Assessment of the Nitrogen and Phosphorus Pollutant Provisions in the Draft NPDES Permit for the Franklin Water Reclamation Facility (City of Franklin, Tennessee)

by

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I. Overview

I am an aquatic scientist with more than 30 years of experience in the assessment of nutrient pollution impacts in freshwaters (curriculum vitae attached). I was asked by the Harpeth River Watershed Association (HRWA) to assess the draft National Pollutant Discharge Elimination System (NPDES) permit for the Franklin Water Reclamation Facility (WRF) (Tennessee Department of Environmental Conservation [TDEC] 2016a), especially concerning nutrient-related impacts from this WRF on the Harpeth River in the vicinity of the WRF and in downstream waters. These river segments are located within U.S. Environmental Protection Agency (EPA) level IV sub-ecoregions 71h and 71i, respectively (TDEC 2004), hereafter referred to as the affected area of the river. This statement contains my expert opinions, which I hold to a reasonable degree of scientific certainty. They are based on my application of professional judgment and expertise to sufficient facts or data, consisting specifically of a review of regulations and documents related to phosphorus, dissolved oxygen (DO), and algal growth. These are facts and data typically and reasonably relied upon by experts in my field.

After consideration of draft NPDES permit for the Franklin WRF, various reports and datasets about the water quality of the Harpeth River, and many science publications about impacts of nutrient (nitrogen, N, and phosphorus, P) over-enrichment on river water quality, my overall assessment is as follows:

- ✓ The Harpeth River in the vicinity of the Franklin WRF, and in downstream waters, is impaired by organic enrichment (nutrient pollution – see U.S. EPA 2004, TDEC 2016b) and low DO, largely caused by the WRF, and also by excessive siltation. The impairment has been ongoing well over a decade (basis: U.S. EPA 2004, TDEC 2016b, and data from TDEC provided by the HRWA).

- ✓ Improved N and P co-management is needed to accomplish reductions in NOx and TP in the treated effluent of the Franklin WRF, and a shift toward reference conditions for N and P supplies and supply ratios, both of which are of major importance in controlling noxious algal species and biomass.

- ✓ The draft permit emphasizes control of N, but the level of total N (TN) in the summer discharge (5.0 mg /L during May through October, the summer season as defined by TDEC) is much higher than can be achieved through biological nutrient removal (BNR) technology which is available or planned at the WRF, and higher than needed to protect the designated use of the Harpeth River for fish and aquatic life in the affected area.

- ✓ The Franklin WRF has reduced its P discharge over the past several years, but its planned summer discharge at ~1.30 mg TP/L (~1,300 μg TP/L) in the draft permit is seven- to eight-fold higher than needed to protect the designated uses of the affected area of the Harpeth

River for fish and aquatic life.

- ✓ Although federal law requires these assessments, TDEC has not assessed available technology for N and P reductions. The draft permit for the Franklin WRF also has not assessed whether TBELs for N and P can achieve appropriate nutrient criteria, or whether WQBELs are needed.

In the following, more detailed comments, Sections I and II briefly summarize pertinent state water quality criteria, and federal requirements and recommendations including requirements for NPDES permits to include (i) an assessment of technologies for reducing pollutants (here, N and P) prior to selection of possible technology-based effluent limitations (TBELs) and, (ii) as a second necessary step, an assessment of the potential need for water quality-based effluent limitations (WQBELs). The latter information was especially germane in this evaluation because the draft permit for the Franklin WRF provides no indication that either of these federally required assessments was conducted. My analysis considered the applicability of TBELs vs. WQBELs in improving the quality of the treated effluent discharged by the Franklin WRF, from the perspective of restoring and protecting the designated us of the affected area of the Harpeth River. This perspective was appropriate because, as explained in Section IV below, the affected area of the Harpeth River is impaired due to nutrient pollution (TDEC 2015b) and has had extremely poor water quality for well over a decade, a condition which would be exacerbated by operation of the Franklin WRF following the draft permit in its present version.

My analysis of the efficacy of TBELs versus WQBELs for N and P in treatment of the effluent from the Franklin WRF first required determination of what the targeted TP and N (specifically here, and nitrate+nitrite, NOx) concentrations should be in the affected area of the mainstem Harpeth River (sub-ecoregions 71h and 71i), in order to restore good water quality and prevent noxious algal overgrowth. Section V examined that important question. The U.S. EPA recommended (below) that targeted nutrient concentrations for restoring good water quality in nutrient over-enriched rivers should be based on what the natural background (reference) or minimally impacted conditions historically were, prior to European settlement. TDEC previously conducted such an analysis, which culminated in its selection of “numeric translators” for TP and NOx in the affected area of the Harpeth River. These “numeric translators” are the agency’s targets for water quality in the Harpeth. My evaluation (Section V) of each step taken by TDEC in that task, however, showed that TDEC had overestimated the TP concentration, and had greatly the NOx concentration, which should be considered as targeted “reference” conditions. Remarkably, TDEC had acknowledged that, far from actual reference conditions, its selected so-called “reference” streams were as nutrient-polluted as the other streams in sub-ecoregions 71h and 71i. The agency used them as “reference” conditions anyway, and even then, chose not to follow a U.S. recommendation to base numeric criteria (or translators) for TP and NOx on the 75th percentile of reference conditions. Instead, TDEC used the less protective, higher nutrient levels at the 90th percentile of its already-seriously-compromised “reference” streams to choose its numeric translator concentrations for TP and NOx. The agency (Section Vb) also overlooked data showing a threshold TP concentration above which sensitive biota declined, which is important cause-and-effect information that should have been considered in developing the numeric translator for TP.

Based on re-assessment of the available data, I identified more protective, actual reference conditions (Section Vb,c) that should be used as targets for restoring good water quality in the affected area of the Harpeth River. These targets would re-establish P-limiting conditions to control algal growth (Section VI); in addition (Section VII), these targets would re-establish healthy N:P supply ratios. Both of these characteristics – the amount or supply of nutrients, and the proportion of those supplies – are very important in selecting for natural, beneficial algal assemblages and avoiding noxious algal overgrowth.

Finally, in Section VIII WQBELs to protect the designated use of the affected area of the Harpeth River were estimated for TP and NOx, based on the more realistic, re-assessed natural background (reference) conditions. The technology required to achieve these WQBELs was also considered. Based on available information about the facility design, it was concluded that these WQBELs for TP and NOx can be achieved through biological nutrient removal technology which is already available or planned at the Franklin WRF.

II. *Pertinent Tennessee Water Quality Criteria*

The State of Tennessee has a narrative (qualitative) criterion for nutrients (TDEC 2004), referred to here as "Offensive Conditions":

> The waters shall not contain nutrients in concentrations that stimulate aquatic plant and/or algae growth to the extent that aquatic habitat is substantially reduced and /or the biological integrity fails to meet regional goals. Additionally, the quality of downstream waters shall not be detrimentally affected.

Interpretation of the narrative standard has been made by TDEC using "numeric nutrient translators" (TDEC 2001), from regionally based interpretations of the narrative criterion (but see Section V below).

In contrast, the state has quantitative criteria for DO, promulgated by the Tennessee Water Quality Control Board (T.C.A. §§4-5-201 et seq., and 69-3-105). For the designated use of "fish and aquatic life" in the Harpeth River (U.S. EPA level IV sub-ecoregions 71h, 71i), the DO criterion is $\geq$ 5 milligrams per liter (mg/L) throughout the day (i.e., 24-hour diel period):

> The dissolved oxygen shall be a minimum of 5 mg/l except in limited sections of streams where it can be clearly demonstrated that (i) the existing quality of the water due to irretrievable man-induced conditions cannot be restored to the desired minimum of 5 mg/l dissolved oxygen; or (ii) the natural background quality of the water is less than the desired minimum of 5 mg/l (U.S. EPA 2004).

III. Federal Requirements and Recommendations

a. U.S. EPA Recommendations

The U.S. EPA mandated that states adopt ambient numeric nutrient criteria for streams and rivers by the end of 2003 (National Strategy for the Development of Regional Nutrient Criteria, June 1998, p. iv). To facilitate that effort, the U.S. EPA provided a series of nutrient criteria guidance documents and recommended criteria for nutrients (causal variables TP and TN or N forms such as nitrate) in lakes and streams within designated nutrient ecoregions. The U.S. EPA developed

14 ecoregions for the nation based on present land use, and various sub-ecoregions within each ecoregion. The recommended criteria for each were based on conditions in reference streams, which were defined as having natural background nutrient concentrations, unaffected or minimally affected by nutrients from human activities. The U.S. EPA recommended use of the 75th percentile of reference stream data (past ~decade) or, if reference streams could not be found, use of the 25th percentile of all streams data. States were given the option of using the numeric nutrient criteria recommended by the U.S. EPA, or developing their own scientifically defensible numeric criteria that protect the designated uses of surface waters.

