A Review of Reports and Selected Literature for Development of Nutrient TMDL Targets for the Cahaba River

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by

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Executive Summary

- Developing relationships between nutrient concentrations and valued ecological attributes in streams (i.e., full support of designated use) is challenging because of the temporal variability in stream ecosystems and the dynamics of transformation and translocation of nutrients in stream ecosystems.
- To determine the nutrient concentrations to protect valued ecological attributes, such as full support of aquatic life use, we need to know the conditions of valued attributes and stressors when human activity is low in watersheds (i.e. reference condition) and the effects of increasing stressors on valued attributes (i.e. stressor-response relationships).
- The goal of nutrient TMDLs in the Cahaba River is to protect and restore conditions protective and supportive of several threatened or endangered species of fish and mussels that have been adversely affected (i.e. extirpated or rendered non-viable). Two likely causal pathways link nutrients to health of these sensitive fish and mussels: 1) nutrient pollution enables nuisance growths of benthic macroalgae that alter habitat of the sensitive fish and mussels and 2) nutrient pollution enables microbial and algal activities that deplete dissolved oxygen concentration that stress sensitive fish and mussels.
- The EPA/SESD reports show that considerable portions of the Cahaba River have low aquatic life use support, and that nutrients and sediments are likely stressors.
- The JCESD reports show that considerable portions of the mid-reaches of the Cahaba River have low aquatic life use support, and that nutrients and sediments are likely stressors.
- The ADEM report shows that nutrient concentrations in streams cited by ADEM to be similar with least impacted conditions have 75th and 90th percentiles of 30 and 39 μg TP/L and 484 and 572 μg TN/L. They argue that a TMDL target for TN is not necessary if TP is managed aggressively.
- Stressor-response relationships between valued ecological attributes were not developed with studies in the Cahaba River, but relations have been observed in other regions of the country that are useful for managing the Cahaba River.
    - Although no statistical relations between algal biomass, macroalgal cover, and impairment of sensitive fish and mussel populations have been developed, algal biomass greater than 100 mg/m^2 and macroalgal growths exceeding 40% cover of river bottom will be used as benchmarks for discussion of problem levels that can negatively affect sensitive fish and mussels.
    - Statistically sound stressor-response relations show nuisance growths of benthic algae and <u>Cladophora</u> occur when TP exceeds 20-30 μg/L in other regions of the US.
    - Stressor-response relations between nutrients, DO concentrations, and pH variability have not been found.
- Given that 75% of streams with least impaired conditions have less than of 30 μg TP/L and the likelihood of nuisance algal and <u>Cladophora</u> growths above 30 μg TP/L, 30 μg TP/L is a TMDL target with sufficient certainty to restore habitat conditions that are capable of supporting populations of the species of concern in

the Cahaba River and it is probably not overprotective. This is a reasonable target for an aggressive management policy as proposed by ADEM.

- A TMDL target for TN should be investigated because N pollution may enable processes that affect aquatic life in the Cahaba River and downstream. N as well as P can limit microalgal and macroalgal growth in streams. Nuisance levels of benthic algae and Cladophora are probably limited below 500-600 μg TN/L, which should restore habitat conditions that will likely support the fish and mussel species of concern.
- Compliance with TP and TN TMDL targets should be assessed seasonally with mean TP and TN concentrations at 5 or more permanent sites within the Cahaba River and by using monthly averages of two or more TP concentration measurements, collected at random times, and excluding values when discharge exceeds an appropriate high-flow criterion. A TMDL target for N may not be necessary if P is aggressively managed.

Framework for Establishing Criteria and TMDL Targets

Many methods have been and could be used to set environmental criteria and targets for TMDLs. Historically, criteria for toxic contaminants have been based on laboratory bioassays and whole effluent toxicity studies. More recently, observations in ecosystems and watershed studies have been used to relate the human activities, contaminants, and habitat alterations that those activities produce (stressors), and the valued ecological attributes (responses) affected. Fundamentally, we need to know two things to establish criteria and TMDL targets (Fig. 1): 1) what is the expected condition that we want to protect and restore and 2) what are the relationships between stressors and responses?

In the Cahaba River, TMDL nutrient targets are being established to restore habitat conditions supportive of healthy, reproducing, and sustainable populations of threatened and endangered fish and mussel species that have been recently extirpated or rendered non-viable. Therefore, the expected conditions for valued ecological attributes in streams that fully support these sensitive fish and mussel species should be characterized so that a target for protection and restoration can be established. These expected conditions, sometimes referred to as reference conditions, can be predicted with stressor-response relationships. Alternatively, they can be characterized by sampling multiple sites that fully support the designated use and by describing the central tendency (mean, median, mode) and range in usual conditions at those sites, such as those found in the best 75% or 90% of sites. This describes the range of conditions in which you can expect a reasonably high probability of full support of designated use. Precedent has been set to use these percentiles to establish criteria, such as the biological condition that characterizes the expected or reference condition and indicates full support of aquatic life use (Fig. 1).

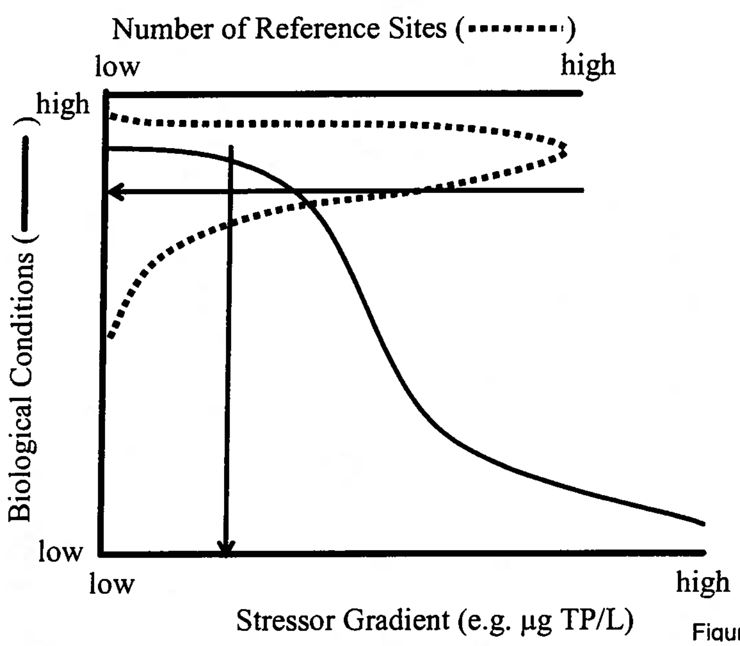

Figure 1

Figure 1. The relationship between frequency distributions (dotted line) characterizing the central tendency in biological condition at reference sites, which can be used to set targets for TMDL protection, and stressor-response relationships (solid line) that describe how biological condition decreases with increasing stressor levels.

