Chlorophyll-a Indicator

Bill Hall

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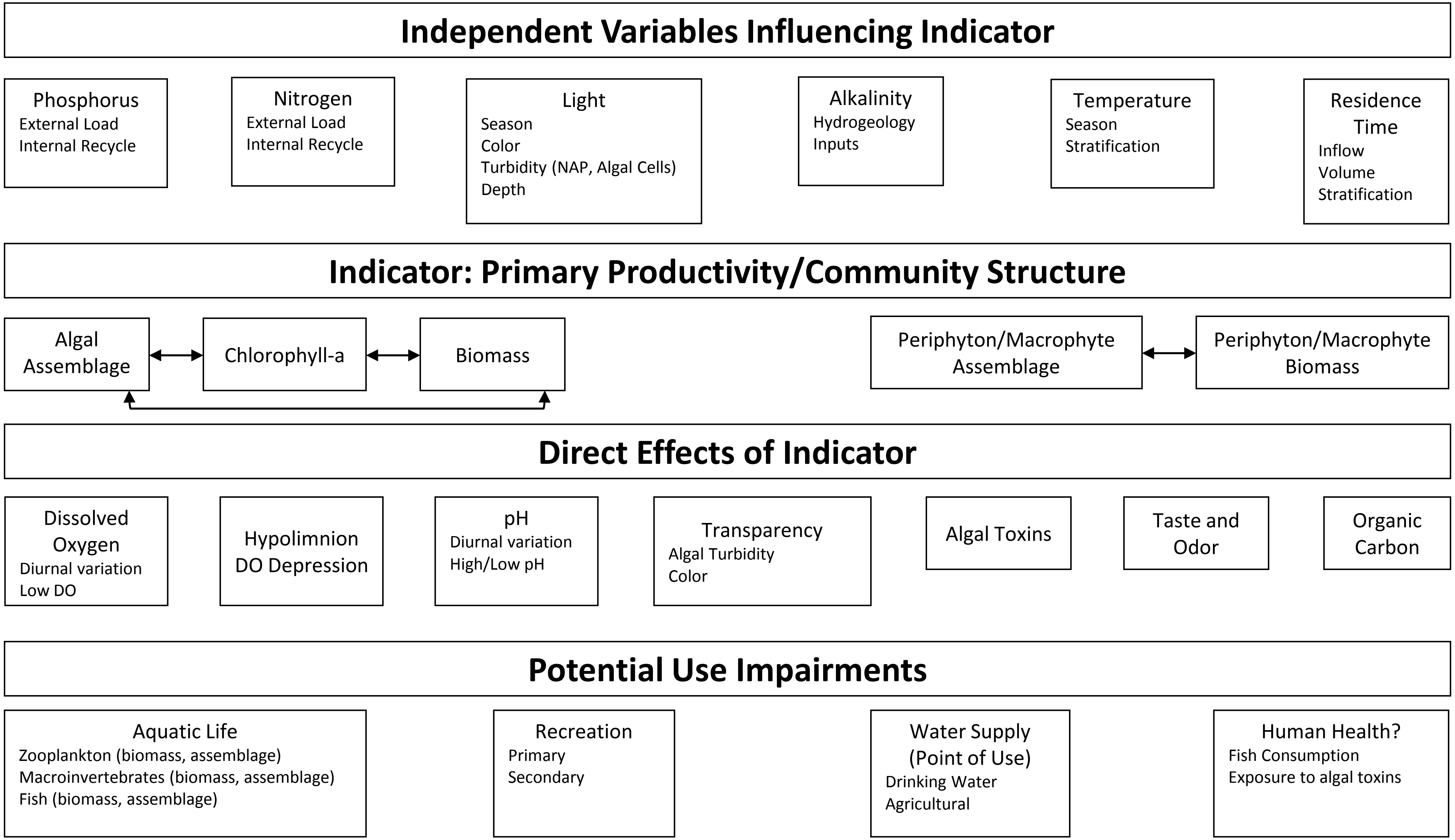
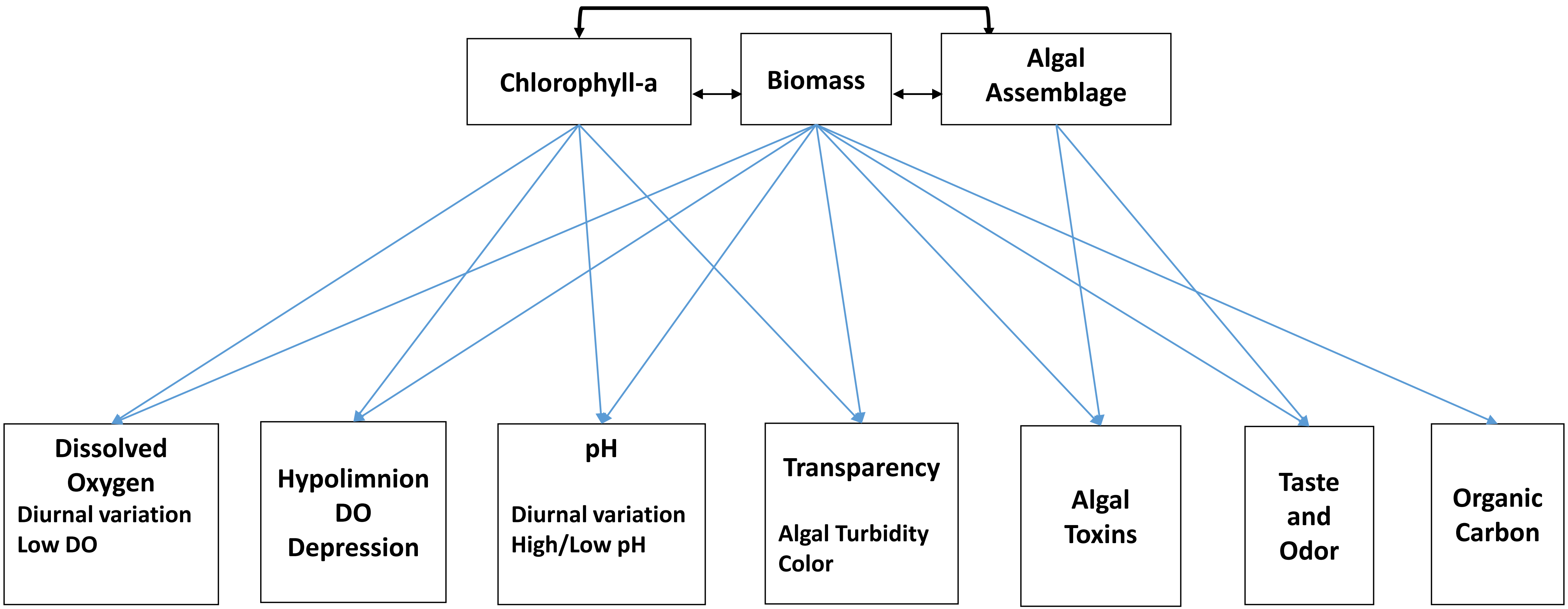
December 9, 2015

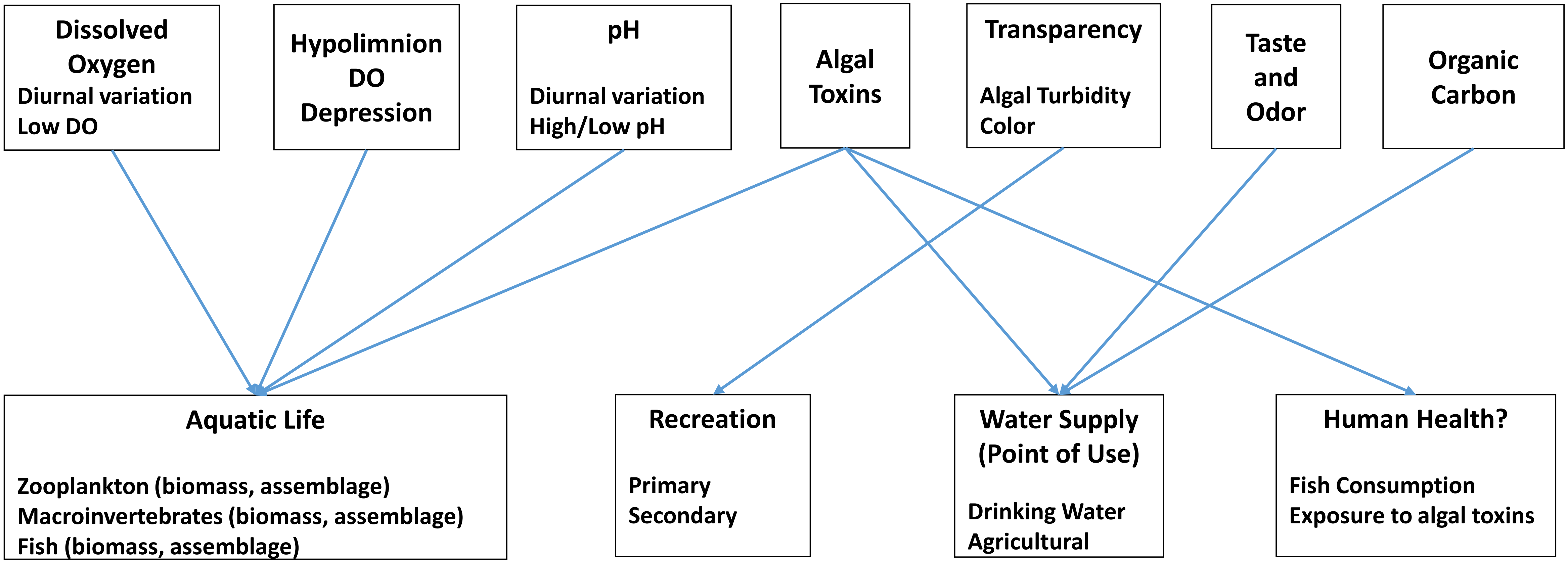
Conceptual Model for Chlorophyll-a Indicator

