BUREAU OF POINT AND NON-POINT SOURCE MANAGEMENT

DEVELOPMEMT OF A NUTRIENT IMPACT ASSESSMENT PROTOCOL FOR IDENTIFYING NUTRIENTS AS A CAUSE OF AQUATIC LIFE USE IMPAIRMENT IN PENNSYLVANIA WADEABLE STREAMS

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INTRODUCTION

This document provides technical documentation of the process that Pennsylvania Department of Environmental Protection (PADEP) used to develop its Nutrient Impact Assessment Protocol for identifying nutrients as a cause of aquatic life use (ALU) impairment in wadeable streams. The full assessment methodology document is available at:

http://www.portal.state.pa.us/portal/server.pt/community/water_quality_standards/10556/2013_assessment_methodology/1407203

The overall effect of nutrient enrichment on stream biological communities occurs through a complex series of relationships involving numerous abiotic and biotic factors. In general, nutrient enrichment can lead to increased productivity of heterotrophic microbes (fungi and bacteria) and aquatic plants (algae and macrophytes) (Chambers and Prepas,1994; Biggs, 2000; Dodds et al., 2002; Carr et al., 2005). Increased productivity of heterotrophic microbes and aquatic plants modifies rates of photosynthesis and respiration, and can lead to wide diel fluctuations in dissolved oxygen (DO) concentrations, low DO levels, and an overall shift to biological communities that are more tolerant of low DO conditions (Miltner and Rankin, 1998; Dodds and Welch, 2000; Slavik et al., 2004; Miltner, 2010; Yuan, 2010).

Determining the impact of nutrient enrichment on the biological condition of a given stream is complicated by the fact that the relative impact of nutrient enrichment on the productivity of heterotrophs and aquatic plants is influenced by a number of factors such as scour regime, substrate composition, water temperature, and factors such as turbidity, shading, and water depth that influence the light conditions. Thus, a wide range of factors influence how nutrient levels ultimately affect the biological integrity of a given waterway. The conceptual model diagram shown in Figure 1 is a visual representation of relationships among human activities, stressors such as nitrogen /phosphorus pollution, biotic responses, and designated uses in aquatic systems. This diagram is from the U.S. Environmental Protection Agency (US EPA) document entitled: Using Stressor-response Relationships to Derive Numeric Nutrient Criteria, and describes the known causal pathways connecting nitrogen/phosphorus pollution to impacts on the designated uses of streams (US EPA, 2010).

The conceptual model diagram shown in Figure 1 includes both nutrient-related and non-nutrient pathways linking human activities to designated uses. The model diagram depicts relationships between anthropogenic activities that both generate and affect the

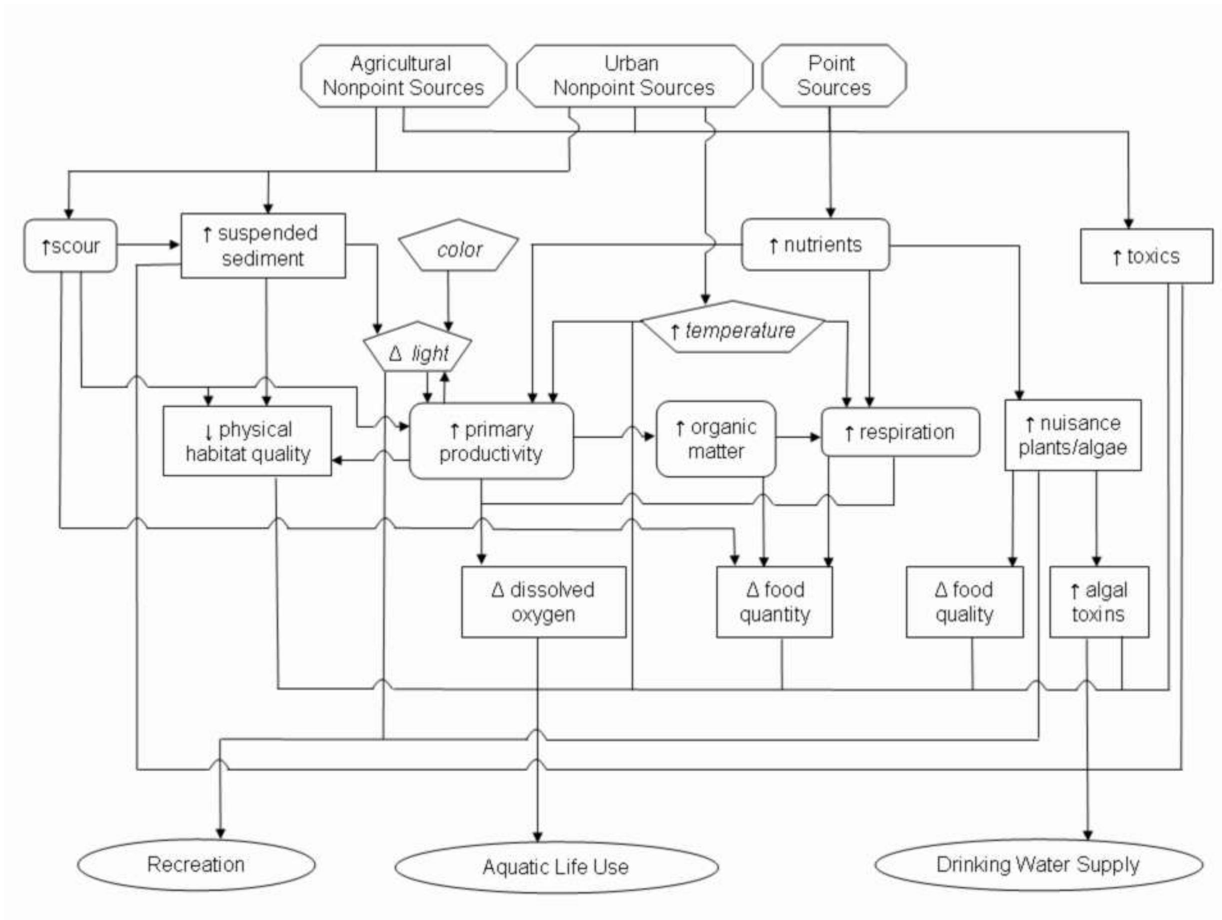


Figure 1. Conceptual Model Diagram Describing the Known Causal Pathways Connecting Nitrogen/Phosphorus Pollution to Impacts on the Designated Use in Streams (Figure 2-2 from Using Stressor-response Relationships to Derive Numeric Nutrient Criteria (US EPA, 2010)).

transport of pollutants, the key intermediate steps linking increased nitrogen and phosphorus concentrations and other stressors, and the proximate stressors that ultimately affect designated use responses. Interacting or confounding factors that modify or influence the effect of stressors or steps along the stressor-response pathway are also depicted. US EPA (2010) mentions that all relevant pathways are not included in the model diagram, and that it is expected that analysts would modify the diagram by adding or removing concepts and pathways and adapt the diagram to activities that are relevant to a particular location or system being studied.

PADEP's Nutrient Impact Assessment (NIA) Protocol is based on the conceptual model diagram shown in Figure 2. This model focuses on diel DO fluctuations as the proximate stressor ultimately affecting stream biological condition in response to nutrient enrichment. Nutrient, diel DO fluctuation, and benthic macroinvertebrate

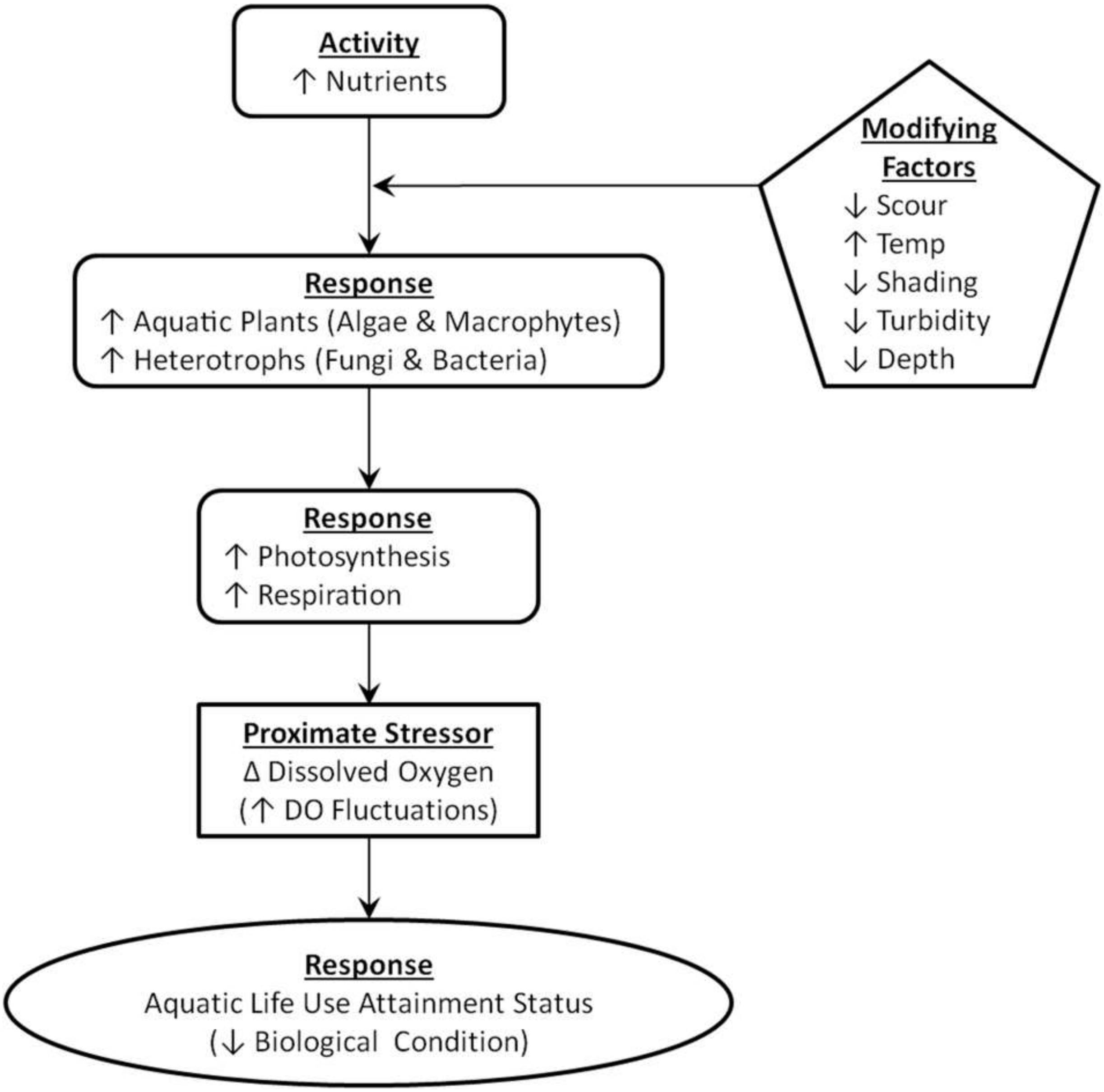


Figure 2. Conceptual Model Used in the Development of PADEP's Nutrient Impact Assessment Protocol.

community data from Pennsylvania wadeable streams were analyzed within the context of the conceptual model shown in Figure 2. The results of these analyses were used to develop a two-tiered assessment procedure for determining if nutrients are a cause of aquatic life use (ALU) impairment, after an ALU impairment decision is made and Department staff view nutrients as a potential cause of the impairment. The remainder of this document describes the NIA protocol and the technical basis upon which it was developed.

