DRAFT EUTROPHICATION CAUSE DETERMINATION PROTOCOL FOR SMALL STREAMS (≤50 Mi^2 DRAINAGE AREA)

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INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) describes nutrient pollution as one of America's most widespread, costly and challenging environmental problems. Within the context of nutrient pollution of streams, the term eutrophication refers to the process by which elevated nutrient levels (especially phosphorus and nitrogen) stimulate the growth of algae and/or aquatic plants, and alters the quantity and quality of organic matter available as food for aquatic organisms. In addition to modifying the trophic structure of stream ecosystems, eutrophication can alter physical habitat conditions, stimulate the growth of toxin-producing algae, and can produce large daily (diel) fluctuations in dissolved oxygen (DO) and pH that, in some cases, fall below or rise above levels protective of aquatic life.

Over the past several years, PADEP staff have collected nutrient; benthic chlorophyll-a; continuously monitored DO, pH, and water temperature; and benthic macroinvertebrate community data from small streams statewide. The technical background behind the development of the ECD Protocol can be found in McGarrell (2018). The conceptual model shown in Figure 1 illustrates the cause/response relationships linking nutrient enrichment to stream biological integrity that was used as a framework for developing this Eutrophication Cause Determination (ECD) Protocol. The ECD Protocol provides a method for quantitatively assessing the impact of nutrient enrichment on Pennsylvania's small streams (drainage area ≤ 50 mi^2) The intended use of the ECD protocol is for determining if eutrophication is a cause of aquatic life use (ALU) impairment, under the context of nutrient enrichment, after an appropriate PADEP protocol indicates non-attainment of the aquatic life use.

The ECD Protocol uses a multiple lines of evidence approach for determining if eutrophication is a cause of ALU impairment. Stream ecosystem parameters used in the protocol include: diel DO swing characteristics, water quality criteria for DO and pH, benthic chlorophyll-a concentration, diel DO swing-diel pH swing relationships, and diel DO swing- diel water temperature swing relationships. A graphical summary of the ECD Protocol is shown in (Figure 2).

THE EUTROPHICATION CAUSE DETERMINATION (ECD) PROTOCOL

Data Collection and Analysis

Baseflow (non-storm event) water column total phosphorus (TP) and total nitrogen (TN) samples are to be collected for laboratory analysis when continuous data sondes are first deployed, during each subsequent data sonde maintenance event (approximately monthly), and when sondes are retrieved. Water column nutrient samples are to be collected and processed in accordance with Shull (2013).

