Appendix A-5. A Method to Identify Total Phosphorus as a Cause of Aquatic Life Impairment in Connecticut Freshwater High Gradient Non-Tidal Streams

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INTRODUCTION

Cultural eutrophication is a serious threat to water quality in the State of Connecticut, USA (CT) (Becker, 2014; CASE, 2014) and is one of the most pressing water quality issues facing the nation (U.S. EPA, 2017). The United States Environmental Protection Agency (U.S. EPA) has identified cultural eutrophication as one of the primary factors resulting in impairment of United States surface waters and encourages all states and tribes to develop strategies to reduce nutrient (nitrogen and phosphorus) pollution that address impairments caused by cultural eutrophication (Grumbles, 2007; Stoner, 2011; U.S. EPA, 2017, 2000). Anthropogenic phosphorus is a major driver of cultural eutrophication in rivers and streams, leading to numerous water quality impairments, including detrimental shifts in biological communities. The CT Department of Energy and Environmental Protection (CT DEEP) is proposing a new methodology to identify total phosphorus (TP) as a cause of aquatic life impairment in high gradient, non-tidal, wadeable rivers and streams using a weight of evidence approach. The approach draws on previous research conducted on phosphorus in CT and follows recommendations in the phosphorus strategy report pursuant to CT public act 12-155 to use a stressor response model with multiple response parameters to establish phosphorus impairment (PA 12-155 Coordinating Committee, 2017). The methodology will be used to identify phosphorus as cause of aquatic life impairments for Connecticut's 2018 Integrated (305b and 303d) Water Quality Report to Congress as required under the Clean Water Act.

METHOD

This method only applies to non-tidal, high gradient, wadeable rivers and streams. The methodology is limited to these areas because CT DEEP biological monitoring protocols for diatoms is currently only conducted in these rivers and streams (Becker, 2017). The weight of evidence approach includes using a combination of three measures: stream aquatic life assessments, TP concentrations, and diatom TP tolerance metrics (Table 1 and 2). If an overall aquatic life impairment is established in a stream, TP concentrations and diatom TP tolerance metrics for that stream are evaluated and assigned a qualitative weight (Table 1). Qualitative weights were assigned to each piece of evidence using U.S. EPA's stressor identification and weight of evidence guidance to determine whether a piece of evidence "somewhat" (+), "strongly" (++) or "convincingly" (+++) supports or weakens the case for a candidate cause (Cormier et al., 2000; Suter II & Cormier, 2011; Suter II, 2016). TP is added as a cause of aquatic life impairment to a given waterbody segment on the 303(d) list of impaired waterbodies based on the combined weight of the evidence (Table 1). In order for TP to be listed as a cause, the combined evidence must consistently and "convincingly" (+++) support the case (Table 2). For this to occur, a site must be identified as impaired for overall aquatic life and both the TP concentration and inferred diatom TP tolerance classification threshold must be met (Table 2).

Table 1: Identified measures providing supporting evidence that TP is a cause of aquatic life impairment. + symbols indicate supporting evidence. - symbols indicate weakening evidence. The number of symbols (e.g. ++ or --) indicates the strength of evidence as defined below the table.

Measure	Reason	Threshold	Above	Below
TP Concentration Threshold	Sensitive taxa steeply decline. Tolerant taxa increase.	MID - HIGH (> 0.04 mg/L)	+ (++)	- (--)
Inferred Diatom TP Tolerance Classification	Inferred high TP conditions using biology that capture conditions over a longer time period than a single grab sample.	Inferred HIGH	++	--

+++, - - -	Convincingly supports or weakens
++, - -	Strongly supports or weakens
+, -	Somewhat supports or weakens
0	No effect (neutral or ambiguous)
NE	No evidence

The first measure is a determination of overall aquatic life impairment using established methods in the CT CALM (CT DEEP, 2016). CT DEEP uses a combination of methods to assess aquatic life and determine overall impairment primarily relying on water chemistry, macroinvertebrates and fish. This measure provides evidence of aquatic life impairment, but not enough evidence to add TP as a cause.