The U.S. EPA (2000a, 2001) has also recommended use of stressor-response relationships to derive numeric nutrient criteria, mainly by identifying threshold or changepoint concentrations at which large changes in biological metrics (e.g. algal biomass as chlorophyll *a*, or sensitive biota such as aquatic macroinvertebrate insects) occur as a result of increasing nutrient concentrations. The U.S. EPA (2000a) and various states recognized that biological thresholds are valuable for setting nutrient criteria because there is a direct link between biological responses and protection of designated uses for aquatic life.

b. Requirement for Antidegradation Review

Federal regulations (40 CFR 131.12) require state water quality standards programs to conduct an antidegradation review when a new or expanded point source which will degrade or lower water quality is proposed for discharge to surface waters. According to the U.S. EPA (1994), no activity is allowable under the antidegradation policy which would partially or completely eliminate any existing use – for the Harpeth River in the affected area, fish and aquatic life. The effect of an expanded point source discharge should result in no mortality and no significant growth or reproductive impairment of resident species. *Thus, antidegradation analysis is supposed to consider actual conditions in the river, rather than simply assessing permit loads.* The Guidelines of Section 404(b)(1) state that significant adverse effects on life stages of aquatic life, and/or on species diversity contribute to significant degradation.

For example, considering the affected area of the Harpeth River as shown below (Figure 1), TDEC data (Denton et al. 2001; pp. 9-11 below) show that, because of excessive P pollution, TP concentrations were already strongly linked to loss of sensitive aquatic macroinvertebrate species well over a decade ago. Permits to this WRF (then, a sewage treatment plant) during the intervening time continued to add P pollution, which would have exacerbated the loss of sensitive species. If the draft permit is approved, the TP pollution from the expanded Franklin WRF will contribute to significant additional degradation through adverse impacts on species diversity.

c. Requirements for TBELs and WQBELs

TBELs, derived from technology standards, must be developed for all pollutants of concern in NPDES permits (NPDES regulations at Title 40 of the Code of Federal Regulations (CFR).125.3(a), Hair and Currey 2015a). A TBEL should be set base on thorough assessment of the available technology for reduction of a given pollutant, and what that technology can actually achieve. TBELs are described as only a "first step" in wastewater treatment considerations: When TBELs are assessed as inadequate to meet water quality criteria in a receiving waterbody, WQBELs are required (Hair and Currey 2015b). Yet, the draft permit for the Franklin WRF

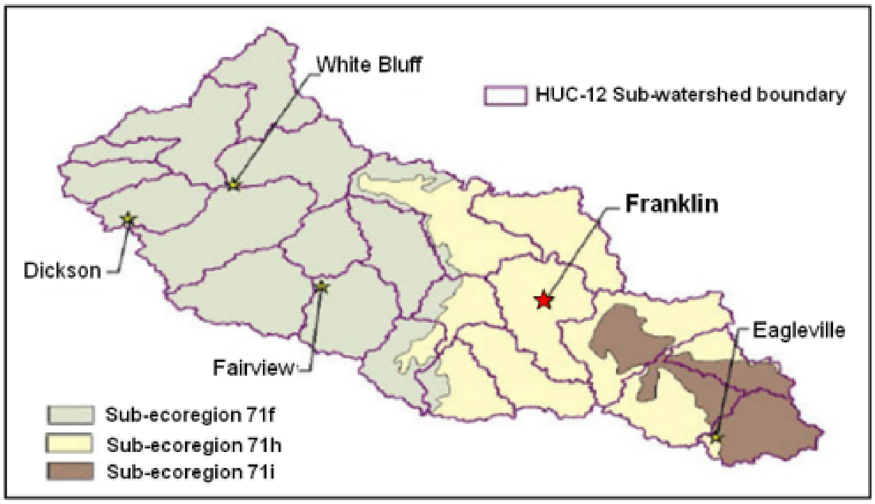


Figure 1. The segments of the mainstem Harpeth River affected by the Franklin WRF discharge are in sub-ecoregions 71h and 71i.

fails to include assessment of the available technologies for removal of P and N. Also lacking is an analysis of whether the TBEL can meet protective N and P criteria for the receiving river (see below), or whether WQBELs for N and P are needed.

The latter analysis is also a federal requirement: Federal law requires TDEC to impose effluent limitations necessary to protect receiving waters and meet standards, including permit requirements in addition to or more stringent than standard or promulgated technology-based limitations. Under the regulations for the Clean Water Act, 40 C.F.R. § 122.44:

> . . .each NPDES permit shall include conditions meeting the following requirements when applicable. . . .(d) Water quality standards and State requirements: any requirements in addition to or more stringent than promulgated effluent limitations guidelines or standards under sections 301, 304, 306, 307, 318 and 405 of CWA necessary to: (1) Achieve water quality standards established under section 303 of the CWA, including state narrative criteria for water quality. (i) Limitations must control all pollutants or pollutant parameters (either conventional, nonconventional, or toxic pollutants) which the Director determines are or may be discharged at a level which will cause, have the reasonable potential to cause, or contribute to an excursion above any State water quality standard, including State narrative criteria for water quality.

The requirements of the regulation apply whether the facility's pollutant load is increasing or decreasing, and whether or not the permits have been issued after completion of a TMDL. If a TMDL has not been completed and no wasteload allocation is available, which is the situation for the Franklin WRF, the permit must impose an effluent limit that "is derived from and complies with all applicable water quality standards" (40 C.F.R. § 122.44(d)(1)(vii)(A)). If state numeric criteria for N and P are not available, then WQBELs should be derived using science-based nutrient translators. TDEC has developed TP and NOx translators for the narrative criteria given on p.2 of this assessment, but they are not science-based and more protective translators are needed as explained below.

IV. Present-Day Water Quality of the Affected Area of the Harpeth River

The Franklin WRF is being upgraded for an average wet weather flow of 16 million gallons per day (mgd). Over the past three years (2013-2015), its permitted discharge was 12 mgd and its permitted TP concentration in summer initially was 5.0 mg/L. The average concentration in the discharge from Nov. 2010 through May 2016 was 1.26 mg TP/L, based on data from the Franklin provided to TDEC and HRWA, and additional data added from the City's monthly reports to TDEC through July 2016. The planned summer discharge of the upgraded WRF, according to the draft permit, will be ~1.30 mg TP/L (~1,300 µg TP/L, based on 63,393 pounds per year (rolling average; TDEC 2016a) which clearly is comparable to the present actual discharge. The present permit capped effluent discharge at 12.0 mgd. The effluent discharge is commonly at ~6-8 mgd, but discharge has exceeded the cap and has been as high as nearly 14 mgd on some dates.

The Franklin WRFP discharges into the Harpeth River at river mile (RM) 85.2 (TDEC 2016a). River discharge during dry periods can be as low as 1-3 cubic feet per second (cfs), based on data from U.S. Geological Survey (USGS) gaging station 03432350 on the Harpeth River at Franklin. The 7Q10 low flow of the river in the effluent discharge area is 0.54 mgd (TDEC 2016a). Thus, at low-flow periods this WRF discharge, to be permitted at up to 16 mgd, overwhelms the river flow so that the "river" is mostly treated effluent. This was already the situation, although not as extreme, at the presently permitted maximal discharge of 12 mgd. Not surprisingly, the river in this area and downstream from the WRF has been impaired over more than a decade from nutrient pollution and low dissolved oxygen as mentioned (U.S. EPA 2004, TDEC 2016a,b). There is no evidence in the draft permit or the present permit that TDEC considered the assimilative capacity of the river for N and P pollutants.

Although TDEC (permit) states that the Harpeth River in the vicinity of the WRF is impaired only for one nutrient, P, the river in some locations has been listed as impaired for both N and P (TDEC 2016b), and previously was listed as impaired for "organic enrichment" (U.S. EPA 2004) which involves both N and P. The affected area of the Harpeth River presently is characterized by excessive concentrations of both TP and NOx, and extremely low TN:TP ratios that are unhealthy for the ecosystem (see Section VII below). The river in the discharge area and downstream waters exceeds ecoregion norms for TP and NOx. Monthly operating reports (MORs) filed by the Franklin indicate that effluent loads from the WRF have increased substantially on an annual basis.