The remaining questions are, "Does biological condition change with increases in specific stressors?" and "At what levels do those stressors cause impairment?" Stressor-response relationships are particularly important for answering these questions. These relations between contaminants (or habitat alterations) and valued ecological attributes can describe the likelihood that designated use can be supported at successively higher levels of stressors. Non-linear relationships, especially those showing assimilative capacity at lower stressor levels, are valuable for justifying where to set criteria (Muradian 2001), however we usually observe linear responses due to variability in data. Stressor criteria or TMDL targets should be set based on stressor-response relationships and on an acceptable risk that designated use will be supported. TMDL protocols call for establishing stressor targets with a margin of error. In an ideal world, stressor targets should be established at a stressor level less than the level estimated to cause biological condition (a valued ecological attribute) to be less than an acceptable level (Fig. 1).

Stressor-response relations should ideally be known for all relations in a causal pathway, i.e., for all direct and indirect relationships between stressor and valued ecological attributes. In the Cahaba River, nutrients could affect fish and mussels directly through toxic effects, such as toxicity due to high ammonia, or indirectly through physical habitat alteration by nuisance macroalgal and dissolved oxygen depletion. Therefore, in the Cahaba River, we want to know relationships among the sensitive fish and mussels, invertebrate and fish indicators of conditions supporting designated use, algal biomass and filamentous algal cover, DO, and one of the main ultimate stressors, nutrients. In practice, we know few of these relationships quantitatively. Other relations should be estimated semi-quantitatively with best professional judgment and stated explicitly.

In some cases, stressor criteria or TMDL targets are established with less information (Fig. 2). For example, frequency distributions based on stressor conditions at reference sites (e.g. ADEM 2003) or all sites (e.g. USEPA 2000a) could be used. Criteria and TMDL targets established with only a frequency distribution of stressor conditions may over-protect or under-protect the valued ecological attributes. Without stressor-response relations, targets could be set for variables that do not affect biological condition. If contaminants are known to affect biological condition,

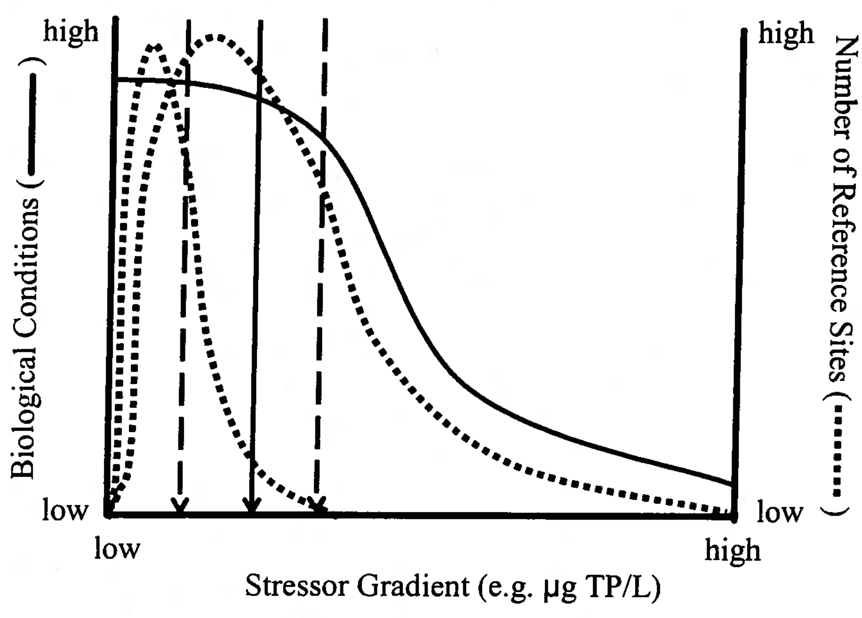

Figure 2. Comparing stressor criteria (or TMDL targets, vertical dashed arrow) based on two hypothetical frequency distributions (dotted lines) characterizing stressor conditions at reference sites defined two ways versus establishing stressor criteria (TMDL targets, vertical solid arrow) based on biological endpoints and effects of stressors on endpoints by using stressor-response relationships (solid line).

then possibilities of error differ with frequency distributions based on conditions at reference sites versus all sites. If contaminants are known to affect biological condition, targets based on frequency distributions of conditions at reference sites only are more likely to be over-protective than under-protective, given reference conditions are known to fully support designated use. Targets based on frequency distributions of conditions at all sites in a region are not effects based and are difficult to assess whether they would or would not support designated uses.

In the following review, reports from the EPA/SESD, ADEM, and JCESD will be reviewed for strengths, weaknesses, and the contributions that each make to establishing nutrient TMDL targets for the Cahaba River. Comparisons between results will be made. Information from the scientific literature will be presented when sufficient regional information is not available, particularly in the form of stressor-response relationships. Finally, the information gathered will be synthesized in a review of the information needed for establishing a TMDL nutrient target based on the discussion above and methods used to determine if TMDL targets are being met.

EPA/SESD Reports

I reviewed (1) EPA/SESD Field Studies on Cahaba River Fall, 2001 and (2) EPA/SESD Field Studies on Cahaba River Spring/Summer, 2002. These studies were conducted to provide EPA with a basis for determining an appropriate target for a nutrient TMDL for the nutrient impaired portions of Cahaba River near Birmingham, AL. The strengths and weaknesses of conclusions in those reports will be reviewed.