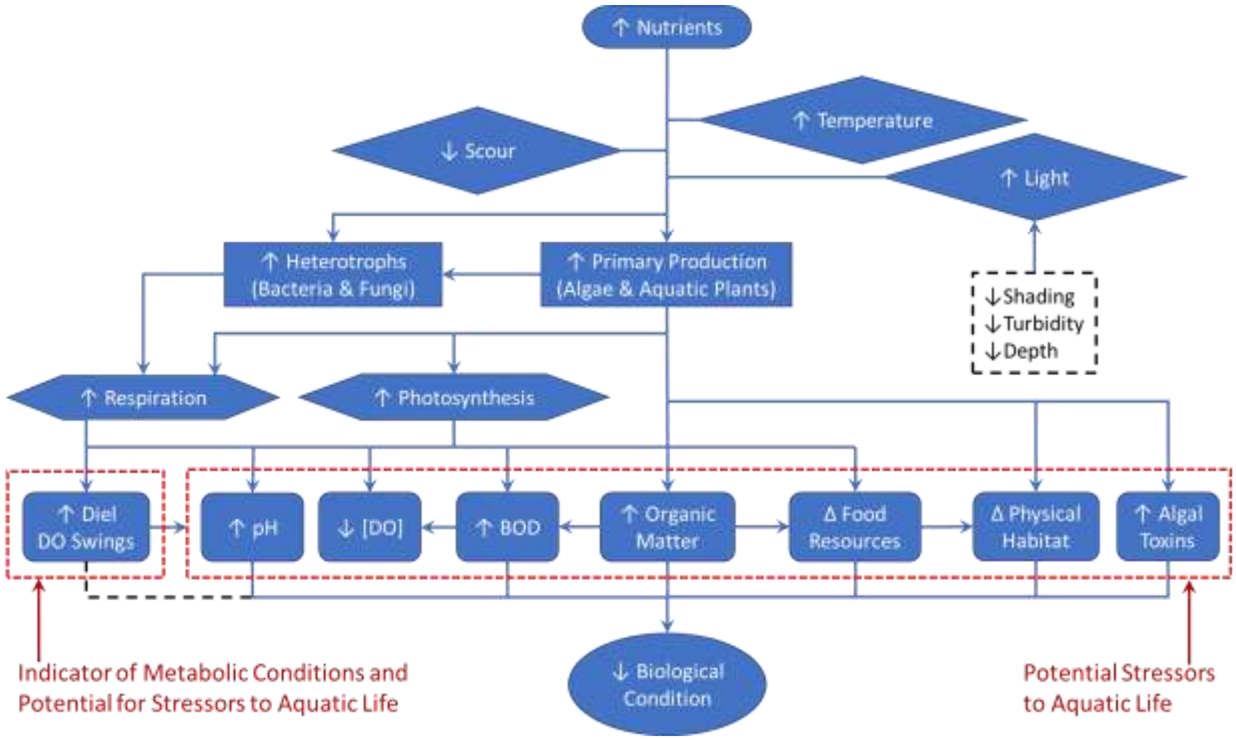


Figure 1. Conceptual model of how nutrient enrichment and eutrophication impact stream biological condition (modified from Heiskary and Bouchard (2015), Minnesota Eutrophication Criteria for Streams and Rivers).

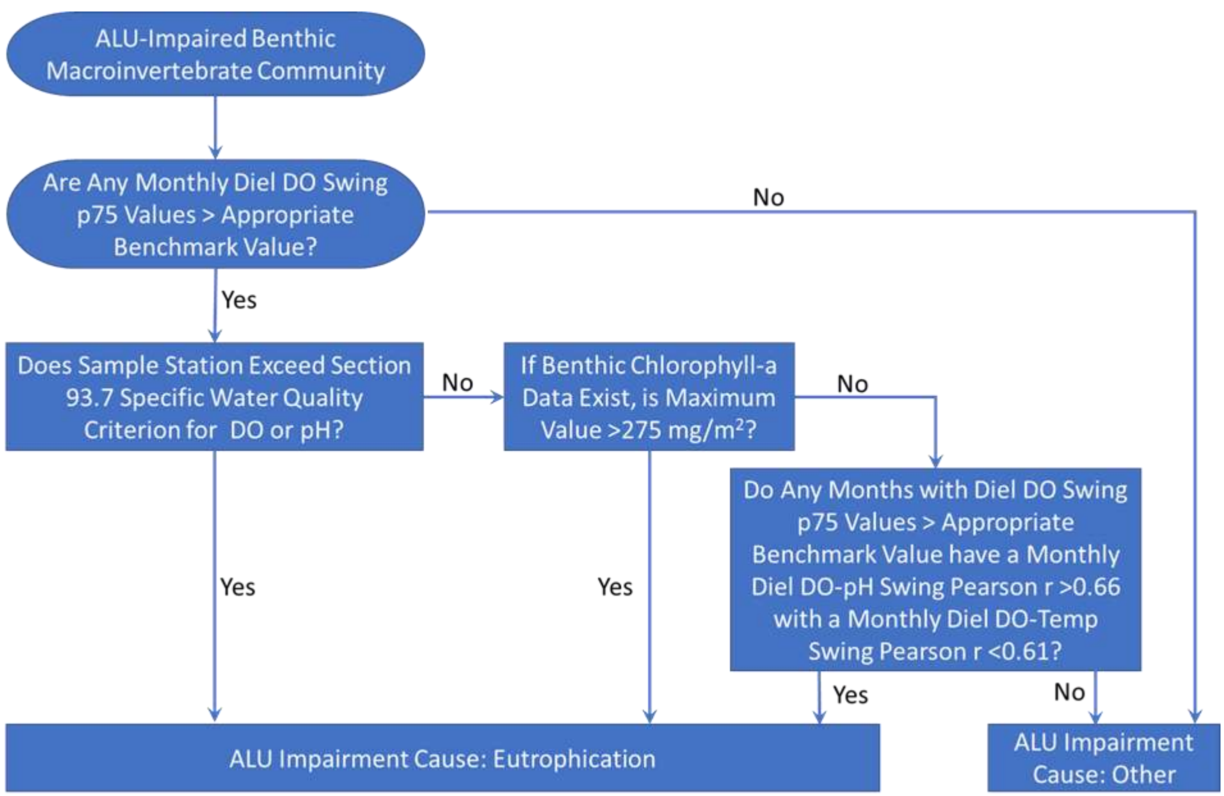


Figure 2. Graphical summary of the Eutrophication Cause Determination Protocol.

