BUREAU OF CLEAN WATER

LAKE ASSESSMENT PROTOCOL

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Lake Assessment Protocol

Introduction/Background

The main water quality concerns relating to Pennsylvania lakes are conditions associated with eutrophication, particularly cultural eutrophication. All lakes undergo eutrophication, an aging process that ensues from the gradual accumulation of nutrients and sediment resulting in increased productivity and slow filling of the lake with silt and organic matter from the surrounding watershed. Human activity within the lake watershed hastens the eutrophication process and often results in increased algal growth stimulated by an increase in nutrients. Increased macrophyte growth can also ensue from this nutrient-rich environment along with expanding shallow areas resulting from high rates of sedimentation. Wide fluctuations in pH and dissolved oxygen (DO) often result from increased photosynthesis and respiration by plants and biological oxygen demand (BOD) from the decay of organic matter. Low dissolved oxygen concentrations may lead to fish kills and other aquatic life impairments.

Natural lake succession progresses through several increasing productivity stages over time: oligotrophic, mesotrophic, eutrophic, and hypereutrophic states. Oligotrophic lakes are typically nutrient-poor, clear, deep, cold, and biologically unproductive. Hypereutrophic lakes, at the other end of the spectrum, are extremely nutrient-rich, often with algal bloom-induced pea-soup conditions, abundant macrophyte populations in shallower areas, fish kills, and high rates of sedimentation. Although lakes naturally go through the trophic states in a slow successional process, anthropogenic influences can greatly accelerate the progression. This phenomenon is known as "cultural eutrophication", a process that normally requires thousands of years, but can be accelerated to decades in locations where human influences are persistent.

Most lakes in Pennsylvania are dimictic, meaning they completely mix twice each year when the lake's water temperatures are uniformly close to 4°C - once in spring and again in autumn. These lakes are directly thermally stratified in summer and inversely stratified in winter. The spring turnover occurs soon after any ice cover has melted, aided by surface winds. Summer stratification ensues as the surface waters rapidly warm, causing the upper layer to become less dense than the cooler bottom layer. The summer stratification typically involves the formation of three stable layers. The hypolimnion (bottom layer) has the coldest (often near 4°C), densest water. The epilimnion (surface layer) is comprised of warm, circulating, less-dense water that floats upon the cold and relatively undisturbed hypolimnion (Figure 1). The boundary layer between the two is the metalimnion, characterized by a steep thermal gradient, or thermocline, defined as a thermal change of at least 1 degree C per meter of depth. In autumn, when the lake surface waters cool again, the density difference between the layers decreases to a point where lake mixing occurs. This turnover lasts until ice covers the lake and a weak inverse stratification sets up.

During summer stratification, waters of the hypolimnion are isolated from the atmosphere and cannot be replenished with oxygen. Dead algae and other organic

material from the upper waters settle and decompose in the hypolimnion, resulting in an increase in BOD. In most eutrophic waterbodies, this oxygen depletion causes anoxic conditions (<1 mg/L DO) in the hypolimnion. Anoxic conditions are a natural condition near the bottom of many lakes, however, severe conditions can occur in greater proportions of the hypolimnion of eutrophic and hypereutrophic lakes. A resulting phenomenon such as re-suspension of nutrients and dissolved metals from the bottom sediment, along with low DO content, can cause problems when these elements are mixed throughout the lake during fall overturn. Fall plankton blooms (usually diatoms, and often green or bluegreen algae) are common because of the influx of nutrients during mixing, but sometimes a combination of weather and overturn events plus decomposition can result in critically low dissolved oxygen levels. Ice cover and rapid spring warming of the lake can also foster low oxygen events resulting in fish kills.
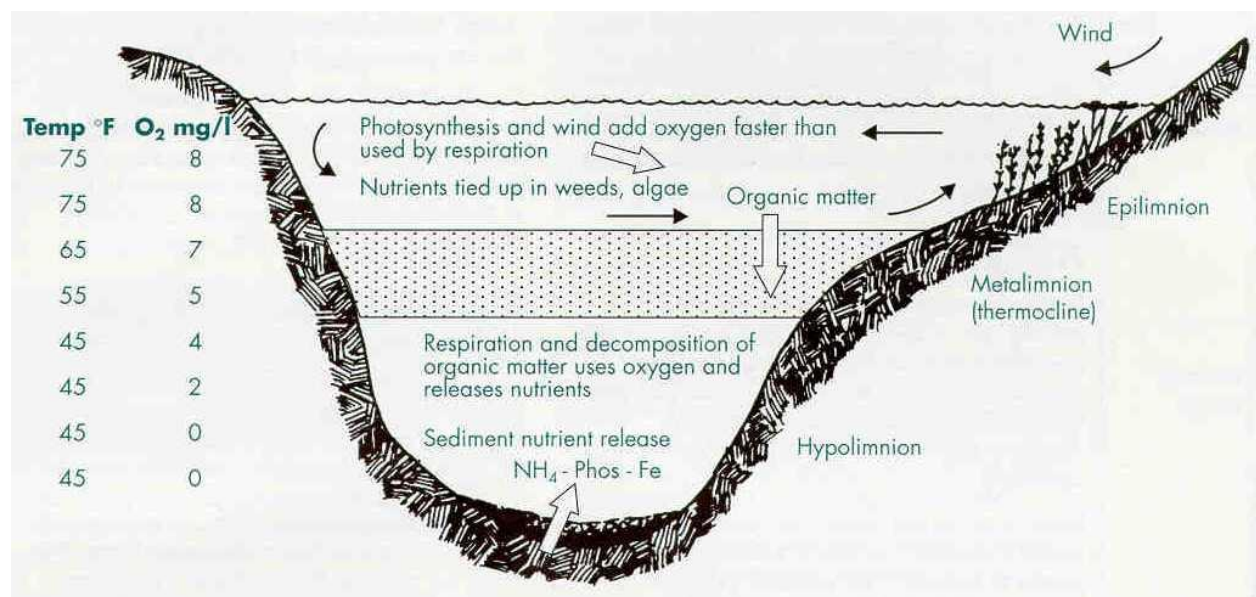

Figure 1. Lake Stratification (Wisconsin Department of Natural Resources)

Shallow lakes may behave differently than deeper lakes. For our purposes, a shallow lake or pond is defined as a permanent standing body of water that is shallow enough to allow light penetration to bottom sediments, adequate to potentially support photosynthesis of higher aquatic plants over the entire lake bottom (Wetzel 2001). In Pennsylvania, the light attenuation of most waterbodies is normally about 15 ft. depth. Shallow lakes often do not stratify in summer as wind or even internal flow is enough to keep the waters mixed.

Physical and Chemical Parameters Important in Lake Assessments

Water Clarity
Water clarity not only affects aesthetic qualities of waterbodies, but can also be biologically important. Water clarity in lakes is typically measured with a Secchi disk.

The Secchi depth is read off the shady side of the boat, without using sunglasses. The depth at which the disk disappears when lowered, and reappears when raised again is averaged and recorded. Secchi disk depth (or "Secchi depth") data taken over time (weekly, monthly, seasonally, or yearly) can be translated into Trophic State Indices for a lake (see below).

Secchi readings vary by season and are typically affected by three major factors: planktonic algae (and sometimes zooplankton), suspended sediments, and stained water color. Planktonic algae are present in every standing body of water and comprise the photosynthetic base of the aquatic food web. In nutrient rich waters, algal densities can often result in blooms which can become a nuisance by affecting recreational use, aesthetics, and water taste and odor. Suspended sediments (commonly clay/soil particles or organic matter) can impart an opaque or brown tint to the water, which contributes to nuisance conditions. High suspended solids concentrations generally occur after significant precipitation runoff events, which affect a lake directly via sediment loads carried in by tributary streams. Stained lake water is normally caused by brown pigmented tannins from organic matter, such as leaf litter, that impart a tea color to otherwise clear water. Tannins are natural and are not a result of pollution.

Secchi depth has a long history as a lake assessment tool. Secchi readings are an important parameter for assessing lake trophic status (see below) and are one of three Trophic State Index (TSI) calculations relied upon to assess lake status. A good reference on the history and use of Secchi data can be found at http://www.secchidipin.org/index.html.