The 2001 EPA/SESD field study was conducted during late August and assessed aquatic invertebrate assemblages, algal growth potential, and algal biomass and community health metrics using relatively standard methods. 12 study sites along the Cahaba River were established from an upstream reference site (CR-1) to far downstream from the major sources of WWTP discharge (CR-11). The study was able to show that support of aquatic life in many sections of the Cahaba River was impacted, and that degradation was consistent with the kinds of effects associated with excessive nutrients and sediments. Moderate degradation of invertebrates was observed at 2 sites, CR-2 & CR-4, and greater degradation was shown at another 2 more downstream sites, CR-7 & 8. Moderate degradation of algal assemblages was evident at CR-3 and CR-5, and CR-6 and more severe degradation was observed at CR-7. Algal growth potential assays indicated P limitation at the 7 sites tested. Conductivity was relatively high at stations CR-6, CR-7, and CR-10. Total P and N were measured at only 7 sites. TP was 0.038-0.083 mg/L at sites with some sort of biological impairment and was less than 0.019 mg/L at sites without biological impairment. TN was between 1.5 and 3.2 mg/L at sites with some sort of biological impairment and was less than 0.5 mg/L at sites without biological impairment. WWTP discharge reports coincided with observed impairments at sites CR-3, CR-7, and perhaps CR-8.

Summary of Tables in Report and my interpretation of results of impairment.

	Impairment			WWTP	TP	TN	Stressor
Station ID	Inverts	Algae	Conduct	Numbers	(mg/L)	(mg/L)	(likely)
CR-1					0.010	0.4	
CR-2	Mod				--	--	Seds
CR-3		Mod		Mod	0.038	2.1	Nutes
CR-3D			--		--	--	
CR-4	Mod				--	--	
CR-5		Mod			--	--	
CR-6		Mod	Mod	High	--	--	seds&nutes
CR-7	High	High	Mod	High	0.083	3.2	seds&nutes
CR-8	High			Upstr*	0.043	1.5	
CR-9	--	--			0.042	0.9	
CR-10			Mod		0.019	0.5	
CF-11					0.017	0.5	

Relationships between biological impairment, nutrient and sediment stressors, and human disturbance are indicated by multiple facts, but missing data and the study design constrain inference of cause-effect relationships and establishment of specific targets for nutrient TMDLs. The lack of replicate samples at sites limits credibility of even the observed patterns, although the general tendency of observing algal or invertebrate impairment at sites with indicators of disturbance does provide multiple facts indicating relationships between valued ecological attributes (inverts and algae), sediment and nutrient stressors, and human activities. The evidence for the following statements in the discussion was limited or lacking, such as:

- "Nutrient-related impairment was obvious below major NPDES point source municipal discharges in three distinct reaches of the mainstem Cahaba River." Although degradation was obvious, the relation between discharges and 3 reaches with low ecological condition were not well established and not obvious.
- CR-9 had little evidence of nutrient impairment because no biology was assessed, however TP and TN were in the range that was associated with impairment elsewhere.

Over-stating and misstating results reduced credibility of other statements. However, impairment of algae or invertebrates and 7 of 12 sites indicated that over half of the Cahaba River shows signs of degradation.

<u>The 2002 EPA/SESD field study</u> was conducted during spring (March/April) and early summer (July). Algae and water quality were sampled and assessed during both spring and summer. Invertebrates were sampled during spring and fish were sampled once during 2002 (the time was not evident in the methods). This study again showed that at least half of the reaches assessed in the Cahaba River did not fully support aquatic life uses. Fish had fair or poor biotic condition at half the sites in the Cahaba River, which tended to be the sites at which WWTP discharge was noted during the 2001 EPA/SESD or close to those sites. Biotic condition of invertebrates as indicated by the IAI was higher during spring of 2002 than August 2001, which would be expected for the cooler

waters and higher diversity period of spring. As a result, fewer sites showing past degradation should be classified as impaired based on absolute values of invertebrate metrics and multimetric indices (e.g., CR-7, Table 3, EPA/SESD 2002). Assessment of low TP conditions is complicated by a high, 0.025 mg/L detection limit. In general, nutrient concentrations tended to be higher during spring and early summer of 2002 versus August 2001.

Algae biomass was assessed with chl a in the water column, on artificial substrata, and at a few sites on natural substrata. Chl a in the water column tended to be low in the Cahaba River, always less than 13.8 μg/L and usually less than 3 μg/L. Suspended algae have been associated with oxygen depletion in low gradient streams with high residence time, but these conditions were not evident in any Cahaba River studies reviewed. Algal biomass on artificial substrata was low. Although diatom species composition on artificial substrata can have high similarity to natural substrata, actual biomass similarities are usually lower. Similarity in current, light, horizontal versus vertical position, and time of exposure commonly differ among natural and artificial substrata. The most important difference is the lack of growth of Cladophora on artificial substrata. However, algal accrual on artificial substrata can be a good *in situ* indicator of microalgal growth potential, but I would not put much emphasis on that interpretation in this study because of the importance of Cladophora response and potential differences in microalgal and Cladophora responses to nutrients. Algal biomass on natural substrata is highly patchy in streams, as indicated in Table D3, but higher average algal biomass among reference (CR-1) and sites downstream from intensive watershed development (CR-6 and CR-7) was evident. The differences between algal biomass are significantly (P=0.048) different among these sites based on an ANOVA and log-transformed biomasses. High snail densities at sites CR-6 and CR-7 may have constrained even higher accrual of algal biomass at those sites.

Algal biomass in the 2002 EPA/SESD report was also assessed with the visual observation of % cover of the suitable substrata by filamentous macroalgae (Tables D5, D6, D7 & D8), which I have found to be a useful approach. This assessment is done by systematically assessing whether suitable substrata exist and then the % of suitable substrata that are covered by filamentous algae. These assessments are done at multiple locations within a reach to account for spatial variability in substrata, other environmental factors, and patchiness of macroalgae. When no suitable substratum is present, no record is made (Table D-5). When suitable substrata are present but no algae, then a 0 is entered for that observation. The average cover for sections of the reach with suitable substrata is then calculated. Average cover at sites ranged from 0-100% cover by filamentous macroalgae and mosses. Cover of filamentous algae was greater during spring than summer, which corresponds to known seasonal preferences of the most prevalent macroalga, Cladophora.