Photo-documenting or otherwise noting field observations of primary production levels (algal and/or aquatic macrophyte growth) at continuously monitored sample stations is an important part of the field data collection component of the ECD Protocol. Photographs that clearly show in-stream primary production levels should be taken on each sample station visit. At least one benthic periphyton sample should be collected at each sample station while the data sonde is deployed. Benthic periphyton samples are to be collected using PADEP's Quantitative Benthic Epilithic (QBE) Periphyton Sampling Method (Butt 2017), and efforts should be made to collect samples when primary production rates appear to be relatively high, based on professional judgement and visual observations made during routine data sonde maintenance events.

Water column nutrient data and information pertaining to primary production levels can be very helpful when trying to ascertain the extent of nutrient enrichment at a specific reach of stream. In some cases, water column nutrient levels are excessively high and indicative of a nutrient-enriched system. However, some nutrient-enriched, highly productive stream reaches have very high diel DO swings that are strongly correlated with daily pH swings, but have very low water column phosphorus and nitrogen concentrations due to algal uptake of nutrients. In these cases, where elevated levels of primary production occur under seemingly low levels of nutrient enrichment, benthic chlorophyll-a concentration values and photo-documentation of excessive algal or aquatic macrophyte growth become even more important.

Continuously monitored DO, pH, and water temperature data are collected between March and October and are collected, graded, and approved for use in accordance with PADEP's Continuous Physicochemical Data Collection Protocol (Hoger et al. 2017). Diel DO, pH, and water temperature swing values are calculated for days in which continuous data are collected over at least 75% of the day (e.g., a minimum of 36 readings at ½ hour intervals). Diel swing values are calculated as the difference between the maximum and minimum values recorded on a given day (Figure 3).

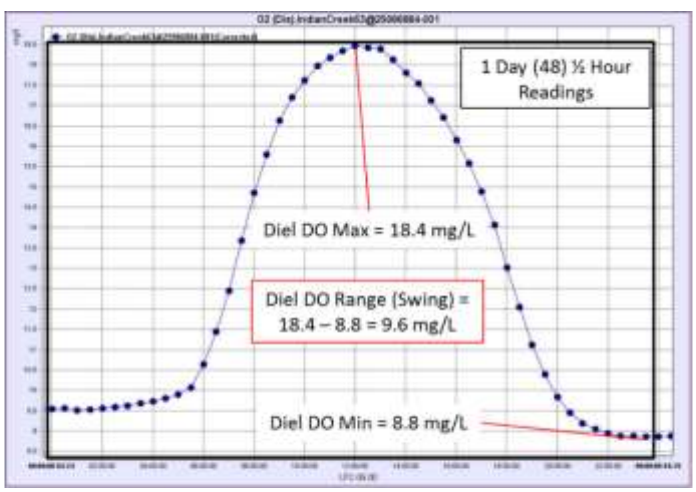


Figure 3. Graphical representation of the calculation of diel DO swing values from DO data monitored continuously over a period of 24 hours.

All useable diel DO swing values recorded within a given month are summarized using the 75th percentile (p75) value of the diel swing values recorded in that month. Diel DO swing p75 values are only generated for months that have usable diel DO swing values recorded for a minimum of 50% of days in that month. For example, if a sonde was deployed at Station X from March 1 to March 31, 2017, and yielded only 12 diel DO swing values, no p75 would be calculated for that month, because 12 days are less than 50% of the 31 days in March.

In addition to the requirement of having usable diel DO swing values recorded for a minimum of 50% of the days in a given month, a minimum of 15 pairs of diel DO-pH swing and diel DO-water temperature swing values are required for calculating monthly correlation values. Examples of how monthly diel DO swing p75 and correlation values are calculated are provided in Table 1 with results shown graphically in Figures 4 and 5.

Table 1. Example spreadsheet calculation of a monthly diel DO swing p75 value of 8.0 mg/L and monthly diel DO swing-diel pH swing and monthly diel DO swing-diel water temperature swing correlation coefficients of 0.95 and 0.14, respectively, from 31 days of data recorded at a small (drainage area ≤50 mi^2) ALU impaired stream in Physiographic Region A.