DATA USED

Nutrient, continuously monitored DO, and benthic macroinvertebrate data from 40 wadeable stream sampling events were used to develop the NIA protocol. Each of the 40 samples consisted of data collected during a given year. For example, the dataset includes two samples from the Buffalo Creek sample station, one sample in 2013 and one sample in 2014. The 2013 sample consists of five nutrient samples, 175 approved diel DO values, and one benthic macroinvertebrate sample. The 2014 sample consists of four nutrient samples, 144 approved diel DO values, and one benthic macroinvertebrate sample (Table 1).

Chemical water quality samples were collected in accordance with PADEP's sampling protocol (2013-a), and the number of chemical water quality samples collected at a given station in a given year ranged from 1 to 15 samples. Continuously monitored DO data were collected in accordance with PADEP's monitoring protocol (2013-b), and the number of days of diel DO values collected at a given station in a given year ranged from 23 to 263 days. At each sample station, a single 200-organism benthic macroinvertebrate sample was collected in accordance with methods described in PADEP's sampling protocol (2013-c) during each year DO was continuously monitored. PADEP's surface water collection, continuous instream monitoring, and macroinvertebrate sampling protocols can be accessed at:

http://www.portal.state.pa.us/portal/server.pt/community/water_quality_standards/10556/2013_assessment_mehtodology/1407203

The 40 samples were collected from 33 sample stations on 26 streams distributed among USEPA Nutrient Ecoregions VII, VIII, IX, and XI (Figure 3). Drainage areas ranged from 1.41 to 738 mi^2 and from 0 to 35% carbonate geology. Watershed land use ranged from 9 to 99% forested, 0 to 86% urban, and from 0 to 46% impervious cover (Table 2).

CONFIRMATION OF CONCEPTUAL MODEL RELATIONSHIPS

Linear regression analysis was used to provide empirical support for and to confirm the key relationships shown in the conceptual model used to develop the NIA protocol (Figure 2). Linear regression models were developed for the relationships among the maximum total phosphorus (TP), total nitrogen (TN), and diel dissolved oxygen range value recorded at each sample station in each year, and benthic macroinvertebrate index of biological integrity (IBI) and Hilsenhoff biotic index scores. Outliers (samples

Table 1. Wadeable Stream Dataset of 40 Samples Consisting of Total Phosphorus (TP) and Total Nitrogen (TN) Values, Continuously Monitored DO Data, and Benthic Macroinvertebrate Data.

Station-Year	Number of Total Phosphorus Samples	Number of Total Nitrogen Samples	Continuous DO Monitoring Start Date	Continuous DO Monitoring End Date	Number of Approved Diel DO Values	Number of Benthic Macroinvertebrate Samples
Big Ellk Cr 2014	10	10	4/15/2014	11/14/2014	198	1
Browns Run 2013	10	7	1/2/2013	11/7/2013	208	1
Buffalo Cr 2013	5	5	4/21/2013	11/7/2013	175	1
Buffalo Cr 2014	4	4	5/13/2014	11/14/2014	144	1
Chillisquaque Cr 2013	11	11	6/18/2013	11/21/2013	157	1
Cooks Cr 2013	3	3	3/5/2013	4/24/2013	51	1
Frankstown Br 2014	15	15	8/20/2014	11/6/2014	79	1
Goose Most 2014	13	13	4/17/2014	10/26/2014	122	1
Goose Oak 2014	13	13	5/7/2014	11/4/2014	122	1
Goose Thorn 2014	13	13	5/8/2014	11/13/2014	143	1
Grays Run 2013	10	6	1/2/2013	11/6/2013	214	1
Indian Berg 2013	4	4	3/6/2013	11/26/2013	102	1
Indian Berg 2014	11	11	3/19/2014	11/13/2014	119	1
Indian Rt 63 2013	4	4	3/5/2013	12/10/2013	263	1
Indian Rt 63 2014	11	11	4/24/2014	11/13/2014	198	1
Jacks Cr 2013	5	5	4/20/2013	11/7/2013	202	1
Kish Cr 2013	7	7	4/24/2013	11/20/2013	127	1
Kish Cr 2014	6	6	3/8/2014	10/14/2014	156	1
Little Swatara 2014	3	3	6/10/2014	11/4/2014	148	1
Loyalsock Cr 2008	8	8	6/27/2008	12/10/2008	146	1
Loyalsock Cr 2011	4	4	6/16/2011	8/26/2011	72	1
Loyalsock Cr 2013	5	5	6/13/2013	11/21/2013	162	1
Neshaminy Cr 2013	5	5	3/6/2013	4/25/2013	51	1
Penns Cr 2011	13	13	6/14/2011	9/22/2014	77	1
Perkiomen Cr 2014	8	8	4/16/2014	11/12/2014	190	1
Pine Berks 2014	10	10	4/16/2014	11/11/2014	167	1
Pine Cr Lycoming 2011	1	2	6/15/2011	8/26/2011	73	1
Pine Cr Lycoming 2013	6	6	5/25/2013	11/7/2013	167	1
Raccoon Cr 2013	5	5	4/20/2013	11/7/2013	199	1
Red Clay Cr 2014	9	9	4/15/2014	11/14/2014	165	1
Sherman Cr 2013	13	13	3/16/2013	11/20/2013	250	1
Skippack Ridge 2013	3	3	3/6/2013	4/26/2013	52	1
Skippack Rt 63 2013	2	2	3/6/2013	11/14/2013	222	1
Swatara Harp 2014	3	3	4/25/2014	10/16/2014	160	1
Swatara Hersh 2014	4	4	4/25/2014	11/5/2014	190	1
Towamencin Cr 2013	2	2	3/28/2013	4/25/2013	23	1
Tuscarora Cr 2013	4	4	4/11/2013	7/8/2013	45	1
Tuscarora Cr 2014	6	6	4/15/2014	11/6/2014	206	1
Wissahickon 2013	3	3	3/6/2013	4/17/2013	43	1
Wyalusing Cr 2011	5	5	5/24/2011	8/26/2011	82	1
Sum	**277**	**271**			**5,670**	**40**
Minimum	**1**	**2**			**23**	**1**
Maximum	**15**	**15**			**263**	**1**
Average	**7**	**7**			**142**	**1**

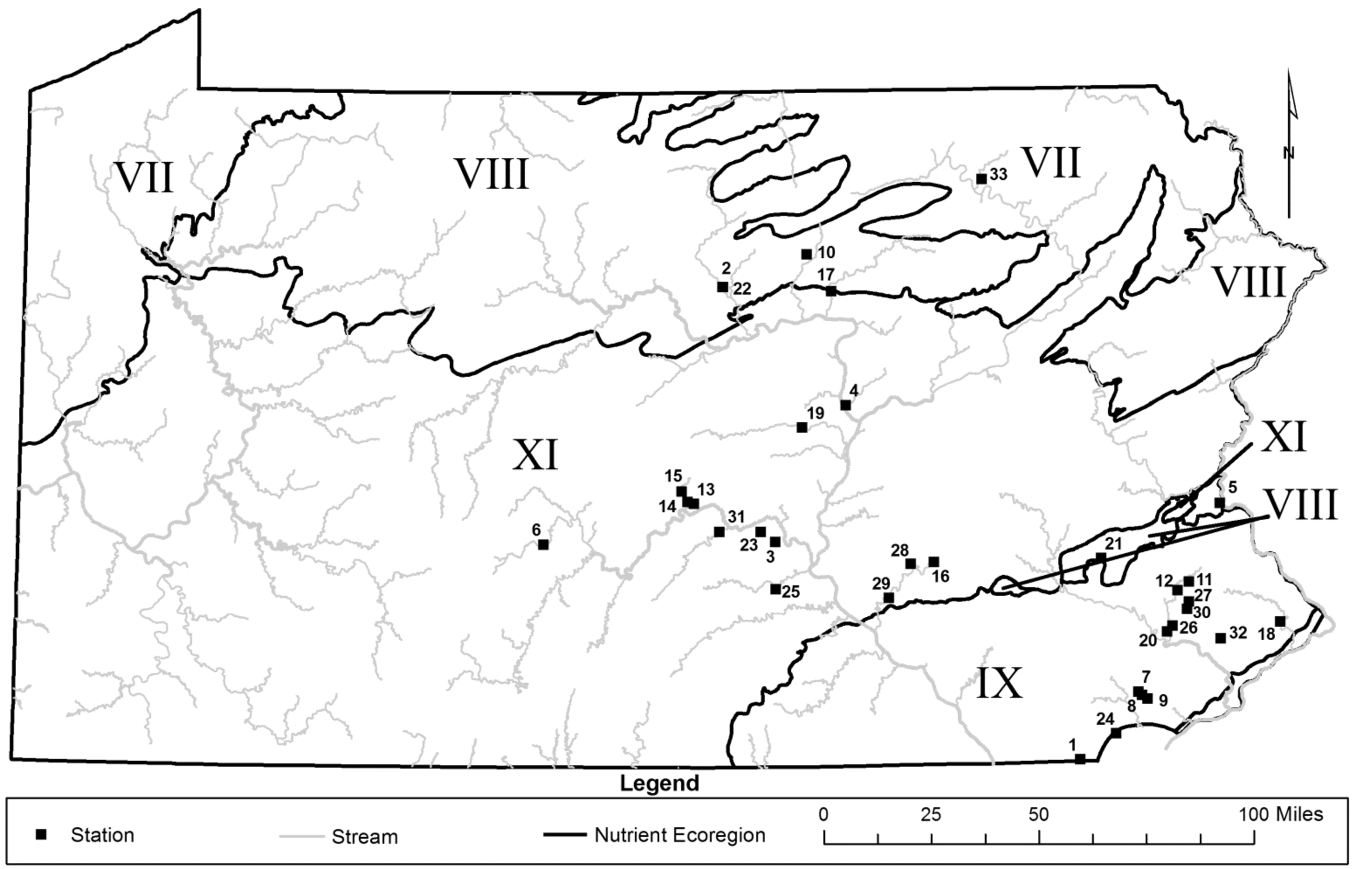


Figure 3. Map of Sample Site Locations.