The second measure is a TP concentration threshold. Smucker et al. (2013) identified ecologically relevant TP concentration thresholds in CT streams using a variety of statistics to characterize ecological responses. The CT Water Quality Standards note biological impairment along the biological condition gradient when major changes in structure of the biotic community and moderate changes in ecosystem function as such that the sensitive taxa are markedly diminished. A threshold concentration of 0.04 mg/L is used because this is the point in which Smucker et al. (2013) observed major changes to ecological community structure where sensitive diatoms steeply declined and tolerant diatoms increased. Grab samples collected in streams with concentrations of TP above this threshold provide some evidence (+) that TP may be a cause of impairment, however do not provide a direct biological measurement. The number of samples and the magnitude of the concentration are considered when determining whether the TP concentration data "somewhat" (+) or "strongly" (++) support or weaken the case for TP impairment.

The third measure is an inferred TP stream condition based on diatom species indicators. Becker et al. (2018) identified diatom species in CT that were either sensitive or tolerant of high TP conditions. These tolerance values were combined into metrics which discriminated well between high and low phosphorus concentrations. These biological metrics are used to infer TP conditions in a stream. Biological inference metrics are useful for identifying biological impairments due to pollutants that do not lend themselves to conventional toxicity testing, like phosphorus, that vary dynamically across space and time (CASE, 2014; Karr and Chu, 2000). Biota integrate past disturbances occurring over their lifespan and can therefore provide a more informative measure of environmental conditions over this time period (Karr et al., 1986). Inferring environmental conditions from biological observations provides a biologically relevant measure of environmental conditions at a site (Karr, 2006). Thus, these inferences provide a complementary line of evidence that can strengthen a case made with other measurements (Yuan, 2006). A stream with greater than 25% tolerant diatoms and less than 25% sensitive indicates that TP conditions are likely high (Figure 1). Streams meeting this threshold "strongly" (++) support evidence that TP is cause of aquatic life impairment. In this case, there is direct evidence that the aquatic life community has shifted to a community with higher percent of tolerant diatom taxa and the diatoms capture TP conditions over a longer period of time than a single chemistry grab sample.