Algal growth potential shifted from P at upstream sites to N and mid-reach sites most impacted by nutrient loading and watershed disturbance. This does indicate an important ecological imbalance. However, it does not by itself justify development of a N criterion as well as a P criterion. Algal growth potential does not indicate that a nutrient is limiting at a site at the nutrient concentrations observed at a site. Rather it indicates which nutrient would be limiting if nutrients were depleted by Selenastrum, a green alga commonly found in lake plankton. This information is not very valuable for setting nutrient targets for TMDLs that will protect habitat for fish, mussels, and other forms of aquatic life in streams. Nutrient limitation assays determine if algal growth in a flask will be enhanced if additional N, P or N and P are added and nutrients are not significantly depleted during 14 days in a culture flask. It is not clear if the results presented are nutrient limitation or growth potential assays. It is hard to believe that nutrients would be limiting at the sites indicated with the high concentrations of nutrients present. I would prefer to see results of nutrient diffusing substrata which indicate whether nutrient concentrations limit periphyton accrual at the site where they are placed and which nutrient limits accrual. Don Blancher with TIA did some of these assays.

Changes in diatom species composition are commonly used in ecological assessment and are particularly sensitive to changes in nutrient concentrations. They are good indicators of nutrient availability and limitation. Diversity (d-bar) was the only algal indicator calculated based on species composition. I expected to see one of many trophic status indices calculated, but that calculation may have been prevented by the level of taxonomic identification performed in the study. The methods report that 300 frustules of cleaned diatoms were identified at 100X with an AO microscope. If this is 100X, and not 1000X, then species identification would have been difficult, but species distinction would be possible. Thus calculation of a species-based trophic status index based on species and their nutrient requirements would have been impossible, but a diversity metric like a sequential comparison index would be possible. Species richness and evenness of assemblages can be low in low nutrient conditions because species membership in the community is limited by higher nutrient requirements of many diatoms species. As nutrient concentrations increase, species richness and evenness of abundances may also increase, and thereby, increase diversity indices that account for both diversity and evenness. However, at higher nutrient concentrations, we could expect competition for space and light to exclude sensitive taxa and evenness to decrease as dissimilarities among species reproduction rates are manifested. High diversity may indicate moderate nutrient enrichment, but this is likely a complex relationship. Trophic status indicators based on species composition and species autecological information would have been a more reliable method for showing effects of nutrient concentrations on diatoms and corroborating nutrient conditions indicated by nutrient concentrations (which can be highly variable in streams).

High nutrient concentrations and impaired invertebrate communities provide justification for extending the 303(d) listing for nutrients to upstream reaches of the Cahaba. Impairment is evident in the upper reaches of the Cahaba River downstream from Trussville, in Little Cahaba Creek, and in the un-named tributary of Little Cahaba Creek. These impairments are associated with elevated nutrient concentrations as well as sedimentation. Replicate samples were not collected at stations during a single season, which would provide statistical certainty that the few sites sampled upstream were indeed impaired. However, several sites were sampled downstream of known discharges and they consistently indicated degraded conditions (either biological condition, elevated nutrients or changed water chemistry) relative to upstream reference sites within the same stream.

Nutrient targets of 12 μg TP/L and 230 μg TN/L as monthly means were recommended to "minimize exceedances of high biomass and over 40% coverage" and "reduce excess phosphorus and nitrogen to driving the system to phosphorus limitation, and allowing the non-filamentous diatoms to predominate at diversity levels of 3.0 or less d-bar while maintaining periphyton chlorophyll a biomass below the 100 mg/m2 nuisance level...". These numbers were based on an "all-sites" reference approach with low sample sizes and professional opinion. The "all-sites" reference approach actually defined 27 μg TP/L and 580 μg TN/L as criteria because these concentrations represented the (lower) 25th percentile of nutrient concentrations at all sites. The 12 μg TP/L and 230 μg TN/L benchmarks recommended as TMDL targets (pg. 38, paragraph 3) were based on professional opinion and 12 μg TP/L was below the analytical detection limit of P for the 2002 study. Both the "all-site" reference approach and best professional judgment have credibility, of course. The sampling design and sample number constrains application of a more statistically rigorous approach involving both reference approach and stressor-response relations. However, more evidence from the literature could have been used to support best professional judgment.

A relatively routine reference approach was used in which reference conditions were defined as the 25th percentile of nutrient concentrations and algal attributes. For all these attributes, low values are the desired values, so the 25th versus the 75th percentiles are appropriate. Again, 27 μg TP/L and 580 μg TN/L were the 25th percentile of nutrient concentrations. 9.7% filamentous algal cover and 1.997 d-bar (diatom diversity) were the associated 25th percentiles of algal attributes. Unfortunately, invertebrate attributes were not included in the analysis, but they could be easily calculated. The assumption of this approach is that there is a relationship between nutrient concentrations and algal attributes represented by these numbers. This approach was used by Dodds et al. (1988) to recommend nutrient concentrations and chlorophyll concentrations in streams that could be used to delineate trophic status. However, I am concerned that with small sample sizes, there is little certainty that these values are closely enough related. When Dodds et al. used this approach, they had 100s of samples in the analysis, so the "law of averages" created greater correspondence among variables. Less than 20 sites were studied in the Cahaba Basin. In Table D9, different sites are listed for each parameter. In some cases, some of the most impacted sites (e.g. CR-6 & UT-1) are listed as reference stations. These kinds of reference studies are usually conducted on large regional scales to include the range of conditions within the region, not within watersheds where most sites are impacted. An additional problem is that both spring and summer observations from the same site are assumed to be independent and are used in the analysis. Repeated measures analysis should be conducted to see if two observations from the same site can be used independently in the same analysis. This is sometimes referred to as pseudo-replication, and does fit the definition to some extent. The easiest solution is to choose the spring season data or an average of spring and summer season data to evaluate the pattern. Then only 1 observation will be used from each site. And finally, if this approach were credible, the 9.7% filamentous algal cover and 1.997 d-bar diatom diversity are over-protective compared to the <40% algal cover and <3.0 d-bar biocriteria proposed (EPA/SESD 2002, pg. 38, paragraph 3).