Nutrients and Other Chemicals
The two most critical nutrients to plant growth in lakes are nitrogen (N) and phosphorus (P). Increasing N and P over time leads to higher abundances of plant organisms (algal or aquatic macrophytes). The N and P forms analyzed by DEP for lake assessments are normally, but not limited to, total phosphorus and total nitrogen. Other forms of N and P species are analyzed at the discretion of the biologist in charge.

Total nitrogen (TN) and total phosphorus (TP) are collected from lake surface and bottom waters using a Kemmerer or Van Dorn sampler. The samplers are deployed, tripped, and retrieved at a 1-m depth for "surface" samples or at 1-m above the lake bottom for "bottom" samples. Alternatively, a 2-m long integrated tube sampler may be used for collections in surface waters. Either method has been shown to return results within 10% of the other (using DEP data). Field collections for either method employs the mandatory use of plastic, non-powdered gloves for biologists handling the sample equipment and sample jars to prevent contamination of the water sample. Additionally, HDPE bottles, field-rinsed three times with sample water, are used for sample collections. Full sample collection methods are described in the document, *Evaluations of Discharges to Lakes, Ponds and Impoundments* (DEP 2015, pending chlorophyll methods updates).

Both TN and TP parameters can be used for Trophic State evaluations of a lake (see "Data Analyses" below). Phosphorus is an important predictor of lake productivity in north-temperate lakes (Dillon and Rigler 1974; EPA 1998). Though trophic status is not related to any water quality standard, it is a mechanism for "rating" a lake's productive state. Information on calculating trophic status is included in the interpretation section below.

The ratio of TN to TP is also a useful tool in lake management. An N/P ratio of greater than 15:1 indicates phosphorus limitation; a ratio less than 7:1 indicates nitrogen limitation. Most lakes in PA are P limited. Many severely impaired lakes in PA are N limited, especially in summer.

Other chemical parameters analyzed as part of the background information on each lake include alkalinity, total suspended solids, and total dissolved solids. The samples are analyzed from the same collection bottles as N and P. If needed, other parameters are analyzed such as turbidity, nitrogen and phosphorus species, dissolved or total metals, dissolved or total organic carbon, acid neutralizing capacity, color, chloride, sulfate, floride, and/or phenolics. Lake sediment samples may also be collected and analyzed for a variety of parameters. Peterson or Eckman Dredges or corers like the KB Corer are used to collect lake bottom sediments for analyses.

Dissolved Oxygen

Dissolved oxygen (DO) in water is necessary for aquatic life; DEP has specific DO standards set forth in Chapter 93 of the PA Code (PA Code, Title 25, Chapter 93 §93.7). DO information in lakes is collected *in-situ* at each meter of depth (or half-meter in shallow lakes) during each sampling event. DO criteria applies to the epilimnion only, unless a lake is nonstratified. Naturally stratified lakes become oxygen-depleted in the hypolimnion in summer, but the beginning point of oxygen decline is an important datum, as is the overall extent of hypoxia. Nonstratified lakes tend to be lakes that are either shallow or narrow with rather short detention times (i.e. high flushing rates). Sometimes these lakes will not be able to meet dissolved oxygen standards beyond the epilimnion in the summer, as written in 25 Pa. Code Chapter 93, §93.7, but will have no other indications of impairment. Biological activity and decay will naturally tend to deplete oxygen near the bottom layers. A lake should not be listed as impaired based on low dissolved oxygen found only near or in the bottom waters.

pH

Measurements of pH are in profile, *in-situ*, as dissolved oxygen and temperatures are collected, with a calibrated multi-parameter probe (See Methods documents for description of use). pH standards for PA are established in 25 Pa. Code Chapter 93, §93.7. pH is an important environmental parameter for aquatic life; fluctuation in pH as well as low and high values is stressful to organisms. High primary productivity in eutrophic lakes causes most of the high pH occurrences in lakes. Low pH can result from natural as well as anthropogenic causes including acid mine drainage and atmospheric deposition. A separate document covers sampling techniques to identify a

naturally acidic lake from one impacted by anthropogenic sources. Refer to the Defining and Assessing Natural Conditions section of the 2015 Assessment Methodology.

Biological Parameters Important in Lake Assessments

Biological information collected on lakes include: chlorophyll-a, pelagic plankton, aquatic macrophyte coverage, fish populations, cyanobacteria toxins, and bacteria. Aquatic macrophyte, fishery assessment, bacteria and cyanobacteria toxin sampling methods are covered in separate DEP documents (see below references).

Chlorophyll-a
Chlorophyll-a is an important water quality parameter. Chlorophyll-a is measured via a field-filtered water grab sample obtained from either a Van Dorn or Kemmerer sampler deployed, set, and retrieved from 1-m or with a 2-m depth integrated sampler. Phaeophytin can be analyzed from the same filter. The filter is frozen as soon as possible and analyzed in the lab. A minimum of six samples are collected on each lake using the normal sampling protocol (spring, summer, and fall, two stations each event). For the full methodology, refer to the "Chlorophyll A Sampling " document in the 2015 Assessment Methodology. Chlorophyll-a is linked to primary productivity of a lake and can often be tied to TP concentrations. Phaeophytin is a breakdown product of chlorophyll and can be used to help determine if the plankton bloom is declining. A separate Trophic State Index is calculated from chlorophyll-a and is used in comparison with indices calculated for TP, TN, and Secchi depth to assess lake status (see below).

Plankton
Plankton, including both phytoplankton and zooplankton assemblages, are assessed from tow-net collections and/or grabs at the established lake stations, using the sampling protocol described in the "Quantitative Plankton Sampling" document in the 2015 Assessment Methodology. A subset of the sample is normally identified to genus. . If nuisance blooms are noted alongshore, separate grab samples are taken for algal identification and counts, along with cyanotoxin samples to screen for toxicity. Data are screened for high counts of blue-green algae (cyanobacteria) as supporting evidence for eutrophication and impairment decisions. DEP continues to assemble statewide background data on lake plankton. When a robust database is obtained, metrics could be established on seasonal average or summer assemblages to summarize the status of this biological community as another numeric tool to gauge use attainability of lakes.

Pathogens
Bacteria and algal toxin sampling for fecal coliforms, *E. coli* and/or micocystins, saxotoxins, nodolarian and/or other cyanotoxins, provides information on swimmable waters for public safety purposes and to help identify contamination problems. Standards for fecal and total coliforms are established in the 25 Pa. Code Chapter 93, §93.7. The World Health Organization's (WHO) algal toxin guidelines are used for recreational purposes (1999).

Bacteria

All waters of the Commonwealth with the exception of Lake Erie Coastal Beaches and waters specified with exceptions to the criteria in §93.9 a-z (25 Pa. Code Chapter 93) are evaluated for water contact recreation use attainment according to the criteria for fecal coliform bacteria in 25 Pa. Code §93.7. This specifies that during the swimming season (May 1- September 30), the maximum fecal coliform level shall be a geometric mean of 200 cfu/100 mL based on a minimum of 5 samples collected in a 30-day period. In addition, no more than 10% of samples collected in a 30-day period shall exceed 400 cfu/100 mL. Additionally, during the swimming season, the PA Department of Health (DOH) and PA Department of Conservation and Natural Resources (DCNR) collect weekly samples for *E.coli* at public beaches for monitoring purposes (28 Pa. Code Chapter 18, §18.30). Closure notices when violations of criteria occur are also issued by DOH. In cooperation with DEP, the DOH and DCNR provide a list of closures that DEP will utilize to focus future fecal coliform assessment sampling in areas where the closures indicate a possible recreational impairment. Beach samples are analyzed for *E.coli* bacteria and reported as the number of colony forming units per 100 milliliters (CFUs/100 mL). Analysis must be conducted by DEP-certified labs typically following EPA Method 1603 (SIS Code MMTECMF). (Laboratory certification by other nationally recognized certification organizations is also permissible). Other certified *E. coli* methods may also be considered by the Department.