	A	B	C	D	E	F	G	H
1	Example Continuous Monitoring Data							
2	Date	Diel DO Swing (mg/L)	Diel pH Swing	Diel Water Temp Swing (C$^{\circ}$)	Diel DO Swing p75 (mg/L)	Correlation Pairs (N)	Diel DO-pH Swing Correlation Coefficient r	Diel DO-Temp Swing Correlation Coefficient r
3	5/1/2013	7.1	1.5	4.8	8.0	31	0.95	0.14
4	5/2/2013	8.4	1.6	3.5				
5	5/3/2013	9.2	1.7	5.1	Formula in Cell E3		=PERCENTILE.INC(B3:B33,0.75)	
6	5/4/2013	9.2	1.6	1.7	Formula in Cell F3		=COUNT(B3:B33)	
7	5/5/2013	9.8	1.8	5.3	Formula in Cell G3		=CORREL(B3:B33,C3:C33)	
8	5/6/2013	9.1	1.6	4.3	Formula in Cell H3		=CORREL(B3:B33,D3:D33)	
9	5/7/2013	7.7	1.6	4.3				
10	5/8/2013	8.0	1.6	2.8				
11	5/9/2013	8.3	1.6	3.7				
12	5/10/2013	6.5	1.4	4.6				
13	5/11/2013	7.4	1.5	5.4				
14	5/12/2013	8.1	1.6	5.0				
15	5/13/2013	7.6	1.5	4.4				
16	5/14/2013	7.2	1.6	3.6				
17	5/15/2013	2.2	0.3	1.7				
18	5/16/2013	3.1	0.7	5.0				
19	5/17/2013	4.4	0.8	4.8				
20	5/18/2013	4.4	0.8	3.9				
21	5/19/2013	6.0	1.1	5.9				
22	5/20/2013	6.3	1.2	4.6				
23	5/21/2013	7.1	1.3	3.0				
24	5/22/2013	6.5	1.2	4.3				
25	5/23/2013	7.2	1.4	5.8				
26	5/24/2013	7.7	1.4	6.3				
27	5/25/2013	7.6	1.4	6.9				
28	5/26/2013	8.0	1.5	6.5				
29	5/27/2013	8.0	1.4	4.0				
30	5/28/2013	7.7	1.5	6.3				
31	5/29/2013	7.1	1.3	4.4				
32	5/30/2013	6.9	1.0	2.8				
33	5/31/2013	6.7	1.3	6.0				