A second reference approach was used (Table D10) in which the sites with the lowest 25% of TP and TN concentrations were defined as reference sites and the percent algal cover at these reference sites was characterized. This analysis showed that <40% algal cover occurred at these reference sites and times, or in some cases no data on cover was available. I like this second approach better, even though repeated measures are still a problem. In addition, reference condition is usually defined based on a set of characteristics that include land use attributes so that non-point and point source loading of contaminants and habitat alterations are distinguished from natural variability across landscapes. In the EPA/SESD study, upstream reference sites routinely had the lowest P conditions, so the assumption that high P concentrations result from human activity and defining reference condition based on lowest P concentrations are justified. However, with this reference approach we know that the numerous sites with less than or equal to 27 μg TP/L and 580 μg TN/L do support a basic aquatic life criterion, such as less than 40% filamentous algal cover.

Justification of a TP criterion less than 25 μg/L will be difficult because the detection limit for TP concentration in the 2002 EPA/SESD project was 25 μg/L and is not necessary if the results of the reference approach alone are used to establish a TP criterion. Use of 12.5 μg TP/L to represent all data points less than 25 μg TP/L requires the assumption that TP concentrations less than 25 were evenly distributed between 0 and 25. At least as likely is the assumption that more values were closer to 25 than 0 because some P in the water column is natural and the 3 TP concentrations less than 25 in the 2001 EPA/SESD report were more often greater than 12.5 than less than 12.5 μg TP/L. If 27 μg TP/L as the 25th percentile of TP concentrations is used as the criterion, requirements for these assumptions are not needed because less than 25% of the TP observations are less than or equal to the detectable TP concentration.

Sufficient data were not collected to develop stressor-response relationships between valued ecological attributes and TP concentrations. % filamentous algal cover, mg chl a/m2, and the IAI invertebrate metric were not significantly related to TP concentration. Few sites had TP concentrations in the range between 30 and 100 μg TP/L. The presence of relatively low values of valued ecological attributes at sites with low TP concentrations indicates 27 μg TP/L or 580 μg TN/L TMDL targets would protect relatively high fish IBI, invert IAI, and <40% filamentous algal cover.

In summary, the EPA/ SESD report shows that aquatic life use is degraded in substantial portions of the Cahaba River and some of its tributaries. Sediments and nutrients are the likely stressors because of known effects of sediments and nutrients from other studies and correspondence where WWTP discharges occur. Although this study could have been designed better, developing relations between human activities, nutrient concentrations, and valued ecological attributes is challenging. Sampling with sufficient frequency to adequately characterize conditions at a site and at enough sites is not standard protocol for assessment programs, which often sample just once per year. Although frequent sampling of many sites could be expensive, limiting assessments to easy to measure attributes that specifically address issues of concern can reduce costs and still provide valuable information. Aside from professional judgment, the use of 12 μg TP/L and 230 μg TN/L is overly protective based on the results of the "all-site" reference approach. These are the lowest levels of nutrients in the study, not the criteria of 27 μg TP/L and 580 μg TN/L, which represent the 25^{th} percentile of all sites. The latter criteria seem reasonable protective of supporting aquatic life use of <40% filamentous algal cover and <3.0 d-bar diatom diversity.

JCESD Reports

Dec 1999, Blancher, E.C. and S. Sklenar, "Nutrient Utilization and Primary Production during Low-Flow Conditions in the Cahaba River, AL"

This report describes microbial metabolism, nutrient concentrations, DO, temp, alkalinity, and algal biomass in the Cahaba River during a low flow period from August 17-19, 1999. Many of these measurements were taken at 9 stations in the UCR. The objectives of this report were to estimate primary production, respiration, nutrient uptake, and nutrient limitation along this section of the UCR. Nutrient concentrations were substantially greater downstream than upstream from the Cahaba WWTP (sites at river mile 138.5 downstream and 139.5 upstream). P:R ratios varied from 0.73 to 1.31, but were not really related to spatial patterns in the river. Nutrient uptake rates were calculated with rates of decrease in concentrations with distance downstream from the Cahaba WWTP. Dissolved oxygen concentrations were usually higher than 5 mg/L and were not apparently related to distance from the WWTP. These data represent a relative snap-shot of conditions and provide little value for developing models or assessment of conditions, because the parameters measured vary so much with weather and season.

Jul-Aug 2000, "Jefferson County, AL, Cahaba River - MOA Data"

This report lists basic methods and data on habitat assessment, algal biomass, and alkaline phosphatase activity at 8 sites from Bibb Co. Hwy 24 (rivermile 95.8) to Caldwell Rd. (rivermile 144.9) in the Cahaba River. No abstract, results or discussion was provided with the report. Brief methods were provided with each section of data. Greater than 30% cover of filamentous algae was observed at 3 sites but not related to distance from the Cahaba WWTP. Algal biomasses exceeding 150 mg/m2 were observed on natural substrata at 4 sites on Aug 22-24, 2000 and were over 700 mg/m2 at one site, Hoover High School (rivermile 134.3). This is one of the few summer samplings in the reports reviewed to show high algal biomasses in the Cahaba River. Alkaline phosphatase activity was generally low, but may have been high enough at one site to indicate P limitation.

Jul-Sep 2001, TAI Environmental Services, "Periphyton Standing Crop in the Cahaba River, AL During Low-Flow Conditions, 2001"
Jul-Sep 2002, TAI Environmental Services, "Periphyton Standing Crop in the Cahaba River, AL During Low-Flow Conditions, 2002"

These reports describe habitat assessments, water quality parameters, periphyton qualitative cover assessments, chl a of periphyton and suspended algae, and alkaline phosphatase activity during summers of 2001 and 2002. 10 sites in the Cahaba River and 3 tributary sites were assessed during July and August, 2001 and 2002. Habitat assessments indicated sediments were a problem. Filamentous algae were relatively rare at all sites in July 2001 and August 2002 when habitat assessments were conducted, which contrasts with 2000 when they were abundant and dominant at half of the sites.