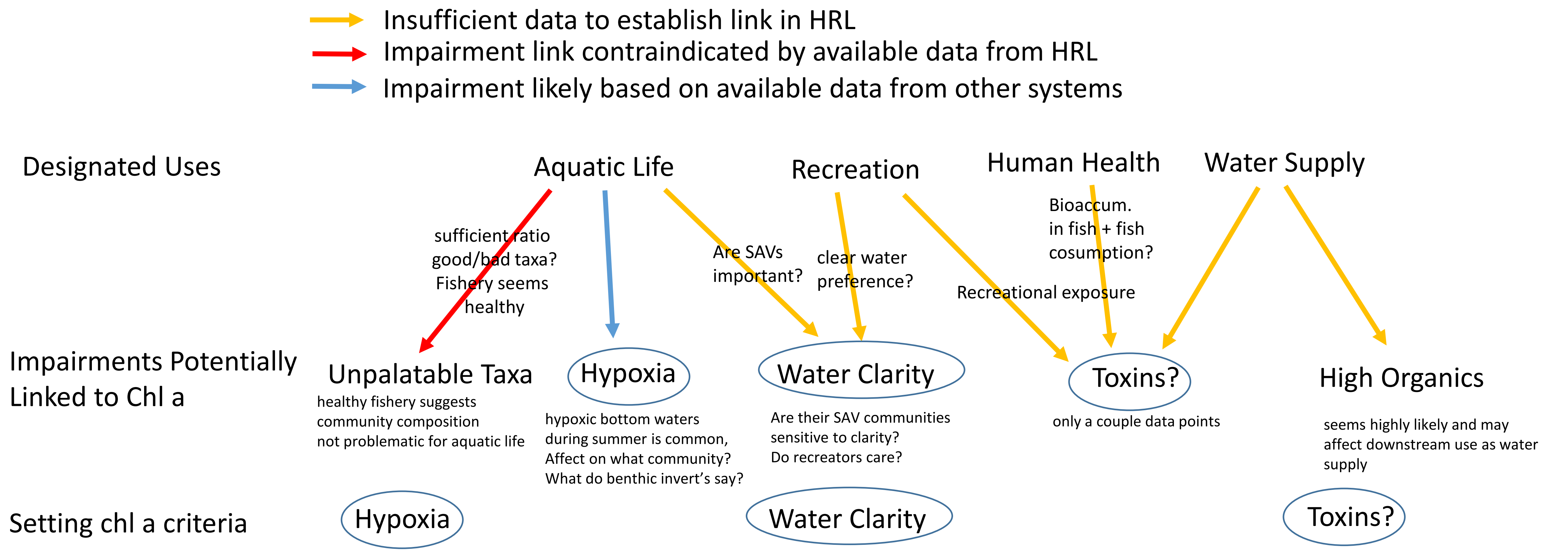


Conceptual Model for Indicator Direct Effects



Conceptual Model for Direct Effects and Potential Use Impairment





slope of ~0.1-0.2 mg DO/ µg chl a (Harding et al. 2013; Miss. DEQ 2011) Resulted in chl a criteria of 20 µg/L as an annual mean to maintain 2 mg/L in Chesapeake Bay bottom waters, and daily min above 4 in Miss. reservoir surface waters

Need to look at relationship between summer bottom water DO vs. spring-early summer chl a in High Rock Lake.

Easy to relate to chl-a.

Need to determine whether SAV communities are present and would benefit if clarity was enhanced (e.g. water levels stable enough)

Need to understand user perception for determining recreational use. Perceptions are region specific.

Small amount of data suggests insignificant microcystin concentrations. Didn't look at cylindrospermopsin which is found in the dominant cyanobacteria, Pseudanabaena and Cylindrospermopsis.

Could look at chl-a toxin relationships from other systems and use a conservative value that would keep toxins within EPA guidance levels.

Notes on Fishery Quality Indicators for High Rock Lake

Clifton Bell December 8, 2015 (Working Draft)

These notes focus on potential indicators of sport fishery quality in High Rock Lake. Much of this discussion is derived from a 7 Dec 2015 personal communication with Lawrence Dorsey of the NC Wildlife Resource Commission (WRC). Non-game fish, "priority" taxa (e.g., native fish, mussels), and other benthic macroinvertebrates are not a focus at this time, because such taxa are either not expected to be present in a artificial reservoir environment, or not typically used as indicators in reservoirs.

Fishery Metrics

The metrics provide in Table 1 are among those typically tracked by WRC, using data from triennial reservoir surveys:

TABLE 1 – Examples of Fish Metrics Utilized by WRC

Metric Category	Examples
Catch rate	• Fish/hour (electrofishing) • Fish/net night (trap netting)
Individual fish metrics	• Length • Weight • Age
Composite Metrics	• Length/age • Relative weight • Length distribution • Age distribution

No single metric is sufficient to describe the sport fishery, because anglers are concerned with both catch rate and size. Catch rates and average fish size can be inversely correlated in reservoirs; i.e., high catch rates can correspond to smaller average fish size. In practice, WRC attempts to manage reservoirs to attain both a catch rate and size distribution that is desired by anglers. WRC does not currently track fish anomalies such as lesions, tumors, or deformities.

The Tennessee Valley Authority has established a reservoir fish assemblage index (RFAI) that is similar in concept to an index of benthic integrity (IBI). It is a composite of 12 fish community metrics that measure species richness, trophic composition, abundance, and fish health (Carriker, 1999). However this approach is unusual, in that most state game commissions do not use apply IBI concepts to reservoir sport fisheries. Among other reasons, an IBI is dependent on the ability to define a minimally-disturbed reference condition, and this concept has questionable merit for artificial reservoirs (L. Dorsey, NC WRC, pers. comm. 7 Dec 2015). TVA also utilizes a sport fishing index (SFI) that is dependent upon angler success, catch rates by biologists, angler pressure, and other population indicators.

Potential Targets

Absent the development of an RFAI or SFI in North Carolina, the most practical manner in which to evaluate fishery quality is by comparison of fishery metrics from a reservoir to average values from other reservoirs within the region. WRC is capable of publishing catch rates and length distributions (by fish type) from annual surveys, so that anglers may compare reservoirs. High Rock Lake would be compared to other piedmont reservoirs in NC.

Based on information presented to the SAC, High Rock Lake is currently considered one of the best largemouth bass and crappie fisheries in the state. Striped bass are stocked and do not reproduce in NC piedmont reservoirs. The striped bass abundance is more difficult to evaluate in High Lake Rock than the abundance of other fish, because the fish tend to cluster, and surveys tend to be hit-or-miss. However, based on individual fish metrics, WRC considers the striped bass population in High Rock Lake to be healthy. Overall, High Rock Lake must be considered "above average" as a sport fishery.

A logical management goal for High Rock Lake would be to maintain the quality of the existing sport fishery. This goal might have to be balanced against other uses or indicators of potential impairment (e.g., algal toxins). In general, eutrophic lakes support more and larger sport fish than oligotrophic or mesotrophic lakes (Jones and Hoyer, 1982; O'Brien, 1990), and nutrient reduction has been shown to be capable of reducing reservoir fish populations (Axler and others, 1988; Ney, 1996; Ney and others, 1990). However, other studies have concluded that fishery quality can be similar across a wide range of eutrophic lakes with very different chlorophyll-*a* concentrations (Bayne and others, 1994). As the SAC proceeds with discussing potential nutrient-related targets for High Rock Lake, it would be recommended to closely consider the impacts of achieving such targets on the existing fishery.

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Notes on pH as a Potential Nutrient Indicator for High Rock Lake

Clifton Bell December 8, 2015 (Working Draft)

Existing pH Criteria

North Carolina's existing pH criterion for freshwater is provided in 15A NCAC 2B .0211 and is expressed as follows:

> pH: shall be normal for the waters in the area, which range between 6.0 and 9.0 except that swamp waters may have a pH as low as 4.3 if it is the result of natural conditions.

Although the text above includes numeric values, NC DWR (2007) describes the pH criterion as a narrative criterion. In practice, DWR uses the 6.0 – 9.0 range as a numeric translator of the narrative standard for assessment purposes. This pH range is similar to the range recommended by USEPA for protection of aquatic life (6.5 – 9.0), which can be traced to the 1976 "Red Book" (EPA 440-9-76-023). This range is also recommended in USEPA's 1986 "Gold Book" (EPA 440-5-86-001), but that document includes no pH-related information or references that were not also in the Red Book.

Neither North Carolina's nor USEPA's pH recommended pH range have an explicit duration component / averaging period or frequency component, and thus agencies typically use them as instantaneous, not-to-exceed values. North Carolina applies its 10% rule when assessment water bodies for pH impairment; *i.e.*, an impairment is determined if more than 10% of the data are outside the criteria range at a 90% level of confidence. Some states explicitly use the 85th percentile (e.g., Colorado) or 90th percentile (e.g., Virginia, California) of long-term pH values for planning and permitting purposes.

Effects of pH on Aquatic Life

Both and high and low pH can cause adverse effects on aquatic life. In general, more research has been conducted on the effects of low pH, due to phenomena such as acid raid. The lesser amount of research on high pH may reflect the lesser degree of high pH as a widespread ecological problem (Alabaster and Lloyd, 1980). Because nutrients generally cause excursions on the alkaline side of the pH spectrum, this review focuses on potential impact of high pH on aquatic life.

A survey of the literature reveals three general categories adverse of impacts of high pH on aquatic life: (1) increasing the toxicity of other substances; (2) disrupting electrolytic balance and metabolism; and (3) physical damage to tissues such as gills, eyes, or skin. The first effect is highly dependent not only on the pH, but also on the presence/concentration of other substances whose toxicity is pH-dependent (e.g., copper, cyanide, ammonia). Where the concentration of those substances is low, these adverse effects would not be expected to occur.

The exposure of fish to high pH cause at least a temporary reduction in the branchial uptake of electrolytes (e.g., Na^+, Cl^-) without a corresponding reduction in efflux, which in turn can increase electrolyte levels in plasma (Wilkie and Wood, 1994; Wilkie and others, 1999; Laurent and others, 2000; Scott and others, 2005). High pH can also cause a reduction in ammonia excretion, and a corresponding increase in plasma ammonia levels (Wilkie and others, 1996; Wilson and others, 1998; Laurent and others, 2000; Scott and others, 2005). Because this effect is dependent upon the partial pressure of ammonia across the gills (Salama and others, 1999), it would be directly dependent on ambient ammonia concentrations. Fish have various respiratory and metabolic mechanisms for compensating for these alkaline effects (Ferosekhan, 2009; Wilkie and others, 1999; Laurent et al., 2000; Scott and others 2005). For this reason, harmful effects would be expected to be more likely for fish from a neutral pH environment suddenly exposed to high pH water, than for fish that were acclimated to a higher pH condition. The ability to avoid harmful effects is dependent on the species, the pH, and ambient water quality.