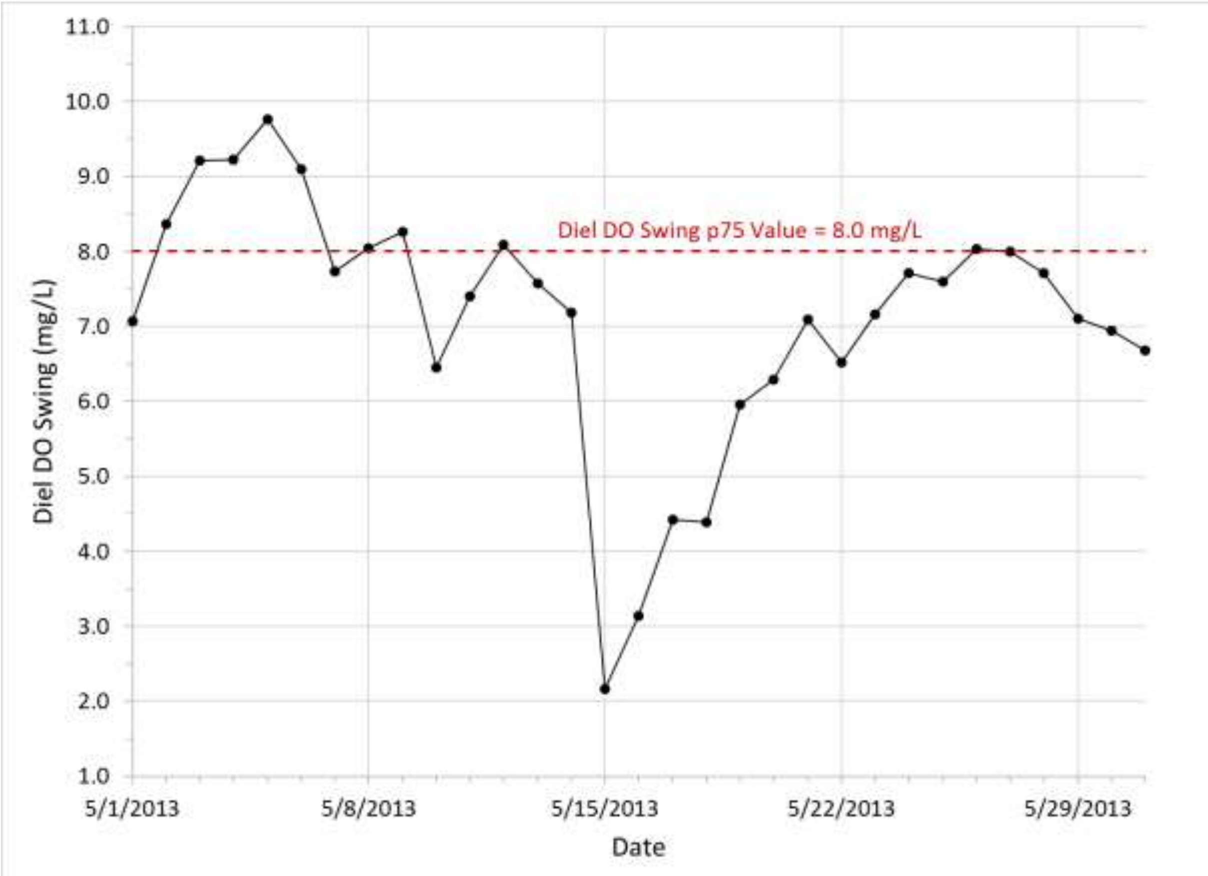
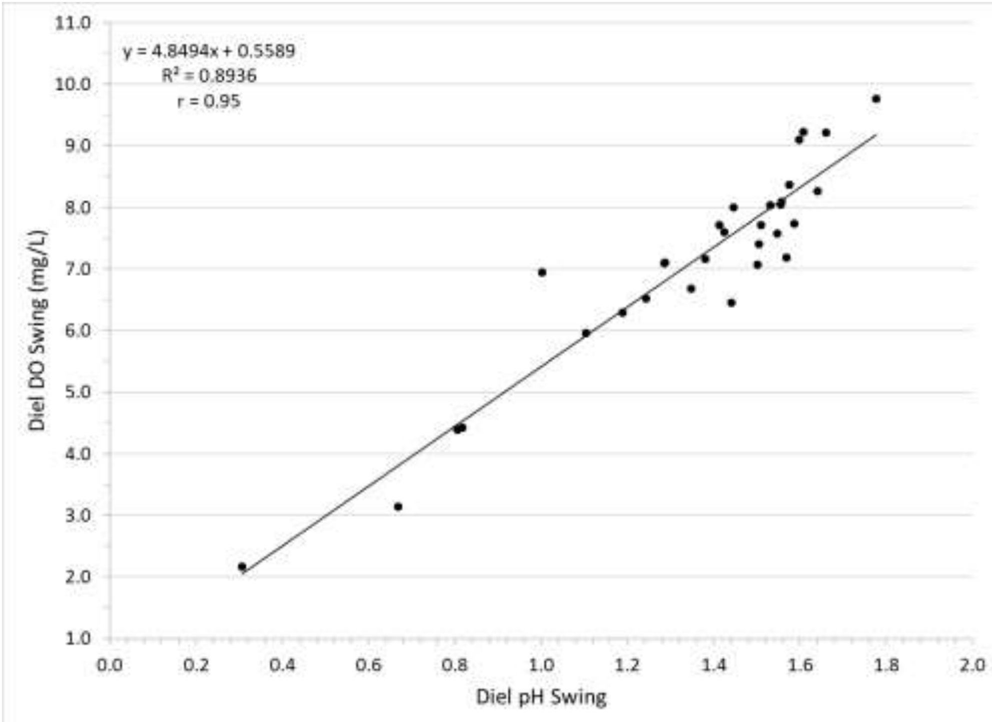
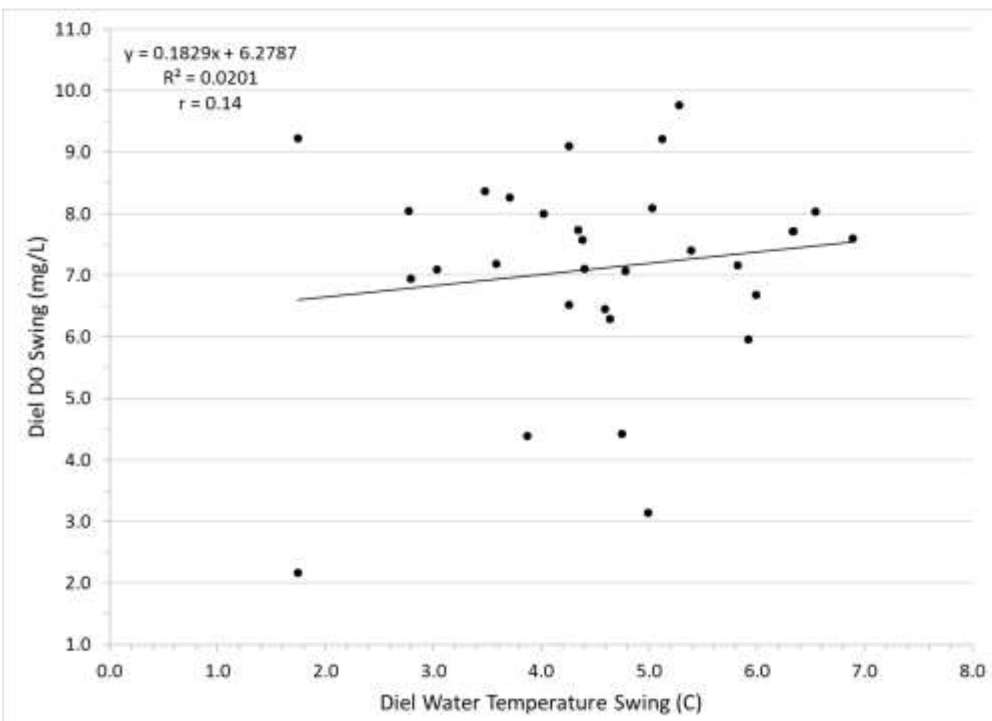