The WRF discharge dominates not only the river flow, but also the N and P entering the river during low-flow periods, based on a comparison (2009-2014) between Harpeth River sites upstream (45.7 meters or 50 yards) versus downstream (137.2 meters or 150 yards) from the WRF discharge site (City of Franklin river monitoring data and effluent data in monthly reports to TDEC). Upstream nutrient concentrations averaged 420 µg TP/L and 940 µg TN/L, whereas effluent concentrations averaged 1,480 µg TP/L and 1,830 µg TN/L. Downstream from the WRF discharge, TP and TN were 3.5-fold and ~2.0-fold higher, respectively, during low-flow periods when the effluent contributed 15% or more of the river flow. A healthy TN:TP ratio (by mass) for these waters is 12.1 based on reference conditions (see p.12 below), but the TN:TP ratio was 2.2 in the upstream site, 1.2 in the finished effluent, and 2.1 downstream from the WRF.

The treated effluent contributed nearly three-fourths (73%) of the P load to the affected segments of the mainstem Harpeth River when it comprised 15% of river discharge (duration, 52 days), increasing to 85% and 90% of the P load, respectively, when the effluent was at least 20% (duration, 32 days) or 25% (duration, 25 days) of river discharge. The effluent contributed 50% of the N load when it was 15% or more of river discharge, increasing to 63% and 68%, respectively, when the effluent was at least 20% and 25% of river flow.

Based on continuous monitoring studies during July-September (2001, 2002, 2003) which, importantly, captured the warmest period of the year when DO levels are usually lowest (Wetzel 2001), low DO concentrations at RMs 79.8 and 84.4 (above and below the Franklin WRF, respectively) characterize the night (dark) period of diel cycles (24-hour, commonly misnamed as "diurnal") in warm periods, with DO "sags" as low as ~0.5 mg/L and diel variations ("swings") up to 4.3 mg/L (U.S. EPA 2004). More recent USGS continuous monitoring data from mid-October through early November 2016 at RM 81.33 (Berry's Chapel) above the Franklin WRF show that, although well past the warmest period when DO conditions usually are most stressful for aquatic life, DO conditions during the dark period of diel cycles were at 4 to less than 5 mg/L – that is, below the state standard – one-third (33%) of the time. Downstream from the City of Franklin at RM 90.5, low DO characterized the river in dark portions of the diel cycle during 18 of 23 days, or 78% if the time.

High biomass of algae, which are fueled by the excessive nutrients and organic matter in the treated effluent, cause or contribute to low DO in violation of the state standard. The excessive biomass occurs because the nutrient pollution over-stimulates growth, analogous to too much fertilizer on a lawn causing overgrowth of weeds (Vallentyne 1974). The high nutrient regime tends to select for noxious, rapidly-growing species which are favored by high nutrient supplies, and can tolerate the associated adverse changes in environmental conditions. Diel DO swings above 3.5-4 mg/L have been shown to be detrimental to beneficial aquatic life (Heiskary and Markus 2003). Excessive algal growth, whether suspended or benthic, commonly causes low DO at night and large diel DO fluctuations in rivers, especially during warm periods (Sabater et al. 2000, Jones and Graziano 2013, Riley and Dodds 2013, and references therein). In contrast, growth of natural algal/plant species in reference or minimally impacted river systems is balanced rather than excessive, and does not cause violations of the DO standard or large diel DO swings that adversely impact aquatic life (Caraco and Cole 2002, Goodwin et al. 2008).

Weekly data have been collected for several years at three sites on the mainstem Harpeth River: Site 1 (latitude 35.942866, longitude -86.867046) is ~45.7 meters (50 yards) upstream from the WRF outfall (RM 85.2); Site 2 (latitude 35.944408, longitude -86.869593) is ~137.2 meters (150 yards) downstream from the WRF outfall (RM 85.2); and Site 3 (latitude 35.945406, longitude -86.871355) is downstream from the WRF at the Cotton Road Bridge, RM ~79.8. As an example of nutrient conditions, in 5 May through 25 August 2015 (n = 17 weekly sample collections), the TN:TP ratio at the three sites was 2.1 (Site 1), 1.8 (Site 2), and 1.9 (Site 3). Such low TN:TP ratios in river water generally result from wastewater treatment practices that emphasize N, but not P, removal (Heaton 1986, Jankowski et al. 2012), as has been done by the Franklin WRF managers. These extremely low TN:TP ratios differ markedly from the estimated TN:TP ratios that historically characterized natural (reference) conditions in the affected segments of the Harpeth River (see Section V below). The high nutrient supplies and the very low TN:TP ratio collectively are known to stimulate noxious algal growth (e.g. Smith 1983, Glibert et al. 2011) which, along with the oxygen-demanding organic materials discharged in the treated effluent, promotes low oxygen conditions and large diel DO variations that can stress and kill beneficial aquatic life (Burkholder and Glibert 2013, Heiskary et al. 2013 and references therein).

Overall, the available data show that the Harpeth River in the affected segments is characterized by both excessive N supplies and P supplies, and by a stoichiometric TN:TP ratio that has shifted far off-balance (see below). The shift is so extreme that the river has a "sewage signature" of N:P ratios of ~1-2 in the affected area of the Harpeth River. The TN:TP ratio is only a little higher (better) even upstream from the WRF, indicating substantial nutrient pollution in upper segments of the Harpeth River as well.

V. Reference N and P concentrations for the Harpeth River in sub-ecoregions 71h and 71i, versus TDEC's numeric translator

Natural sources of P to surface waters include weathering of soil parent materials, the atmosphere, riparian and terrestrial vegetation (e.g. leaf fall), and riverbank erosion (Holtan et al. 1988, Walling et al. 2008). These sources usually are very small (less than 0.9 pound of P per acre [0.1 kilogram or kg per hectare]) relative to anthropogenic sources (human-related sources, i.e., pollution from various human activities), as is the situation in the affected area of the Harpeth River based on comparison of reference conditions versus present-day nutrient data. Excessive P contamination from human-related sources can cause algae and plants to become P-saturated, stimulate overgrowth of algae and/or plants, select for certain noxious species that thrive in the polluted conditions, and drive the aquatic ecosystem out of balance (Burkholder and Glibert 2013).

a. Reference Conditions vs. TDEC's Numeric Translators for TP and NOx

Reference or minimally impacted waters are considered to have natural P concentrations – that is, P levels similar to the natural water quality prior to the influence of European settlement, population growth, and industrialization. The U.S. EPA (2000a) recommended use of the 75^{th} percentile of water quality data (past ~decade) for relatively pristine streams as reference or minimally impacted conditions. The Harpeth River lies within U.S. EPA Level III Aggregate Nutrient Ecoregion IX, more specifically, within Level IV sub-ecoregions 71h and71i (U.S. EPA 2000b, 2004). Sub-ecoregion 71h contains the Franklin WRF (Figure 1, modified from U.S. EPA 2004). U.S. EPA recommendations for true reference or minimally impacted streams in sub-ecoregions 71h and 71i (75^{th} percentile of data) are shown in Table 1 below.

In contrast, TDEC used the 90^{th} percentile of a portion of its reference stream data (Denton et al. 2001) to derive its numeric interpretations of the narrative standard for TP and NOx (nitrate + nitrite) (Table 1). The rationale used by TDEC is not science-based, explained here using Denton et al.'s (2001) example of sub-region 71i: First, TDEC considered its "reference" streams database (1996-2000) and its database from a short-term probabilistic study of a larger group of streams including "reference" sites (2000, n = 5 samples or less per site) (Denton et al. 2001, pp. 31-38). There was no clear difference between nutrient levels in TDEC's "reference streams" versus other streams in sub-ecoregion 71i, indicating that a major proportion of

Table1. Comparison of reference stream conditions recommended by the U.S. EPA versus those used by TDEC for sub-ecoregions 71h and 71i. Numbers in brackets are based on data from TDEC (Denton et al. 2001), if different than U.S. EPA recommended concentrations.

Sub-ecoregion	TP (µg/L)	NOx (µg/L	TDEC selected criteria
75th percentile (U.S. EPA) or [TDEC]			90th percentile of TDEC data
71h	60 [42]	605	180 (TP)
71i	160 [110]	610	920 (NOx)
			(applied to both sub-ecoregions)

TDEC's "reference" streams were substantially compromised by nutrient pollution. Thus, the reason given by TDEC for similar nutrient levels in its "reference" streams and other streams in sub-ecoregion 71i was that "even reference streams have been subjected to substantial alteration." Nevertheless, in ***non***-science-based action, TDEC continued to define streams that mostly (see below) were described as substantially compromised by nutrient pollution as "reference" streams.