Technical Basis for pH Criteria or Alternative Targets

The USEPA Red Book bases its pH criteria range (6.5 – 9.0) on two lines of reasoning: (1) general statements that the toxicity of certain substances is higher outside a neutral pH range; and (2) citation of of a relatively small number of studies of the impacts of pH on aquatic life. The Red Book includes one reference for the upper limit (9.0) of the freshwater pH range, which is a literature review performed by the European Inland Fisheries Advisory Commission (EIFAC, 1969). A review of this document reveals that the upper limit of 9.0 was based primarily on salmonids. As stated in that document:

> Chronic exposure to pH values above 10.0 are harmful to all species studied, while salmonid and some other species are harmed at values above 9.0.

Although the EIFAC (1969) [and it's more recent edition; Alabaster and Lloyd (1980)] includes "perch" with salmonids as exhibiting higher sensitivity to high pH, this was based on a single study (Bandt, 1936) that used a European perch variety. In contrast, the most common perch in NC reservoirs (yellow perch – *Perca flavescens*) is common in reservoirs with pH up to 9.5 (Johnson and others, 1977), and the pH that can cause lethality in this species with chronic exposure has been identified as 10.4 (Rahel, 1983). A wider review of the literature confirms that salmonids are more sensitive to high pH than other species, probably at least partly due to a great sensitivity to ammonia toxicity. Table 1 provides a summary of the literature in this regard, as compiled by Alabaster and Lloyd (1980) and Cleveland (1998).

Observations on pH in High Rock Lake

Based on information provided to the SAC, two mainstem segments of High Rock Lake are 303(d)-listed as impaired for pH, represented by stations YAD152C and YAD169B. However, the small downstream-most segment (adjacent to the dam) is not listed as impaired for pH. An evaluation of water quality data reveals that surface pH values at stations YAD152C and YAD169B commonly exceed 9.0 but rarely exceed 9.5 (Table 2). Depth-integrated pH values are significantly lower than surface pH values.

TABLE 1 – Summary of pH Effects on Aquatic Life

pH Range	Effect on Aquatic Species
3.0-3.5	Unlikely that fish can survive for more than a few hours in this range although some plant and invertebrates can be found at pH levels this low.
3.5-4.0	Known to be lethal to all salmonids.
4.0-4.5	All fish, most frogs and insects are not present.
4.5-5.0	Mayfly and many other insect species are not found. Most fish eggs will not hatch.
5.0-5.5	Bottom-dwelling decomposing bacteria begin to die off. Leaf litter and dead plant and animal materials begin to accumulate. Plankton begin to disappear.
6.0-6.5	Freshwater shrimp are not present.
6.5-8.5	Optimal for most organisms.
8.5-9.0	Unlikely to be harmful to fish, but indirect effects from chemical changes in the water may occur.
9.0-9.5	Likely to be harmful to salmonids and perch if present for a considerable length of time.
9.5-10.0	Lethal to salmonids over a prolonged period of time, but can be withstood for short periods. May be harmful to development stages of some species.
10.0-10.5	Can be withstood by roach and salmonids for short periods but lethal over a prolonged period.
10.5-11.0	Prolonged exposure is lethal to carp and perch.
11.0-11.5	Lethal to all species of fish.

Sources: Alabaster and Lloyd (1980); Cleveland (1998)

TABLE 2 – Surface pH Percentiles at Stations YAD152C and YAD169C

[based on 2005-2011 data, all seasons, ≤1 m depth]

Percentile pH	YAD152C	YAD169B
50th	8.50	8.78
75th	9.04	9.20
85th	9.20	9.30
90th	9.20	9.37

The pH at stations YAD152C and YAD169B is correlated with chlorophyll-*a* when data from all parts of the year are lumped, but this correlation appears to be driven by non-summer values, and in the summer (when pH is the highest), pH does not appear to be strongly correlated with chlorophyll-*a* (Figure 1).

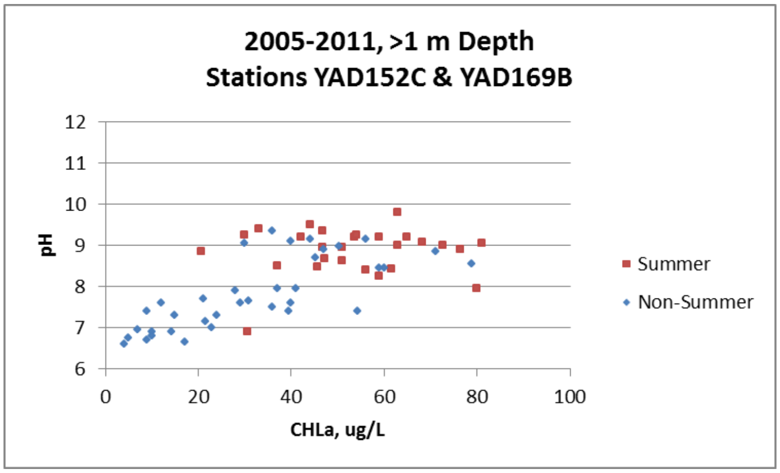

Figure 1 – Scatterplot of surface pH vs. chlorophyll-a stations YAD152C and YAD169B.

Ammonia concentrations are low in these segments, so the high pH values are not associated with toxic ammonia conditions (Figure 2). Ammonia is actually inversely correlated with pH, probably due to algal uptake of ammonia, so that high pH and high ammonia concentrations rarely coincide.

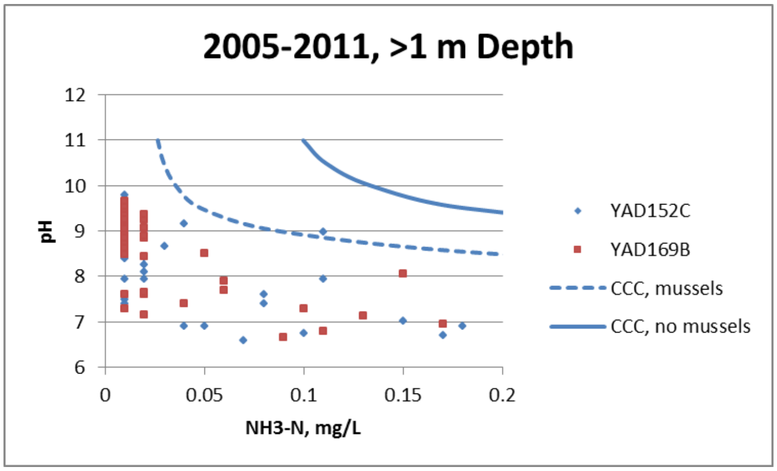

Figure 2 – Scatterplot of surface pH vs. ammonia nitrogen at stations YAD152C and YAD169B. Blue lines represent chronic ammonia criteria from USEPA (2013), assuming that early life stages are present.

Potential pH Targets for High Rock Lake

Target of 9.0 vs. 9.5: The upper value of the pH range currently used for assessment (9.0) is protective of uses of High Rock Lake, and downstream uses as well. The 9.0 has the advantage of being consistent with NC's existing regulatory protocols and USEPA's criteria recommendations. This target makes no distinction between trout fisheries and warmwater fisheries, and appears to be conservative for the latter. The 9.0 target would be problematic as the primary controller of nutrient management for High Rock Lake, because the existing model is not calibrated to pH, and empirical data suggest that summer pH is not strongly correlated to chlorophyll-*a* in the critical segments. The attainability / practicality of the 9.0 pH target cannot currently be determined for High Rock Lake

Based on this review, pH values of up to 9.5 may also be protective of uses in High Rock Lake. The two primary bases for this conclusion are: (1) the excellent status of the existing fishery, which experiences surface pH in the 9.0 to 9.5 range; and (2) the scientific literature, which suggests that the 9.0 value was based primarily on salmonids (for which High Rock Lake is not managed as a fishery), and that adverse effects to most other fish species would not be expected until pH exceeds 10.0 on a prolonged basis. The use of a 9.5 target would be predicated on low concentrations of pH-dependent toxics. Although this merits more investigation, ammonia concentrations in High Rock Lake appear to be well below levels at which toxicity would occur.

Disadvantages of a 9.5 pH target include a less degree of conservatism (relative to 9.0) and inconsistency with long-established pH range recommendations. Almost all of High Rock Lake currently has pH levels below 9.5, expressed as a 90th percentile. Therefore, another potential disadvantage of a 9.5 target would be that it could actually allow increases in pH from existing levels.

Alternative Approach– Target Based on Antidegradation: If it is determined that the existing pH conditions of High Rock Lake do not themselves represent an impairment of recreational or aquatic life uses, an alternative approach would be to set pH goals based on antidegradation. These values (expressed as long-term 90th percentiles) would be in the 9.2 – 9.4 range for segments YAD152C and YAD169B, and lower in other segments of High Rock Lake. Under this approach, pH would not be a controlling parameter for nutrient reductions, but might decrease in response to nutrient reductions driven by other parameters. An antidegradation approach could also be interpreted as consistent with NC's narrative pH criterion, which states that pH "shall be normal for the waters in the area".

Strawman Recommendation: The preliminary recommendation is to take an antidegradation approach to pH goals in High Rock Lake. This approach seems to be a reasonable balance between (1) recognizing that the existing warmwater fishery can tolerate and even thrive under the existing pH condition (<9.5); and (2) the desire to prevent future increases in pH. This approach also the advantage of relative simplicity, and would not require explicit modeling of pH in High Rock Lake. It would be recommended to continue to track the pH response to nutrient reductions that might be driven by other parameters, as part of an overall adaptive management strategy.

For downstream protection, it would be recommended to set a pH target for High Rock Lake that would not cause pH impairments of downstream waters, based on the typical pH range of 6.0 – 9.0. This merits additional investigation. However, a preliminary review of available information indicates that releases from High Rock Lake are not currently causing pH impairments of downstream waters.

Because most pH-related studies have examined longer-term effects of pH on aquatic life exposure, it is not recommended to apply the pH target as an instantaneous, not-to exceed value. Rather, it would be recommended to apply the pH target as a longer-term percentile target (e.g., 90^{th} percentile), which is consistent with NC's existing assessment method and pH criteria implementation methods used by other states.

Spatial Averaging: Another topic for additional discussion is whether the pH goal should be based on the surface samples at individual stations, or some other spatial averaging approach. If goals are based on longer-term exposure of mobile species, additional vertical or horizontal spatial could be appropriate. The higher the degree of spatial averaging (especially vertical), the lower the pH target that could be attained. For example, a preliminary assessment of 2005-2011 indicates that the long-term 90^{th} percentile of pH at stations YAD152C and YAD169B close to 9.0 if data > 1 m depth are included.