Lake Erie Coastal Beach samples are evaluated for water contract recreational use attainment according to the *E.coli* standard referenced in the 28 Pa. Code §18.28 (b) (2) and (3) that specifies that a bathing beach will be considered contaminated for bathing purposes when either a 30-day geometric mean in all water samples collected exceeds 126 cfu per 100 mL or a sample exceeds 235 cfu/100 mL. For sampling protocols and assessment, refer to the document "Bacteria Assessment Methodology" in the 2015 Assessment Methodology.

Cyanotoxins

Microcystin and other blue-green algal (or cyanobacteria) toxins are analyzed by the DEP Lab when needed; lake samples can be collected when indicated, as in eutrophic waters with visible algal scums. At a minimum for background information, algal toxin samples should be collected in lakes during the summer sampling event at the mid- or deepest station and also at least one shore-zone, either near the boat launch, or a public use area. Mid-lake samples can be taken with the 1-m Kemmerer sampler; shoreline samples should be collected where water depth is about 1m and the sample should be grabbed from 0.5m depth following EPA's methodology (EPA 2012, National Lakes Assessment Field Operations Manual.) Each sample is placed into two glass amber TOC vials, and placed on ice for delivery to the DEP Lab.

For more specific sampling instructions during shoreline bloom conditions, refer to the new Harmful Algal Bloom Monitoring and Response Strategy for Recreational Waters developed by Lake Erie partners (DEP, DCNR and DOH, 2014).

Aquatic Macrophytes

Aquatic macrophyte coverage and species in a lake are important gauges of not only trophic condition and productivity of the lake, but also quality of aquatic life and recreational opportunities. Aquatic plants are important components of a balanced lake ecosystem. 'Acceptable' plant coverage, especially those visible on a lake's surface, depends largely on the human usage of a lake. For aquatic life use more coverage is better since increasingly enriched and 'productive' lakes display the most floral and faunal biomass. Therefore, assessing the macrophyte coverage in a lake for use attainability incorporates a compromise between what is desired by humans for optimal recreation and what is needed for unimpaired aquatic life use.

Invasive aquatic plants are increasing in Pennsylvania inland lakes, most notably *Hydrilla verticillata* (water thyme or water weed) and *Trapa natans* (water chestnut). These two invasives, more than any other non-native assemblage, tend to severely and quickly impair aquatic habitat as well as recreational opportunities. When identified, the plants should be reported to the PA Fish and Boat Commission as well as the Governor's Invasive Species Council, and a Rapid Response Plan of action should be initiated with local stakeholders.

Fisheries

The ideal fishery in a lake, as with aquatic macrophytes, is probably embodied by two different sets of values. The natural function of fish in a lake ecosystem serves as the middle-to-top end of the food web (depending on life stage and species). As such, the biomass of fish populations will be balanced by the availability of appropriate food types, which will be dependent upon a myriad of physical, chemical, and biological factors. This natural balance might not be what a human user would desire both in species and in size availability. The composition and characteristics of fish populations are valuable tools in lake assessments as supporting evidence for use attainments. Fish tissue collections are part of PA's overall waterbody assessments and evaluate the Fish Consumption/Human Health Use.

Refer to the Fisheries Collection and Consumption/Human Health Use Methodology in the 2015 Assessment Methodology.

Data Analyses

To review assessed lakes for 305(b) and 303(d) listings, PA DEP uses data collected from the Lake TSI Protocol which is set forth in the DEP Document, *Evaluations of Phosphorus Discharges to Lakes, Ponds, and Impoundments* (PA DEP 2015), and is included as a separate document in the 2015 Assessment Methodology. Data from a minimum of three lake visits per year (yielding at least 6, but normally 12 water quality samples of any one parameter) includes *in-situ* temperature, oxygen, pH, and conductivity all collected in a profile of 1-m (or in shallow lakes, 0.5-m) increments from lake surface to lake bottom, plus Secchi depth, chlorophyll-a, and surface and bottom nutrient samples from at least two stations per lake per visit. Plankton tows are collected, at a minimum, at the mid-lake or deepest station on the summer visit. Additional information collected includes summer macrophyte coverage and fisheries

data but not necessarily in the same calendar year.   Although perhaps only 6 to 12 samples of some parameters are collected, once a lake assessment is completed, anywhere from 50 to over 100 data points or details from that assessment are available to evaluate each lake.

A. Carlson's Trophic State Indices

Carlson's Trophic State Indices (TSIs) (Carlson 1977) are the main tool to classify lakes to begin the use attainment decision process. These indices are used to describe the trophic state of a lake in terms of water transparency, algal biomass, and nutrient content. The surrogate tools to measure transparency and algal biomass are Secchi depth and chlorophyll-a. Nutrient content is determined by analyzing total phosphorus and total nitrogen from a grab sample. Carlson's TSI is based on a scale of approximately 0 to 100, corresponding with the clearest lakes having a low TSI value, such as 32, and the least clear (also presumably the most nutrient-rich) with the higher TSIs (perhaps in the 70's). A TSI of 50 represents the beginning value for eutrophic conditions, although nuisance conditions may not be noticed until TSIs reach 58 to 65. Depending on the time of year and the limiting nutrient in a lake or the dominance of either algae or aquatic macrophytes, one parameter may provide a better estimate over the other two. Total phosphorus TSI is best used when P is the limiting nutrient in the lake. Sometimes in spring and fall, phosphorus TSI may be high but P may not be the limiting factor in algae growth (e.g. temperature or sunlight would constrain algal growth). High phosphorus TSI values should be indicative of a potentially highly productive lake, which would be confirmed during the phytoplankton growing season (May-October). Each of the TSI results needs to be carefully evaluated with regard to each other when lakes have significant internal loading, are highly colored with tannins, have high amounts of turbidity or suspended solids, or when they support significant macrophyte growth but little algal growth. Each of the TSIs should be evaluated seasonally as well to isolate differences and clarify perturbations.

Carlson's original TSI equations (1977):

Secchi TSI = 10(6 - (ln SD/ln2)) where SD is the measured Secchi Depth in meters and ln is natural log.

Chlorophyll-a TSI = 10(6 – ((2.04 – 0.68*ln CHL))/ln2) where CHL is the measured chlorophyll-a concentration in ug/L (or mg/m3) and ln is natural log.

Total Phosphorus TSI = 10(6 – (ln(48/TP))/ln 2), where TP is the total phosphorus concentration in ug/L and ln is natural log.

TSI calculations on total nitrogen are a fairly new development and are used in conjunction with the other three. The following formula is from Kratzer and Brezonik (1981) as cited in Carlson and Simpson (1996).

Total Nitrogen = 54.45 + 14.43ln(TN), where TN is the total nitrogen concentration in mg/L and ln is natural log.

B. Use Attainment Lake Data Review

1. Data Types Reviewed for General Use Categories

The determination of Use Attainment for lakes is based on a myriad of information, including applicable water quality standards 25 Pa. Code Chapter 93, and selected data types as listed in EPA's Guidelines specific to lakes in <u>Table 5-1</u>: *Recommended Water Quality Indicators for General Use Categories* (EPA 2005, p.52).   All available data is used to determine water body impairments for each Use Category, as reproduced in Table 1 below.

Table 1. EPA's Recommended Water Quality Indicators for General Designated Use Categories

	Aquatic Life & Wildlife	Recreation	Drinking Water	Fish/Shellfish Consumption
Recommended Core Indicators	Condition of biological communities (EPA recommends the use of at least two assemblages): Dissolved Oxygen Temperature Conductivity pH Habitat assessment Flow Nutrients Landscape conditions (e.g., % cover of land uses) Additional indicators for lakes: Eutrophic condition	Pathogen indicators (*E. coli*, enterococci) Nuisance plant growth Flow Nutrients Chlorophyll Landscape conditions (e.g., % land uses)

Additional indicators for lakes: Secchi depth | Trace metals Pathogens Nitrates Salinity Sediments/TDS Flow Landscape conditions (e.g., % land cover uses) | Pathogens Mercury Chlordane DDT PCBs Landscape conditions (e.g., % land use cover) |
| **Supplemental Indicators** | Ambient toxicity Sediment toxicity Other chemicals of concern in | Other chemicals of concern in water column | Volatile organic compounds (VOCs) Hydrophyllic | Other chemicals of concern in water column |

	Aquatic Life & Wildlife	Recreation	Drinking Water	Fish/Shellfish Consumption
	water column or sediment Health of organisms	or sediment Hazardous chemicals Aesthetics	pesticides Nutrients Other chemicals of concern in water column or sediment Algae	or sediment

Aquatic Life Use
DEP uses the following information, most of which is collected on each lake within a 2 to 5 year time period: condition of biological communities (plankton, aquatic macrophytes, and fish assemblages); dissolved oxygen; temperature; conductivity; total dissolved solids; pH; nutrients; trophic condition; and, if available, other chemicals of concern in the water column or sediment. One exception is the presence of temporarily high metal concentrations in anoxic bottom waters, often detected in summer samples. Since metals such as iron and manganese dissociate from sediments in anoxia, and resorb again during lake mixing, their presence in bottom samples is not used to assess Aquatic Life Use (nor any other Use). Those and other metals, salts, ions and cations are used, however, to track background levels in lakes statewide.