In the 2001 report, algal biomass in composite samples from natural substrata recorded in tables on pages 5-4 and 5-5 was less than 150 mg/m2 at all sites, except upstream from Buck Creek and Buck Creek where they were higher. The biomass illustrated in the figure on page 5-6 was much less than in the tables for natural substrata and is apparently the average of biomass on both artificial and natural substrata. Biomass on periphytometers was regularly less than on natural substrata and usually much less. Three statements in the text (pg. 5-1) are incorrect: 1) that highest standing crops were 95.1 mg chl a/m2; 2) that these assessment indicate biomass was relatively low throughout the Cahaba during 2001; and 3) average biomass in composite samples was less than 150 mg/m2 (unless this refers to a basin-wide rather than site-specific average, which would not make sense). All this chl a may not be algae. Some may be bryophytes, which were apparently not removed from samples.

Algal biomass during the summer of 2002 was moderate (<100 mg/m^2) through most of river, but only around 100 mg chl a/m^2 upstream from Buck Creek and over 200 mg chl a/m^2 downstream at Bibb Co. Rd. 24. Relatively high abundances of filamentous algal cover were also observed at this downstream Bibb Co. Rd. 24 site.

Alkaline phosphatase activity was high enough at 1 or 2 stations upstream from the Cahaba WWTP to indicate P limitation. Chlorophyll a concentrations of suspended algae were low.

Species composition of periphyton was determined during one summer, but no analysis of the data was conducted. No indicators were calculated and no relation to environmental factors in the Cahaba was made.

Nutrient samples were collected 8 times throughout July and August. In general, nutrient concentrations were high enough to support nuisance algal growth according to known relations between benthic diatom and chl a accrual in experiments and stream surveys (e.g. Bothwell 1989, Dodds et al. 1997). No averaging of data, graphs, or analyses relating nutrients to location in the river or algal attributes were presented. Alkaline phosphatase may indicate P limitation in streams with relatively high P concentrations if high biomasses of benthic algae accumulate. Nutrient flux into thicker mats may be sufficiently retarded in moderate P habitats to generate temporary P limitation and consequently, phosphatase.

July and August are not when you want to measure Cladophora impacts of habitats, but it may be the period of greatest DO stress. Warm temperatures and long retention times of water in streams during summer low flow periods may facilitate DO depletion. However, habitat alteration due to Cladophora is most likely during the spring and fall periods when water temperatures are optimum for Cladophora growth. Thus, during all the JCESD sponsored studies, they did not sample during the spring when algal biomass on substrata would have been highest.

These JCESD results were consistent with EPA/SESD results when biomass downstream from the WWTP could accumulate to >100 mg chl a/m^2, at various times. These biomasses are high for warm water seasons, if composed mostly of diatoms, blue-green algae, and filamentous green algae and not contaminated with bryophytes. Biomasses were variable with time, probably due to weather related factors, and among composite samples at a site, which is common for algae on natural substrata.

Dec 2001, Howell, W. M. and Davenport, L.J., "Report on Fishes and Macroinvertebrates of the Upper Cahaba River and Three Additional Sites"
Dec 2002, Howell, W. M. and Davenport, L.J., "Report on Fishes and

Macroinvertebrates of the Upper Cahaba River and Four Additional Sites"
May 2002, "Data Pertinent to 303(d) List Cahaba River U.S. Highway 280 to Buck Creek Confluence"

Fish and invertebrate assemblages were assessed at 10 Cahaba River sites and 3 tributary sites during June-August 2001 and May 2002. Invertebrate assemblages were collected from the riffle/run habitat only during 2001. During 2002 the riffle/run method again was used, but the ADEM/EPA multihabitat method was also used. Separate analyses of all invertebrate samples were conducted using a comparable genus-level of invertebrate identification as EPA/SESD. The Indicator Assemblage Index for invertebrates (see EPA/SESD table 3) was not calculated, but a biotic index was. Based on discussion of results, I assume that the Biotic Index is the Hilsenhoff Index and is the same as the Biotic Index calculated by EPA/SESD. EPT taxa richness (one of the more reliable and transferable metrics among ecoregions) was lower in the mid-reaches of the study area during both years, thus higher upstream and downstream, but these patterns were not assessed for statistical significance. The Biotic Index was also lower in the mid-reaches during 2001, but not 2002. Other metrics such as % shredders and % predators, which also tend to be EPT taxa, were lower in the mid-reaches of the study area than at upstream and downstream sites. Similar patterns were observed by EPA/SESD.

The report says fish assemblages were collected by seining all key habitats of each study area for a period of 30 minutes. Since it was not clear in the report, I assumed that this was 30 minutes for all habitats combined versus 30 minutes for each habitat. This seems much less thorough than O'Neil's methods described in the EPA/SESD report and is reflected in the almost 50% lower number of total fish taxa reported by JCESD than O'Neil reported for total native taxa. JCESD calculated fish IBI scores using Karr's methods, whereas O'Niel used a modified calculation based on calibrations made for Alabama streams and for the intensive sampling effort. JCESD fish IBI scores during 2001 and 2002 were higher upstream than in the mid-reaches at Riverford Drive and Chace Lake Country Club. During 2001 downstream fish IBI scores were higher than the mid-reach stations, but not during 2002. This pattern is similar to O'Neil's pattern in fish IBI scores.