TABLE 3 – Summary of pH Target Approaches

Approach	Advantages	Disadvantages
9.0 target	• Most consistent with NC's previous approach & USEPA recommendations • Conservative, protective	• Probably overprotective for HRL's existing warmwater fishery • Difficult to set nutrient allocations directly on this basis o No pH model o No pH correlation with CHLa in summer • Attainability in question
Antidegradation approach (target varies by segment)	• Protective of existing warmwater fishery • Would not allow degradation of existing water quality • Would not require pH modeling • Known to be attainable	• Less conservative than 9.0 target • Less consistent with NC's current criterion & USEPA pH range recommendations.
9.5 target	• Based on literature, probably protective of existing warmwater fishery • Would not require pH modeling • Known to be attainable	• Less conservative than 9.0 target • Less consistent with NC's current criterion & USEPA pH range recommendations. • Could allow pH increases in HRL

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Candidate Indicator Discussion

Aesthetics

Jim Bowen and Bill Hall

Nutrient Criteria Development, SAC Meeting
December 9, 2015, Raleigh NC

Aesthetics – Literature Review

- Aesthetics typically a concern for recreational use of water body
- References back to late 80’s - nutrient criteria development in lakes w/r aesthetics
  - e.g. Vermont, Minnesota, Texas, New York, Montana
- Very little variation in approach between these efforts

Aesthetics – Literature Review

- Criteria development typically based on user and/or observer survey
- Ask user/observer to assess lakes on two metrics (MN, VT - Smeltzer & Heiskary 1988)
  1. Physical condition
  2. Suitability for recreation & aesthetic enjoyment

Example Survey Form (Smeltzer & Heiskary 1988)

Table 1.—Lake user survey form.

A. Please circle the one number that best describes the *physical condition* of the lake water today.
   1. Crystal clear water.
   2. Not quite crystal clear, a little algae visible.
   3. Definite algal greenness, yellowness, or brownness apparent.
   4. High algal levels with limited clarity and/or mild odor apparent.
   5. Severely high algae levels with one or more of the following: massive floating scums on lake or washed up on shore, strong foul odor, or fish kill.

B. Please circle the one number that best describes your *opinion* on how suitable the lake water is for recreation and aesthetic enjoyment today.
   1. Beautiful, could not be any nicer.
   2. Very minor aesthetic problems; excellent for swimming, boating, enjoyment.
   3. Swimming and aesthetic enjoyment slightly impaired because of algae levels.
   4. Desire to swim and level of enjoyment of the lake substantially reduced because of algae levels.
   5. Swimming and aesthetic enjoyment of the lake nearly impossible because of algae levels.

User Survey Approach - Aesthetics

- Survey responses correlated w/ monitoring data (e.g. TP, chl-a, secchi) across multiple lakes
- Survey responses grouped by ecoregion

Table 2.—Data set description.

ECOREGION	NUMBER OF LAKES	NUMBER OF OBSERVATIONS														
					QUESTION A						QUESTION B					
		TP	CHL a	SECCHI	1	2	3	4	5	ALL	1	2	3	4	5	ALL
1	44	195	507	689	115	392	142	40	9	698	158	366	115	47	5	691
2	24	521	535	531	26	323	170	26	1	547	30	360	127	31	0	548
3	216	0	0	3672	953	1546	653	126	59	3337	1203	1404	502	162	66	3337
4	175	0	0	3168	460	1003	788	292	86	2629	598	981	657	319	104	2659
5	5	0	0	43	0	0	9	10	3	22	0	0	7	12	3	22
6	18	0	0	228	2	50	121	49	10	232	0	61	125	35	9	230
Total:	493	716	1042	8331	1556	3314	1883	544	168	7465	1989	3172	1533	606	187	7487

Regions:

1. VT–IL Vermont Inland Lakes
2. VT–LC Vermont Lake Champlain Stations
3. MN–NLF Minnesota Northern Lakes and Forests
4. MN–CHF Minnesota Central Hardwood Forests
5. MN–NGP Minnesota Northern Glaciated Plains
6. MN–WCP Minnesota Western Corn Belt Plains

Site Specific Criteria w/r Aesthetics (Wasley & Heiskary, Lake Pepin, MN)

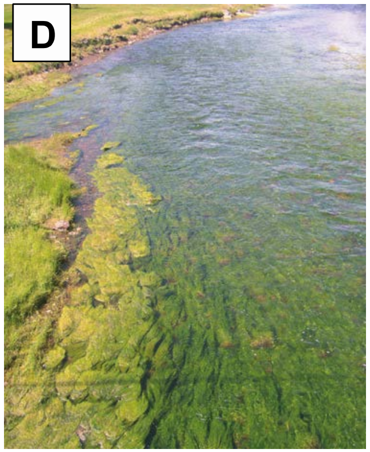
- Some similarity to High Rock Lake (shallow, low residence time, low transparency)
- Survey info combined w/ other lines of evidence to develop TP criteria
  - Sediment sampling of diatoms to reconstruct historical TP record
  - Model prediction of chl-a & secchi assuming TP limit
  - Model prediction of bloom frequency & B-G fraction of algal biomass

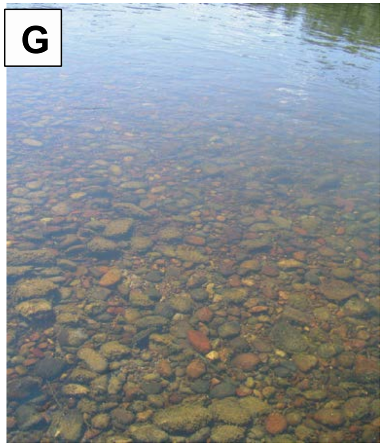
Other Recent Nutrient Criteria Development – Survey of Stream Desirability for Recreation, Montana

- Used on-river and by-mail surveys
- Respondents looked at pictures of algae in stream and rated desirable/undesirable for recreation
- Desirability percentage correlated w/ chl-a concentration (mg/m^2) at site
- Candidate criteria value – chl-a concentration corresponding to undesirable rating by majority of respondents

Algae Pictures (Suplee et al. 2009)

How Green is Too Green? Public Opinion of What Constitutes Undesirable Algae Levels in Streams





Problems/Limitations of Approach

- Bill Hall will fill in these
  - Criteria should not be derived by a popularity contest
  - Conditions during actual use versus conditions that prohibit use (how is question presented)
  - Need to include economics (would cost to achieve condition prevent use more than frequency of water quality condition)
  - How to establish exceedance frequency

Problems/Limitations of Approach

- Requires that a user survey be conducted
- Difficult to implement in systems with highly variable ISS concentrations
- Limited system sensitivity w/r transparency as nutrient loading is reduced

Discussion

- How would approach be applied to HRL?
- Not an indicator in itself, instead a consideration for criteria development (e.g. TP, chl-a, secchi depth)
- This is likely not the most restrictive factor on chl-a given ISS concentrations

Candidate Indicator Ranges and Conceptual Models: Algal Assemblages and Algal Toxins

DWR- Nutrient Scientific Advisory Council Meeting

December 9, 2015

Algal Assemblages

Data Review (Lin, 2015; Vanderborgh, 2015)

* Algal Unit Density (08-10)
  * Increased from ~ 1,000 units/mL to >80,000 units/mL, positively correlated with chl *a*
  * Consistent blooms >45,000 units/mL in July and August

* Algal Community Structure
  * 140 taxa
  * Most common groups:
    * Cryptomonads
    * Diatoms
    * Cyanobacteria
  * Other groups: greens, prymnesiophytes
  * Cyanobacteria clearly dominant
    * Community 61.5% cyanos when chl *a* >40 ug/L

Most Influential: Filamentous Cyanobacterium, *Pseudanabaena*

* Blooms >80,000 units/mL
* 83% frequency
* Often >60% total density
* Responsible for many DO, pH, chl *a* violations

Literature Review and Anecdotal Observations

How Does a Cyanobacteria-Dominated Assemblage Affect the Food Web?

Some Studies Indicate Inadequate Food Value of Cyanobacteria (papers aggregated by David Kimmel)

* Relatively low essential fatty acid levels limited zooplankton production; might affect larval fish nutrition
* Phytoplankton species in lakes with high TP favor cyanos with less nutritious (HUFA content) for grazers
* Assemblages dominated by diatoms, chrysophytes, and cryptophytes have higher PUFA levels; can sustain higher trophic level production

- A diet of *Pseudanabaena* reduced survival and fecundity in daphnids (Olvera-Ramirez)
  - Asserted that smaller cyanos like *Pseudanabaena* might exceed larger species, e.g. *Microcystis*, in terms of biomass and produce adverse effects
- Shrimp exposed to mixed community of diatoms, green algae, *Lyngbya*, *Spirulina*, and *Anabaenopsis* preferred diatoms; rarely consumed cyanos

Some Studies and Observations Suggest Cyanos May Support Healthy Grazers

* *Spirulina* – high levels of PUFAS, all essential amino acids, B vitamins
* *Spirulina* diet increased growth, survival in prawns; increased synthesis of essential fatty acids in *Tilapia*
* Shrimp grew well in culture ponds dominated by *Planktothrix, Planktolyngbya, Merismopedia/Synechococcus, Pseudanabaena*
* Shrimp actively grazed *Lyngbya*; grew well, produced above average levels of desirable astaxanthin pigment

Fishery Health in High Rock Lake
(Dorsey, 2015)

* Deemed generally healthy; largemouth bass best in state
* Generally very high catch rates; rates have increased
* Generally large biomass; no size limit; no fish kills
* Good condition of game species, especially striped bass, which feed on shad, suggests lower trophic level species doing well
* High nutrient levels support forage species

Conclusions?

- Striped bass is stocked, not naturally reproducing in HRL
- Thus, effects of cyanobacteria-dominant algal assemblage on primary consumers are uncertain

Algal Toxins

Known or Possible Toxin Producers in High Rock Lake (Vanderborgh, 2015)

* *Microcystis* – 7% of samples
* *Aphanizomenon* – 17% of samples
* *Anabaena* – 22% of samples
* *Pseudanabaena* – 83% of samples

Current EPA Cyanotoxin Health Advisory Guidelines (USEPA, 2015)

* Microcystins:
  * 0.3 µg/L for children under 6 yrs
  * 1.6 µg/L above 6 yrs
* Cylindrospermopsin:
  * 0.7 µg/L for children under 6
  * 3.0 µg/L above 6 yrs
* Anatoxin-*a* ????