Recreational Use
DEP uses pathogen indicators (bacteria and/or microcystin associates); if available, nuisance aquatic plant growth; plankton density and types; nutrients; suspended solids, chlorophyll-a; Secchi depth; and other chemicals of concern in the water column or sediment.

Potable Water Use (specific to lakes)
For the assessment of ambient lake water for the drinking water use, DEP uses trace metals, if available; pathogens, if available; nitrate-nitrogen (or TN as a surrogate); sediments/TDS/TSS; nutrients; algal assemblages; all specified water quality standards in Chapter 93 except Fe and Mn; and other chemicals of concern in the water column or sediment. Some metals, especially iron and manganese are often very high in the anoxic bottom waters of a lake as a result of the temporary dissociation of the metals from sediments. Since this is a largely natural occurrence that reverses once the lake remixes, the metals are not used in assessments or determination of this nor any other use attainments.

Fish/Shellfish Consumption Use
This is a separate program within DEP under the Bureau of Clean Water. The DEP Lake Program, as well as other sampling programs, provides fish samples to assess this use in lentic waterbodies. For lake fish collecting methods, reference the "Fish Tissue Sampling" section of this 2015 Assessment Methodology.

Supplemental Data
When available, supplemental water chemistry data, aquatic biological data, and related information from a variety of sources (e.g., PA Department of Health, PA Fish and Boat Commission, US Army Corps of Engineers, County Conservation Districts, PA Department of Conservation and Natural Resources) are also gathered and used by DEP to make the assessments.

2. Data Review

Both narrative and numeric water quality standards are the fundamental benchmarks used to assess the quality of all surface waters. Numeric criteria in 25 Pa. Code Chapter 93 Water Quality Standards for any particular parameter are used for surface water assessments. The decision process follows Water Use Assessment Decision-Making Based On Physicochemical And Bacteriological Sampling (PA DEP 2013) found on the 2015 Assessment Methods webpage. In general, if sufficient available water quality or biological data show that standards are not met, along with other supporting evidence such as high TSIs, the waterbody is considered impaired. For non-quantitative narrative standards, evaluation of impairment requires a variety of information and a weight of evidence approach. The weight of available evidence should lead most evaluators to the same conclusion regarding impairing or attaining uses. Borderline situations entail the use of both numeric and narrative standards and the weight of evidence approach. In general, if these standards are met, the associated beneficial uses will be protected. Healthy lakes have clean water, balanced algal growth, adequate oxygen levels, and balanced fish and invertebrate populations. In addition, healthy lakes will support uncontaminated bottom habitat and appropriate habitat for native aquatic plants to flourish. The relative balances for each individual lake will vary, so an array of assessment tools should be evaluated for each lake. A vast majority will yield all four Trophic State Indices below 60. Borderline lakes with one, two, or three Indices falling in the 60 to 65 TSI range need to be carefully evaluated, and may require more information before being placed on an impairment or attainment use list. Any lake falling into this 60-65 TSI range should, at the least, be considered "threatened" and appropriate stakeholders should be encouraged to develop and implement a lake and watershed plan, targeting BMPs that will restore water quality and prevent further impacts to the lake. Biannual or triennial lake sampling should be scheduled to track water quality conditions in threatened lakes.

a. Aquatic Life Use – Numeric Values from Chapter 93 Standards

Temperature
Lakes in PA may be designated as any of the following: Warm Water Fishery (WWF), Trout Stocked Fishery (TSF), Cold Water Fishery (CWF), High Quality (HQ), or Exceptional Value (EV). The WWF temperature criteria (the least restrictive) are used as a guideline only, since open waters naturally gain solar energy more than shaded streams. Most lakes in Pennsylvania naturally reach temperatures in the mid 80's (F) at the surface in summer, which is not considered an impairment; however, temperature

criteria must be considered if the lake receives a heated discharge. In that case, data and Chapter 93 standards should be reviewed in detail.

Dissolved Oxygen
Dissolved oxygen (DO) criteria under Chapter 93 applies only to the epilimnion during stratification because almost all lakes, whether natural or impounded, commonly experience lower DO in the hypolimnion during summer stratification due to the natural decomposition of organic matter and the non-mixing of water during that time. Not all PA lakes completely stratify, but most experience low DO close to the bottom of the lake in summer. This is considered a natural process that is expected to occur in newer impoundments as well as in our 10,000 year-old natural lakes. For fishery management in lakes, the PA Fish and Boat Commission (PFBC) uses their own temperature, oxygen, and alkalinity criteria and *specific characteristics of each lake* to determine if the lake is appropriate for trout (and other species) stocking.   For stratified lakes, the DO criteria currently stand at a minimum (*in the epilimnion only*) of 5.0 mg/L for WWF, CWF, HQ-WWF, HQ-TSF, and HQ-CWF. These criteria should easily be met 99% of the time in unimpaired lakes. An impaired lake will show oxygen depletion beginning in the epilimnion, with continued decreasing DO levels each meter to the lake bottom, and the lake will have other supporting factors that point to impairment. The hypolimnion in stratified lklakes is protected by the narrative water quality criteria in Chapter 93.6.   For nonstratified lakes, the DO criteria apply throughout the waterbody

pH
Statewide pH standards are used (6 to 9 units, Chapter 93) in lake assessments. pH below 6 suggests a relationship with natural bogs, acid rain, AMD, or natural geology. Lakes may or may not be impaired by pHs between 5 and 6; the reviewing biologist will determine if the low pH is a result of natural conditions or impacted by an anthropogenic condition. Refer to the "Defining and Assessing Natural Conditions" section of this 2015 Assessment Methodology for guidance on identifying naturally acidic lakes from those anthropogenically influenced. A macrophyte survey and a fishery survey will help to determine if the pH contributes to impairment. Macrophyte populations dominated (>50% occurrence) by *Utricularia spp.* (bladderwort) indicate natural long-term acidic waters, as does the presence of bog plants such as sundew (*Drosera spp.)* or pitcher plants. Assessing a fishery can be more difficult because most native fish assemblages in PA have been impacted by the introduction of non-native species. Most fish species presently occupying lake habitats are not able to reproduce well in a consistently low pH environment. In general, the presence of acid-tolerant native species such as spotted or banded sunfish, chain pickerel, yellow perch, brown bullhead, lake chubsucker, and possibly golden shiner indicate a low pH acid-tolerant, natural fish assemblage, but very few lakes in PA have this fish assemblage. Most lakes contain introduced "fishable" species. pH units above 9.0 suggest a high degree of biological productivity (e.g., algal bloom) stimulated by excess nutrients. Many eutrophic lakes will yield pH >9.0 in the epilimnion in summer. If the water column profile pH median or mode is above 9.0 on any one date, the lake could be impaired for Aquatic Life Use. Since our pH meters usually state a + or − 0.2 accuracy, median pH < 9.25 should not be considered an

impairment. (Note that it is mathematically incorrect to calculate a mean value on any log numbers, so use only the median and mode values for pH).

b. Aquatic Life Use - Narrative Standards from Chapter 93

Besides the numeric standards from Chapter 93 above, other parameters (below) are used in assessment of lakes; these are considered our narrative standards or general water quality criteria (25 Pa. Code §93.6). The values cited originate from data collected on 221 lakes from 1997-2007. Overall mean values (i.e. the three sampling sets for the assessment averaged over the seasons, removing flagged data as necessary) were calculated for each parameter. This data was then graphed and overall means, medians, and 25% low and high values were determined for reference points (see Figures below).