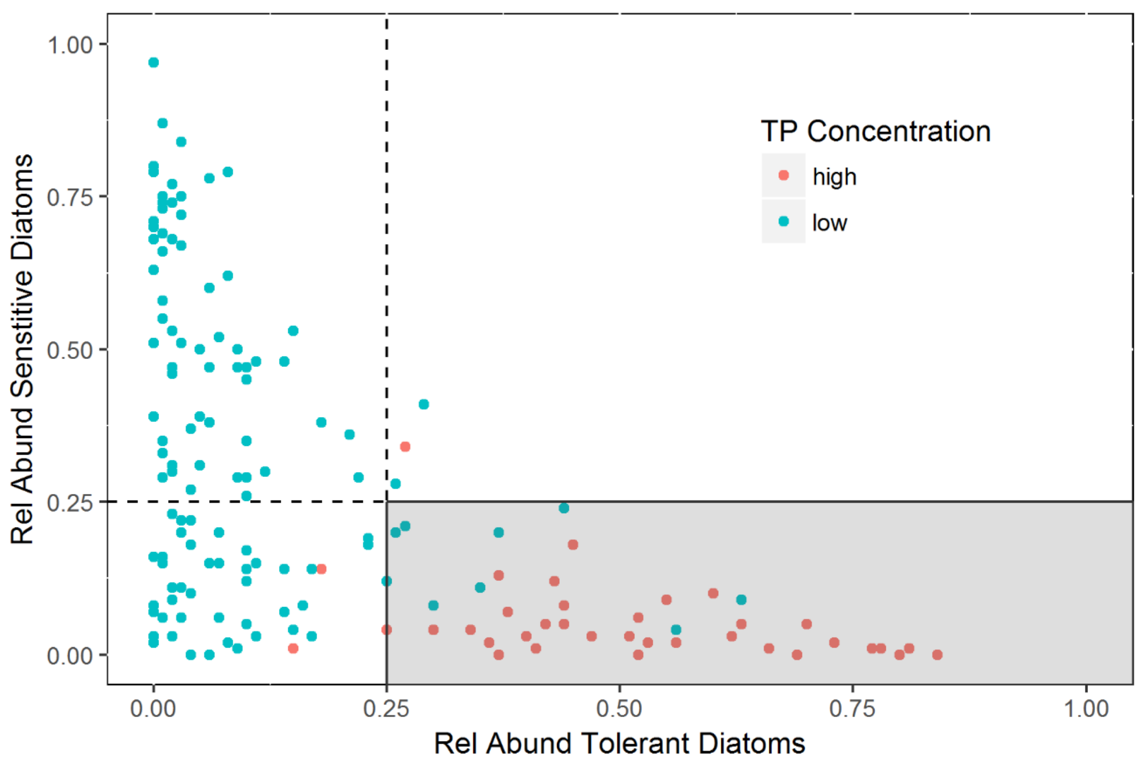

Figure 1: The grey shaded area contains sites likely to have altered conditions due to TP based on the CT diatom metrics (Becker et al 2018). These sites have >= 25% relative abundance of tolerant TP diatom species and < 25% sensitive TP diatom species, as depicted by the lines. The lines are positioned at the optimized point of separation between sites with high TP concentrations (>=0.065 mg/L) where most sensitive taxa are lost (Smucker et al 2013) and low/mid TP concentrations (<0.065 mg/L).

In addition to identifying streams with consistent "convincingly" supporting evidence (+++) that TP is a cause, the approach can also be used to target streams for further study where there is consistent "convincingly" supporting evidence (+++), but overall aquatic life use is assessed as supporting or there is inconsistent evidence (++-) that TP is impacting a stream (Table 2). These streams may be prioritized for additional sampling or a more detailed stressor identification study.

Table 2: Examples of management outcomes for TP assessment using a weight of evidence approach.

Measure				
AQL assessment using bugs &/or fish	IMPAIRED	IMPAIRED	SUPPORTING	IMPAIRED
TP Concentration Threshold	+	-	+	-
Inferred Diatom TP Tolerance Classification	++	--	++	++
Combined Evidence	+++	---	+++	++-
Management Outcome	***List TP as a cause***	***TP not a cause***	***Target for further study***	***Target for further study***

+++, - - -	Convincingly supports or weakens
++, - -	Strongly supports or weakens
+, -	Somewhat supports or weakens
0	No effect (neutral or ambiguous)
NE	No evidence

TP ASSESSMENT

Diatoms and TP grab samples collected at 125 sites from 2012 through 2017 were assessed for aquatic life impairment caused by TP (Figure 2). These samples were collected in non-tidal, high gradient, wadeable rivers and streams and followed CT DEEP biological monitoring protocols (Becker, 2017, 2012). Fifteen 305(b) assessment segments contained 17 sites meeting the threshold for aquatic life impairment where the cause includes, but is not limited to, total phosphorus using the methodology described above (Table 3). Only three of these sites are not downstream of discharges containing TP, while the remaining 13 sites are downstream of wastewater treatment plants at which phosphorus load reductions are already taking place as part of the CT Phosphorus Strategy for Non-Tidal Waste Receiving Streams (TP Strategy) (Becker, 2014) (Figure 3). However, final limits are still not being met at the majority of these plants. The objective of the TP Strategy is to reduce or cap the phosphorus loading from point sources in waste receiving streams. All of the NPDES permittees discharging to the impaired segments currently have TP limits in the permits for their facilities and are in the process of making upgrades to meet the final limits. As these upgrades for final limits are completed, the TP concentrations in the stream are expected to decrease.

In addition there are several sites that provide evidence that TP could be issue, but did not meet all three criteria to list TP as a cause. These 9 sites are suggested targets for further study (Figure 4). At all of these sites the diatom model inferred high TP conditions indicating “strong” (++) evidence for TP impairment, however there was conflicting evidence in either the TP concentration where the grab sample was less than the threshold or the overall aquatic life impairment assessment was supporting. Because there was conflicting evidence or a supporting overall aquatic life use, these sites require further investigation before listing TP as a cause of impairment.