Cyanotoxin Data for High Rock Lake

* None

Striped bass

“Spawning dissolved oxygen associations Dissolved oxygen concentrations greater than 5 mg/L are recommended for all life stages of striped bass (USEPA 1976; Setzler-Hamilton and Hall 1991). Given that spawning adults are present in the spring of the year when river temperatures are usually lower, oxygen concentration is not generally a limiting factor. However, historically, striped bass spawning areas in the Delaware River were eliminated due to low oxygen concentrations. Collections of fish throughout the freshwater sections of the Delaware River from 1963 to 1966 contained no striped bass. Gross pollution of the tidal freshwater zone of the river destroyed its utility as a spawning area, and resulted in the extirpation of the striped bass from the tidal fresh and freshwater portions of the river. Restoration of striped bass was deemed possible if pollution was decreased so that the tidal freshwater portion of the river was functionally restored (Chittenden 1971a). Such restoration did in fact occur, and the striped bass once again spawns in the Delaware River (W. Laney, personal observation).”

See also Coutant (1985)

Largemouth bass, bluegill, and channel catfish

Moss & Scott (1961)

“Critical dissolved-oxygen levels and standard metabolic rates were determined for the bluegill, Lepomis macrochirus; largemouth bass, Micropterus salmoides; and the channel catfish, Ictalurus punctatus, at 25° C., 30° C., and 35° C. Two types of experiments were conducted: shock tests in which the dissolved oxygen was dropped rapidly from near saturation to a critically low point; and acclimation tests in which the dissolved oxygen was lowered gradually over a longer period of time. The minimal dissolved oxygen survived by fish in acclimation tests was lower than that survived in shock tests at any given temperature. In shock tests the minimum dissolved oxygen survived by bluegills was 0.75 p.p.m. at 25° C., 1.00 p.p.m. at 30° C., and 1.23 p.p.m. at 35° C. Slightly higher values were obtained for the largemouth bass at all three temperatures and for the channel catfish at 25° C. and 30° C. At 35° C. the channel catfish was more tolerant of low dissolved oxygen than either the bluegill or largemouth bass. In the acclimation tests the critical oxygen values obtained for bluegills were 0.70 p.p.m. at 25° C., 0.80 p.p.m. at 30° C., and 0.90 p.p.m. at 35° C. With the exception of the channel catfish at 35° C. slightly higher values were obtained with the largemouth bass and channel catfish. Within each species there was little difference between standard metabolic rates at the three temperatures. The standard metabolic rate of the bluegill at 25° C. was lower than that of the other species at the same temperature. Bluegills and largemouth bass weighing more than 15 grams showed no change in metabolic rate with increasing size, but below this weight, metabolic rate varied inversely with weight.”

References

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Moss D, Scott DC. 1961. Dissolved-oxygen requirements of three species of fish. Trans. Am. Fish. Soc. 90(4): 377-393

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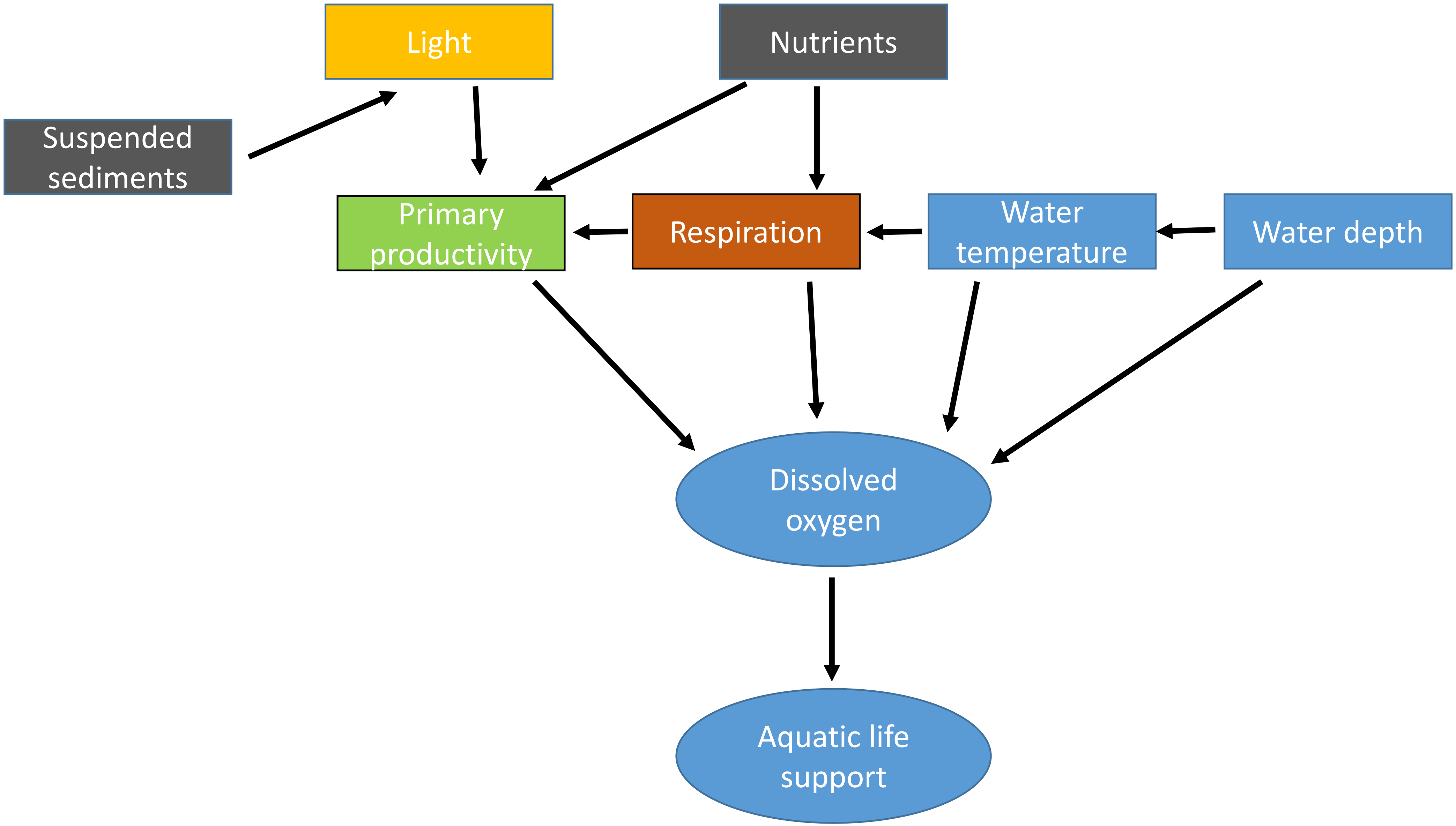
Light
Nutrients
Suspended sediments
Primary productivity
Respiration
Water temperature
Water depth
Dissolved oxygen
Aquatic life support

NC
Nothing Compares
NORTH CAROLINA

Rebecca Sadosky, Ph.D.

Department of Environmental Quality

Nutrient Over-Enrichment and Drinking Water

Overview

- Algae
- Indicators
- Treatment Challenges
- Reservoir Management
- Cost
- EPA Recommendations
- Examples

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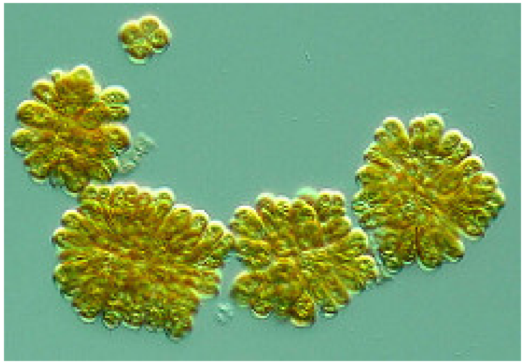
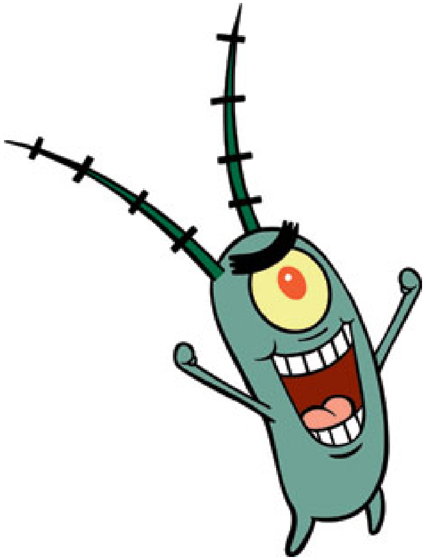
Algae and other Microorganisms



- N and P limiting factors to growth
- Can proliferate quickly - < 1 day
- Primarily spring and summer, but can be anytime (December, March)
- Found in NC
  - Microcystin (10 day EPA health advisory level 0.3 ug/L for infants and young children and 1.6 ug/L for school age children through adults) – UCMR4
  - Cylindrospermopsin (10 day EPA health advisory level of 0.7 ug/L for infants and young children and 3 ug/L for school age children through adults) – UCMR4
  - Aphanizomenon (T&O)
  - Anaebaena (T&O)
  - Fragillaria (filter clogging)
  - Rotifers



Indicators

- Diurnal pH swings (increase with algae presence)
- Drop in DO
- Taste and Odor
  - 10 days to eliminate from system