Nutrients
Presently, lakes are assessed for potential impairment due to excess nutrients based on narrative standards.

Mean values of nutrients, total phosphorus (TP) and total nitrogen (TN), are examined over each season from lake "bottom" and "surface" samples (i.e., 1-m above the bottom, and 1-m below the surface). Each parameter is averaged over all seasons to yield a mean overall value for the sampling year. The justification of this procedure is that it deemphasizes the worst-case scenario (i.e., summer conditions when algae or macrophytes may concentrate TP and affect its presence in water samples) and weighs more heavily on mixed water conditions (spring and fall) when more unincorporated TP is distributed throughout the water column. If any of the TN or TP values are outliers, a second mean value is calculated for all the seasons for the entire lake, excluding the outliers. Examples of outliers would be high values coming from internal (bottom) loading during anoxic periods. If the TN/TP ratio in summer bottom samples is below 10 (when normally the lake is definitely P limited) or if the resulting bottom TSI calculation is 10 or more points greater than the surface TSI values on the same day, then the TN and TP numbers should be flagged and not used in the overall lake means and the TSI evaluation.

Seasonal mean values below 0.05 mg/L TP and 1.5 mg/L TN (each translates to a TSI of 60) are considered indicators of attainment. Values above these levels are considered as indicators of nutrient loading and perceptible problems. These values were derived from screening 221 PA lake assessments completed from 1997-2007.

For TP, the mean PA lake value (based on a mean of all seasonal values -i.e., the mean of all samples taken over the 3 seasons) is 0.034 mg/L; the 25% least enriched lakes have TPs of < 0.016 mg/L and 25% most enriched lakes have TPs > 0.035 mg/L. Ten percent of PA's lakes have mean seasonal TPs of 0.065 mg/L or greater (TSI = or

> 64.4). Most of the lakes at or above the 10% point are impaired, but other data must support this position. Phosphorus levels are also gauged according to EPA criteria (Table 2).

For TN, the mean PA lake value (based on a mean of all seasonal values -i.e., the mean of all samples taken over the 3 seasons for 218 lakes) is 0.887 mg/L; the 25% least enriched lakes have TNs <0.44 mg/L and the 25% most enriched lakes have TN values >1.04 mg/L.   At 1.57 mg/L and above, lakes could be considered impaired. However, because TP is usually the limiting factor, lakes with the 10% highest TNs may not show other indications of impairment. Other data on these lakes must be carefully evaluated to gain insight as to how and if the higher TN affects the lake and its uses.

Nitrogen to phosphorus ratios (N/P) should be examined for all data points and for mean season values to determine nutrient limitation. Schindler's (1977) guideline states that generally large N to P ratios (>7) indicate that algal growth will be P limited, while N to P ratios < 7 indicate phytoplankton will be limited by nitrogen. Another guideline, the "Redfield ratio", uses a higher N to P ratio to declare P limitation at 14 and higher. This ratio is based on the actual ratio of nutrients needed by phytoplankton for ideal growth, i.e., 16 N to 1 P. Some researchers interpret ratio values in the range of 7 to 14 to mean co-nutrient dependence.

When ratios are low, keep in mind that blue-green algae are capable of fixing N from the atmosphere, so their blooms will not be limited by N; in fact, an N-limited system can give them a competitive advantage over other types of algal growth. Plankton samples can provide important supporting data as to the presence and extent of blue-green algal problems in the lake.

Secchi Depth Evaluations
Secchi disk depths recorded for the three assessed dates are evaluated as per EPA's criteria (Table 2). As a guideline for PA lakes, based on data from 220 lakes, mean seasonal average Secchi depths were 1.96 m; the 25% best lakes averaged 2.37 m Secchi depth and the 25% least clear averaged 1.16 m Secchi depth.   Secchi data should be evaluated while assessing color, TP, chlorophyll, TSS (total suspended solids), and pH data. Secchi depths can be affected by not only algal blooms, but non-algal TSS (suspended organic or non-organic material, and/or highly colored tannic waters).   In clear shallow lakes, Secchi information may not be obtainable if the disk reaches the bottom while still visible. TSIs should not be calculated or used on such data.

Chlorophyll-a
Data from PADEP's 10-year dataset indicates state-wide mean seasonal chlorophyll-a value of 0.0169 mg/L in PA lakes. Twenty-five percent of lakes were at levels of 0.019 mg/L or more, with the 10% worst having chlorophyll-a at 0.0389 mg/L or more.   Keep in mind that the above are full assessment mean values, not just summer values. Chlorophyll-a data should also be reviewed as per EPA's criteria (Table 2), which compares single samples, and can be used for summer samples alone.   Since

chlorophyll-a is analyzed from the algal cells in a lake sample, consider that algal growth (and thus chlorophyll data) will likely be lower than expected in a lake with abundant aquatic macrophytes. In this situation, TP may be lower in the summer set of samples as well. An assessment of the aquatic macrophyte coverage is advisable and should be an integral part of the lake evaluation process. TSIs can be significantly lower in a lake with significant macrophyte coverage, especially in shallow lakes where coverage can extend lake-wide. In this case, the TSIs may indicate low-eutrophic or even mesotrophic conditions, but visibly the lake is entirely impacted by macrophytes and appears eutrophic. By definition the TSI describes the *water* quality condition, but perhaps not the *waterbody* condition. The evaluation of the bottom line for any particular Use should be made with this in mind. For macrophyte method details, reference the "Aquatic Macrophyte Cover" section of this 2015 Assessment Methodology.

Alkalinity (as CaCO3)
Lake alkalinity in PA varies as a result of native geology; data on 120 lakes shows a range from 1.2 to 151 mg/L with a mean of 31 mg/L and a median of 24 mg/L. Alkalinity criteria under Chapter 93 Water Quality Standards require a minimum of 20 mg/L "except where natural conditions are less". This datum is collected more or less as additional information for the purposes of relating to pH data and assessing the fishery, and will apply as mercury data are gathered and assessed. Although low alkalinity impairs a lake in mitigating acid precipitation, it does not necessarily translate into Aquatic Life Use or Recreational Use impairment. Consistently low acidic conditions will affect fish population dynamics and may impair a fishery for recreation, if that is a major use of the lake.

Total Suspended Solids (TSS) and Total Dissolved Solids (TDS)
TSS and TDS are collected as additional information with which to assess chlorophyll-a and Secchi depth data, and as a tag for watershed inputs. TSS can indicate planktonic as well as non-organic sediment components; observations, field notes, and other data (e.g. Secchi depths, rainfall in the past few days) can help delineate between them. Average TSS on 124 lakes was 8.4 mg/L; any value over 10 or 15 should be scrutinized as to the possible source. Sources can include watershed/tributary runoff after storm events, bottom-sediment re-suspension in shallow lakes or embayments (from storm events, wind, or fish activity), or even abundant zoo- and/ or phyto-plankton in the water column. TDS may arise from roadway salts showing up in spring chemistry samples, old mine sites or new gas drilling sites in the watershed, or very old septic or holding tanks near the lakeshore. If high TDS (>300 mg/L) occurs in lake samples, an investigation as to the source is warranted. Median TDS in PA lakes was approximately 101 mg/L from 24 lakes; more data on this parameter will be collected over the next several years.

Other Chemicals
Other water chemistry components such as dissolved metals, total metals, and P and N species (nitrate-nitrogen, nitrite-N, ammonia, total or dissolved ortho-P) may also be collected specifically to identify problems such as internal loading from bottom

sediments during anoxia or septic contamination of lake water, or to help understand algal vs. macrophyte growth dynamics in a lake. These parameters are not part of the normal protocol but can be included at the discretion of the field biologist. Water Quality Criteria for metals and ammonia are available in Chapter 16 and 93, respectively. For lakes, high metal or nutrient content in samples collected during summer anoxic conditions in the bottom waters are not to be considered lake-wide contaminants. These elements will quickly resorb back into the sediment during lake turnover and re-oxygenation of the water, and are normally not present most of the year. If the configuration or the trophic state of the lake results in persistence of these elements, then the extent of their presence needs to be considered along with other indications of any use impairments.