Table 2. Map ID Numbers and Watershed Characteristics of Sample Stations.

Station	Map ID Num	Latitude	Longitude	County	EPA Nutrient EcoRegion	Drainage Area (mi2)	% Carbonate Geology	% Forest	% Urban	% Impervious Cover 2011
Big Ellk Cr	1	39.7317	-75.8503	Chester	IX	38.80	0	25	4	3
Browns Run	2	41.3428	-77.3990	Lycoming	VIII	5.79	0	96	0	0
Buffalo Cr	3	40.4824	-77.1743	Perry	XI	65.00	5	67	0	1
Chillisquaque Cr	4	40.9409	-76.8547	Northumberland	XI	112.00	7	30	1	1
Cooks Cr 2013	5	40.5829	-75.2051	Bucks	VIII	29.20	35	60	1	1
Frankstown Br	6	40.4757	-78.1961	Blair	XI	295.00	27	65	7	4
Goose Most	7	39.9538	-75.5892	Chester	IX	1.85	0	9	86	46
Goose Oak	8	39.9423	-75.5724	Chester	IX	3.27	0	15	77	36
Goose Thorn	9	39.9299	-75.5500	Chester	IX	6.34	0	22	61	23
Grays Run	10	41.4508	-77.0198	Lycoming	VIII	16.20	0	99	0	0
Indian Berg	11	40.3210	-75.3523	Montgomery	IX	1.41	0	10	58	24
Indian Rt 63	12	40.2934	-75.4035	Montgomery	IX	5.73	0	17	20	13
Jacks Cr	13	40.6129	-77.5317	Mifflin	XI	57.10	13	65	1	1
Kish Cr 2013	14	40.6181	-77.5595	Mifflin	XI	185.00	25	63	2	2
Kish Cr 2014	15	40.6547	-77.5858	Mifflin	XI	163.00	25	63	1	1
Little Swatara	16	40.4078	-76.4747	Lebanon	XI	99.10	3	27	2	3
Loyalsock Cr	17	41.3261	-76.9123	Lycoming	XI	437.00	0	88	0	0
Neshaminy Cr	18	40.1743	-74.9574	Bucks	IX	209.00	2	32	27	12
Penns Cr	19	40.8665	-77.0486	Snyder	XI	306.00	24	69	1	1
Perkiomen Cr	20	40.1535	-75.4560	Montgomery	IX	301.00	1	48	7	5
Pine Berks	21	40.4085	-75.7363	Berks	VIII	9.87	7	84	0	0
Pine Lycoming	22	41.3432	-77.3965	Lycoming	VIII	738.00	0	89	0	0
Raccoon Cr	23	40.5160	-77.2364	Perry	XI	11.80	9	80	0	0
Red Clay Cr	24	39.8163	-75.6914	Chester	IX	27.60	11	30	18	7
Sherman Cr	25	40.3223	-77.1732	Perry	XI	198.00	12	68	0	1
Skippack Ridge	26	40.1722	-75.4309	Montgomery	IX	53.00	0	33	25	13
Skippack Rt 63	27	40.2539	-75.3561	Montgomery	IX	11.50	0	24	27	18
Swatara Harp	28	40.4026	-76.5774	Lebanon	XI	336.00	1	53	3	2
Swatara Hersh	29	40.2886	-76.6756	Dauphin	XI	485.00	13	45	5	4
Towamencin Cr	30	40.2289	-75.3640	Montgomery	IX	10.10	0	20	60	20
Tuscarora Cr	31	40.5167	-77.4202	Juniata	XI	198.00	11	74	0	0
Wissahickon	32	40.1240	-75.2199	Montgomery	IX	40.60	8	28	54	17
Wyalusing Cr	33	41.6967	-76.2303	Bradford	VII	211.00	0	70	1	0
Minimum						1.41	0	9	0	0
Maximum						738.00	35	99	86	46
Average						141.46	7	51	17	8

with relatively large residual values) were removed from some datasets, prior to generating the regression models discussed below. The nutrient, diel DO, and benthic macroinvertebrate data used in regression analysis are summarized in Table 3.

Table 3. Nutrient, Diel DO, and Benthic Macroinvertebrate Data from 40 Sample Dataset.

Station-Year	Total Phosphorus Maximum (mg/l)	Total Nitrogen Maximum (mg/l)	Diel DO Range Maximum (mg/l)	Hilsenhoff Biotic Index Score	Macroinvertebrate IBI Score
Big Ellk Cr 2014	0.04	5.6	3.8	4.92	47
Browns Run 2013	0.01	0.5	1.2	1.39	89
Buffalo Cr 2013	0.04	1.8	6.8	4.01	68
Buffalo Cr 2014	0.02	1.8	5.1	3.52	93
Chillisquaque Cr 2013	0.23	5.6	5.3	3.50	71
Cooks Cr 2013	0.01	1.8	5.5	3.17	67
Frankstown Br 2014	0.33	2.4	4.1	4.87	56
Goose Most 2014	0.12	3.3	10.2	5.60	23
Goose Oak 2014	2.10	21.1	6.2	6.28	22
Goose Thorn 2014	1.79	17.6	6.0	5.28	23
Grays Run 2013	0.01	0.5	1.5	2.43	94
Indian Berg 2013	0.08	14.0	10.1	5.42	21
Indian Berg 2014	0.16	11.4	8.8	5.55	21
Indian Rt 63 2013	0.06	4.1	15.1	5.05	30
Indian Rt 63 2014	0.21	4.8	11.9	6.29	29
Jacks Cr 2013	0.03	1.4	4.1	3.60	88
Kish Cr 2013	0.12	3.9	5.4	4.91	53
Kish Cr 2014	0.19	3.6	5.0	4.09	56
Little Swatara 2014	0.08	6.5	7.1	3.82	62
Loyalsock Cr 2008	0.05	0.4	5.3	2.91	84
Loyalsock Cr 2011	0.01	0.3	3.2	2.90	66
Loyalsock Cr 2013	0.03	0.5	2.8	3.42	86
Neshaminy Cr 2013	0.19	3.0	10.9	5.13	29
Penns Cr 2011	0.19	2.1	8.3	4.32	69
Perkiomen Cr 2014	0.08	2.1	8.9	4.65	52
Pine Berks 2014	0.03	0.7	3.4	4.31	65
Pine Cr Lycoming 2011	0.01	0.2	5.9	3.35	93
Pine Cr Lycoming 2013	0.02	0.4	3.8	3.55	73
Raccoon Cr 2013	0.05	1.4	3.1	4.48	61
Red Clay Cr 2014	0.16	6.0	4.7	5.16	33
Sherman Cr 2013	0.26	3.1	6.1	3.94	69
Skippack Ridge 2013	0.15	4.9	12.4	5.10	32
Skippack Rt 63 2013	0.35	15.0	14.6	5.75	22
Swatara Harp 2014	0.04	3.0	4.2	4.25	50
Swatara Hersh 2014	0.07	4.1	2.4	3.82	62
Towamencin Cr 2013	0.29	6.2	9.8	5.93	17
Tuscarora Cr 2013	0.02	0.9	4.6	4.32	58
Tuscarora Cr 2014	0.03	1.3	5.7	4.84	63
Wissahickon 2013	0.32	5.9	16.0	5.59	24
Wyalusing Cr 2011	0.02	0.6	5.7	2.80	82

Linear regression analysis results demonstrate clear relationships between elevated nutrient levels (TP and TN) and macroinvertebrate communities with elevated levels of tolerance to low-DO conditions (i.e., elevated Hilsenhoff biotic index scores), and lower macroinvertebrate IBI scores (Table 4 and Figures 4 - 7). These results provide empirical support for the conceptual model used to develop the NIA protocol, and confirm the relationships between nutrients, diel DO fluctuations, and biological condition depicted in the conceptual model diagram (Figure 2).

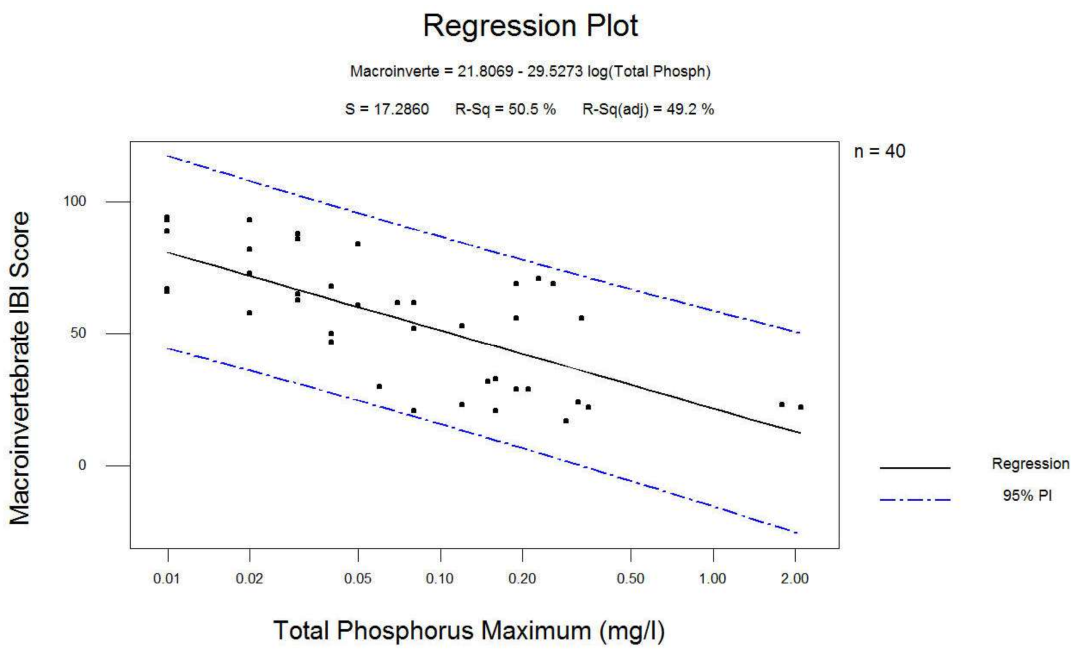
NUTRIENT IMPACT ASSESSMENT (NIA) PROTOCOL

The intended use of the NIA protocol is for determining if nutrients are a cause of impairment after a given wadeable stream is determined to be ALU-impaired and PADEP staff view nutrients as a potential cause of the impairment, based on the presence of known point and/or non-point sources of nutrients or field indicators such as excessive algal or macrophyte growth (Figure 8). The protocol is based on the relationships between nutrients, DO characteristics, and benthic macroinvertebrate integrity, depicted in the conceptual model diagram, Figure 2.