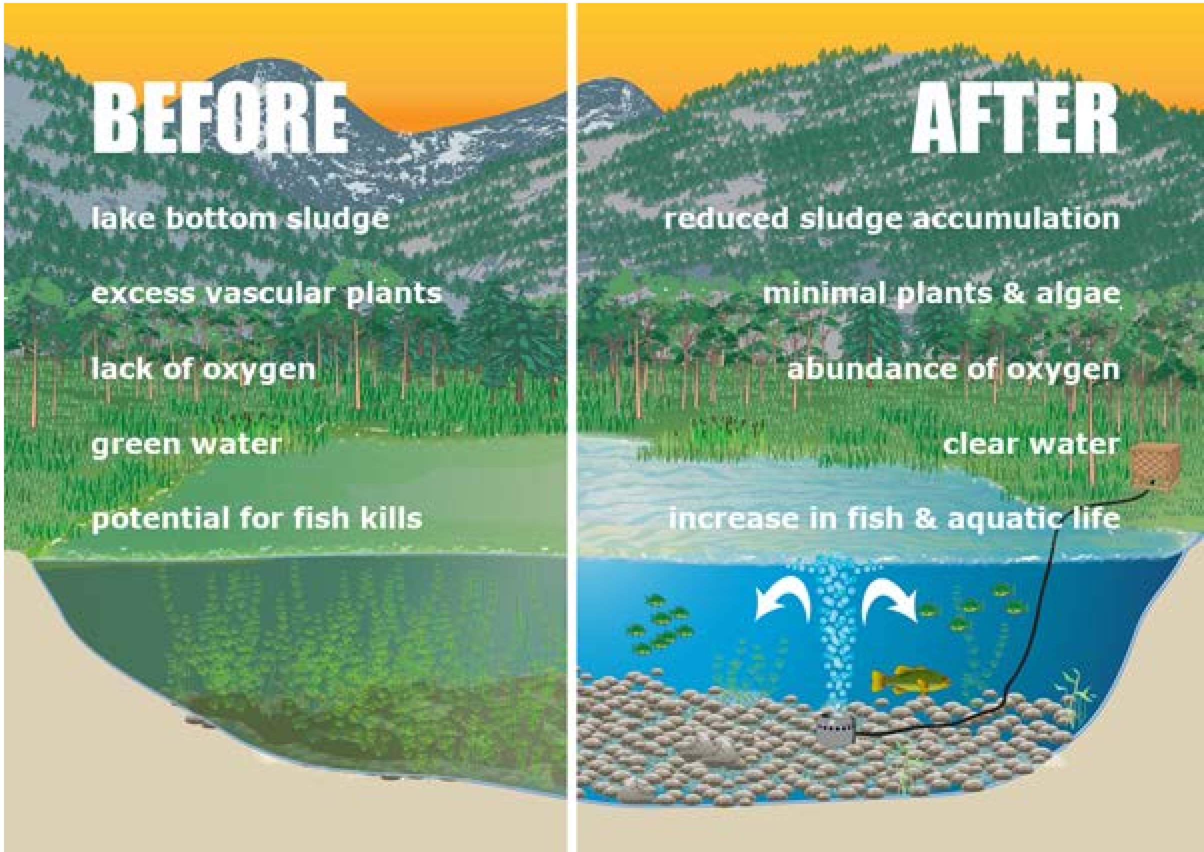
Treatment Challenges

- Settleability
  - Chemicals (Alum, potassium permanganate, granulated activated carbon)
- Filter Clogging
  - Increase backwash frequency
- Disinfection By-products

❖Release Cyanotoxins

Reservoir Management

- Algaecides
  - Copper Sulfate
- Potassium permanganate
- Aerators
- Alternative Sources
- Ultrasonic Treatment
- Skimming



Costs

- $1,000's /day
  - Backwash water
  - Chemicals
  - Basin cleaning

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EPA Recommendations

- System-specific Surface Water Source Evaluation

Source Water Vulnerable

- Preparation and Observation

Evidence Indicates Cyanotoxins

- Monitor for Cyanotoxins in Raw Water and Treatment Adjustments

Toxins Detected

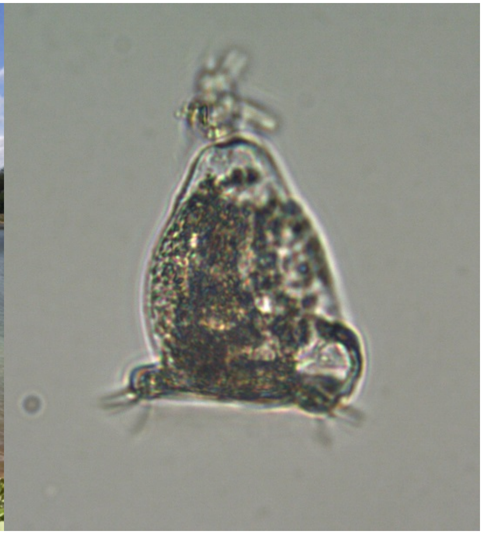
- Monitor for Cyanotoxins in Raw and Finished Water and Treatment Adjustments

Toxins Detected in Finished Water

- Monitor for Cyanotoxins in Raw and Finished Water, Treatment Adjustments/Additions, and Public Communications

Examples

- Almost all systems in WS Region have issues with algae
  - Davie Co – feeding potassium
  - Asheboro – switch lakes
  - App State – added aeration
  - Jonesville – yeast based organism – feed potassium and new peroxide feed
  - Eden – rotifer issue
  - Davidson Water
  - Blowing Rock
  - Burlington
  - Denton
  - Dobson
  - Reidsville
  - Ramseur
  - Pilot Mtn



Examples Cont'd

    - PTRA
    - Lexington
    - King
    - Greensboro
    - High Point
    - Graham
    - Elkin
    - Winston-Salem
    - Yadkinville
    - Yanceyville
- MRO (2-8/yr most commonly following dry springs)
    - Bessemer City (Arrrowood)– green paint
    - Monroe – fish kills in spring (cause investigation ongoing)
- WiRO
    - CFPUA

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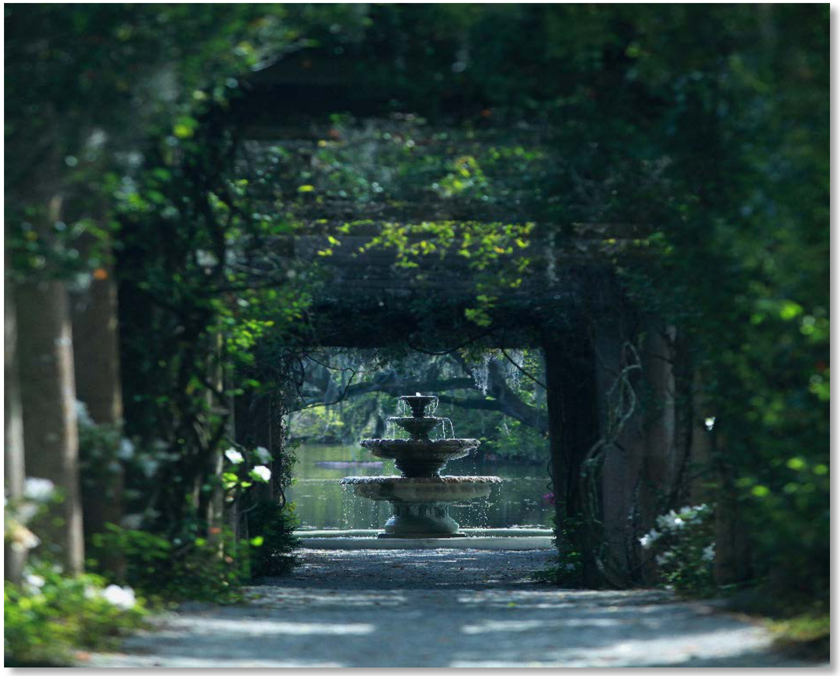

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Water Clarity Issues

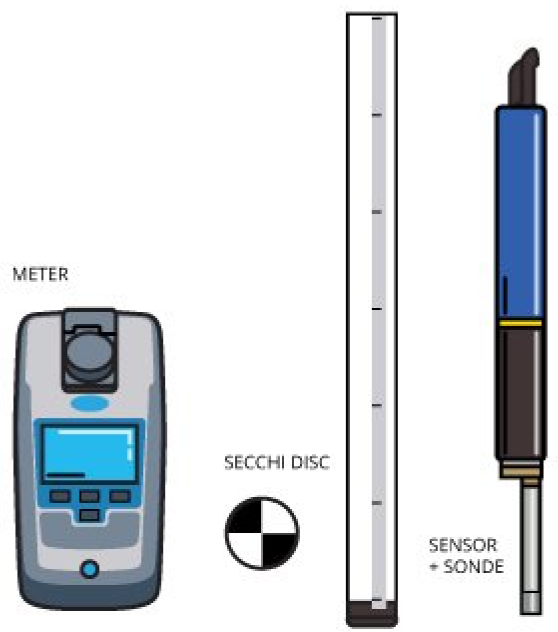
- Clarity can be reduced by mineral sediment, dissolved organic matter, plankton, chlorophyll

Issues with poor clarity and suspended sediments include:

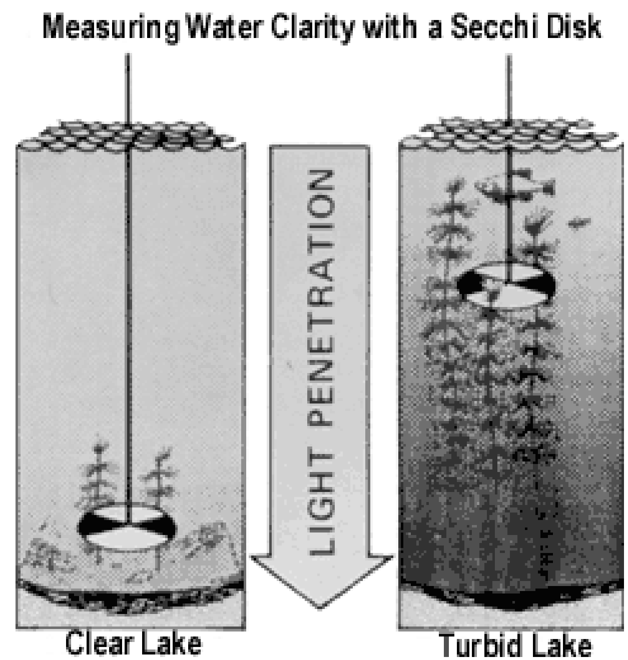
- Benthic smothering
- Irritation of fish gills
- Transport of sorbed contaminants
- Reduced visual range (fish feeding)
- Light availability for photosynthesis
- Increased water treatment costs
- Aesthetics and recreation value

Water Clarity Indicators

- Turbidity (Inversely related to water clarity)
- Secchi depth (Directly related)
- Total suspended sediments



http://www.fondriest.com/



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United States Environmental Protection Agency | Office of Water 4304 | EPA 822-B-00-011 December 2000