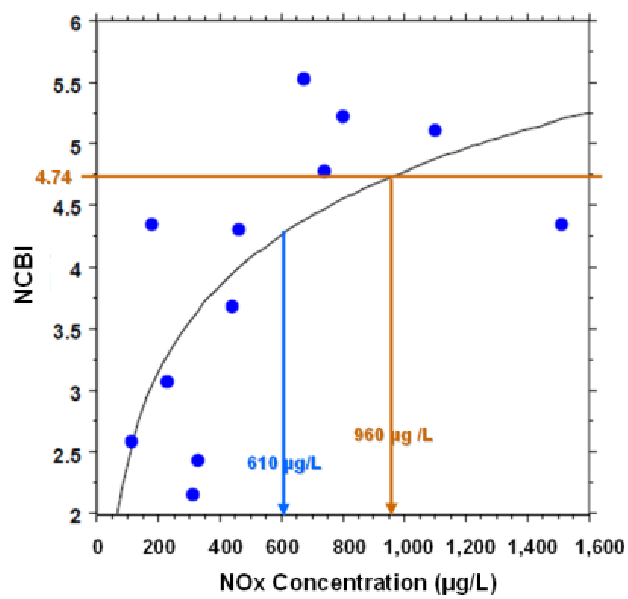
TDEC then selected the 90th percentile concentrations from its [non]-"reference" streams for interpreting the Tennessee narrative standard for nutrients. This decision was not made in an effort to protect the water quality of Tennessee streams. Instead, as explained by TDCE, the choice was made to err on the side of *less* protection (Denton et al. 2001, pp. 31-38), because TDEC worried that the 75th percentile might be "too protective." TDEC assessed the number of its "reference" streams that would have fallen within the 75th percentile nutrient levels, versus within the 90th percentile nutrient levels. Among the 50 "reference" streams, only 22% (11) would have been considered reference streams for NOx and TP based on the 75th percentile of nutrient data as recommended by the U.S. EPA (2000a). This supported TDEC's finding (above) that many of its "reference" streams had been substantially compromised. In contrast, 31 of the 50 streams "passed" as reference streams if defined using the 90th percentile of data. TDEC then compared the 75th versus 90th percentiles of nutrient data for its "reference" streams with proposed biological criteria. As would be expected, the 90th percentile of nutrient data were more lenient (less protective): Using the 90th percentile, the biological criteria would have been violated at 64% of the "reference" stations; using the 75th percentile of nutrient data, 78% of the stations would have had violations (Denton et al. 2001). From that comparison, TDEC decided that the 75th percentile of nutrient data was "too protective" for use as nutrient criteria because it captured more "reference" streams as being impacted than the biocriteria.

When attempting to find reference streams in developed or partly developed landscapes, the least disturbed streams that have the lowest nutrient concentrations logically should be selected. The 11 streams mentioned above which met the 75th percentile recommendation of the U.S. EPA were clearly the streams most unaffected (minimally impacted) by nutrient pollution. They clearly were distinct from the other 39 streams, and from other streams in the area in general, as reference streams should be. They should have been considered by TDEC as the only reference streams for sub-ecoregion 77i. It should be noted that the number of reference streams was not stipulated by TDEC for sub-ecoregion 77h, but an analysis by TDEC shown in Figure 2 (below) indicates that there were only 12 streams selected as reference streams for that sub-ecoregion.

Thus, TDEC used 50 streams as its "reference" conditions for sub-ecoregion 71i despite knowledge that most of those streams had been substantially altered by nutrient pollution, so much so that most of them did not even differ in TP and NOx levels from those in the other streams of the sub-ecoregion. Then, TDEC selected the 90th percentile of nutrient data from that compromised group rather than the more protective 75th percentile because, with circular "rationale," biocriteria that TDEC had developed using similar rationale supported use of the 90th percentile of nutrient data, illustrated as follows:

Denton et al. (2001) used sub-ecoregion 71h as an example for the observation that the 90th percentile of nutrient data roughly fit the 90th percentile for biocriteria in TDEC's "reference" streams. Two graphs were presented for two very similar biological indices, the Hilsenhoff biological index (HBI) and the North Carolina Biotic Index (NCBI). The latter index (data shown below in Figure 2) is simply a localized version of the HBI (Denton et al. 2001). Both indices are based on responses of aquatic macroinvertebrate insects to organic pollution; the higher the index, the lower (worse) the quality of the biological community. TDEC's proposed biocriteria for sub-ecoregion 71h indicated that the 90th percentile of the NCBI data for its "reference" streams was 4.74. Thus, a NCBI score of 4.74 was defined as TDEC's biological goal for sub-ecoregion 71h (Figure 2), corresponding to a NOx concentration of 960 μg/L (or 1,100 μg/L for the HBI). These corresponding NOx concentrations were similar to, although even higher than, the 90% numeric translator for NOx which had been selected by TDEC (920 μg/L; Table 1).

Figure 2. Relationship between NOx concentrations and the NCBI (North Carolina Biotic Index) in sub-ecoregion 77h. Modified from Denton et al. (2001) to show the draft TDEC biocriterion (NCBI score of 4.74) for sub-ecoregion 71h, and the corresponding NOx concentration (960 μg/L, similar to TDEC's 90th percentile-based, water-quality numeric translator for NOx (920 μg/L). The 75th percentile NOx concentration of 610 μg/L is also shown, which corresponds to a lower (higher-quality of biota) NCBI of 4.3.



Regarding TP, importantly, TDEC asserted that there was evidence of only weak relationships or no relationships between TP and sensitive biota (TDEC 2001 – p.36, and 2007 – pp. 16-18); that is, a cause-and-effect relationship between the number of sensitive biota species (Figure 3) and TP levels could not be detected. That assertion was not science-based: TDEC failed to conduct appropriate data analysis and, therefore, missed the fact that the EPT vs. TP data indicated a threshold for adverse effects on sensitive EPT taxa at a concentration of ~170 µg TP/L, slightly higher than the U.S. EPA (2004) recommendation for reference conditions in sub-ecoregion 71i (160 µg TP/L – Table 2 above). In other words, sensitive biota that historically occurred in the affected area of the Harpeth River were adversely affected by levels of TP just a little higher than the 75th percentile of data in reference streams in sub-ecoregion 71i. The most sensitive EPT taxa likely have been lost from these streams and, so, probably are not represented by data points in Figure 3. The U.S. EPA (2000a) has acknowledged the potential for such limitations in use of present-day land use conditions to derive reference stream water quality.

b. Evidence from TDEC's data for a Cause-and-Effect Relationship between TP Concentrations and Sensitive Biota

TDEC asserted that the 90th percentile of nutrient data was "more consistent" than the 75th percentile of data in predicting biological impairment, based on a circular argument, and that its approach:

> …meets Tennessee's desire to base nutrient guidelines on a cause and effect relationship [referring, evidently, to the biotic indices vs. NOx] rather than a purely statistical approach and is consistent with both Tennessee's and EPA's goals to protect designated uses…Tennessee feels that the regional nutrient guidelines at the 90th percentile in conjunction with documentation of macroinvertebrate assemblages is an effective way to assess nutrient impairment.

These assertions by TDEC are in error, first, because the use of recognized non-reference conditions (nutrient-"compromised" streams, as explained above) is inconsistent with U.S. EPA (2000a) guidance; that is, the use of the 90th percentile of such non-reference conditions is not sufficiently protective and, therefore, it is inconsistent with the goal to protect designated uses. Second, regarding TP, nutrient impairment of sensitive macroinvertebrate assemblages was not correctly assessed; instead, TDEC missed a classic cause-and-effect relationship shown by its stream data for a threshold response of sensitive biological metrics to TP. As a result, TDEC applied an inappropriate, simple linear regression analysis to the data to test for what in fact was evidence of a biological threshold concentration for TP levels. The data indicate that sensitive species of biota begin to decline above a threshold concentration of 160 µg TP/L.

Figure 3 (left graph, below) shows TDEC's (2001, p.23) attempt to assess whether the TP data influenced sensitive macroinvertebrates (Ephemeropteran, Plecopteran, and Trichopteran [EPT] taxa) in sub-ecoregion 71i. In non-science-based action (based on Wang et al. 2007, Weigel and Robertson 2007, Brenden et al. 2008, Evans-White et al. 2009, Sokal and Rolff 2012), TDEC imposed a linear analysis on nonlinear data. Figure 3 (right graph) shows the appropriate fit to the data. The data depict a classic nonlinear threshold response of sensitive biota to low levels of a stressor, similar to that of Stevenson et al. (2008 - see Figure 4 below). Such a response is what would be expected of the sensitive EPT metric in response to TP pollution.