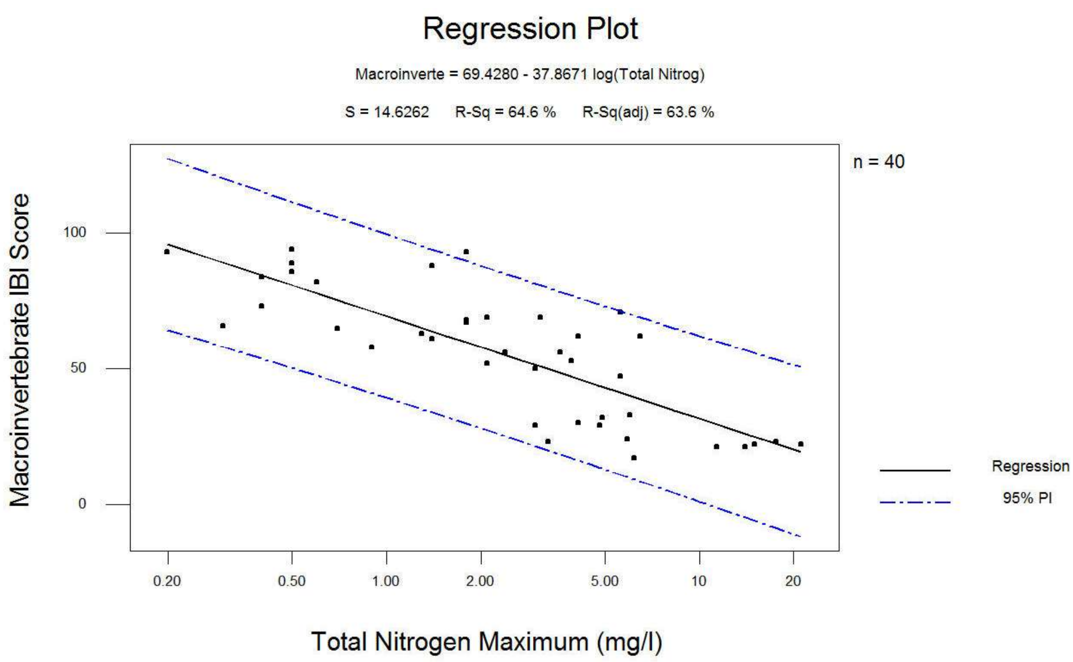
The protocol consists of two tiers of data evaluation. Tier 1 consists of evaluating three screening parameters (TP, TN, and Hilsenhoff Biotic Index score) against screening benchmark values. If one or more Tier 1 screening parameter value equals or exceeds the screening benchmark value, the waterway fails the Tier 1 screening process, and is targeted for additional data collection and evaluation (Tier 2). The second tier of the protocol involves the collection and evaluation of continuously monitored DO data. Continuously monitored DO data are used to determine if nutrients are a cause of ALU impairment, by comparing DO values to Tier 2 nutrient impairment benchmark values.

Table 4. Linear Regression Analysis Results.

Response (Y)	Predictor (X)	r^2	n	p	Equation Coefficient
Macroinvertebrate IBI	TP Maximum	0.505	40	<0.001	-29.5273 (log X)
Macroinvertebrate IBI	TN Maximum	0.646	40	<0.001	-37.8671 (log X)
Hilsenhoff Biotic Index	TP Maximum	0.549	40	<0.001	+1.40699 (log X)
Hilsenhoff Biotic Index	TN Maximum	0.582	40	<0.001	+1.64351 (log X)
Hilsenhoff Biotic Index	Diel DO Range Max	0.434	40	<0.001	+0.197960 (X)
Macroinvertebrate IBI	Hilsenhoff Biotic Index	0.802	40	<0.001	-19.5985 (X)
Diel DO Range Max	TP Maximum	0.478	36	<0.001	+5.02187 (log X)
Diel DO Range Max	TN Maximum	0.358	36	<0.001	+3.94765 (log X)

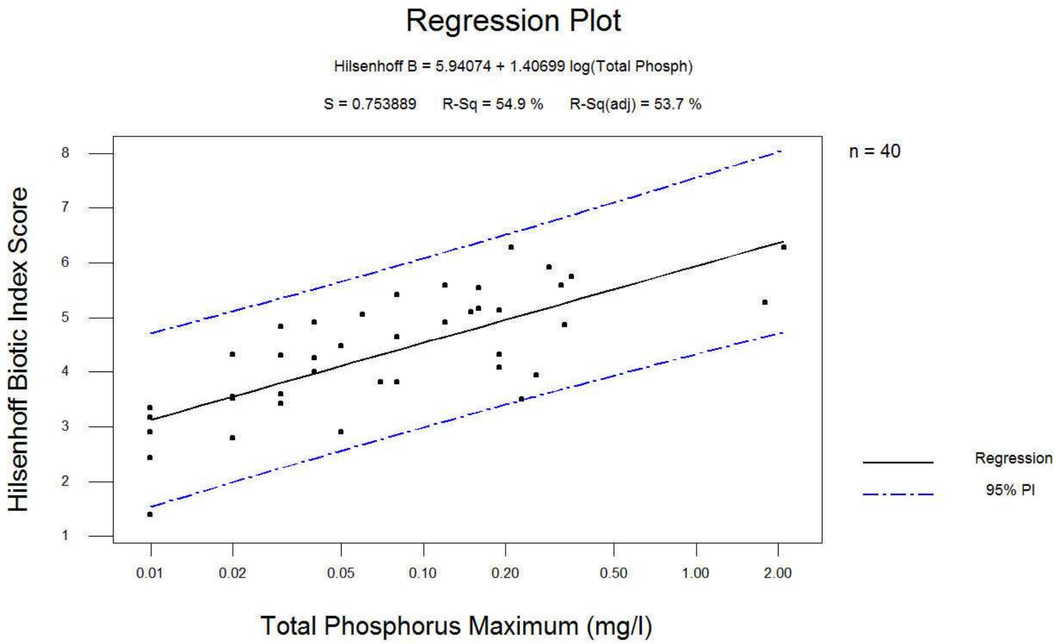


(A)



(B)

Figure 4. Linear Regression Model of Macroinvertebrate IBI Score vs. Total Phosphorus Maximum (A) and Total Nitrogen Maximum (B).



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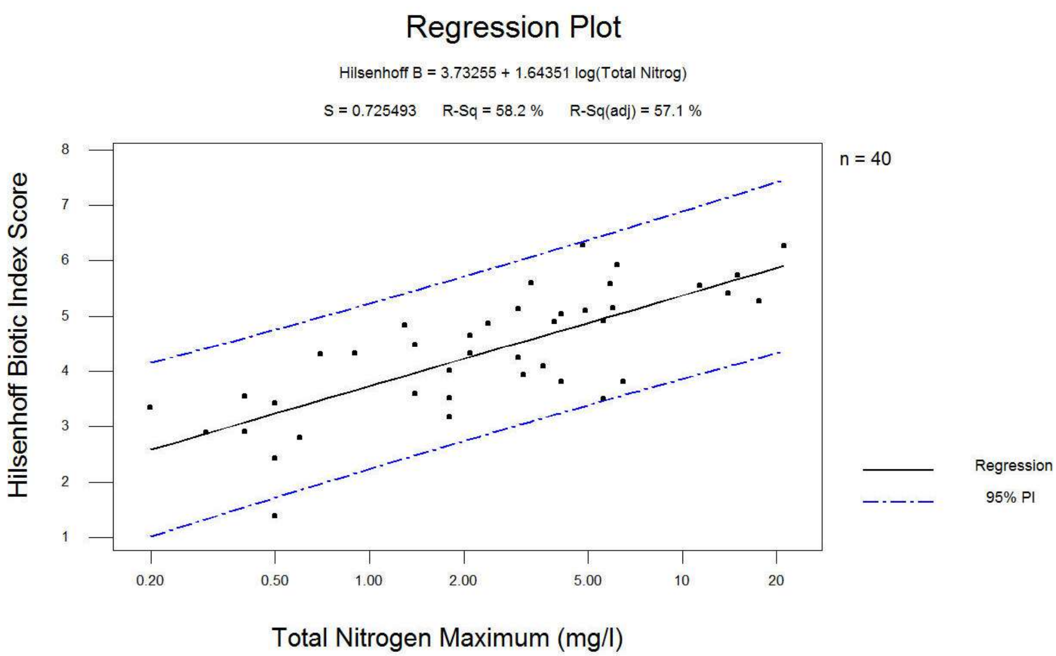
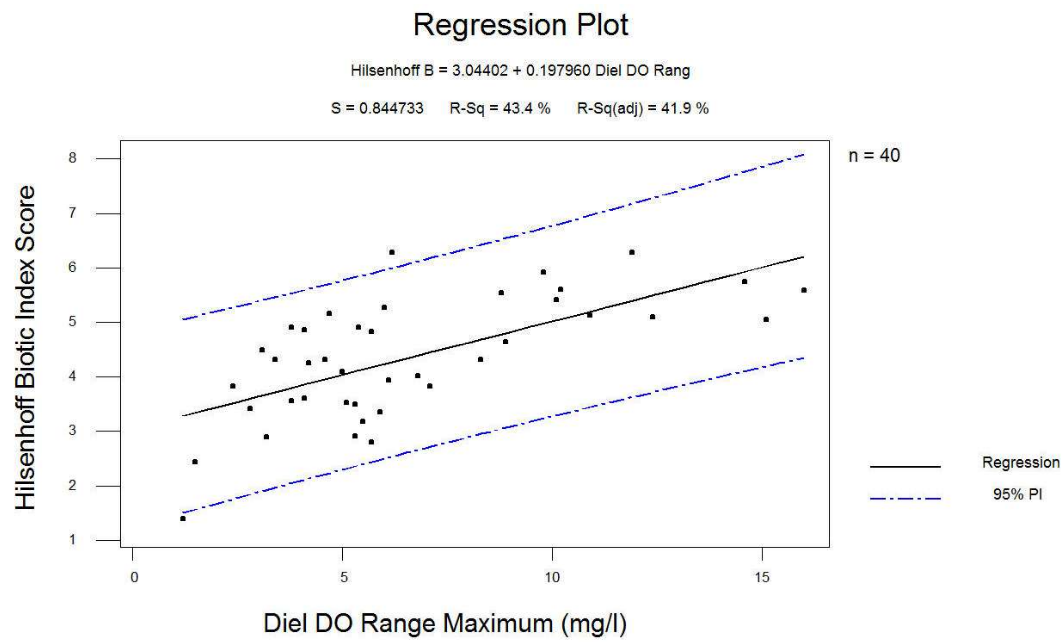
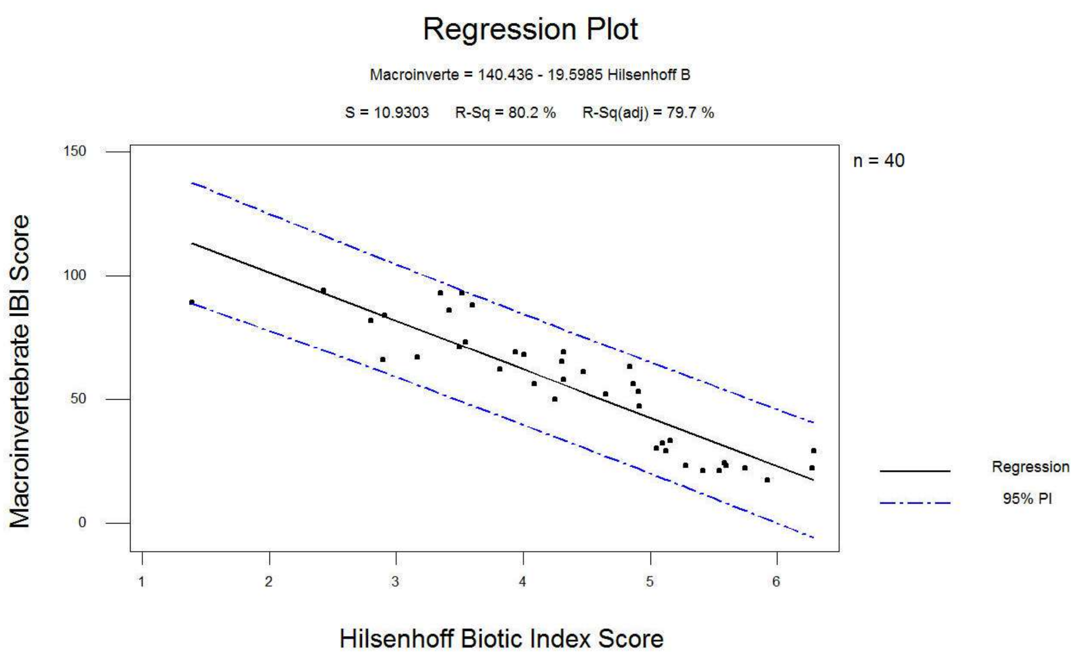