JCESD makes the argument that invertebrate and fish assemblages are "fully supporting" and not impaired in the listed section of the Cahaba River. Their results show consistently lower metrics in the mid-reaches of the Cahaba, but they argue that these depressed conditions are not sufficiently depressed to be "impaired." They use criteria for the invertebrate Biotic Index from North Carolina for streams in the Piedmont Region (which I did not check). The EPA/SESD report shows "excessive impairment" based on the Indicator Assemblage Index and they do not discuss assessment based on the Biotic Index. The IAI seems to be more sensitive than the Biotic Index, but the lack of Alabama criteria and information on reference conditions makes it difficult to judge whether the Cahaba River is "fully supporting" invertebrates assemblages or not. Similarly, fish assemblages are listed as "poor" by O'Neil at one site downstream from the Cahaba WWTP. Several sites studied by JCESD have fish IBI less than 40 in both 2001 and 2002 and 2 sites ranked 34 or less during 2002. Karr et al. (1986) classifies Illinois streams with a 28-34 rank as "poor" and 40-44 rank as "fair." JCESD use this assessment system in the 2001 report by modifying it to "better 'fit' known fish communities in the upper Cahaba watershed." I question the rationale of this modification, but also question the transferability of fish IBI assessment criteria from Illinois streams to this region of Alabama. Without Alabama-specific criteria or reference condition characterization, determining whether the mid-reaches of the Cahaba are "fully supporting" is difficult when using invertebrate and fish indices. However, the lack of "full support" cited by the EPA is due to loss or weakening of sensitive, native fish populations that were once in the Cahaba River. This impact is apparently not reflected in fish IBI or invertebrate IBI indices. The loss or weakening of sensitive, native fish populations that were once in the Cahaba River was observed by the Fish and Wildlife Service. I have not seen this report and can not assess its merit.

Dec 2002, Blancher, E.C., "Procedure for Calculating the Total Phosphorus TMDL Target Value for the Cahaba River, Alabama"

I am concerned that the fit of the AQUATOX model to algal biomass patterns in the Cahaba River is not sufficient to warrant development of nutrient TMDL targets. In particular, I am concerned about the need for and lack of prediction of the frequency, temporal extent, and temporal duration of Cladophora growths. I think the model is actually based on predictions for Stigeoclonium growth. Stigeoclonium is another filamentous green alga that is easily constrained by grazing and seldom develops nuisance growths in streams. However, they may have recalibrated the model with Cladophora-TP relations from Dodds et al. (1997). Blancher also suggest on page 5 of the report that Dodds et al. (1997) predict mean chlorophyll a values of 100 mg/m^2 in a Cladophora dominated stream at 221 µg TP/L. This differs from the provisional TP target of 30 µg/L that Dodds et al. recommend, the 20.5 µg TP/L in reference conditions, and the 35-38 µg TP/L predicted by regression models from empirical results (see Dodds et al. 1997, pg. 1744-1746) to keep chl a less than 100 mg/m^2. Blancher may have used one of Dodd's equations to predict the 221 mg/m^2. Dodds et al. had many equations. The polynomial regression models used by Dodds et al. may underestimate algal biomass at higher TP levels (see later discussion in Literature review of Dodds et al. 1997).

ADEM Report

The following comments are based on the report, "Nutrient Target Proposal for the Cahaba River TMDL," by the Alabama Department of Environmental Management. In this report ADEM develops a target for nutrient TMDLs for the Cahaba River by using the reference approach as outlined in USEPA's Nutrient Criteria Technical Guidance Manual: Rivers and Streams (USEPA 2000b) with two datasets. One dataset used established reference conditions, but only for 12 sites that occurred in the ecoregions (67& 68) near or surrounding the Cahaba River. The other dataset added 18 sites selected based on ≥90% very low impact land use (e.g., pasture) or forested landscape. With just the 12 sites, the 75th and 90th percentiles were 33 and 36 µg TP/L and 484 and 572 µg TP/L. With the 30 sites, the 75th and 90th percentiles were 30 and 39 µg TP/L. These values were intended to represent the least impacted sites of the region in which the Cahaba River occurs.

ADEM acknowledges that we do not know if these sites support sensitive fish and mussels species like those lost or weakened in the Cahaba River. Thus we do not know with certainty whether these conditions support the valued ecological attributes that we are trying to restore in the Cahaba. We also do not know if these conditions are over-protective. Knowledge of invertebrate assemblages at reference sites and their "condition" in Ecoregions 67 and 68 would have helped characterize the quality of reference sites and would have provided a translator to better compare Alabama reference sites with data from other streams and rivers with hydrogeomorphology similar to the Cahaba and that support sensitive fish and mussels. But no information about the invertebrate assemblages at reference sites in Ecoregions 67 and 68 were provided. All in all, the ADEM reference site characterization shows the TP and TN conditions that ADEM considers to represent reference conditions.

ADEM's proposal for a TMDL P target is one of the most reliable sources of information of all the studies by ADEM, USEPA, and Jefferson County, because it does identify, with considerable certainty, the TP concentrations in the least impaired streams and rivers of the Cahaba River region and in streams and rivers similar to the Cahaba River. In addition, it follows EPA recommended procedure for setting nutrient criteria. However, ADEM's proposal does not provide an effects-based P target and is, therefore, not completely studied. ADEM's proposal identifies TP concentrations in least impacted conditions, but it does not does not use stressor-response relations to confirm that least impacted condition would support or be over-protective for the sensitive fish and mussel populations that were extirpated or render non-viable in the Cahaba River.

Using multiple lines of evidence as ADEM did was also valuable. ADEM evaluated that certainty of their 30-39 μg TP/L range as appropriate for TMDL targets by comparing results from several approaches that are based on frequency distributions of TP concentrations. They compared the upper limits of reference conditions with two datasets based on differing definitions of reference conditions and thus arrived with the 30 and 33 as 75^{th} percentiles and 36 and 39 as 90^{th} percentiles of frequency distributions of TP conditions with the two datasets. They also compared their results to USEPA-recommended ecoregion-specific nutrient criteria derived from existing data at all sites in ecoregions of Alabama. The nutrient TMDL P targets derived by the ADEM reference approaches were higher than the 10 μg TP/L criterion recommend by USEPA based on all sites in Ecoregion 67 and the 6 μg TP/L for the adjacent Ecoregion 68. Conceptually, using the upper limits of a frequency distribution of stressor levels (e.g. nutrient concentrations) of least-disturbed reference sites is better than using the lower limits of a frequency distribution for all sites. At least theoretically, we expect that reference conditions would support valued ecological attributes (e.g. weakened fish and mussel populations of the Cahaba River), but we don't know if the lower range (25th percentile for example) of all sites, i.e. the best of all sites, support valued ecological attributes. In regions with substantial landscape alteration (e.g. Ohio), they would be less likely to support valued ecological attributes than in regions with little landscape alteration (e.g., Maine). Thus, characterizing conditions at only reference sites is the best of the frequency distribution approaches for setting nutrient criteria and TMDL targets.