Table 3: Sites with data indicating TP cause of aquatic life impairment and associated 305(B) segments.

Site ID	Stream Name	Municipality	Assessment Segment	Upstream Discharger (Permit Limit mg/L) where Applicable
14263	Kahn Brook	BOZRAH	CT3900-07_01	
14393	Pequabuck River	FARMINGTON	CT4315-00_01	Plymouth (0.5), Bristol (0.1) and Plainville (0.2)
14392	Pequabuck River	BRISTOL	CT4315-00_02	Bristol (0.1) and Plymouth (0.5)
14390	Pequabuck River	BRISTOL	CT4315-00_05	Plymouth (0.5)
14397	Piper Brook	NEWINGTON	CT4402-00_02	
14241	Hockanum River	VERNON	CT4500-00_05	Vernon (0.14)
14414	Quinnipiac River	WALLINGFORD	CT5200-00_02	Cheshire (0.2), Meriden (0.1) and Southington (0.2)
14413	Quinnipiac River	MERIDEN	CT5200-00_04	Cheshire (0.2) and Southington (0.2)
15479	Quinnipiac River	SOUTHINGTON	CT5200-00_05	
14520	Factory Brook	SALISBURY	CT6005-00_01	Salisbury (0.62)
14458	Still River	BROOKFIELD	CT6600-00_02	Danbury (0.1)
14332	Naugatuck River	NAUGATUCK	CT6900-00_02	Waterbury (0.2), Thomaston (1) and Torrington (0.4)
14317	Naugatuck River	BEACON FALLS	CT6900-00_02	Naugatuck (0.4), Waterbury (0.2), Thomaston (1) and Torrington (0.4)
16049	Naugatuck River	LITCHFIELD	CT6900-00_07	Torrington (0.4)
16050	Naugatuck River	LITCHFIELD	CT6900-00_07	Torrington (0.4)
14362	Ridgefield Brook	RIDGEFIELD	CT7300-02_01	Ridgefield (0.1)
18463	Fivemile River	NEW CANAAN	CT7401-00_01	New Canaan (0.19)