(B)

Figure 5. Linear Regression Model of Hilsenhoff Biotic Index Score vs. Total Phosphorus Maximum (A) and Total Nitrogen Maximum (B).

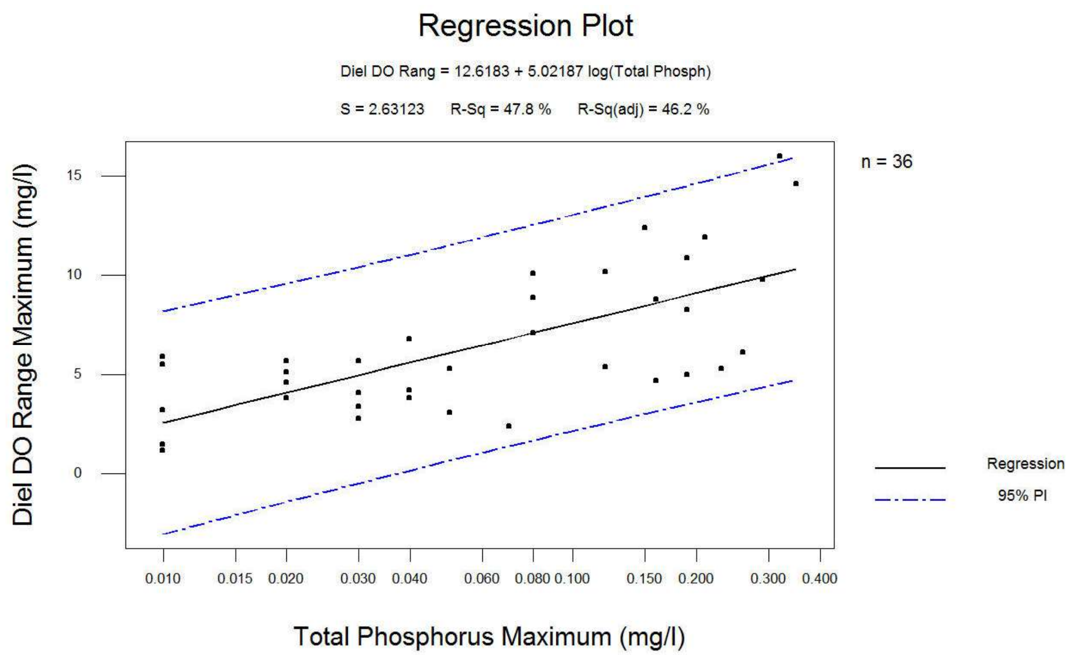


(A)

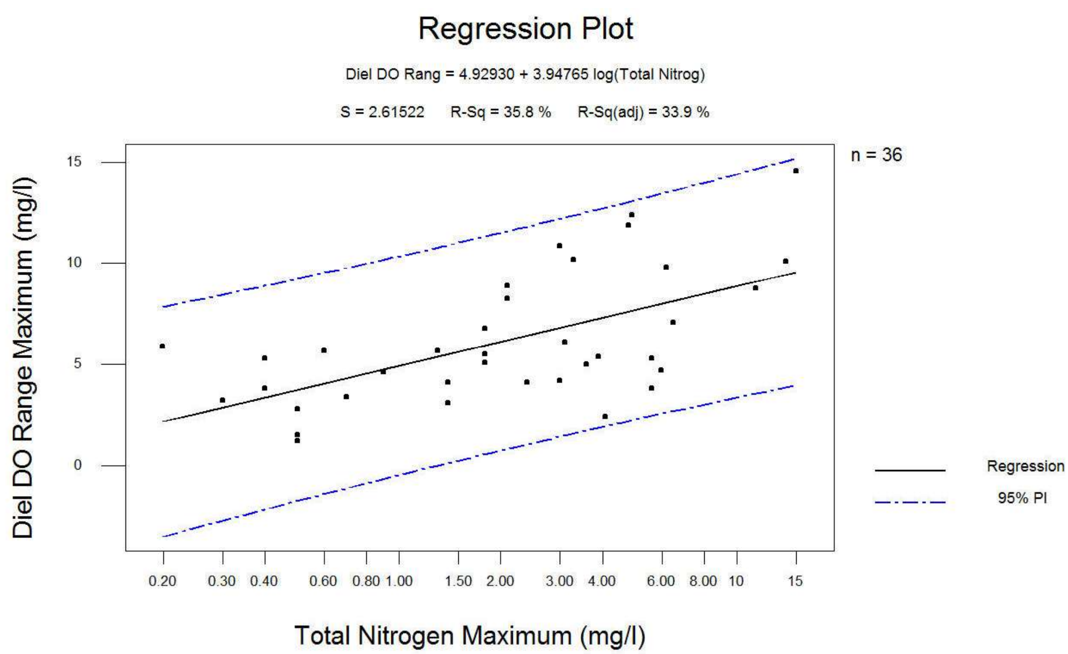


(B)

Figure 6. Linear Regression Model of Hilsenhoff Biotic Index Score vs. Diel DO Range Maximum (A) and Macroinvertebrate IBI Score vs. Hilsenhoff Biotic Index Score (B).



(A)



(B)

Figure 7. Linear Regression Model of Diel DO Range Maximum vs. Total Phosphorus Maximum (A) and Total Nitrogen Maximum (B).

Figure 8. Photographs of Excessive Algal Growth in a Southeastern Pennsylvania Stream.

TIER 1 NUTRIENT SCREENING BENCHMARK VALUES

Tier 1 nutrient screening parameters include TP, TN, and Hilsenhoff biotic index scores. TP and TN screening benchmark values were derived using PADEP Water Quality Network (WQN) data. The average TP and average TN values for the months of April through September were calculated for each wadeable, WQN station and year, and the 90th percentile value of the average values was used as the screening benchmark value for each of the nutrient parameters. Data from mining-impaired WQN stations were not used in the analysis. This analysis yielded a TP screening value of 0.06 mg/l and a TN screening value of 2.6 mg/l.

The Hilsenhoff biotic index screening benchmark value was derived using values from the 40-sample dataset shown in Table 3. The dataset was divided into two groups based on ALU-attainment status, and the highest Hilsenhoff biotic index score recorded at an ALU-attaining station was used to set the benchmark value of 4.60 (Figure 9).

Tier 1 nutrient screening benchmark values are shown in Figure 10, and summarized as follows:

- Hilsenhoff Index Score ≥ 4.60, or
- Total Phosphorus ≥ 0.06 mg/l, or
- Total Nitrogen ≥ 2.6 mg/l