Figure 4. Graphical representation of data from Table 1 showing individual diel DO swing values and the monthly diel DO swing 75th percentile (p75) value of 8.0 mg/L.



(A)



(B)

Figure 5. Graphical representation of data from Table 1 showing (A) diel DO swing vs. diel pH swing values and corresponding monthly Pearson Correlation r-value of 0.95 and (B) diel DO swing vs. diel water temperature swing values and corresponding monthly Pearson Correlation r-value of 0.14.

Eutrophication Cause Determinations

The first step in the ECD Protocol is to determine if the ALU impaired stream is subject to excessive diel swings in DO. This is accomplished by comparing the monthly diel DO p75 values recorded at the ALU impaired stream to the benchmark values shown in Table 2. Separate diel DO swing benchmark values were developed within the context of 2-month sample periods and the Physiographic Regions shown in Figure 6.

If no monthly diel DO swing p75 values recorded at the ALU impaired stream exceed the appropriate Table 2 diel DO swing benchmark value the cause of ALU impairment is determined to be something other than eutrophication (Figure 2). If any monthly diel DO swing p75 value recorded at an ALU impaired stream segment exceeds the appropriate diel DO swing p75 benchmark value, eutrophication is identified as a cause of ALU impairment if:

1. The stream segment exceeds water quality criteria for DO or pH greater than 1% of the time, based on Hoger et al. (2017) (Figure 2), or

2. Any benthic periphyton sample collected in the stream segment has a chlorophyll-a concentration >275 mg/m^2 (Figure 2), or

3. Any monthly diel DO swing p75 that exceeds the appropriate diel DO swing p75 benchmark value has a monthly diel DO swing-diel pH swing Pearson correlation r-value >0.66 with a monthly diel DO swing-diel water temperature swing Pearson correlation r-value <0.61 (Figure 2).

Table 2. Eutrophication Cause Determination Protocol benchmark values.