Plankton
Zooplankton and phytoplankton are normally collected at the mid-lake station during the summer sampling event, at a minimum. Samples should be collected (vertically hand towed) from oxic depths of the lake only; including anoxic areas will negatively affect density calculations. Samples are identified in the lab to genus whenever possible. Data helps to ascertain the balance and size of phyto- versus zooplankton, and/or to determine the extent of blue-green algae (cyanobacteria). A balanced appropriate plankton assemblage is an important indication of the available food base; trends towards small-sized zooplankton or towards dominant blue-green components can corroborate other information in understanding an unbalanced fishery, eutrophication, or other problems. The presence and density of nuisance algal types (such as *Microcystin, Anabaena, Aphanizomenon,* and *Oscillatoria*) are documented in the regional lake reports for future reference. A number of blue-green genera are known to produce toxins, and it is DEP's intent to gain a database on both the algal types and toxins present for future reference.

Trophic State Indices (TSI)
Calculated TSIs (formulas given above) are examined for surface and bottom samples for each parameter, each season. Seasonal values are calculated on the appropriate mean values (TSIs are themselves never averaged because they are log values). Seasonal mean TSI values below 60 suggest no impairments; TSIs above 65 indicate problems and probable impairment. Lakes with TSIs between 60 and 65 need to be examined carefully to determine threats or impairments. EPA's criteria and guidelines are given in (Table 2).

The median phosphorus TSI value (calculated from TP data), based on 222 PA lakes, was 48.6; the 25% best lakes had TSIs below 44; the 25% worst had TSIs greater than 56 (Figure 2). Ten percent had a TP TSI of 65 or above and are candidates for, or already are listed as Impaired for one or more Uses. Lakes with a TSI of 55 or greater are candidates for management intervention to protect them from further eutrophication. An ongoing monitoring program should be established with (or by) the stakeholders of the lake and development of a lake and watershed management plan to identify and mitigate water quality threats and impairments is advisable. Numerous state and local programs support these types of initiatives.

The median TSI value calculated on chlorophyll-a for PA lakes was 53. Twenty-five percent of PA's lakes were above TSI 59 for chlorophyll-a. The ten percent most algal-productive lakes had chlorophyll-a TSIs above 66.5 (Figure 3) and are candidates for Impaired Use listing.

For Secchi TSIs, the statewide median value was 53; 10 percent of the least-clear lakes in PA revealed TSIs above 61.5 (Figure 4), and these may be candidates for Impairment listing.

TN TSIs are calculated for supporting evidence but are not used in impairment decisions until after the other three TSIs are reviewed (Figure 5). Most lakes in PA are phosphorus limited, so high TN values may not necessarily translate into use impairment. Before any of the three or four TSIs are used to support an impairment decision, all available data from Table 5-1 of EPA's Recommended Water Quality Indicators for General Designated Use Categories must be reviewed and evaluated (Table 1).

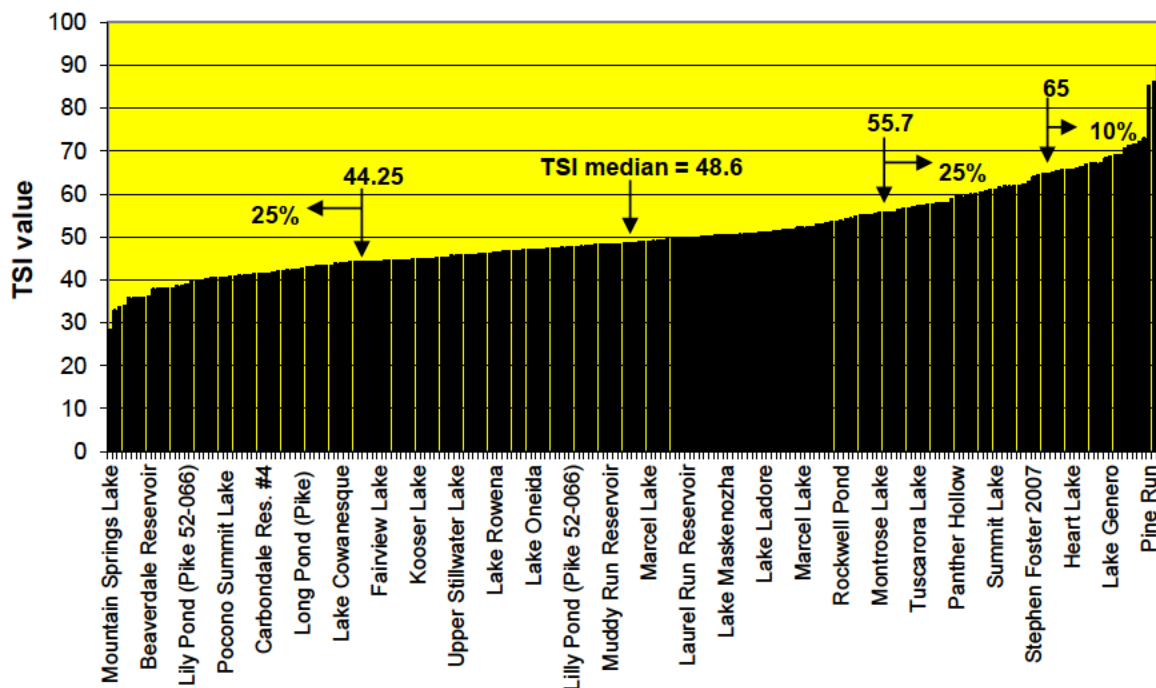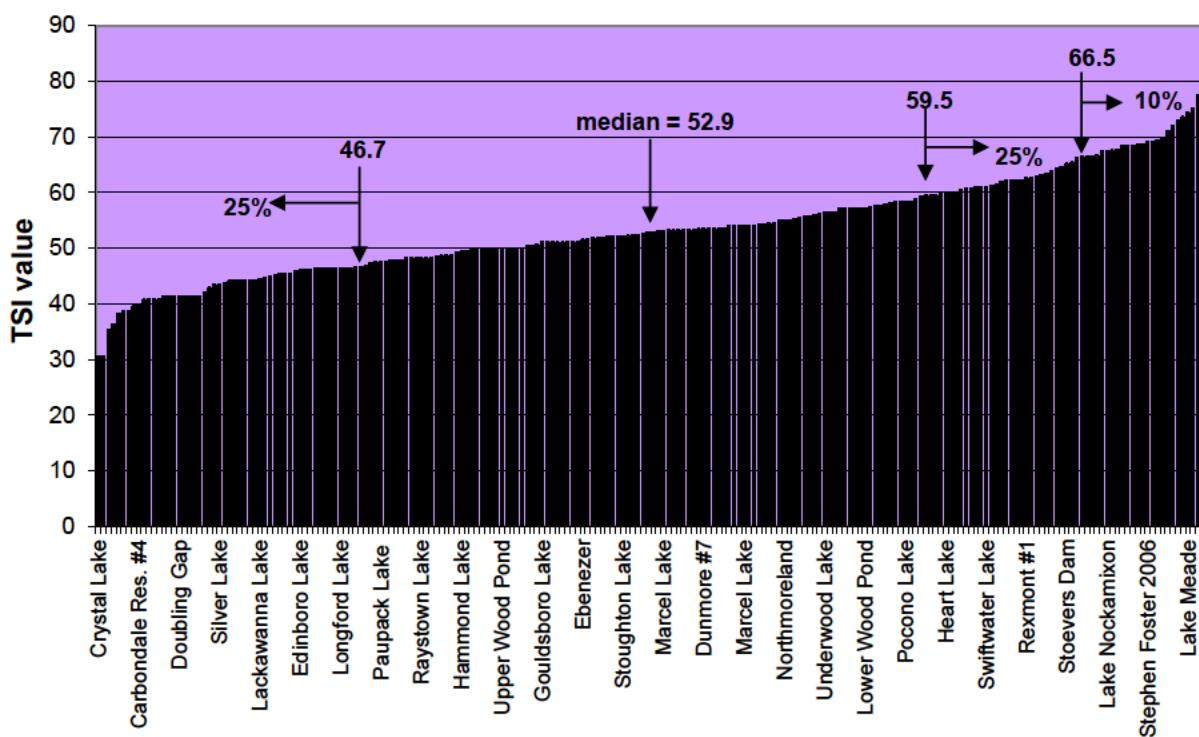Figure 2. Trophic State Indices for total P collected from 1997-2007 in 221 PA lakes.