Two ecoregions were included in the selection of reference sites so that enough could be identified for the analysis. Sites were located in Ecoregion 67, in which the Cahaba River is located, and the adjacent Ecoregion 68. The latter Ecoregion is a good second region to expand options for selecting sites because TP concentrations at the best sites are lower in Ecoregion 68 than in the Cahaba River Ecoregion, based on the "surrogate" reference condition defined with all sites in a database compiled by the USEPA (see Table 3-1).

Although the analysis was, overall, appropriate, I had concerns about several details that could affect setting a higher nutrient TMDL than justified. I was concerned about whether sufficient criteria were used to evaluate the suitability of the additional 18 reference sites. Two sites had nutrient concentrations substantially greater than observed at the other sites (48 & 130 μg TP/L). 48 & 130 μg TP/L are high concentrations for reference sites and I'd be surprised if they supported high-quality invertebrate assemblages, if these values truly characterized conditions in the streams. It's possible that these concentrations were temporal anomalies for these streams because the streams were characterized with just one observation. TP concentrations can vary greatly in streams with time due to weather-related and seasonal factors. Criteria or TMDL targets based on reference approaches should be based on precise characterizations of nutrient concentrations in streams. With greater uncertainty associated with imprecise assessments of P conditions in streams, lower TP targets should be established to ensure protection of valued ecological attributes.

The high TP concentrations in two reference streams may also be due to intensive human activity in the 10% of disturbed watershed allowed based on 90% low impact or forested land use in watersheds of reference streams. When such impacts are observed, the use of additional criteria for reference condition should be used, such as absence of any local, intensive human activity generating high stressors. This is not a circular argument. It is simply an iterative process of defining reference condition and is often used. In this case more than one criterion is used to define reference condition. The two streams with unusually high TP concentrations should be eliminated from the analysis, either because they were not true reference sites or they had unusually high TP for the time they were sampled. If these two streams were removed from the analysis of the frequency distribution of reference sites, then the TMDL targets (derived from the 75th and 90th percentiles of TP concentrations at reference sites) would be lower than 30 and 39 μg TP/L.

Considerable evidence from the Midwest US and Montana indicate that nuisance algal growths by Cladophora develop in streams with TP concentrations between 20 and 30 μg TP/L. ADEM decided to use the reference approach for defining nutrient criteria because no information about algal-nutrient relations was available from the Southeastern US. In particular, no relations were observed in the Cahaba River. This is not sufficient justification to ignore well-established stressor-response relations in other parts of the country. The inability to detect relations between Cladophora and nutrients in the Cahaba River was related to small sample size, substrate and light variability, and the frequent sampling during summer when Cladophora is relatively rare. Genetic analysis of Cladophora from many regions of the country indicates that it is almost always the same species, Cladophora glomerata. Thus we would expect a more similar response across regions for Cladophora than if many species were occurring in different regions of the country. Latitudinal differences between regions where Cladophora-TP relations were developed and Alabama would affect when Cladophora would bloom during the year, not Cladophora-TP relations. Cladophora blooms in restricted temperature (16-24°C) and high-light, longer daylight conditions. So the month of blooms may vary, but not the TP requirements for blooming.

ADEM recommends a range of TP concentrations, 30-39 μg/L, as a TMDL target. The target should be a specific number that is considered a maximum, not a range of numbers. Thus, a decision should be made on whether to use the 75th or 90th percentile of reference conditions, the rationale for the 30-39 μg TP/L range. Conceptually, the rationale for using a 75th versus a 90th percentile is that the 75th is more certainly protective than the 90th. The 75th is also chosen because of the TMDL target represents a maximum allowable concentration, that conditions in natural ecosystems do vary (particularly in streams), and consequently, conditions can exceed the TMDL target half of the time and still meet the TMDL target when it is based on a mean of measurements made at different times.

The 75th rather than the 90th percentile of the TP frequency distribution in reference streams determined by ADEM is better justified for use as a TMDL target. If conditions frequently exceeded 39 μg TP/L, allowed because of likely measurement averaging methods that will be used to determine if targets are being met, then known Cladophora-TP relations would predict frequent and extensive nuisance growths. In addition, 2 sites in the group of 18 new reference sites that had high TP values should probably not have been included in the frequency distribution analysis of reference conditions for reasons described above. The observation by ADEM that chl a concentrations were less than 15 mg/m^2 at reference sites when sampled would not reflect the spring potential for nuisance algal growths by Cladophora, if ADEMs characterization is based on sampling during summer when TP measures were made for many streams. Finally, Cladophora-TP relations known from other regions should be included in the rationale for establishing a TMDL P target.

Literature & Data Review

Dodds et al. 1997

Dodds gathered data from sources around the world to make a global database of benthic algal biomass (measured as chl a) and nutrient concentrations. They then used three methods to study relations between chl a, dissolved nutrients, and total nutrients: regression, reference, and probabilistic approaches. They observed an asymptotic relationship between algal biomass and nutrient concentrations with increasing algal biomass with nutrient concentrations until a saturating nutrient concentration was found. They found regression models explained more variation in chl a (Table 2):

- with total nutrient concentrations than with dissolved nutrients;
- with TN only than with TP only (when using polynomial regression to model the asymptotic relationship[1]); and
- when both TN and TP were included in models than with either alone.

Reference streams without algae had mean summer TN and TP concentrations of 318 and 20.5 μg/L, respectively.

[1] This modeling would probably be better with a different non-linear regression technique. Simple polynomial regression models generate hyperbolic (u-shaped) curves or sinusoidal curves, rather than asymptotic curves or near-asymptotic curves.