It should be noted that this apparent threshold indicated by the EPT versus TP data, and recommended by the U.S. EPA for sub-ecoregion 71i, is higher than TP thresholds for streams in other areas, as illustrated by the following examples. The natural background P level in Illinois streams, known to drain watersheds with fertile loess soils, was estimated at ~70 µg TP/L (Royer

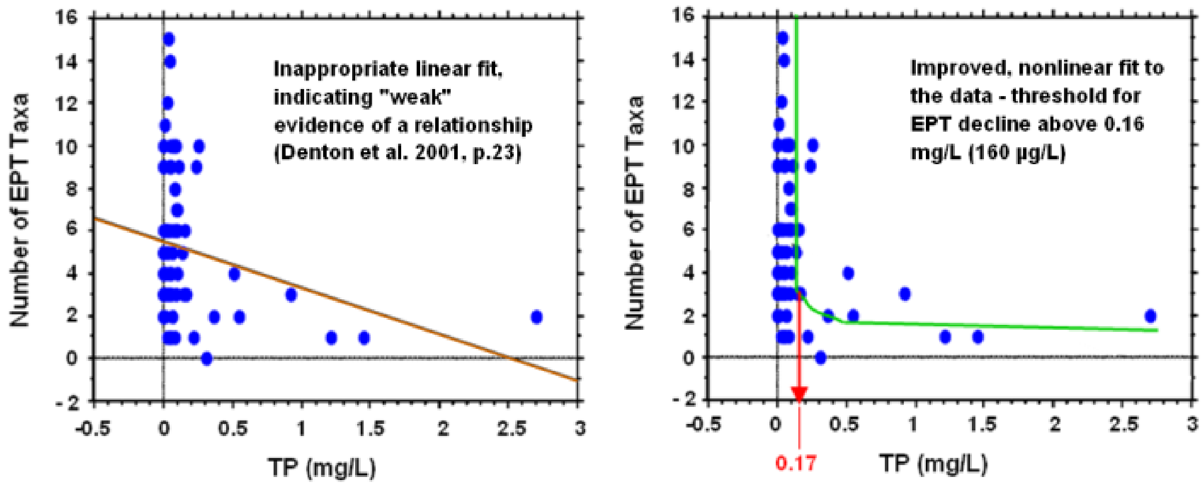


Figure 3. Relationship between TP concentration and the EPT metric (= sensitive aquatic macroinvertebrate insects including ephemeropterans - mayflies, plecopterans - stoneflies, and trichopterans - caddisflies): <u>Left</u> – Inappropriate fit of the data to a straight line. <u>Right</u> – The appropriate fit to the data, indicating a threshold response at ~170 µg TP/L (see Stevenson et al. 2008 and references therein – see Figure 4 below).

et al. 2008). In Wisconsin streams, the reference condition was reported to be ~64 µg TP/L (Robertson et al. 2008). Changepoints for benthic algal biomass (as chlorophyll *a*) in Ohio wadeable streams were estimated at 40 µg TP/L for protected (reference) streams, and 100 µg TP/L for minimally impacted (managed) streams (Miltner 2010). The higher threshold indicated for streams in sub-ecoregion 71i in comparison to these analyses of reference streams in other areas is expected, considering the more P-rich soils in the sub-ecoregion.

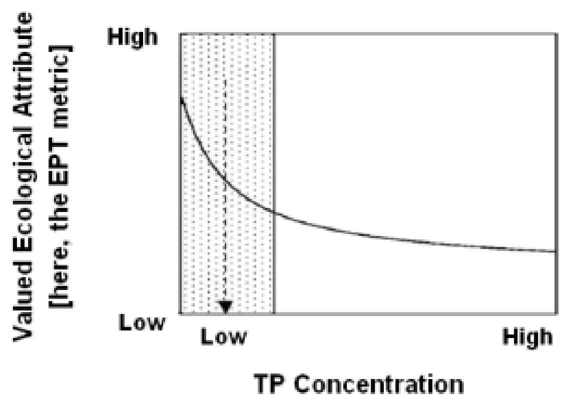


Figure 4. Development of stressor criteria when the potential response of a valued ecological attribute [here, the EPT metric] to stressors such as TP is nonlinear with strong sensitivity to changes at low levels of the stressor. The threshold (arrow) is at the point where the line just begins to curve. From Stevenson et al. (2008). Note the similar shape of this curve to that shown in Figure 3 (right graph) above. The more angular appearance of the curve in Figure 3 (right graph) suggests a more abrupt threshold stressor level (here, TP) for the decline of sensitive biota.

Also noteworthy is that TDEC (Denton et al. 2001, TDEC 2007) used a numeric translator for the narrative criteria of 180 µg/L, which was based on the 90th percentile of data for sub-ecoregion 71h as explained above. Yet, sub-ecoregion 71h is more sensitive to TP enrichment than sub-ecoregion 71i, based on the U.S. EPA (2000) analysis of the 75th percentile of (true) reference stream data (only 60 µg TP/L – see Table 1 above, and U.S. EPA 2004, p.20). Data were not provided by TDEC to enable assessment of the relationship between EPT taxa and TP for sub-ecoregion 71h. TDEC set the same TP numeric translator for both sub-ecoregions based on the following explanation:

> [TDEC] used standard statistical methods to identify differences in nutrient concentrations between sub-ecoregions….where differences between sub-ecoregions were not significant, it was considered advantageous to aggregate sub-ecoregions…(Denton 2001, p.47).

While there may be few differences *now* in nutrient concentrations for sub-ecoregions 71h and 71i, TDEC's entire effort to develop numeric translators to interpret the narrative criteria for nutrients was confounded by its use of "substantially compromised" nutrient-polluted streams as "reference" sites. Reference stream data for sub-ecoregion 71h (75th percentile of real reference streams, as defined by the U.S. EPA) indicate that the Harpeth River in the vicinity of the Franklin WRF was once characterized by much lower TP concentrations than were characteristic of sub-ecoregion 71i.

c. Reference or minimally impacted NOx condition for sub-ecoregion 71i

Reference NOx conditions for sub-ecoregion 71i, similarly, should follow U.S. EPA recommendations for use of the 75th percentile of data. Information for EPT taxa versus NOx concentrations was not available from TDEC (Denton 2001, TDEC 2007) for the two sub-ecoregions. Moreover, the data that were shown for the relationship between two biotic indices and NOx concentrations in sub-ecoregion 71h, explained above, are not amenable to similar analysis as the number of EPT taxa. Analogously as for TP, the natural or historic background (true reference or minimally impacted) NOx condition in these sub-ecoregions would have been the 75th percentile concentration recommended by the U.S. EPA, 610 µg NOx/L. As shown in Table 1 above, the two sub-ecoregions were very close in the 75th percentile of data from true reference conditions according to the U.S. EPA (605 versus 610 µg NOx/L). Overall, based on the available data and comparison with the science literature, reference or minimally impacted conditions for streams in sub-ecoregion 71i are 160 µg TP/L and 610 µg NOx/L. These values should be considered as targets for desired conditions in the affected segments of the Harpeth River. TDEC's numeric translator of 180 µg TP/L for these waters is fairly close to the threshold indicated by the EPT data, but the agency's numeric translator for NOx is much higher than supported by the above assessment of reference conditions.

Note that the NOx concentrations should not be used to assess reference conditions for N:P ratios; rather, TN:TP ratio should be used. The 75th percentile TN:TP ratios for reference conditions in sub-ecoregions 71h and 71i were derived from U.S. EPA (2004) (Table 2). The 12:1 ratio (mass basis), describing natural conditions in sub-ecoregion 71h, is considered to indicate P-limiting conditions (Dillon and Rigler 1974), whereas the lower ratio of 4.7 indicates N-limiting conditions historically in sub-ecoregion 71i – that is, actual limiting conditions, far different from the present-day excessive TP and NOx supplies and the strongly shifted, very low TN:TP ratios in surface waters of both sub-ecoregions which are much less than 3:1 (mass ratio – see p.6).

VI. Re-establishment of Nutrient-Limited Conditions to Prevent Noxious Algal Growth in the Affected Area of the Harpeth River

Reference levels of 170 µg TP/L and 610 µg NOx/L indicate naturally mesotrophic/eutrophic conditions. Research on streams and rivers worldwide has indicated that P is at limiting levels –

Table 2. The 75th percentile of true reference stream conditions recommended by the U.S. EPA for setting numeric nutrient criteria in sub-ecoregions 71h and 71i (U.S. EPA 2004, p. 20); the corresponding TN:TP ratios (by mass); and the optimum ratio for microalgal growth according to the Redfield ratio (see p.17 of this assessment). Note that the reference conditions for the sub-ecoregions are considered here as a more important target than the Redfield ratio, which is generalized across aquatic ecosystems.