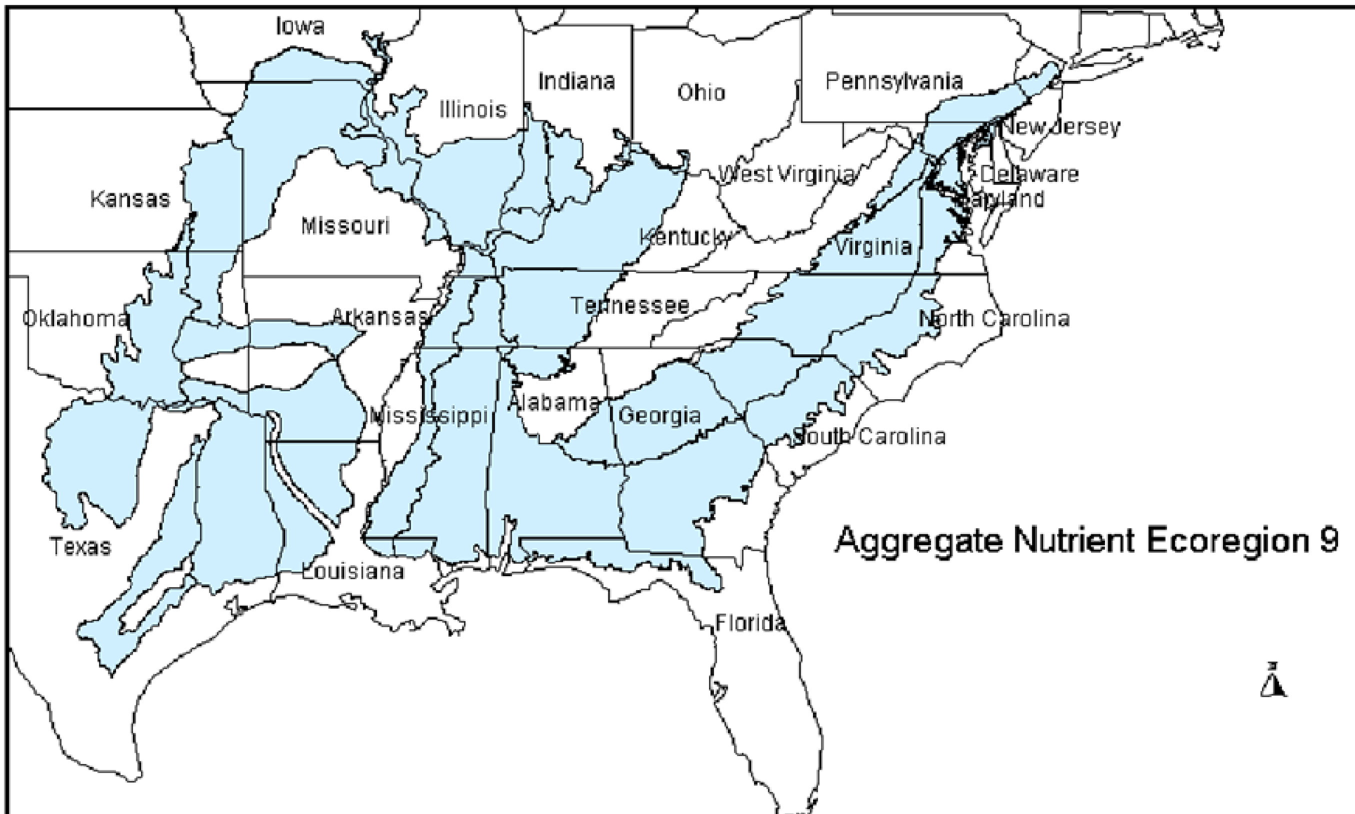
EPA

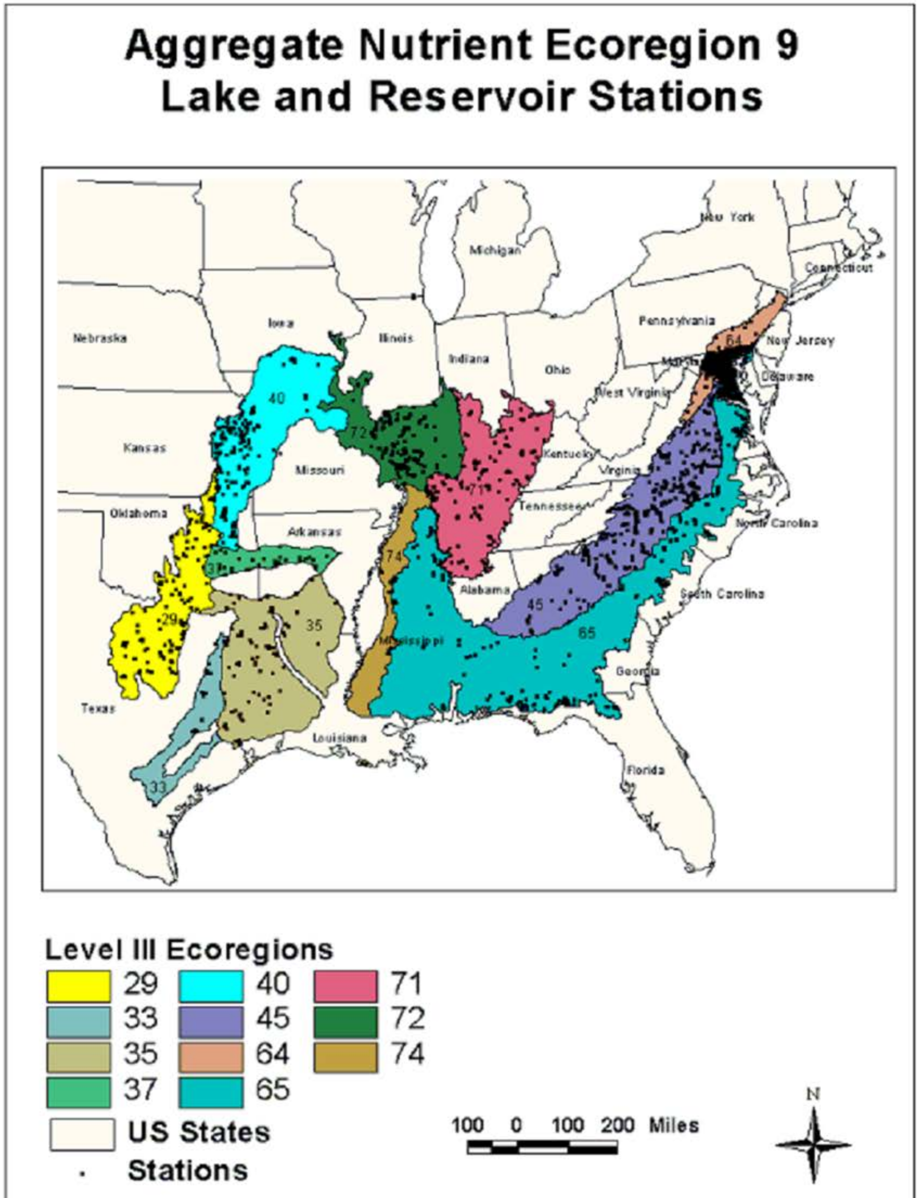
Ambient Water Quality Criteria Recommendations

Information Supporting the Development of State and Tribal Nutrient Criteria

Lakes and Reservoirs in Nutrient Ecoregion IX

EPA, 2000





45. Piedmont

Considered the nonmountainous portion of the old Appalachians Highland by physiographers, the northeast-southwest trending Piedmont ecoregion comprises a transitional area between the mostly mountainous ecoregions of the Appalachians to the northwest and the flat coastal plain to the southeast. Once largely cultivated, much of this region has reverted to pine and hardwood woodlands.

Table 1. Lake records for Aggregate Ecoregion IX - Southeastern Temperate Forested [illegible] Hills

	Aggregate Ecoregion IX	Sub ecoR 29	Sub ecoR 33	Sub ecoR 35	Sub ecoR 37	Sub ecoR 40	Sub ecoR 45	Sub ecoR 64
# of Lakes / Reservoirs	987	94	17	68	26	116	268	13
# of Lake Stations	2,965	154	32	122	36	200	741	406
Key Nutrient Parameters (listed below)								
- # of records for Secchi depth	24,869	786	186	1,144	150	1,041	4,380	21
- # of records for Chlorophyll *a* (all methods)	3,558	360	118	451	25	1,114	3,409	21
- # of records for Total Kjeldahl Nitrogen (TKN)	18,132	1,111	140	934	59	1,780	7,252	160
- # of records for Nitrate + Nitrite (NO_2 + NO_3)	18,019	992	95	624	129	1,067	6,154	51
- # of records for Total Nitrogen (TN)	1,492	0	0	0	0	0	0	19
- # of records for Total Phosphorus (TP)	23,261	1,242	211	1,188	149	2,071	7,472	158
Total # of records for key nutrient parameters	89,331	4,491	750	4,341	512	7,073	28,667	430

741 monitoring stations in Piedmont
268 Piedmont Lakes
4380 Secchi Depth Measurements
Samples from 1990-1998

Figure 3. Sampling locations within level III ecoregions

Reference Conditions for Piedmont Lakes

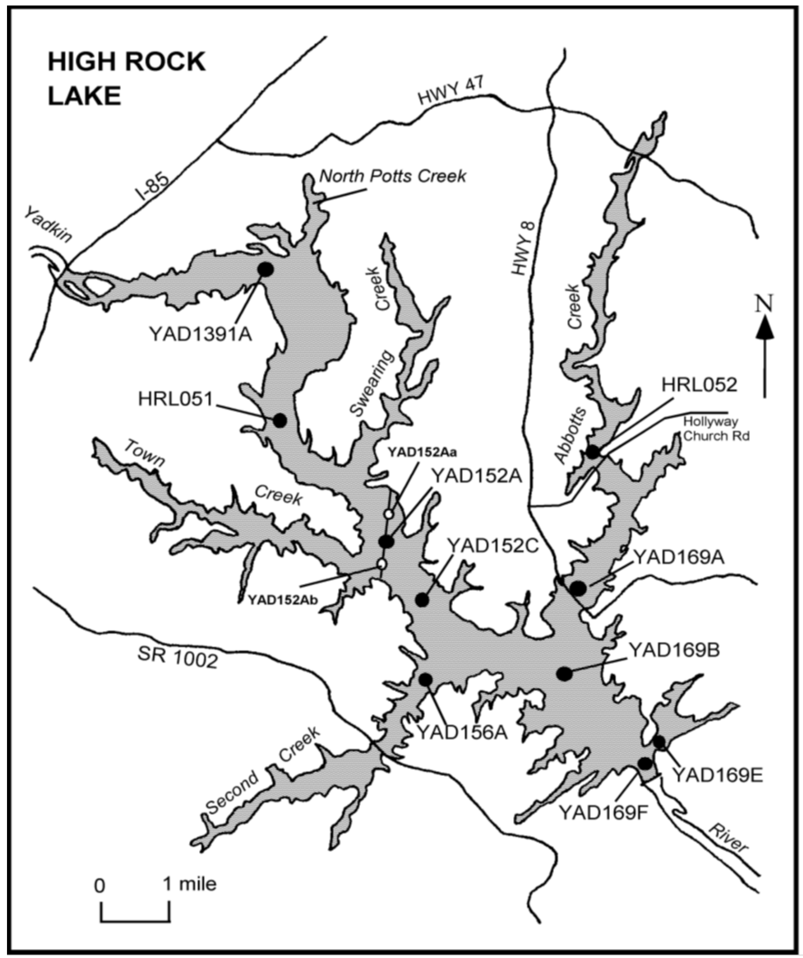
Table 3f. Reference conditions for level III ecoregion 45 lakes and reservoirs.