Figure 3. Trophic State Indices for chlorophyll-a data collected from 1997-2007 in 222 PA lakes.
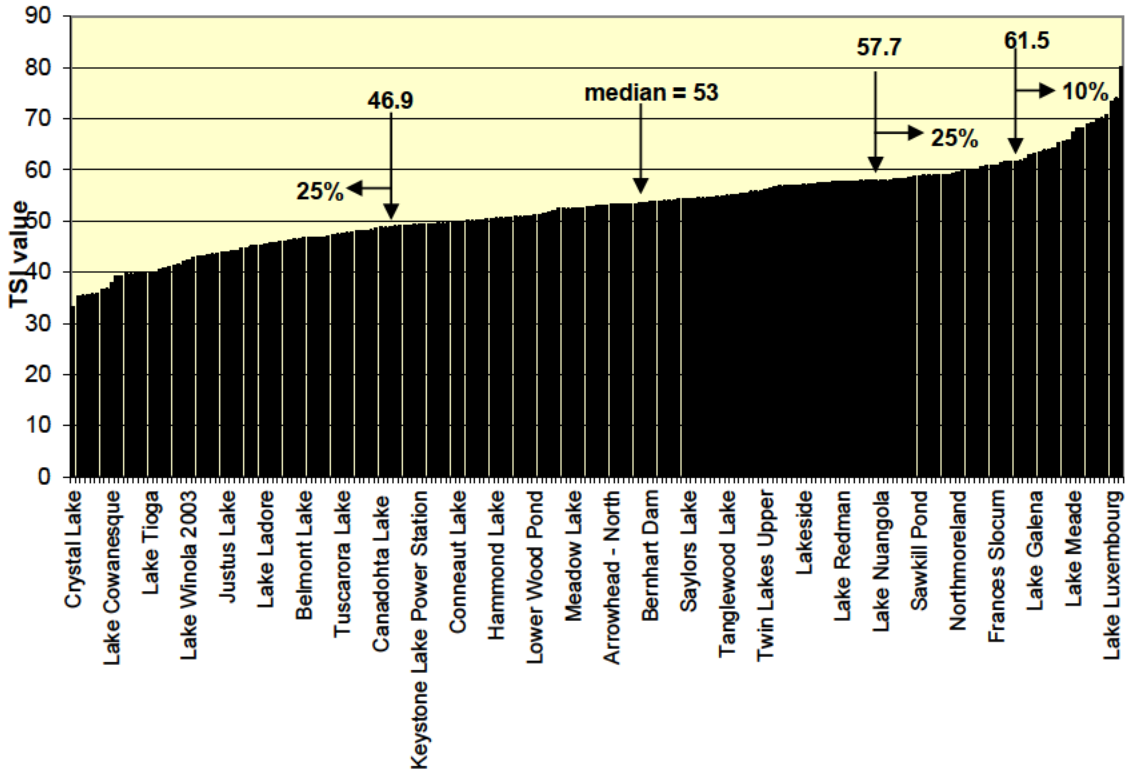
Figure 4. Trophic State Indices for Secchi Depth data collected from 1997-2007 in 220 PA lakes.
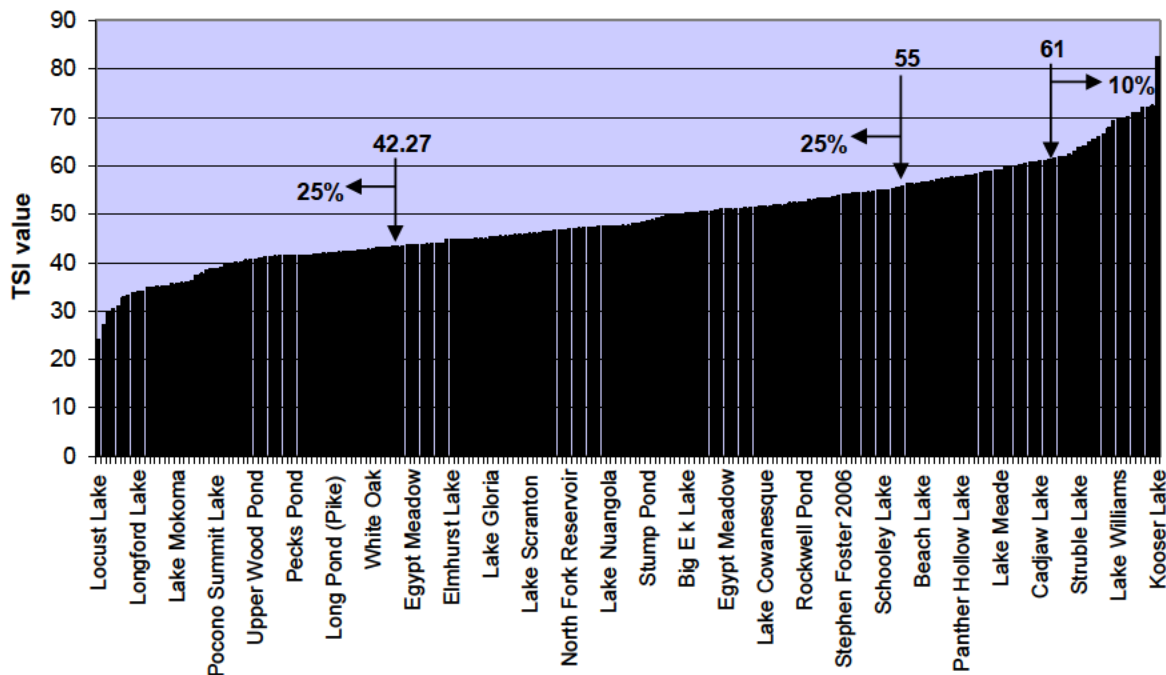
TN TSI on 218 PA Lakes

Figure 5. Trophic State Indices for total N from 1997-2007 in 218 PA lakes.

A lake that yields any one TSI of 65 or more is a candidate for Impairment listing but requires scrutiny of all available information to support that decision.

TSIs can also be used for trend analyses. TSIs can indicate improvements in a lake after a TMDL has been implemented, or they can indicate degradation. A 'measurable' change in trophic status is a change that can be discerned above normal variability in water quality data using a weight of evidence approach. The change in trophic status does not require a demonstration of statistical significance to be considered measurable although mathematical models may be used as a tool in data analysis to help predict changes in trophic status or in nutrient or other indicator parameters. A few of our TMDL lakes are tracked (by water quality monitoring) annually or biannually. Additionally, historical data is available on a number of our public lakes which can be used in trend analyses.

Overall Aquatic Life Use Assessment
To make the final assessment on aquatic life use, incorporate supporting data from Table 1 (EPA's 2006 Guidance for Assessment, Listing and Reporting [EPA 2005]). The lake's TSIs will be an important indicator to consider along with all other available

parameters as discussed above. If any of the values in the sections above indicate possible problems, each lake's data is scrutinized and ancillary data is sought. Ancillary data may include data that is available externally, including user perception.   If conclusive data is not available, the lake is catalogued as "needing more information". The lake is then targeted for a supplemental survey or study to gather watershed, land use, habitat, tributary/runoff, fishery, macrophyte, plankton, and water and/or sediment chemistry information to identify conditions.

c. Recreational Use

Macrophyte Coverage
Once field data is organized onto a coverage map as described in the "Aquatic Macrophyte Cover" section of the 2015 Assessment Methodology, the extent of coverage along with best profession judgment is used to assess recreational impairment. The general consensus is that 40% or more _surface_ coverage may impair boating, fishing, water contact sports, or aesthetics. This assessment is not applied to lakes where public access is restricted or lakes are managed by the Pennsylvania Game Commission as waterfowl areas.   Macrophyte coverage may also be used as a tool to assess habitat for Aquatic Life/Wildlife Use.   In this case, 40% _underwater_ coverage is considered good (or sometimes minimal) habitat condition and 10% or less coverage is considered to be poor habitat.   Mitigating factors to consider are the presence and extent of invasive, non-native species which may degrade habitat, and the extent of weed management measures conducted by lake stakeholders (e.g., harvesting, application of herbicides or aqua-shades, etc.). The over-management of weeds may reduce fish nursery areas, but judicious management could improve boat and swimming access without drastically reducing aquatic life habitat.