Sub-ecoregion	TN (µg/L)	TP (µg/L)	TN:TP (by mass)	Redfield optimum for algae (p.17)
71h	728	60	12.1	7:1 (by mass)
71i	755	170	4.7	

that is, P strongly influences suspended algal biomass – until concentrations reach ~200-250 µg TP/L (Van Nieuwenhuyse and Jones 1996; Figure 5). At TP levels below ~250 µg/L in the Van Nieuwenhuyse and Jones (1996) study, TP controlled algal biomass such that chlorophyll *a* increased with increasing P. Above ~250 µg TP/L, the algae became P-saturated and there was no apparent stimulatory effect of adding more P. That is, algal biomass will not increase with increasing TP concentration above ~250 µg TP/L. A similar analysis is not available for TN or NOx, so the following analysis emphasizes TP. Nevertheless, reference conditions for NOx are also considered to have been at limiting levels, that is, at levels which limited the growth of the natural algal assemblage.

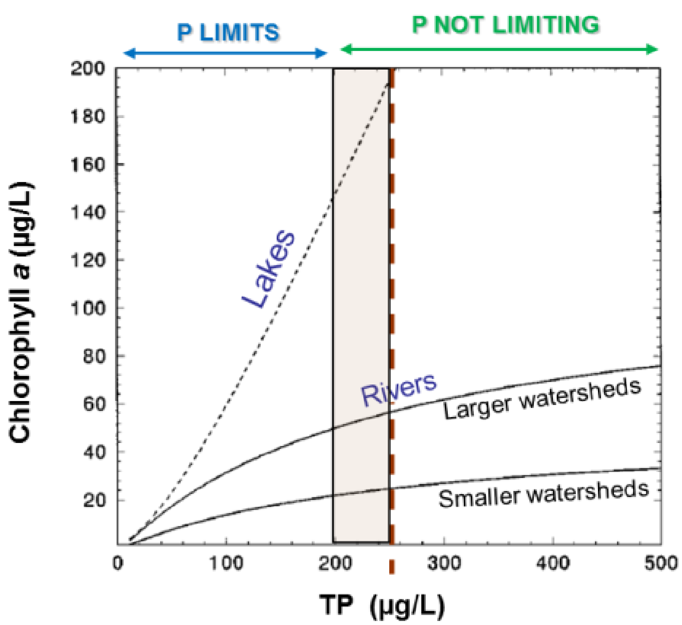


Figure 5. The TP–suspended microalgal chlorophyll relationship in temperate streams (rivers) and lakes (Van Nieuwenhuyse and Jones 1996). Regression analysis of data from 292 temperate streams draining smaller and larger watersheds (100 and 100,000 km^2 area, respectively) showed that summer mean chlorophyll levels were strongly curvilinearly related to summer mean TP concentrations at TP levels less than ~200-250 µg/L. Solid and dashed curves show predicted chlorophyll concentrations in streams and P-limited lakes, respectively. The gray area indicates the TP range below which algal biomass (here, represented by chlorophyll *a*) is controlled (limited) by the TP concentration. At higher TP, the curves become increasingly flat; that is, an incremental increase in TP results in little or no increase in chlorophyll *a* because P is too high to control algal growth.

The Harpeth River in the affected area is characterized by excessive TP concentrations and, thus, has been pushed out of ecosystem balance into a TP range where the algae, including seasonally abundant noxious forms that replaced naturally abundant taxa, are P-saturated so that P is no longer controlling their growth. Noxious algal blooms (both benthic and planktonic) in rivers are sporadic and often ephemeral (exemplified by the remnant *Microcystis* bloom mentioned above) and, therefore, easily missed by infrequent sampling (Whitton 1975, Wetzel 2001). *There has been remarkably little algal sampling in the Harpeth River* within sub-ecoregions 71h and 71i. Noxious blooms doubtless have occurred but have not been documented due to *extremely poor testing* in nearly all years of the past decades. Compounding this problem, the river is saturated with N and P. The lack of an apparent stimulatory effect on algal growth of adding more P in rivers such as the affected area of the Harpeth has led some people to mistakenly assert that N or other factors control algal biomass, and P is unimportant. Such an assertion misses the central point: These systems already have been degraded by excessive nutrient contamination. Their P levels would need to be reduced to less than ~200 µg TP/L before P would noticeably, visually limit or control the suspended algal biomass. Note that the reference condition recommended from this assessment (170 µg TP/L) falls well below the P-replete level of ~200 µg TP/L, which also would provide a margin of safety. TDEC's (2001, 2007) recommended numeric nutrient translator of 180 µg TP/L, if achieved for the affected area of the Harpeth River, would also bring the system back into P-limited state.

The graph in Figure 5 shows a "gray area," or range where P saturation occurs, at 200-250 µg/L. The above writing recommends reduction of TP to less than 200 µg/L, rather than less than 250 µg/L, for two reasons: <u>First</u>, nearly all of the P in the treated effluent is *phosphate*, the form of P that is rapidly available to fuel algal growth (Reynolds and Davies 2001, Wetzel 2001, Peters and Bergmann 2011). Aquatic ecosystems that receive high P enrichment mostly from sewage are *much more vulnerable* to the adverse impacts of P pollution, because ~80 to 95% of the P in treated sewage is phosphate, the form that is directly available for algal/plant uptake (Young et al. 1982, Ekholm and Krogerus 2003, Millier and Hooda 2011). For that reason, wastewater discharges are ranked as the highest P source in "ecological relevance," that is, in terms of composition (solubility and concentration) and patterns of delivery (mode and timing) (Withers and Jarvie 2008). The P supplies in sewage-affected systems are much more potent in causing adverse impacts. From a study of north temperate rivers, for example, Jarvie et al. (2006) concluded that "point sources of P provide a greater risk for river eutrophication than diffuse sources from agricultural land, even for rural areas with high agricultural P losses." Risk of increased impacts on downstream segments can be greater as well: Large dissolved phosphate loads from treated sewage can saturate stream communities and depress nutrient retention efficiency, in comparison to streams of similar size with lower phosphate inputs (Marti et al. 2004). Surface waters dominated by P inputs from point sources have been shown to need strengthened protection because of their enhanced vulnerability to high inputs of bioavailable P (Bowes et al. 2010, Neal et al. 2010). <u>Second</u>, the TP load from the Franklin WRF will continue to include stormwater runoff as well as sewage. Stormwater runoff is much more sporadic, variable, and difficult to control than the P in sewage. Therefore, a modest margin of safety is added by reducing the TP contributed by the WRF to less than 200 µg/L rather than less than 250 µg/L.

The affected area of the Harpeth River can develop noxious biomass of suspended microalgae in low-flow periods as noted above, but more typically sustains major growth of benthic filamentous algae, based on photographic documentation provided by the HRWA. Aside from that qualitative information and anecdotal descriptions of periodic thick benthic algal growth, however, information is not available about the amount of benthic algal biomass per unit stream bottom area that forms periphyton "blooms" under conducive conditions. Suspended microalgae are immersed in water-column nutrients, whereas benthic algae commonly form a thick biofilm layer that impedes the movement of nutrients (Burkholder 1996). Longer filaments can have a competitive advantage over smaller unicellular organisms within the biofilm (Burkholder et al. 1990, Burkholder 1996, Hill et al. 2009). Benthic filamentous green algae (chlorophytes) and cyanobacteria, which I have documented in the affected area of the Harpeth River based on photographs and samples provided by the HWRA, are well-known responders to nutrient pollution from sewage (Burkholder 2009, Lapointe et al. in press).

Limiting P inputs from unnatural sources such as the treated effluent from the Franklin WRF can prevent violations of the DO and Offensive Conditions standards, <u>only</u> <u>if</u> P levels are reduced to limiting levels, that is, below the non-limiting threshold of ~200 µg TP/L. Because the available data for the Harpeth River in sub-ecoregions 71h and 71i indicate that the river is P-saturated, P supplies must be reduced in order to protect these waters from excessive algal biomass and DO violations. P reductions have been effective in reducing the algal blooms and/or higher plant overgrowth that drive eutrophication impacts in rivers worldwide – if, and only if, the reductions push the systems back into a P-limited condition (Van Nieuwenhuyse and Jones 1996, Bowes et al. 2007, Elser et al. 2007). Improvements in river ecology have occurred from reduced P concentrations, mostly achieved through stricter sewage (point source) controls (Bowes et al. 2011 and references therein). In the upper Midwest, a recent example of success was reported by the Minnesota Pollution Control Agency (MPCA) for the Minnesota River, which is impacted by one of the urban population centers in the U.S., the Minneapolis-St. Paul metropolitan area. The Minnesota River had been described as one of Minnesota's dirtiest waterways (Rook 2012). A ~50% reduction in P from sewage, achieved after a decade-long, costly effort to improve wastewater. This high-quality treatment plant discharges also significantly improved DO levels. Previously the river had been known for excessive P enrichment from sewage and major fish kills during low-flow summer conditions. The MPCA Commissioner stated, "It's often difficult to show environmental gains because it can take decades to show significant progress….This happy discovery really emphasizes that environmental advances are long-term and the resources dedicated are worth it."