Parameter	No. of Lakes N ++	Reported values		25th Percentiles based on all seasons data for the Decade	Reference Lakes **
		Min	Max	**P25* all seasons +**	P75 all seasons
TKN (mg/L)	200	0.025	1.908	**0.245**	
$NO_2 + NO_3$ (mg/L)	153	0.002	3.799	**0.059**	
TN (mg/L) - calculated	NA	0.027	5.707	**0.304**	
TN (mg/L) - reported	0	–	–	--	
TP (*ug*/L)	198	5	265	**22.5**	
Secchi (meters)	175	0.263	6.225	**1.655**	
Chlorophyll *a* (*ug*/L) - F	132	0.963	31.938	**4.513**	
Chlorophyll *a* (*ug*/L) - S	40	2.2	45.8	**5.95**	
Chlorophyll *a* (*ug*/L) - T		–	–	--	

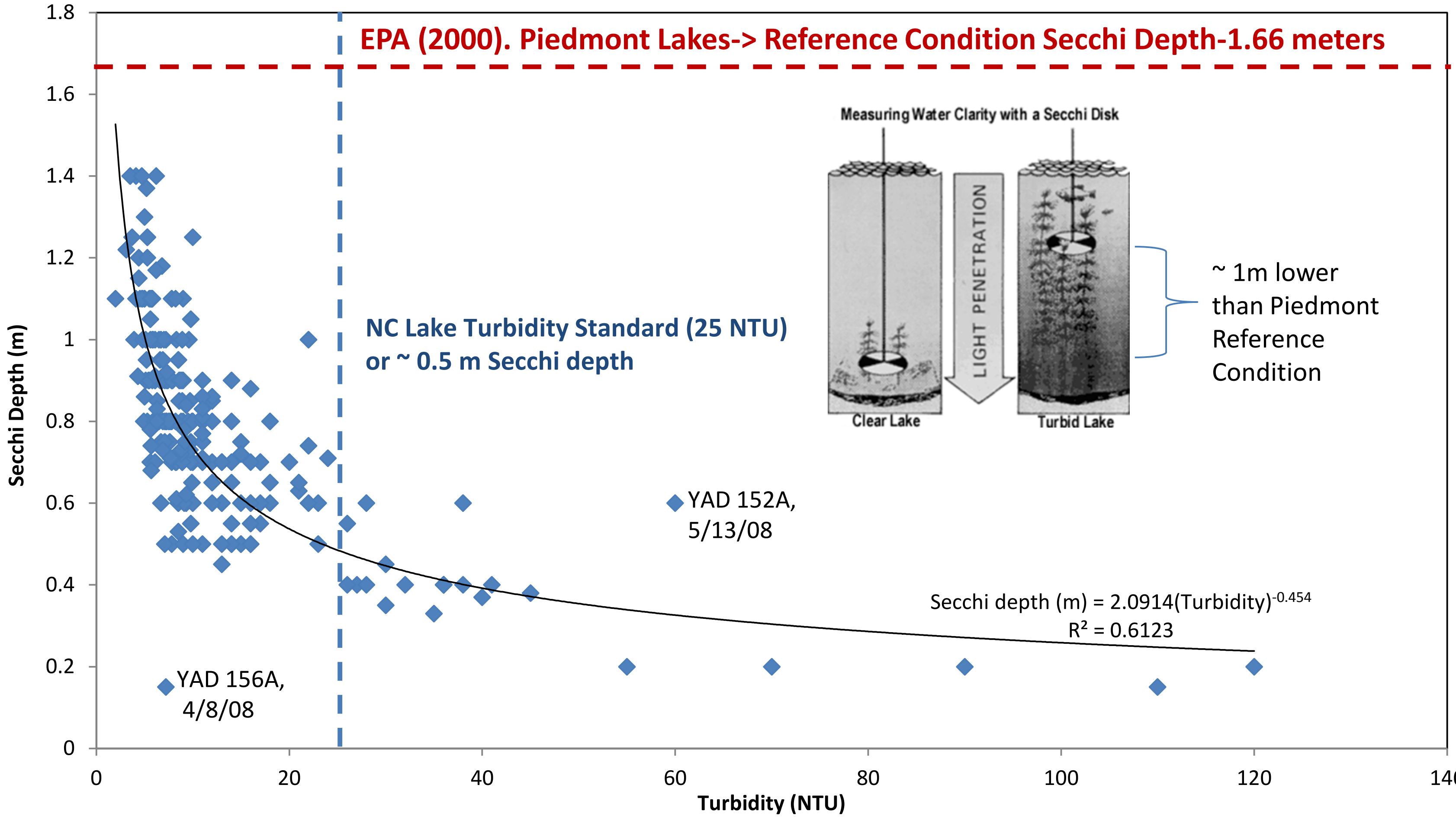
- Note – for Secchi Depth it is actually the 75^{th} percentile (since > depth indicates better condition)

- For Piedmont Lakes-> Reference Conditions for Secchi Depth was **1.66 meters**
- **1.53 meters for aggregate ecoregion 9.**
- **Provides a starting point**

High Rock Lake Water Clarity Data (2008-2010)



High Rock Lake Data (2008-2010)



~ 1 m secchi depth difference between Piedmont Reference and NC Lake Turbidity Standard

Reference Condition for Piedmont Lakes

- EPA (2000). Piedmont Lakes-> Reference Condition Secchi Depth-1.66 meters

- Maximum Secchi Depth (m) for High Rock Lake from 2008-2010 was 1.4 m (YAD 169F, 6/4/08)

- May need to develop more localized reference condition for NC Piedmont Lakes

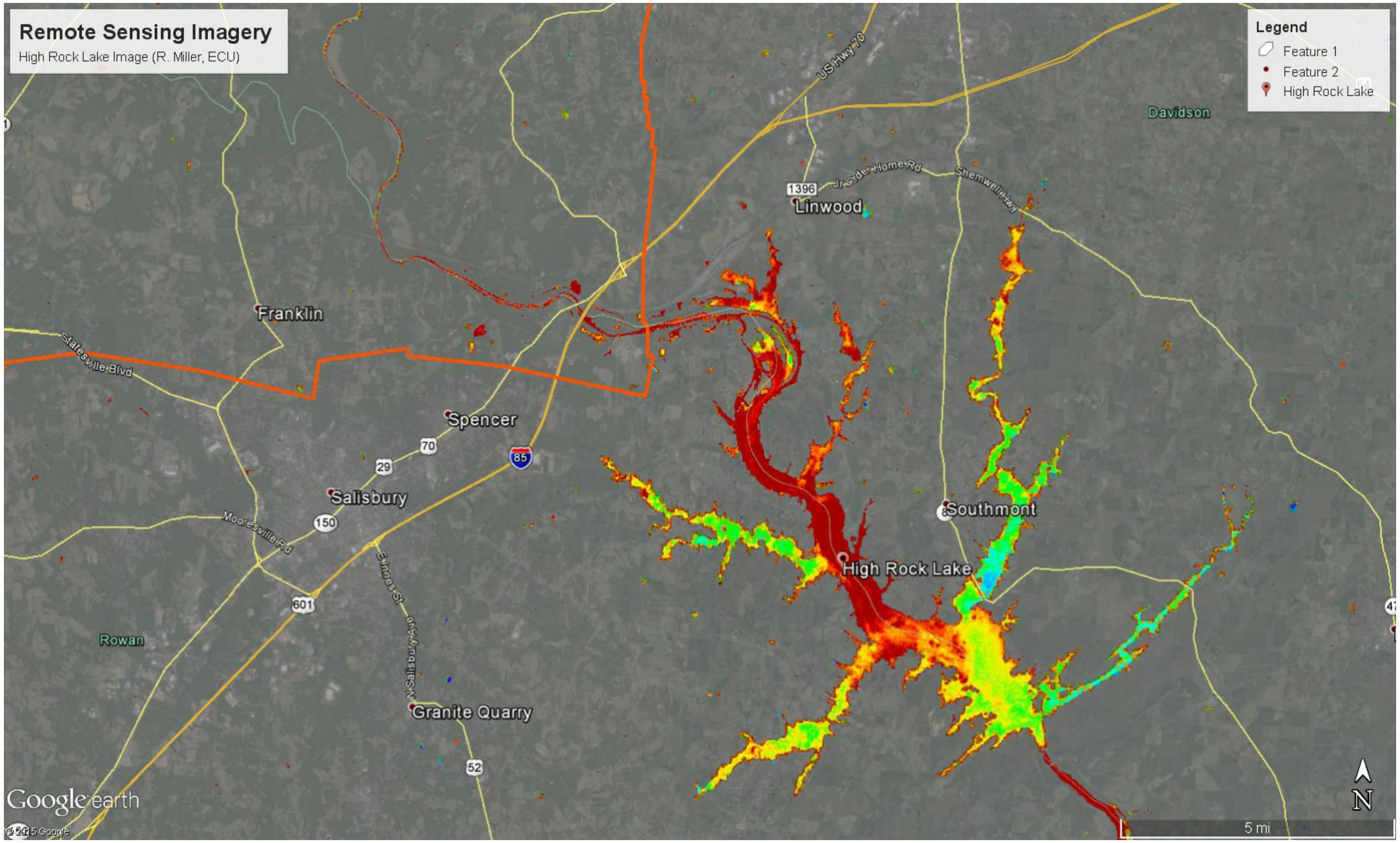
Are there any data gaps that prohibit us from reaching consensus today on ranges for this Clarity indicator?

- 1. Historical analyses of turbidity and secchi depth for High Rock Lake
- 2. Present day reference condition for similar Piedmont lakes in NC (and possibly surrounding states)
- 3. Models of historical and reference condition to understand the importance of mineral vs. organic contributions to turbidity.

- Is there any data that can be collected immediately to assist with criteria generation (short term)?

- Remote sensing has potential to help provide a better understanding of the turbidity dynamics and spatial variability of water clarity.

LANDSAT Oct. 18, 2015; Red Reflectance



Processed Landsat 8 OLI (Operational Land Imager) image from 18 Oct. 2015. Shows red reflectance at the Earth's surface (the effects of the atmosphere have been removed) which is most correlated with suspended material (e.g., TSS). The color code is, warmer colors (res, yellows) are high values and the cooler colors (violets, blues) are lower values.
DATA COURTESY OF RICK MILLER, ECU