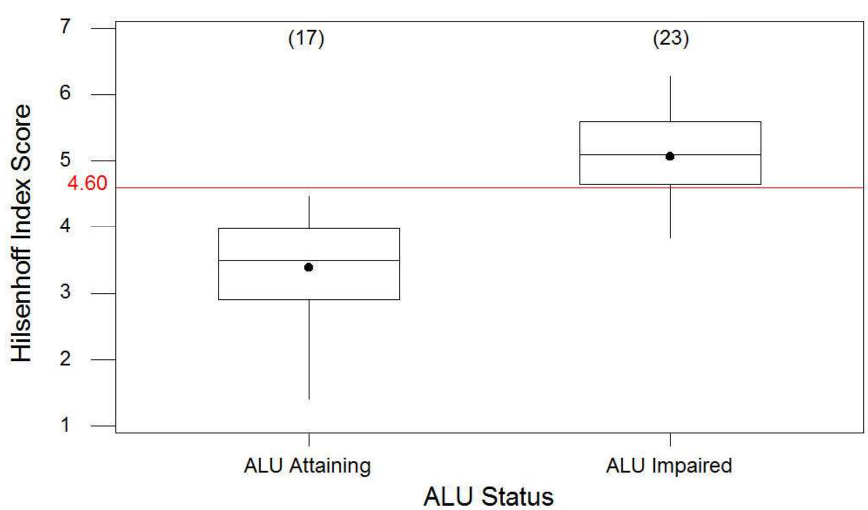
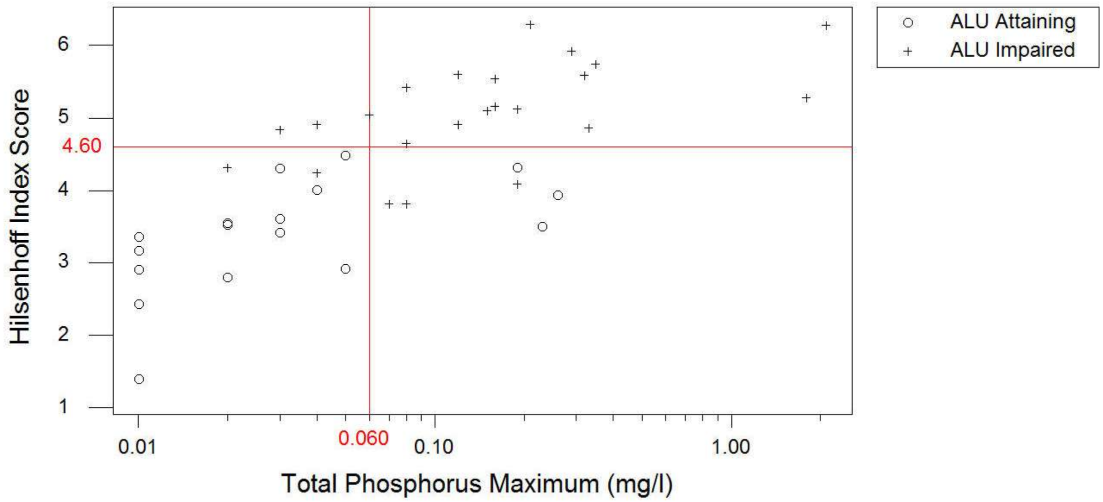
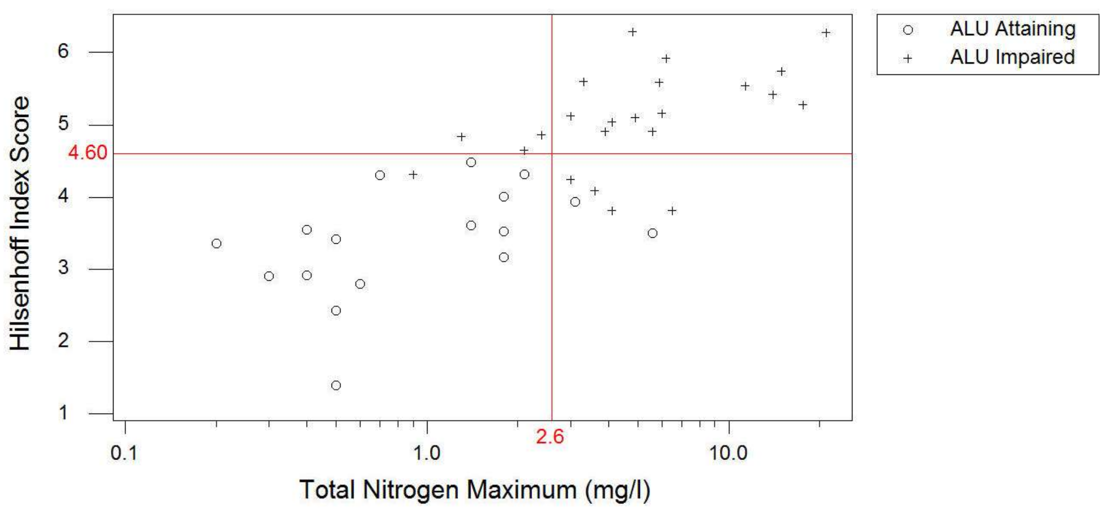


Figure 9. Hilsenhoff Biotic Index Scores of ALU-Attaining and ALU-Impaired Stations.



(A)



(B)

Figure 10. Hilsenhoff Biotic Index Score vs. Total Phosphorus Maximum (A) and vs. Total Nitrogen Maximum (B) of 40-Sample Dataset, by Aquatic Life Use Attainment Status.

If one or more of the screening parameters equals or exceeds the screening benchmark value, the waterway fails the Tier 1 screening process, and is targeted for the collection and evaluation of continuously monitored DO data (Tier 2).

TIER 2 NUTRIENT IMPAIRMENT BENCHMARK VALUES

Nutrient impairment benchmark values were developed for maximum diel DO range and maximum 7-day average diel DO range, based on the diel DO characteristics of ALU-attaining stations that passed the Tier 1 screening. Applying the Tier 1 screening benchmark values of:

- Hilsenhoff Index Score ≥ 4.60, or
- TP Max ≥ 0.06 mg/l, or
- TN Max ≥ 2.6 mg/l

in conjunction with the ALU attainment status, the samples in the 40-sample dataset were classified into one of the four categories below, and shown in Table 5 :

- Category 1- ALU-Attaining and Passed Screening (n = 14)
- Category 2 – ALU-Attaining and Failed Screening (n = 3)
- Category 3- ALU-Impaired and Passes Screening (n = 1)
- Category 4- ALU-Impaired and Failed Screening (n = 22)

The maximum diel DO range data from Category 1 and Category 4 sample stations were reviewed for potential seasonal patterns in diel DO fluctuations. A graphical examination of the maximum diel DO range value recorded at a Category 1 sample station on a given day of the year, and the same information recorded at Category 4 sample stations, shows clear, and opposing, seasonal patterns in the diel DO fluctuations of these two groups of streams Figure 11. Diel DO range values tend to peak in the mid- to late-summer in Category 1 streams, and these values tend to peak in the spring and fall in Category 4 streams. Based on the seasonality pattern observed in Category 1 streams, separate nutrient impairment benchmarks were developed for the warm season (June 15 – September 15) and cool season (the remainder of the year) (Figure 12).

For each season, nutrient impairment benchmarks were developed for two diel DO fluctuation parameters, one for the maximum diel DO range, and one for the maximum 7-day average diel DO range. The 90th percentile values of the maximum diel DO range and the maximum 7-day average diel DO range recorded at each Category 1 sample station during a given season, were used as benchmark values (Figure 13).

Table 5. Aquatic Life Use Attainment and Tier 1 Screening Status of Samples in the 40-Sample Dataset.

Station-Year	ALU-Attainment Status	TP Max (mg/l)	TN Max (mg/l)	Hilsenhoff Biotic Index Score	Tier 1 Sreening Status	Category
	Benchmark Value:	≥0.06	≥2.6	≥4.60		
Browns Run 2013	ALU Attaining	0.01	0.5	1.39	Pass	1
Buffalo Cr 2013	ALU Attaining	0.04	1.8	4.01	Pass	1
Buffalo Cr 2014	ALU Attaining	0.02	1.8	3.52	Pass	1
Cooks Cr 2013	ALU Attaining	0.01	1.8	3.17	Pass	1
Grays Run 2013	ALU Attaining	0.01	0.5	2.43	Pass	1
Jacks Cr 2013	ALU Attaining	0.03	1.4	3.60	Pass	1
Loyalsock Cr 2008	ALU Attaining	0.05	0.4	2.91	Pass	1
Loyalsock Cr 2011	ALU Attaining	0.01	0.3	2.90	Pass	1
Loyalsock Cr 2013	ALU Attaining	0.03	0.5	3.42	Pass	1
Pine Berks 2014	ALU Attaining	0.03	0.7	4.31	Pass	1
Pine Cr Lycoming 2011	ALU Attaining	0.01	0.2	3.35	Pass	1
Pine Cr Lycoming 2013	ALU Attaining	0.02	0.4	3.55	Pass	1
Raccoon Cr 2013	ALU Attaining	0.05	1.4	4.48	Pass	1
Wyalusing Cr 2011	ALU Attaining	0.02	0.6	2.80	Pass	1
Chillisquaque Cr 2013	ALU Attaining	0.23	5.6	3.50	Fail	2
Penns Cr 2011	ALU Attaining	0.19	2.1	4.32	Fail	2
Sherman Cr 2013	ALU Attaining	0.26	3.1	3.94	Fail	2
Tuscarora Cr 2013	ALU Impaired	0.02	0.9	4.32	Pass	3
Big Ellk Cr 2014	ALU Impaired	0.04	5.6	4.92	Fail	4
Frankstown Br 2014	ALU Impaired	0.33	2.4	4.87	Fail	4
Goose Most 2014	ALU Impaired	0.12	3.3	5.60	Fail	4
Goose Oak 2014	ALU Impaired	2.10	21.1	6.28	Fail	4
Goose Thorn 2014	ALU Impaired	1.79	17.6	5.28	Fail	4
Indian Berg 2013	ALU Impaired	0.08	14.0	5.42	Fail	4
Indian Berg 2014	ALU Impaired	0.16	11.4	5.55	Fail	4
Indian Rt 63 2013	ALU Impaired	0.06	4.1	5.05	Fail	4
Indian Rt 63 2014	ALU Impaired	0.21	4.8	6.29	Fail	4
Kish Cr 2013	ALU Impaired	0.12	3.9	4.91	Fail	4
Kish Cr 2014	ALU Impaired	0.19	3.6	4.09	Fail	4
Little Swatara 2014	ALU Impaired	0.08	6.5	3.82	Fail	4
Neshaminy Cr 2013	ALU Impaired	0.19	3.0	5.13	Fail	4
Perkiomen Cr 2014	ALU Impaired	0.08	2.1	4.65	Fail	4
Red Clay Cr 2014	ALU Impaired	0.16	6.0	5.16	Fail	4
Skippack Ridge 2013	ALU Impaired	0.15	4.9	5.10	Fail	4
Skippack Rt 63 2013	ALU Impaired	0.35	15.0	5.75	Fail	4
Swatara Harp 2014	ALU Impaired	0.04	3.0	4.25	Fail	4
Swatara Hersh 2014	ALU Impaired	0.07	4.1	3.82	Fail	4
Towamencin Cr 2013	ALU Impaired	0.29	6.2	5.93	Fail	4
Tuscarora Cr 2014	ALU Impaired	0.03	1.3	4.84	Fail	4
Wissahickon 2013	ALU Impaired	0.32	5.9	5.59	Fail	4

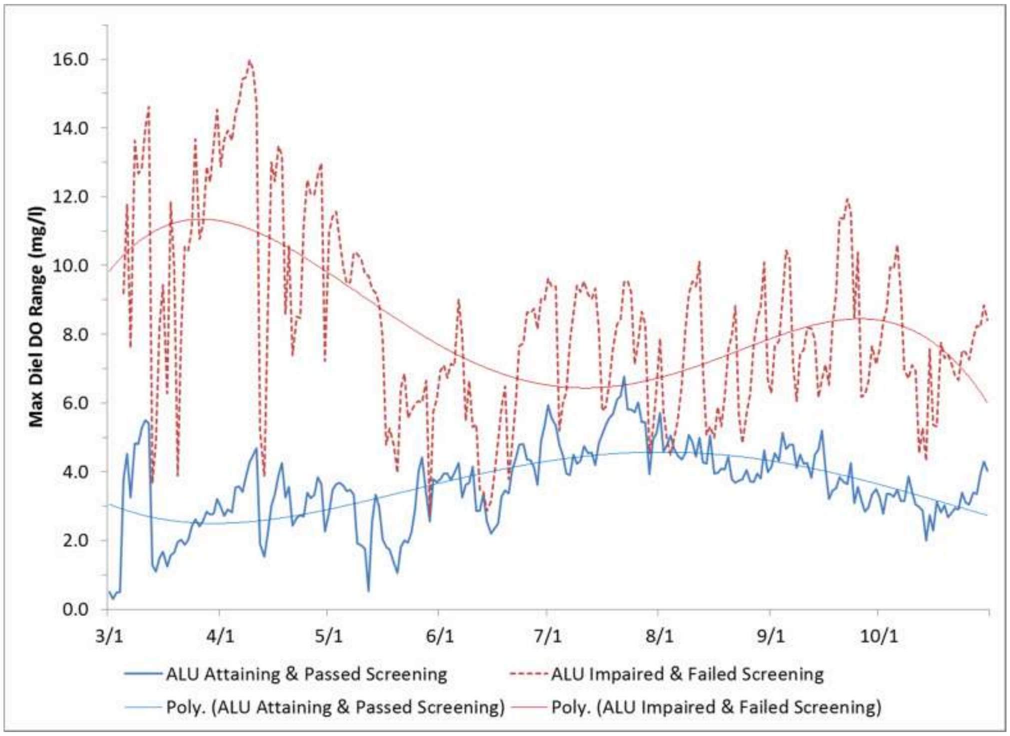


Figure 11. Maximum Diel DO Range Values Recorded at Category 1 and Category 4 Sample Stations, on a Given Day of the Year.