VII. The Importance of Re-Establishing Historic N:P Ratios As Well As N:P Supplies

Nutrient stoichiometry refers to changes in the relative proportions of critical nutrients available in the water, relative to differences in the allocation of these elements in organisms (Burkholder and Glibert 2013). Nutrient stoichiometry controls the relative availability of critical elements such as the essential nutrients for algal growth, N and P. The Harpeth River in sub-ecoregions 71h and 71i is not only over-enriched with N and P, but is in a trophic state of stoichiometric imbalance, which is worse than simply eutrophic (nutrient-rich). Stoichiometric imbalance refers to a unique, forced trophic state in an aquatic ecosystem that develops when one nutrient (generally N <u>or</u> P), is altered either due to enrichment from human activities or management-related nutrient control (Burkholder and Glibert 2013).

At the level of community dynamics and structure, changes in nutrient ratios, especially the relative proportions of N and P supplies, alter metabolism, species composition, and food webs (Glibert et al. 2011, Burkholder and Glibert 2013). The changes are largely translated from algae at the base of the food web to higher trophic levels through food quality. Altered N:P ratios from excessive nutrient pollution generally shift the algal assemblage from dominance by beneficial, desirable taxa to dominance by noxious bloom formers such as cyanobacteria and various filamentous forms. This change in food quality at the base of the food web leads to undesirable changes in zooplankton taxa and, eventually, undesirable changes in the fish community as well. Thus, water-column N:P ratios are important in controlling the structure of the whole food web through the abundance of beneficial versus noxious algae at the base of it.

Historic use of nutrient ratios was to infer whether N or P was the primary limiting nutrient, that is, the nutrient that algae ran out of first. Nutrients are essential for algal growth and survival. In freshwaters, P historically was least abundant among the nutrients needed in large quantity (macronutrients) by algae. Therefore, it was the first element that became limiting to algal growth in many freshwater systems, with N secondary in importance. Total phosphorus is usually used to evaluate freshwaters for P limitation, rather than inorganic P (phosphate) which is the form most often used by algae, because algae commonly take up and store more P than they need in a process called luxury consumption. In "natural" systems or surface waters that are affected by minimal P inputs related to human activities, phosphate ions are rapidly taken up by algae as fast as they are released, sometimes within seconds, so phosphate concentrations typically are low (less than 5 µg/L) – yet a phosphate measurement only offers a glimpse or brief snapshot of the P actually available for algal growth. In marked contrast, systems that are strongly affected by nutrient pollution can have phosphate concentrations from about 500 to 2,000 µg/L (0.5 to 2 mg/L) or more. That description characterizes the Harpeth River in sub-ecoregions 71h and 71i. Inorganic N, especially nitrate and ammonia and its ionized form, ammonium, are directly taken up by algae (and some organic forms can also be consumed).

Although scientists still evaluate surface waters in terms of N or P *limitation* in this way, these key nutrients are no longer limiting in many freshwaters. Instead, it is the ***excess*** of N and P loads that is at issue in present-day waters, not the lack of supply (Glibert et al. 2011). In the Harpeth River (sub-ecoregions 77h and 77i), managers' mistaken view that N rather than P is "limiting algal growth" is analogous to the following situation: A man sits down to have dinner at a restaurant. The server apologetically informs the man that 200 steaks are available for him to eat, but only 150 potatoes. Which will the man run out of first, steaks or potatoes? This question is nonsensical. Obviously, one person cannot consume 200 steaks or 150 potatoes at a dinner – the supplies of each are so high that they are at saturating (non-limiting) levels. The draft permit for the Franklin WRF controls N much more than P, but both N and P supplies will still be *extreme* in comparison to what the natural algal assemblage needs. The river has been driven out of balance and the high N and P supplies, added in unhealthy proportions, will increasingly encourage noxious algal overgrowth when other conditions (e.g., temperature, light) are conducive (assuming that an appropriate sampling frequency is applied that enables bloom detection).

The TN:TP ratios in the affected segments of the Harpeth River vary from about 1.2 to 2.2, a range known as a "sewage signature," far from the much higher N:P ratio that once characterized the natural, healthy system as explained above. Yet, TDEC has designed the draft permit for the

WRF to emphasize control of N over P based on the irrational premise that "N is limiting" in the Harpeth River. The draft permit reflects no understanding by the writers of the critical importance of N:P stoichiometric balance in aquatic ecosystems, or of the fact that N:P ratios can only be used to interpret nutrient *limitation* when N or P are in *limited supply* (that is, limitation should only be invoked when something is limiting). Like the analogy of the overabundance of steaks and potatoes nonsensically suggested as "limiting" dinner for a restaurant diner, nutrient limitation should not be invoked in this river. Extreme supplies of both nutrients and stoichiometric imbalance are, instead, the reality, and that combination of factors has been shown repeatedly in the peer-reviewed science literature to promote noxious algal blooms (Glibert et al. 2011, Burkholder and Glibert 2013 and references therein).

Noxious planktonic and benthic cyanobacteria are especially adept at thriving in *low N:P* waters, in part due to the ability of some species to fix nitrogen gas into ammonia (Smith 1983, Glibert and Burkholder 2011, and references therein). Nearly all cyanobacterial taxa tested thus far have been found to produce an insidious, potent toxin called β-N-methylamino-L-alanine (BMAA), which has recently been linked to Parkinson's disease and Alzheimer's-like symptoms in humans (Cox et al. 2005, Holtcamp 2012 and references therein). Many other cyanotoxins are produced by a large group of cyanobacteria species, and these toxins can cause food web dysfunction and liver disease in fish (Burkholder 2002, 2009 and references therein). In addition, cyanotoxins can cause gastrointestinal diseases, neurological diseases, liver failure, and even death in humans (Burkholder 2009 and references therein). In contrast, while green algae (chlorophytes) are generally considered beneficial to aquatic life (Graham et al. 2016), they can be stimulated by nutrient pollution to form thick, massive overgrowths, leading to oxygen depletion for beneficial animals such as fish at night, major diel oxygen swings that can stress and kill beneficial animals, and degraded habitat (Burkholder 2009, Burkholder and Glibert 2013, Lapointe et al. in press). Chlorophytes in freshwater systems are not known to produce toxins, but certain noxious filamentous green algal taxa tend to have very high N requirements and are well known to proliferate in river systems downstream from sewage effluent discharges rich in N relative to P, that is, at *high N:P* ratios *if the supplies are also excessive* in comparison to the N and P supplies characteristic of natural conditions (Perrin et al. 1988, Benke and Cushing 2005, Burkholder 2009).

Systems that are manipulated by adding mostly N ***or*** mostly P are <u>not</u> simply eutrophic. Application of traditional eutrophication indices will lead to an erroneous conclusion that such systems are not nutrient stressed when, in reality, they have been forced into a state of stoichiometric imbalance. The N:P supply ratios of these systems have shifted markedly from natural conditions for algal growth, often referred to as Redfield proportions or the Redfield ratio (Redfield 1958). The Redfield ratio includes other essential elements for making the organic substances that form algal cells, but here the focus is on N and P: The atomic (molar basis) N:P Redfield ratio is 16N : 1P, and whereas the mass ratio (µg to µg or mg to mg) is 7N : 1P (Harris 1986). This assessment has reported TN:TP ratios on a mass basis. Rapidly growing algae have N and P uptake ratios that can closely follow the Redfield ratio, expected since N and P cycles are closely related to biological processes. Thus, N and P ratios in the algae can reflect N and P processing in the habitat. Although Redfield ratios are widely applied as "the" only ratio used by healthy algal cells in natural ecosystems, nature is more complicated, so that the optimum ratio for algal growth can vary somewhat depending on the species and the growth rate. At maximum growth rate, the N:P ratio converges to a more narrowly defined range that differs depending on the species (Hillebrand et al. 2013 and references therein).