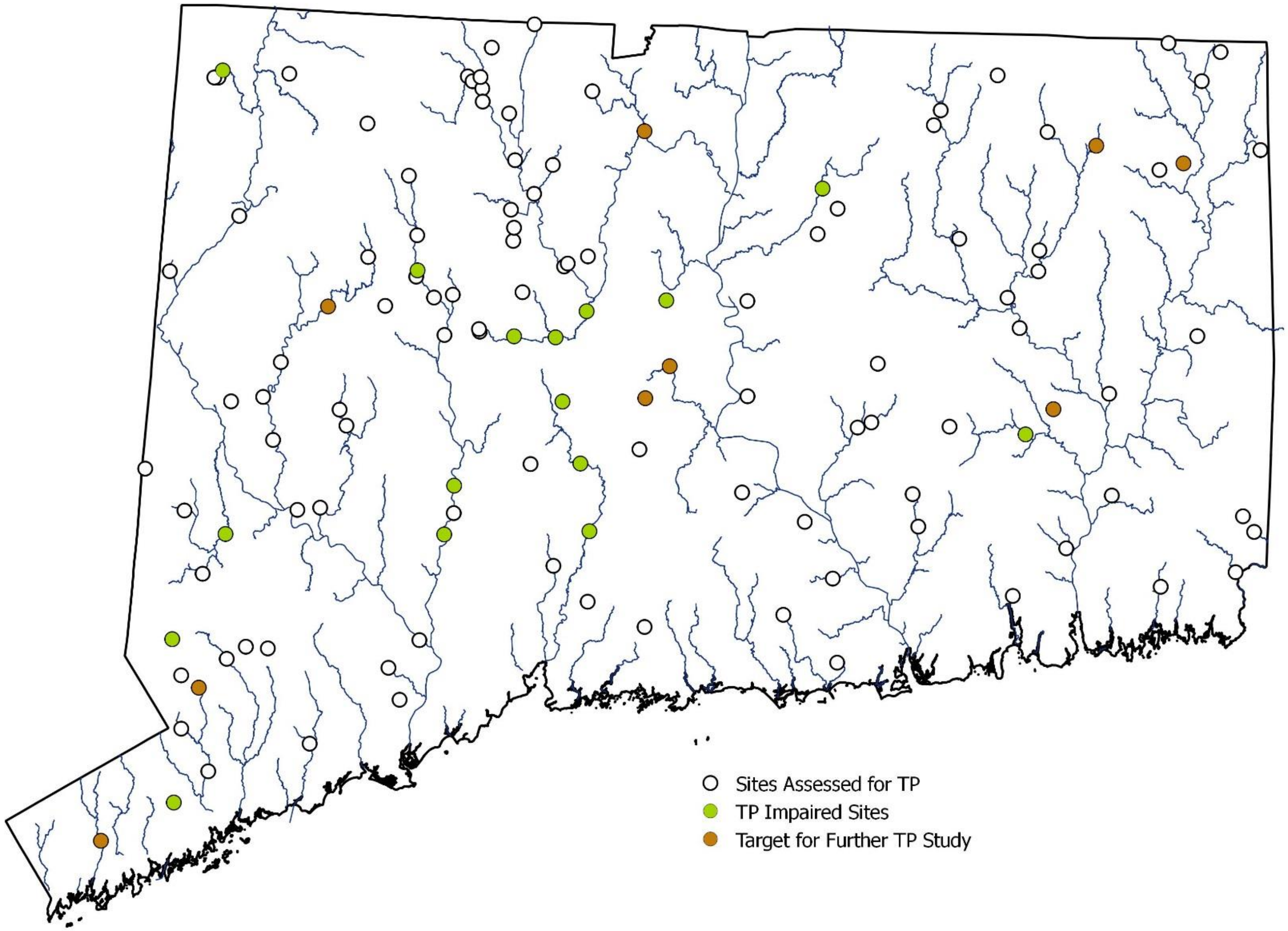

Figure 2: Sites assessed to determine whether TP should be listed as a cause of aquatic life use impairments.