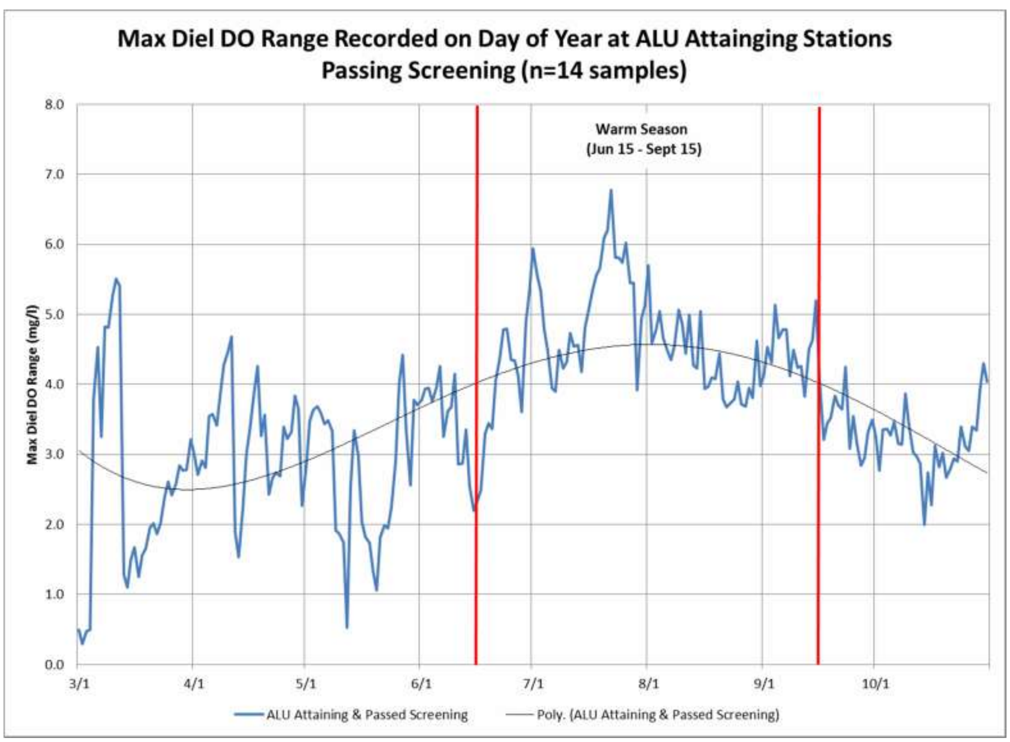
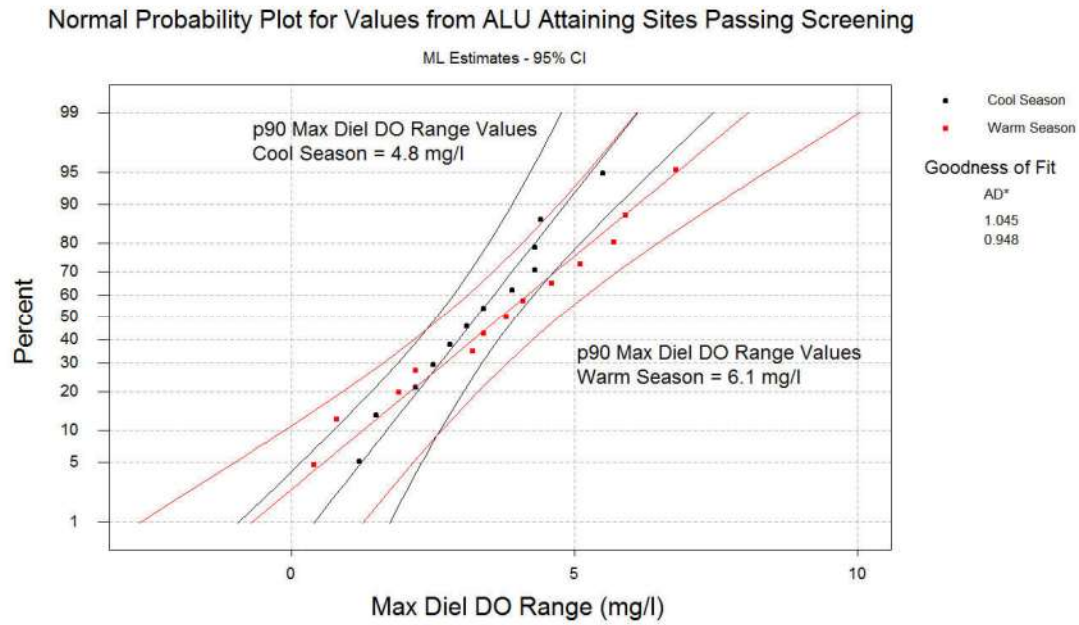
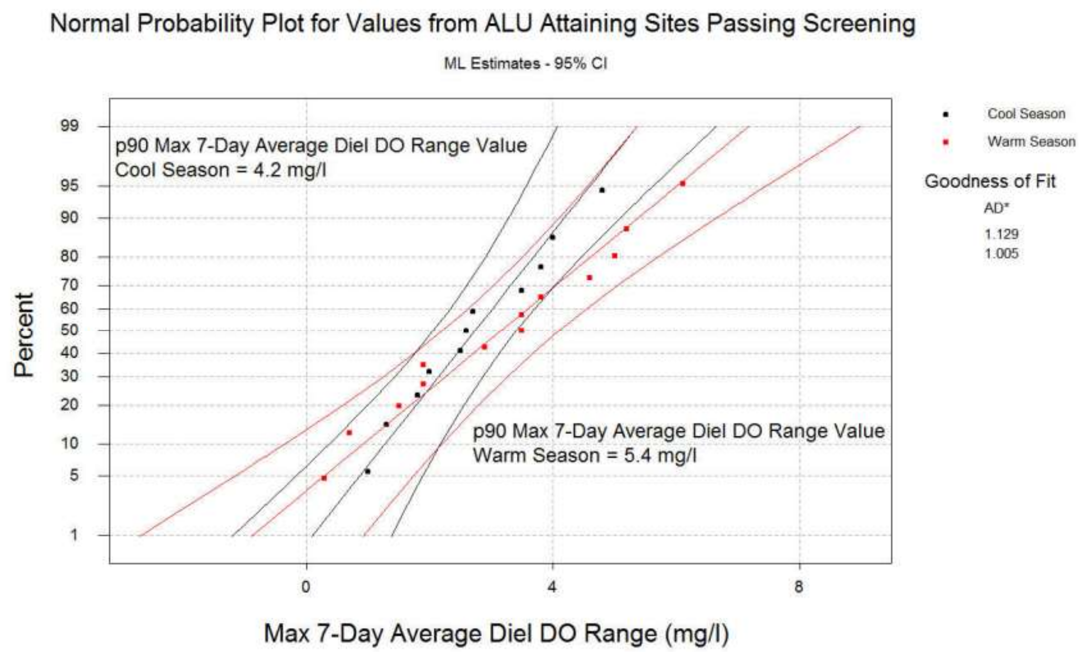


Figure 12. Seasonality Pattern Observed in Maximum Diel DO Range Values Recorded at Category 1 Sample Stations and the Delineation of the Warm (June 15 – September 15) and Cool Seasons.



(A)



(B)

Figure 13. Normal Probability Plots of the Maximum Diel DO Range and the Maximum 7-Day Average Diel DO Range Recorded at Each Category 1 Sample Station During a Given Season.

This process yielded the benchmarks summarized below, and shown graphically in Figure 14.

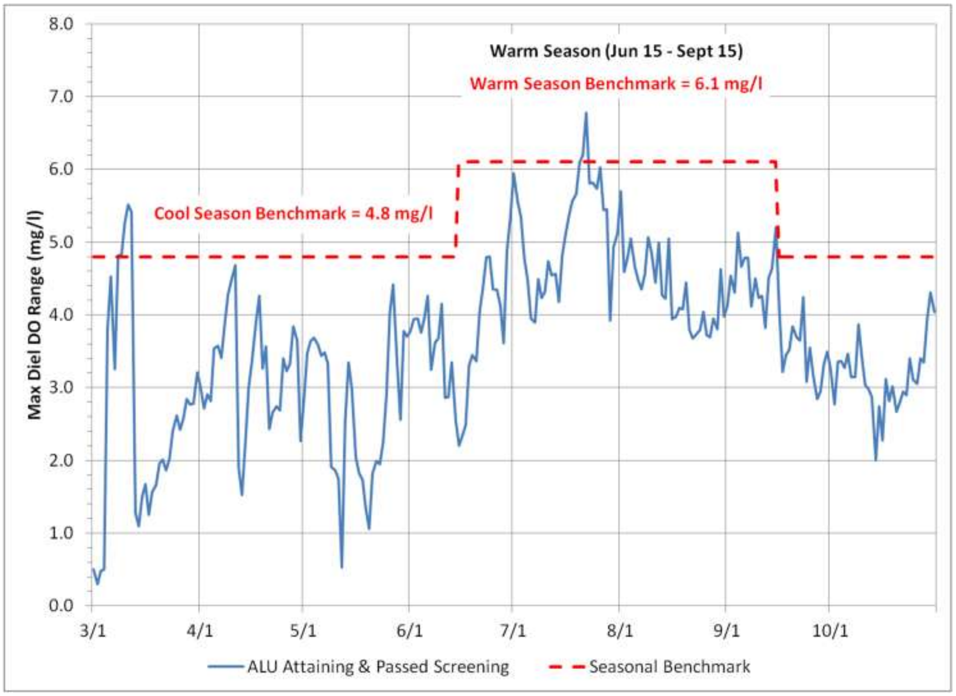
- Cool Season Maximum Diel DO Range ≥ 4.8 mg/l, or
- Cool Season Maximum 7-Day Average Diel DO Range ≥ 4.2 mg/l, or
- Warm Season Maximum Diel DO Range ≥ 6.1 mg/l, or
- Warm Season Maximum 7-Day Average Diel DO Range ≥ 5.4 mg/l

If a Tier 1 nutrient screening benchmark is exceeded, and one or more of the Diel DO fluctuation parameters equals or exceeds the impairment benchmark values, then nutrients are identified as a cause of aquatic life use impairment. Applying the nutrient impairment benchmarks to the ALU-impaired stations that failed the Tier 1 screening in the 40-sample dataset produced the nutrient impairment decisions summarized in Table 6.