The U.S. EPA (2015) has recognized that restoration of waters which have been driven far out of balance in their nutrient stoichiometry and their nutrient supplies will require reducing **both** P and N pollution (that is, N and P co-management) toward re-establishing natural (reference) N:P ratios. Unfortunately, managers have often emphasized control of one nutrient while minimizing control of the other, as reflected by the draft permit for the Franklin WRF – its NPDES permits have emphasized control of N and minimized control of P. During the summer season when noxious algal growth is often maximal, the previous (present) permit had limits of 5 mg TN/L and 0.4 mg ammonia-N/L, but the limit for TP was also 5 mg/L, obviously effecting a nearly 1:1 ratio of TN:TP.

VIII. WQBELs for N and P Are Needed to Protect the Designated Uses of the Affected Segments of the Harpeth River

Consistent with U.S. EPA regulations (40 CFR 122.4(d)(1)(i)), TDEC is required to make a "reasonable potential" determination for all point sources as to whether NPDES discharges have reasonable potential to cause or contribute to a water quality impairment by exceeding calculated WQBELs. The highest possible effluent TP and NOx concentrations (or loads) are compared with the desired (target) concentrations in the receiving water, and if they exceed the target concentrations, reasonable potential is concluded and a WQBEL is needed. As a straightforward, simplified approach (Hair and Currey 2015b), a protective numeric TP effluent limit for NPDES permits can be calculated using a mass-balance (conservation of mass) equation and an assumption of rapid and complete mixing:

$$\text{Mass} = \text{Flow (Q, mgd or cfs)} \times \text{Pollutant concentration (C, } \mu\text{g/L)}$$

Point source WQBELs for TTP and TNOx added to rivers and streams are calculated by solving for C_d (Figure 6) as follows:

$$\text{TTP or TNOx} = \frac{(Q_d)(C_d) + (Q_s)(C_s)}{Q_r},$$

where

C_s = critical upstream TP or NOx concentration (units, mg/L or µg/L - here, taken as the average concentration at Site #1 during May-August 2015). The value for TP is **494 µg TP/L** as explained above (see p.13). The NOx value, **570 µg NOx/L**, was estimated from available TN concentrations, assuming that NOx is ~55% of the average TN in the same period (1,037 µg TN/L; average TN:TP ratio was 2.1). The 55% value was taken from the average NOx-to-calculated TN ratio for level III ecosystem 71 given in U.S. EPA (2000b).

Q_s = critical upstream flow (units, mgd or cfs above the discharge point); e.g., the 7Q10, the 7-day average, once-in-10-years low flow = **0.54 mgd** for the Harpeth River above the Franklin WRF discharge point);

C_d = critical effluent TP or NOx concentration (units, mg/L or µg/L), the WQBEL;

Q_d = discharge effluent flow (the annual average design flow; or the maximum demonstrated monthly average flow; units, million gallons per day, mgd (**16 mgd**);

TTP or TNOx = the targeted TP or NOx concentration in the receiving water (units, µg/L), taken as reference conditions (**170 µg TP/L** [this analysis] or **180 µg TP/L** [TDEC], as both values are less than the cutoff value for limitation, 200 µg/L; **NOx = 610 µg/L** [this analysis] vs. **920 µg NOx/L** [TDEC], with the latter target excessive and, therefore, not recommended for use; and

Q_r = receiving water minimum flow (the average minimum 7Q10 flow = the resultant in-stream flow after discharge (units, mgd or cfs; $Q_r = Q_s + Q_d$, or **16.54 mgd**.

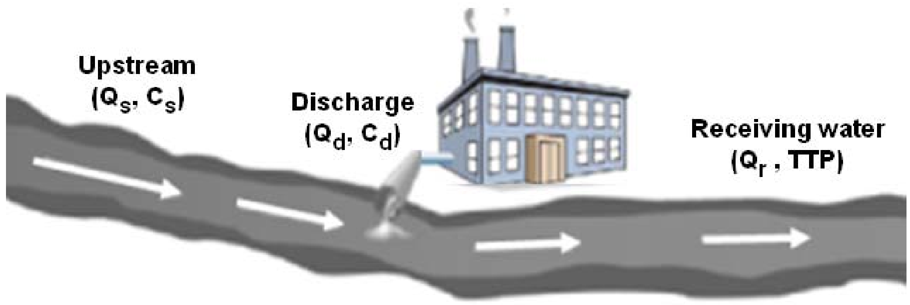


Figure 6. Diagram showing the parameters used to calculate TP and NOx WQBELs for the Franklin WRF. Modified from Hair and Currey (2015b). This approach assumes rapid, complete mixing, thus avoiding a need for steady state modeling or inclusion of dilution or mixing zones. The state of Wisconsin also uses this approach for calculating TP WQBELs (see s. NR 106.06(4)(b) Wisc. Admin. Code).

The above mass-balance equation could be used to assess whether a given discharge would cause, have reasonable potential to cause, or contribute to an excursion above the TTP.

Applying the above information to the equation on p.17 yields the following WQBELs. The recommended WQBELs, based on actual reference conditions, are given first for each nutrient; the second WQBEL for TP and for NOx was derived using TDEC's non-reference "numeric translators" for TP and NOx.

170 µg TP/L = (16 mgd)(C_d) + (0.54 mgd)(494 µg TP/L) /16.54 mgd; WQBEL = 159 µg TP/L (~0.16 mg/L)
or
180 µg TP/L = (16 mgd)(C_d) + (0.54 mgd)(494 µg TP/L) /16.54 mgd; WQBEL = 169 µg TP/L (~0.17 mg/L)

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610 µg NOx/L = (16 mgd)(C_d) + (0.54 mgd)(570 µg NOx/L) /16.54 mgd; WQBEL = 611 µg NOx/L (~0.6 mg/L)
or
920 µg NOx/L = (16 mgd)(C_d) + (0.54 mgd)(570 µg NOx/L) /16.54 mgd; WQBEL = 932 µg NOx/L (~0.93 mg/L)

Either WQBEL for TP that was developed from actual reference conditions, rather than from TDEC's excessive "nutrient translators," can be accomplished with biological P removal technology. The existing facility could be operated to discharge P concentrations below 0.3 mg/L by adding P precipitating chemicals such as ferric chloride and alum (e.g., U.S. EPA 2007, Tetra Tech 2013). Biological P removal (BPR) could be maximized by not reducing the biochemical oxygen demand of the raw influent wastewater by primary sedimentation, or by including a fermentation step for the settled sludge in order to produce volatile fatty acids needed for BPR. The latter process can reliably produce effluent soluble P concentrations below 0.1 mg/L. The U.S. EPA (2007) published a fact sheet on biological nutrient removal technologies and costs, which indicated that effluent P concentrations could be removed down to 0.1 mg/L with technologies that existed eight years ago. Tetra Tech (2013) has published a guide for P removal down to 0.1 mg/L as well.

Removal of NOx down to 1-2 mg/L was described by the U.S. EPA (2007) and Water Quality Treatment Solutions, Inc. (2013) through existing BNR technology. Effluent concentrations of NOx were in the range of ~0.95 to 1.4 mg/L during the 2015 growing season, very close to the nutrient translator suggested by TDEC. The denitrification filter of the existing facility could be used to move the NOx removal closer to 0.6 mg/L. Such action would not be supported by Randall (2016) unless significant P reduction was also accomplished, which is in accord with this assessment.

Recommendations

The following corrective actions are needed to strengthen the draft permit so that the Franklin WRF discharge protects the designated used of the affected area of the Harpeth River for fish and aquatic life, and moves the system toward restoration of N- and P-limiting conditions.

- ✓ The numeric translators developed by TDEC should be reduced to reflect reference conditions. It is obvious that the “reference” streams selected by TDEC are not science-based and do not reflect reference or minimally impacted conditions, because their nutrient concentrations do not differ from concentrations in the other streams of sub-ecoregions 71h and 71i, especially NOx. Based on this assessment, the reference conditions used for numeric translators of the narrative criterion should be 170 μg TP/L (similar to TDEC’s numeric translator of 180 μg TP/L), and 610 μg NOx/L (much lower than TDEC’s value of 920 μg/L).

- ✓ The draft permit should include an assessment of the available technologies for removal of TP and NOx. The design of the draft permit suggests that TDEC invoked “best professional judgment” without considering this information.

- ✓ Science-based WQBELs for TP and NOx should be developed for setting the final permit levels for these pollutants, based on target concentrations in the receiving river water of 170-180 μg TP/L and 610 μg NOx/L. This analysis suggests that the WQBEL for TP in the summer season should be 160-170 μg TP/L (0.16 to 0.17 mg/L), and the WQBEL for NOx should be 610 μg NOx/L (0.61 mg/L). Based on the available information on river water quality and Franklin WRF design, these WQBELs for TP and NOx can be achieved through BNR technology which is already available or planned at the WRF.

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