Monthly Diel DO Swing p75 Benchmark Values (mg/L)	**Physiographic Region**	
Sample Period	**A**	**B**
March-April	2.8	1.5
May-June	1.7	1.4
July-August	1.8	1.3
September-October	2.0	1.5
Maximum Benthic Chlorophyll-a Value (mg/m^2)	275	
Monthly Correlation Benchmark Values	**Pearson Correlation Coefficient (r)**	
Monthly Diel DO Swing-Diel pH Swing	>0.66	
Monthly Diel DO Swing-Diel Water Temperature Swing	<0.61	

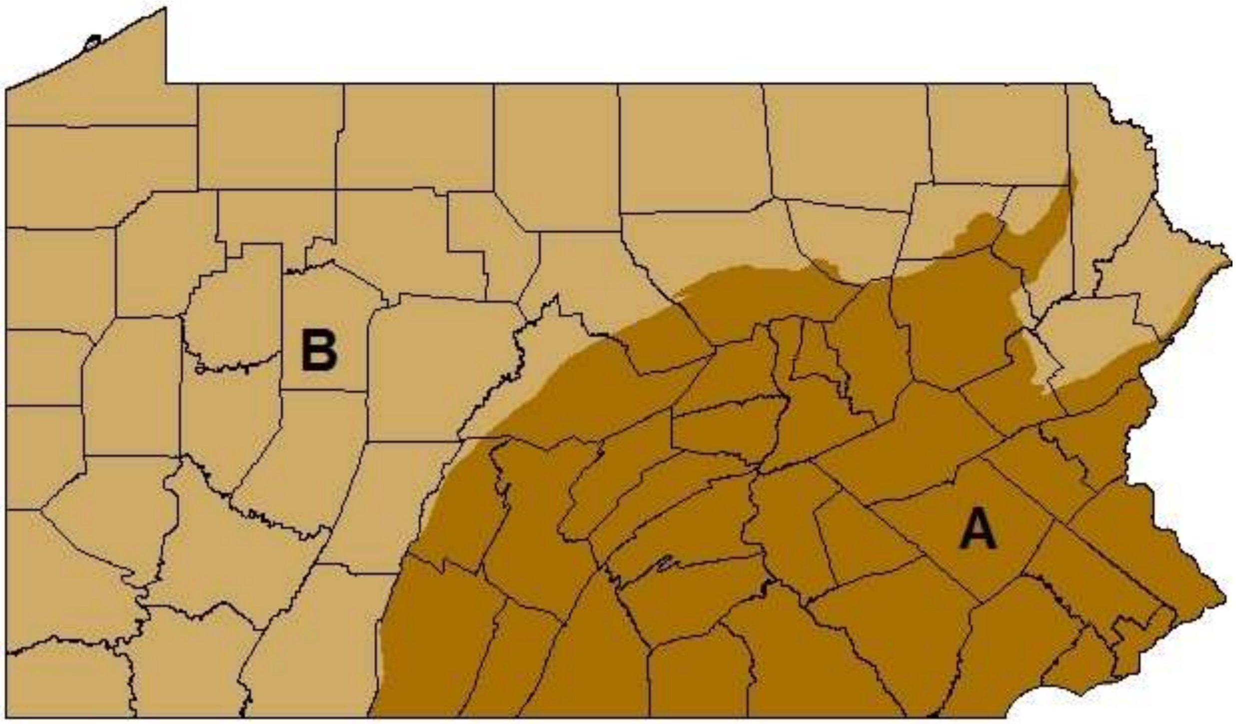


Figure 6. Eutrophication Cause Determination Protocol Physiographic Regions.

The following is an example application of the ECD Protocol to the data shown in Table 1. In this example, it is assumed that the stream segment meets water quality criteria for DO or pH and no benthic chlorophyll-a samples exceeded a concentration of 275 mg/m^2. Based on the ECD Protocol, eutrophication is identified as a cause of ALU impairment because the following conditions are met:

1. The monthly diel DO swing p75 value of 8.0 mg/L exceeds the benchmark value of 1.7 mg/L for Physiographic Region A streams during the May-June sample period, **AND**

2. The monthly diel DO-pH swing correlation r-value of 0.95 is >0.66, **AND**

3. The monthly diel DO-water temperature swing correlation r-value of 0.14 is <0.61.

In the example above, ECD Protocol results indicate the sample station has excessively high diel DO swings. Furthermore, the strong correlation between diel DO swings and diel pH swings, in conjunction with a weak correlation between diel DO swings and diel water temperature swings, indicates the excessive diel DO swings are related to stream metabolic processes (photosynthesis and respiration rates), not the water temperature conditions of the stream.

LITERATURE CITED

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