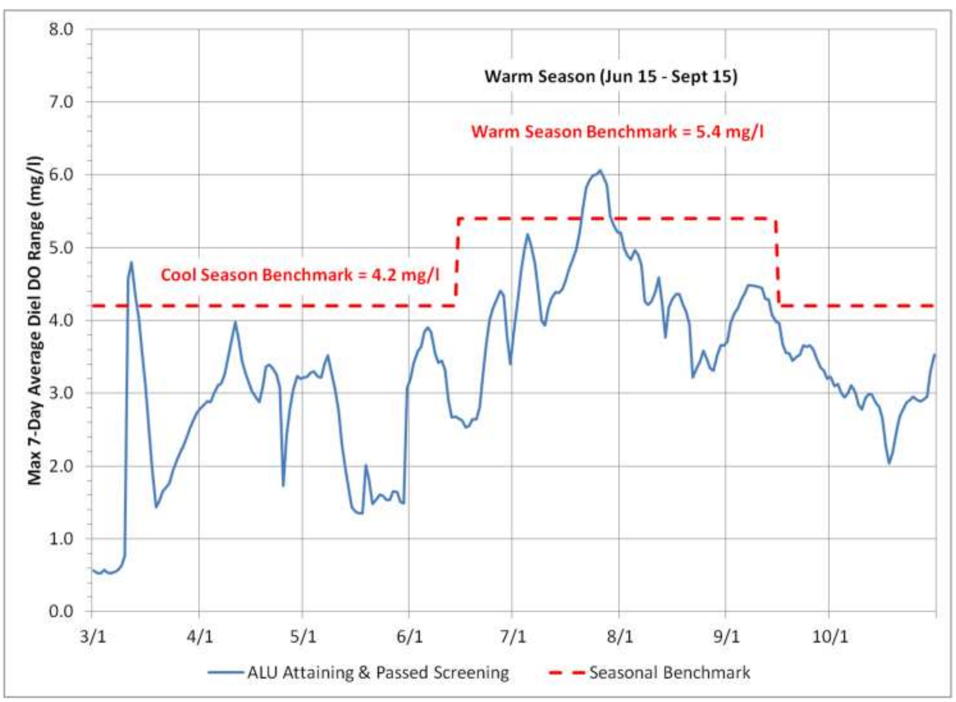
SUMMARY

PADEP used a stressor-response approach, based on known relationships between nutrient concentrations and biological responses, to develop a two-tiered protocol for assessing nutrient impacts to wadeable streams. The intended use of the protocol is for identifying where nutrients are a cause of impairment in ALU-impaired streams. The protocol takes into consideration that there may be cases where a given waterbody may be subject to elevated nutrient levels, but due to characteristics such as scour conditions, substrate composition, temperature, shading, turbidity, depth, etc., elevated nutrient levels may, or may not, affect the photosynthesis, respiration, and dissolved oxygen characteristics of the waterway to a degree that ultimately results in non-attainment of aquatic life use (ALU).

After a given wadeable stream is determined to be ALU-impaired and PADEP staff view nutrients as a potential cause of the impairment, stream nutrient (TP and TN) and macroinvertebrate information (Hilsenhoff Biotic Index Score) are compared to screening benchmark values (Tier 1) to determine if additional data should be collected and evaluated (Tier 2). Waterways that fail one or more of the Tier 1 screening parameters are targeted for the collection and evaluation of continuously monitored dissolved oxygen data (Tier 2), which are ultimately used to confirm if nutrients are a cause of the ALU impairment. The nutrient impact assessment protocol is summarized in Figure 15.



(A)



(B)

Figure 14. Seasonal Nutrient Impairment Benchmark Values and Maximum Diel DO Range Values (A) and Maximum7-Day Average Diel DO Range Values Recorded at Category 1 Sample Stations.

Table 6. Nutrient Impairment Status of Aquatic Life Use-Impaired Sample Stations in the 40-Sample Dataset that Failed Tier 1 Screening.

Station-Year	ALU-Attainment Status	Tier 1 Screening Status	Cool Season: Max Diel DO Range (mg/l)	Cool Season: Max 7-Day Average Diel DO Range (mg/l)	Warm Season: Max Diel DO Range (mg/l)	Warm Season: Max 7-Day Average Diel DO Range (mg/l)	Nutrient Impact Assessment
		Benchmark Value:	≥4.8	≥4.2	≥6.1	≥5.4	
Big Elk Cr 2014	Impaired	Fail	3.8	3.5	3.3	3.0	ALU Impaired-Nutrients Not a Cause of Impairment
Frankstown Br 2014			4.1	3.6	2.5	2.3	
Kish Cr 2013			4.5	3.9	5.4	4.9	
Red Clay Cr 2014			4.7	2.9	2.8	2.4	
Swatara Cr Harpers 2014			4.2	2.8	2.8	2.5	
Swatara Cr Hershey 2014			2.4	1.9	2.3	1.9	
Tuscarora Cr 2014			4.5	4.0	5.7	4.8	
Goose Cr Most 2014	Impaired	Fail	10.2	8.1	3.2	2.2	ALU Impaired-Nutrients a Cause of Impairment
Goose Oak 2014			3.8	3.4	6.2	3.7	
Goose Thorn 2014			6.0	5.2	5.0	4.5	
Indian Bergey 2013			10.1	6.8	7.9	6.8	
Indian Bergey 2014			8.8	6.0	8.0	6.6	
Indian Rt 63 2013			15.1	14.0	9.1	7.8	
Indian Rt 63 2014			11.9	10.6	10.4	9.2	
Kish Cr 2014			5.0	3.4	3.1	2.7	
Little Swatara 2014			7.1	6.2	7.0	6.4	
Neshaminy Cr 2013			10.9	10.2	No Data	No Data	
Perkiomen Cr 2014			8.9	8.0	6.7	6.2	
Skippack Ridge 2013			12.4	10.6	No Data	No Data	
Skippack Rt 63 2013			14.6	13.4	8.2	6.7	
Towamencin Cr 2013			9.8	9.3	No Data	No Data	
Wissahickon Cr 2013			16.0	15.2	No Data	No Data	

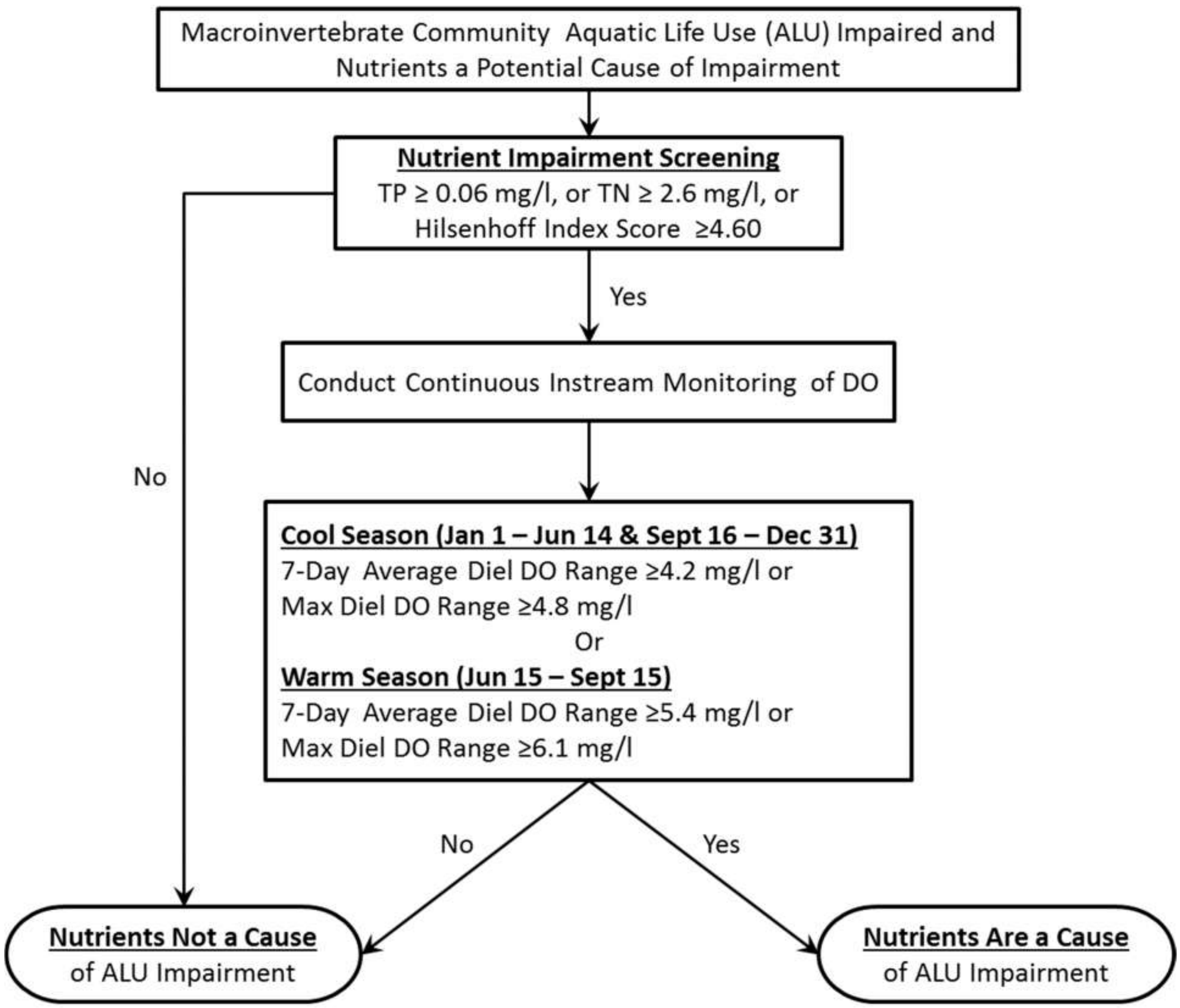


Figure 15. Summary of the PADEP Nutrient Impact Assessment Protocol.

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