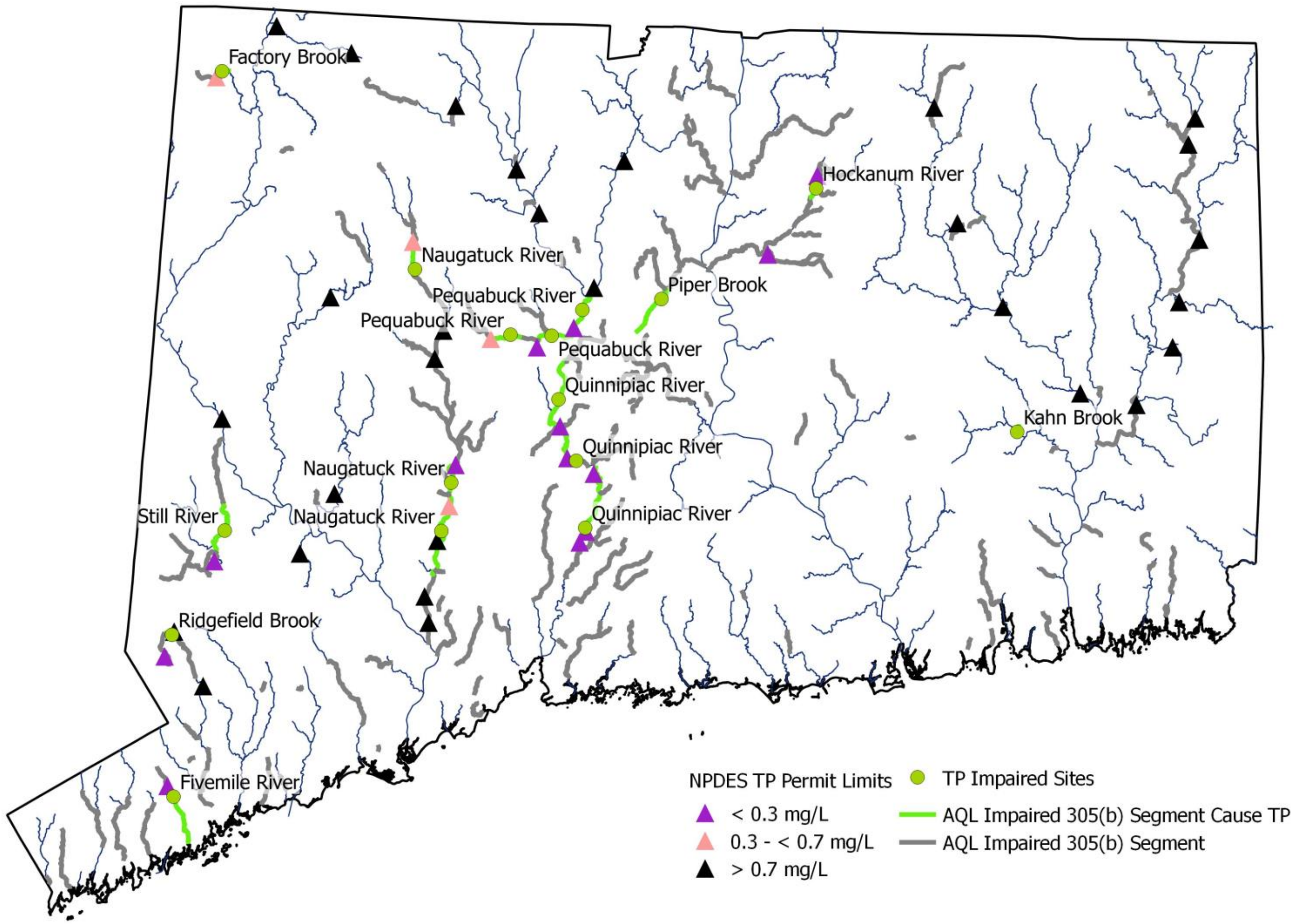

Figure 3: Sites impaired for aquatic life caused in part by TP. Sites are shown in relation to wastewater discharges with TP permit limits and 305(b) segments impaired for aquatic life.

