23/04	Sutton	1	10.0	1.2	11.1	0.57
7/23/04	Sutton	1	10.0	1.2	11.1	0.57
9/27/04	Sutton	2	10.0	3.0	8.3	0.27
9/27/04	Sutton	1	10.0	3.0	8.3	0.27
10/12/04	Sutton	1	10.0	2.0	7.2	0.36
10/12/04	Sutton	2	10.0	2.0	7.2	0.36