Fishery Protocols
Refer to the "Lake Fisheries" document for assessment methods in the 2015 Assessment Methodology. Condition of the lake's fishery can be assessed by either a DEP regional biologist or from information from the PFBC (either an official report, or by written statement). Basically, fishery data is examined to review the status and balance of the fish population. The lake should support a trophic balance, containing several size classes of predator species (indicating successful reproduction and adequate food and habitat resources) and also an array of insectivorous, benthic, and forage species. The specific species present in these categories will vary in PA lakes depending on the type and location of the lake, and the degree of past or present fish management. PA has naturally low productive (oligo- and mesotrophic) and low pH lakes where fish populations will be less diverse than populations in eutrophic lakes.   See the "Lakes Fisheries" protocol noted above for further discussion.

Bacteria/Pathogens
Bacteria samples can be valuable in assessing the recreational use of a lake, especially those with community beaches or where swimming is common at private cabins. Bacteria protocols, both sampling methods and assessments, are given in a separate document – "Bacteriological Sampling Protocol" section of the 2015 Assessment

Methodology. The bacteria protocols follow the requirements in the Department's Chapter 93 Water Quality Standards. Bacteria sampling is sometimes also used for investigating septic contamination and, along with an array of water chemistry samples, can be used to support an impairment decision. Blue-green algal toxins are another health concern that DEP intends to expand investigations with ongoing background and indicator sampling. In cases where cyanotoxins are found, DEP should return to the lake and collect multiple samples around the lake to determine extent of toxins and if public warnings are warranted. EPA is expected to provide states with protocols and thresholds for recreation in late 2015 or early 2016. DEP can also refer to World Health Organization's (WHO, 2009) guidelines on toxic levels of cyanobacteria types, until EPA's standardized guidelines are finalized:
http://www.who.int/water_sanitation_health/resourcesquality/toxicyanbact/en/

Overall Recreational Use Assessment

To make the final assessment on recreational use, incorporate supporting data as listed in Table 1, which highlights EPA's 2006 Guidance for Assessment, Listing, and Reporting (EPA 2005). The lake's TSI values will be an important indicator to consider along with the three main tools above. If any of the tools above indicate possible problems, each lake's data is scrutinized and ancillary data is sought, including user perception. If conclusive data is not available, the lake is catalogued as "needing more information" and is targeted for further study and a supplemental survey to gain watershed, land use, tributary, macrophyte, phytoplankton, and any other missing information to identify conditions.

d. Potable Water Use

The main tools used to assess the drinking water use are the water quality standards in Chapter 93, except dissolved Fe and total Mn. (These elements tend to dissolve from lake sediments in high concentrations in the anoxic summer hypolimnion, but resorb back into the sediments during lake turnover in the Fall. They will not typically become part of the overall lake chemistry). For lakes used as public drinking water sources, a minimum of eight samples are collected from near the point of entry of the drinking water intake. For all other lakes, the normal set of lake data is examined. Total nitrogen is used as a surrogate for nitrates, since nitrate-N is a smaller component of total N (TN). A TN concentration less than 10 mg/L will accommodate the standard. At a minimum, 8 water chemistry data points are collected in any one calendar year and reviewed for TN values. If no value is greater than 10 mg/L, the waterbody is considered meeting the drinking water use. Before listing as such, other available data as listed in Table 1 (EPA's 2006 Guidance for Assessment, Listing, and Reporting (EPA 2005)) is used to support the decision. TDS and TSS are usually readily available parameters normally collected during lake surveys, as well as plankton types and density, and each can contribute to evaluation of the Potable Water Supply Use.

Table 2. Lake Trophic Criteria
(Source: Clean Lakes Program Guidance Manual, 1980, U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, DC, Publication Document: EPA-440/5-81-003)

Trophic State (EPA 1980 Criteria)	Total P (mg/L) - Spring	Chlorophyll-a (ug/L) - Summer	Secchi Depth (m)	Relative Productivity
Oligotrophic	< 0.005	< 2.0	> 8	Low
Mesotrophic	0.005 - 0.030	2.0 - 6.0	4 to 8	Moderate
Eutrophic	0.030 - 0.100	6.0 - 40.0	2 to 4	High
Hypereutrophic	> 0.100	> 40.0	< 2	Excessive

TSI Value	Secchi Depth (m)	Surface TP (ug/L)	Surface Chl-a (ug/L)	Surface Chl-a (mg/L)
0	64	0.75	0.04	0.00004
10	32	1.5	0.12	0.00012
20	16	3	0.34	0.00034
30	8	6	0.94	0.00094
40	4	12	2.6	0.0026
50	2	24	6.4	0.0064
60	1	48	20	0.02
70	0.5	96	56	0.056
80	0.25	192	154	0.154
90	0.12	384	427	0.427
100	0.062	768	1183	1.183

General Guidelines

PHOSPHORUS: EPA eutrophic criterion – mean in-lake concentration of 0.02 to 0.03 mg/L for TP (USEPA, 1980).

   TP below 0.01 mg/L - relatively unproductive; provides a high level of protection from aesthetic impairment.

   TP < 0.02 mg/L will avoid nuisance algal growth.

   TP above 0.03 mg/L - productive lakes likely to experience problems w/nuisance blooms and/or aquatic weed growth.

CHLOROPHYLL-A: 0 to 10 ug/L - no problems evident
10 to 20 ug/L - algal scums evident
20 to 30 ug/L - nuisance conditions encountered
> 30 ug/L - severe nuisance conditions encountered

SECCHI: Depth < 2.0 m = undesirable for recreational lake users.

Trophic State (TSI) Values Used for Pennsylvania Lakes (DEP):

TSI Value	Trophic State
< 40	Oligotrophic
40 - 50	Mesotrophic
50 - 65	Eutrophic
> 65	Hypereutrophic

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pennsylvania
DEPARTMENT OF ENVIRONMENTAL
PROTECTION

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF POINT AND NON-POINT SOURCE MANAGEMENT

LAKE/RESERVOIR FIELD DATA SHEET

Lake Name _____   County _____

Station _____   Lat._____   Long_____

Date _____   Time _____   Collectors _____

Weather _____

Cloud Cover (%)   0   25   50   75   100   Comments (Hazy/Foggy) _____

Wind Conditions: None   Light   Moderate   Heavy   Direction _____

Rain Conditions: None   Drizzle   Light   Moderate   Heavy

Surface Turbulence _____   Air Temperature (ºC) _____

Station Depth (meters) _____

SECCHI DISK READING (TENTHS OF A METER) _____

FIELD MEASUREMENTS

DEPTH (meter)	TEMP (ºC)	D.O. (ppm)	pH	Sp. Cond. (Umhos)	DEPTH (meter)	TEMP (ºC)	D.O. (ppm)	pH	Sp. Cond. (Umhos)
surface					11M				
1M					12M				
2M					13M				
3M					14M				
4M					15M				
5M					16M				
6M					17M				
7M					18M				
8M					19M				
9M					20M				
10M									

SAMPLES COLLECTED

TYPE/DEPTH	SAC	VOLUME FILTERED	TIME COLL.	COLLECTION NUMBER
WATER QUALITY (Top)				
WATER QUALITY (Bottom) Depth of Sample:				
CHLOROPHYLL A				
OTHER (blank/dup.)				
PLANKTON TOW (2x _____ m w/net diameter _____)				

COMMENTS: _____

_____

_____

_____