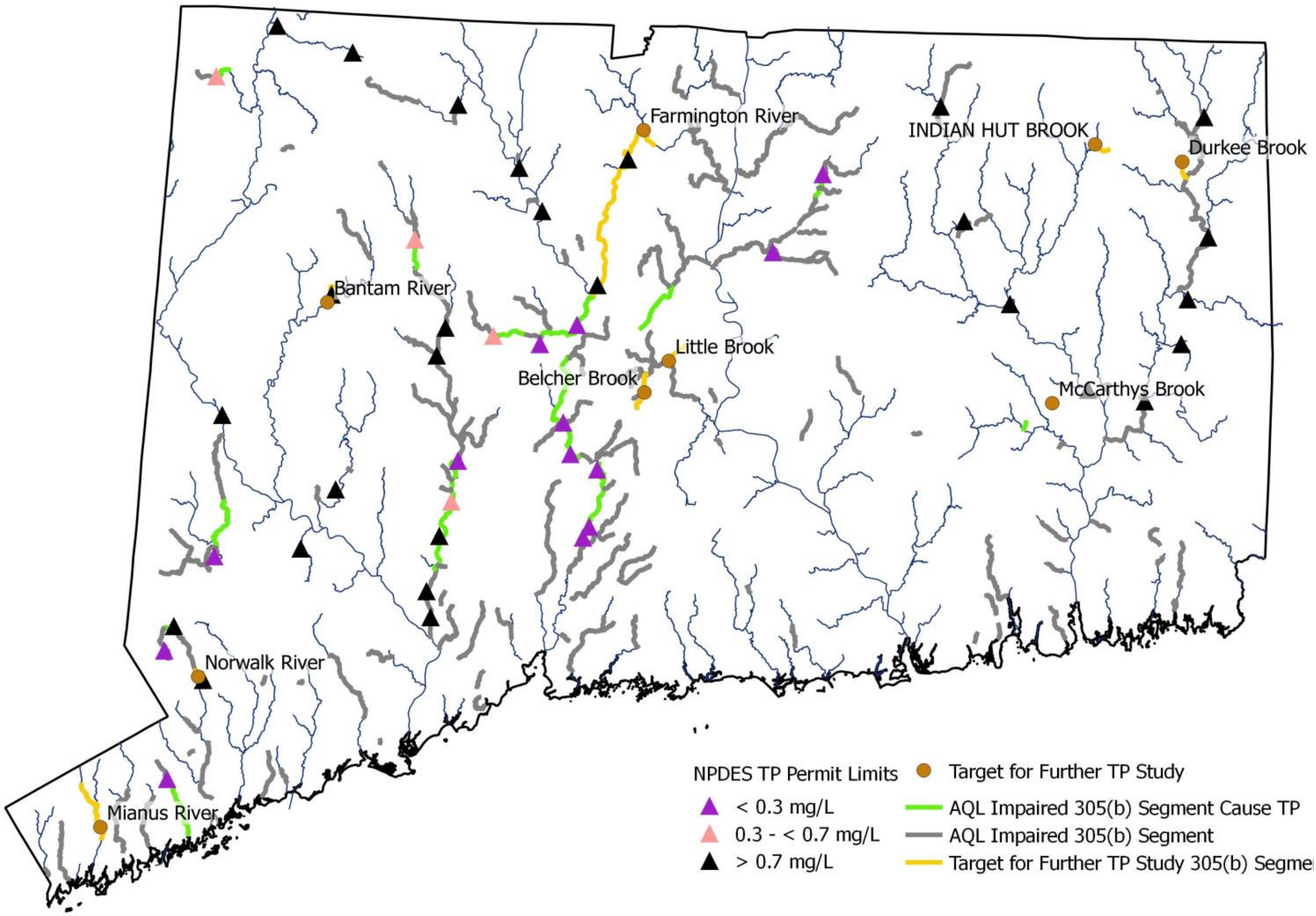

Figure 4: Sites and associated 305(b) segments with some evidence that TP may be impacting the site (orange points and lines). These sites are suggested for further study.

TP ASSESSMENTS: NEXT STEPS

This approach provides a scientifically sound method to identify TP as a cause of aquatic life impairment in non-tidal, wadeable, high gradient rivers and streams. This methodology will be added to the CT CALM and used to identify TP as a cause in these types of rivers and streams.

Work outside of this project is being conducted to better assess impacts from total phosphorus in other water body types, particularly large rivers and lakes.

Large Rivers

CT DEEP is collaborating with the CT USGS office to measure and assess diurnal variation in dissolved oxygen (DO). Investigating diurnal variation in DO to assess TP impacts was recommended in the PA 12-155 report. The diurnal variation in DO is sensitive to eutrophication caused by phosphorus impacts. Diurnal DO integrates over long spatial scales (tens to hundreds of meters) making it useful to assess impacts in large rivers and can provide a rapid assessment of biotic integrity. Over the past four years, CT DEEP in collaboration with CT USGS has monitored 8 to 10 sites from June to September. The data from this monitoring effort is currently being synthesized in a report.

Lakes

The CT DEEP monitoring and assessment program increased lake sampling over the past 8 years. The program collects samples from at least 10 lakes per year. Sampling has focused on water chemistry collected at the deep hole of the lake during spring turnover and summer stratification. Important parameters for assessing the trophic status of lakes are chlorophyll a, total nitrogen, total phosphorus, Secchi disc transparency, and aquatic macrophyte growth. In addition, the program is involved with several ongoing efforts to further the science of cyanobacteria to better inform the public in the future and explore the use of sediment diatoms as a biological indicator of trophic condition. This data is currently being synthesized to report on lake trends and effects of anthropogenic nutrient loads to lakes.

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